FOLIAR NITROGEN RANGE AND VARIABILITY IN A SECOND GROWTH DOUGLAS-FIR FOREST AND ITS RELATIONSHIP TO CERTAIN STAND AND TREE CHARACTERISTICS

by

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A thesis submitted in partial fulfillment
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Approved by Stanley P. Gessel

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Date Mar 10, 1970

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We have carefully read the dissertation entitled Foliar Nitrogen Range and Variability in a Second Growth Douglas-fir Forest and Its Relationship to Certain Stand and Tree Characteristics submitted by Ian George Morison in partial fulfillment of the requirements of the degree of Doctor of Philosophy and recommend its acceptance. In support of this recommendation we present the following joint statement of evaluation to be filed with the dissertation.

An understanding of the mineral nutrient needs of coniferous forest trees is basic information needed for modern forest management. Researchers at the University of Washington have been examining this problem for a number of years and have developed a considerable body of knowledge on the subject. One outstanding result has been the need of coniferous forests of the Northwest for nitrogen and the growth response resulting from application of nitrogen over a wide range of growing conditions. The development of this information has created an interest in large-scale application of fertilizers to forest lands, and therefore, many other questions have arisen. Not the least of these is proper diagnosis of the nutritional status of any forest area and the subsequent expected response by the trees to a fertilizer application. Levels of essential elements in needles of conifers and interactions between nitrogen and the other elements is a most fruitful approach to this problem which needs to be pursued intensively.

Mr. Morison has made a distinct contribution to elemental diagnostic problems by analyzing the foliage of a large number of individual Douglas-fir in a restricted growing area and then relating results to observable stand and tree characteristics. He sampled foliage so that recommendations for standardization of position within the stand could also be made. The clear demonstration that nitrogen content of Douglas-fir growing within a given local environment follows a normal distribution when sampling is standardized is extremely valuable. The further development that nitrogen content of trees on a small sample plot can be reliably evaluated by the proper selection of samples based on current height growth of the trees provides a practical solution to nutrient diagnosis.

Mr. Morison also clearly established how greenhouse pot trials using soils from the study area can be related to field research in the same area and to nutrient diagnosis and recommendation.

This research constitutes an important advance in the field of forest tree nutrition. It is a scholarly work in which Mr. Morison clearly exhibits scientific thoroughness and expertise in an investigation of complex and elusive phenomena.

DISSERTATION READING COMMITTEE: Stanley P. Gessel

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In presenting this thesis in partial fulfillment of the requirements for an advanced degree at the University of Washington, I agree that the Library shall make it freely available for inspection. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by my major professor, or, in his absence, by the Director of Libraries. It is understood that any copying or publication of this thesis for financial gain shall not be allowed without my written permission.

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University of Washington

Abstract

FOLIAR NITROGEN RANGE AND VARIABILITY IN A SECOND GROWTH DOUGLAS-FIR FOREST AND ITS RELATIONSHIP TO CERTAIN STAND AND TREE CHARACTERISTICS

By Ian George Morison

Chairman of Supervisory Committee: Professor Stanley P. Gessel
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The purpose of this study was to investigate the variability and range of foliar nitrogen in a second growth Douglas-fir stand and to determine the relationship of foliar nitrogen to characteristics of the tree and to characteristics of the stand.

Nitrogen content was chosen because deficiencies of this element over large areas of the Douglas-fir region are widely reported in the literature. This deficiency was confirmed by preliminary pot culture trials which were carried out in duplicate using *Pinus radiata* grown on soil from the study area. In addition to a pronounced response to nitrogen and magnesium, there were lesser responses to potassium, sulphur and boron.

An area of 1,000 acres (404 hectares) of second growth Douglas-fir in the northern part of Washington State (Whatcom County) was chosen for the study area.

One hundred and eighty eight one-tenth-acre plots were established over the study area. Half of these were sampled according to a procedure developed in which the foliage from one tree had nitrogen values representative of the plot. The other half of the plots were sampled by choosing a single dominant or codominant tree randomly from each plot.

Abstract (cont.)

The nitrogen content of needles on the first whorl and one-year-old needles on the third whorl was determined. For each plot, 15 stand and tree characteristics were measured.

No pattern of distribution of foliar nitrogen content over the study area could be found; however, the frequency of these values formed a normal curve. No relationship between foliar nitrogen percentage and the stand characteristics of site index, age and stocking could be established, but there was a significant relationship with characteristics that measured the current vigor of the tree.

An investigation was conducted to compare the foliar nitrogen content relationship to the stand characteristics with the vigor characteristics of the tree. Foliar nitrogen percentage was more closely related to the current vigor of the tree than to site index or age and stocking. A further analysis revealed no relationship between site index of the stand and the current vigor of the tree.

An investigation was made into possible interactions between stand and tree characteristics (variables). Simple regression analyses of each variable and nitrogen content divided into classes of a second variable were conducted. The correlation coefficients of the class regressions showed no rising or falling trends so that no clear interactions could be established.

Certain sample trees were taken from areas adjoining nitrogen fertilizer trial plots on the study area. The trees in these plots were showing substantial growth response to nitrogen application. Foliar nitrogen of adjacent unfertilized trees varied from 1.53% to 1.03% in the first whorl, and from 1.34% to 1.02% in the third whorl, so that foliar nitrogen of 1.53% in the first whorl was still in the deficiency range.

Abstract (cont.)

Each sample tree was felled and the foliage removed by scissors and oven dried at 70° C for 48 hours. The needles were separated from the stems and buds by hand and ground in a Waring blender. Digestion of the ground foliage was carried out by the Caro's acid wet ashing method. Tree height was measured with a steel tape to the nearest inch. Radial growth was measured to the nearest one-tenth of an inch using a dissecting microscope. Tree age was determined by ring counts at the base, and site index from tables in U. S. D. A. Bulletin 201. Stocking was measured by prism counts.

The range and frequency distribution of foliar nitrogen content is presented by histograms for first and third whorl nitrogen in the three groups of data (i.e., all 188 samples, 94 representative samples and 94 random samples). In each case, tests showed that the distribution of foliar nitrogen contents followed a normal curve.

The relationship of foliar nitrogen in the first and third whorls to the 15 stand and tree characteristics was investigated by several statistical analysis procedures.

Initially the data from all 188 samples were examined together by analysis of variance and multiple range tests to determine where strong relationships might exist. The simple correlation matrix of these data was examined and compared to the results of the previous tests.

Simple regression analyses were made of nitrogen contents in the first and third whorls against the stand and tree characteristics.

No relationships between foliar nitrogen and any of the characteristics could be established using data from 188 samples or the two groups of 94 samples.

Abstract (cont.)

Multiple regression analyses were carried out between foliar nitrogen and the 15 stand and tree characteristics. Using data from representative samples, four significant variables in the first whorl nitrogen analysis gave a multiple correlation coefficient of .8259. This accounted for 68% of the variation. Three of these variables (height growth and radial growth in the last five years and leader length) are easily measured in the field and give a multiple correlation of .8140 which accounted for 66% of the variation. Prediction equations for foliar nitrogen percentage using these variables were calculated.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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FOLIAR NITROGEN RANGE AND VARIABILITY IN A SECOND GROWTH DOUGLAS-FIR FOREST AND ITS RELATIONSHIP TO CERTAIN STAND AND TREE CHARACTERISTICS

CHAPTER I. INTRODUCTION

The development of practices for increasing forest productivity has become one of the urgent priorities in forest research the world over. Population pressures, increasing demand largely for pulp products and decreasing areas of the high volume old forests have contributed to this situation.

The various factors influencing site productivity are being examined to a greater or lesser degree, depending on the likelihood of a practical solution. For example, the biological factors of genetic variation, stand density, competing vegetation and pathological and entomological influences are being investigated and significant progress is being made.

However, of the environmental factors influencing site productivity, viz., the meteorological conditions, topographic effects and edaphic factors made up of the moisture regime and the physical and chemical properties of the soil, the manipulation of the chemical properties of the soil appears to be the only likely one to produce some practical solution. In fact, the manipulation of the chemical properties of the soil by the application of artificial fertilizer has become the major cultural practice for increasing forest yield and, although much remains to be done, sufficient progress has been made in this area for forest fertilization to be the standard practice over large areas of forest. In Finland, for example, 2,000 hectares (4,940 acres) were fertilized in 1961, 50,000 hectares (133,500 acres) in 1966, and it is expected that by 1975 the area will be 633,000 hectares (156 million acres), and after that about 1,000,000 hectares (247 million acres). This same sort of trend is taking place in the nitrogen fertilization of second growth Douglas-fir in the Pacific Northwest of the United States where a total of 60,000 acres (24,300 hectares) were fertilized in 1969.

The application of fertilizer to forest stands is an expensive operation and is only economically possible when the returns from increased growth can justify it. Bailey (1959) concluded that fertilizing second growth Douglas-fir stands can be justified only under certain conditions. These conditions are largely involved with the amount of growth response. The ability to predict growth response has therefore become one of the critical issues in the financial success of forest fertilization.

It has become the practice in the Pacific Northwest to use the site index of a stand, that is, the height at some predetermined age, as an indicator of a tree's need for fertilizer. Based on the assumption that low height at that particular age indicates a mineral nutrient deficiency and high height at that age indicates a mineral sufficiency. Indications now, however, suggest that this method of diagnosis may not be entirely valid and that the only true measure of a tree's nutrient deficiency or sufficiency is the nutrient status of the tree, generally reflected best in the foliage.

A considerable amount of work has been done recently on the foliar nutrient status of a variety of species and its use as a diagnostic tool.

The purpose of this study is to examine the variability of the foliar nitrogen of second growth Douglas-fir; firstly, to determine whether this variability is sufficiently small and predictable for its satisfactory use as a diagnostic tool and, secondly, to determine what relationships exist between foliar nitrogen and the main characteristics of the stand and the tree.

CHAPTER II. REVIEW OF LITERATURE

I. FERTILIZATION

Development in Agriculture

The amelioration of agricultural soils by the addition of plant nutrients was recognized and practiced almost from the time man first started to till the soil.

References to the use of manure were made by Xenophon between 450 and 350 B.C. and by Theophrastus between 372 and 287 B. C. The value of leguminous crops for enriching the soil was recorded by Cato (234 - 149 B.C.) and by Virgil (70 - 19 B.C.).

Inorganic plant nutrition was investigated by van Helmont, Mayow, Glauber, Boyls and Bacon in the 17th century and by Woodward, Tull and Baker in the 18th century. De Saussure, Davy Boussingault and Liebig continued the work of the earlier investigators and made significant advances (Tisdale and Nelson, 1956). These authors report in some detail the development of soil fertility investigations in this country from the time of Oglethorpe in 1733 up to the beginning of the 20th century, and the tremendous advances that have been made during this century in the use of fertilizers for increasing production of agricultural crops.

Parker (1963) gives a comprehensive report on the world situation with regard to the use of fertilizer in providing for the current and future food and fibre requirements of the various global regions.

Forest Fertilization

The first published record of manurial use in forests appeared in 1844 in the Forest and Game Management Review. This was followed by a report by von Berg (1857) on the use of lupins in forest stands, and Schwappach (1923) produced a book on the subject. However, with these three exceptions, it appears from the literature that investigations into the use and application of manures and chemical fertilizers for increasing forest productivity have, by agricultural standards, just begun. Laurie (1960), in a review on the place of fertilizers in forestry, records as his earliest reference work done by Stirling Maxwell in 1925. Leyton (1948, 1958a) produced comprehensive reviews of the knowledge in this field up to those dates, and Hoagland (1948) produced a text book on inorganic nutrition of plants in that year.

In the Review of Forest Fertilizing in Canada (Armson, 1967), it is reported that the first study carried out in that country for which there is published information was done in 1920, and that, with this exception, forest fertilization studies have been initiated almost exclusively since 1950. Helms (1911) reported on fertilizer investigations in Denmark. Stoate (1920) reported on some Eucalypts in Australia in relation to soil fertility. Work begun in 1920 on pine nutrition in Australia is reported by Stoate (1950).

Over the last half century, a mass of literature has been published describing forest fertilization investigations from all over the world. The following references are not exhaustive and are given only as examples of the wide range of species, nutrients and geographical regions which were investigated. Almost exclusively, the literature reports increased growth following application of nutrient elements.

Lent (1928), Kessell and Stoate (1936), von Becker and Dilligen (1937), Wilde (1938), Demontier (1938), Fabricus (1940), Nemec (1940), Cummings (1941), Kessel (1944), Lunt (1945), Maki (1950), Heidberg and White (1950), Coile (1952), Stone (1953), Youngberg and Austin (1954), Walker et al. (1955), Savina (1956), Tamm (1956), Mayer and Kropoll (1956), Leyton (1957), Stoate and Bednall (1957), Shibamoto (1957), Wilde (1958), Wittich (1958), Brüning (1959), Zöttl (1959), Steinbrenner et al., (1960) Heilman (1961), Viro (1961), Gessel (1962), Walker and Youngberg (1962), Hall and Raupach (1963), White (1965), Brackett (1965), Bernier (1966), Moehring (1966), Broadfoot (1966), Neumann (1966), Martin and Carter (1967), Kreutzer (1967), Hagner (1967), Binns and Grayson (1967), Haveraaen (1967), Laflamme and Lafond (1967), Sander (1967), Tamm (1967), and Benzian (1967).

The results of these various investigations demonstrate a stimulus to growth by each of the macronutrients and micronutrients to a wide range of nursery stock species and forest trees, both hardwoods and conifers, in Germany, Finland, the United States, Japan, Australia, India, France, Belgium, the United Kingdom, Sweden and Norway pointing to extensive nutrient deficiencies in large areas of forest across the world.

Nitrogen Fertilization in Douglas-fir

The general chlorotic condition of second growth Douglas-fir in the Pacific Northwest of the United States has been evident for several decades.

The deficiency of nitrogen was demonstrated in green house trials by Gessel et al. (1951). Ahmed (1956) showed that the annual height and radial growth of Douglas-fir trees following the application of nitrogenous fertilizer increased by 25%. Gessel and Walker (1956) reported that nitrogen applications increased the rate of height growth from 2 to 3 times in all height classes. In 1958 Gessel and Walker concluded that the evidence to that date gave clear indications that forest fertilizing was a necessary management tool in the Douglas-fir region.

Steinbrenner, et al., (1958) reported that, in a study on Douglas-fir cone production, it was observed that vigor, lateral shoot growth and diameter growth were increased with applications of nitrogen-phosphorus combinations. Gessel and Walker (1958) point out that fertilizing low site stands increased the natural competition and accelerated the thinning process in overstocked stands. Bailey (1959) reported that 50 lbs. of nitrogen per acre (56 kilogrammes per hectare) produced a volume increase of 30%, 100 lbs. (112 kilogrammes per hectare) produced a 75% increase, and 200 lbs. (224 kilogrammes per hectare), a 100% increase 4 1/2 years following application. Gessel, et al., (1960) demonstrated that 100 to 150 lbs. of nitrogen (112 to 168 kilogrammes per hectare) were required to correct the deficiency.

Miller (1961) showed that applications of nitrogen fertilizer increased the rate of diameter, height, basal area and volume growth.

Heilman (1963) confirmed the work of earlier investigators and showed increases in growth following fertilization.

Gessel, et al., (1965) reported a rise in growth of Douglas-fir up to about 1/2 inch (1.27 centimeters) diameter at breast height in a year and that maximum growth is reached with the addition of about 180 lbs. of element nitrogen per acre (201.6 kilogrammes per hectare). Gessel, et al., (1969) concluded that the condition of the stand or its nutritional status influences growth response and that these should be considered in addition to physical stand characteristics such as site index. They also conclude that the optimum rate of application is between 150 and 300 lbs. of nitrogen per acre.

Subsequently, Gessel (personal communication, 1969) found that 80% of the increased yield obtained by the addition of 300 lbs. of nitrogen per acre (336 kilogrammes per hectare) will be obtained by the addition of 180 lbs. of nitrogen per acre (201.6 kilogrammes per hectare).

Strand and Miller (1969) in a review of nitrogen fertilization in the Douglas-fir region state:

> Many short term trials show a nearly constant linear increase in growth response per unit of nitrogen added between 100 and 200lbs N per acre. Above 200 to 300lbs N per acre there is usually a gradually decreasing response per pound of N. U. S. Forest Service data however suggests that heavier applications may extend the period of response and thus shift the optimal amount of N to a higher rate of application than current short term data suggest."

Economics

Anderson (1969) reports that over 60,000 acres (2,430 hectares) were fertilized in the Douglas-fir region in 1969 and it is anticipated that this will increase to 100,000 (40,500 hectares) per year within about 5 years. He also reports that costs of application have decreased from $35-$40 per acre to $16-$20 per acre, depending on application rates and that two large organizations in the region are applying urea at the cost of one cent per pound.

Even at these relatively low costs, the economics of fertilizing is becoming more important as larger areas are covered each year. The selection of areas which will give the highest returns then becomes important.

Strand and Miller (1969) state that "currently there is no reliable basis for selecting stands by site index or site quality except for some local areas." They point out that soil and foliar analyses have proved useful for this purpose in agriculture only after a close correlation has been established between growth and nutrient status.

The economics of fertilization are analyzed by Haley (1966), Jensen and Williams (1963) and others and in each case the conclusion is that selection of areas to give maximum response is the first and probably most important decision to be made.

Physiological Effects of Nitrogen Fertilization

A comprehensive review of the function of nitrogen in the growth and physiology of plants is given by Donald, et al., (1963).

Gase (1937) found an increase in photosynthetic efficiency in trees following the application of nitrogenous fertilizer. Brix and Ebell (1969) found in Douglas-fir that, as result of nitrogen additions, leaf length and width increased and that there was an increased production of the number of leaves per shoot, first order branch length and the number of second order lateral branches but they were unable to detect any difference in the photosynthetic rate between treated and control trees. They concluded that the increased foliar area is not the full explanation of increased growth following fertilization, and that an optimum leaf area per tree was attained 2 years after fertilization and that further increases in the following years had no effect on stem growth. In subsequent work, these investigators found substantially higher rates of photosynthesis in the first year following spring applications of 400 lbs. of nitrogen per acre (448 kilogrammes per hectare) and also for part of the summer in the following year, but no difference by the end of August. They concluded that the effect of nitrogen fertilization on the rate of photosynthesis is highly dependent on the light condition and that growth response will therefore vary with the light environment and on stand and crown characteristics affecting this environment. The effect of leaf age on assimilation was investigated by Koch and Keller (1962) who noted a definite relationship between age and assimilation and respiration. Younger leaves had much higher respiration rates than older leaves. Fully developed leaves had higher net assimilation than either younger or older leaves.

II. PLANT ANALYSIS

The chemical analysis of plants and trees has become an accepted tool of the agricultural and forest scientist in determining nutrient status.

Specifically, plant analysis is used to diagnose visible symptoms of deficiency and give indications of fertilizer requirements, to indicate specific nutrient deficiencies where a plant or crop shows a general lack of vigor, to demonstrate whether nutrients have been taken up by the plant following fertilization, to demonstrate interactions and antagonisms between nutrients as they are absorbed by the plant and in delineating site classes and site indexes.

Plant analysis dates back to the beginning of the nineteenth century when de Saussure examined the ash content of plants (Ulrich, 1952). Later the work of Schültze (1869, 1876), Ebermayer (1876), Schröder (1878), Wolff (1880), Counder (1886), Ramann (1892), Schmitz and Dumont (1896) and others resulted in a considerable accumulation of knowledge by the beginning of the present century.

Little work was done for some thirty years until Lagatu and Maume published the results of their work on foliar analysis ("Diagnostic Foliar").

For the last forty years, innumerable investigations have been made into the uses and value or otherwise of plant analysis.

Gilbert and Hardin (1927) proposed the composition of plant crop "as an index of fertilizer need." Mitchell (1936) and Lundegardh (1951) proposed a relationship between the plants nutrient status and the effectiveness of its rooting system. Cain (1959) suggested that plant analysis of trees was not as meaningful as for perennial plants because "the physical mass of the tree acts as a buffer against violent fluctuations in its composition."

Foliar Analysis

As these investigations progressed, the question of what part of the plant or tree to analyze became of prime concern. The reviews of Ulrich (1948) and Lundegardh (1951) for agricultural crops indicated that the plant tissues which gave the most meaningful results were those whose mineral concentrations were most affected by fertilizer application. As a result, the leaf blades and petioles of agricultural crops were favored by agricultural workers and analysis of tree crops has largely been concerned with foliage.

Leyton (1958a) points out the problems of sampline the foliage of large trees due to the influences of tree age, foliar age, location of the foliage in the crown, and nutrient supply. In this work, he also lists 23 conifer and broad-leafed trees setting our deficiency levels and optimum levels of certain nutrients for each, the investigator and the age of the tree sampled.

Levy (1968) stated that chemical analysis of the foliage of the trees gave the most effectual results because the leaves of trees are the best indicators of nutrient deficiency, as it is in the leaf composition that deficiencies are best reflected. This he attributes to the fact that the leaf is an active organ and the most important in the metabolism of the tree. He lists other advantages for using tree foliage--the leaves are a known age, they occupy an easily definable place on the tree and have a relatively uniform anatomy.

Smith (1962) stated that the leaf was the best and probably the only tissue that reflects the nutrient status of the plant. Thomas (1945) observed that only in the leaf are the ontogenetic drifts in major nutrients known to resemble those of the whole plant. Qureshi and Srivastava (1966) list the advantages of choosing the leaf for analysis.

It has been suggested by some workers that the meristimatic tissues would reflect the nutrient status of the plant but Clements, et al., (1942) working on that tissue in sugar cane for nitrogen concentrations, discarded it because of its lack of sensitivity. Thomas (1945) notes that only in the leaf have critical investigations been made into the relationship of nutrient status, fertilizer application and growth. Marion, et al., (1968) working with *Pinus resinosa* showed that buds were suitable tissues for diagnosis of the nutrient status of trees.

Critical Levels

The use of minimum values of an inorganic nutrient for determining deficiencies has been recognized for many decades. In culture trials, the point at which growth ceases and the foliar content of a whole range of elements has been determined for many species.

Macy (1936) determined the relationship between the percentage of a particular nutrient in the plant and its growth. Evidence from a number of sources demonstrated the existence of breaks in the curves relating the percentages of an element in the plant with increments and yield. This evidence led to the concept of the threshold "optimum" and "minimum" with luxury consumption occurring above the former (the critical valve) and poverty adjustment below the latter (the minimum valve).

Minimum valves below which a deficiency of a particular element is assumed to exist have been determined for a number of species and have been used with success in field practice. Most of this work is concerned with horticultural species. Batjer and Magness (1938) related potassium foliar concentration in apple trees with deficiency levels. Critical concentrations of foliar nutrients in forest trees are reported by Mitchell (1939), Stone (1953), Tamm (1956), Gessel and Walker (1956), Walker (1956). Gessel and Walker concluded that foliar nitrogen concentration of 1.0% or less in Douglas-fir probably indicates a deficiency of this element. Eidmann and Ingestad (1963) working with *Pinus sylvestris* reported a critically low level of 0.8% nitrogen in stagnating stands. Barrows (1959) stressed the need to study the "critical range of concentration."

Limitations and Usefulness

Ulrich and Hills (1967) state that "one of the greatest values of plant analysis is the prevention of deficiencies rather than their correction after they occur."

Reviews by the soil scientists Wilde (1958), White (1958) and Viro (1961) suggest that soil analysis may be a more valuable basic method for determining nutrient status while tissue analysis may be useful in detecting deficiencies and in studying the nutrient status of nursery stock.

Guha and Mitchell (1966) conclude that because of antagonisms between different elements and the complex translocation and distribution factors, that "analysis of leaves and other organs cannot be considered to be an unequivocal indicator of nutritional status." Leech (1965) favors soil analysis for determining nutrient requirements of forest trees but states that: "The soil analysis may be supplemented by foliar analysis. Since each tree species may make different use of a given level of soil nutrients, foliar analysis is particularly useful in measuring the uptake of soil nutrients of a particular species on a particular site."

Leyton and Armson (1955) conclude that soil analyses have not proved as reliable in the assessment of site fertility for forest trees as for agricultural crops and that, as a result, many investigators have turned to foliar analysis to give better indications of mineral deficiencies. This view was supported by Gessel and Walker (1958) when they stated that forest tree nutrition needs cannot be diagnosed correctly by chemical soil testing. Kramer and Kozlowski (1960) report that soil analysis has proved of limited value in assessing adequacy of mineral supply but can lead to most useful results when used in combination with results from other techniques like fertilizer trials and plant tissue analysis. Evers (1967) consideres that soil analysis was a more efficient and more convenient method than foliar analysis for the determination of nutrient status. Swan (1966) in his investigations into fertilizer requirements of *Pinus banksiana* showed that visual symptoms, soil analysis, foliage analysis and soil bioassays contributed to the diagnosis but that the data for each individually were inconclusive and misleading. Boynton and Compton (1945) working on the nutritional deficiencies of fruit trees in New York concluded that "chemical analysis of leaves for these constituents (potassium, magnesium and nitrogen) cannot take the place of careful observations on tree behavior and appearance, on the development of visible leaf and fruit symptoms and on past climatic and management conditions but that "chemical analysis of leaves coupled with these observations may make possible a positive diagnosis that neither alone would have permitted."

Specific Uses of Foliar Analysis

It is not the intention here to give a comprehensive review of the multitude of publications demonstrating the value of foliar analysis. Rather it is the intention to quote the works of a selected number of investigators to demonstrate the variety of problems to which foliar analysis has contributed a solution at least in part.

Kennel and Wehrmann (1967) used the technique successfully to test whether optimum foliar nitrogen concentrations for growth measured in seedlings also applied to older trees. They found that optimum foliar nitrogen percent for maximum increment was 1.9% in 3 to 6 year-old *Pinus sylvestris* and was lower than that determined for seedlings. Finck (1968) prepared a table of symptom, yield and toxicity limits for all important nutrient elements covering a series of plants. Although he regarded his data as probable and tentative a suggestion is made for their utilization with regard to fertilizer requirements. Mustanoja (1967) concluded from his studies that foliar analysis proved a reliable method for determining fertilizer treatment. Walker (1955) reports that foliar analysis of native vegetation was found useful as a diagnostic aid in selecting tree species for planting on adverse sites. He found foliar analysis useful in the indication of soils deficient in potassium for normal growth of certain conifers.

Roth, et al., (1948) were able to effect the recovery of shortleaf and loblolly pine to little leaf disease by comparing the nitrogen and calcium foliar contents of healthy trees with those of the diseased trees. They state that "the improvement of diseased trees on high nitrogen plots was accompanied by a rise to normal of the nitrogen content of the foliage. Where trees failed to recover their nitrogen content remained low. Walker, et al., (1955) determined for the first time boron and iron concentrations in foliage of western red cedar with a view to determining possible deficiencies of these elements. This work was followed by Beaton, et al., (1965a) in which, for the same reason, the concentrations of all essential micronutrients and some other elements were investigated for this species.

Mustanoja and Leaf (1965) report that foliar analysis is the conventional method for studying the nutritional status of oil palms.

Gessel, et al., (1969) reported that Douglas-fir in Washington showed a trend toward rising growth rates with rising foliar nitrogen content up to about 1/2 inch (1.27 centimeters) diameter breast height per year and that this maximum was reached when foliar nitrogen was 1.75%.

III. FOLIAR NUTRIENT STATUS

Causes of Variation

Limitations to a wider use of foliar nutrient status stem mainly from the large number of factors which influence the nutrient content and contribute to its variation. The successful use of foliar analysis depends on the degree to which these variables can be kept constant.

Nutrient variation during the year. As indicated by Deleano and Borderanu (1933), Mitchell (1936), Olsen (1948) and Kramer and Kozlowski (1960), most of the studies on varying nutrient status of leaves give results only as a percentage of the dry weight. Because changes in the dry weight of leaves during the season cause changes in the concentration, the value of these results is doubtful and findings may in fact only be artifacts of the changing dry weight.

It is generally conceded that sampling should be made during periods of physiological stability in relation to the metabolic rhythm of the trees (Mustanoja, 1967). Srivastava (1965) working with *Shorea robusta* showed that leaf samples should be collected during May - June or January - February as concentration of most nutrients decreased during the yellowing period. He found a definite rise in sesquioxides, calcium and potassium from March to June and a sudden fall from June to September.

Jung and Riekle (1966) emphasize the importance of taking samples at the same time of the year. Járó (1967) working with poplar and pine in Hungary concluded that deciduous leaves should be collected from mid-May to mid-September and that pine should be collected in the middle of the growing season and second year needles at any time of the year. These latter two conclusions are at variance with general results of other investigations. Hoffman (1967) reports that the nitrogen percentage of *Robinia* decreased progressively throughout the growing season. Guilimondi (1966) found considerable variation in nitrogen, ash content and the main ash constinents of Poplar during the growing season (May to October). Prozt (1967) working with Scots pine, *Quercus borealis* and *Q. cerris* showed that nitrogen uptake was highest in spring and dropped sharply before leaf fall and that potassium uptake was highest in spring and gradually decreased during the course of the growing season. Miller (1966) working with loblolly pine showed large variations in foliar nitrogen content which he attributed to weather factors. The weather factors most commonly correlated with nitrogen percentage were mean maximum and mean minimum temperatures for certain periods preceding the sampling date. He found no period of nitrogen stability during the year. Cannon, et al., (1960) working with Crataegus, Quercus and Gleditsia, found an increase of calcium, magnesium, iron and manganese percentages during the growing season and a decrease in nitrogen, phosphorus, and potassium percentages, with the exception of Quercus where potassium increased. Olsen (1948) working with beech foliage found that nitrogen percentage was much higher in May than in the summer months and that it maintains this high level constantly through to September. The phosphorus percentage was very high just after leafing but dropped substantially during May and June and remained fairly constant during the following months. The potassium content was highest just after leafing but fell rapidly during May, rose again from early June and reached a new maximum in July. It then fell steadily until defoliation. Calcium content was lowest just after leafing and then rose steadily and regularly until shortly before defoliation. Chandler (1939), working with Fagus, Populus, Magnolia, Juniperus and pine, found that in each case calcium increased during the growing season. Walker (1955) found that foliar potassium decreased as the season progressed for *Pinus strobeus, Acer rubrum* and *Prunus virginiana*.

Chapman (1935) found a decrease in nitrogen percentage during the growing season in *Ulmus pumila* and the same worker (1941) found a decrease in nitrogen and phosphorus in *Hevea brasiliensis* during the same period. Lavender and Carmichael (1966) working with Douglas-fir found an increase in calcium, magnesium, nitrogen, phosphorus and potassium during the growing season. Guha and Mitchell (1966) working with three deciduous trees, sycamore, horse chestnut and beech, found that cobalt, nickle, iron, vanadium, titanium, chromium, lead and aluminum showed a fall in foliar percentage early in the season followed by a steady rise until senescense when a further fall occurs. They found that manganese, boron, silica, calcium, stronium, barium and magnesium percentages rose continually until late in the season, and that copper, molybdenum, zinc, potassium and phosphorus fell gradually followed by a relatively stable period.

Boonstra, et al., (1957) working with *Taxus media* found that the percentage of calcium, magnesium, potassium and manganese increased during the growing season, while nitrogen, phosphorus, boron and iron decreased during the same period.

Davidson (1960) found for all the following species *Gleditsia triacanthose, Acer platanoides, Syringa vulgaris, Eurnymus alatus, Juniperus chinensis, Taxus cuspidata, Euronymus fortunei* that concentrations of calcium, iron and manganese increased during the growing season, nitrogen and potassium decreased during the growing season and there was no change in the concentrations of phosphorus, boron, copper and magnesium. Beaton, et al., (1965) state that the sampling dates for Douglas-fir are not critical between October and February and that sampling of lodge-pole pine needles between September and May would be satisfactory. White (1954) found stable foliar contents of nitrogen, phosphorus and potassium between November and mid-April and the results of the two latter workers confirm the generally held opinion that stability is attained in the dormant period and that sampling during this period eliminates the variation due to season. As these results are given in terms of percentage of dry weight, they may reflect more the stability of the dry weight of the leaf than the stability of absolute foliar nutrient content. Hoyle (1965) working with yellow birch states that "nutrient percentages decreased during early June. Thereafter, nitrogen, phosphorus, sulphur and potassium percentages fluctuated slightly until September then decreased until abscission while magnesium fluctuated considerably and calcium increased steadily." Henry (1908) records that for Quercus, Fagus, Picea and Larix, calcium percentage increased with the growing season while nitrogen, phosphorus and potassium decreased. McVicker (1949) confirmed these results for Quercus. Tamm (1951) reports the same results for *Betula verrucosa* as did McHargue and Roy (1932) with a variety of hardwoods.

There is a mass of literature on results of foliar analysis of horticultural crops and the pattern here follows fairly closely the general pattern found in tree species. That is, calcium, magnesium, iron and boron percentages tend to increase during the growing season while nitrogen, phosphorus, potassium, zinc, copper and sulphur tend to decrease. It appears that almost universally there is a period of stability of foliar nutrient concentrations during the dormant period of evergreens and that it is during this period that sampling should be made.

Nutrient variation between years. Boynton and Compton (1945) found that potassium and magnesium percentages in apple leaves could vary considerably from year to year. They attributed this to seasonal effects, as have other investigators. Cannon, et al., (1960), working with *Gleditsia triacanthos, Quercus palustris* and *Cretaegus phaenopyrum*, found that while nitrogen, phosphorus, magnesium and manganese percentages remained fairly constant, potassium, calcium and iron percentages varied with the years they were sampled. Forshey (1963a) attributes the varying potassium levels in apple trees from year to year to rainfall. Labanauska and Puffer (1964) working with orange leaves found significant differences in manganese and zinc content from year to year.

Nutrient variation with tree age. The literature on this source of variation is meager compared to the work that has been done on the age of the foliage on the tree. To some extent, this is due to the fact that in most instances where foliage analysis is used as a practical tool for assessing fertilizer requirements the forests are either even aged or plantations. Also where a number of variables are considered in correlating nutrient status with site productivity, provision can be made in the regression analysis techniques for differing tree age. What literature does exist generally points to a variation of foliar nutrient status with tree age.

Peterson (1961) working with *Agathis australis* found that potassium and manganese percentages increased with increasing tree age and nitrogen, phosphorus, calcium, sulphur and iron percentages decreased. Askew (1937) working with Monterey pine found that nitrogen, magnesium, potassium and manganese percentages increased with increasing tree age and calcium, potassium and sodium percentages decreased. Differences in foliar nutrient content between years have also been identified by Plice (1944) and Tamm (1956a).

Nutrient variation with age of foliage. Work on this subject has been extensive and these studies show that, as leaves age, concentrations of potassium, phosphorus and nitrogen decrease; magnesium does not change consistently and calcium increases.

Madgewick (1964) working with Red pine found that nitrogen percentages in one- and two-year-old needles were approximately the same but that it decreased in three-year needles. He also found that potassium and phosphorus percentages decreased and calcium percentage increased with age, and that magnesium percentage did not change consistently. Nakajima and Tsujita (1967) working with *Pinus densiflora* showed that the percentages of nitrogen, phosphorus and potassium were higher in younger leaves than in older. Beaton, et al., (1965a) working with Western red cedar and Douglas-fir showed that aluminum, manganese and iron increased with increasing foliar age, while boron, cobalt, molybdenum and copper decreased. Beaton, et al., (1965b) working with these same two species together with a range of other conifers, found that calcium and magnesium percentages were higher in the older foliage, while nitrogen, phosphorus and potassium were higher in the younger foliage. Nommik and Popovic (1968), working with eleven-year-old pine, found that needle age was not of great significance in determining nitrogen content.

Lavender and Carmichael (1966), working with Douglas-fir, generally confirmed these results but found that magnesium percentage decreased with increasing foliar age. Fielder and Wunderlich (1967) found there was little difference in the foliar nutrient status of one- and two-year-old pines.

The general trend for increased calcium percentage and decreased nitrogen, phosphorus and potassium percentages with increasing age had also been demonstrated over a wide range of coniferous species by Leyton and Armson (1955), Peterson (1961) and Will (1957).

Variations in nutrient concentrations with either foliar age or tree age are probably due to dilution effects or nutrient mobility. In the former, dry weight of the tissue might increase with no increase in absolute amount of a nutrient, producing lower concentrations. In the latter, it has been demonstrated that there is considerable movement of elements in and out of tissues which may occur at regular periods each year for some physiological purpose or the movement may be random, following the sap stream.

Nutrient variation with position in the crown. There is a considerable volume of literature on this subject but the results are so variable it is difficult to make any generalized statements. The review which follows selects examples to show the diversity of the results. There appears to be some correlation between nutrient content of foliage of the same age in varying positions in the crown. Leyton (1948) gives detailed results of work carried out to that date. Heinsdorf (1967) and Járó (1967) conclude that exposed foliage from any part of the crown of deciduous trees is suitable for comparative analysis and that nutrient status of spruce foliage tends to decrease slightly in an upward direction from whorl to whorl. Wehrmann (1957) found that irrespective of the quantity of nitrogenous fertilizer applied to a stand of spruce, the foliar nitrogen content decreased from the top downwards in the current foliage. Lavender and Carmichael (1966) found that nitrogen, phosphorus, potassium and magnesium increased toward the top of the crown in Douglas-fir and calcium decreased. In a variety of conifers, Swan (1962) found a general trend of increasing nitrogen toward the top of the crown with no trend apparent in phosphorus, potassium, calcium and magnesium. Madgwich (1964) obtained the same results with Red pine. Jung and Riehle (1966), following a discussion on the reliability of foliar analysis, emphasize the importance of taking samples from the same position in the tree. Young, et al., (1967) found that in general the concentration of nutrients in the foliage of *Picea rubens* increased with increasing height, but in *Pinus strobus* it decreased with increasing height. Nommik and Popovic (1968) report that in pint there is very little variation in the top part of the crown and that total nitrogen content of shoots also varied little with position in the crown. Gagnon (1964) reports an increase in nitrogen toward the top of the crown. Humphries and Kelly (1962) found no variation of phorphorus percentage with crown position, while Wallihan (1944) found no variation in phosphorus, potassium, or calcium in *Acer saccharum* but a decrease in nitrogen toward the top. Strebel (1961) found significant differences in foliar content of current needles in spruce from top to bottom of the crown but there were inconsistent. In some instances needles from terminal shoots of lower whorls had sometimes higher and sometimes lower concentrations of nutrients than needles from the apical whorl.

Leech (1965) states "The nutrient content of the leaves of the leading shoots probably serves as the best guide to tree vigor, since, if there is a nutrient lack in the leaves which are most active photosynthetically the need throughout the rest of the foliage would be even more critical." Raupach (1967) reports that in foliar analysis of Monterey pine in Australia there was considerable variation in nitrogen, phosphorus, copper, zinc, boron, nickle and molybdenum levels for different sample positions in the tree. White (1954) found an increase in potassium toward the top of the tree but recommended mid-crown positions as expressions of crown mean. Wells and Metz (1963) report that in loblolly pine percentages of nitrogen, calcium and magnesium were greater in the needles from the bottom part of the crown, whereas phosphorus and potassium percentages were greater in the upper part of the crown.

While these examples illustrate the wide range of results varying with species and with nutrient elements, the literature generally points to the conclusion that in most cases nitrogen percentage increases toward the top of the crown, potassium and phosphorus content are independent of crown position, and calcium and magnesium are either independent of crown position or decrease toward the top.

Nutrient variation with branch aspect. Here again the literature is meager and inconclusive. Two investigators, Walliham (1944) and White (1954), showed that foliar nutrient content of oak and pine respectively were independent of aspect, as did Young, et al., (1967) with spruce and white pine.

On the other hand, Peterson (1961) and Tamm (1951), working with *Agathis australia* and *Quercus ithaburensis* respectively, found that aspect did affect nutrient concentrations.

Other factors. Other factors thought to influence foliar nutrient content are time of day when the sample is taken, management practices in the stand, disease, fruit production and leaf size. Very little investigation has been carried out to establish the importance of these factors and what has been done is in most cases contradictory and inconclusive.

Sampling

The foregoing review on causes of variation in foliar analysis gives obvious leads on when and where sampling should take place. Methods of sampling also play an important part in obtaining meaningful foliage analysis data. Robinson and Freeman (1967), working with *Pinus patula*, showed that the coefficient of variation of 15% in his results was largely due to field sampling, less to laboratory handling and least to analytical techniques. The great variation in foliar nutrient status of adjacent trees compounds the difficulties of defining a satisfactory sampling procedure.

Reemtsma (1966) attributes this to differences in site factors. Metz et al., (1966) found that only a small proportion of the variation in nutrient content of loblolly pine could be accounted for by variation in the nutrient level of the soil. Hoffman (1967) emphasizes the effect of phenology on fluctuations. Mustanoja (1967) recommends that small sample plots, i.e., about 1/2 acre (0.202 hectares) should be used in very young stands, as the older stands are likely to have a common root system and probably only require the sampling of a few representative trees. He also recommends that sample plots should be laid out more in relation to stand than to site homogeneity. Rennie (1966) sets out guide lines for sampling in *Pinus resinosa* stands which include the choice of forest material, nature and size of sample plot, size of sample, time of sampling, preparation of samples and units of measurement.

Wehrmann (1959), working with Scots pine, recommended that at least ten trees should be sampled to estimate nitrogen and phosphorus percentages, 30 trees, the potassium and magnesium percentages, and 100 trees, the calcium percentage. Lowry and Avard (1967) report that from 7 to 15 trees are sufficient to establish the concentrations of all these nutrients in black spruce.

Most workers recommend the removal of foliage from the branchlet immediately after sampling to minimize the possibility of ion migration or changes in dry weight. White (1954), working with *Pinus resinosa*, has shown that the drying of needles on the branch introduces substantial errors. On the other hand, Tamm (1951), working with Betula foliage, could not establish any difference in results when the material was dried on the branch and when it was removed immediately after sampling.

Lowry and Avard (1967) recommend that only dominant and co-dominant trees be sampled when site quality relationships are involved.

Tamm and Troedsson (1955) showed that the presence of dust and aerosols on foliage could affect analyses results but Ward and Johnson (1962) recommend that unless this contamination was particularly severe, cleaning should be done by gentle brushing of the foliage rather than washing as the latter method could introduce even greater errors through leaching.

Effect of Fertilization

An important use of foliar analysis is in the detection of nutrient uptake following the application of fertilizer to the soil. Generally, the literature points to increase in nutrient status but instances of no increase or a reduction in the concentration of certain elements give indications of interactions and antagonisms.

Nitrogen content of foliage invariably increases following the application of nitrogenous fertilizer. Heilman (1961) reports that needles of Douglas-fir on control plots had nitrogen concentrations of 0.893% to 1.051%, while needles on fertilized plots varied from 1.002% to 1.438%. He also found that accompanying this increase in nitrogen was a marked reduction in phosphorus concentrations and that potassium concentrations were lower but that potassium uptake had increased. Gessel and Walker (1956) reported that control plots of Douglas-fir had 1.0% or less foliar nitrogen while fertilized plots ranged from 1.2% to 1.8%. Broadfoot (1966), working with sweet gum, water oak and willow oak, found that leaves from trees fertilized with 150 pounds (68.04 kilogrammes) of nitrogen, 150 pounds of nitrogen plus 36 pounds (16.33 kilogrammes) of phosphorus and 66 pounds (29.94 kilogrammes) of potassium per acre (0.405 hectares) contained more nitrogen than unfertilized plots. The foliage from trees fertilized with 300 pounds of nitrogen per acre (336 kilogrammes per hectare) was greater than that of other leaves. He reports that foliar phosphorus content decreased as nitrogen was increased and that the reverse appeared to be true for oak. There was no alteration in foliar content of potassium with any of the foliar treatments. Martin and Carter (1967) found no significant increase in foliar nitrogen concentrations following applications of ammonium nitrate. Watt (1967), working with black spruce, found that foliar nitrogen increased with heavier applications of nitrogen, but that increases in applied nitrogen resulted in decreases in phosphorus foliage percentage.

Moehring (1966) found nitrogen content of *Pinus taeda* increased following fertilization but the response only lasted 2 years. Beaton, et al., (1964), working with Douglas-fir, found that unfertilized trees contained 1% or less and that fertilized trees contained 2% more. This is in accord with the observations of Gessel and Walker (1956) and Heilman and Gessel (1963) working with the same species. Beaton's work also confirms the results of the latter worker regarding potassium which was observed to decrease with nitrogen fertilization.

Lacey, et al., (1966), using flooded gum seedlings in Australia in hydroponic solutions, found that increasing the phosphorus supply resulted in marked increases in foliar nitrogen, phosphorus and potassium, and decreases in calcium percentage. Magnesium content was unaffected. Hall and Raupach (1963), working with Monterey pine in Australia, found that the addition of potassium chloride fertilizer in general did not affect nitrogen and phosphorus foliar concentrations while potassium concentrations increased. Miller and Walker (1967), working with Corsican pine, found that the nitrogen concentrations in both top whorl foliage and needle litter was more than doubled following application of ammonium sulphate. Wehrmann (1957) applied ammonium sulphate at varying rates to spruce and found that increases in application resulted in increases in foliar nitrogen percentage. Kennel and Wehrmann (1967), working with pine, established a linear correlation between amount of nitrogen applied and foliar nitrogen content. Materna (1966) found an increase in foliar nitrogen in spruce following application of nitrogenous fertilizer but noted that it was only temporary. Porgasaar (1966) found that the foliar nitrogen in pine rose from 0.93% to 2.59%, foliar phosphorus rose from 0.07% to 0.32% and foliar potassium was unaltered following the application of nitrogen, phosphorus and potassium fertilizer. Sander (1966) found that the nitrogen concentration of *Pinus contorta* seedlings was not significantly influenced by application of urea and urea formaldehyde.

Heinsdorf (1967) found that foliar nitrogen and potassium contents of pines from fertilized stands were correlated with the amounts of fertilizer added. Hippeli (1967) found that the poorer the nitrogen concentration of pine needles, the greater was the effect of nitrogen fertilizing on the nutrient content on the trees. Lee (1967) fertilized European black pine with nitrogen and found that foliar concentrations of nitrogen and manganese were increased, while contents of potassium, phosphorus, magnesium, boron, zinc, and aluminum were decreased. Finn (1967) in sand culture experiments with yellow poplar showed a significant positive correlation between nutrient solution concentrations of nitrogen, phosphorus, potassium and calcium and foliar concentrations. White (1965) in green house trials with *Picea mariana* and *Pinus strobus* showed an increase in foliar nitrogen following application of ammonium phosphate. Swan (1970) demonstrated a close positive relationship between graduated increases in nutrient supply and foliar nutrient concentrations in pot culture experiments with black spruce and jack pine seedlings. Earlier work by Van Goor (1953), Leyton (1954, 1957) and Tamm (1956, 1957) also showed an increase of foliar nitrogen following fertilization. Antagonisms between nutrient elements were also demonstrated in earlier work by Van Goor (1953), Tamm (1956) and Leyton (1957) who demonstrated that nitrogen fertilization decreased the phosphorus content of conifer foliage. Interactions were likewise demonstrated by Leyton (1954) and Tamm (1956) between nitrogen, phosphorus and calcium following application of nitrogen. These decreases in concentration of certain elements may be due to the increased tree mass producing dilution effects and lowering the concentration per unit dry weight of the tissue while the total amount in the tissue remains unchanged.

Relationship to Growth

Although tree growth is not a function of nutrient uptake alone, foliar analysis does provide a means of appreciating more fully the relationships between nutrient uptake and growth.

Many studies of the relationship between foliar nutrient status and various aspects of tree growth have been made. In some cases, there appears to be a direct relationship with certain nutrient elements and in others the varied relationships point to antagonism and interaction influences.

It is generally agreed that the concentration of foliar nitrogen of many conifers is directly related to tree growth. This has been demonstrated by Armson (1959) in spruce, Leaf (1956) in Finland, Leyton (1948) and (1956) working with Japanese larch, Linteau (1955) with coniferous species in Canada and confirmed by Swan (1962), Weetman (1962) with black spruce, Wehrmann (1957) with spruce and (1959b) with *Pinus sylvestris*, Zöttl (1960) with Bavarian spruce and pine, Zöttl and Velasco (1966) with pine in Spain, Höhne and Fiedler (1967) working with Scots pine, Lowry and Avard (1967), Kennel and Wehrmann (1967) with *Pinus sylvestris* in Bavaria. A correlation between foliar nitrogen content and tree height was found by Strebel (1960) in Bavaria and Wright (1958) reported similar results from England. Leyton (1958) showed that there was a relationship between foliar nitrogen and total height and between the foliar content of one-year-old foliage and height increment. Shear, et al., (1953), working with tung trees, Leyton and Armson (1955) with Scots pine, Leyton (1957) working with Japanese larch, Hoyle and Mader (1964) with *Pinus resinosa*, Raupach (1967) with Monterey pine in Australia, and Rehfuess (1968) working with silver fir demonstrated the relationship between several nutrients and tree growth by multiple regression techniques.

The concept of nutrient balance (Shear, et al., 1948, Kenworth, 1961) has been demonstrated by Fowells and Krauss (1959), May, et al, (1962) and McGee (1963) in their studies on the relationship between foliar nutrient status and growth where they found that normal growth occurred over a wide range of foliar nutrient concentrations.

"There is no single optimum level for any one nutrient element in the foliage," Steinbeck, et al., (1966). These latter workers found that when the supply of nitrogen, phosphorus, potassium and calcium in a green house study was varied, these variations were reflected in foliar content and growth and that growth and foliar content were related. Similar correlations between varying nutrient supply and growth had been demonstrated earlier by Okšbjørb (1956) and Leyton (1957). Leech (1965), working with Red pine, found that nutrient content of foliage samples from the leading shoot correlated well with growth rates.

There appears to be a well-recognized relationship between foliar content and leader length and internodal growth. Steinbech (1966) found this in Scots pine. Leyton (1958) demonstrated a relationship between height increment and foliar nitrogen content of one-year-old foliage. Kim and Chang (1967) showed that foliar nitrogen and phosphorus were significantly correlated with current height growth.

Significant linear correlations were established by Leyton and Armson (1955) between height growth of Scots pine and the needle concentration of a series of nutrient elements. Kawada, et al., (1967) in the work with *Pinus densiflora* in Japan found a good relationship between nitrogen and phosphorus content of the foliage and current height growth. Hoyle and Mader (1964) found that foliar calcium was strongly related to height growth and potassium to basal area growth.

Kreutzer (1967b) reports that following two applications of 100 kg of nitrogen per hectare (89.2 pounds per acre) to Norway spruce stands, the increase in foliar nitrogen was closely correlated with increase in increment and that an increase of 0.1% in the mean nitrogen content of needles corresponded with an increment of two cu. m. of stem wood per hectare (14.3 cu. ft. per acre) per year.

Finn (1953) found a generally good relationship between total height growth and foliar nitrogen for a range of species. Schomaker and Rudolph (1964) found that both nitrogen and phosphorus concentrations in the foliage of yellow poplar were closely correlated with height and diameter growth. Gessel, et al., (1969) have shown there is a relationship between increment and foliar nitrogen in Douglas-fir. Nebe (1967) found no correlation between magnesium content of spruce needles and growth. Lee (1967) working with European black pine found no correlation between growth and foliar nutrient status.

Relationship to Tree and Stand Characteristics

The relationship between site index or site class and foliar nutrient status has been investigated by a number of workers. While site index gives a measure of the growth of a stand over a period of time, the results obtained by the investigators did not parallel those obtained when current growth rates were compared with foliar nutrient status as was described in the previous section. The current vigor of the tree is represented by current growth and may not reflect the vigor or growth rate of the tree or stand over its life; that is, its site index or site class.

Watt (1967) found nitrogen and phosphorus content of *Picea mariana* correlated with site index and were deficient on poor sites. Porgasaar (1965) found nitrogen and phosphorus content of pine needles rose with rising site.

Bhatnagar (1957), working with *Shorea robusta* in India, found that nitrogen, calcium and magnesium were negatively correlated with site index and that potassium and phosphorus concentrations showed a random distribution with site index but that their concentrations were lowest in the highest site qualities and vice versa. Seth and Bhatnagar (1960), working with the same species, showed almost a linear negative correlation between nitrogen and phosphorus and site index and that the combined concentrations of calcium, magnesium and potassium were constant for all site indices. However, Kaul, et al., (1963) found for the same species that nitrogen, potassium, and calcium concentration decreased as site index decreased, that phosphorus remained constant and magnesium increased with lowering site.

Von Rehfuess (1968) found significant positive simple correlations between phosphorus, nitrogen, calcium and iron content of silver fir needles and site index. Watt (1967) found that, on examination of nitrogen, phosphorus, potassium, calcium, magnesium, manganese, copper, iron, boron, zinc, molybdenum, aluminum and sodium content of black spruce foliage, nitrogen and phosphorus were the only two elements significantly and positively correlated with site index. Potassium was inversely related and the concentration of the other ten elements showed no relation to site index. Viro (1962) found that the nutrient content of the needles varied entirely independently of site index in Lapland. There is the possibility of dilution effects influencing the results in the faster growing high site trees and in the case of Viro's work in Lapland, the extreme cold possibly influenced the normal physiological processes of the tree and the results.

The relationship of foliar nutrient status to other stand characteristics has also been investigated. Lowry and Avard (1967) found no significant differences in foliar nitrogen, phosphorus and calcium with crown class of black spruce but significant differences in foliar potassium and magnesium with crown class. However, they state that "in general, dominant and co-dominant trees showed closer nutrient relationships with growth yield than did the intermediate and suppressed trees."

Certain relationships have been established between foliar nutrient status and tree characteristics. Miller and Miller (1967) showed that the nitrogen content of Corsican pine was increased following fertilization with nitrogen and that this increased foliar nitrogen content caused an increase in needle retention on the tree.

Höhne and Fiedler (1967) showed that the nitrogen content of Scots pine foliage was increased by nitrogen fertilizer and this was followed by a 63% increase in the number of trees having 3-year-old needle bundles, and that cone yields were more than 30% higher. The relationship between needle size or weight and nutrient content should be viewed with caution. Zelawski and Gowin (1966) and Zelawski and Niwinski (1966) showed for Scots pine that needle size and weight differed greatly between provenances and between years and ecological conditions.

Some work has been done on the relationship between visual characteristics of needles, notably color, and their nutrient status. Color alone as an indicator of foliar nitrogen appears doubtful. Brackett (1964) classified Douglas-fir needles into color classes using the Munsell Color Charts for Plant Tissues (1952), but found that the majority of color values were in the 7.5 GY hue, on chips 3/4 and 4/6 in spite of a wide variation in foliar nitrogen content. Steinbech (1966) states in reference to Scots pine that "genetically controlled color differences are not related to difference in nutrients."

Wilde and Voight (1952) found the Munsell Color Charts useful in diagnosing deficiencies in nursery stock. Leech (1965) states that "leaf color changes are sometimes useful diagnostic guides to nutrient conditions but only if used in conjunction with other indicators." Steinbech, et al.,

(1966) note that normal needle color occurs over a wide range of nutrient concentrations. There are numerous reports of nitrogen fertilizer "improving the color," that is, turning a chlorotic leaf to a darker green, and as has already been described, there is an accompanying rise in foliar nitrogen levels.

Foliage symptoms have long been correlated with nutrient deficiencies and foliar nutrient status. Walker (1956) established such a correlation for a number of hardwood species.

It would appear, however, that for most coniferous tree species color alone is not sufficient to make predictions on foliar nutrient status, at least until a more subtle range of colors is established than those in the Munsell Color Chart.

IV. SITE PRODUCTIVITY AND SITE INDEX

Measures of Site Productivity

Methods of assessing the capacity of a site to grow forest crops have been under investigation for many years, and it is apparent from the literature that foresters, ecologists and plant physiologists alike have a need for such assessments. In some cases, the need is for predictive information and, in other, to establish and understand the variety of factors involved.

Tree growth and thus site productivity depends on both biological and environmental influences on the tree (Kramer, 1956). Biological factors include genetic variation, stand density, competing vegetation and insects and diseases (Ralston, 1964). Site factors include meteorological conditions, topographic effects and edaphic factors (Ralston, 1964).

Voluminous literature points to the topographic and edaphic factors as the most significant.

The general techniques used in traditional soil site studies fall into two groups. Up until 1942, the "rating" or classification system was commonly used (Hanzlick, 1914, Westveld, 1933, Coile, 1935, Donahue, 1936). In this type of study, the tree growth observed on a plot was simply noted concurrently with various site parameters.

Coile (1942), Slade (1949), and McClurkin (1951) pioneered the application of regression analysis techniques to the study. This regression approach enabled the investigator to measure or evaluate many site and/or soil parameters acting in the presence of each other. Tamm, et al., (1967) describe this procedure in detail.

Many examples appear in the literature of site productivity studies indicating the wide variety of species, location, measure of site productivity and the factors which were found significant in predicting site productivity in each study. Certain general conclusions can be drawn from an examination of these investigations. Soil moisture is the most frequent significant factor and appears to be the critical site factor, while soil nutrient status occurs with less frequency as a significant factor and presumably is not as critical as soil moisture. However, such factors as texture, total depth of soil, depth of the A_1 horizon are all frequently significant factors each of which reflects to some extent the capacity of the site to supply nutrients.

An extreme case of the effect of soil moisture on growth is reported by Zahner and Connelly (1967) working with *Pinus resinosa*. They found that moisture deficits alone in a particular season had a simple correlation of

-.83 with ring width for that season and that multiple regression of both rainfall and moisture deficit for the current and previous seasons accounted for over 80% of the annual variation in ring width (R = .91). They conclude however that correlation coefficients of .80 to .90 are approaching the upper limit for relating in a single environmental factor (in this case, moisture) to tree growth. A more typical example is reported by Griffith (1960) following his investigations into the growth of Douglas-fir as related to climate and soil, where he found that available soil moisture in the "B" horizon was the most important single variable and it accounted for 47.05% of the total variation in growth.

Measures of Site Index

The most popular and probably the most useful method for measuring site index involves the determination of stand height at specified age points (generally, the rotation age) on either computed or graphically derived height-age curves.

The standard system in Germany at the beginning of the century was based on the volume at 100 years (Roth, 1916), and this was accepted in principle in this country. However, its usefulness was criticized because it was not satisfactorily applicable and numerous workers turned to height growth as a basis. Although Roth (1916) initiated the move, Frothingham (1918, 1921), Sterrett (1921) and Watson (1917) laid the foundation for our present system based on the height of dominants and codominants at a specified age.

These workers favored height as the basis because its measurement was simple and accurate. They also believed it was free of stocking density effects and that it was a reliable indicator of volume yields. On this point, they generally agreed with Bates (1918) that "the only final criterion of site quality is the current annual cubic foot increment of a fully stocked stand," but they rejected this as a standard as being too difficult to apply in practice.

A committee set up by the Society of American Foresters to consider and report on methods of classifying forest sites and to make recommendations (Society of American Foresters, 1923) concluded that volume production was the ultimate measure of site productivity but there was a favorable opinion expressed toward height growth as a basis.

More recently, Mader (1963) reviewed the advantages of defining site in terms of periodical volume growth and stated that "continued evaluation of site in terms of volume growth as well as height growth is desirable." He suggested the use of growth at a selected stage of development and Stage (1966) proposed that this stage of development be the point at which mean annual increment is a maximum for fully stocked stands.

Carbonnier (1968) described various methods of determining site quality and stressed the advantages of using top height at 100 years for pine. Bugaev (1967) proposed a scale of productivity classes based on the mean increment of the gross volume of mature stands where gross volume equals standing volume plus thinnings plus natural mortality plus branches. Svalov (1967) reviewed the statistical methods in compiling site class tables based on tree height and produced a table for Scots pine. McArdle and Meyer (1930) prepared curves for the determination of site index for Douglas-fir in the Pacific Northwest based on the height of dominants and co-dominants at 100 years. Curtis (1966) indicated that the site index curves from which this table was prepared tended to underestimate the site index of younger stands. King (1966) prepared curves for the same species based on the height of dominants and co-dominants at 50 years of age.

Investigations into the relationship between foliar or soil nutrient status and site index are sparse but what little evidence exists points to the fact that site index based on height at a specified age does not correlate well with or give indications of either soil or foliar nutrient status. Mader and Owen (1961) investigating the relationships between soil nitrogen and growth of red pine showed that better correlations occurred using periodic volume growth estimates than with total height at 25 years, periodic height growth or volume at 25 years. Mader (1963) reports that this work was continued at a later date with another series of multiple regression analyses and that there was a considerably higher multiple correlation coefficient using volume data as compared to height data. Also the standard partial regression coefficients for nitrogen values were strong when volume was used as a dependent variable and weak when height growth was used.

Hoyle (1961) working with the same species in the same area, studied the relationship between foliar nutrient status and growth and found that although the extent of the study was limited there were clear indications that height and volume growth do not react in the same way to differences in foliar nutrient status. The nitrogen content of the foliage was strongly related to volume growth and weakly related to height growth. The evidence from a number of similar studies leads to the conclusion that height growth does not reflect site differences to the same extent as volume production. Height growth varies with climatic characteristics of the growing season (Pearson, 1918, Brester, 1918, Baker, 1950), although some workers have found the opposite to be true (Fielding, 1966). Height growth seems to be more strongly controlled genetically than volume growth (Mader, 1963). Hoffman (1963) concludes that height alone cannot indicate site quality because of the great influence he found of stand treatment on height. Sjolte-Jørgensen (1967) states that, for a number of coniferous species, mean height of a stand is increased with increasing spacing. Cromer and Pawsey (1957) and Cromer (1961) working with Monterey pine found a significant linear correlation between spacing and average height of 15 sample trees in each plot and between spacing and the average height of the five tallest trees in each plot. Eversole (1955), working with a 27-year-old Douglas-fir stand, concluded that increased spacing resulted in increased height growth. Staebler (1956) reported that the height growth of residual trees in a 23-year-old Douglas-fir stand was decreased by thinning. Miller (1961) in thinning investigations of the same species showed that increases in height growth were directly proportional to the degree of release, although height growth was reduced during the first two years after thinning.

In the final analysis, it would seem that the great body of literature points to the fact that site index based on height at a specific age is not a satisfactory indicator of the current growth or vigor of the stand and therefore cannot be expected to be related strongly to the nutrient status of the stand or to be a satisfactory indicator of nutrient requirement. It has been shown repeatedly that there is a strong relationship between nutrient status or the tree and current growth and a weak relationship between the height-age site index and current growth.

V. SUMMARY

The fertilization of forests to increase productivity has become an accepted and sometimes necessary management practice over a wide range of species and geographic areas of the globe. Almost all the essential macronutrients and micronutrients have given growth responses to some species somewhere.

Plant analysis, and particularly foliar analysis, has been shown to be a useful diagnostic tool in detecting nutrient deficiencies and in predicting growth response to fertilization. There is evidence that it has greater potential than soil analysis for these purposes.

For a large number of nutrients which have given substantial growth respons in certain species, a considerable body of knowledge, essential to the use of this tool , has been gained concerning such questions as the distribution pattern of foliar nutrient concentrations in the crown, the sensitivity or certain foliar ages and positions in reflecting environmental conditions, the range and variability of foliar nutrient levels in a forest stand and the relationship of foliar nutrient concentrations and growth response to site index and other characteristics of the stand and the tree.

Growth response of Douglas-fir in the Pacific Northwest to applications of nitrogenous fertilizer has been well demonstrated and the practice of fertilizing Douglas-fir forests with urea to obtain substantial increases in productivity has been firmly established.

The potential use of foliar nitrogen analysis for detecting deficiencies and predicting response is recognized but there is a dearth of information on certain fundamental and essential aspects of foliar nitrogen content in Douglas-fir which at present restricts its usefulness.

Primarily the following information is required to assess the usefulness of foliar nitrogen analysis:

1. The distribution of foliar nitrogen in the crown.
2. An appropriate tree sampling procedure.

3. An appropriate procedure for sampling small stand areas.
4. An appropriate procedure for sampling large stand areas.
5. The range and variability of foliar nitrogen within a stand.
6. The effect of stand conditions on foliar age and position.
7. The relationship of foliar nitrogen to the stand characteristics of site, age and stocking and to the vigor and appearance of the tree.

Work reported by Gessel, et al., (1969) suggests that growth response may not be related to site index. It appears that there are so many other sources of variation that response is not site dependent, but may be more closely related to the current vigor of the tree.

This poses the important questions of whether foliar nitrogen status is related to site index, whether it is related to the current vigor of the tree, and whether site index is related to the current vigor of the tree. The answers to these questions may have their explanation in the dilution effects occurring in the foliage of the faster-growing trees.

And finally,

8. If foliar nitrogen concentrations can be related to the current vigor of the stand and hence to growth response, the question is raised whether, for its operational use as a tool, it can be predicted by tree characteristics rather than determined by chemical analysis.

The investigation presented here attempts to find answers to these questions. It is therefore not an explanatory investigation, but an exploratory investigation and is thus, by nature, empirical, using appropriate statistical techniques where necessary to explore the presence or absence of relationships and to give empirical information on such questions as the range and variability of foliar nitrogen levels existing on the study area.

CHAPTER III. LOCATION AND DESCRIPTION OF SAMPLING AREA

I. LOCATION, AREA AND OWNERSHIP

The sampling area is located in Whatcom County in the northwest corner of Washington State, six miles east of the town of Sumas and adjacent to the Canadian border. It lies on the floor of the Columbia Valley two miles east of the railroad siding of the same name on Lat. 49° 0' N., Long. 122° 7' W.

The area is owned by Bloedel Timberlands Development Inc. and has an area of 1,000 acres.

II. PAST HISTORY

The original stand was a fair quality Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), Western hemlock (*Tsuga heterophylla* (Raf.) Sarg) mixture. Logging of the area commenced between 1910 and 1920 and was completed by 1935. A ground lead system of clear cutting was used which flattened all vegetation and bared the surface soil over large areas. These areas were invaded by native grasses and, for several years following logging, the area was grazed with 300 to 400 head of cattle.

Eventually the regeneration of the Douglas-fir and hemlock apparently reached a stage where the grass was suppressed and the cattle were removed, only to be followed by Christmas tree cutters who virtually clear cut the area again. The intense operations of the Christmas tree cutters continued for several years and as their intensity lessened certain parts of the forest were able to reestablish themselves.

It was during these early stages of reestablishment that three major fires swept down from Canada within a 5-year period and took a further toll of the young forest.

A degree of stability was reached about 1940 and there have been no disturbances to the normal development of the forest since the property was purchased by Bloedel Timberlands Development Inc. in 1952, except for a severe setback in 1955 when freezing winds killed the leading shoot on most of the trees in the stand.

III. COMPOSITION AND STRUCTURE OF THE STAND

On the higher quality sites, the forest consists of second growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) over approximately 95% of the area and Western hemlock (*Tsuga heterophylla* (Raf.) Sarg) covering the remaining 5%. On the lower sites, these figures are 64% and 36%, respectively. Mixed with these species but in smaller numbers are Western white pine (*Pinus monticola* Dougl.), Sitka spruce (*Picea sitchensis* (Bong.) Carr) and Western red cedar (*Thuja plicata* Donn).

Thickets of Red alder (*Alnus rubra* Bong), Western paper birch (*Betula papyrifera* Marsh), Quaking aspen (*Populus tremuloides aurea* Michx.) and Vine maple (*Acer circinatum* Pursh) occur irregularly over the area.

Lower story vegetation is generally sparse and consists of Salal (*Gaultheria shallon* Pursh), Bracken (*Pteridium aquilinum* var. *lanuginosum* Kuhn), Oregon grape (*Berberis aquifolium* Pursh), Pacific dogwood (*Cornus nuttallii* Audobon) and Toothed wood fern (*Dryopteris spinulosa* Kuntze).

IV. CLIMATE

The climate of the foothills and lower valley floors on the west side of the Cascade Mountains is equable and mild. The prevailing westerly winds from the Pacific Ocean produce a modified oceanic climate and the Cascade Mountains form a barrier against the extremes of temperature experienced in the continental interior to the east. The combined effect of these winds and mountain ranges produces a climate of high rainfall, cool summers and mild winters.

Climatological data from the Clearbrook weather station 10 miles to the west is given in Table (1). This station is at an elevation several hundred feet lower than the study area but is representative of the climate of the region, except that the study area receives a higher precipitation (U. S. Dep. Com.).

This station has a low temperature record of -4° F and a high of 102° F. The average growing season is 138 days. The average maximum temperature is 59.0° F and the average minimum is 38.6° F. Average annual temperature is 49.2° F and average annual precipitation is 46.82 inches. This precipitation falls largely from October to March with the wettest month being December. July and August are the two driest months with average precipitation of 1.46 and 1.58 inches respectively.

Fog lies on the valley floor for most of the fall and early winter months and is generally accompanied by heavy frosts.

Light snow falls each winter on the study area but it does not usually accumulate.

Table 1. CLIMATOLOGICAL DATA: CLEARBROOK WEATHER STATION*

Month	Average Temp. (°F)	Average Precip. (In.)	Mean Daily Max. Temp. (°F)	Mean Daily Min. Temp. (°F)	Highest Temp. (°F)	Lowest Temp. (°F)
January	35.1	5.75	40.1	28.9	62	-4
February	38.5	4.52	45.4	30.9	65	-1
March	43.1	4.47	51.9	34.0	79	9
April	48.8	3.18	59.4	37.5	86	21
May	54.3	2.63	65.9	41.8	91	26
June	58.8	2.58	70.6	46.1	98	28
July	62.1	1.46	76.4	47.4	102	32
August	61.4	1.58	75.8	46.7	98	30
September	57.6	2.92	70.2	43.7	94	20
October	50.3	5.27	60.0	39.6	84	20
November	42.3	5.72	49.5	35.0	69	8
December	38.4	6.74	43.2	31.6	62	2
Annual	49.2	46.82	59.0	38.6	102	-4

*U.S. Dep. Com. Climatological Data, Vol. 71, No. 13.

V. SOIL

The soil of the sampling area is a Barneston silt loam developed on the smooth glacial valley-train deposits of the Columbia Valley. The United States Department of Agriculture Soil Conservation Service Series, 1941, No. 7 describes the soil as follows:

> The [Barneston] soils are low in organic matter and nitrogen and deficient in phosphate, especially for leguminous crops.
>
> A yellowish-brown mellow surface soil containing much shot and a yellowish brown to yellowish gray upper subsoil characterize Barneston soils. Below these layers there is some silt and clay infiltration, the material often resembling unconsolidated freshly course concrete. Rusty brown and gray mottlings usually occur. The lower subsoil consists of open, poorly assorted and stratified glacial drift in which there is no cementation or clay infiltration. The drift materials are chiefly quartzite, granite and granodiorite; but basalt, andesite, rhyolite, argillite, schist, sandstone and shale commonly occur. The proportionate content of the different materials varies considerably from place to place.

The water holding capacity of the soil is low.

VI. RELIEF AND DRAINAGE

The area is flat to gently undulating with a series of well developed terraces parallel to the valley axis. Height between adjacent terraces varies from 5 feet to 50 feet.

Surface drainage is complete and internal drainage is excessive over most of the area. Internal drainage of the lower terraces is moderate to poor.

The elevation of the valley floor is 600 feet above mean sea level.

VIII. POT CULTURE TRIALS

Nitrogen deficiency over large areas of the Douglas-fir region and substantial growth response of Douglas-fir to the application of nitrogenous fertilizer have been widely reported in the literature. The practice of fertilizing Douglas-fir forests is well established.

The appropriatness of choosing nitrogen as the element for study in a foliar nutrient investigation is obvious. However, to confirm that nitrogen is the critical element in Douglas-fir nutrition on the study area, preliminary pot culture trials were conducted using *Pinus radiata* seedlings grown on surface soil from the study area which had been sifted through a one-quarter-inch mesh. The study was conducted in conjunction with the Department of Botany.

Eleven treatments including a control were established using various combinations of nitrogen, phosphorus, potassium, boron, sulphur, magnesium and molybdenum (Table 2). In each treatment there were four replications. Replicates 1 and 2 were without lime and replicates 3 and 4 had lime added at the rate equivalent to two tons per acre.

The *Pinus radiata* seedlings were planted in the pots on 9/23/68 with shoot height of 7 to 8 cm. (2 3/4 to 3 inches) and harvested on 9/19/69.

Table (2) shows the treatments together with the results. Subscripts indicate additions in hundreds of pounds per acre. The results are given at the time of harvesting for total height in centimeters, fresh weight in grams, average dry weight for each pair of replicates and the percentage of the control of this average weight.

Table 2. SUMMARY OF RESULTS FROM POT CULTURE TRIALS

Treatment		Ht. (cm)	Fresh Wt. (grm)	Dry Wt. (grm)	Ave. Dry Wt. & % of Control (1 + 2)	Treatment		Ht. (cm)	Fresh Wt. (grm)	Dry Wt. (grm)	Ave. Dry Wt. & % of Control (1 + 2)
CONTROL											
No addition	1	45.5	19.9	6.55	6.33 (100)	*F*	1	57.5	41.9	13.29	12.24 (193)
except	2	43.0	16.6	5.90		$N_3P_4K_{\frac{1}{2}}$	2	52.5	36.1	11.19	
lime for	3	52.5	29.8	9.77	8.49 (134)	+ S	3	67.5	65.9	20.30	16.66 (262)
3, 4	4	38.5	20.4	7.21			4	67.5	65.9	13.01	
A	1	43.0	25.8	8.47	9.52 (150)	*G*	1	60.0	51.6	15.90	14.02 (224)
N_3	2	50.5	31.6	10.57		$N_3P_4K_{\frac{1}{2}}$	2	55.0	35.7	12.13	
	3	47.0	27.6	8.80	10.76 (170)	+ Mg	3	56.5	39.2	12.99	14.89 (235)
	4	49.5	31.7	12.71			4	53.0	52.8	16.79	
B	1	63.5	32.9	10.43	10.94 (173)	*H*	1	52.0	38.9	11.21	12.22 (193)
N_3P_4	2	47.5	37.1	11.44		$N_3P_4K_{\frac{1}{2}}$	2	56.0	49.6	13.23	
	3	53.5	33.9	10.78	10.56 (167)	+ B,S,Mg	3	48.0	50.3	15.09	15.72 (248)
	4	49.5	31.3	10.33			4	56.0	51.1	16.35	
C	1	40.0	29.3	9.39	9.64 (152)	*I*	1	53.0	40.3	13.04	13.20 (208)
N_3P_{12}	2	44.5	30.9	9.89		$N_3P_{12}K_{\frac{1}{2}}$	2	58.0	42.2	13.35	
	3	51.0	34.4	11.04	10.08 (159)	+ B,S,Mg	3	51.0	38.0	12.78	14.72 (232)
	4	53.0	28.6	9.12			4	53.0	49.8	16.66	
D	1	49.0	30.5	8.90	9.72 (154)	*J*	1	59.0	45.5	14.26	14.62 (231)
$N_3P_4K_{\frac{1}{2}}$	2	43.5	32.7	10.54		$N_3P_{12}K_{\frac{1}{2}}$	2	61.5	46.6	14.98	
	3	52.0	45.1	14.66	13.63 (216)	+ B,S,Mg, Mo	3	50.0	42.5	14.35	13.62 (215)
	4	50.5	39.5	12.60			4	42.0	36.9	12.88	
E	1	58.5	45.7	14.34	13.86 (219)						
$N_3P_4K_{\frac{1}{2}}$	2	47.5	44.0	13.38							
+ B	3	50.0	33.7	11.68	11.23 (178)						
	4	49.0	33.9	10.77							

Subscripts to element symbols indicate additions in hundreds of pounds per acre.

Results

In replicates 3 and 4 of the control (that is, with calcium added) there was an increase in the growth and vigor of the plants. Figure (1) taken at the time of harvesting shows substantially sturdier plants in the pair treated with calcium. The pair without calcium are yellower and this color difference was more pronounced two months before the photo was taken.

Figure (2) shows the treatment where sulphur was added to the stand-are N_3 P_4 $K_{1/2}$ mix. The pair treated with calcium are taller, sturdier, and have a substantially higher dry weight than replicates 1 and 2 without calcium. Thus, in this particular treatment as in the control, calcium has a stimulating effect and there is a suggestion from the data that this stimulating effect is present to some extent in the N_3 P_{12} and N_3 P_4 $K_{1/2}$ treatments.

Figure (3) illustrates the results of the N_3 P_4 $K_{1/2}$ + Mg treatment where there is almost no difference in the size or dry weight between the two pairs of replicates but replicates 1 and 2 without lime are distinctly yellower than 3 and 4 with lime added, suggesting an interaction between calcium and magnesium. On the other hand, Figure (4) shows the results of the N_3 P_{12} $K_{1/2}$ + B, S, Mg, Mo treatment where the addition of calcium had a very obvious inhibiting effect. Height growth is substantially lower with added lime, as is dry weight, and the plants are obviously yellower.

There was an obvious difference in the foliage of plants in treatments with potassium. Those with potassium added had a bushier appearance with longer, pendulous needles. This is demonstrated in Figures (3) and (5).

Figure (5) shows the array of all treatments chosen from the pair of replicates without lime. The data from Table (2) and this figure show a general trend of increasing height, weight and vigor with the addition of supplemental nutrients. The color of the plants varies from yellow on the left (control) through medium green to dark green on the right (all elements) and the effect of potassium on the foliage is apparent.

The results set out in Table (2) show a substantial response to nitrogen and magnesium and a lesser response to potassium, sulphur and boron. There was no response to additions of phosphorus or molybdenum.

These results confirmed the appropriatness of choosing nitrogen as the element for study in a foliar nutrient investigation.

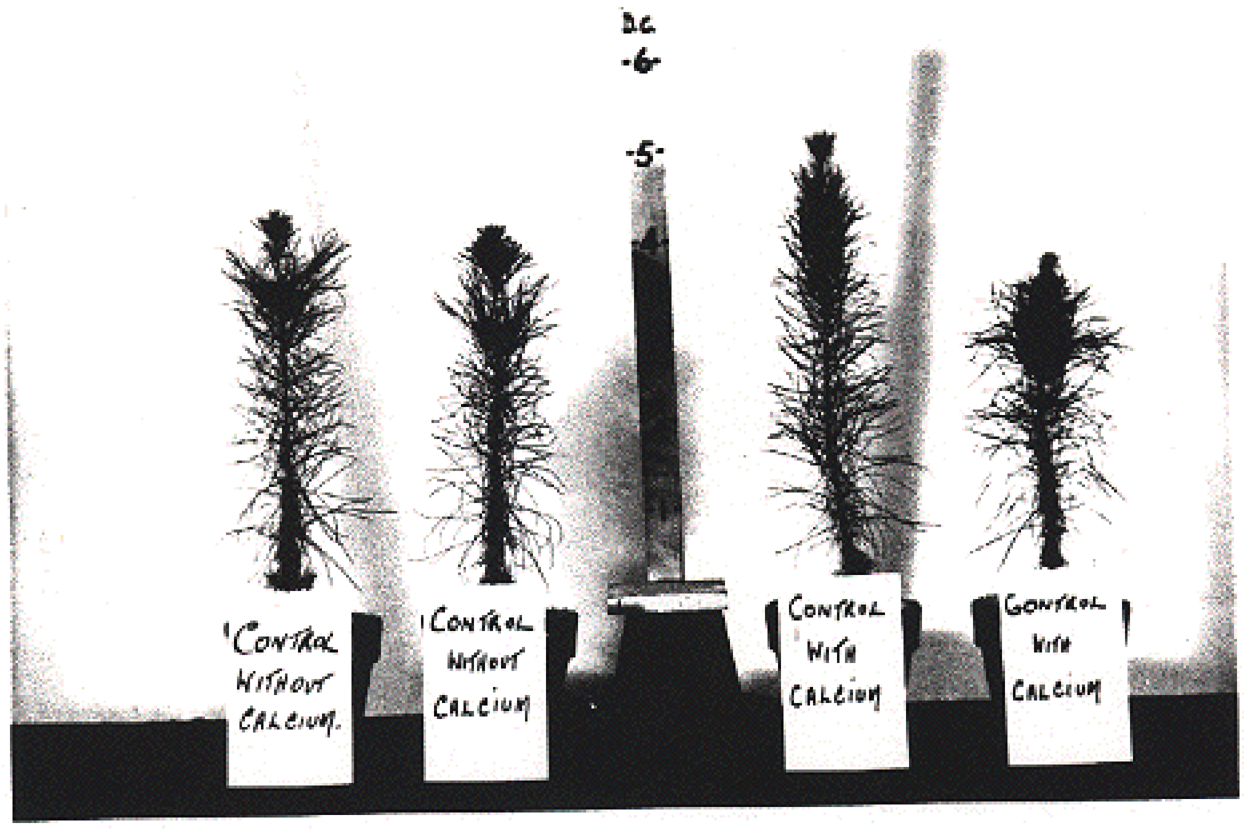

Figure 1. POT CULTURE TRIALS - CONTROL

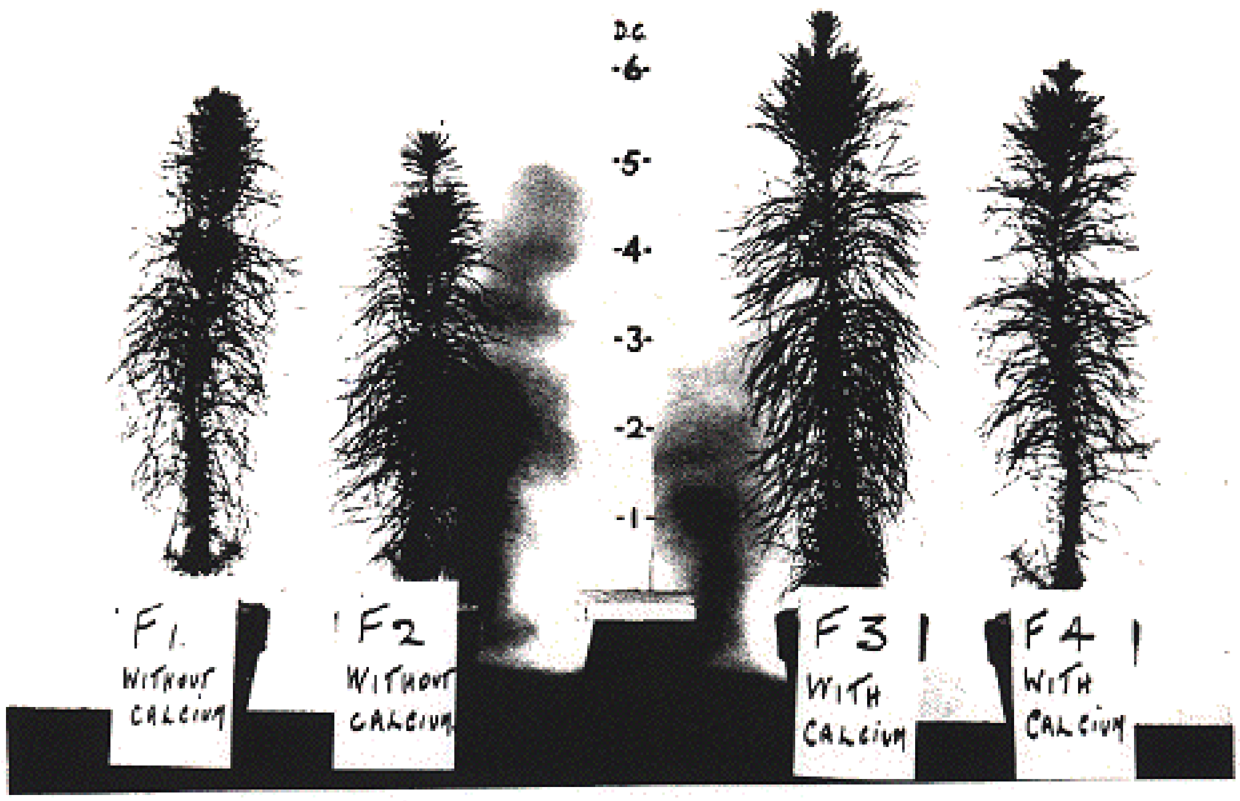

Figure 2. POT CULTURE TRIALS - TREATMENT F

$N_3P_4K_{\frac{1}{2}} + S$

Figure 3. POT CULTURE TRIALS - TREATMENT G

$N_3P_4K_{\frac{1}{2}} + Mg$

Figure 4. POT CULTURE TRIALS - TREATMENT J

$N_3P_{12}K_{\frac{1}{2}}$ + B, S, Mg, Mo

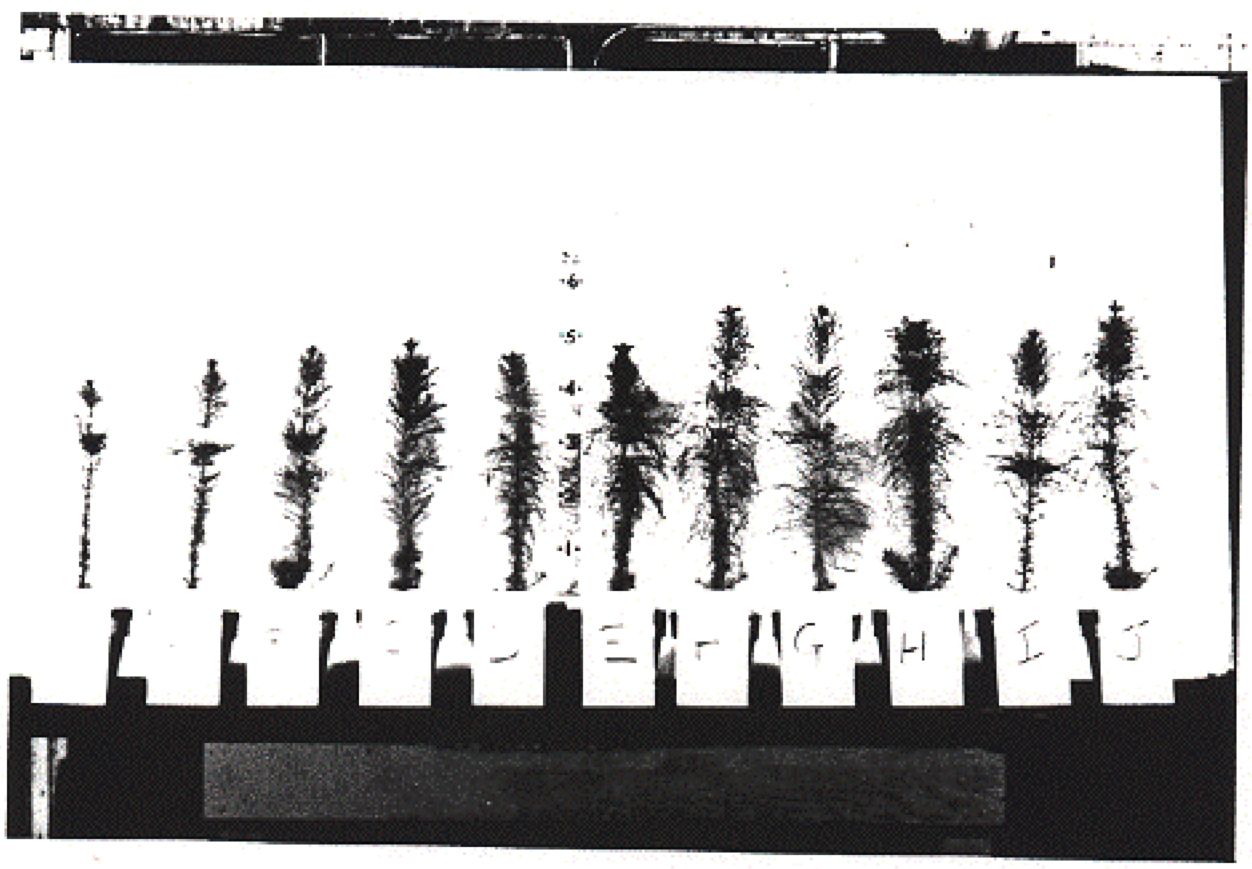

Figure 5. POT CULTURE TRIALS - ARRAY OF ALL TREATMENTS

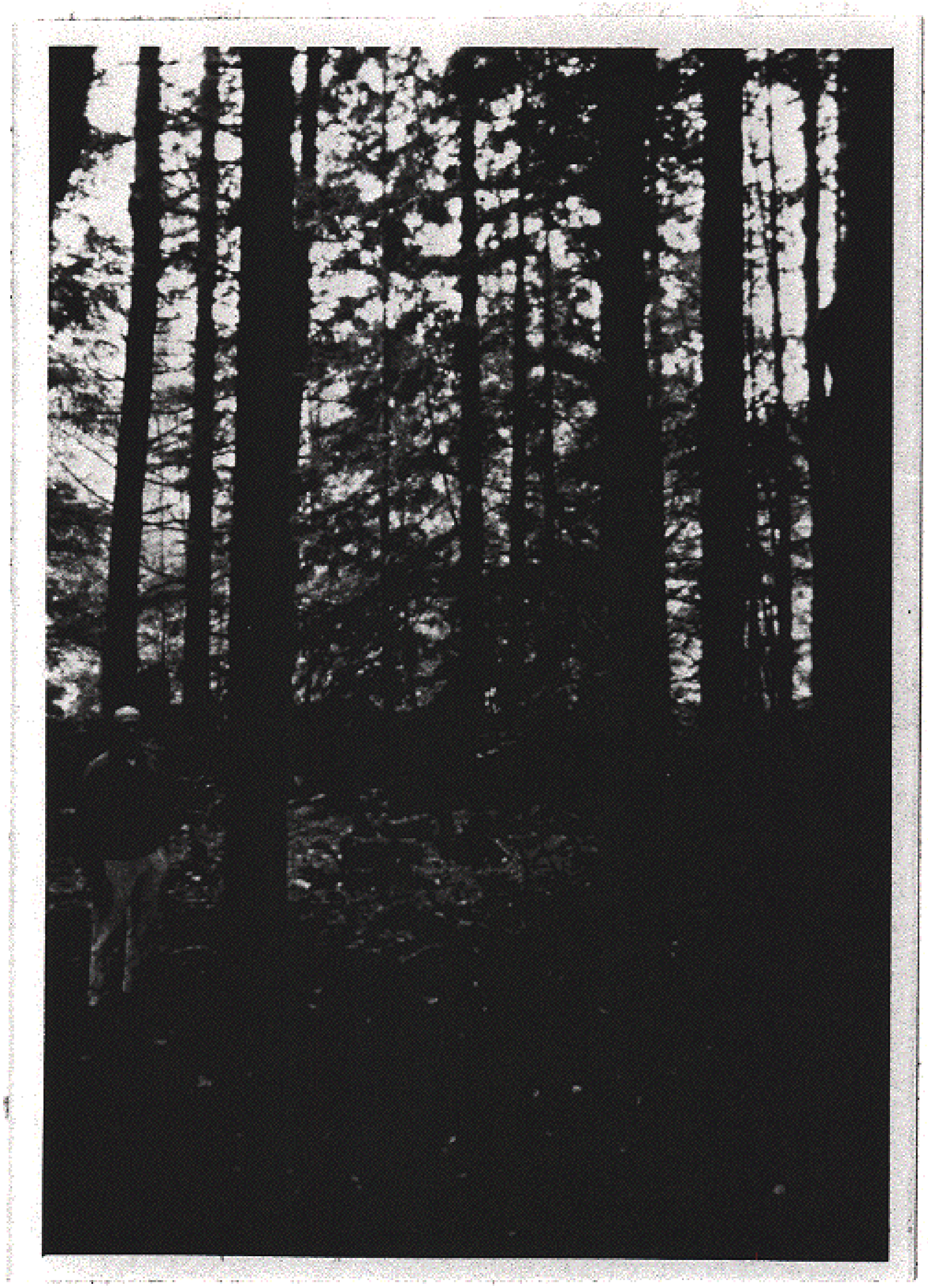

Figure 6. STAND WITH HIGH SITE INDEX AND NORMAL STOCKING

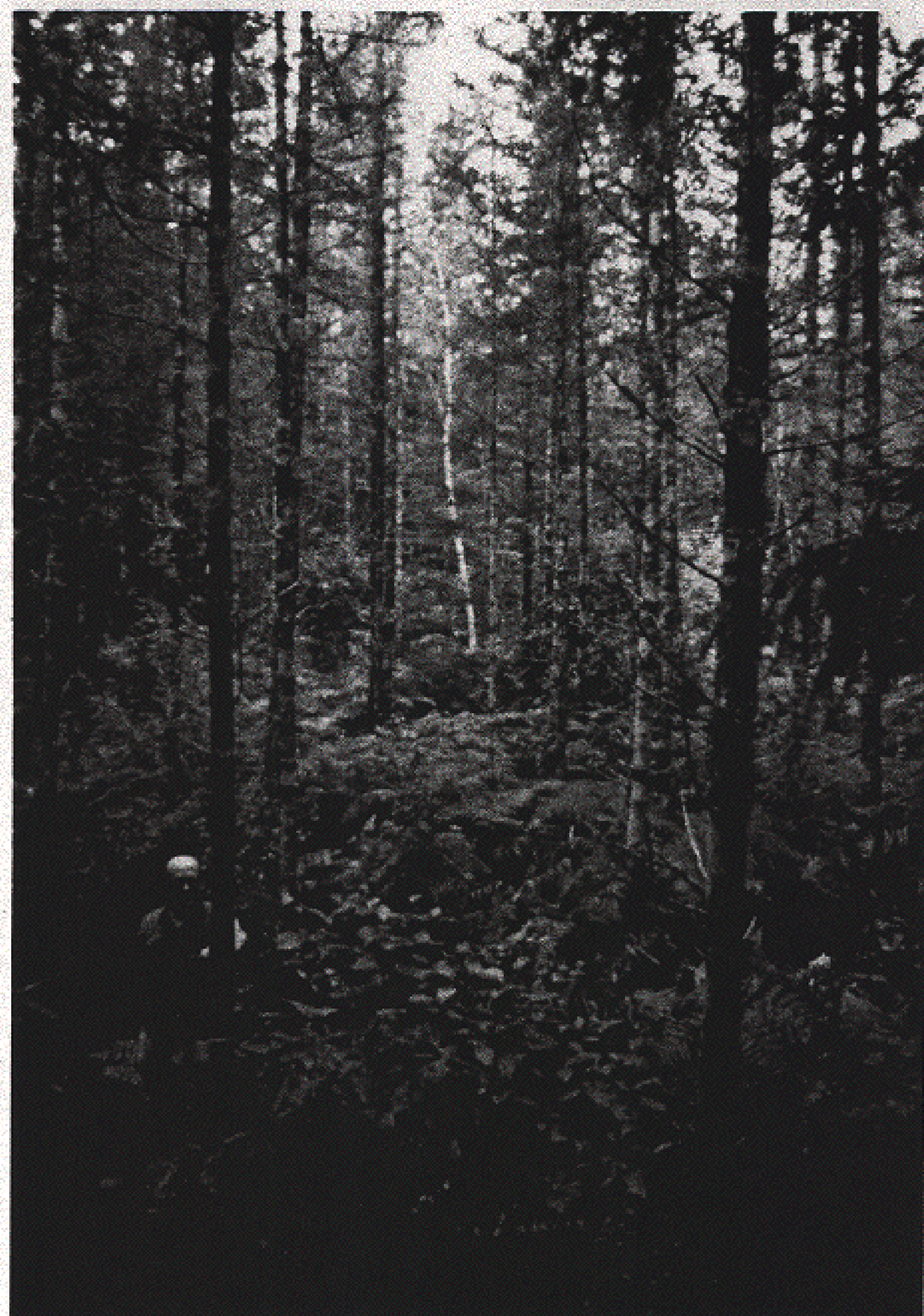

Figure 7. STAND WITH LOW SITE INDEX AND NORMAL STOCKING

Figure 8. OVER STOCKED STAND

Figure 9. UNDER STOCKED STAND

CHAPTER IV. METHODS

I. FIELD SAMPLING

Sampling Position in the Crown

In order to sample foliage in the crown so that relationships between foliar nitrogen content and stand characteristics, tree vigor and appearance characteristics can be examined, a knowledge of the pattern of nitrogen distribution is necessary. Many references indicate that foliage sampling can be done anywhere in the top third of the crown. However, if variations are great in the top third of the crown and the relationships sought are fine, then a more detailed examination is necessary.

Table (3) sets out the nitrogen content in the current foliage of the top 10 whorls in eight dominant Douglas-firs and eight co-dominant Douglas-firs chosen randomly over the study area. All trees were sampled in July, 1967 and composite samples made from all current foliage on a particular whorl to eliminate any variations due to aspect which may be present.

In each case, the first whorl has a substantially higher nitrogen percentage than any whorl below it. In most cases, there is a substantial decrease from the top whorl to the 4th. From the 4th to 10th whorl, there is fluctuation within a narrow range at a lower level. It has been demonstrated that the soils of the sample area, and consequently trees, are

Table 3. VARIABILITY BY CROWN POSITION OF FOLIAR NITROGEN (Percentage of Dry Weight)

Current Year's Growth Collected July, 1967

Whorl Number	Tree Number 1.	2.	3.	4.	5.	6.	7.	8.
			Dominants (N%)					
1.	1.49	1.44	1.63	1.17	1.40	1.61	1.34	1.28
2.	1.35	1.18	1.36	1.01	1.25	1.52	1.26	1.21
3.	1.26	1.16	1.28	1.01	1.11	1.47	1.19	1.17
4.	1.25	1.04	1.22	0.96	1.08	1.39	1.12	1.21
5.	1.20	1.02	1.16	0.95	0.98	1.34	1.10	1.19
6.	1.22	1.04	1.10	1.04	1.01	1.31	1.12	1.20
7.	1.18	0.98	1.19	1.03	0.96	1.33	1.11	1.15
8.	1.15	0.98	1.08	0.96	0.94	1.29	0.95	1.08
9.	1.19	1.01	1.10	0.90	1.02	1.30	0.98	1.13
10.	1.18	0.97	1.12	0.91	0.92	1.27	0.98	1.05
			Co-dominants (N%)					
1.	1.43	1.42	1.51	1.35	1.46	1.61	1.41	1.21
2.	1.33	1.18	1.32	1.28	1.27	1.17	1.19	1.10
3.	1.24	1.15	1.25	1.19	1.13	1.08	1.12	1.11
4.	1.22	1.11	1.21	1.15	1.11	1.06	1.02	1.07
5.	1.18	1.06	1.24	1.18	1.13	1.06	1.02	1.05
6.	1.20	1.04	1.15	1.16	1.09	1.03	1.03	1.05
7.	1.16	1.12	1.10	1.09	1.01	1.01	1.01	1.01
8.	1.14	0.97	1.08	1.14	0.96	0.98	0.98	0.97
9.	1.18	1.02	1.04	1.07	1.02	1.03	1.01	1.05
10.	1.06	0.95	1.06	1.08	0.96	0.95	0.96	1.01

nitrogen deficient and this deficiency might be responsible for this particular distribution pattern.

This result provides an answer to the first question raised on page 41, from examination of the existing literature regarding the distribution of foliar nitrogen in the crown. It is somewhat at variance with the conclusions of several workers with other species who report that little variation occurs in the top third of the crown.

Time of Sampling

Table (4) shows the monthly variation in current foliage from the top third of six Douglas-firs from fertilized and unfertilized areas. Two levels of nitrogen in the form of urea, 320 pounts per acre (358.4 kilogrammes per hectare) and 160 pounds (179.2 kilogrammes per hectare) per acre were applied. In each case, the nitrogen content in the first month (July) was the highest in the trees fertilized with 320 pounds and lowest in the trees with no fertilizer. All trees maintained this trend for the four months they were examined.

In each tree, the nitrogen content increased each month from July to October inclusive. This was an unexpected result, as almost all the tree species investigated have shown an opposite trend. Lavender and Carmichael (1966) showed this rising trend with younger trees.

The results in Table (4) must be treated with some reservations because it was after this random sampling in the top third of the crown that the results in Table (3) showed the wide variation within the top third of the crown. However, the samples were generally collected from the bottom section of the top third where only minor fluctuations take place.

Table 4. MONTHLY VARIATION OF FOLIAR NITROGEN CONTENT (Percentage of Dry Weight)

*Sample No.	Site Index	Age	Lbs. of N fertilizer Applied per Acre**	Foliar Nitrogen Percent*** July	Aug.	Sept.	Oct.
1	75	45	320	1.61	1.69	1.71	1.72
2	75	45	320	1.57	1.67	1.72	1.74
3	78	45	160	1.26	1.37	1.41	1.43
4	78	45	160	1.26	1.42	1.47	1.50
5	78	45	0	1.15	1.23	1.25	1.33
6	63	45	0	1.08	1.15	1.17	1.19

*Samples taken from current foliage in lower part of the top third of the crown.

**Applied in Spring, 1967.

***1967.

The data shown in Table (4) provided the basis for prescribing the month of collection. In each ase, there is a leveling off in the rate of foliar nitrogen change in the month of September. Greatest variations occur between July and August and the least between September and October. Goodall and Gregory (1947) state that the most desirable time of sampling foliage is when there is a large difference between nutrient levels in deficient and healthy plants. An examination of Table (4) shows that the greatest difference in foliar nitrogen levels (in the months sampled) between the trees fertilized with 320 pounds of nitrogen to the acre and the controls was in September and October. On this basis, September was chosen as the month for sampling.

Sampling Prescription

On the basis of the above results, it was prescribed that sampling should be done in September from the foliage on the top whorl of dominants and co-dominants. One-year-old foliage from the third whorl was also sampled. The close relationship between current foliage on the first and third whorls had been established in the preliminary investigations. Older foliage was therefore selected for investigation.

These findings concerning sampling prescription are generally similar to those found in the literature, except that most workers have recommended sampling from anywhere in the top third of the crown. Leech (1965) however recommended that sampling should be done from foliage of the leading shoot.

Magnesium, phosphosur and potassium showed no trend either with rate of fertilizer application or with the month sampled (Table 5). Calcium showed no trend with the month of sampling but for any month there was a

Table 5. MONTHLY VARIATION OF FOLIAR MAGNESIUM, CALCIUM, PHOSPHORUS AND POTASSIUM CONTENTS

Tree Number	Lbs. of nitrogen fertilizer applied per acre	Percentage Dry Weight July	Aug.	Sept.	Oct.
	MAGNESIUM				
1	320	.115	.149	.149	.137
2	320	.141	.137	.135	.142
3	160	.104	.130	.130	.125
4	160	.109	.100	.134	.121
5	0	.118	.135	.125	.133
6	0	.120	.121	.131	.120
	CALCIUM				
1	320	.309	.478	.448	.422
2	320	.345	.285	.426	.420
3	160	.262	.271	.390	.309
4	160	.277	.277	.398	.408
5	0	.220	.230	.280	.215
6	0	.215	.225	.210	.215
	PHOSPHORUS				
1	320	.14	.13	.12	.14
2	320	.11	.12	.14	.11
3	160	.15	.13	.14	.10
4	.60	.15	.12	.12	.14
5	0	.12	.15	.11	.15
6	0	.14	.11	.12	.13
	POTASSIUM				
1	320	.655	.530	.575	.670
2	320	.560	.585	.570	.620
3	160	.635	.615	.600	.515
4	160	.610	.625	.655	.700
5	0	.625	.605	.595	.610
6	0	.590	.635	.575	.650

progressive increase of calcium with increasing amounts of nitrogen fertilizer. This effect could be related to the form of nitrogen (urea) applied.

Crown Distribution of Other Foliar Nutrients (Tables 6 and 7)

Magnesium content showed a very similar distribution pattern to nitrogen. That is, the first whorl was substantially higher than the second and third whorls, but between the 4th and 10th whorls the contents fluctuated within a narrow range. It was previously demonstrated by pot culture trials that the soil of the study area had a pronounced magnesium deficiency and this may account for this particular distribution pattern in the crown.

Calcium content in the first whorl was substantially higher than the lower nine whorls but these latter showed no upward or downward trend and fluctuated randomly. Potassium and phosphorus content fluctuated randomly within a narrow range in all ten whorls examined.

Relationship of Foliar Nitrogen to Other Foliar Nutrients

An investigation was made to determine the relationship between the foliar nitrogen content and the foliar contents of phosphorus, potassium, calcium and magnesium in the twelve samples. Three multiple regression analyses were conducted using data from the first three whorls. Table (46) in Appendix 3 sets out the results of these analyses, all of which reveal that there is no relationship between foliar nitrogen and the other elements in any of the three whorls.

Table 6. VARIABILITY BY CROWN POSITION OF FOLIAR MAGNESIUM, CALCIUM, PHOSPHORUS AND POTASSIUM CONTENT

(Percentage Dry Weight)

Current foliage from dominant trees; collected July, 1967

Tree Number	Whorl	Percent Mg	Percent Ca	Percent P	Percent K
1	1	.164	.448	.18	.575
	2	.147	.326	.20	.505
	3	.134	.334	.19	.625
	4	.112	.326	.22	.645
	5	.121	.310	.19	.590
	6	.115	.295	.21	.615
	7	.109	.315	.17	.555
	8	.110	.322	.18	.585
	9	.119	.290	.20	.610
	10	.105	.300	.21	.590
2	1	.178	.345	.26	.530
	2	.151	.277	.18	.670
	3	.123	.255	.18	.620
	4	.137	.267	.20	.605
	5	.121	.253	.24	.600
	6	.119	.249	.19	.590
	7	.125	.257	.21	.585
	8	.118	.263	.18	.565
	9	.109	.267	.17	.570
	10	.123	.255	.23	.600
3	1	.189	.343	.15	.625
	2	.164	.317	.25	.795
	3	.115	.227	.07	.616
	4	.101	.269	.12	.670
	5	.110	.277	.16	.530
	6	.116	.287	.14	.625
	7	.100	.268	.14	.600
	8	.109	.277	.14	.655
	9	.104	.268	.13	.620
	10	.110	.272	.15	.635
4	1	.164	.234	.19	.635
	2	.131	.226	.21	.620
	3	.126	.229	.20	.595
	4	.125	.248	.20	.440
	5	.127	.230	.18	.500
	6	.126	.255	.17	.435
	7	.121	.227	.17	.475
	8	.119	.235	.18	.495
	9	.123	.240	.19	.445
	10	.119	.232	.17	.500
5	1				
	2	.186	.292	.22	.575
	3	.159	.237	.172	.665
	4	.132	.250	.20	.585
	5	.130	.243	.19	.605
	6	.135	.255	.15	.615
	7	.128	.240	.18	.595
	8	.124	.241	.17	.565
	9	.130	.251	.20	.570
	10	.137	.246	.19	.580
6	1	.191	.346	.20	.595
	2	.163	.315	.18	.590
	3	.142	.267	.20	.600
	4	.150	.270	.19	.605
	5	.145	.281	.18	.580
	6	.139	.265	.20	.555
	7	.145	.273	.17	.600
	8	.147	.281	.18	.560
	9	.129	.270	.18	.565
	10	.133	.265	.20	.575

Table 7. VARIABILITY BY CROWN POSITION OF FOLIAR MAGNESIUM, CALCIUM, PHOSPHORUS AND POTASSIUM CONTENT

(Percentage Dry Weight)

Current foliage from co-dominant trees; collected July, 1967

Tree Number	Whorl	Percent Mg	Ca	P	K	Tree Number	Whorl	Percent Mg	Ca	P	K
1	1	.186	.345	.21	.59	4	1	.162	.332	.24	.49
	2	.153	.234	.17	.59		2	.137	.210	.21	.46
	3	.130	.277	.18	.58		3	.126	.281	.22	.48
	4	.134	.317	.18	.61		4	.131	.224	.19	.41
	5	.128	.221	.16	.59		5	.128	.262	.20	.43
	6	.127	.258	.20	.57		6	.126	.305	.17	.45
	7	.131	.308	.15	.60		7	.128	.270	.21	.47
	8	.136	.315	.19	.56		8	.130	.211	.16	.42
	9	.129	.241	.18	.61		9	.127	.253	.19	.46
	10	.132	.265	.17	.58		10	.129	.200	.20	.46
2	1	.181	.345	.22	.625	5	1	.189	.435	.15	.69
	2	.143	.221	.15	.555		2	.171	.375	.17	.67
	3	.153	.326	.22	.600		3	.153	.355	.19	.65
	4	.141	.263	.17	.615		4	.141	.355	.21	.635
	5	.139	.301	.18	.600		5	.141	.345	.17	.82
	6	.140	.310	.20	.575		6	.143	.350	.15	.70
	7	.136	.265	.19	.590		7	.139	.361	.12	.66
	8	.130	.243	.15	.550		8	.137	.342	.17	.62
	9	.140	.298	.14	.625		9	.140	.351	.13	.69
	10	.135	.308	.19	.580		10	.145	.360	.14	.67
3	1	.181	.345	.24	.475	6	1	.173	.401	.23	.63
	2	.143	.254	.198	.532		2	.152	.275	.19	.61
	3	.137	.296	.23	.620		3	.131	.263	.22	.63
	4	.133	.240	.17	.540		4	.137	.279	.17	.58
	5	.139	.261	.18	.585		5	.129	.210	.18	.57
	6	.145	.299	.18	.560		6	.135	.311	.19	.60
	7	.128	.269	.22	.460		7	.128	.251	.17	.59
	8	.131	.247	.19	.575		8	.129	.302	.20	.57
	9	.127	.271	.21	.480		9	.134	.273	.16	.62
	10	.133	.265	.17	.550		10	.130	.261	.19	.60

Development of Sampling Procedures for Small Areas

Having arrived at a technique for satisfactory sampling of trees, two problems needed to be investigated. The first was to arrive at a sampling technique for selecting a tree or several trees that would characterize the stand for foliar nitrogen in the immediate vicinity (a one-tenth-acre plot for example) so that such stand characteristics as site index, age and stocking could be related to this sample.

Eight one-tenth-acre plots were chosen at random over the study area and eight dominants and co-dominants were sampled in each plot according to the procedure described in the preceding section.

Table (8) shows the relevant data for these trees and the nitrogen content in the first whorl. This table indicates that, although in some cases trees from the same tenth-acre plot had a considerable range of foliar nitrogen values, in most cases the majority of trees fell within a narrow range of values and that any one of these would satisfactorily represent the plot. It was then found by field examination (and can be seen from the data in Table 8) that this one tree sample could be chosen by examining the leaders and selecting the tree with average leader length. This procedure invariably excluded those trees with extreme values for foliar nitrogen content.

It can be seen from Table (8) that the tree chosen in this manner had the closest height-age at 100 years relationship to the average of all eight trees on the plot, and so represented the site-index of the plot.

Thus trees could be chosen to characterize the one-tenth-acre plot either by leader length or by tree site. This result provides an answer

Table 8. FOLIAR NITROGEN CONTENT IN THE FIRST WHORL OF EIGHT TREES SAMPLED FROM EACH OF EIGHT ONE-TENTH-ACRE PLOTS

(Percentage of Dry Weight)

Plot No.	Tree No.	N%	Stand Site Index	Tree Site	Leader Length (Ft.) 1967	Ave.	Plot No.	Tree No.	N%	Stand Site Index	Tree Site	Leader Length (Ft.) 1967	Ave.
1	6 *	1.26	111	101	1.7	1.5	5	31 *	1.32	140	130	1.6	1.25
	6A	1.62	111	114	2.0			31A*	1.32	140	136	1.1	
	6B *	1.23	111	112	1.3			31B	?	140	131	0.9	
	6C *	1.31	111	114	1.2			31C	1.45	140	145	1.8	
	6D	1.51	111	121	2.1			31D*	1.37	140	150	1.3	
	6E	1.17	111	103	1.0			31E*	1.34	140	149	1.1	
	6F *	1.25	111	113	1.4			31F*	1.30	140	135	1.0	
	**6G	1.24	111	111	1.5			**31G	1.35	140	144	1.2	
2	9	1.03	110	98	1.0	1.1	6	42 *	1.34	134	146	1.7	1.7
	9A *	1.25	110	110	0.9			42A*	1.31	134	142	1.9	
	9B	1.49	110	112	1.3			42B	1.40	134	136	2.0	
	9C *	1.34	110	113	1.0			42C	1.25	134	123	1.8	
	**9D	1.27	110	111	1.1			42D*	1.35	134	122	1.6	
	9E *	1.30	110	113	1.0			42E*	1.32	134	126	1.5	
	9F *	1.26	110	107	0.9			**42F	1.36	134	135	1.7	
	9G *	1.29	110	113	1.1			42G*	1.31	134	142	1.5	
3	16 *	1.48	121	126	2.0	1.9	7	59 *	1.53	137	131	1.9	1.9
	16A	1.31	121	136	1.0			59A*	1.54	137	124	2.2	
	16B*	1.44	121	116	1.7			59B*	1.49	137	136	1.8	
	16C*	1.45	121	130	2.1			59C	1.37	137	124	1.6	
	16D	1.63	121	135	2.6			**59D	1.50	137	136	1.9	
	16E*	1.47	121	114	2.1			59E	1.63	137	144	2.4	
	16F*	1.49	121	90	2.0			59F*	1.51	137	150	1.8	
	**16G	1.46	121	120	1.8			59G*	1.48	137	151	1.9	
4	19	1.21	124	118	1.4	1.6	8	65 A	1.17	105	91	0.6	1.1
	19A*	1.59	124	118	1.7			65A	1.47	105	100	1.2	
	19B	1.71	124	99	1.3			65B*	1.18	105	110	1.4	
	19C*	1.55	124	136	1.5			**65C	1.18	105	103	1.0	
	19D*	1.52	124	134	1.8			65D	1.09	105	107	0.8	
	**19E	1.50	124	126	1.6			65E*	1.15	105	100	1.3	
	19F*	1.58	124	130	1.7			65F*	1.19	105	110	1.4	
	19G*	1.60	124	131	1.7			65G*	1.18	105	119	1.3	

*Trees within narrow range of nitrogen percent.

**Trees selected by average leader length to characterize each plot.

to the third question on page 42 concerning the sampling of small areas. No workers have reported the single representative tree sampling method. As quoted in the literature review, Wehrmann (1959), Rennie (1966) and Lowry and Avard (1967) all recommend the sampling of several trees but none has recommended a subjective sampling as is done here.

Table (9) shows the foliar magnesium, calcium, phosphorus and potassium contents in the first whorl of the eight sample trees from each of the eight plots. The values for each element fluctuated unpredictably in each plot, so that no system of sampling could be prescribed which would characterize the plot for any of these elements. From the data in Table (9), it did not appear that any relationship existed between the foliar levels of these elements and either the site-index of the stand or the individual tree. Table (10) shows the content of these four elements as they occurred in one-year-old foliage in the third whorl. As with the first whorl, values fluctuated and were unpredictable.

Sampling Large Areas of Forest

Having developed a procedure for selecting a tree on a one-tenth-acre plot whose first whorl foliar nitrogen is representative of that plot, it was then possible to proceed with the main thrust of the investigation and select samples from over the 1,000 acres of the study area so that the main questions posed on page 42 could be dealt with. These are the range and variability of foliar nitrogen in a stand, effect of stand conditions on foliar age and position and the relationship of foliar nitrogen to stand and tree characteristics.

Table 9. FOLIAR NUTRIENT CONTENT IN THE FIRST WHORL OF EIGHT TREES SAMPLED FROM EACH OF EIGHT ONE-TENTH-ACRE PLOTS

(Percentage of Dry Weight)

Plot	Site Stand	Site Tree	Tree No.	Percent Mg	Percent Ca	Percent P	Percent K
1	111	101	6	.188	.418	.19	.63
		114	6A	.194	.407	.17	.64
		112	6B	.217	.345	.19	.79
		114	6C	.171	.367	.20	.73
		121	6D	.203	.420	.18	.66
		103	6E	.197	.415	.16	.69
		113	6F	.181	.355	.17	.78
		111	6G	.195	.390	.18	.67
2	101	98	9	.176	.418	.15	.65
		110	9A	.158	.430	.18	.76
		112	9B	.244	.418	.14	.75
		113	9C	.237	.481	.20	.53
		111	9D	.163	.421	.16	.55
		113	9E	.240	.470	.19	.74
		107	9F	.220	.441	.17	.63
		113	9G	.178	.468	.20	.69
3	121	126	16	.143	.285	.24	1.18
		136	16A	.153	.327	.28	1.18
		116	16B	.136	.365	.21	1.10
		130	16C	.264	.481	.26	0.86
		135	16D	.163	.295	.22	1.10
		114	16E	.250	.471	.27	0.96
		90	16F	.171	.305	.25	1.20
		120	16G	.223	.451	.23	0.89
4	124	118	19	.141	.248	.19	0.76
		118	19A	.173	.355	.17	1.17
		99	19B	.153	.234	.28	0.74
		116	19C	.161	.360	.16	0.84
		134	19D	.175	.230	.29	0.96
		126	19E	.139	.255	.19	1.20
		130	19F	.167	.275	.25	1.16
		131	19G	.150	.348	.21	0.99
5	140	130	31	.194	.396	.22	.74
		136	31A	.155	.285	.27	.75
		131	31B	.265	.545	.20	.76
		145	31C	.287	.559	.27	.72
		150	31D	.254	.295	.29	.71
		149	31E	.190	.444	.21	.73
		135	31F	.215	.356	.25	.76
		144	31G	.164	.466	.23	.70
6	134	146	42	.164	.430	.18	.84
		142	42A	.158	.336	.18	.74
		136	42B	.160	.310	.16	.70
		123	42C	.164	.385	.17	.90
		122	42D	.158	.326	.15	.86
		126	42E	.165	.425	.19	.91
		135	42F	.161	.416	.17	.79
		142	42G	.163	.340	.16	.89
7	137	131	59	.211	.355	.21	.80
		124	59A	.211	.375	.15	.79
		136	59B	.164	.285	.24	.68
		124	59C	.176	.375	.23	.67
		136	59D	.181	.280	.14	.70
		144	59E	.196	.380	.25	.71
		150	59F	.216	.325	.16	.78
		151	59G	.171	.315	.19	.68
8	105	91	65	.237	.559	.17	.56
		100	65A	.223	.577	.29	.58
		110	65B	.223	.442	.23	.70
		103	65C	.173	.468	.22	.74
		107	65D	.233	.449	.30	.55
		100	65E	.171	.452	.16	.75
		110	65F	.183	.497	.27	.60
		119	65G	.207	.572	.19	.68

Table 10. FOLIAR NUTRIENT CONTENT IN ONE-YEAR-OLD FOLIAGE FROM THE THIRD WHORL

(Percentage of Dry Weight)

Plot	Site Stand	Site Tree	Tree No.	Percent Mg	Percent Ca	Percent P	Percent K
1	111	101	6	.151	.542	.18	.47
		114	6A	.121	.442	.21	.54
		112	6B	.173	.407	.24	.53
		114	6C	.099	.392	.23	.69
		121	6D	.199	.418	.22	.5.
		103	6E	.143	.559	.21	.85
		113	6F	.127	.365	.19	.59
		111	6G	.205	.396	.26	.48
2	101	98	9	.147	.542	.22	.56
		110	9A	.093	.526	.25	.71
		112	9B	.169	.526	.22	.44
		113	9C	.147	.559	.23	.44
		111	9D	.108	.486	.24	.56
		113	9E	.103	.396	.21	.65
		107	9F	.193	.577	.18	.85
		113	9G	.141	.496	.26	.66
3	121	126	16	.121	.736	.17	.60
		136	160	.126	.418	.29	.85
		116	16B	.088	.418	.26	.84
		130	16C	.149	.526	.28	.59
		135	16D	.127	.365	.21	.51
		114	16E	.193	.418	.24	.64
		90	16F	.103	.486	.25	.52
		120	16G	.143	.659	.24	.44
4	124	118	19	.164	.418	.20	.60
		118	19A	.199	.490	.19	.65
		99	19B	.219	.559	.22	.48
		116	19D	.118	.486	.22	.44
		134	19E	.111	.496	.18	.83
		126	19E	.107	.418	.26	.85
		130	19F	.143	.345	.26	.88
		131	19G	.169	.679	.25	.54
5	140	130	31	.108	.396	.21	.54
		136	31A	.099	.365	.21	.53
		131	31B	.143	.496	.17	.52
		145	31C	.211	.577	.28	.66
		150	31D	.103	.559	.27	.60
		149	31E	.171	.345	.19	.47
		135	31F	.127	.407	.17	.44
		144	31G	.135	.421	.23	.71
6	134	146	42	.128	.577	.24	.69
		142	42A	.125	.486	.20	.65
		136	42B	.103	.365	.19	.88
		123	42C	.141	.559	.23	.64
		122	42D	.142	.542	.25	.56
		126	42E	.132	526	.22	.54
		135	42F	.111	.377	.21	.85
		142	42G	.097	.395	.17	.48
7	137	131	59	.121	.345	.22	.85
		124	59A	.169	.496	.17	.69
		136	59B	.143	.327	.25	.59
		124	59C	.118	.396	.15	.66
		136	59D	.147	.573	.26	.85
		144	59E	.179	.607	.22	.60
		150	59F	.121	.709	.24	.75
		151	59G	.111	.393	.24	.73
8	105	91	65	.127	.559	.22	.83
		100	65A	.132	.708	.23	.69
		110	65B	.205	.559	.23	.49
		103	65C	.217	.659	.28	.51
		107	65D	.147	.567	.19	.63
		100	65E	.169	.403	.25	.75
		110	65F	.199	.369	.27	.47
		119	65G	.103	.315	.25	.59

In September 1967, 88 one-tenth-acre plots were established over the study area varying from two chains to seven chains apart. In 45 plots, a tree was chosen for sampling by the prescription developed. In 43 plots, a dominant or co-dominant was chosen randomly.

In September 1968, 100 one-tenth-acre plots were established over the study area generally on a six chain by six chain grid. A representative tree was chosen from 49 of the plots and, in the remaining 51 plots, a tree was chosen randomly. Thus, the total sample collections from the two years consisted of 94 representative samples and 94 random samples. The position of these plots is shown in Figures 16a - 19b in Appendix 3. These 188 plots adequately covered the area, with plots varying from two chains to seven chains apart.

Foliage Collection

Each tree was felled and the first whorl shoots placed in an air tight plastic bag. One shoot was placed in separate bag for determinations of needle weight and number of needles per inch of shoot.

The one-year-old foliage from all branches on the third whorl was cut off by scissors and likewise formed a composite one-aged sample in an air tight plastic bag.

Each afternoon the plastic bags containing the samples were transferred to a field freezer where they remained for up to five days when transport to an oven was available.

Stand and Tree Data Collection

For each sample tree chosen, the following data were collected:

Stand characteristics	- site index (Bulletin 201)
	- age
	- stocking
Vigor characteristics	- length of the leading shoot
	- length of the top 5 internodes
	- length of the top 10 internodes
	- radial growth in last 5 years
	- radial growth in last 10 years
	- oven dry weight of 100 needles
Appearance characteristics	- depth of green crown (%)
	- color class (Munsell Color Chart)
	- number of years needles retained on tree
	- number of needles per inch of shoot
Other tree data	- total height
	- diameter breast height
	- internodal lengths

To determine the oven dry weight of 100 needles and the number of needles per inch of shoot, one of the first whorl shoots was left separate from the composite sample and oven dried at 70°C. One hundred intact needles were separated by hand and dried again at 70°C before weighing. The number of needle bases was counted on each of these shoots and the length of shoot measured to determine the number of needles per inch of shoot.

The depth of green crown was expressed as a percentage of the total bole. Color class determinations were only made for the 88 samples collected in 1967 because almost all were falling into the same class based on the Munsell color chips for plant tissue. The importance of radial growth as a supplementary measure of tree vigor was not realized until the end of the 1967 field work so this data were only determined for the 100 samples collected in 1968.

Age was determined by ring counts at the stump with adjustments for stump height. These ring counts were reconciled with the number of nodes as far as was possible.

In order to provide a basic knowledge of the study-area forest, histograms were prepared from the data of all 188 samples showing the range and frequency of the stand characteristics, the vigor characteristics and the appearance characteristics. The results obtained from these histograms are described in Appendix 1 and summarized in Table (11).

Conversion factors to metric measures are given in Appendix 3 in Table (47).

Table (48) in Appendix 3 presents formulae for the conversion of dry weight of needles to fresh weight.

Table (49) in Appendix 3 sets out data determining the photosynthetic area of Douglas-fir needles.

Table (50) in Appendix 3 defines the abbreviations used in reporting and analyzing the data.

Table (51) in Appendix 3 shows the mean value and standard deviation of each character of the tree or stand measured or determined of all 188 samples.

Table (52) in the same Appendix shows the mean values and standard deviation of each character of the tree or stand measured or determined of the 94 representative samples.

Table (53) in Appendix 3 shows the mean value and standard deviation of each character of the tree or stand measured or determined of the 94 random samples.

Table 11. RANGE, FREQUENCY AND MEAN STAND AND TREE CHARACTERISTICS OF THE STUDY AREA

Characteristic	Range	Maximum Frequency	Type of Distribution Curve	Mean
Age (Years)	25-57	42	Normal	40
Site-Index	76-152	124	Skewed left	120
Stocking (Sq. ft. B.A./Ac)	50-210	110	Skewed right	120
Oven Dry Weight of 100 Needles (Grms)	0.28-0.98	0.60	Normal	0.59
Needles per inch of shoot	12-66	33	Skewed right	28
Green Bole (%)	30-90	69	Skewed left	60.4
Leader Length (Ft)	0.4-3.6	1.8	Skewed right	1.8
Height Growth last 5 years (Ft)	2.1-16.1	9.1	Normal	9.1
Height Growth last 10 years (Ft)	4.5-33.0	16.5	Skewed right	17.3
Radial Growth last 5 years (In)	0.1-0.6	0.30	Normal	0.35
Radial Growth last 10 years (In)	0.1-1.2	0.65	Normal	0.68

II. LABORATORY ANALYSIS (METHODS)

Preparation of Foliage Samples

Frozen samples from the field freezer were thawed in the laboratory and oven dried at 70°C for 48 hours. The freezing was considered necessary as samples had to be kept in the field for up to six days before transport was available to an oven. No moisture loss was apparent during thawing.

The needles were then separated by hand from the stems and buds and ground in a Waring blender allowing one minute of grinding time for each 5 grams of foliage. The ground samples were stored in screw-top glass jars and re-dried at 70°C before analysis.

Chemical Analysis

Digestion of the foliage was carried out by the Caro's acid wet ashing method. One gram of the oven dried sample was placed in a 30-ml. micro-Kjeldahl flask and 5 ml. of concentrated sulphuric acid was added and mixed well with the sample. One to two ml. of 30% hydrogen peroxide was then carefully introduced by dropper. Following the initial reaction, the solution was heated to remove water and a further small addition of hydrogen peroxide was added. This was repeated until the digest became white and clear, when it was cooled, diluted, filtered and made up to 100 ml. volume. Aliquots were taken for the individual elemental analyses described below.

1. Nitrogen was determined by distillation in an electrical micro-Kjeldahl apparatus and collecting the ammonia in 4% boric acid containing a mixed methyl red - methylene blue indicator. This was then titrated with 0.05 N H_2So_4.

2. Phosphorus was determined colorimetrically by a modification of the vanadomolydophosphoric yellow color method. Analyses were made on a Bausch and Lomb spectrophotometer at a wave length of 420 mμ. Standard curves were set up for the appropriate range of phosphorus concentrations.

3. Potassium was determined on a Beckman DU spectrophotometer with an oxyacetylene flame at a wave length of 768 mμ. Standard curves were set up for the appropriate range of potassium concentrations.

4. Calcium was determined on a Techtron AA-3 atomic adsorption instrument with a nitrous oxide - acetylene flame, a wave length of 423 mμ and a Ca-Mg hollow cathode lamp. Again appropriate standard curves were developed.

5. Magnesium was determined in the same way as calcium, using an air-acetylene flame and wave length of 285 mμ.

CHAPTER V. RESULTS AND DISCUSSION

Investigations reported here attempt to answer questions 5, 6 and 7 raised earlier on page 42:

- What is the range and variability of foliar nitrogen within a stand?
- Do certain foliar ages and position reflect the conditions of the stand better than others?
- What is the relationship of foliar nitrogen to the stand characteristics of site, age and stocking and to the vigor and appearance of the tree?

Firstly, the range and variability of the foliar nitrogen content of current foliage from the first whorl and one-year-old foliage from the third whorl is examined. The reasons for choosing these particular ages and positions are explained earlier on page 65.

These data are then statistically analyzed in a number of ways to determine the relationship of foliar nitrogen to stand and tree characteristics:

a) Tables (54) and (55) in Appendix 3 set out the data for the 94 representative trees and 94 random trees. Table (12) presents the stand characteristics and foliar nitrogen values for the 94 representative trees and Table (13) shows the tree characteristics and foliar nitrogen values for these 94 representative samples.

b) Table (14) presents the stand characteristics and foliar nitrogen values for the 94 randomly chosen trees, and Table (15) shows the tree

Table 12. STAND DATA AND NITROGEN CONTENT OF TREES SELECTED TO REPRESENT THE STAND

Height (Ft.)	DBH (In.)	Stocking (Sq. Ft. B.A./Ac.)	Age (Yrs.)	Site (Tree)	Site-Index (Stand) (Bull. 201)	First Whorl N%	Third Whorl N%
72.2	11.2	80	40	120	120	1.43	1.14
65.6	9.0	100	42	106	100	1.30	1.10
66.2	9.3	90	40	110	104	1.31	1.07
70.6	7.9	120	37	126	123	1.38	1.17
66.5	8.6	140	39	114	111	1.62	1.38
65.7	8.7	140	39	113	111	1.23	1.23
66.8	9.1	140	39	114	111	1.31	1.16
51.0	5.6	120	39	87	86	1.16	1.16
60.9	8.1	110	42	98	101	1.03	1.10
58.9	7.8	105	39	100	106	1.31	1.27
62.2	8.5	120	38	109	108	1.37	1.14
65.6	9.2	115	40	109	131	1.29	1.21
74.0	9.1	110	39	126	121	1.48	1.10
73.2	9.3	110	43	116	121	1.44	1.37
72.3	8.8	170	40	120	122	1.24	1.40
83.0	10.1	150	41	136	138	1.51	1.38
71.0	9.3	140	40	118	124	1.21	1.06
73.4	9.0	140	42	118	124	1.59	1.55
65.0	9.8	95	37	116	119	1.47	1.30
55.4	7.7	105	40	92	88	1.18	1.02
100.0	13.7	205	48	147	141	1.14	1.17
87.3	11.7	175	45	134	139	.95	1.21
82.2	9.7	170	47	123	124	1.25	1.12
89.9	12.9	190	49	130	134	1.48	1.12
82.8	10.7	145	44	129	131	1.29	1.28
76.7	9.3	175	47	114	111	1.12	1.08
85.3	11.4	145	46	129	129	1.19	1.23
84.0	12.0	160	42	136	140	1.32	1.18
101.4	14.7	160	40	145	140	1.45	1.41
75.8	10.8	140	41	124	118	1.33	1.34
77.7	11.6	170	42	125	122	1.21	1.18
80.1	11.5	130	42	129	129	1.24	1.12
85.4	13.3	135	43	136	134	1.40	1.25
80.3	12.9	120	39	137	139	1.21	1.18
93.5	13.8	115	40	156	150	1.65	1.35
80.3	10.4	105	40	134	137	1.46	1.24
89.4	12.2	150	41	146	141	1.45	1.40
87.7	13.1	120	37	157	142	1.65	1.38
67.9	9.1	150	34	131	137	1.53	1.20
83.2	10.9	150	41	136	137	1.49	1.43
65.5	7.2	155	42	106	103	1.30	1.29
77.5	10.1	130	42	125	131	1.29	1.21

Table 12 (cont.)

Height (Ft.)	DBH (In.)	Stocking (Sq. Ft. B.A./Ac.)	Age (Yrs.)	Site (Tree)	Site-Index (Stand) (Bull. 201)	First Whorl N%	Third Whorl N%
72.4	10.5	170	53	100	105	1.47	.93
75.6		170	49	110	105	1.18	1.16
73.0	9.5	170	51	103	105	1.18	1.23
72.1	12.0	60	36	135	118	1.78	1.53
65.5	10.8	105	44	102	99	.97	1.00
54.9	9.6	105	29	125	115	1.81	1.43
68.4	9.7	90	33	136	114	1.66	1.55
62.1	11.0	90	32	127	121	1.84	1.60
70.4	10.9	90	32	145	140	1.80	1.68
63.2	12.3	90	36	116	114	1.05	1.27
63.2	8.5	95	34	123	123	1.58	1.38
58.7	9.6	70	34	114	118	1.28	1.26
63.5	10.2	70	34	123	124	1.45	1.45
84.0	10.7	115	45	129	131	1.69	1.70
72.0	11.5	95	38	126	130	1.23	1.19
76.1	12.7	110	42	123	128	1.35	1.51
92.3	15.7	120	41	149	142	1.31	1.40
59.2	10.8	80	32	122	118	1.39	1.26
79.9	11.1	90	32	163	141	1.33	1.30
99.0	15.2	130	41	162	143	1.71	1.39
70.8	10.8	95	36	130	132	1.71	1.53
63.5	11.5	85	36	117	121	1.49	1.15
61.8	10.8	70	35	117	113	1.58	1.36
56.2	9.1	75	30	122	122	1.56	1.33
72.2	9.2	130	45	111	110	1.22	1.20
62.2	10.8	90	41	102	106	1.59	1.45
81.7	11.9	85	42	132	130	1.27	1.24
69.8	10.7	100	35	132	135	1.48	1.48
51.7	9.1	70	32	107	110	1.31	1.17
65.0	10.5	75	33	129	125	1.50	1.50
89.7	14.1	130	43	142	136	1.39	1.54
72.7	9.6	105	35	137	133	1.40	1.43
58.1	10.4	70	34	113	105	1.61	1.22
63.5	9.8	60	37	114	113	1.68	1.32
76.9	12.1	100	40	128	122	1.58	1.36
70.2	8.3	130	42	113	118	1.17	1.23
80.0	10.2	110	45	123	117	1.17	1.39
89.5	12.8	155	51	127	129	1.16	1.43
88.8	14.0	120	49	129	126	1.29	1.33
81.2	11.2	150	45	125	115	1.14	1.28
81.0	10.0	180	53	112	113	1.31	1.53
95.4	14.9	140	54	131	133	1.42	1.46
93.2	14.9	140	52	130	130	1.24	1.60
88.7	11.8	190	55	120	122	1.41	1.23

Table 12 (cont.)

Height (Ft.)	DBH (In.)	Stocking (Sq. Ft. B.A./Ac.)	Age (Yrs.)	Site (Tree)	Site-Index (Stand) (Bull. 201)	First Whorl N%	Third Whorl N%
81.0	12.2	200	52	113	119	1.20	1.34
88.4	11.8	170	52	124	122	1.12	1.36
81.8	11.5	180	47	122	119	1.17	1.34
89.2	14.5	170	55	121	122	1.23	1.29
85.4	12.9	200	50	122	126	1.23	1.24
53.7	7.8	90	48	80	81	1.14	1.20
49.1	7.4	90	44	77	76	1.22	1.22
55.2	6.1	110	40	91	89	1.37	1.43

Table 13. SAMPLE TREE DATA AND NITROGEN CONTENT OF TREES SELECTED TO REPRESENT THE STAND

Needles per Inch of Shoot	Wt. of 100 Needles (Grms)	Needle Years	Color Class	Green Crown %	Radial Growth 5 Yrs. (In.)	Radial Growth 10 Yrs. (In.)	Height Growth Current Yr. (Ft.)	Height Growth 5 Yrs. (Ft.)	Height Growth 10 Yrs. (Ft.)	First Whorl %	Third Whorl %
26.4	.445	5		86.3	*Not measured in first 88 samples taken.*		1.5	9.9	19.1	1.43	1.14
32.3	.489	4		77.0			1.5	10.6	17.0	1.30	1.10
18.4	.585	5		88.5			1.1	6.0	11.2	1.31	1.07
33.3	.523	5		76.3			1.8	10.8	20.5	1.38	1.17
26.2	.694	3	3	49.9			2.0	12.2	16.1	1.62	1.38
26.2	.554	3	5	45.4			1.3	9.4	15.9	1.23	1.23
24.1	.598	4	3	54.9			1.2	8.5	13.2	1.31	1.16
40.4	.450	3		58.0			1.3	4.9	8.4	1.16	1.16
40.2	.394	6		55.3			1.0	3.9	7.8	1.03	1.10
33.2	.565	3	5	53.1			1.6	6.9	11.4	1.31	1.27
23.2	.609	3	3	54.3			1.1	7.2	12.7	1.37	1.14
33.5	.540	6	4	49.5			1.0	4.1	10.9	1.29	1.21
25.9	.587	4	3	67.6			2.0	9.6	16.1	1.48	1.10
29.5	.509	4	3	53.7			1.7	8.1	13.0	1.44	1.37
30.9	.739	5	2	59.9			1.0	5.7	11.5	1.24	1.40
24.9	.788	5	3	67.0			2.0	10.2	19.0	1.51	1.38
35.2	.535	7	3	61.1			1.4	9.7	13.8	1.21	1.06
		4	3	59.0			1.7	8.0	12.3	1.59	1.55
29.8	.526	3	3	74.6			1.6	8.5	14.0	1.47	1.30
41.4	.524	4	3	60.5			1.7	5.2	7.4	1.18	1.02
29.2	.471	4	2	41.7			1.7	8.4	14.3	1.14	1.17
30.1	.536	3	2	52.8			1.2	5.7	10.3	.95	1.21
33.2	.456	4	3	48.8			1.2	6.6	15.1	1.25	1.12
27.1	.604	4	3	56.7			1.9	8.0	13.7	1.48	1.12
24.4	.578	3	3	52.3			1.2	8.1	16.1	1.29	1.28
45.5	.446	4	3	30.2			1.0	5.0	9.6	1.12	1.08
23.1	.552	4	4	61.9			1.8	8.6	15.4	1.19	1.23
17.5	.681	3	3	63.1			1.1	9.0	19.2	1.32	1.18
34.3	.658	3	3	55.4			1.8	9.8	18.3	1.45	1.41
21.8	.714	4	1	58.2			1.7	8.3	15.1	1.33	1.34
31.5	.714	4	1	58.2			1.7	8.3	15.1	1.33	1.34

Table 13 (cont.)

Needles per Inch of Shoot	Wt. of 100 Needles (Grms)	Needle Years	Color Class	Green Crown %	Radial Growth 5 Yrs. (In.)	Radial Growth 10 Yrs. (In.)	Height Growth Current Yr. (Ft)	Height Growth 5 Yrs. (Ft.)	Height Growth 10 Yrs. (Ft.)	First Whorl %	Third Whorl %
31.1	.585	5	4	53.2			1.8	8.9	13.8	1.24	1.12
22.9	.669	3	3				2.0	10.2	17.9	1.40	1.25
32.6	.630	5	1	59.3			1.4	7.2	12.3	1.21	1.18
21.2	.597	4	2	68.8			2.1	11.8	25.4	1.65	1.35
28.7	.457	5	2	50.9			1.3	9.0	16.1	1.46	1.24
33.7	.384	4	2	50.4			1.7	8.9	17.1	1.45	1.40
35.4	.591	4	3	68.5			1.5	10.7	19.9	1.65	1.38
33.8	.584	3	3	62.4			1.9	11.9	21.6	1.53	1.20
15.9	.620	4	3	56.3			1.8	10.3	23.3	1.49	1.43
17.5	.647	5	3	42.4			1.3	7.5	11.5	1.30	1.29
24.7	.404	6	3	44.6			1.0	7.3	13.5	1.29	1.21
44.5	.591	3	3	51.5			1.2	5.0	8.9	1.47	.93
54.9	.394	6	2	54.9			1.4	3.9	7.9	1.18	1.16
23.9	.737	7	3	44.1			1.0	3.3	5.3	1.18	1.23
13.5	.736	4		76.6	.8	1.5	2.5	13.5	22.3	1.78	1.53
63.7	.474	5		39.7	.4	.7	.7	2.2	5.5	.97	1.00
		5		76.6	.8	1.6	1.9	13.6	25.0	1.81	1.43
18.8	.696	4		74.3	.7	1.3	1.8	12.0	24.4	1.66	1.55
25.7	.717	5		82.6	1.0	1.9	2.4	13.5	25.1	1.84	1.60
20.7	.909	3		63.9	1.0	2.2	3.4	15.3	31.9	1.80	1.68
		4		86.7	.8	1.5	1.3	7.2	15.7	1.05	1.27
27.0	.746	2		74.5	.8	1.6	2.5	11.5	26.3	1.58	1.38
20.5	.588	4		79.2	1.0	1.9	2.0	9.8	23.4	1.28	1.26
29.6	.688	4		61.1	1.0	1.9	2.4	12.5	23.6	1.45	1.45
31.5	.514	4		59.9	.5	.8	1.6	8.5	16.1	1.69	1.70
38.4	.594	3		58.1	.5	.9	1.4	7.3	15.4	1.23	1.19
31.1	.625	5		55.3	.8	1.5	1.9	8.0	13.5	1.35	1.51
24.1	.733	4		70.9	.9	1.8	2.6	10.3	20.7	1.31	1.40
24.9	.693	4		75.8	1.0	1.9	2.5	10.3	20.5	1.39	1.26
29.2	.755	4		68.6	.7	1.2	2.2	9.7	21.0	1.33	1.30
19.0	.722	5		54.2	1.0	1.7	2.7	13.7	26.6	1.71	1.39

Table 13 (Cont.)

Needles per Inch of Shoot	Wt. of 100 Needles (Grms)	Needles Years	Color Class	Green Crown %	Radial Growth 5 Yrs. (In.)	Radial Growth 10 Yrs. (In.)	Height Growth Current Yr. (Ft.)	Height Growth 5 Yrs. (Ft.)	Height Growth 10 Yrs. (Ft.)	First Whorl %	Third Whorl %
18.1	.807	4		76.3	.6	1.7	1.5	9.6	21.8	1.71	1.53
23.0	.729	4		82.7	1.1	2.1	.7	10.7	22.1	1.49	1.15
22.2	.740	4		78.2	1.0	2.0	2.8	16.0	31.6	1.58	1.36
21.5	.584	4		78.3	.9	1.8	2.2	11.8	25.4	1.56	1.33
30.0	.459	4		40.2	.3	.6	1.4	6.4	12.0	1.22	1.20
35.8	.546	4		62.9	.4	.9	1.6	8.9	17.2	1.59	1.45
22.4	.561	4		78.5	.6	1.0	2.6	10.6	20.5	1.27	1.24
30.6	.523	4		64.5	.8	1.5	2.2	12.4	22.8	1.48	1.48
22.3	.596	4		77.8	.7	1.9	1.6	9.3	23.7	1.31	1.17
22.8	.779	4		79.4	.8	2.0	2.9	14.3	27.1	1.50	1.50
17.0	.890	5		55.7	.7	1.4	1.0	5.7	16.3	1.39	1.54
26.9	.569	4		68.1	.6	1.4	2.0	12.3	24.3	1.40	1.43
24.1	.822	4		79.9	.8	1.7	2.3	13.5	23.3	1.61	1.22
24.9	.696	5		64.7	.7	1.4	2.6	11.7	20.5	1.68	1.32
20.4	.586	4		67.9	.9	1.7	2.6	11.7	22.9	1.58	1.36
34.7	.463	4		38.0	.7	1.1	1.6	7.7	13.3	1.17	1.23
24.2	.609	4		45.0	.8	1.3	2.2	10.1	17.6	1.17	1.39
34.2	.467	4		39.1	.4	.7	1.1	6.2	12.8	1.16	1.43
41.4	.790	2		36.1	.4	1.0	1.1	5.5	11.3	1.29	1.33
46.5	.473	4		39.2	.4	.8	1.0	5.6	9.7	1.14	1.28
38.5	.510	3		49.8	.4	.7	1.4	7.0	12.9	1.31	1.53
25.8	.579	4		48.2	.4	1.1	2.2	8.6	14.6	1.42	1.46
31.6	.743	4		34.1	.6	1.5	2.4	7.8	13.7	1.24	1.60
39.2	.522	5		31.6	.2	.3	1.7	7.6	11.8	1.41	1.23
35.3	.577	4		47.5	.3	.6	1.5	5.3	9.8	1.20	1.34
42.6	.355	7		44.1	.4	.7	1.4	4.9	9.4	1.12	1.36
39.0	.526	4		47.7	.3	.8	1.9	5.9	11.8	1.17	1.34
30.3	.493	4		40.0	.3	.5	1.2	6.2	11.9	1.23	1.29
30.4	.315	4		38.3	.4	.8	1.1	5.0	9.4	1.23	1.24
30.7	.615	4		40.8	.3	.5	1.2	5.4	8.1	1.14	1.20
44.6	.495	4		58.0	.5	.7	1.4	4.3	7.7	1.22	1.22
31.9	.503	4		35.5	.3	.5	1.5	5.3	12.1	1.37	1.43

Table 14. STAND DATA AND NITROGEN CONTENT OF RANDOMLY SELECTED TREES

Height (Ft.)	DBH (In.)	Stocking (Sq. Ft. B.A./Ac.	Age (Yrs.)	Site (Tree)	Site-Index (Stand) (Bull. 201)	First Whorl %	Third Whorl %
63.8	9.0	120	38	112	102	1.40	1.05
61.8	7.9	140	41	101	111	1.26	1.29
60.8	7.7	125	41	100	87	1.16	1.06
65.9	9.6	110	40	110	101	1.25	1.22
65.6	9.9	110	39	112	101	1.49	1.32
69.0	10.1	110	41	113	101	1.34	1.34
61.6	7.3	150	40	103	113	1.32	1.16
50.0	8.7	70	36	147	94	1.61	1.31
58.3	8.4	125	42	94	106	1.21	1.28
81.3	14.1	110	40	136	121	1.31	1.32
80.7	10.2	110	42	130	121	1.45	1.33
63.6		140	44	99	124	1.71	1.19
78.8	9.8	160	41	129	114	1.40	1.27
95.0	12.8	180	43	151	120	1.25	1.19
88.2	13.9	160	48	130	140	1.32	1.16
90.3	12.3	160	49	131	140		.98
68.5	11.4	100	37	123	116	1.27	1.21
72.0	9.8	130	34	140	121	1.52	1.28
72.1	10.7	125	41	118	130	1.59	1.31
88.8	14.7	150	42	143	134	1.68	1.20
75.7	11.4	135	34	147	133	1.36	1.34
69.3	10.8	90	38	121	135	1.27	1.30
92.8	13.4	120	41	152	132	1.39	1.53
90.3	11.5	135	42	146	134	1.34	1.33
86.8	13.4	135	41	142	134	1.31	1.48
79.9	10.6	135	45	123	134	1.25	1.34
90.8	13.3	135	40	151	144	1.15	1.19
91.0	11.3	125	39	155	134	1.34	1.24
54.6	7.4	100	26	144	121	1.53	1.24
49.7	7.7	75	25	138	117	1.50	1.19
53.5	7.6	65	26	141	114	1.60	1.25
80.5	12.2	150	35	152	134	1.53	1.29
77.4	10.4	130	39	132	139	1.43	1.08
64.8	13.3	115	40	108		1.30	1.23
95.5	12.8	130	41	156	136	1.50	1.31
75.5	12.3	115	38	132		1.30	1.36
75.0	9.9	140	44	117	141	1.24	1.20
76.4	10.2	150	42	124	137	1.54	1.46
78.1	10.1	150	43	124	137	1.37	1.49
78.3	9.7	130	40	130	138	1.53	1.35
69.6	9.1	155	44	109	132	1.48	1.23
77.3	10.3	175	48	99	112	1.27	1.24
64.0	8.8	170	50	91	105	1.17	.98
78.3	11.2	70	34	152	123	1.51	1.26
56.2	8.7	130	35	106	118	1.57	1.39
77.3	12.5	65	36	142	131	1.55	1.30

Table 14. (cont.)

Height (Ft.)	DBH (In.)	Stocking (Sq. Ft. B.A./Ac.)	Age (Yrs.)	Site (Tree)	Site-Index (Stand) (Bull. 201)	First Whorl %	Third Whorl %
70.8	12.4	70	33	141	118	1.26	1.31
75.1	11.1	105	40	125	122	1.35	1.55
64.1	9.2	85	34	124	114	1.39	1.40
57.2	11.3	90	34	111	121	1.61	1.30
65.1	11.2	100	32	133	117	1.40	1.49
70.0	9.7	85	36	129	122	1.41	1.56
77.4	10.2	90	32	158	122	1.42	1.39
81.8	12.0	90	41	134	125	1.34	1.20
85.9	13.0	105	39	147	127	1.27	1.21
68.2	12.6	110	40	114	122	1.14	1.23
53.6	9.6	55	28	127	117	1.59	1.31
62.9	9.3	70	31	133	116	1.66	1.45
64.7	12.1	60	36	119	108	1.47	1.21
70.5	10.5	120	43	112	132	1.61	1.49
76.8	11.5	90	46	116	124	1.24	1.25
61.8	9.4	85	36	114	137	1.48	1.49
69.8	10.2	110	40	116	127	1.51	1.40
62.4	10.4	115	37	112	120	1.73	1.33
55.0	9.5	85	36	101	122	1.31	1.30
85.9	15.3	90	41	141	134	1.34	1.14
74.1	11.2	105	37	133	119	1.37	1.23
77.3	10.1	95	39	132	124	1.43	1.39
59.4	11.5	75	33	119	109	1.54	1.58
76.2	11.1	115	39	130	142	1.48	1.35
85.2	12.7	80	41	140	123	1.50	1.36
68.3	10.0	75	36	126	118	1.42	1.26
75.2	10.8	90	38	131	123	1.76	1.49
76.5	13.3	60	39	131	121	1.13	1.26
80.6	13.1	60	40	134	121	1.35	1.32
90.9	13.0	140	46	138	128	1.65	1.52
77.6	13.0	130	45	119	128	1.05	1.23
65.1	11.4	100	39	111	121	1.28	1.26
70.2	11.0	85	42	113	123	1.36	1.29
86.1	14.6	100	40	144	130	1.49	1.56
75.9	12.7	110	39	130	118	1.72	1.56
70.6	11.3	110	37	127	118	1.34	1.36
101.8	20.4	140	69	121	131	1.08	1.30
70.8	10.1	110	41	116	126	1.46	1.37
73.3	10.0	130	42	118	125	1.28	1.40
76.3	12.8	90	43	121	111	1.31	
94.1	14.1	120	46	143	121	1.48	1.36
98.0	14.5	100	41	161	148	1.64	1.41
82.2	10.8	150	48	121	131	1.10	1.32
93.8	11.0	180	48	138	130	1.46	1.39
86.4	11.3	180	55	117	126	1.07	1.30
91.0	11.3	175	49	132	118	1.64	1.46
92.8	14.2	130	49	134	124	1.41	1.24
88.0	12.9	170	47	131	123	1.35	1.21

Table 15. SAMPLE TREE DATA AND NITROGEN CONTENT OF RANDOMLY SELECTED TREES

Needles per Inch of Shoot	Wt. of 100 Needles (Grms)	Needle Years	Color Class	Green Crown %	Radial Growth 5 Yrs. (In.)	Radial Growth 10 Yrs. (In.)	Height Growth Current Yrs. (Ft.)	Height Growth 5 Yrs. (Ft.)	Height Growth 10 Yrs. (Ft.)	First Whorl %	Third Whorl %
31.4	.445	4		77.3			1.8	9.3	17.6	1.40	1.05
46.0	.379	4		66.2			1.7	6.4	10.6	1.26	1.29
40.6	.539	5		64.8	*Not measured*		1.5	6.8	10.6	1.16	1.06
37.6	.479	3	3	60.5	*in first 88*		.9	4.4	9.3	1.25	1.22
35.1	.511	4	3	69.1	*samples taken.*		1.3	5.0	9.0	1.49	1.32
32.2	.454	4	1	59.6			1.0	5.3	9.8	1.34	1.34
32.8	.622	6		72.9			1.3	10.0	15.3	1.32	1.15
16.4	.638	3	4	80.2			2.4	12.6	22.0	1.61	1.31
39.2	.561	5	5	42.4			1.2	3.9	6.5	1.21	1.28
27.5	.745	5	1	67.3			1.0	10.7	16.3	1.31	1.32
37.8	.671	6	3	75.2			2.1	9.8	16.9	1.45	1.33
30.1	.331	3	3	47.2			1.3	5.9	11.7	1.71	1.19
20.1	.798	4	2	52.0			2.0	11.4	21.2	1.40	1.27
31.7	.851	5	1	59.2			2.2	11.2	17.7	1.25	1.19
24.5	.579	3	3	55.6			1.6	9.1	17.2	1.32	1.16
		3	3	59.1			.9	6.3	13.3		.98
17.3	.652	4	3	72.3			1.0	7.3	17.5	1.27	1.21
21.0	.666	3	3	72.1			2.4	12.3	24.3	1.52	1.28
27.4	.598	4	1	51.0			1.8	5.2	11.3	1.59	1.31
24.6	.861	5	3	62.9			2.3	12.4	21.6	1.68	1.20
19.8	.762	4	3	63.9			3.4	12.7	23.5	1.36	1.34
29.2	.643	4	2	78.5			1.1	8.1	14.2	1.27	1.30
43.4	.523	5	3	48.7			1.2	11.3	22.0	1.39	1.53
15.8	.982	6	1	70.7			1.7	8.6	17.3	1.34	1.33
34.3	.569	4	3	69.6			1.9	10.1	20.0	1.31	1.48
29.4	.617	4	3	57.4			1.8	7.8	16.5	1.25	1.34
16.5	.848	5	3	65.6			1.5	9.3	19.4	1.15	1.19
32.1	.457	5	3	46.4			1.5	10.1	21.1	1.34	1.24
20.8	.779	4	3	82.6			3.2	15.3	27.4	1.53	1.24
31.4	.612	3	5	78.1			1.9	13.0	26.7	1.50	1.19
22.4	.668	3	3	79.1			2.9	12.6	26.0	1.60	1.25

Table 15 (cont.)

Needles per Inch of Shoot	Wt. of 100 Needles (Grms)	Needle Years	Color Class	Green Crown %	Radial Growth 5 Yrs. (In.)	Radial Growth 10 Yrs. (In.)	Height Growth Current Yr. (Ft.)	Height Growth 5 Yrs. (Ft.)	Height Growth 10 Yrs. (Ft.)	First Whorl %	Third Whorl %
17.9	.553	3	1	57.6			2.3	12.6	27.0	1.53	1.29
27.5	.463	4	2	66.3			1.8	8.6	13.2	1.43	1.08
42.9	.329	4		62.8			.8	3.2	9.4	1.30	1.23
		3	3	44.9			2.2	10.7	20.5	1.50	1.31
30.2	.401	5	3	58.9			3.5	12.8	22.8	1.30	1.36
33.1	.408	3	5	51.3			1.0	6.4	11.4	1.24	1.20
17.9	.744	3	3	53.3			2.2	9.8	19.4	1.54	1.46
26.7	.563	3	2	67.9			1.6	9.1	20.6	1.37	1.49
25.4	.458	4	3	70.6			2.0	11.8	23.4	1.53	1.35
18.9	.630	3	1	36.5			1.0	6.1	11.0	1.48	1.23
52.7	.551	6	6	50.8			1.2	6.1	11.1	1.27	1.24
37.1	.429	3		65.6			.6	4.0	7.0	1.17	.98
21.3	.572	4		75.0	.9	1.8	3.1	14.7	30.9	1.51	1.26
34.3	.680	4		63.7	.6	1.0	2.6	8.8	19.9	1.57	1.39
20.5	.631	5		76.3	.8	1.8	3.1	13.9	24.3	1.55	1.30
27.8	.566	4		81.1	1.0	2.0	2.4	12.5	26.1	1.26	1.31
29.0	.554	4		66.0	.6	1.1	1.8	9.2	17.2	1.35	1.55
24.0	.657	4		66.5	.6	1.3	2.0	11.6	21.6	1.39	1.40
36.0	.452	4		66.3	.8	1.7	2.6	11.6	20.2	1.61	1.30
42.5	.640	4		76.0	.8	1.5	2.3	10.5	20.9	1.40	1.49
16.9	.760	4		51.3	.7	1.4	1.0	8.9	19.6	1.41	1.56
19.5	.706	4		74.8	.7	1.6	3.0	14.5	28.7	1.42	1.39
32.3	.809	4		76.3	.6	1.2	2.1	10.4	19.3	1.34	1.20
28.3	.585	5		80.2	.6	1.1	2.0	9.0	18.0	1.28	1.21
31.1	.787	4		64.4	.6	1.2	1.5	8.6	14.7	1.14	1.23
22.2	.780	4		81.9	1.2	2.3	3.3	15.2	30.2	1.59	1.31
25.5	.792	4		79.5	1.1	2.1	2.9	15.5	28.1	1.66	1.45
21.3	.595	4		81.0	1.1	2.2	3.3	10.6	19.2	1.47	1.21
22.7	.613	4		63.4	.5	.8	1.9	8.4	15.6	1.61	1.49
34.9	.453	4		52.1	.3	.6	.9	3.0	7.6	1.24	1.25
23.1	.670	5		73.0	.7	1.3	2.7	11.0	18.2	1.48	1.49
33.3	.657	5		67.9	1.0	1.3	1.9	9.1	16.3	1.51	1.40

Table 15 (cont.)

Needles per Inch of Shoot	Wt. of 100 Needles (Grms)	Needle Years	Color Class	Green Crown %	Radial Growth 5 Yrs. (In.)	Radial Growth 10 Yrs. (In.)	Height Growth Current Yr. (Ft.)	Height Growth 5 Yrs. (Ft.)	Height Growth 10 Yrs. (Ft.)	First Whorl %	Third Whorl %
17.7	.630	4		76.6	.8	1.4	3.4	15.2	23.4	1.73	1.33
20.3	.684	4		66.2	.6	1.2	2.0	10.1	19.8	1.31	1.30
17.5	.649	4		66.7	1.1	1.7	3.0	12.2	20.3	1.34	1.14
21.2	.680	4		80.2	.7	1.4	2.1	13.7	20.5	1.37	1.23
23.1	.621	4		65.3	.7	1.3	3.0	13.5	25.3	1.43	1.39
15.6	.620	4		74.6	1.1	2.2	3.0	12.9	22.8	1.54	1.58
21.7	.845	4		55.2	.4	1.0	1.8	9.5	17.1	1.48	1.35
20.0	.796	4		65.1	.7	1.3	3.1	12.5	26.7	1.50	1.36
21.5	.738	4		70.1	.6	1.1	2.3	8.6	15.9	1.42	1.26
22.9	.794	4		74.6	.6	1.1	2.0	11.2	19.6	1.76	1.49
39.4	.557	4		83.0	.6	1.1	2.2	8.9	18.2	1.13	1.26
35.7	.730	4		88.5	.5	1.4	2.5	12.4	25.5	1.35	1.32
21.3	.667	4		55.6	.5	.7	1.8	9.1	19.9	1.65	1.52
42.6	.470	5		54.4	.6	1.1	1.1	4.3	9.6	1.05	1.23
30.3	.572	3		57.9	.6	1.2	1.8	8.1	13.9	1.28	1.26
30.8	.700			70.1	.4	.5	1.5	5.7	10.2	1.36	1.29
15.8	.671	4		75.7	.9	1.9	2.3	10.4	22.4	1.49	1.56
18.0	.723	5		65.6	.6	1.3	3.0	13.7	25.0	1.72	1.56
26.3	.490	4		32.4	.7	1.6	2.7	12.7	22.2	1.34	1.36
28.0	.668	4		72.1	.6	1.2	1.6	6.6	12.7	1.08	1.30
25.9	.523	4			.6	1.1	1.9	10.0	18.1	1.46	1.37
19.3	.688	5		40.7	.6	1.1	1.7	7.0	15.3	1.28	1.40
23.9	.591	2		65.9	.7	1.4	1.8	6.5	15.9	1.31	
32.0	.588	4		61.7	.5	1.1	1.7	8.7	17.7	1.48	1.36
20.8	.592	4		67.4	.4	1.2	2.0	12.8	24.0	1.64	1.41
36.4	.626	4		30.9	.3	.6	1.3	5.7	11.5	1.10	1.32
29.7	.638	5			.5	.9	2.5	9.5	17.6	1.46	1.39
33.2	.509	4		33.4	.4	.9	1.8	7.2	11.4	1.07	1.30
21.3	.571	6		41.2	.5	.9	1.8	7.6	12.8	1.64	1.46
37.2	.437	4		47.7	.6	1.3	2.0	9.0	15.4	1.41	1.24
38.7	.384	4		59.8	.7	1.3	1.9	9.5	16.8	1.35	1.21

characteristics and foliar nitrogen values for these 94 random samples.

c) Table (16) shows the stand characteristics and foliar nitrogen values for the 49 representative samples taken in September, 1968 which included radial growth data, and Table (17) shows the tree characteristics and foliar nitrogen values for these 49 representative samples.

d) Table (18) shows the stand characteristics and foliar nitrogen values for the 51 random samples taken in September, 1968 which included radial growth data, and Table (19) shows the tree characteristics and foliar nitrogen values for these 51 random samples.

From these statistical treatments, the three major questions from above are considered in detail in the three sections that follow.

1. Range and Variability of Foliar Nitrogen Content

An examination was made of the range and variability of foliar nitrogen content of current foliage from the first whorl and of one-year-old foliage from the third whorl for

i. All 188 samples taken
ii. The 94 random samples
iii. The 94 representative samples.

Figure (10) shows the range and frequency of foliar nitrogen percentage in the first whorl from the 188 samples. Nitrogen content ranged from 0.95% to 1.84% with a maximum frequency of 25 in the 1.3% to 1.35% class. A frequency curve is superimposed on the histogram. This curve depicts a statistical estimate of the form of distribution in the population from which the sample was drawn. Table (56) in Appendix 3 sets out the results of analyses to test the skewness and kurtosis of the curve. This analysis demonstrated that the frequency curve of all 188 samples covering the study

Table 16. STAND DATA AND NITROGEN CONTENT OF 49 TREES SELECTED TO REPRESENT THE STAND (with radial growth data)

Height (Ft.)	DBH (In.)	Stocking (Sq. Ft. B.A./Ac.)	Age (Yrs.)	Site (Tree)	Site-Index (Stand) (Bull. 201)	First Whorl %	Third Whorl %
72.1	12.0	60	36	132	118	1.78	1.53
65.5	10.8	105	44	102	99	.97	1.00
54.9	9.7	105	29	125	115	1.81	1.43
68.4	9.7	90	33	136	114	1.66	1.55
62.1	11.0	90	32	127	121	1.84	1.60
70.4	10.9	90	32	145	140	1.80	1.68
63.2	12.3	90	36	116	114	1.05	1.27
62.3	8.5	95	34	123	123	1.58	1.38
58.7	9.6	70	34	114	118	1.28	1.26
63.5	10.2	70	34	123	124	1.45	1.45
84.0	10.7	115	45	129	131	1.69	1.70
72.0	11.5	95	38	126	130	1.23	1.19
76.1	12.7	110	42	123	128	1.35	1.51
92.3	15.7	120	41	149	142	1.31	1.40
59.2	10.8	80	32	122	118	1.39	1.26
79.9	11.1	90	32	163	141	1.33	1.30
99.0	15.2	130	41	162	143	1.71	1.39
70.8	10.8	95	36	130	132	1.71	1.53
63.5	11.5	85	36	117	121	1.49	1.15
61.8	10.8	70	35	117	113	1.58	1.36
56.2	9.1	75	30	122	122	1.56	1.33
72.2	9.2	130	45	111	110	1.22	1.20
62.2	10.8	90	41	102	106	1.59	1.45
81.7	11.9	85	42	132	130	1.27	1.24
69.8	10.7	100	35	132	135	1.48	1.48
51.7	9.1	70	32	107	110	1.31	1.17
65.0	10.5	75	33	129	125	1.50	1.50
89.7	14.1	130	43	142	136	1.39	1.54
72.7	9.6	105	35	137	133	1.40	1.43
58.1	10.4	70	34	113	105	1.61	1.22
63.5	9.8	60	37	114	113	1.68	1.32
76.9	12.1	100	40	128	122	1.58	1.36
70.2	8.3	130	42	113	118	1.17	1.23
80.0	10.2	110	45	123	117	1.17	1.39
89.5	12.8	155	51	127	129	1.16	1.43
88.8	14.0	120	39	129	126	1.29	1.33
81.2	11.2	150	45	125	115	1.14	1.28
81.0	10.0	180	53	112	113	1.31	1.53
95.4	13.9	140	54	131	133	1.42	1.46
93.2	14.9	140	52	130	130	1.24	1.60
88.7	11.8	190	55	120	122	1.41	1.23
81.0	12.2	200	52	113	119	1.20	1.34
88.4	11.8	170	52	124	122	1.12	1.36
81.8	11.5	180	37	122	119	1.17	1.34
89.2	14.5	170	55	121	122	1.23	1.29
85.4	12.9	200	50	122	126	1.23	1.24
53.7	7.8	90	48	80	81	1.14	1.20
49.1	7.4	90	44	77	76	1.22	1.22
55.2	6.1	110	40	91	89	1.37	1.43

Table 17. SAMPLE TREE DATA AND NITROGEN CONTENT OF 49 TREES SELECTED TO REPRESENT THE STAND (with radial growth data)

Needles per Inch	Wt. of 100 Needles (Grms)	Needle Years	Green Crown %	Radial Growth 5 Yrs. (In.)	Radial Growth 10 Yrs. (In.)	Height Growth Current Yr. (Ft.)	Height Growth 5 Yrs. (Ft.)	Height Growth 10 Yrs. (Ft.)	First Whorl %	Third Whorl %
13.5	.736	4	76.6	.8	1.5	2.5	13.5	22.3	1.78	1.53
63.7	.474	5	39.7	.4	.7	.7	2.2	5.5	.97	1.00
		5	76.6	.8	1.6	1.9	13.6	25.0	1.81	1.43
18.8	.696	4	74.3	.7	1.3	1.8	12.0	24.4	1.66	1.55
25.7	.717	5	82.6	1.0	1.9	2.4	13.5	25.1	1.84	1.60
20.7	.909	3	63.9	1.0	2.2	3.4	15.3	31.9	1.80	1.68
		4	86.7	.8	1.5	1.3	7.2	15.7	1.05	1.27
27.0	.746	2	74.5	.8	1.6	2.5	11.5	26.3	1.58	1.38
20.5	.588	4	79.2	1.0	1.9	2.0	9.8	23.4	1.28	1.26
29.6	.688	4	61.1	1.0	1.9	2.4	12.5	23.6	1.45	1.45
31.5	.514	4	59.9	.5	.8	1.6	8.5	16.1	1.69	1.70
38.4	.594	3	58.1	.5	.9	1.4	7.3	15.4	1.23	1.19
31.1	.625	5	55.3	.8	1.5	1.9	8.0	13.5	1.35	1.51
24.1	.733	4	70.9	.9	1.8	2.6	10.3	20.7	1.31	1.40
24.9	.693	4	75.8	1.0	1.9	2.5	10.3	20.5	1.39	1.26
29.2	.755	4	68.6	.7	1.2	2.2	9.7	21.0	1.33	1.30
19.0	.772	5	54.2	1.0	1.7	2.7	13.7	26.6	1.71	1.39
18.1	.807	4	76.3	.6	1.7	1.5	9.6	21.8	1.71	1.53
23.0	.729	4	82.7	1.1	2.1	.7	10.7	22.1	1.49	1.15
22.2	.740	4	78.2	1.0	2.0	2.8	16.0	31.6	1.58	1.36
21.5	.584	4	78.3	.9	1.8	2.2	11.8	25.4	1.56	1.33
30.3	.459	4	40.2	.3	.6	1.4	6.4	12.0	1.22	1.20
35.8	.546	5	62.9	.4	.9	1.6	8.9	17.2	1.59	1.45
22.4	.561	4	78.5	.6	1.0	2.6	10.6	20.5	1.27	1.24
30.6	.523	4	64.5	.8	1.5	2.2	12.4	22.8	1.48	1.48
22.3	.596	4	77.8	.7	1.9	1.6	9.3	23.7	1.31	1.17
22.8	.779	4	79.4	.8	2.0	2.9	14.3	27.1	1.50	1.50
17.0	.890	5	55.7	.7	1.4	1.0	5.7	16.3	1.39	1.54

Table 17 (cont.)

Needles per Inch	Wt. of 100 Needles (Grms)	Needle Years	Green Crown %	Radial Growth 5 Yrs. (In.)	Radial Growth 10 Yrs. (In.)	Height Growth Current Yr. (Ft.)	Height Growth 5 Yrs. (Ft.)	Height Growth 10 Yrs. (Ft.)	First Whorl %	Third Whorl %
26.9	.569	4	68.1	.6	1.4	2.0	12.3	24.3	1.40	1.43
24.1	.822	4	79.9	.8	1.7	2.3	13.5	23.3	1.61	1.22
24.9	.696	5	64.7	.7	1.4	2.6	11.7	20.5	1.68	1.32
20.4	.586	4	67.9	.9	1.7	2.6	11.7	22.9	1.58	1.36
34.7	.463	4	38.0	.7	1.1	1.6	7.7	13.3	1.17	1.23
24.2	.609	4	45.0	.8	1.3	2.2	10.1	17.6	1.17	1.39
34.2	.467	4	39.1	.4	.7	1.1	6.2	12.8	1.16	1.43
41.4	.790	2	36.1	.4	1.0	1.1	5.5	11.3	1.29	1.33
46.5	.473	4	39.2	.4	.8	1.0	5.6	9.7	1.14	1.28
38.5	.510	3	49.8	.4	.7	1.4	7.0	12.9	1.31	1.53
25.8	.579	4	48.2	.6	1.1	2.2	8.6	14.6	1.42	1.46
31.6	.743	4	34.1	.6	1.5	2.4	7.8	13.7	1.24	1.60
39.2	.522	5	31.6	.2	.3	1.7	7.6	11.8	1.41	1.23
35.3	.577	4	47.5	.3	.6	1.5	5.3	9.8	1.20	1.34
42.6	.355	7	44.1	.4	.7	1.4	4.9	9.4	1.12	1.36
39.0	.526	4	47.7	.3	.8	1.9	5.9	11.8	1.17	1.34
30.3	.493	4	40.0	.3	.5	1.2	6.2	11.9	1.23	1.29
30.4	.315	4	38.3	.4	.8	1.1	5.0	9.4	1.23	1.24
30.7	.615	4	40.8	.3	.5	1.2	5.4	8.1	1.14	1.20
44.6	.495	4	58.0	.5	.7	1.4	4.3	7.7	1.22	1.22
31.9	.503	4	45.5	.3	.5	1.5	5.3	12.1	1.37	1.43

Table 18. STAND DATA AND NITROGEN CONTENT OF 51 RANDOMLY SELECTED TREES (with radial growth data)

Height (Ft.)	DBH (In.)	Stocking (Sq. Ft. B.A./Ac.)	Age (Yrs.)	Site (Tree)	Site-Index (Stand) (Bull. 201)	First Whorl %	Third Whorl %
78.3	11.2	70	34	152	123	1.51	1.26
56.2	8.7	130	35	106	118	1.57	1.39
77.3	12.5	65	36	142	131	1.55	1.30
70.8	12.4	70	33	141	118	1.26	1.31
75.1	11.1	105	40	125	122	1.35	1.55
64.1	9.2	85	34	124	114	1.39	1.40
57.2	11.3	90	34	111	121	1.61	1.30
65.1	11.2	100	32	133	117	1.40	1.49
70.0	9.7	85	36	129	122	1.41	1.56
77.4	10.2	90	32	158	122	1.42	1.39
81.8	12.0	90	41	134	125	1.34	1.20
85.9	13.0	105	39	147	127	1.28	1.21
68.2	12.6	110	40	114	122	1.14	1.23
53.6	9.6	55	28	127	117	1.59	1.31
62.9	9.3	70	31	133	116	1.66	1.45
64.7	12.1	60	36	119	108	1.47	1.21
70.5	10.5	120	43	112	132	1.61	1.49
76.8	11.5	90	46	116	124	1.24	1.25
61.8	9.4	85	36	114	137	1.48	1.49
69.8	10.2	110	40	116	127	1.51	1.40
62.4	10.4	115	37	112	120	1.73	1.33
55.0	9.5	85	36	101	122	1.31	1.30
85.9	15.3	90	41	141	134	1.34	1.14
74.1	11.2	105	37	133	119	1.37	1.23
77.3	10.1	95	39	132	124	1.43	1.39
59.4	11.5	75	33	119	109	1.54	1.58
76.2	11.1	115	39	130	142	1.48	1.35
85.2	12.7	80	41	140	123	1.50	1.36
68.3	10.0	75	36	126	118	1.42	1.26
75.2	10.8	90	38	131	123	1.76	1.49
76.5	13.3	60	39	131	121	1.13	1.26
80.6	13.1	60	40	134	121	1.35	1.32
90.9	13.0	140	46	138	128	1.65	1.52
77.6	13.0	130	45	119	128	1.05	1.23
65.1	11.4	100	39	111	121	1.28	1.26
70.2	11.0	85	42	113	123	1.36	1.29
86.1	14.6	100	40	144	130	1.49	1.56
75.9	12.7	110	39	130	118	1.72	1.56
70.6	11.3	110	37	127	118	1.34	1.36
101.8	20.4	140	69	121	131	1.08	1.30
70.8	10.1	110	41	116	126	1.46	1.37
73.3	10.0	130	42	118	125	1.28	1.40

Table 18 (cont.)

Height (Ft.)	DBH (In.)	Stocking (Sq. Ft. B.A./Ac.)	Age (Yrs.)	Site (Tree)	Site-Index (Stand) (Bull. 201)	First Whorl %	Third Whorl %
76.3	12.8	90	43	121	111	1.31	
94.1	14.1	120	46	143	121	1.48	1.36
98.0	14.5	100	41	161	148	1.64	1.41
82.2	10.8	150	48	121	131	1.10	1.32
93.8	11.0	180	48	138	130	1.46	1.39
86.4	11.3	180	55	117	126	1.07	1.30
91.0	11.3	175	49	132	118	1.64	1.46
92.8	14.2	130	49	134	124	1.41	1.24
88.0	12.9	170	47	131	123	1.35	1.21

Table 19. SAMPLE TREE DATA AND NITROGEN CONTENT OF 51 RANDOMLY SELECTED TREES (with radial growth data)

Needles per Inch of Shoot	Wt. of 100 Needles (Grms)	Needle Years	Green Crown %	Radial Growth 5 Yrs. (In.)	Radial Growth 10 Yrs. (In.)	Height Growth Current Yr. (Ft.)	Height Growth 5 Yrs. (Ft.)	Height Growth 10 Yrs. (Ft.)	First Whorl N%	Third Whorl N%
36.0	.452	4	66.3	.8	1.7	2.6	11.6	20.2	1.61	1.30
42.5	.640	4	76.0	.8	1.5	2.3	10.5	20.9	1.40	1.49
16.9	.760	4	51.3	.7	1.4	1.0	8.9	19.6	1.41	1.56
19.5	.706	4	74.8	.7	1.6	3.0	14.5	28.7	1.42	1.39
32.3	.809	4	76.3	.6	1.2	2.1	10.4	19.3	1.34	1.20
28.3	.585	5	80.2	.6	1.1	2.0	9.0	18.0	1.28	1.21
31.1	.787	4	64.4	.6	1.2	1.5	8.6	14.7	1.14	1.23
22.2	.780	4	81.9	1.2	2.3	3.3	15.2	30.2	1.59	1.31
25.5	.792	4	79.5	1.1	2.1	2.9	15.5	28.1	1.66	1.45
21.3	.595	4	81.0	1.1	2.2	3.3	10.6	19.2	1.47	1.21
22.7	.613	4	63.4	.5	.8	1.9	8.4	15.6	1.61	1.49
34.9	.453	4	52.1	.3	.6	.9	3.0	7.6	1.24	1.25
23.1	.670	5	73.0	.7	1.3	2.7	11.0	18.2	1.48	1.49
33.3	.657	5	67.9	1.0	1.3	1.9	9.1	16.3	1.51	1.40
17.7	.630	4	76.6	.8	1.4	3.4	15.2	23.4	1.73	1.33
20.3	.684	4	66.2	.6	1.2	2.0	10.1	19.8	1.31	1.30
17.5	.649	4	66.7	1.1	1.7	3.0	12.2	20.3	1.34	1.14
21.2	.680	4	80.2	.7	1.4	2.1	13.7	20.5	1.37	1.23
23.1	.621	4	65.3	.7	1.3	3.0	13.5	25.3	1.43	1.39
15.6	.620	4	74.6	1.1	2.2	3.0	12.9	22.8	1.54	1.58
21.7	.845	4	55.2	.4	1.0	1.8	9.5	17.1	1.48	1.35
20.0	.796	4	65.1	.7	1.3	3.1	12.5	26.7	1.50	1.36
21.5	.738	4	70.1	.6	1.1	2.3	8.6	15.9	1.42	1.26
22.9	.794	4	74.6	.6	1.1	2.0	11.2	19.6	1.76	1.49
39.4	.557	4	83.0	.6	1.1	2.2	8.9	18.2	1.13	1.26
35.7	.730	4	88.5	.5	1.4	2.5	12.4	25.5	1.35	1.32

Table 19 (cont.)

Needles per Inch of Shoot	Wt. of 100 Needles (Grms)	Needle Years	Green Crown %	Radial Growth 5 Yrs. (In.)	Radial Growth 10 Yrs. (In.)	Height Growth Current Yr. (Ft.)	Height Growth 5 Yrs. (Ft.)	Height Growth 10 Yrs. (Ft.)	First Whorl N%	Third Whorl N%
21.3	.667	4	55.6	.5	.7	1.8	9.1	19.9	1.65	1.52
42.6	.470	5	54.5	.6	1.1	1.1	4.3	9.6	1.05	1.23
30.3	.572	3	57.9	.6	1.2	1.8	8.1	13.9	1.28	1.26
30.8	.700		70.1	.4	.5	1.5	5.7	10.2	1.36	1.29
15.8	.671	4	75.7	.9	1.9	2.3	10.4	22.4	1.49	1.56
18.0	.723	5	65.6	.6	1.3	3.0	13.7	25.0	1.72	1.56
26.3	.490	4	32.4	.7	1.6	2.7	12.6	22.2	1.34	1.36
28.0	.668	4	72.1	.6	1.2	1.6	6.6	12.7	1.08	1.30
25.9	.523	4		.6	1.1	1.9	10.0	18.1	1.46	1.37
19.3	.688	5	40.7	.6	1.1	1.7	7.0	15.3	1.28	1.40
23.9	.591	2	65.9	.7	1.4	1.8	6.5	15.9	1.31	
32.0	.588	4	61.7	.5	1.1	1.7	8.7	17.7	1.48	1.36
20.8	.592	4	67.4	.4	1.2	2.0	12.8	24.0	1.64	1.41
36.4	.626	4	30.9	.3	.6	1.3	5.7	11.5	1.10	1.32
29.7	.638	5		.5	.9	2.5	9.5	17.6	1.46	1.39
33.2	.509	4	33.4	.4	.9	1.8	7.2	11.4	1.07	1.30
21.3	.571	6	41.2	.5	.9	1.8	7.6	12.8	1.64	1.46
37.2	.437	4	47.7	.6	1.3	2.0	9.0	15.4	1.41	1.24
38.7	.384	4	59.8	.7	1.3	1.9	9.5	16.8	1.35	1.21

area did not vary significantly from a normal curve. Thus in the study area, foliar nitrogen in the first whorl follows a normal distribution curve with a mean value of 1.40% and extreme values of 0.95% and 1.84%.

Similar histograms and curves were drawn for:

- Range and frequency of foliar nitrogen in the third whorl from the 188 samples (Figure 11)
- Range and frequency of foliar nitrogen in the first whorl from the 94 representative samples (Figure 12)
- Range and frequency of foliar nitrogen in the first whorl from the 94 random samples (Figure 13)
- Range and frequency of foliar nitrogen in the third whorl from the 94 representative samples (Figure 14)
- Range and frequency of foliar nitrogen in the third whorl from the 94 representative samples (Figure 15)

In all cases, statistical analysis demonstrated that the frequency curves did not vary significantly from normal distribution curves. This pattern of a normal distribution of foliar nutrient level over an area has not been recorded in the literature for any species or nutrient.

Table (20) presents the range and frequency of foliar nitrogen content for each of the above six groups of samples.

Figures (16a) and (16b) in Appendix 3 show the foliar nitrogen percentages in the first whorl from representative samples and the location from where the samples were taken in the western and eastern sections of the study area respectively. An effort was made to stratify the area into foliar nitrogen classes but the variation between samples even within two chains of each other was so great that no pattern of distribution was

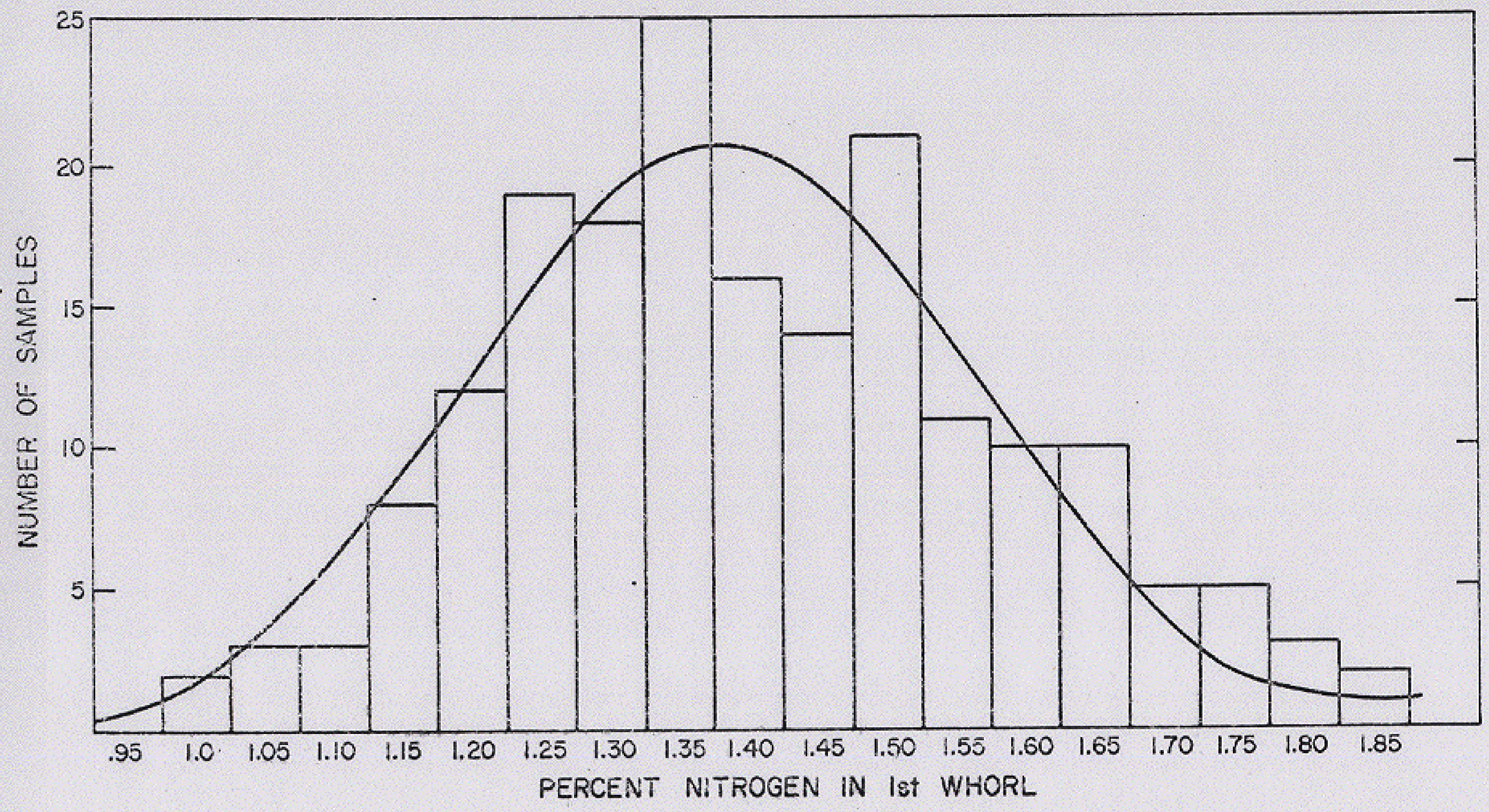

Figure 10. Range and frequency of foliar nitrogen percentage in the first whorl from 188 samples.

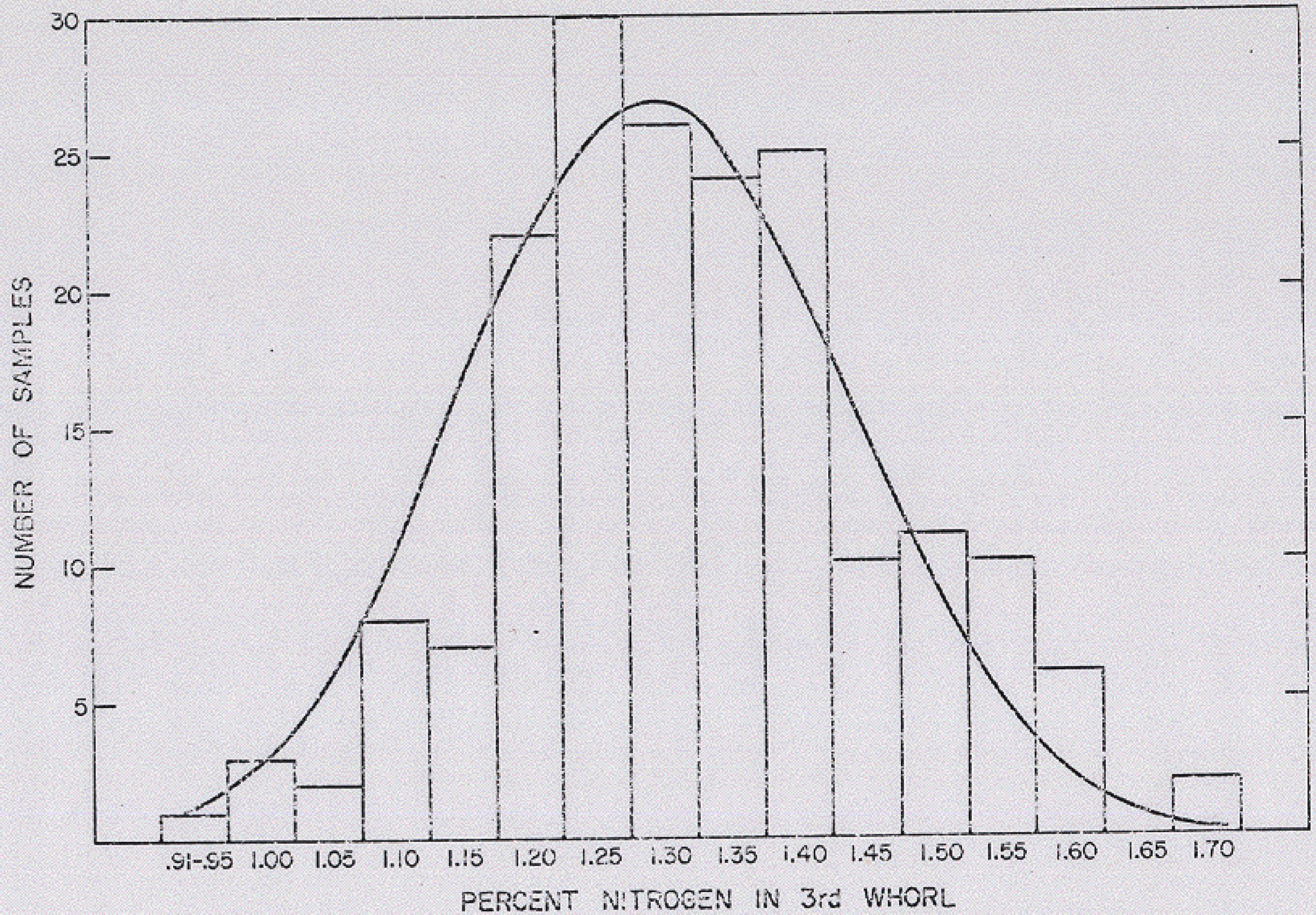

Figure 11. Range and frequency of foliar nitrogen percentage in the third whorl from 188 samples.

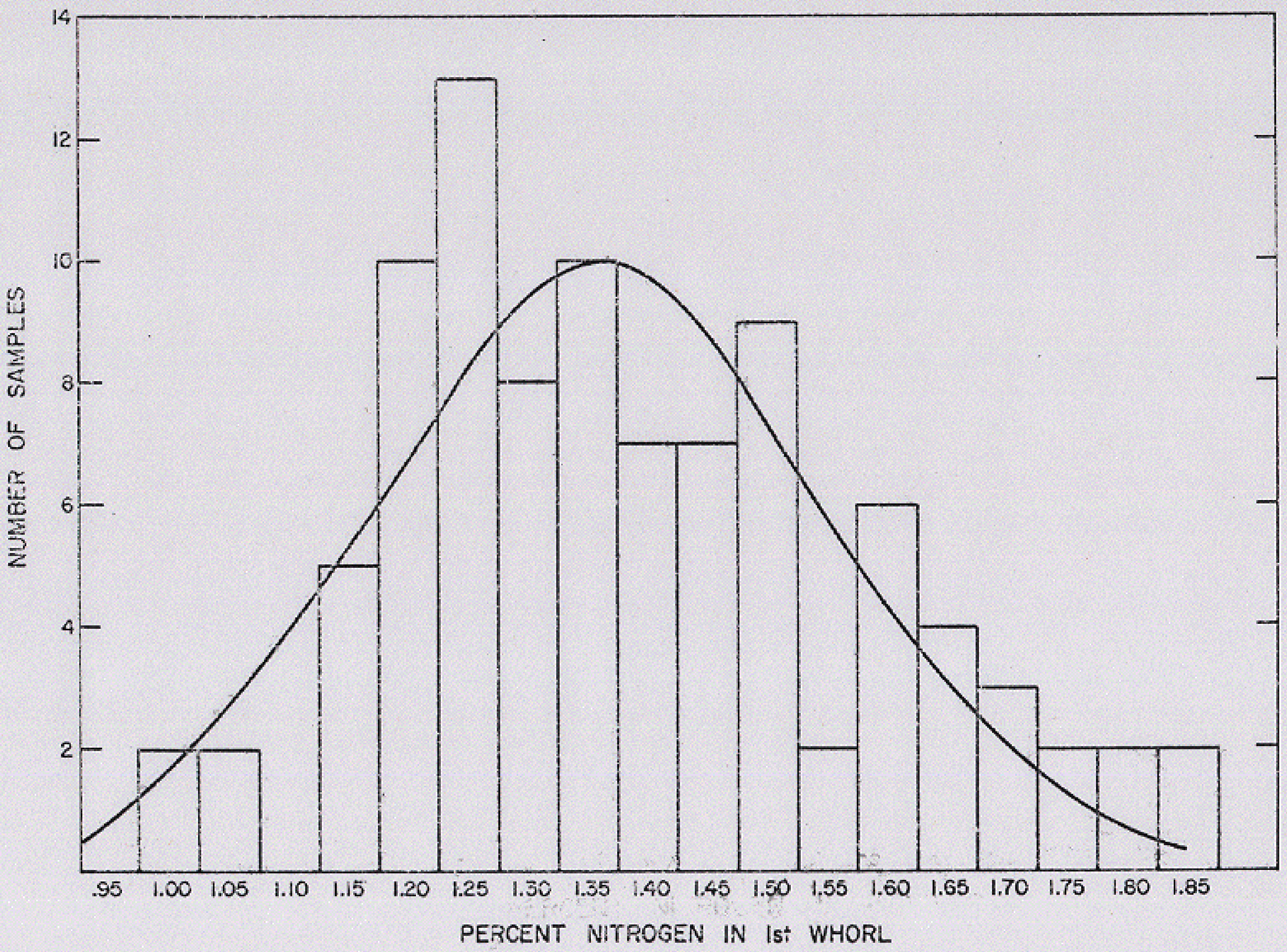

Figure 12. Range and frequency of foliar nitrogen percentage in the first whorl from 94 representative samples.

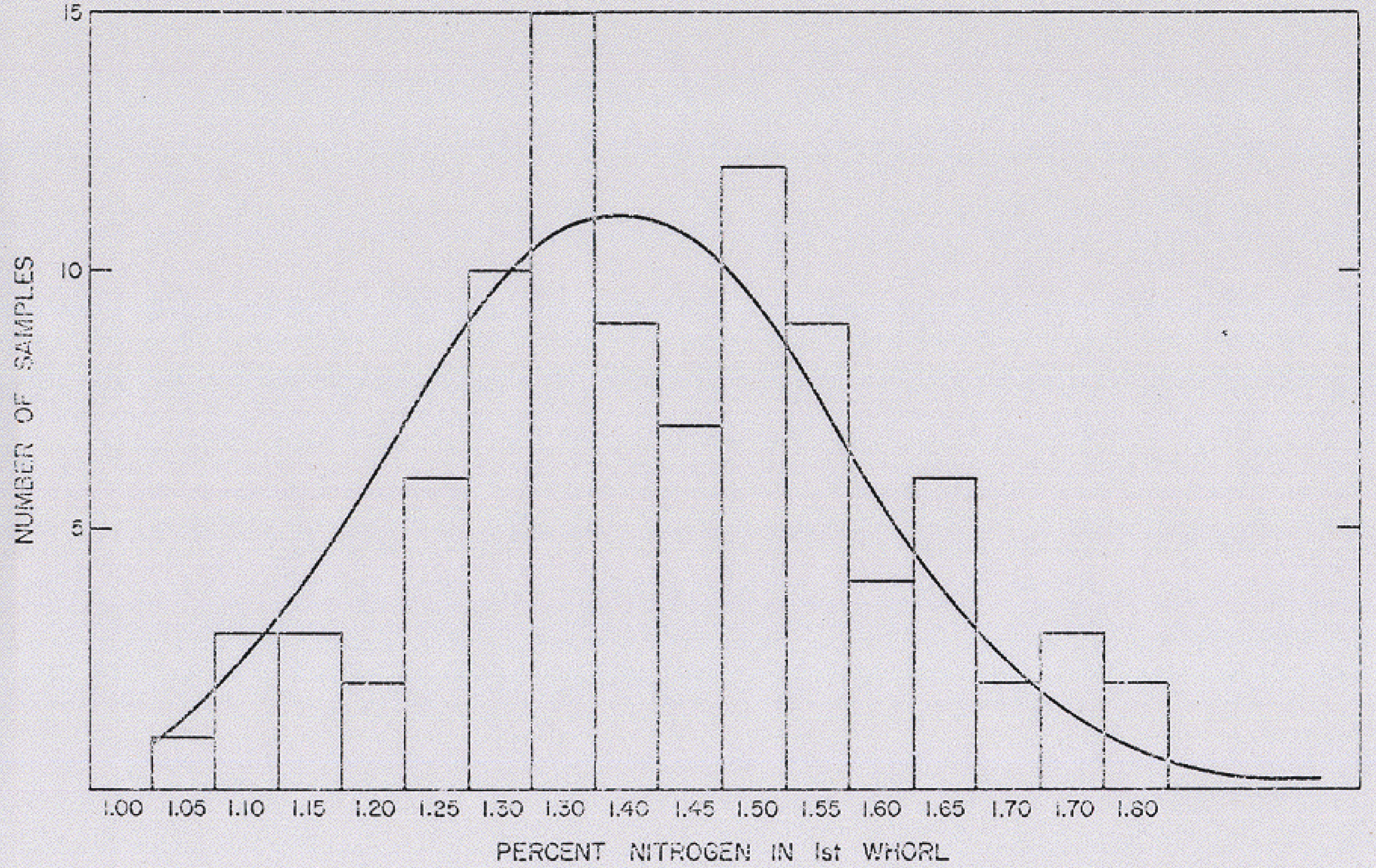

Figure 13. Range and frequency of foliar nitrogen percentage in the first whorl from 94 random samples.

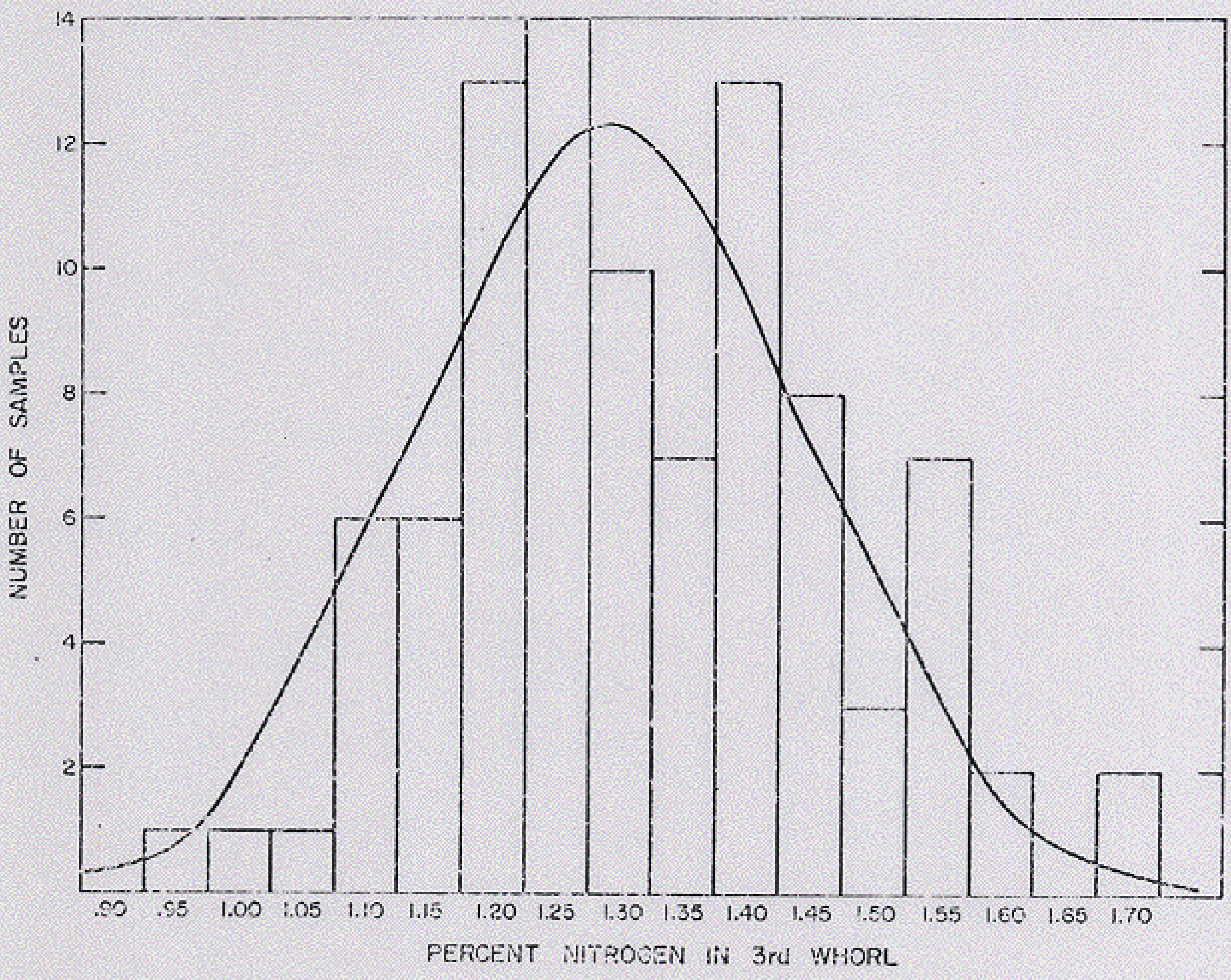

Figure 14. Range and frequency of foliar nitrogen percentage in the third whorl from 94 representative samples.

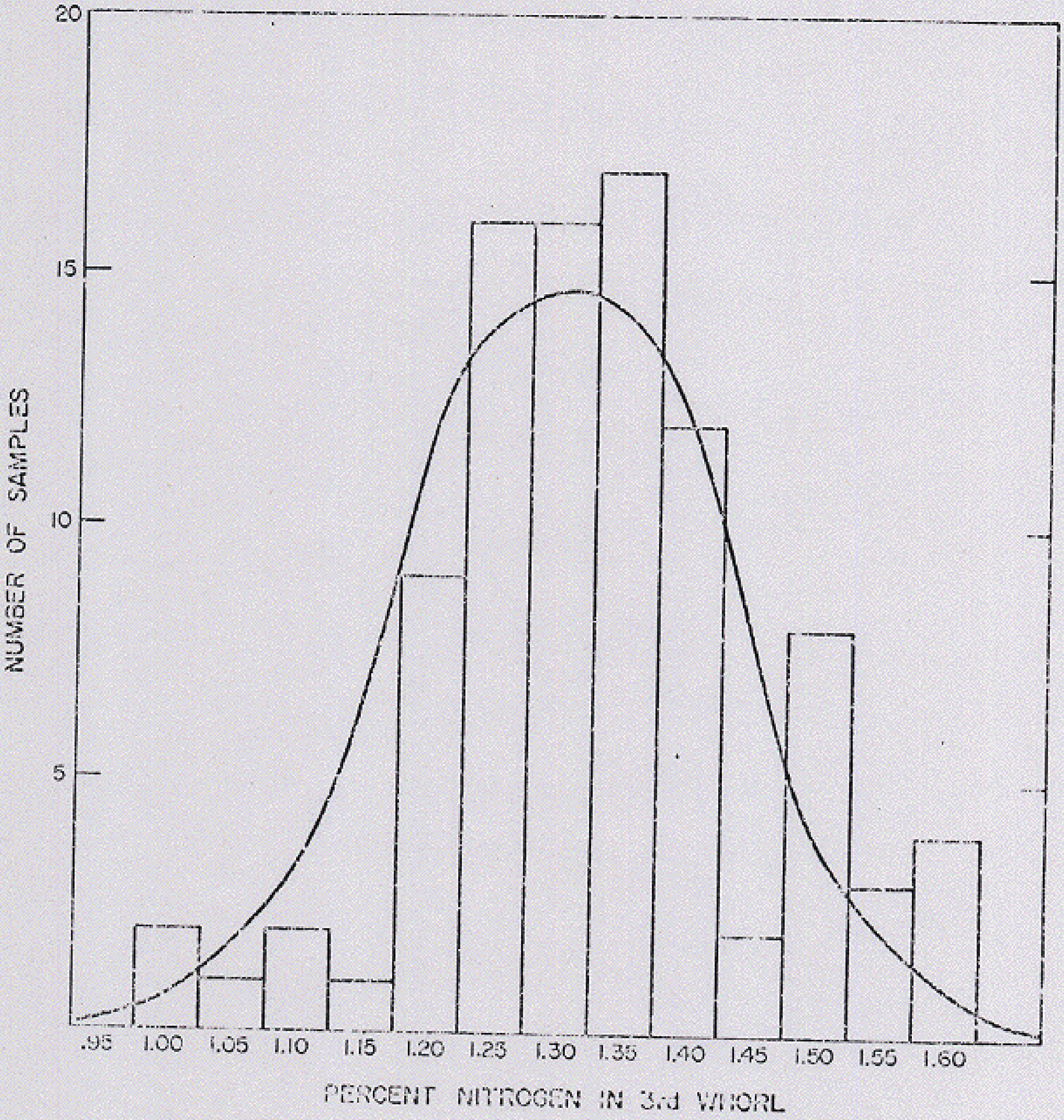

Figure 15. Range and frequency of foliar nitrogen percentage in the third whorl from 94 random samples.

Table 20. RANGE AND FREQUENCY OF FOLIAR NITROGEN CONTENT

N% Class	0.95	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85
FREQUENCY OF SAMPLES IN EACH N% CLASS																			
188 samples First Whorl	1	1	3	3	8	12	18	17	25	16	14	21	11	10	10	5	5	3	2
188 samples Third Whorl	1	3	2	8	7	22	30	26	24	25	10	11	10	6	-	2	-	-	-
94 representative samples First Whorl	1	1	2	-	5	10	13	8	10	7	7	9	2	6	4	3	2	2	2
94 representative samples Third Whorl	1	1	1	6	6	13	14	10	7	13	8	3	7	2	-	2	-	-	-
94 random samples First Whorl	-	-	1	3	3	2	6	10	15	9	7	12	9	4	6	2	3	2	-
94 random samples Third Whorl	-	2	1	2	1	9	16	16	17	12	2	8	3	4	-	-	-	-	-

evident. From this data, therefore, it is concluded that foliar nitrogen values in the first whorl of trees chosen to represent the stand form a normal distribution curve and these values are randomly scattered over the area in such a fashion that they form no basis for stratification of the area or characterizing any area greater than a square chain of the nature of stands at Columbia Valley. The only manner in which a stand can be characterized for foliar nitrogen is to produce a normal curve of distribution and quote the mode and mean values and the range.

Figures (17a) and (17b) in Appendix 3 show the foliar nitrogen contents in the third whorl from representative samples and the location from where the samples were taken in the western and eastern sections of the study area, respectively. Again there was no pattern of distribution over the area so that stratification or characterization of areas was impossible and the same remarks apply in this case as above for first whorl data. Figures (18a) and (18b) in Appendix 3 show the foliar nitrogen contents in the first whorl from random samples and the location from which the samples were taken in the western and eastern sections of the study area, respectively. Figures (19a) and (19b) in Appendix 3 show the foliar nitrogen contents in the third whorl from random samples and the location from which the samples were taken in the western and eastern sections, respectively. In the cases of both the first and third whorl, distribution patterns were again not evident and the same conclusions are made for random samples as are made for representative samples.

The range and variability of both current and one-year-old foliar nitrogen content was examined in the following classes to determine whether they varied with either site-index, age or stocking:

i. Three age classes
ii. Five stocking (basal area) classes
iii. Six site index classes.

Range and Frequency of Foliar Nitrogen by Age Classes

The range and frequency of foliar nitrogen was studied in the following three age classes by examining histograms of first and third whorl frequency:

25 - 34 years
35 - 44 years
45 - 54 years

Results are recorded in Table (21).

For the data from all 188 samples in the first whorl in the youngest age class, the range does not include values below 1.3% but includes the highest value found on the area of 1.85%. The maximum frequency occurs at the high level of 1.6%. In the middle age class which contains most of the samples, the distribution follows a normal curve with values covering the full range from 0.95% to 1.80%. The frequency occurs in the 1.30% to 1.35% class. In the oldest age class the range is narrower, from 1.0% to 1.7% with the maximum frequency in the first whorl occurring in the relatively low 1.1% to 1.2% class.

In the third whorl in the lowest age class, the frequency curve is skewed to the right with the maximum frequency occurring in the 1.2% - 1.3% class which contrasts with the 1.5% - 1.6% class in the first whorl. The range in this age class is even more narrow than occurred in the first whorl and covers only values from 1.2% to 1.7%.

Table 21. RANGE AND FREQUENCY OF FOLIAR NITROGEN BY AGE CLASSES

N% Class	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80
	Frequency of Samples in Each N% Class								
Age Class (Years)									
25 - 34									
1st Whorl				2	6	4	9	4	3
3rd Whorl			3	9	7	5	3	1	
35 - 44									
1st Whorl	1	2	7	26	31	23	12	8	7
3rd Whorl	1	9	19	33	33	12	10		
45 - 54									
1st Whorl	1	2	13	8	3	7		3	
3rd Whorl	3	1	7	10	9	4	3	1	

The frequency distribution curve and the mode in the middle age class is similar for the third whorl data as for the first whorl but the range is narrower.

In the oldest age class, the data form a normal distribution curve with a range and mode similar to that found in the first whorl and in the two younger age classes for the same whorl.

This investigation revealed a trend toward lower foliar nitrogen values with increasing age.

Histograms were drawn for the data in the 94 random samples and the 94 representative samples by the same three age classes for both the first and third whorl. However nothing conclusive was determined from this investigation. There was a variability of range, mode and frequency distribution which showed no pattern or trend and comparisons between each sampling type revealed no consistent difference.

<u>Range and Frequency of Foliar Nitrogen by Stocking Classes</u>

The range and frequence of foliar nitrogen was examined in the following five stocking classes in square feet of basal area per acre:

60 - 85
90 - 115
120 - 145
150 - 175
180 - 205

The results are set out in Table (22).

The ranges in each stocking class did not vary significantly in the 188 samples. The narrower range in the highest stocking class was due to the small number of samples. The shape of the distribution curve was normal in each class except the highest which had a limited number of samples.

Table (22) RANGE AND FREQUENCY OF FOLIAR NITROGEN BY STOCKING CLASS

Stocking Class (Sq. Ft. B.A./Ac.)	N% Class 1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80
	Frequency of samples in each N% class								
60 - 85									
1st Whorl			1	3	6	10	6	4	1
3rd Whorl			4	12	8	4	3		
90 - 115									
1st Whorl	1	2	4	12	15	12	5	5	5
3rd Whorl	1	5	4	18	17	8	7	2	
120 - 145									
1st Whorl	-	2	5	14	13	5	5	4	2
3rd Whorl	-	4	10	13	15	3	5		
150 - 175									
1st Whorl	1	1	7	6	6	5	4	2	
3rd Whorl	3	1	8	10	5	6			
180 - 205									
1st Whorl		1	3	2	1	3			
3rd Whorl			3	3	3		1		

The maximum frequency was constant in each class and occurred at about 1.3% - 1.5%.

Similar histograms were prepared for the third whorl. With the exception of the highest stocking class which had a small number of samples, there was little difference between the classes. The 90 - 115 stocking class had the widest range, probably because it had the greatest number of samples. Frequency curves were normal and the mode lay consistently in the 1.3% class. This was lower than the general position of the mode in the first whorl. The range in each class was consistently narrower than the range in the equivalent class of the first whorl.

No variation of foliar nitrogen with stocking could be established by this investigation.

Histograms were prepared for each of the five stocking classes using data from the 94 random samples and the 94 representative samples separately for both the first and third whorls. An examination revealed no major difference between the random samples and the representative samples in any stocking class. In both cases the range was narrower and the mode smaller in the third whorl than the first whorl for each stocking class.

Range and Frequency of Foliar Nitrogen by Site Index Classes

The range and frequency of foliar nitrogen was examined in the following six site index classes:

81 - 99
100 - 109
110 - 119
120 - 129
130 - 139
140 - 150

Results are set out in Table (23)

Table 23. RANGE AND FREQUENCY OF FOLIAR NITROGEN BY SITE INDEX CLASSES

Site Index Class	N% Class 1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80
	Frequency of samples in each N% class								
81 - 99									
1st Whorl	1		4		1			1	
3rd Whorl	1		4		1		1		
100 - 109									
1st Whorl		1	3	5	5	3	2	1	
3rd Whorl	2	4	2	8	2	1	1		
110 - 119									
1st Whorl		1	6	7	12	3	4	5	3
3rd Whorl		1	5	14	12	4	4		
120 - 129									
1st Whorl		2	5	13	9	15	8	2	4
3rd Whorl		2	9	19	18	4	6		
130 - 139									
1st Whorl	1	2		8	10	11	7	3	1
3rd Whorl		1	6	12	9	9	5	1	
140 - 150									
1st Whorl			2	1	4	3		3	2
3rd Whorl	1		5	1	6	2		1	

With the data from all 188 samples from the first whorl, the highest and lowest classes did not contain sufficient samples to give a meaningful result.

There was little variation between the four classes. The second site index class had a narrower range than the others, but this was probably due to the limited data. In each class the mode fell at the 1.4% - 1.5% level and the samples were normally distributed within the range.

Similar histograms for the third whorl were examined. There was no major difference in the range, the frequency distribution within the range and the mode between the classes. The range lay fairly consistently between 1.0% and 1.6% and the mode at the 1.3% level. This is a narrower range and lower mode than occurred in each class of the first whorl data.

No variation of foliar nitrogen with site index could be established in this investigation.

These results provide answers to the first question raised at the beginning of this chapter and to question No. 5 on page 42 regarding the nature and extent of the range and frequency of foliar nitrogen on the study area.

II. RELATIONSHIP OF FOLIAR NITROGEN TO TREE AND STAND CHARACTERISTICS

In this investigation several statistical analysis procedures were used in an attempt to answer questions 6 and 7 on page 42 concerning the nature and extent of the relationship between foliar nitrogen percentage in the first and third whorls with tree and stand characteristics. Abbreviations used in presenting regression analysis data are explained in Table (50) in Appendix 3.

The tree and stand characteristics are divided into three groups as follows:

i. Stand Characteristics
- Site (Site Index U.S.D.A. Bull. 201)
- Age (Years)
- Stocking (Basal area in square feet per acre)

In addition to the site-index of the stand, a characteristic called "tree site" for the purposes of this study was also examined. This is the height-age relationship at 100 years of the sample tree, taken from U.S.D.A. Bull. 201 and is a reflection of the vigor of the sample tree.

ii. Vigor Characteristics
- Height growth in the current year (leader length)
- Height growth in the last 5 years
- Height growth in the last 10 years
- Radial growth in the last 5 years
- Radial growth in the last 10 years
- Oven dry weight of 100 needles (reflecting needle size)

iii. Appearance Characteristics
- Color
- Percentage of green crown on the bole
- Number of needles per inch of shoot
- Number of years needles are retained on the tree

The statistical analysis procedures used were:

i. Analysis of variance and multiple range tests

ii. Examination of simple correlation matrix

iii. Simple regression analysis

iv. Stepwise multiple regression analysis

The results of these analyses are summarized in Table (24). In no case could a significant relationship be established between foliar nitrogen and site-index or the other stand characteristics of age or stocking. A significant relationship was established by multiple regression analysis between foliar nitrogen and the current vigor of the tree as measured by leader length, height growth in the last 5 years, radial growth in the last 5 years and the number of needles per inch of the first whorl shoots. This result provided an answer to the question raised on page 42 regarding the relationship of foliar nitrogen to the stand and vigor characteristics.

The multiple range tests and the simple correlation matrix revealed that third whorl foliar nitrogen was weakly related to site index and unrelated to either age or stocking, while the reverse was true for first whorl foliar nitrogen. This result provided an answer to question No. 6 raised on page 42 regarding the effect of stand conditions on foliar age and position for sampling.

Analysis of Variance and Multiple Range Tests

The statistical results are set out in Tables (28) to (45) in Appendix 2 together with a detailed interpretation of these tests. In addition to providing information on foliar nitrogen relationships, these tables give mean values of foliar nitrogen by classes of stand characteristics examined. These are summarized in Table (25).

Table 24. SUMMARY OF STATISTICAL ANALYSES RESULTS

	Analysis of Variance and Multiple Range Tests		Simple Correlation Matrix		Stepwise Multiple Regression Analysis	
	Relationship to foliar nitrogen content					
	Whorl		Whorl		Whorl	
	1	3	1	3	1	3
Site Index	*	**	*	**	*	*
Stocking	**	*	**	*	*	*
Age	**	*	**	*	*	*
Ht. Growth (Current Yr.)	0	0	*	*	***	***
Ht. Growth (5 Yrs.)	0	0	**	*	***	***
Ht. Growth (10 Yrs.)	0	0	*	**	**	**
Radial Growth (5 Years)	0	0	*	*	***	***
Radial Growth (10 Years)	0	0	*	*	**	**
Wt. of 100 Needles	0	0	*	*	**	**
Color Class	*	*	*	*	0	0
# Yrs. Needles Retained on Tree	*	*	*	*	*	*
# Needles per Inch of Shoot	0	0	*	*	***	***
Green Bole %	0	0	*	**	*	*

Relationship with foliar nitrogen:

*** Significant (over 60% of the variation explained)

** Weak (40% - 60% of the variation explained)

* Not Significant (less than 40% of variation explained)

0 Not Examined

Note: Variables in the stepwise multiple regression are only significant when regressed together.

Table 25. MEAN FOLIAR NITROGEN PERCENTAGES BY CLASSES OF STAND AND TREE CHARACTERISTICS

Characteristic	Class	Mean Foliar Nitrogen Percentage First Whorl	Mean Foliar Nitrogen Percentage Third Whorl
Site Index	81-99	1.23	1.17
	100-109	1.34	1.21
	110-119	1.40	1.29
	120-129	1.39	1.31
	130-139	1.47	1.35
	140-150	1.35	1.31
Tree Site	91-99	1.28	1.18
	100-109	1.32	1.20
	110-119	1.37	1.29
	120-129	1.35	1.30
	130-139	1.41	1.33
	140-149	1.45	1.34
	150-160	1.46	1.32
Age (Years)	25-34	1.52	1.36
	35-44	1.39	1.29
	45-54	1.24	1.28
Stocking (Sq. Ft. B.A./Ac.)	60-85	1.46	1.32
	90-115	1.41	1.31
	120-145	1.36	1.29
	150-175	1.29	1.26
	180-205	1.27	1.28

A weak relationship was demonstrated between site index and the number of needles per inch of shoot on the first whorl, the number of needles per inch decreasing with increasing site.

Simple Correlation of All Variables

Table (56) in Appendix 3 lists the variables with the highest correlation; Table (57) sets out the simple correlation matrix of all 18 variables measured or determined from the 188 trees sampled. The matrix was exampled and compared to the results from the analysis of variance and multiple range tests. There are substantial limitations on the value of such a matrix as the correlation coefficients represent only the correlation of one variable with another in the absence of other variables. It should be noted in examining the simple correlation matrix that even the highest correlation coefficients are not significant and at best the coefficients should be used only for comparative purposes within the matrix.

Simple Regression Analyses

Simple regression analyses were made between foliar nitrogen content in the first and third whorls separately and each of the four stand characteristics, each of the six vigor characteristics (plus D.B.H. and height), and each of the three appearance characteristics. Tables (59) to (62) in Appendix 3 set out the results of these analyses. These results varied with the data groups. When data from all 188 samples were used, the highest correlation coefficient obtained was .5932 between first whorl nitrogen and height growth in the last 5 years (Table 59). However, when data from 94 representative samples were used, the highest correlation coefficient was

.7573 between first whorl nitrogen and height growth in the last 5 years (Table 60). In contrast, the data from 94 random samples gave a maximum correlation coefficient of .4549 for nitrogen in the first whorl and leader length (Table 61).

Multiple Regression Analyses

Multiple regression analyses were carried out to examine the accumulative relationships between foliar nitrogen and the 15 stand and tree characteristics and to investigate the value of equations for predicting foliar nitrogen content from these characteristics. Tables (64) to (68) in Appendix 3 set out the results of these analyses.

The results of these analyses also varied with data groups. When data from all 188 samples were used (Table 64), in the regression with first whorl nitrogen, the three variables of height growth in the last five years, D.B.H. and weight of 100 needles were significant, giving a multiple correlation coefficient of .6262. However when data from the 94 representative samples were used (Table 65), the significant variables were height growth in the last 5 years and number of needles per inch of shoot, giving a multiple correlation coefficient of .7608. In contrast, regression data from the 94 random samples (Table 66) showed that significant variables were height growth in the current year, weight of 100 needles, D.B.H. and leader length, giving a multiple correlation coefficient of .5798.

The results of the multiple regressions using data from the 49 representative samples and 51 random samples (Tables 67 and 68) are probably the most valuable as they contain radial growth measures. In the former there were four significant variables in the first whorl nitrogen regression giving a multiple correlation coefficient of .8259. They were height growth in the last 5 years, radial growth in the last 5 years, leader length and weight of 100 needles. In the latter case (51 random samples), four significant variables gave a lower multiple correlation coefficient of .6757.

To avoid the high covariance between leader length and the other growth measures, an analysis was conducted omitting leader length from the data of the 49 representative samples (Table 69 in Appendix 3). There were four significant variables in the first whorl nitrogen regression giving a multiple correlation coefficient of .8183. These were height growth in the last 5 years, radial growth in the last 5 years, weight of 100 needles and number of needles per inch of shoot.

Table (70) in Appendix 3 shows the results of a multiple regression analysis using only the four significant vigor characteristics, and Table (71) in Appendix 3 shows the results when transformations are used.

An investigation was made using multiple regression analysis to compare the relationship of foliar nitrogen content to the stand characteristics and to the vigor characteristics. The results are given in Tables (72) and (73) in Appendix 3 and summarized below showing the multiple correlation coefficients of significant variables.

	Stand Characteristics	Vigor Characteristics
188 samples		
First Whorl	.4630	.6076
Third Whorl	.2400	.3889
94 representative samples		
First Whorl	.5751	.7573
Third Whorl	.4239	.5555
94 random samples		
First Whorl	.3945	.5141
Third Whorl	.1733	.2903
49 representative samples		
First Whorl	.5925	.8259
Third Whorl	.4227	.4670

Table (74) in Appendix 3 shows the results of regressing site-index against the vigor characteristics revealing that no relationship could be established.

Tables (75) to (84) in Appendix 3 set out the correlation and covariance matrices from the multiple regression analyses of all variables.

Discussion. It was apparent from the results of the multiple range tests and the correlation matrix that third whorl nitrogen content should be used in examination of site index relationships while first whorl data (being more closely related to stand conditions) should be used in examinations of stand relationships. The correlation matrix data supported this conclusion. When simple regression analyses were conducted using the data from the 49 representative trees with radial growth data this conclusion was strongly confirmed (Table (62) in Appendix 3).

There is also evidence from the results that data from samples chosen to represent the stand provide more significant relationships than randomly chosen samples. The comparison of simple regression analyses using the two sets of 94 representative and random samples (Tables 60 and 61 in Appendix 3) demonstrates this.

A comparison of Tables (65) and (66) in Appendix 3 showing regression analyses of the 94 representative samples (multiple correlation coefficient .7608) and the 94 random samples (multiple correlation coefficient .5798) also demonstrates the stronger relationships obtained from representatively selected trees than randomly selected trees.

In both simple and multiple regression analyses, correlation coefficients with first whorl nitrogen were higher than correlation coefficients with third whorl nitrogen, suggesting that relationship studies (particularly with vigor characteristics which were the only ones with significant coefficients) should be carried out using foliage from the first whorl.

Even when data from the 49 representative samples (which provided the best relationships with other characteristics) was used, in both the simple and multiple regression analyses, no significant relationship could be established between foliar nitrogen and site index. The correlation coefficient obtained in the simple regression analysis of the first whorl nitrogen and site index was .2423 and in the analysis of the third whorl nitrogen and site index, .4227. In none of the multiple regression analyses did site index appear as a significant variable.

The evidence that foliar nitrogen content may not be related to site index confirms the results of Gessel, et al., (1969) and agrees with the findings of Bhatnagar (1957) and Seth and Bhatnagar (1960) for calcium, magnesium and potassium in *Shorea robusta*. They also agree with the findings of Watt (1967) for a range of ten nutrients (not included were nitrogen and phosphorus) and with Viro (1962) who found that foliar nutrient content varied entirely independently of site-index in Lapland.

On the other hand, workers with species other than Douglas-fir have found relationships between foliar nutrient content and site-index. Seth and Bhatnagar (1960) found a linear negative relationship with foliar nitrogen and phosphorus in *Shorea robusta*. Kaul, et al., (1962) found for the same species that foliar nitrogen concentration was positively related to site. Von Rehfuess (1968) found positive simple correlations of foliar nutrient status and site-index in silver fir and Watt (1967) found that nitrogen and phosphorus were significantly and positively correlated with site-index in black spruce.

The diversity of these results might be explained in part by the principle of limiting factors. When one nutrient alone is deficient and all other nutrients and factors of growth are optimal, then a relationship between the deficient nutrient and site-index should be expected. If, however, two or more nutrients were also deficient or one of the factors of growth was unfavorable, then it would be probable that the relationship between the first nutrient under investigation and site-index would be disturbed by these additional influences so that the relationship would be considerably weakened.

For example, it was demonstrated by pot culture trials described in Chapter III that there was pronounced deficiency of both nitrogen and magnesium in the soil on the study area. In this case, site-index might be influenced by the availability of magnesium (particularly at the lower levels of magnesium) and as a result be less dependent on nitrogen availability reflected in foliar concentrations.

Considering the influence of the factors of growth other than nutrient supply, it is possible that in a situation in the far north, such as reported by Viro (1962), for temperature alone to be the factor governing site-index. In this case, the finding of Viro that there is no relationship between site-index and foliar nutrient content should not be unexpected.

Site-index is a height-total age relationship and does not necessarily reflect the current growth characteristics of the tree. It is possible in a nutrient deficiency situation for a deficiency to be more pronounced as the tree's requirement for that deficient nutrient increases with its size and age. Conditions might arise through the influence of some soilameleoration factor which could cause natural correction of a deficiency. In either case, the average growth rate of the tree over its life would not be related to its current rate of growth, or expressed in other terms, to its current vigor or the current quality of the site. It is not surprising, therefore, to find that no relationship could be established between site-index and foliar nitrogen content.

On the other hand, the fact that no relationship could be established between site-index and the current vigor of the tree (as measured by current height and radial growth and number of needles per unit length of first whorl shoot) is to be expected and it reflects a change in site quality over the period of age of the tree. Likewise the significant relationship that was established between the current vigor of the tree and foliar nitrogen content is to be expected and reflects the influence of current site conditions on the current vigor.

In this study, the faster growth rate, giving rise to a greater mass of foliage, would tend to reduce the concentration of nutrients in the foliage when the concentration might be expected to be higher on better sites. There is obviously an irregularity of foliar nitrogen concentration over relatively small areas and between trees with similar site-indexes and this could be due, at least in part, to these dilution effects, where there is no reduction (or, possibly, increase) in the total amount of the nutrient in the foliage mass. If this is the case, foliar nutrient concentration might be a less reliable diagnostic tool for nutrient deficiency.

The simple regression of first whorl nitrogen and height growth in the last 10 years gave a correlation coefficient of .7882 which explains more than 60% of the variation. This result gave the first indications that foliar nitrogen might be more strongly related to current vigor characteristics than to site-index. The results of the multiple regression analysis demonstrate this repeatedly. In each analysis, irrespective of the data group, the significant variables for both first and third whorl nitrogen were vigor characteristics. Neither site-index nor the other stand characteristics were significant in any analysis. As stated above, no relationship could be established between site-index and the current vigor of the tree (Table 74 in Appendix 3).

These findings case some doubt on the practice of judging a forest's vigor, and hence its requirement for fertilizer, on site-index data. They do suggest that the current vigor of the tree, as reflected in foliar nitrogen concentration, is a better basis and that foliar nitrogen concentrations can be predicted reasonably well in the field from tree features, as pointed out below.

However, the practice of using foliar nitrogen for diagnosis should be carried out bearing in mind the findings that the foliar nitrogen levels are not constant over an area but form a normal distribution curve. This curve should be produced for any area in excess of one-tenth acre and compared to the "deficiency level" or level above which there is little or no growth response to nitrogen fertilizer additions.

The question was raised earlier (Page 42) as to whether there was any possibility of predicting foliar nitrogen percentage from any of the characteristics measured. One analysis reported in the results had four significant variables which gave a multiple correlation coefficient of .8259 explaining 68% of the variation in the samples. These were height growth in the last 5 years, radial growth in the last 5 years, leader length and weight of 100 needles (all vigor characteristics).

The prediction formula using these variables is

$$Y = .9055 + .0790(Ht.5) - .2470(Rad.5) - .1007(Ht.Crt.) + .1900(Wt.)$$

The first three characteristics (variables) are easily measured in the field and give a multiple correlation coefficient of .8140 which accounts for 66% of the variation in the samples so that prediction equations using vigor characteristics are a possibility. These results were obtained from data from representative samples using nitrogen content in the first whorl. Data from random samples gave insignificant correlation coefficients and no data groups gave significant coefficients for predicting third whorl nitrogen. The conclusion is that the first whorl should be sampled from representative trees for predictive purposes.

In the analysis reported in the results, where leader length was omitted to avoid covariance, two of the significant variables are easily measured in the field. They are height growth in the last 5 years and radial growth in the last 5 years. These gave a multiple correlation coefficient of .8025 which explains 64% of the variation in the sample. The prediction formul is

$$Y = 1.002 + 0.057(Ht.5) - 0.268(Rad.5)$$

for first whorl nitrogen percentage.

Interaction Between Variables

A study was made of interactions between the various characteristics to determine whether relationships of foliar nitrogen content might exist with a characteristic at certain levels of some other related characteristic.

Simple regression analyses were conducted between foliar nitrogen and each stand and tree characteristic after they had been divided into classes of a second characteristic. The regression analyses in Table (26) were made using first and third whorl nitrogen content separately. The results of these analyses are given in Tables (85) to (87) in Appendix 3.

A test was conducted in each case to determine if the simple regressions by classes varied significantly from the single regression with the grouped nitrogen data. Where there was no significant difference, then no interaction existed. These cases are listed in the tables as Regression Equation Type 1 and are of the form

$$Y = a + bX$$

An example of this is shown in Figure (20) where no significant difference between the regressions by classes and the single regressions of the grouped data could be established.

Where a significant difference was established between class regressions and the grouped data, the regressions are referred to as Type 2 in Tables (89) to (92) in Appendix 3 and are of the form

$$Y = a + bx + cy + d(xy)$$

An example of this case is given in Figure (21).

However, in cases where the F value was not significant, this form was not appropriate and an equation of the form

$$Y = a + bX + cy + d(x/y) + e(x/y)^2$$

was used. This is termed Regression Equation Type 3 and is used where the regressions by classes change from an upward to a downward trend. An example of this is given in Figure (21).

Tables (93) to (96) in Appendix 3 set out the appropriate prediction equation for each of the 29 analyses for both first and third whorl data in the representative group and the random group. An examination of the

Table 26. SIMPLE REGRESSIONS OF FOLIAR NITROGEN AND EACH CHARACTERISTIC IN CLASSES OF A SECOND CHARACTERISTIC

Nitrogen content as a function of:

	First Characteristic	Second Characteristic	Number of Classes
1.	Age	Tree Site	6
2.	Stocking	Tree Site	6
3.	Age	Site-Index	6
4.	Stocking	Site-Index	6
5.	Tree Site	Stocking	5
6.	Site-Index	Stocking	5
7.	Age	Stocking	5
8.	Tree Site	Age	3
9.	Site-Index	Age	3
10.	Stocking	Age	3
11.	Leader Length	Total Height	5
12.	Height Growth (5 years)	Total Height	5
13.	Height Growth (10 years)	Total Height	5
14.	Weight of 100 Needles	Tree Site	6
15.	Weight of 100 Needles	Site-Index	6
16.	Radial Growth (5 years)	Stocking	5
17.	Radial Growth (10 years)	Stocking	5
18.	D.B.H.	Stocking	5
19.	Leader Length	Age	3
20.	Height Growth (5 years)	Age	3
21.	Height Growth (10 years)	Age	3
22.	Total Height	Age	3
23.	Needles per Inch	Tree Site	6
24.	Needles per Inch	Site-Index	6
25.	Needle Retention	Tree Site	6
26.	Needle Retention	Site-Index	6
27.	Green Crown (%)	Stocking	5
28.	Needle Retention	Stocking	5
29.	Needle Retention	Age	3

correlation coefficients for each of the class regressions in Tables (89) to (92) in Appendix 3 shows no rising or falling trends which would indicate clear interactions. In fact in most cases the correlation coefficients fluctuate randomly and wildly indicating that while the class regressions may have differed significantly from the grouped data regression, it was not due to an interaction that could be detected. In most cases, the correlation coefficients were so low as to be meaningless and the odd high value was traced to a shortage of data in that group. The correlation coefficients were lower in the third whorl than the first whorl and lower in the random group than the representative group. The prediction equations generally have significant F values with correlation coefficients that range from .7573 to .2994 in the first whorl data of the representative group. No better prediction equations could be obtained by this method than by multiple regression analysis.

III. FOLIAR NITROGEN STATUS AND RESPONSE TO NITROGENOUS FERTILIZER

A continuing study of growth response to nitrogenous fertilizer application is being conducted by the College of Forest Resources, University of Washington, on the study area. Interim results are reported by Gessel, et al., (1969).

Certain of the trees sampled in the present study (which were all unfertilized) were deliberately taken adjacent to the nitrogen fertilizer trial plots to compare the foliar nitrogen percentage of unfertilized trees with response. Six such trees were chosen to represent the stand and six trees were chosen randomly.

The first whorl nitrogen from the six representative trees ranged from 1.47% to 1.03%. Third whorl nitrogen ranged from 1.30% to 1.02%.

The first whorl nitrogen from the six random trees ranged from 1.53% to 1.25%. Third whorl nitrogen ranged from 1.34% to 1.16%. Gessel, et al., (1969) repor that for 12 fertilizer trial plots on the study area the response equation is

$$Y = 2.324171 + 0.007643(\text{Nitrogen added}) + 0.831032(\text{Basal area/age})$$

and that for average site index of 100 and age 40, the basal area periodic annual increment in square feet per acre is 5.29 on the controls and 6.82 following the application of 200 pounds of nitrogen per acre (224 kilogrammes per hectare) as urea.

An examination was then made on a plot by plot basis comparing the growth response on individual plots with foliar nitrogen content of unfertilized adjoining trees. These results are set out in Table (27). Growth response data has been brought up to date in a personal communication from Gessel.

There was a significant response to nitrogen fertilizer on all plots. Adjoining unfertilized trees had foliar nitrogen contents up to 1.53% in the first whorl and 1.34% in the third whorl. It is concluded therefore that unfertilized trees with foliar nitrogen as high as these values may still be nitrogen deficient.

Table 27. FOLIAR NITROGEN CONTENT OF UNFERTILIZED TREES AND GROWTH RESPONSE ON ADJOINING FERTILIZER TRIAL PLOTS

Plot Number	Increase in Basal Area (%)	Nitrogen Applied (Lbs/Ac.)	Type of Sampling	First Whorl N%	Third Whorl N%
Helicopter Trials Plots					
1.	3.75	184	Representative	1.17	1.23
3.	6.73	184	Representative	1.14	1.28
5.	6.17	184	Random	1.31	1.21
7.	4.46	184	Random	1.53	1.29
Heady Road Trial Plots					
1.	5.24	200	Representative	1.47	1.30
			Representative	1.03	1.10
			Random	1.25	1.22
			Random	1.49	1.32
2.	5.33	200	Representative	1.18	1.02
			Representative	1.31	1.27
			Random	1.34	1.34
			Random	1.32	1.16

CHAPTER VI. CONCLUSIONS

As stated earlier, the investigation here is exploratory and thus empirical, so that the following conclusions can only be made confidently for the study area. Further work is required to determine whether these conclusions apply over the whole of the Douglas-fir region. The fact that there is no stratification pattern of foliar nitrogen values over an area of 1,000 acres and considerable variation within a few feet indicates the presence of a variable factor or combination of factors affecting the amount of available nitrogen in the soil. This varying factor (or factors) requires investigation as the results could provide a new concept to nitrogen nutrition of Douglas-fir.

1. Surface soil on the study area has substantial deficiencies in nitrogen and magnesium and less deficiencies in sulphur, potassium, and boron. Additions of calcium have either a stimulating or inhibiting effect on growth in pot culture trials, depending on the combination of other nutrient additions. (Pages 51, 52, and Table 2)

2. The nitrogen content of current foliage falls substantially in the top four whorls with a leveling off to lower values in whorls six to ten which fluctuate within a narrow range. (Page 61 and Table 3).

3. Magnesium content of current foliage follows the same pattern in the top ten whorls of the crown as nitrogen. Calcium content is higher in the first whorl than the lower nine whorls which fluctuate randomly. Potassium and phosphorus contents fluctuate randomly within a narrow range in all ten whorls. The pattern of falling values of nitrogen and magnesium might be explained by a deficiency of these nutrients. (Page 67 and Tables 6, 7).

4. There is no relationship between foliar nitrogen content and phosphorus, potassium, calcium or magnesium in the current foliage in any of the top three whorls. (Page 67 and Table 46 in Appendix 3)

5. First whorl foliar nitrogen contents on a one-tenth-acre plot have a considerable range but in most cases the majority of trees fall in a narrow range and any of these satisfactorily represent the foliar nitrogen level of the plot. This sample can be selected in the field by choosing a tree with average leader length. This procedure invariably excludes those trees with extreme values. No procedure of sampling foliage for phosphorus, potassium, calcium and magnesium contents could be developed because values of each fluctuated unpredictably within any one-tenth-acre plot. (Pages 70, 72 and Table 8)

6. The frequency of foliar nitrogen values over the study area formed a normal distribution curve. (Pages 93, 101 and Figures 11-15)

7. In both the first and third whorls there was no pattern of distribution of representative foliar nitrogen values over an area up to 1,000 acres in size. Values from sample trees separated only by a few chains were generally vastly different. The same irregularity of distribution of foliar nitrogen values was true when the trees were randomly chosen from the dominants and codominants. There was no basis for stratifying an area up to 1,000 acres in size on foliar nitrogen values. (Pages 101, 109 and Figures 16a - 19b)

8. No relationship could be established between foliar nitrogen content and the stand characteristics of site-index, age and stocking. There is a significant relationship with the current vigor of the tree as assessed by the height growth in the current year (leader length), height growth in the last 5 and 10 years, radial growth in the last 5 and 10 years and needle

mass. Three of these characteristics which are easily measurable in the field (height growth in the last 5 years, radial growth in the last 5 years and leader length) give a multiple correlation coefficient of .8140 which accounts for 66% of the variation in the samples. This is the closest relationship that could be established between foliar nitrogen content and any stand, tree or appearance characteristics.

Only a weak relationship could be established with the appearance characteristics of percentage of the bole carrying green branches and the number of needles per inch of shoot. (Pages 118, 121-129 and Tables 64-73)

9. First whorl foliar nitrogen should be used in examinations of its relationship with site-index as it is more dependent on the latter than on age and stocking.

Third whorl foliar nitrogen should be used in examinations of its relationship with the stand characteristics of age and stocking as it is more dependent on the latter than on site-index. (Page 124 and Table 24)

10. There is no relationship between site-index and the current vigor of the tree at the age of the stand studied in this investigation, that is 35 to 45 years. (Page 124 and Table 74).

11. No interactions between the various characteristics could be identified or used to improve the relation of any characteristics with nitrogen content. (Pages 129-132 and Figures 20-22)

12. Substantial growth response takes place on nitrogen fertilizer trial plots where adjacent unfertilized trees have foliar nitrogen contents in current foliage on the first whorl as high as 1.53% and one-year-old third whorl foliar contents up to 1.34%. (Pages 132, 133 and Table 27)

BIBLIOGRAPHY

Aaltonen, V. T. 1950. Die Blattanalyse als Bonitierungsgrundlage des Waldbodens. Comm. Inst. For. Fenn. 37:8.

Adams. W. R. 1928. Studies in tolerance of New England forest trees. VIII. Effect of spacing in jack pine plantation. Bull. Vt. Agric. Exp. Sta. No. 282.

Ahmed, S. 1956. The effect of application of artificial fertilizer on height, radial, and branch growth of 35-year-old Douglas-fir. Unpublished Master's Thesis, University of Washington, Seattle.

Alexander, R. R. 1966. Site indexes for Lodgpole Pine with corrections for stand density: instructions for field use. U.S. For. Serv. Res. Pap. Rocky Mt. For. Range Exp. Sta. No. RM-24, 1966.

Anderson, H. W. 1969. Douglas-fir region aerial fertilization makes strides in a brief span of years. For. Ind., Vol. 96, No. 2.

Anonymous. 1957. Nitrogen content of the needles of Douglas-fir. Korte Meded. Bosbouwproefsta. T.N.O. Wageningen. No. 30:8-9.

Armson, K. A. 1959. An example of the effect of past use on land fertility levels and growth of Norway spruce *Picea abies* L. Karst. Tech. Rept. No. 1 Fac. of For. Univ. of Toronto.

Armson, K. A. 1967. A review of forest fertilization in Canada. Publ. Dep. For. Can. No. 1186.

Askew, H. O. 1937. The chemical composition of *Pinus radiata* needles. New Zealand J. Sci. Technol. 18(8):651-655.

Bailey, E. E. 1959. Some economical aspects of forest fertilization. Unpublished Master's Thesis, University of Washington, Seattle.

Baker, F. S. 1950. Principles of Silviculture. Mc-Graw-Hill, New York.

Barrows, H. L. 1959. Evaluating the micronutrient requirements of trees. Mineral nutrition of trees. A symposium. Bull. Duke Univ. Sch. For. No. 15.

Bates, C. G. 1918. Concerning site. Jour. For. 16:383-388.

Batjer, L. P. and Magness, J. R. 1938. Potassium content of leaves for commercial orchards. Proc. Amer. Soc. Hort. Sci. 36:197-201.

Beaton, J. D., Kosick, R. and Speer, R. C. 1964. Chemical composition of foliage from fertilized plus Douglas-fir trees and adjacent unfertilized check trees. Proc. Soil Sci. Soc. Amer. 28(3):445-449.

Beaton, J. D., Brown, G., Speer, R. C., MacRae, I., McGhee, W. P. T., Moss, A. and Kosick, R. 1965a. Concentration of micronutrients in foliage of three coniferous tree species in British Columbia. Proc. Soil Sci. Soc. Amer. 29:299-302.

Beaton, J. D., Moss, A., MacRae, I., Konkin, J. W., McGhee, W. P. T. and Kosnick, N. 1965b. Foliar analysis of Douglas-fir from aerial forest fertilization trials on Vancouver Island, B. C. Paper presented at Fourth Calif. For. Soil Fertility Conf., Redding, Calif., May, 1965.

__________ 1965c. Observations on foliage nutrient content of several coniferous tree species in British Columbia. For. Chron. 41(2):222-236.

Becker, J. von. 1937. Die Gelbspitsigkeit der Kiefer, eine Magnesia mangelerscheinung. Ernahr. Pfl. 33. 1-7.

Beeson, K. C., et al. 1955. Some plant accumulators of the micronutrient elements. Ecology 36(1):155-156.

Benzian, B. 1967. Risk of damage from certain fertilizer salts to transplants of Norway spruce and use of slow release fertilizers. Phys. of Trees. Report on Sixth Discussion Mtg., Edinburgh, Jan 7-9, 1966. Oxford Univ. Press.

Berg, von. 1857. [Use of Lupins in Bohemian Communal Forests.] Thar. For. Jahrb. 12:117-122.

Berg, E. 1952. Gjødsling av myr. Tidsskr. Skogbr 57(1):7-9. For. Abstracts 1951-52, 2126.

Bernier, B. 1966. Fertility of forest soils and economics of fertilizing in natural forest. Bull. Fonds. Rech. For. Univ. Laval No. 9.

Bhatnagar, H. P. 1957. Mineral constituents of foliage of Sal (Shorea busta) of different quality classes. Indian For. 84(11):647-650.

Bingham, F. T. 1961. Seasonal trends in nutrient composition of Hass avocado leaves. Proc. Amer. Soc. Hort. Sci. 79:149-160.

Binns, W. O. and Grayson, A. J. 1967. Fertilization of established crops: prospects in Britain. Scot. For. 21(2):81-98.

Boggess, W. R. 1959. Foliar nitrogen content of Shortleaf Pine as influenced by thinning. For. Note Ill. Agric. Exp. Sta. No. 80.

Boonstra, R., Kenworthy, A. L. and D. P. Watson. 1957. Nutritional status of selected plantings of *Taxus media* Hicksi. Proc. Am. Soc. Hort. Sci. 70:432-436.

Böszörményi, Z. 1958. Leaf analysis investigations with Scots pine seedlings: The problem of the constancy of critical nutrient concentrations. Acta. Bot. Acad. Sci. Hungar. 4:19-44. For. Abstracts, 1959, 1554.

Bould, C. 1964. Plant analysis and fertilizer problems. IV. Amer. Soc. Hort. Sci.

Clements, H. F. and Moriguchi, S. 1942. Nitrogen and sugar-cane. The nitrogen index and certain quantitative field aspects. Hawaii Planters'. Rec. 46:163-190.

Coile, T. S. 1935. Relation of site index for shortleaf pine to certain physical properties of the soil. J. For. 33:726-729.

__________. 1942. Physical properties of B horizons of Piedmont soils. Soil Sci. 54:101-103.

__________. 1952. Soil and the growth of forests. Adv. in Agron. 4:339-340.

Cromer, D. A. N. 1961. Developments in the study of initial spacing and growth. Pacif. Sci. Congr. 10.

Cromer, D. A. N. and Pawsey, C. K. 1957. Initial spacing and growth of *Pinus radiata*. For. Timb. Bur. Aust. Bull., 36.

Cummings, W. H. 1941. Fertilizer trials for improved establishment of short leaf pine, white ash and yellow poplar plantings on adverse sites. J. For. 39:1942-46.

Curtis, R. O. 1966. A comparison of site curves for Douglas fir. U.S. For. Serv. Res. Note. Pacif. N.W. For. Range Exp. Sta. No. PNW-37.

Cybulko, T. 1967. Investigations on the content of some trace elements in *Pinus sylvestris*. Folia for. polon. (Lesn) No. 13:85-110.

Davidson, H. 1960. Nutrient-element composition of leaves from selected species of woody ornamental plants. Proc. Am. Soc. Hort. Sci. 76: 667-672.

Deleano, N. T. and Bordeianu, C. 1933. Beiträge zum Studium der Rolle und Wirkungweise der Mineral-und organischen Substanzer in der Blattern und geschalteren samen von Zesculus hippo-castanum während ihrer Entwicklung. Beiträge Biol. Pflanzen 20:179-197.

Demontier, G. 1938. Nitrogen phosphoric acid and potash as fertilizers in Scots pine seedlings. Bull. inst. agron. sta. recherereches Gembloux. 7:173-191.

Donald, L., Stangel, H. J. and Pesek, J. T. 1963. Advances in knowledge of nitrogen fertilization in the U.S.A. since 1950. Fert. Tech. and Usage. Ed McVicker. Soil Sci. Soc. of Amer., Madison, Wisconsin.

Donahue, R. L. 1936. Soil and site quality relationships. Am. Soil Surv. Assoc. 17:79-80.

Ebermayer, E. 1876. Lehre der Waldstreu. Julius Springer, Berlin.

Evers, F. H. 1967a. Determining the nutrient status of forest stands from the C ratios of nutrient elements (C/N, C/P, C/K, and C/Ca). Proc. 14th Cong. Int. Union For. Res. Organ., Munich, 1967. IV, Sect. 23: 171-187.

__________.1967b. The relationship between site, stand type, growth and the soil nutrient status. Proc. 14th Cong. Int. Union For. Res. Organ., Munich, 1967. Part II, Sec. 21:177-193.

Eversole, K. R. 1955. Spacing tests in a Douglas-fir plantation. For. Sci. 1:14-18.

Fabricius, L. 1940. Ein 10-jahringer N-Dungungsversuch. Forstwiss. Cbl. 62:76-89.

Fiedler, H. J., Wunderlick, H. and Höhne, H. 1967. The effect of tree age and site type on the development and nutrient content of pine needles. Arch. Forstw. 16(6/9):609-616. For. Abstracts, 1968, 3345.

Fielding, J. M. 1966. The seasonal course of height growth and development of *Pinus radiata*. Aust. For. Res. 2(1):46-50.

Finck, A. 1968. [Limiting values of mineral contents of plants and their use in estimating fertilizer requirements.] Z. Pflanzenernaehr. Dueng. Bodenk., No. 3:197-308.

Finn, R. F. 1953. Foliar nitrogen and growth of certain mixed and pure forest plantings. J. For. 51(1):31-33.

__________. 1963. Mineral nutrition of Yellow-poplar (*Liriodendron tulipifera* L.). Abstr. of thesis, 27B(9):2998-2999.

Forshey, C. G. 1963a. Potassium-magnesium deficiency of McIntosh apple trees. Proc. Am. Soc. Hort. Sci. 83:12-20.

Fowells, H. A. and Krauss, R. W. 1959. The inorganic nutrition of loblolly pine and Virginia pine with special reference to nitrogen and phosphorus. For. Sci. 5:95-112.

Frothingham, E. H. 1918. Height growth as a key to site. J. For. 16:754-760.

__________. 1921. Classifying forest sites by height growth. J. For. 19: 374-381.

Gagnon, J. D. 1964. Relationship between site index and foliate nitrogen at two crown levels for mature black spruce. For. Chron. 2:169.

Garcia Nuno, J. J. 1966. Methods and techniques in leaf analysis. 1. Perchloric acid in the digestion of samples. A new collecting apparatus for the gases arising from the process. An. Inst. For. Invest. Exp., Madrid (Tomol):75-90. For. Abstracts, 1968, 81.

Gast, P. R. 1937. Studies on the development of conifers in raw humus. III. The growth of scots-pine (*Pinus sylvestris* L.) seedlings in pot cultures of different soils under varied radiation intensities. Medd. Fr. Stat. Skogfor. Anst. 29:7.

Gessel, S. P., Turnbull, K. J. and Tremblay, F. T. 1960. How to fertilize trees and measure response. Nat. Plant Food Inst., Wash., D. C.

Gessel, S. P., Walker, R. D. and Haddock, P. 1958. Preliminary report on mineral deficiencies in Douglas-fir and western red cedar. Proc. Soil Sci. Soc. Amer. 15:364-368.

Gessel, S. P. and Walker, R. D. 1956. Height growth response of Douglas-fir to nitrogen fertilization. Soil Sci. Amer. Proc. 21:236-239.

__________. 1958. Research on forest fertilization in the Pacific Northwest. Presented at Calif. For. Soils Fert. Conf. at Sonora, Calif., Feb. 28, 1958.

Gessel, S. P. and Schareef, A. 1957. Response of 30-year-old Douglas-fir to fertilization. Soil Sci. Amer. Proc. 21:236-239.

Gessel, S. P., Stoate, T. N. and Turnbull, K. J. 1969. The growth behavior of Douglas-fir with nitrogenous fertilizer in western Washington. The second report. Inst. of For. Prod., Univ. of Washington.

Gifford, G. F. 1967. The influence of growth media, temperatures, and light intensities on aspen root and top growth. U.S. For. Serv. Res. Note Intermt. For. Range Exp. Sta. No. INT-67.

Gilbert, B. E. and Hardin, L. J. 1927. The current mineral nutrient content of the plant solution as a means of chemical control of optimum fertilization. Jour. Agr. Res. 35:185-192.

Giulimondi, G. 1966. [Investigations on the mineral nutrition of poplar by means of foliar analysis. Variations of mineral contents in fertilizer trials.] Publ. Cent. Sper. AGric. For., Roma 8:39-54. For. Abstracts, 1967, 3474.

Gilmore, A. R. 1965. Growth and survival of planted sycamores as related to chemical content of the foliage. Univ. ILlinois. Agr. Expt. Sta. Dept. of For. Forest Note No. 11.

Goor, C. P. van. 1953. The influence of nitrogen on the growth of Japanese larch (*Larix leptolepsis*). Plant and Soil 5:29-35.

Griffith, B. G. 1960. Growth of Douglas-fir at the University of British Columbia Research Forest as related to climate and soil. Univ. of Brit. Col. Forestry Bull. No. 2.

Guha, M. M. and Mitchell, R. L. 1966. The trace and major element composition of the leaves of some deciduous trees. II. Seasonal changes. Plant and Soil 24(1):90-112.

Hagner, S. O. 1967. Fertilization as a productive factor in industrial forestry. H. R. MacMillan Lectureship. Univ. of Brit. Colum.

Haley, D. 1964. Factors influencing the financial rotation of Douglas-fir in coastal British Columbia. Univ. of Brit. Colum. Fac. of For. Mimeo.

__________. 1966. The economics of forest fertilization. For. Chron. 42(4):390-394.

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

Hanzlick, E. I. 1914. A study of the growth and yield of Douglas-fir on various soil qualities in western Washington and Oregon. For. Quart. 12:440451.

Hausser, K. 1958. Ergebnisse von Dungungsversuchen zu schlectwuchsigen Nadelholzkulturen auf Buntsandstein des Württembergischen Schwarzwalds. Auswertung von Düngung- und Meliorations-versuchen in der Forstwirtschaft. Ruhr-Stickstoff, Bochum, 129-169.

Haveraan, O. 1967. Growth and nutrient studies in a fertilizer trial with *Picea mariana* on peatland. Medd. Norske Skogforsøksv. 23(85):137-175. For. Abstracts, 1968, 3858.

Heiberg, S. O. and White, D. P. 1950. Potassium deficiency of reforested pine and spruce stands in northern New York. Abstracts of Papers, 7th Int. Bot. Cong., Stockholm.

Heilman, P. E. 1961. Effects of nitrogen fertilization on the growth and nitrogen nutrition of low site Douglas-fir stands. Ph.D. thesis. Univ. of Washington, Seattle.

Heilman, P. E. and Gessel, S. P. 1963. The effect of nitrogen fertilization on the concentration and weight of nitrogen, phosphorus, and potassium in Douglas-fir trees. Proc. Soil Sci. Soc. Amer. 27(1):102-105.

Heinsdorf, D. 1964. Correlations of the nutrient content of the soil and of the needles with growth in pine plantations on sands with a low water table. Arch. Forstw. 13(8):865-888. For. Abstracts, 1965, 1885.

__________. 1967. Characterizing the nutrient status of scots pine by the nutrient contents of needles from terminal shoots. Arch. Forstw. 16(6/9):679-682. For. Abstracts, 1968, 3346.

Helms, J. 1911. Experiments with fertilizer on poor spruce plantations on the heath. Tidsske Skovvaes. 23:65-85.

Henry, E. 1908. Les Sols Forestiers. Berger-Levault, Paris and Nancy. Taken from Leyton, L. Mineral nutrient relationships of forest trees. 9:399-408.

Hesselman, H. 1937. On humustackets beroende av bestandets alder och sammansattning i den nordiska granskogen av blabarsrik Va ccinium-typ och des inverkan pa skogens foryngring och tillvaxt. Medd. f. Stat. Skogsforskanstalt. 30:529-716.

Hippeli, P. 1967. The influence of repeated N, P, K, Ca, Mg fertilizing on the nutrition of medium-aged pine stands on the extensive low-water-table sites in the lowlands of northeast Germany. Arch. Forstw. 16(10):1073-1086. For. Abstracts, 1968, 3861.

Hoagland, D. R. 1948. Lectures on the inorganic nutrition of plants. Waltham, Mass. Chronica Botanica.

Hoffman, D. 1963. Is height class of beech an indicator of site quality? Allg. Forstzeitschr. 18(12):177-180. For. Abstracts, 1963, 5388.

Hoffman, G. 1967. Seasonal changes in the N content of leaves, wood and bark of *Robinia pseudoacacia* L. Arch. Forstw. 16(5):509-514. For. Abstracts, 1968, 1817.

Höhne, H. 1963. Foliar analysis studies in young spruce. Arch. Forstw. 12:341-360. For. Abstracts, 1964, 270.

Höhne, H. and Fiedler, H. J. 1967a. Nitrogen fertilizing in scots pine stands of medium age (II). Needle analysis in the first year after 3-years N fertilizing. Arch. Fortw. 16(4):333-355. For. Abstracts, 1968, 602.

__________. 1967b. Nitrogen fertilizing in scots pine stands of medium age (III). Relations between growth and nutrition in the first year after a 3-year N fertilizing treatment. Arch. Forstw. 16(5):487-507. For. Abstracts, 1968, 2287.

Hoyle, M. C. 1961. Relationship of foliar nutrient contents to growth of red pine *Pinus resinosa* Ait in western Massachusetts. Unpub. Master's thesis. Dept. of For. and Wildlife Mgmt. Univ. of Massachusetts.

__________. 1965. Variation in foliage composition and diameter growth of yellow birch with season, soil, and tree size. Proc. Soil Sci. Soc. Amer. 29(4):475-480.

Hoyle, M. C. and Mader, D. L. 1964. Relationships of foliar nutrients to growth of red pine in western Massachusetts. For. Sci. 10(3):337-347.

Huchler, H. 1956. StickstoffdÜngungsversuche in Tannenaltholzern. Allg. Forstz. 11:157-158.

Humphreys, R. F. and Kelly, J. 1962. The variation of phosphorus content in *Pinus elliottii* foliage. Aust. For. 76-86.

Járo, Z. 1967. The relationship of deficiency diseases to site. Proc. 14th Congr. Int. Union For. Res. Organ., Munich, 1967. II, Sect. 21:239-245.

Jensen, H. R. and Williams, M. S. 1963. Economics of fertilizer use. Fertilizer technology and usage. Ed. McVickar. Soil Sci. Soc. of Amer. Madison, Wisc.

Jung, J. and Reihle, G. 1966. Foliar and needle analysis evaluations in long term fertilization studies with forest plants in pots. Forstw. Dbl. 85(9/10):295-305. For. Abstracts, 1967, 1911.

Kaul, O. N., Srivastava, P. B. L., Gupta, A. C. and Sharma, R. P. 1964. Mineral content of fir *Abies pindrow* and Kail *Pinus wallichiana*. J. Soc. Indian For. 4(2/3):114-120.

Kaul, O. N. 1963. Site quality and nutrition uptake in Sal *Shorea robusta* forests of U.P. and Bihar. Indian For. 89(4):293-300.

Kawada, H., Maruyama, A. and Kinugasa, T. 1967. Studies on *Pinus densiflora* forest soils in Kansai area. I. A study of correlations among nutrient concentrations of *Pinus densiflora* needles, growth and soil conditions. Bull. For. Exp. Sta. Meguro, Tokyo No. 199:67-97. For. Abstracts, 1962, 260.

Keinholz, R. 1935. Leader, needle, cambial and root growth of certain conifers and their interrelations. Bot. Gaz. 96:73.

Kennel, R. and Wehrmann, J. 1967. A fertilization trial with very high nitrogen applications in a pine stand of moderate site quality. Proc. 14th Cong. Int. Union For. Res. Organ., Munich, 1967. VI, Sect. 25: 216-231.

Kenworthy, A. L. 1961. Interpreting the balance of nutrient elements in leaves of fruit trees. Am. Inst. Biol. Sci. Publ. No. 8:28-43.

Kim, C. M. and Chang, N. K. 1967. Growth of the chestnut tree *Castanea crenata* in relation to soil nutrients in Korea. Jap. J. Ecol., Sendai 17(4):143-148. For. Abstracts, 1968, 3542.

King, J. E. 1966. Site index curves for Douglas-fir in the Pacific Northwest. Weyerhaeuser For. Pap., Centralia, Wash. No. 8.

Koch, W. and Keller, T. 1961. The influence of aging and excision on the CO_2 exchange of poplar leaves. Ber. Dtsch. Boges. 74(2). For. Abstracts, 1962, 1562.

Konkin, J. W. 1964. Foliar analysis with respect to site and stand improvements by soil fertilization. Unpub. BSF thesis, Univ. Brit. Colum.

Kormanik, P. P. 1966. Predicting site index for Virginia, loblolly, and shortleaf pine in the Virginia Piedmont. U.S. For. Serv. Res. Pap. Stheast. For. Exp. Sta. No. SE-20.

Kosel'kov, S. P. 1967. The nutrient regime of scots pine stands in the S. tagia. Lesolved., Moskva (4):64-70. For. Abstracts, 1968, 1968.

Kramer, P. J. 1956. The role of physiology in forestry. For. Chron. 32: 279-308.

Kramer, P. J. and Kozlowski, T. T. 1960. Physiology of trees. McGraw-Hill, N. Y.

Krapfenbauer, A. 1967. A study of a serpentine site in the Dunkelsteinerwalk (Lower Austria) and a pot trial with *Pinus sylvestris* and *Pinus nigra* var. austriaca on serpentine soil. Cbl. Ges. Forstw. 84(2/6): 207-230. For Abstracts, 1968, 3546.

Kreutzer, K. 1967a. Nutritional status and volume increment of scots pine stands in new fertilizer trials in Bavaria. Forstwiss. Cbl. 86(1): 28-53. For. Abstracts, 1967, 3826.

__________. 1967. Nutritional status and volume increment of Norway spruce stands in new fertilizer trials in Bavaria. Forstwiss 86(3):176-189. For. Abstracts, 1967, 598.

Krueger, K. W. 1967. Nitrogen, phosphorus, and carbohydrate in expanding one-year-old Douglas-fir shoots. For. Sci. 13(4):352-356.

Laatsch, W. 1967. Relationship between site factors, nutrient status and growth of forest stands. Proc. 14th Cong. Int. Union For. Res. Organ., Munich, 1967. II, Sect. 21:22-35.

Labanauskas, C. K. and Puffer, R. E. 1964. Effects of foliar applications of manganese, zinc and urea on Valencia orange yield and foliage composition. Proc. Am. Soc. Hort. Sci. 84:158-164.

Lacey, C. J., Leaf, A. L. and Talli, A. R. 1966. Growth and nutrient uptake by flooded gum *Eucalyptus grandis* seedlings subjected to various phosphorus supplies. Aust. For. 30(3):212-222.

Laflamme, Y. and Lafond, A. 1967. The influence of molybdenum on the development of some forest tree species. Contr. Fonds. Rech. For. Univ. Laval No. 12.

Laurie, M. V. 1960. The place of fertilizers in forestry. Empire. For. Rev. 39(3):286-93.

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

Leaf, A. L. 1956. Growth of forest plantations on different soils of Finland. For. Sci. 2(2):121-126.

Lee, C. H. 1967. Anatomical characters and chemical composition of European black pine needles as influenced by geographical origina and nitrogen fertilization. Abst. of thesis, Dissert. Abst. 27B(9):2946-2947.

Leech, R. H. 1965. Fertilization of red pine plantations on sandy slopes. Res. Rep. Ont. Dep. Lds. For. No. 68.

Lent, J. 1928. Der Owinger. Forstdungungsversuch. Z. Forst u Jagdw. 60:641-659.

Levy, G. 1968. Practical use of foliar analysis in the study of nutrition of forest species. Rev. For. Franc. 20(4):249-263. For. Abstracts, 1968, 5063.

Leyton, L. 1948. Mineral nutrient relationships of forest trees. For. Abstracts 9:399.

__________. 1954. The growth and mineral nutrition of spruce and pine in heathland plantations. Inst. Pap. Imp. For. Inst. Oxford. No. 31.

__________. 1956. The relationship between the growth and mineral composition of the foliage of Japanese larch *Larix leptolapsis*. Plant and Soil 7:167-177.

__________. 1967. The relationship between the growth and mineral composition of the foliage of Japanese larch. II. Evidence from manural trials. Plant and Soil 9:31-48.

__________. 1958a. The mineral requirements of forest plants. Ency. of Plant Phys., Vol IV. Ed. W. Ruhland.

__________. 1958b. The relation between the growth and mineral nutrition of conifers, in Physiology of forest tree. Ed. K. Thimann. Ronald Press, New York.

Leyton, L. and Armson, K. A. 1955. Mineral composition of the foliage in relation to the growth of scots pine. For. Sci. 1:210-218.

Liani, A. 1966. Research on the influence of the physical properties of the soil on the rooting capacity, growth and mineral nutrition of poplar. Pubbl. Cent. Sper. Agric. For., Roma 8:103-120. For. Abstracts, 1967, 3461.

Linteau, A. 1955. Forest site classification of the northeastern coniferous section, boreal forest region, Quebec. Bull. For. Br. Can. No. 118.

Loach, K. 1966. Relations between soil nutrients and vegetation in wet heaths. I. Soil nutrient content and moisture conditions. J. Ecol. 54(3):597-608.

Lohwasser, W. 1953. KalkdUngungsversuche im Eggegebirge und Hunsruck. Ertragkundliche Untersuchungen. Forstarchiv. 24:213-222.

Lowry, G. L. and Avard, P. M. 1967. Nutrient content of black spruce needles. II. Variations with crown class and relationships to growth and yield. Pulp and Pap. Res. Inst. of Can. Tech. Report 523.

Lundegargh, H. 1951. Leaf analysis. Trans. by R. L. Mitchell. Hilger and Watts Ltd., London.

__________. 1954. Physiological basis and plant analysis. Proc. 8th Int. Bot. Congr. I.H.R.O. Paris. 1-6.

Lunt, H. A. 1945. Effect of fertilizer treatment on field planted spruce. Soil Sci. Soc. of Am. Proc. 10:406-409.

Macy, P. 1936. The quantitative mineral nutrient requirements of plants. Plant Physiol. 11:749-764.

Mader, D. L. 1963. Volume growth measurement--an analysis of function and characteristics in site evaluation. J. For. 61(3):193-198.

Mader, D. L. and Owen, D. F. 1961. Relationships between soil properties and red pine growth in Massachusetts. Soil Sci. Soc. of A. Proc. 25:62-65.

Madgwick, H. A. I. 1964. The chemical composition of foliage as an index of nutritional status in red pine *Pinus resinosa* Ait. Plant and Soil 21(1):70-80.

Maki, T. E. 1950. Effect of varying amounts of potash and nitrogen on the development and vigor of long leaf pine seedlings. Sthn. Agric. Workers Assn. Proc. 47th Ann. Conv. p. 141.

__________. 1955. Effect of fertilizers on the growth of loblolly pine plantations. Unpub. manuscript. N.C. St. Coll., Raleigh.

Marion, G. M., Berglund, J. V. and Leaf, A. L. 1968. Morphological and chemical analyses of red pine *Pinus resinosa* Ait. buds--their relationships to tree growth on K-deficient to non-deficient site continuum. Plant and Soil 28(2):313-324.

Martin, J. W. and Carter, M. C. 1967. Nitrogen improves growth of Populus deltoides nursery stock. Tree Plant. Notes 18(3):24-26.

Martinović, J., Komlenović, N. and Milković, S. 1967. Seasonal fluctuations in soil moisture content and mineral nutrients in the needles in a plantation of *Pinus sylvestris* and *P. strobus* near Ogulin. Sum. List 91(3/4):111-121. For. Abstracts, 1968, 2061.

Materna, J. 1966. Preliminary results of fertilizer trials in older Norway spruce stands. Prace Byzkum. Ust. Lesn. Hsop. Mysl., Zbraslav-Strnady No. 32:89-110. For. Abstracts, 1967, 5622.

May, J. T., Johnson, H. H. and Gilmore, A. R. 1962. Chemical composition of southern pine seedlings. Georgia For. Res. Pap. 10. Georgia For. Res. Counc., Macon.

Mayor-Krapoll, H. 1956. The use of commercial fertilizers particularly nitrogen in forestry. Transl. by Nitrogen Div., Allied Chem. and Dye Corp., New York. Ruhr-stickstoff, Bochum.

McArdle, R. E. and Meyer, W. H. 1930. The yield of Douglas-fir in the Pacific Northwest. U.S.D.A. Tech. Bull. No. 201.

McClurkin, D. C. 1951. Soil and climatic factors related to the growth of longleaf pine. M.F. thesis, School of For., Duke University. 21 pp.

McGee, C. E. 1963. A nutritional study of slash pine seedlings grown in sand culture. For. Sci. 9(4):462-469.

McHargue, J. S. and Roy, W. R. 1932. Mineral and nitrogen content of the leaves of some forest trees at different times in the growing season. Bot. Gaz. 93:381-389.

McVicker, J. S. 1949. Composition of white oak leaves in Illinois as influenced by soil type and soil composition. Soil Sci. 68:317-328.

Metz, L. J., Wells, C. G. and Swindel, B. F. 1966. Sampling soil and foliage in a pine plantation. Proc. Soil Sci. Soc. Amer. 30(3): 397-399.

Miller, R. E. 1961. Further analysis of the effect of thinning and fertilizing on the growth of a 30-year-old Douglas-fir stand. Unpub. Master's thesis. Univ. of Washington, Seattle.

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

Miller, H. G. and Miller, J. D. 1967. Changes in weight and nutrient content of litter fall beneath corsican pine following application of nitrogen. Proc. 14th Cong. Int. Union For. Res. Organ., Munich. II, Sect. 21:335-351.

Mitchell, H. L. 1936. Trends in the nitrogen, phosphorus, potassium and calcium content of the leaves of some forest trees during the growing season. Black Rock For. Paper 1 (6).

__________. 1939. The growth and nutrition of white pine seedlings in cultures with varying nitrogen, phosphorus, potassium, and calcium. Black Rock For. No. 9.

Moehring, D. M. 1966. Diameter growth and foliar nitrogen in fertilized loblolly pines. U.S. For. Ser. Res. Note S. For. Exp. Sta. No. SO-43.

Møller, C. M. 1954. Gødningsforsøg i skov. Dansk Skovforen. Tidsskr. 39: 165-216. For. Abstracts, 1963.

Müller, W. 1967. The determination of micronutrients in conifer needles by extensive application of selective methods. Arch. Forstw. 16(6/9): 635-640. For. Abstracts, 1968, 3344.

Munsell Color Co. 1952. Munsell Color Charts for Plant Tissues.

Mustanoja, K. 1967. Foliar analysis, variation in nutrient contents during the growing season, and the nutrient status of trees. Metsat. Aikak. 84(4):122-124. For. Abstracts, 1967, 5073.

Mustanoja, K. J. and Leaf, A. L. 1965. Forest fertilization research, 1957-1964. Bot. Rev. 31:152-246.

Nakajima, Y. and Tsunita. 1967. The distribution of nutrients in a Akamatsu tree. Bull. of the Ehime Univ. For., Matsuyama No. 5: 17-28. For. Abstracts, 1968, 5065.

Nebe, W. 1966. Assessment of the fertilizer requirement of spruce stands in the central mountain region. Arch. Forstw. 15(9):929-952. For. Abstracts, 1967,3465.

__________. 1967. Manganese nutrition of spruce. Arch. Forstw. 16(2): 109-118. For. Abstracts, 1968, 270.

Nemec, A. 1940. On the effect of nitrogen fertilizing of young spruce on the nutrient uptake of the needles as dependent upon the soil reaction and nutrient status of the soil. Bodenk. u PflErnähr. 17:204-235. For. Abstracts, 1941-43, Vol. 3, p. 21.

__________. 1947. Biochemical and pedological studies on the causes of checking Norway spruce and scots pine in the Smrcek circle, State Forest of Slatinany, near Chrudim. Zpr. Vyzkum. Ust. lesn. CSR No. 1:31-52.

Neumann, E. E. 1966. Nutrient balance and increment of a fertilized pole-stage pine stand on a degraded sandy site of medium quality. Arch. Forstw. 15(10):1115-1138. For. Abstracts, 1967, 3823.

Nommik, H. and Popovit, B. 1968. Translocation of N^{15}, Sr^{90}, and Cs^{137} and the movement of some nutrient substances in different parts of the tree in pine. Angew. Bot. 41(5):181-193. For. Abstracts, 1968, 3347.

Oksbjerg, E. 1956. [About the uptake of nutrients of spruce on poor soils.] Hedeselsk. Tidsskr. 77:103-116. For. Abstracts, 1957, 4043.

__________. 1968. Needles and their nutrition content. Hedeselsk. Tidsskr. 88:3-5, 65-70, 83-89, 99-103; 89(2,3):29-34, 46-56. For. Abstracts, 1968, 5069.

Olsen, C. 1948. The mineral, nitrogen and sugar content of beech leaves and beech leaf sap at various times. Comptes rendus des Travaux du Laboratoire Carlsberg (Serie chimique), Copenhague 26(5):197-230. For. Abstracts, 1948-49, 2440.

Orman, H. R., et al. 1960. The nutrient content of *Pinus radiata* trees. N.Z. J. Sci. 3(3):510-522.

Ovington, J. D. 1956. The composition of tree leaves. For. 29:22-28.

__________. 1957. The volatile matter, organic carbon and nitrogen contents of tree species grown in close stands. New Phytol. 56(1):1-11.

__________. 1959a. Distribution of organic and plant nutrients in a plantation of scots pine. For. Sci. 5:344-355.

__________. 1959b. Mineral content of plantations of *Pinus sylvestris* L. Annals of Bot., 23:75-88.

Paddock, R. W. 1962. Certain quantitative nutrient descriptions for different stages of plant succession of the Fern Lake watershed. M.F. thesis, Univ. of Washington, Seattle.

Parker, F. W. 1963. Fertilizer technology and usage. Ed. McVickar. Soil Sci. Soc. of Amer. Madison, Wisc. 464 pp.

Pearson, G. A. 1918. The relation between spring precipitation and height growth of western yellow pine saplings in Arizona. Jour. For. 16: 677-689.

Peterson, P. J. 1961. Variation in the mineral content of Kauri *Agathis australis* Salisb. leaves with respect to leaf age, leaf position and tree age. N.Z. J. Sci. 4(4):669-678.

Phillips, J. J. 1966. Site index of yellow poplar related to soil and topography in southern New Jersey. U.S. For. Ser. Res. Pap. N.E. For. Exp. Sta. No. NE-52.

Plice, M. J. 1944. Uptake of minerals by trees in successive years. Proc. Okla. Acad. Sci. 24:60-73.

Porgasaar, V. 1965. The nutrient content of pine needles in relation to site type. Metsanduse Tead. Uxurim. Lab. Metsandusl. Uurim., Tall inn No. 4:92-100. For. Abstracts, 1967, 1914.

__________. 1966. Chemical composition of pine needles in varying nutrient conditions. Eesti Nsv Tead. Akad. Toimet. (biol. Seer.) 15(2):231-238. For Abstracts, 1967, 102.

Proszt, S. 1967. Changes in nutrient uptake by forest nursery plants during the growing season. Proc. 14th Cong. Int. Union For. Res., Munich. III, Sec. 22:636-644.

Puri, G. S., et al. 1954. Seasonal variation in foliar composition of some Indian forest trees. J. Indian Bot. Soc. 33(4):382-393.

Qureshi, I. M. and Srivastava, P. B. L. 1966. Foliar diagnosis and mineral nutrition of forest trees. Indian For. 92(7):447-460.

Ralston, C. W. 1964. Evaluation of forest site productivity. Int. Rev. of For. Res. 1:171-201.

Ramann, E. 1892. The nutrition of dominant, co-dominant and dominated trees. Z. Forst. Jagdw. 24. Forest Bibliog. to 1933, Oxford Univ.

Raupach, M. 1967. The growth of *Radiata* pine on lateritic soils at Second Valley, South Australia. Aust. For. 31(4):246-262.

Reemtsma, J. B. 1966. The nutrient content of needles of different ages in spruce and other conifers. Flora., Jena 156B (2):105-121.

Rehfuess, K. E. 1967. Site and nutrient conditions of silver fir in a S.W. German region where geological strata meet. Forstw. Cbl. 87(6):321-348. For. Abstracts, 1968, 5265.

__________. 1968. Nutrient status of S.W. German silver fir stands in relation to growth. Forstw. Cbl. 87(1):36-58. For. Abstracts, 1968, 5266.

Rennie, P. J. 1966. A forest-sampling procedure for nutrient-uptake studies. Commonw. For. Rev. 45(2):199-28.

Roth, F. 1916. Concerning site. For. Quart. 15:3-13.

Robinson, J. B. D. and Freeman, G. H. 1967. Sources of variation in leaf analysis in East Africa. E. Afr. Agric. For. J. 33(1):8-13.

Rohmeder, E. 1951. Aufforstungs- und Meliorationsprobleme auf armen Waldboden. Mitt. Staatsforstverein. Bayern. 26:179-194.

Roth, E. R., Toole, E. R. and Hepting, G. H. 1948. Nutritional aspects of the little leaf disease of pine. J. For. 46(8):578-587.

Sander, D. H. 1966. Effect of urea and ureaformaldehyde on the growth of lodgepole pine seedlings in a nursery. Tree Plant. Notes No. 79: 18-23.

__________. 1967. Investigation of the relationship between soil properties and the growth of Siberian elm trees in the loess plains of Nebraska. Abstr. of thesis, in Dissert. Abstr. 28B(2):409-410.

Savina, A. V. 1956. Physiological justification for the thinning of forests. Nat. Sci. Found., Washington, D.C. Israel Program for Scien. Translations. Translated by B. Toker, 1960.

Schairer, E. 1967. Report of the working party on the fertilizing of forest soils. Proc. 14th Cong. Int. Union For. Res. Organ., Munich. IV, Sec. 23:528-538.

Schmidt, H. 1953. Kronen and Zuwachs--Untersuchungen an Fichten des bayerischen Alpenvorlandes. Forstw. Cbl. 72:276-286.

Schomaker, C. E. and Rudolph, V. J. 1964. Nutritional relationships affecting height growth of planted yellow poplar in southwestern Michigan. For. Sci. 10(1):66-76.

Schnappach. 1923. Ertragstafeln der Wichtigeren Holzarten. 2nd Ed. Neudamm: J. Neumann.

Seth, S. K. and Bhatnegar, H. P. 1960. Interrelations between constituents of foliage, soil properties, site quality and regeneration status in some *Shorea robusta* forests. Indian For. 86(10):590-601.

Schmitz-Dumont, W. 1894. Tharandt. Forstl 44.

Schröder, J. 1878. Chemische Zusammensetzung der Pflanz (A) Dresden 1878. [Notes on manuring of pine seed beds.] Oxford Univ., For. Bibl. to 1933.

Shibamoto, T. 1957. Fertilizing forest lands. Forest and Estate Mutual Found., Tokyo. (Distr. by Nitrogen Div., Allied Chem. and Dye Corp.)

Shear, C. B., Crane, H. L. and Meyers, A. T. 1948. Nutrient element balance. Application of the concept to the interpretation of foliar analysis. Proc. Amer. Soc. Hort. Sci. 51:319-326.

__________. 1953. Nutrient element balance. Response of tung trees grown in sand culture to potassium, magnesium, calcium and other interactions. U.S.D.A. Tech. Bull. 1085.

Sjolte-Jørgensen, J. 1967. The influence of spacing on growth and development of coniferous plantations. Inter. Rev. of For. Res. Vol 2. Ed. J. A. Romberger and P. Mikola.

Slade, R. W. 1949. M.F. thesis, School of For., Duke University, 33 pp.

Smith, P. F. 1962. Mineral analysis of plant tissues. Ann. Rev. Plant Plysiol. 13:81-108.

Snowdon, P. 1967. Foliage phosphorus determination using an auto analyzer. Aust. For. Res. 2(4):31-36.

Srivastava, P. B. L. 1965. Seasonal variation of nutrient content in the leaves of Sal *Shorea robusta* tree seedlings. J. Indian Bot. Soc. 44 (4):429-438.

Staebler, G. R. 1956. Effect of controlled release on growth of individual Douglas-fir trees. Jour. For. 54:567-568.

Stage, A. R. 1967. Simultaneous derivation of site-curve and productivity rating procedures. Proc. Soc. Amer. For. 1967:134-136.

Strebel, O. 1960. Mineralstoffernährung und Wuchsleistung von Fichtenbeständen (*Picea abies*) in Bayern. Forstwiss. Cbl. 79(1/2): 17-42.

Steenbjerg, F. 1951. Yield curves and chemical plant analysis. Plant Soil, 3(2):97-100.

__________. 1954. Manuring and plant production - Analyse des plantes et problemes des Engrais mineraux. VIII e Congres Intern. deBotanique I.R.H.O., Paris, p. 31-34.

Steinbeck, K. 1966. Foliar mineral accumulation by several scots pine *Pinus sylvestris* L. provenances. Abstr. of thesis, in Dissert. Abstr. 26(9):4149.

Steinbrenner, E. C., Duffield, J. W. and Campbell, R. K. 1960. Increased cone production of young Douglas-fir following nitrogen and phosphorus fertilization. J. For. 58(2):105-110.

Sterrent, W. D. 1921. A generalized yield table for even aged well stocked stands of southern uplands hardwood. Jour. For. 19:382-389.

Stoate, T. N. 1920. The Eucalypts in relation to soil fertility. Aust. Jour. For. 3-4:112-113.

__________. 1950. The nutrition of the pine. For. and Timb. Bur. Aust. Bull. 30. 61.7.7.

Stoate, T. N. and Bednall, B. H. 1957. Disorders in conifer forests. Bull. 11, Woods For. Dept. S. Aust.

Strand, R. F. and Miller, R. E. 1969. Douglas-fir growth can be increased-report from Pacific Northwest shows. For. Industries, 96(2).

Strebel, O. 1961. Needle analysis in old spruce stands of very good growth in Bavarian Alpenvorland. Forstw. Cbl. 80(11/12):344-352. For. Abstracts, 1962, 4879.

Svalov, N. N. 1967. Methods of compiling site class tables. Lesn. Hoz. 6:46-49. For. Abstracts, 1968, 112.

Swan, H. S. D. 1962. The mineral nutrition of Grand'mere plantations. Pulp and Pap. Res. Inst. of Can. Tech. Rep. No. 276.

__________. 1966. Studies of the mineral nutrition of Canadian pulpwood species. The use of visual symptoms, soil and foliage analyses and soil bio-assays for the determination of the fertilizer requirements of forest soils. Woodl. Res. Index Pulp Pap. Res. Inst. Can. No. 179.

__________. 1970. Relationship between nutrient supply, growth and nutrient concentrations of the foliage of black spruce and jack pine. Pulp and Pap. Res. Inst. Can. Woodl. Pap. No. 19.

Tamm, C. O. 1951. Seasonal variation in the composition of birch leaves. Physiol. Plant., Copenhagen 4(3):361-369.

__________. 1955. Studies on forest nutrition. I. Seasonal variation in the nutrient content of conifer needles. II. An experiment with application of radioactive phosphate to young spruces and birches. Medd. Skogsforskn Inst., 45(5/6). For. Abstracts, 1955, 3769.

__________. 1957. The effects of nitrogen fertilizationoon tree growth and foliage composition in a forest stand. Plant Analy. and Fert. Probl., I.R.H.O., Paris, 150-156.

__________. 1958. The effects of nitrogen fertilization on tree growth and foliage in a forest stand. Coll. VI Congr. Int. Sci. du Sol.

__________. 1967. The analysis of leaves as a method for the determination of the nutrient supply of a forest. Transl. For. Comm., London, No. 329.

Tamm, C. O. and Troedsson, T. 1955. An example of the amounts of plant nutrients supplied to the ground in road dust. Oikos. 6:61-70.

Tamm, C. O., Troedsson, T., Lundmark, J. E. and Persson, O. 1967. Forecasting forest yield from observations of site characteristics: A critical discussion. Proc. 14th Cong. Int. Union For. Res. Organ., Munich. II, Sec. 21:2-21.

Themlitz, R. 1954. Die Anwendung von Kalkstickstoff zur Rohhumusumwandlung und Ertragssteigerung im Walde. Z. Pfl. Ernahr. Dung. 64:54-66.

Thomas, W. 1945. Present status of diagnosis of mineral requirements of plants by means of leaf analysis. Soil Sci. 59:353-374.

Tisdale, S. L. and Nelson, W. L. 1956. Soil fertility and fertilizers. The MacMillan Co., New York. 430 pp.

Tuil, H. D. W. van. 1967. The organic-salt content of trees in relation to their growth. Proc. 14th Cong. Int. Union For. Res. Organ., Munich. IV, Sec. 23:579-596.

Ulrich, A. 1943. Plant analysis as a diagnostic procedure. Soil Sci. 55: 101-122.

__________. 1948. Plant analysis as a guide in the nutrition of sugar beets in California. Proc. Amer. Soc. Sug. Beet. Tech. 5:346-377.

__________. 1952. Physiological basis for assessing the nutrition requirements of plants. Ann. Rev. Plant Physiol. 3:207-228.

Ulrich, A. and Hills, F. J. 1967. Principles and practices of plant analysis. Soil testing and plant analysis Pt. II. Soil Sci. Soc. of Amer. Madison, Wisconsin.

U. S. Department of Commerce. Climatological data. Vol. 71(13).

Van Camp, J. C., Jr. 1948. The nutrient element content of the foliage of certain species of minor forest vegetation. J. For. 46:823-826.

van der Driessche, R. 1969. Relationships between Douglas-fir seedlin growth and levels of some soil and tissue nutrients. For. Chron. 45(4):273-276.

Vanselow, V. K. 1951. Krone únd zuwachs der Fichte in gleichaltrigen Rein-bestanden. Forstw. Cbl. 70:705-719.

Vincent, A. B. 1961. Is height/age a reliable index site? For. Chron. 37(2):144-150.

Viro, P. J. 1961. Evaluation of site fertility. Unasylva 15(2):91-97.

__________. 1962. Forest site evaluation in Lapland. Comm. Inst. For. Fen. 55(9), Helsinki.

Walker, L. C. 1955. Foliar analysis as a method of indicating potassium-deficient soils for reforestation. Proc. Soil. Sci. Soc. Amer. 19(2): 233-236.

Walker, L. C. and Youngberg, C. T. 1962. Response of slash-pine to nitrogen and phosphorus fertilization. Proc. Soil. Sci. Soc. Amer. 25(4): 399-401.

Walker, R. B., Gessel, S. P. and Haddock, P. 1955. Greenhouse studies in mineral requirements of conifers: western red cedar. For. Sci. 1(1): 51-60.

Wallace, T. 1951. The diagnosis of mineral deficiencies in plants by visual symptoms: a colour atlas and guide. H. M. Stationery Off., London. 2nd Ed., (Rev.).

Wallihan, E. F. 1944. Chemical composition in leaves in different parts of sugar maple trees. J. For. 42:684.

Ward, G. M. and Johnston, F. B. 1962. Chemical methods of plant analysis. Pub. No. 1064, Res. Branch, Can. Dept. of Agric.

Watson, R. 1917. Site determination, classification and application. Jour. For. 15:553-565.

Watt, R. F. 1967. Growth of black spruce stands after fertilization treatment based on foliar analysis. Proc. Soc. Amer. For. 85-88.

Weetman, G. F. 1962. Nitrogen relations in a black spruce *Picea mariana* Mill. stand subject to various fertilizer treatments. Woodl. Res. Index Pulp Pap. Res. Inst. Can. No. 129.

Wehrmann, J. 1957. The N content of spruce needles in relation to the N supply of the trees. Mitt. St-Forstverw. Bayerns No. 29:62-72. For. Abstracts, 1958, 1473.

__________. 1959a. Methodische Untersuchungen zur Durchfuhrung von Nadelanalysen in Kiefernbestanden. Forstw. Dbl. 78(3/4):77-97.

__________. 1959b. The mineral nutrition of *Pinus sylvestris* stands in Bavaria. Forstw. Dbl. 79:221-236. For. Abstracts, 1960, 233.

Weinkauff, R. 1941. Die Fortentwicklung der Forswirtschaft durch N-Düngung. Forstw. Dbl. 63:243-255.

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

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

__________. 1958. Foliar analysis in tree nutrition research. 1st N. Amer. For. Soils Conf., Sept. 8-11, 1958. Ag. Exp. Sta. Mich. State Univ., East Lansing.

__________. 1965. Survival, growth and nutrient uptake by spruce and pine seedlings as affected by slow-release fertilizer materials. In For. soil Relationships in N. Amer., Ore. St. Univ. Press, Corvallis.

Wilde, S. A. 1938. Soil fertility standards for growing northern conifers in forest nurseries. J. Agric. Res. 57:945-952.

__________. 1958. Diagnosis of nutrient deficiencies by foliar and soil analyses in silvicultural practice. 1st N. Amer. For. Soils Conf., Sept. 8-11, 1958. Agric. Exp. Sta. Mich. St. Univ., East Lansing.

__________. 1958. Forest soils, their properties and relation to silviculture. The Ronald Press, New York.

Wilde, S. A. and Voight, G. K. 1952. Determinatin of colour of nursery stock foliage (for the diagnosis of nutrient deficiencies) by means of Munsell Color Charts. J. For. 50(8):622-623.

Will, G. M. 1957. Variations in the mineral content of *Radiata* pine needles with age and position in tree crown. Res. Note N.Z. For. Serv. No. 11.

Wittich, W. 1942. Die Aktivierung von Rohhumus extrem ungungstiger Beschaffenheit. Z. Forst-u. Jagdw. 7:8.

__________. 1958. Auswertung eines forstlichen Dungungsversuches auf einem Standort mit fur weite Gebiete Duetschlands typischem Nahrstoffhaushalt. Ruhr-Stockstoff, Bochum.

Wood, L. K. 1947. Seasonal variation in leaf and soil potassium. Soil Sci. 63:305-314.

Worswick, G. D. 1950. Tree symptoms and leaf analysis determine potash needs. Better Crops with Plant Food 34:11.

Young, H. E., Dyer, R. F. and Dube, G. F. 1966. Chemical elements in complete mature trees of seven species in Maine. TAPPI 49(5):190-197.

__________. Nutrient distribution in the crown of pole size red spruce and white pine. Repr. from Main Farm Res., Orono..

Youngberg, C. T. and Austin, R. C. 1954. Fertility standards for raising Douglas-fir in nurseries. J. For. 52:4-6.

Zahner, R. and Connelly. 1967. Refining correlations of water deficits and radial growth in young red pine. Ecol. 48(4):525-530.

Zelawski, W. and Gowin, T. 1966. Variability of some needle characteristics in scots pine *Pinus sylvestris* L. ecotypes grown on the comparative plantation. Ekol. polska 14A(17):275-283. For. Abstracts, 1968, 160.

Zelawski, W. and Niwinski, Z. 1966. Variability of some needle characteristics in scots pine *Pinus sylvestris* L. ecotypes grown in native conditions. Ekol. polska. 14A(19)301-308. For. Abstracts, 1968, 161.

Zöttl, H. W. 1959. Voraussetzungen fur eine wirkungsvollc Verbesserung der Stickstoffversorgung von Nadelholzbeständen. Z. Pfl. Ernähr Düng. 84(1-3):116-122.

__________. 1960. The supply of mineral nitrogen in Bavarian spruce and pine stands. Forstw. Cbl. 79:221-236. For. Abstracts, 1961, 1333.

Zöttl, H. W. and Velasco, F. 1966. Nutrient status and growth of different plantations of the genus *Pinus* in Spain. An edafol. Agrobiol. 25(5/6):249-268. For. Abstracts, 1967, 5250.

APPENDIXES

APPENDIX I

RANGE AND FREQUENCY OF STAND, VIGOR AND APPEARANCE CHARACTERISTICS OF THE STUDY AREA

A histogram was prepared to show the age range of the 188 dominants and co-dominants sampled. Ages range from 25 years to 57 years with one tree of age 69. The frequency of ages within this range approaches a normal curve. Twice as many trees fall in the 40 - 42-year age class as any other 2-year class and 72% of the samples range from 34 to 45 years. Very similar patterns of age range and frequency in the histograms prepared from the 94 randomly chosen samples and from the 94 samples chosen to represent the stand for foliar nitrogen content. In view of the sampling procedures in each case, there is no reason to expect a difference.

A histogram was prepared to show the range and frequency of the site index of the stand at each point from which the 188 samples were taken. Site index ranges from 76 to 152 with twice as many stand sites falling in the 121 - 124 class as any other 3-foot class. The frequency curve is skewed to the left with 66% of samples falling between site index 117 and site index 140. An almost identical pattern is shown in histograms for the 94 samples chosen randomly and the 94 samples chosen to represent the stand, except that site index does not fall below 100 in the samples chosen randomly. This change in pattern is explained by sampling procedure where irregularly behaving trees were excluded when trees were chosen to characterize the area for foliar nitrogen.

A histogram was prepared to show the range and frequency of the stocking in square feet of basal area per acre for the plots from which the 188 samples were taken. Stocking ranges from 50 to 210 square feet per acre. The curve is skewed to the right with 79% falling between 80 and 150 square feet of basal area per acre. Similar patterns are shown for the stocking on the plots from which the 94 trees were randomly chosen and the plots from which the 94 trees were chosen to represent the area and this similarity was expected.

A histogram was prepared to show the range and frequency of the weight of 100 needles found on each of the 188 samples. These range from 0.280 grams to 0.980 grams with 64% falling between 0.455 grams and 0.700 grams. The frequencies again form a normal curve with a maximum at 0.600 grams. An almost identical range, frequency and curve is shown for the weight of 100 needles taken from the 94 trees chosen to represent the stand for foliar nitrogen content. However, the pattern for the weights taken from the 94 randomly chosen trees shows a narrower range and a greater concentration of trees in the middle of the range although it is still of the normal curve type.

A histogram was prepared to show the range and frequency of the number of needles per inch on the first whorl shoot on the 188 sample trees. These range from 12 to 66 with the curve skewed to the right. In fact, 80% of the samples lie between 15 and 36 needles per inch of shoot. As with the previous case, the almost identical range, frequency and curve is shown for the number of needles per inch of shoot from the 94 trees chosen to represent the stand for foliar nitrogen content. However, the pattern for the number of needles taken from randomly chosen trees shows no trends and there is little variation from one end of the scale to the other. This again reflects the closer association of foliar nitrogen with the number of needles per length of shoot as many trees which were not representative of the foliar nitrogen content of the stand were included in the random sampling.

A histogram was prepared to show the range and distribution of the percentage of the tree bole carrying green branches on each of the 188 samples. These range from 30% to 90% and the distribution curve is skewed to the left. The bole of 75% of the sample carries between 50% to 80% green branches. There is a similar pattern of range and distribution for the 94 randomly chosen samples, and the pattern for the trees chosen to represent the stand shows a fairly even frequency distribution within the range indicating little relationship between foliar nitrogen content and percentage of green crown.

The histogram showing the range and frequency of height growth in the terminal shoot for 188 samples ranges from 0.4 ft. to 3.6 ft. with the curve skewed to the right. Maximum frequency occurs between 1.7 ft. and 2.0 ft. The pattern for the 94 random trees and 94 representative trees respectively show a marked difference in frequency distribution but a similar range. In the random samples there is a fairly regular frequency distribution within the range except for a marked increase in the 1.7 to 2.0 ft. class. The 94 samples from characterized plots show a curve sharply skewed to the right with 67% of the samples lying between 1.0 and 2.0 ft. There is an indication here that the average leader length of most samples taken from across the whole of the sampling area falls in a relatively narrow range.

The histogram of range and frequency distribution of the height growth in the last 5 years of the 188 samples ranges from 2.1 to 16.1 feet with very little change in frequency between 5 feet and 12.5 feet except for a high frequency in the 8.5 to 9.0 class. There is a similar pattern for the 94 trees randomly chosen and for the trees chosen to represent the stand. These patterns contrast with those set out above for the length of the leading shoot.

The histogram of range and frequency distribution of the height growth in the last 10 years of the 188 sample trees ranges from 4.5 feet to 33 feet and frequency distribution is a normal curve with maximum frequency in the 16.5 - 18 ft. class. The pattern is similar for the 94 trees chosen randomly but the curve is skewed slightly to the right for the 94 representative trees.

Comparing the leader length data with that of height growth in the last 5 years and height growth in the last 10 years, there is a trend for the frequency to assume a normal curve and this is to be expected as increasing age tends to smooth out year-by-year variations and irregularities of growth.

The histogram of range and frequency distribution of radial growth in the last 5 years for the 188 samples ranges from 0.1 inches to 0.6 inches with a maximum frequency in the 0.25 - 0.30 inch class and the curve is skewed very slightly to the right. The pattern is similar for the 94 trees chosen at random but is vastly different for the 94 trees chosen to represent the stand. In this case, there is no trend of frequency with radial growth and in fact the frequency is most irregular.

The histogram of range and frequency distribution of the radial growth over the last 10 years of the 188 samples ranges from 0.1 inches to 1.2 inches with a maximum in the 0.5 to 0.7 inch class and the curve is skewed slightly to the right. The pattern for the 94 randomly chosen trees is similar but for the 94 representative trees it is irregular and shows no trend of frequency with diameter growth class. Each of these 3 patterns for radial growth over the last 10 years is similar to the 3 patterns for the growth over the last 5 years.

Six chips of the Munsell Color Chart for plant tissues were identified with the foliar color of the 188 samples. For simplification, these chips are identified by numbers from one to six as follows:

Color Class 1.	Chip Number 7.5 GY 3/4
2.	7.5 GY 4/4
3.	7.5 GY 4/6
4.	7.5 GY 5/4
5.	7.5 GY 5/6
6.	7.5 GY 6/8

The histogram of the frequency of samples matching up with the chips shows 60% of these falling into class 3 or chip number 7.5 GY 4/6. There being no relationship between foliar nitrogen content and color, this data was only collected in the first year from 77 samples. There are similar patterns respectively for each of the sampling methods.

The histogram of frequency distribution of the number of years green needles were retained on the tree for the 188 samples show green needles held from 1 to 7 years. The frequency curve is normal except that the maximum of 4 years retention accounts for 57% of the samples.

Similar patterns are shown for the random and representative samples.

APPENDIX 2

DETAILED RESULTS OF ANALYSIS OF VARIANCE AND MULTIPLE RANGE TESTS

Stand Characteristics

Nitrogen in the first whorl and site index. Table (28) sets out the results of this test. Site index is divided into six classes and a multiple range test carried out on the nitrogen data in each group to determine if the six groups of data differed significantly. The test shows that there is no statistically significant difference at the 95% level in the foliar nitrogen data between any of the site index groups indicating that there is no significant relationship between foliar nitrogen in the first whorl and site index.

However, an examination of the mean values of foliar nitrogen in each group shows a generally rising value with rising site index (except for the highest 140 - 150 site index classes.)

Nitrogen in the third whorl and site index. Table (29) sets out the results of this test. Site index is divided into six classes and a multiple range test carried out as described above.

The test shows that there are statistically significant differences in the foliar nitrogen in the two lowest site index classes (80 - 99 and 100 - 109) and the fourth and fifth highest classes (120 - 129 and 130 - 139).

As with nitrogen in the first whorl, there is a general rise in value of the mean nitrogen in the third whorl with rising site index except in the

Table 28. ANALYSIS OF VARIANCE AND MULTIPLE RANGE TEST OF FOLIAR NITROGEN IN THE FIRST WHORL IN SIX SITE INDEX CLASSES

Analysis of Variance

	Sums of Squares	D.F.	Mean Square	F-ratio
Between Groups	0.2553	5	0.0511	1.1975
Within Groups	7.6314	179	0.0426	
TOTAL	7.8867	184		

Treatment Means in Original Order

Class	Mean	Standard Deviation	Number of Replications
81-99	1.227	0.2049	7
100-109	1.340	0.1530	20
110-119	1.397	0.1969	41
120-129	1.390	0.1755	58
130-139	1.470	0.1598	43
140-150	1.352	0.4128	16

There is one homogeneous subset listed as follows:

(81-99, 100-109, 140-150, 120-129, 130-139)

Table 29. ANALYSIS OF VARIANCE AND MULTIPLE RANGE TEST OF FOLIAR NITROGEN IN THE THIRD WHORL IN SIX SITE INDEX CLASSES

Analysis of Variance

	Sums of Square	D.F.	Mean Square	F-ratio
Between Groups	0.4053	5	0.0811	2.9287
Within Groups	4.9539	179	0.0277	
TOTAL	5.3592	184		

Treatment Means in Original Order

Class	Mean	Standard Deviation	Number of Replications
81-99	1.169	0.1590	7
100-109	1.207	0.1534	20
110-119	1.287	0.2360	41
120-129	1.313	0.1252	58
130-139	1.347	0.1424	43
140-150	1.309	0.1596	16

There are two homogeneous subsets listed as follows:

(110-119, 140-150, 120-129, 130-139)
(81-99, 100-109, 110-119, 140-150)

highest class, 140 - 150, where the mean falls to a lower level. With this fall in mind, there are indications from this test of some direct relationship between foliar nitrogen in the third whorl and site index.

Nitrogen in the first whorl and tree site. Table (30) sets out the results of this test. Tree site is divided into seven classes. The test shows no significant difference in the foliar nitrogen values between any of the seven classes so that there is no significant relationship between nitrogen in the first whorl and tree site.

However, an examination of the means of each of the seven classes shows consistently rising values of foliar nitrogen with rising site index classes. These results are similar to those obtained using stand site index.

Nitrogen in the third whorl and tree site. Table (31) sets out the results of this test. Again the results are similar to those obtained using stand site index. Except for the highest tree site class 150 - 160, there is a consistently rising value of foliar nitrogen means of the tree site classes with rising tree site. The two lowest classes vary significantly from the fifth and six classes indicating some direct relationship between foliar nitrogen in the third whorl and tree site.

Nitrogen in the first whorl and age. Table (32) sets out the results of this test. Age is divided into three classes. The test shows that there are significant differences in the foliar nitrogen values between each of the three age classes indicating a relationship between foliar

Table 30. ANALYSIS OF VARIANCE AND MULTIPLE RANGE TEST OF FOLIAR NITROGEN IN THE FIRST WHORL IN SEVEN TREE SITE CLASSES

Analysis of Variance

	Sums of Square	D.F.	Mean Square	F-ratio
Between Groups	0.3536	6	0.0589	1.4152
Within Groups	7.3285	176	0.0416	
TOTAL	7.6821	182		

Treatment Means in Original Order

Class	Mean	Standard Deviation	Number of Replications
91-99	1.277	0.2170	7
100-109	1.323	0.1499	17
110-119	1.371	0.1866	41
120-129	1.355	0.1749	46
130-139	1.408	0.2845	40
140-149	1.447	0.1559	21
150-160	1.457	0.1657	11

There is one homogeneous subset listed as follows:

(91-99, 100-109, 120-129, 110-119, 130-139, 140-149)

Table 31. ANALYSIS OF VARIANCE AND MULTIPLE RANGE TEST OF FOLIAR NITROGEN IN THE THIRD WHORL IN SEVEN TREE SITE CLASSES

Analysis of Variance

	Sums of Square	D.F.	Mean Square	F-ratio
Between Groups	0.3674	6	0.0612	2.1712
Within Groups	4.9631	176	0.0282	
TOTAL	5.3304	182		

Treatment Means in Original Order

Class	Mean	Standard Deviation	Number of Replications
91-99	1.177	0.1571	7
100-109	1.203	0.1325	17
110-119	1.288	0.1280	41
120-129	1.305	0.2372	46
130-139	1.333	0.1497	40
140-149	1.346	0.1353	21
150-150	1.322	0.1031	11

There are two homogeneous subsets listed as follows:

(91-99, 100-109, 110-119, 120-129, 150-160)

(110-119, 120-129, 150-160, 130-139, 140-149)

Table 32. ANALYSIS OF VARIANCE AND MULTIPLE RANGE TEST OF FOLIAR NITROGEN IN THE FIRST WHORL IN THREE AGE CLASSES

Analysis of Variance

	Sums of Square	D.F.	Mean Square	F-ratio
Between Groups	1.2580	2	0.6290	17.6340
Within Groups	6.4561	181	0.0357	
TOTAL	7.7141	183		

Treatment Means in Original Order

Class	Mean	Standard Deviation	Number of Replications
25-34	1.519	0.1530	28
35-44	1.395	0.1651	118
45-54	1.245	0.2669	38

There are no homogeneous subsets. Any two means vary significantly.

nitrogen in the first whorl and age. An examination of the mean foliar nitrogen levels in each class shows a steady decrease in foliar nitrogen with age.

Nitrogen in the third whorl and age. Table (33) sets out the results of this test. These results contrast with those above for nitrogen in the first whorl. There is no significant difference in the nitrogen values between any of the three age classes so that age and foliar nitrogen in the third whorl bear no significant relationship to each other. The trend of falling means of nitrogen values in each class as age increases is present but is weak.

Nitrogen in the first whorl and stocking. Table (34) sets out the results of this test. Stocking is divided into five classes. There are significant differences in foliar nitrogen levels between the low, middle and high stocking classes indicating a relationship between first whorl nitrogen content and stocking. An examination of the mean nitrogen values in each class shows a consistent fall in nitrogen with rising stocking.

Nitrogen in the third whorl and stocking. Table (35) sets out the results of this test. In contrast to the results obtained above for nitrogen in the first whorl, the test shows no significant difference in nitrogen values between any of the five stocking classes and indicates that there exists no relationship between nitrogen in the third whorl and stocking.

Except for the highest stocking class (180-205), there is a consistent decrease in the nitrogen means of each class with rising stocking.

Table 33. ANALYSIS OF VARIANCE AND MULTIPLE RANGE TEST OF FOLIAR NITROGEN IN THE THIRD WHORL IN THREE AGE CLASSES

Analysis of Variance

	Sums of Square	D.F.	Mean Square	F-ratio
Between Groups	0.1339	2	0.0670	2.3149
Within Groups	5.2351	181	0.0289	
TOTAL	5.3690	183		

Treatment Means in Original Order

Class	Mean	Standard Deviation	Number of Replications
25-34	1.361	0.1349	28
35-44	1.288	0.1783	118
45-54	1.283	0.1665	38

There is one homogeneous subset listed as follows:

(45-54, 35-44, 25-34)

Table 34. ANALYSIS OF VARIANCE AND MULTIPLE RANGE TEST OF FOLIAR NITROGEN IN THE FIRST WHORL IN FIVE STOCKING CLASSES

Analysis of Variance

	Sums of Square	D.F.	Mean Square	F-ratio
Between Groups	0.7042	4	0.1761	4.4651
Within Groups	7.1761	182	0.0394	
TOTAL	7.8803	186		

Treatment Means in Original Order

Class	Mean	Standard Deviation	Number of Replications
60-85	1.464	0.1416	31
90-115	1.413	0.1967	63
120-145	1.361	0.1667	50
150-175	1.288	0.2871	33
180-205	1.272	0.1395	10

There are three homogeneous subsets which are listed as follows:

(180-205, 150-175, 120-145)

(90-115, 60-85)

(120-145, 90-115)

Table 35. ANALYSIS OF VARIANCE AND MULTIPLE RANGE TEST OF FOLIAR NITROGEN IN THE THIRD WHORL IN FIVE STOCKING CLASSES

Analysis of Variance

	Sums of Square	D.F.	Mean Square	F-ratio
Between Groups	0.0937	4	0.0234	0.8076
Within Groups	5.2798	182	0.0290	
TOTAL	5.3735	186		

Treatment Means in Original Order

Class	Mean	Standard Deviation	Number of Replications
60-85	1.324	0.1194	31
90-115	1.311	0.2257	63
120-145	1.295	0.1358	50
150-175	1.255	0.1434	33
180-205	1.285	0.1210	10

There is one homogeneous subset which is listed as follows:
(150-175, 180-205, 120-145, 90-115, 60-85)

Appearance Characteristics

Nitrogen in the first whorl and color. Table (36) sets out the results of this test. Color is divided into five classes, each class representing a Munsell Color chip. Class 6 was omitted as it only contained one sample. The test shows no significant difference in the nitrogen between the five color classes indicating no statistically significant relationship between foliar nitrogen and color class within the color ranges and nitrogen content ranges tested.

However, there is a slight but general trend of falling nitrogen means in the color classes as these move from the greener to the yellower chips.

Nitrogen in the third whorl and color. Table (37) sets out the results of this test. Again there was no significant difference in the nitrogen levels between the color classes, indicating no significant relationship between color class and foliar nitrogen in the third whorl. There is a slight trend of falling nitrogen means in the color classes as they move from the greener to the yellower chips.

Within the foliar nitrogen ranges found on the study area, neither first whorl nor third whorl nitrogen levels could be related to color classes based on the Munsell Color Chart for Plant Tissue. It is possible that the color differences in the chips are not subtle enough to detect color differences in the foliage in this particular range.

Nitrogen in the first whorl and number of years needles were retained on the tree. Table (38) sets out the results of this test. The number of years are divided into six groups from two years to seven years. The test

Table 36. ANALYSIS OF VARIANCE AND MULTIPLE RANGE TEST OF FOLIAR NITROGEN IN THE FIRST WHORL IN FIVE COLOR CLASSES

Analysis of Variance

	Sums of Square	D.F.	Mean Square	F-ratio
Between Groups	0.0350	4	0.0087	0.1736
Within Groups	3.5752	71	0.0504	
TOTAL	3.6102	75		

Treatment Means in Original Order

Class	Mean	Standard Deviation	Number of Replications
C1	1.352	0.1266	9
C2	1.337	0.1839	12
C3	1.372	0.2543	46
C4	1.332	0.1895	4
C5	1.298	0.1190	5

There is one homogeneous subset which is listed as follows:

(C5, C4, C2, C1, C3)

Table 37. ANALYSIS OF VARIANCE AND MULTIPLE RANGE TEST OF FOLIAR NITROGEN IN THE THIRD WHORL IN FIVE COLOR CLASSES

Analysis of Variance

	Sums of Square	D.F.	Mean Square	F-ratio
Between Groups	0.0186	4	0.0047	0.3112
Within Groups	1.0612	71	0.0149	
TOTAL	1.0798	75		

Treatment Means in Original Order

Class	Mean	Standard Deviation	Number of Replications
C1	1.282	0.0632	9
C2	1.275	0.1181	12
C3	1.255	0.1375	46
C4	1.217	0.0780	4
C5	1.234	0.0404	5

There is one homogeneous subset which is listed as follows:
(C4, C5, C3, C2, C1)

Table 38. ANALYSIS OF VARIANCE AND MULTIPLE RANGE TEST OF FOLIAR NITROGEN IN THE FIRST WHORL IN SIX NEEDLE RETENTION CLASSES

Analysis of Variance

	Sum of Square	D.F.	Mean Square	F-ratio
Between Groups	0.2290	5	0.0458	1.0772
Within Groups	7.6957	181	0.0425	
TOTAL	7.9247	186		

Treatment Means in Original Order

Class	Mean	Standard Deviation	Number of Replications
2 years	1.393	0.1620	3
3 years	1.361	0.3040	32
4 years	1.393	0.1731	105
5 years	1.393	0.2076	34
6 years	1.302	0.1621	10
7 years	1.170	0.0458	3

There is one homogeneous subset which is listed as follows:

(7 years, 6 years, 3 years, 5 years, 4 years, 2 years)

shows no significant difference in foliar nitrogen levels between the six classes, indicating no relationship between needle retention on the tree and foliar nitrogen in the first whorl. An examination of the mean values of foliar nitrogen in each class shows a remarkable uniformity except for class 6 (where the needles were retained for seven years) which had a lower value. There were only three of the 186 samples in this class.

Nitrogen in the third whorl and number of years needles were retained on the tree. Table (39) sets out the results of this test. The 2 year class and 7 year class are omitted in this examination as they each only contained three samples. Although the test reveals two homogeneous subsets of three classes each, there is insufficient evidence to conclude that any relationship exists between needle retention and foliar nitrogen in the third whorl. There is also no evidence of any trend in the means of nitrogen levels with the years of retention classes.

Stand site index and percent of bole carrying green branches. Table (40) sets out the results of this test. The site index of the stand is divided into six classes. The test shows no significant difference in percentage of green crown between the site classes, indicating no significant relationship of site index to percentage of bole with green branches. The mean values of percentage green crown in each of the 6 site classes fluctuate randomly within a narrow range.

Tree site and percentage of bole carrying green branches. Table (41) sets out the results of this test. Although the test shows two homogeneous subsets of tree site classes, each subset contains six of the seven

Table 39. ANALYSIS OF VARIANCE AND MULTIPLE RANGE TEST OF FOLIAR NITROGEN IN THE THIRD WHORL IN SIX NEEDLE RETENTION CLASSES

Analysis of Variance

	Sum of Square	D.F.	Mean Square	F-ratio
Between Groups	0.6782	5	0.1356	5.2290
Within Groups	4.6954	181	0.0259	
TOTAL	5.3736	186		

Treatment Means in Original Order

Class	Mean	Standard Deviation	Number of Replications
2 years	0.903	0.7827	3
3 years	1.254	0.1525	32
4 years	1.328	0.1327	105
5 years	1.305	0.1529	34
6 years	1.238	0.1066	10
7 years	1.217	0.1504	3

There are two homogeneous subsets which are listed as follows:

(7 years, 6 years, 5 years, 4 years)

(7 years, 6 years, 3 years, 5 years)

Table 40. ANALYSIS OF VARIANCE AND MULTIPLE RANGE TEST OF STAND SITE INDEX IN SIX GREEN BOLE PERCENTAGE CLASSES

Analysis of Variance

	Sum of Square	D.F.	Mean Square	F-ratio
Between Groups	1198.0508	5	239.6102	0.9575
Within Groups	44794.2891	179	250.2474	
TOTAL	45992.3394	184		

Treatment Means in Original Order

Class	Mean	Standard Deviation	Number of Replications
81-99	54.214	16.2378	7
100-109	62.145	13.9147	20
110-119	63.076	16.0226	41
120-129	61.497	16.5527	58
130-139	56.977	17.3157	43
140-150	59.981	8.3831	16

There is one homogeneous subset which is listed as follows:

(81-99, 130-139, 140-150, 120-129, 100-109, 110-119)

Table 41. ANALYSIS OF VARIANCE AND MULTIPLE RANGE TEST OF TREE SITE IN SEVEN GREEN BOLE PERCENTAGE CLASSES

Analysis of Variance

	Sum of Square	D.F.	Mean Square	F-ratio
Between Groups	2091.0358	6	348.5060	1.4130
Within Groups	43408.8101	176	246.6410	
TOTAL	45499.8457	182		

Treatment Means in Original Order

Class	Mean	Standard Deviations	Number of Replications
91-99	51.014	10.4409	7
100-109	57.941	12.8124	17
110-119	60.090	17.6464	41
120-129	58.865	15.3010	46
130-139	61.717	18.6371	40
140-149	67.900	10.9307	21
150-160	61.536	10.9588	11

There are two homogeneous subsets which are listed as follows:

(100-109, 120-129, 110-119, 150-160, 130-139, 140-149)

(91-99, 100-109, 120-129, 110-119, 150-160, 130-139)

classes so that there is no evidence of any relationship between tree site and percentage of the crown carrying green branches. The mean values of percentage green crown in each tree site class vary randomly within a narrow range.

Vigor Characteristics

Stand site index and number of needles per inch of shoot on first whorl. Table (42) sets out the results of this test. The test shows a significant difference in the number of needles per inch of shoot between the low, middle and high site classes indicating some direct relationship between site index and number of needles per inch. An examination of the means shows a consistent trend of decreasing needle number with increasing site index.

Tree site and number of needles per inch of shoot on first whorl. Table (43) sets out the results of this test. Here again there are three homogeneous subsets of data which are made up of the two smallest site classes, the next two classes, and the five highest classes, indicating a weak relationship between tree site and number of needles per inch of shoot.

However, there is a well established and consistent trend for the average number of needles per inch of shoot in each class to fall with rising tree site classes.

Stand site index and weight of 100 needles. Table (44) sets out the results of this test. There is no significant difference in the weight of 100 needles between the six site index classes so that there is no

Table 42. ANALYSIS OF VARIANCE AND MULTIPLE RANGE TEST OF STAND SITE INDEX IN SIX NEEDLES PER INCH OF SHOOT CLASSES

Analysis of Variance

	Sum of Squares	D.F.	Mean Square	F-ratio
Between Groups	1574.6164	5	314.9233	3.8057
Within Groups	14812.2708	179	82.7501	
TOTAL	16386.8870	184		

Treatment Means in Original Order

Class	Mean	Standard Deviation	Number of Replications
81-99	37.871	14.3847	7
100-109	31.550	9.9086	20
110-119	26.859	10.8812	41
120-129	28.641	7.6724	58
130-139	25.381	7.5806	43
140-150	23.806	8.9459	16

There are three homogeneous subsets which are listed as follows:

(140-150, 130-139, 110-119, 120-129)

(100-109, 81-99)

(110-119, 120-129, 100-109)

Table 43. ANALYSIS OF VARIANCE AND MULTIPLE RANGE TEST OF TREE SITE IN SEVEN NEEDLES PER INCH OF SHOOT CLASSES

Analysis of Variance

	Sum of Squares	D.F.	Mean Square	F-ratio
Between Groups	2024.9062	6	337.4844	4.1392
Within Groups	14349.9432	176	81.5338	
TOTAL	16374.8494	182		

Treatment Means in Original Order

Class	Mean	Standard Deviation	Number of Replications
91-99	38.943	7.3952	7
100-109	33.276	11.9954	17
110-119	28.241	10.1953	41
120-129	27.752	7.9709	46
130-139	26.400	8.1151	40
140-149	23.619	6.2834	21
150-160	23.618	11.5961	11

There are three homogeneous subsets which are listed as follows:

(150-160, 140-149, 130-139, 120-129, 110-119)

(100-109, 91-99)

(110-119, 100-109)

Table 44. ANALYSIS OF VARIANCE AND MULTIPLE RANGE TEST OF STAND SITE INDEX IN SIX NEEDLE WEIGHT CLASSES

Analysis of Variance

	Sum of Square	D.F.	Mean Square	F-ratio
Between Groups	0.0814	5	0.0163	0.6519
Within Groups	4.4689	179	0.0250	
TOTAL	4.5503	184		

Treatment Means in Original Order

Class	Mean	Standard Deviation	Number of Replications
81-99	0.535	0.0697	7
100-109	0.551	0.1091	20
110-119	0.587	0.1684	41
120-129	0.597	0.1536	58
130-139	0.610	0.1526	43
140-150	0.614	0.2245	16

There is one homogeneous subset which is listed as follows:
(81-99, 100-109, 110-119, 120-129, 130-139, 140-150)

significant relationship between the two. However, there is a distinct and constant trend in the average values of needle weight in the classes showing a progressive increase in needle weight with increasing site index class.

Tree site and weight of 100 needles. Table (45) sets out the result of this test. The test shows that there is a significant difference in the needle weights of three groups of tree site classes which approximate the four lowest, the four middle, and the three highest tree site classes indicating that a relationship exists between tree site and needle weight. There is a general trend of rising average needle weights in each tree site class with increasing tree site.

Table 45. ANALYSIS OF VARIANCE AND MULTIPLE RANGE TEST OF TREE SITE IN SEVEN NEEDLE WEIGHT CLASSES

Analysis of Variance

	Sum of Square	D.F.	Mean Square	F-ratio
Between Groups	0.4306	6	0.0718	3-0487
Within Groups	4.1432	176	0.0235	
TOTAL	4.5738	182		

Treatment Means in Original Order

Class	Mean	Standard Deviation	Number of Replications
91-99	0.470	0.0872	7
100-109	0.568	0.1062	17
110-119	0.543	0.1633	41
120-129	0.589	0.1470	46
130-139	0.615	0.1544	40
140-149	0.688	0.1470	21
150-160	0.572	0.2273	11

There are three homogeneous subsets which are listed as follows:

(110-119, 100-109, 150-160, 120-129, 130-139)

(91-99, 110-119, 100-109, 150-160, 120-129)

(150-160, 130-139, 140-149)

APPENDIX 3

Table 46. MULTIPLE REGRESSIONS OF FOLIAR NITROGEN AGAINST FOLIAR PHOSPHORUS, POTASSIUM, CALCIUM AND MAGNESIUM

Dependent Variable (%)	Independent Variables (%)	Multiple R-Squared	F to Remove
	FIRST WHORL		
Nitrogen in First Whorl	Calcium	0.0505	0.4791
	Potassium	0.0863	0.3129
	Phosphorus	0.0889	0.0205
	SECOND WHORL		
Nitrogen in Second Whorl	Phosphorus	0.1384	1.6062
	Calcium	0.1557	0.1841
	Potassium	0.1583	0.0252
	THIRD WHORL		
Nitrogen in Third Whorl	Phosphorus	0.0828	0.9033
	Potassium	0.2698	2.3053

Table 47. CONVERSION FACTORS

Acre	0.404 686	hectares
	4046.86	square inches
Centimetre	0.393 701	inches
Chain (66 feet)	20.116 8	metres (exactly)
Cord (128 stacked cubic feet)	3.624 56	stacked cubic metres
Cubic metre	27.736 1	hoppus feet
	35.314 7	cubic feet
	1.307 95	cubic yards
Cubic metre per hectare	11.224 4	hoppus feet per acre
Cubic yards	0.764 555	cubic metres
Foot	0.304 8	metres (exactly)
Gallon	4.546 09	litres (cubic decimetres)
Hectare	2.471 05	acres
Hundredweight	0.050 802 3	tonnes
Hundredweight per acre	125.535	kilogrammes per hectare
Inch	0.025 4	metres (exactly)
Kilogramme	2.204 62	pounds
Kilometre	0.621 371	miles
Litre (cubic decimetre)	0.219 969	gallons
	1.759 76	pints
Metre	1.093 61	yards
	3.280 84	feet
Mile (statute)	1.609 34	kilometres
Pint	0.568 261	litres (cubic decimetres)
Pound	0.453 592	kilogrammes
Pound per acre	1.130 85	kilogrammes per hectare
Pound per cubic foot	16.018 5	kilogrammes per cubic metre
Square chain	404.686	square metres
Square foot	0.092 903 0	square metres
Square inch	6.451 6	square centimetres
Square metre	1.195 99	square yards
Square yard	0.836 127	square metres
Ton (United Kingdom)	1.016 05	tonnes
Tonne	0.984 207	tons (United Kingdom)
Yard	0.914 4	metres (exactly)

Table 48. FORMULAE FOR CONVERSION OF DRY WEIGHT OF NEEDLES TO FRESH WEIGHT

1. Current Foliage from First Whorl

Green weight of needles	25.20 grams
Dry weight of needles	9.80 grams
Moisture content	15.40 grams

Moisture content of green foliage (%) $\frac{15.40}{25.20} \times 100 = 61.1\%$

$$\text{Green Weight} = \frac{\text{Dry Weight}}{39.8\%}$$

2. One-Year-Old Foliage from Third Whorl

Green weight of needles	19.80 grams
Dry weight of needles	8.50 grams
Moisture content	11.30 grams

Moisture content of green foliage (%) $\frac{11.30}{19.80} \times 100 = 57.0\%$

$$\text{Green Weight} = \frac{\text{Dry Weight}}{43\%}$$

Table 49. PHOTOSYNTHETIC AREA OF DOUGLAS-FIR NEEDLES[1]

1. Dimensions of Current Foliage from First Whorl Measured Green

Needle No.	Sample 1 (Inches) Width	Depth	Length	Sample 2 Width	Depth	Length
1.	0.055	0.030	1.55*	0.055	0.020	1.15
2.	0.065*	0.035*	1.35	0.055	0.025	0.90#
3.	0.065	0.025	1.45	0.055	0.020	1.10
4.	0.060	0.025	1.50	0.060	0.025	0.95
5.	0.055	0.025	1.45	0.060	0.025	0.95
6.	0.060	0.025	1.55	0.050#	0.020#	1.10
Total Sample	0.360	0.165	8.85	0.335	0.135	6.15

	Width	Depth	Length
Average	0.058	0.025	1.25

2. Dimensions of One-Year-Old Foliage from Third Whorl Measured Green

Needle No.	Sample 1 (Inches) Width	Depth	Length	Sample 2 Width	Depth	Length
1.	0.050	0.020	0.95	0.055	0.020	1.05
2.	0.065*	0.020*	1.35*	0.050	0.015	1.10
3.	0.050	0.105#	0.90	0.045	0.015	0.80#
4.	0.045#	0.015	0.90	0.050	0.015	1.10
5.	0.050	0.020	1.20	0.050	0.020	0.95
6.	0.050	0.020	1.15	0.045	0.015	0.90
Total Sample	0.310	0.110	6.40	0.295	0.100	5.95

	Width	Depth	Length
Average	0.050	0.017	1.03

*Highest value

#Lowest value

[1] The photosynthetic area of a needle is the area of the top surface of the needle so that in *current foliage* the average area equals *0.072 square inches* with a maximum of *0.100 square inches* and a minimum of *0.045 square inches*. In one-year-old foliage the average equals *0.005 square inches* with a maximum of *0.087 square inches* and a minimum of *0.036 square inches*.

Table 50. ABBREVIATIONS

Age	= total age of tree in years
DBH	= diameter breast height in inches
GrnCrn	= percentage of green crown on the bole
Ht	= total height of tree in feet
HtCrt	= amount of height growth of the tree in the current year, in feet
Ht5	= amount of height growth of the tree in the last 5 years, in feet
Ht10	= amount of height growth of the tree in the last 10 years, in feet
NdlYrs	= number of years needles are retained on the tree
Ne-In	= number of needles per inch of shoot
Rad5	= radial growth of the tree in the last 5 years, in inches
Rad10	= radial growth of tree in the last 10 years, in inches
SitS	= site index of the stand (100 year index)
SitT	= site index of the sample tree (100 year index)
Stock	= stocking (basal area per acre in square feet)
Wt	= weight of 100 oven-dried needles in grams
Pct N1	= foliar nitrogen in the first whorl (%)
Pct N3	= foliar nitrogen in the third whorl (%)
Diam5	= diameter growth of the tree in the last 5 years, in inches
Diam10	= diameter growth of the tree in the last 10 years, in inches

Table 51. MEANS AND STANDARD DEVIATIONS OF TREE AND STAND CHARACTERISTICS (188 samples)

	Mean	Standard Deviation
Ht. (Feet)	74.4	12.0
D.B.H. (Inches)	10.8	2.35
Stock (B/A Sq. Ft. Per Acre)	119.7	33.98
Site T. (Site Index Bull. 201)	124.0	16.0
Age (Years)	40.7	6.13
Ne/In.	27.9	9.50
Wt. (Grams)	0.60	0.15
Ndl. Yrs.	4.11	0.92
Grn. Crn. (Percentage of Bole)	60.4	15.7
Pct. N1 (%)	1.38	0.20
Pct. N3 (%)	1.30	0.17
Rad. 5 (Inches)	0.35	0.37
Rad. 10 (Inches)	0.69	0.73
Ht. Crt. (Feet)	1.84	0.64
Site S. (Site Index)	122.0	13.0
Ht. 10 (Feet)	17.28	5.84
Ht. 5 (Feet)	9.15	2.99

Table 52. MEANS AND STANDARD DEVIATION OF TREE AND STAND CHARACTERISTICS (94 representative samples)

	Mean	Standard Deviation
Ht. (Feet)	74.1	12.15
D.B.H. (Inches)	10.6	2.33
Stock (B/A Sq. Ft. Per Acre)	124.0	35.93
Site T. (Site Index Bull. 201)	122.0	16.0
Age (Years)	41.4	6.12
Ne/In.	28.6	9.9
Wt. (Grams)	0.574	0.158
Ndl. Yrs.	4.2	0.96
Grn. Crn. (Percentage of Bole)	58.0	15.5
Pct. N1 (%)	1.37	0.19
Pct. N3 (%)	1.30	0.15
Rad. 5 (Inches)	0.34	0.37
Rad. 10 (Inches)	0.66	0.74
Crt. Ht. (Feet)	1.68	0.54
Ht. 5 (Feet)	8.65	2.91
Ht. 10 (Feet)	16.33	5.9
Site S. (Site Index)	120.0	14.67

Table 53. MEANS AND STANDARD DEVIATIONS OF TREE AND STAND CHARACTERISTICS (94 random samples)

	Mean	Standard Deviation
Ht. (Feet)	74.8	11.0
D.B.H. (Inches)	11.1	2.35
Stock (B/A Sq. Ft. Per Acre)	115.1	31.4
Site T. (Site Index Bull 201)	127.0	15.0
Age (Years)	40.1	6.10
Ne/In.	27.2	9.0
Wt. (Grams)	0.604	0.15
Ndl. Yrs.	4.05	0.88
Grn. Crn. (Percentage of Bole)	62.9	15.5
Pct. N1 (%)	1.39	0.21
Pct. N3 (%)	1.30	0.18
Rad. 5 (Inches)	0.36	0.37
Rad. 10 (Inches)	0.71	0.72
Ht. Crt. (Feet)	2.0	0.70
Ht. 5 (Feet)	9.6	3.01
Ht. 10 (Feet)	18.24	5.65
Site S. (Site Index)	120.0	21.0

Table 54. DATA AND NITROGEN CONTENT OF TREES SELECTED TO REPRESENT THE STAND

						Needles		
Height (Ft.)	DBH (In.)	Stocking (Sq. Ft. B.A./Ac.)	Site (Tree)	Age (Yrs.)	Color Class	per Inch	Weight of 100 (grms)	Years
72.2	11.2	80	120	40		26.4	.445	5
65.6	9.0	100	106	42		32.3	.489	4
66.2	9.3	90	110	40		18.4	.585	5
70.6	7.9	120	126	37		33.3	.523	5
66.5	8.6	140	114	39	3	26.2	.694	3
65.7	8.7	140	112	39	5	26.2	.554	3
66.8	9.1	140	114	39	3	24.1	.598	4
51.0	5.6	120	87	39		40.4	.450	3
60.9	8.1	110	98	42		40.2	.394	6
58.9	7.8	105	100	39	5	33.2	.565	3
62.2	8.5	120	109	38	3	23.2	.609	3
65.6	9.2	115	109	40	4	33.5	.540	6
74.0	9.1	110	126	39	3	25.9	.587	4
73.2	9.3	110	116	43	3	29.5	.509	4
72.3	8.8	170	120	40	2	30.9	.739	5
83.0	10.1	150	136	41	3	24.9	.788	5
71.0	9.3	140	118	40	3	35.2	.535	7
73.4	9.0	140	118	42	3			4
65.0	9.8	95	116	37	3	29.8	.526	3
55.4	7.7	105	92	40	3	41.4	.524	4
100.0	13.7	205	147	48	2	29.2	.471	4
87.3	11.7	175	134	45	2	30.1	.536	3
82.2	9.7	170	123	47	3	33.2	.456	4
89.9	12.9	190	130	49	3	27.1	.604	4
82.8	10.7	145	129	44	3	24.4	.578	3
76.7	9.3	175	114	47	3	45.5	.446	4
85.3	11.4	145	129	46	4	23.1	.552	4
84.0	12.0	160	136	42	3	17.5	.681	3
101.4	14.7	160	145	50	3	34.3	.658	3
75.8	10.8	140	124	41	1	21.8	.714	4
77.7	11.6	170	125	42	3	31.5	.565	6
80.1	11.5	130	129	42	4	31.1	.585	5
85.4	13.3	135	136	43	3	22.9	.669	3
80.3	12.9	120	137	39	1	32.6	.630	5
93.5	13.8	115	156	40	2	21.2	.597	4
80.3	10.4	105	134	40	2	28.7	.457	5
89.4	12.2	150	146	41	2	33.7	.384	4
87.7	13.1	120	157	37	3	35.4	.591	4
67.9	9.1	150	131	34	3	33.8	.584	3
83.2	10.9	150	136	41	3	15.9	.620	4
65.6	7.2	155	106	42	3	17.5	.647	5
77.5	10.1	130	125	42	3	24.7	.404	6
72.4	10.5	170	100	53	3	44.5	.591	3

Table 54

Green Crown (%)	First Whorl N%	Third Whorl N%	Radial Growth 5 yrs. (In.)	Radial Growth 10 yrs. (In.)	Height Growth Current Year (Ft.)	Height Growth 5 Years (Ft.)	Height Growth 10 Years (Ft.)	Site-Index (Stand) (Bull. 201)
86.3	1.43	1.14			1.5	9.9	19.1	120
77.0	1.30	1.10			1.5	10.6	17.0	100
88.5	1.31	1.07			1.1	6.0	11.2	104
76.3	1.38	1.17	*Not measured*		1.8	10.8	20.5	123
49.9	1.62	1.38	*in first 88*		2.0	12.2	16.1	111
45.4	1.23	1.23	*samples taken.*		1.3	9.4	15.9	111
54.9	1.31	1.16			1.2	8.5	13.2	111
58.0	1.16	1.16			1.3	4.9	8.4	86
55.3	1.03	1.10			1.0	3.9	7.8	101
53.1	1.31	1.27			1.6	6.9	11.4	106
54.3	1.37	1.14			1.1	7.2	12.7	108
49.5	1.29	1.21			1.0	4.1	10.9	131
67.6	1.48	1.10			2.0	9.6	16.1	121
53.7	1.44	1.37			1.7	8.1	13.0	121
59.9	1.24	1.40			1.0	5.7	11.5	122
67.0	1.51	1.38			2.0	10.2	19.0	138
61.1	1.21	1.06			1.4	9.7	13.8	124
59.0	1.59	1.55			1.7	8.0	12.3	124
74.6	1.47	1.30			1.6	8.5	14.0	119
60.5	1.18	1.02			1.7	5.2	7.4	88
41.7	1.14	1.17			1.7	8.4	14.3	141
52.8	.97	1.21			1.2	5.7	10.3	139
48.8	1.25	1.12			1.2	6.6	15.1	124
56.7	1.48	1.12			1.9	8.0	13.7	134
52.3	1.29	1.28			1.2	8.1	16.1	131
30.2	1.12	1.08			1.0	5.0	9.6	111
61.9	1.19	1.23			1.8	8.6	15.4	129
63.1	1.32	1.18			1.1	9.0	19.2	140
55.4	1.45	1.41			1.8	9.8	18.3	140
58.2	1.33	1.34			1.7	8.3	15.1	118
49.5	1.21	1.18			1.2	7.7	13.7	122
53.2	1.24	1.12			1.8	8.9	13.8	129
	1.40	1.25			2.0	10.2	17.9	134
59.3	1.21	1.18			1.4	7.2	12.3	139
68.8	1.65	1.35			2.1	11.8	25.4	150
50.9	1.46	1.24			1.3	9.0	16.1	137
50.4	1.45	1.40			1.7	8.9	17.1	141
68.5	1.65	1.38			1.5	10.7	19.9	142
62.4	1.53	1.20			1.9	11.9	21.6	137
56.3	1.49	1.43			1.8	10.3	23.3	137
42.4	1.30	1.29			1.3	7.5	11.5	103
44.6	1.29	1.21			1.0	7.3	13.5	131
51.1	1.47	.93			1.2	5.0	8.9	105

Table 54 (cont.)

Height (Ft.)	DBH (In.)	Stocking (Sq. Ft. B.A./Ac.)	Site (Tree)	Age (Yrs.)	Color Class	Needles per Inch	Needles Weight of 100 (grms)	Needles Years
75.6		170	100	49	2	54.9	.394	6
73.0	9.5	170	103	51	3	23.9	.737	7
72.1	12.0	60	132	36		13.5	.736	4
65.5	10.8	105	102	44		63.7	.474	5
54.9	9.7	105	125	29				5
68.4	9.7	90	136	33		18.8	.696	4
62.1	11.0	90	127	32		25.7	.717	5
70.4	10.9	90	145	32		20.7	.909	3
63.2	12.3	90	116	36				4
63.2	8.5	95	123	34		27.0	.746	2
58.7	9.6	70	114	34		20.5	.588	4
63.5	10.2	70	123	34		29.6	.688	4
84.0	10.7	115	129	45		31.5	.514	4
72.0	11.5	95	126	38		38.4	.594	3
76.1	12.7	110	123	42		31.1	.625	5
92.3	15.7	120	149	41		24.1	.733	4
59.2	10.8	80	122	32		24.9	.693	4
79.9	11.1	90	163	32		29.2	.755	4
99.0	15.2	130	162	41		19.0	.772	5
70.8	10.8	95	130	36		18.1	.807	4
63.5	11.5	85	117	36		23.0	.729	4
61.8	10.8	70	117	35		22.2	.740	4
56.2	9.1	75	122	30		21.5	.584	4
72.2	9.2	130	111	45		30.3	.459	4
62.2	10.8	90	102	41		35.8	.546	4
81.7	11.9	85	132	42		22.4	.561	4
69.8	10.7	100	132	35		30.6	.523	4
51.7	9.1	70	107	32		22.3	.596	4
65.0	10.5	75	129	33		22.8	.779	4
89.7	14.1	130	142	43		17.0	.890	5
72.7	9.6	105	137	35		26.9	.569	4
58.1	10.4	70	113	34		24.1	.822	4
63.5	9.8	60	114	37		24.9	.696	5
76.9	12.1	100	128	40		20.4	.586	4
70.2	8.3	130	113	42		34.7	.463	4
80.0	10.2	110	123	45		24.2	.609	4
89.5	12.8	155	127	51		34.2	.467	4
88.8	14.0	120	129	49		41.4	.790	2
81.2	11.2	150	125	45		46.5	.473	4
81.0	10.0	180	112	53		38.5	.510	3
95.4	14.9	140	131	54		25.8	.579	4
93.2	14.9	140	130	52		31.6	.743	4
88.7	11.8	190	120	55		39.2	.522	5
81.0	12.2	200	113	52		35.3	.577	4

Table 54

Green Crown (%)	First Whorl N%	Third Whorl N%	Radial Growth 5 Yrs. (In.)	Radial Growth 10 Yrs. (In.)	Height Growth Current Year (Ft.)	Height Growth 5 Years (Ft.)	Height Growth 10 Years (Ft.)	Site-Index (Stand) (Bull. 201)
54.9	1.18	1.16			1.4	3.9	7.9	105
44.1	1.18	1.23			1.0	3.3	5.3	105
76.6	1.78	1.53	.8	1.5	2.5	13.5	22.3	118
39.7	.97	1.00	.4	.7	.7	2.2	5.5	99
76.6	1.81	1.43	.8	1.6	1.9	13.6	25.0	115
74.3	1.66	1.55	.7	1.3	1.8	12.0	24.4	114
82.6	1.84	1.60	1.0	1.9	2.4	13.5	25.1	121
63.9	1.80	1.68	1.0	2.2	3.4	15.3	31.9	140
86.7	1.05	1.27	.8	1.5	1.3	7.2	15.7	114
74.5	1.58	1.38	.8	1.6	2.5	11.5	26.3	123
79.2	1.28	1.26	1.0	1.9	2.0	9.8	23.4	118
61.1	1.45	1.45	1.0	1.9	2.4	12.5	23.6	124
59.9	1.69	1.70	.5	.8	1.6	8.5	16.1	131
58.1	1.23	1.19	.5	.9	1.4	7.3	15.4	130
55.3	1.35	1.51	.8	1.5	1.9	8.0	13.5	128
70.9	1.31	1.40	.9	1.8	2.6	10.3	20.7	142
75.8	1.39	1.26	1.0	1.9	2.5	10.3	20.5	118
68.6	1.33	1.30	.7	1.2	2.2	9.7	21.0	141
54.2	1.71	1.39	1.0	1.7	2.7	13.7	26.6	143
76.3	1.71	1.53	.6	1.7	1.5	9.6	21.8	132
82.7	1.49	1.15	1.1	2.1	.7	10.7	22.1	121
78.2	1.58	1.36	1.0	2.0	2.8	16.0	31.6	113
78.3	1.56	1.33	.9	1.8	2.2	11.8	25.4	122
40.2	1.22	1.20	.3	.6	1.4	6.4	12.0	110
62.9	1.59	1.45	.4	.9	1.6	8.9	17.2	106
78.5	1.27	1.24	.6	1.0	2.6	10.6	20.5	130
64.5	1.48	1.48	.8	1.5	2.2	12.4	22.8	135
77.8	1.50	1.50	.8	2.0	2.9	14.3	27.1	125
79.4	1.50	1.50	.8	2.0	2.9	14.3	27.1	125
55.7	1.39	1.54	.7	1.4	1.0	5.7	16.3	136
68.1	1.40	1.43	.6	1.4	2.0	12.3	24.3	133
79.9	1.61	1.22	.8	1.7	2.3	13.5	23.3	105
64.7	1.68	1.32	.7	1.4	2.6	11.7	20.5	113
67.9	1.58	1.36	.9	1.7	2.6	11.7	22.9	122
38.0	1.17	1.23	.7	1.1	1.6	7.7	13.3	118
45.0	1.17	1.39	.8	1.3	2.2	10.1	17.6	117
39.1	1.16	1.43	.4	.7	1.1	6.2	12.8	129
36.1	1.29	1.33	.4	1.0	1.1	5.5	11.3	126
39.2	1.14	1.28	.4	.8	1.0	5.6	9.7	115
49.8	1.31	1.53	.4	.7	1.4	7.0	12.9	113
48.2	1.42	1.46	.4	1.1	2.2	8.6	14.6	133
34.1	1.24	1.60	.6	1.5	2.4	7.8	13.7	130
31.6	1.41	1.23	.2	.3	1.7	7.6	11.8	122
47.5	1.20	1.34	.3	.6	1.5	5.3	9.8	119

Table 54 (cont.)

Height (Ft.)	DBH (In.)	Stocking (Sq. Ft. B.A./Ac.)	Site (Tree)	Age (Yrs.)	Color Class	Needles per Inch	Needles Weight of 100 (grms)	Needles Years
88.4	11.8	170	124	52		42.6	.355	7
81.8	11.5	180	122	47		39.0	.526	4
89.2	14.5	170	121	55		30.3	.493	4
85.4	12.9	200	122	50		30.4	.315	4
53.7	7.8	90	80	48		30.7	.615	4
49.1	7.4	90	77	44		44.6	.495	4
55.2	6.1	110	91	40		31.9	.503	4

Table 54

Green Crown (%)	First Whorl N%	Third Whorl N%	Radial Growth 5 Yrs. (In.)	Radial Growth 10 Yrs. (In.)	Height Growth Current Year (Ft.)	Height Growth 5 Years (Ft.)	Height Growth 10 Years (Ft.)	Site-Index (Stand) (Bull. 201)
44.1	1.12	1.36	.4	.7	1.4	4.9	9.4	122
47.7	1.17	1.34	.3	.8	1.9	5.9	11.8	119
40.0	1.23	1.29	.3	.5	1.2	6.2	11.9	122
38.3	1.23	1.24	.4	.8	1.1	5.0	9.4	126
40.8	1.14	1.20	.3	.5	1.2	5.4	8.1	81
58.0	1.22	1.22	.5	.7	1.4	4.3	7.7	76
35.5	1.37	1.43	.3	.5	1.5	5.3	12.1	89

Table 55. DATA AND NITROGEN CONTENT OF RANDOMLY SELECTED TREES

Height (Ft.)	DBH (In.)	Stocking (Sq. Ft. B.A./Ac.)	Site (Tree)	Age (Yrs.)	Color Class	Needles per Inch	Needles Weight of 100 (Grms)	Needles Years
63.8	9.0	120	112	38		31.4	.445	4
61.8	7.9	140	101	41		46.0	.379	4
60.8	7.7	125	100	41		40.6	.539	5
65.9	9.6	110	110	40	3	37.6	.479	3
65.6	9.9	110	112	39	3	35.1	.511	4
69.0	10.1	110	113	41	1	32.2	.454	4
61.6	7.3	150	103	40		32.8	.622	6
50.0	8.7	70	147	36	4	16.4	.638	3
58.3	8.4	125	94	42	5	39.2	.561	5
81.3	14.1	110	136	40	1	27.5	.745	5
80.7	10.2	110	130	42	3	37.8	.671	6
63.6		140	99	44	3	30.1	.331	3
78.8	9.8	160	129	41	2	20.9	.798	4
95.0	12.8	180	151	43	1	31.7	.851	5
88.2	13.9	160	130	48	3	24.5	.579	3
90.3	12.3	160	131	49	3			3
68.5	11.4	100	123	37	3	17.3	.652	4
72.0	9.8	130	140	34	3	21.0	.666	3
72.1	10.7	125	118	41	1	27.4	.598	4
88.8	14.7	150	143	42	3	24.6	.861	5
75.7	11.4	135	147	34	3	19.8	.762	4
69.3	10.8	90	121	38	2	29.2	.643	4
92.8	13.4	120	152	41	3	43.4	.523	5
90.3	11.5	135	146	42	1	15.8	.982	6
86.8	13.4	135	142	41	3	34.3	.569	4
79.9	10.6	135	123	45	3	29.4	.617	4
90.8	13.3	135	151	40	3	16.5	.848	5
91.0	11.3	125	155	39	3	32.1	.457	5
54.6	7.4	100	144	26	3	20.8	.779	4
49.7	7.7	75	138	25	5	31.4	.612	3
53.5	7.6	65	141	26	3	22.4	.668	3
80.5	12.2	150	152	35	1	17.9	.553	3
77.4	10.4	130	132	39	2	27.5	.463	4
64.8	13.3	115	108	40		42.9	.329	4
95.5	12.8	130	156	41	3			3
75.5	12.3	115	132	38	3	30.2	.401	5
75.0	9.9	140	117	44	5	33.1	.408	3
76.4	10.2	150	124	42	3	17.9	.744	3
78.1	10.1	150	124	43	2	26.7	.563	3
78.3	9.7	130	130	40	3	25.4	.458	4
69.6	9.1	155	109	44	2	18.9	.630	3
77.3	10.3	175	99	48	1	52.7	.551	6
64.0	8.8	170	91	50	6	37.1	.429	3
78.3	11.2	70	152	34		21.3	.572	4
56.2	8.7	130	106	35		34.3	.680	4
77.3	12.5	65	142	36		20.5	.631	5
70.8	12.4	70	141	33		27:8	.566	4
75.1	11.1	105	125	40		29.0	.554	4

Table 55

Green Crown (%)	First Whorl N%	Third Whorl N%	Radial Growth 5 Yrs. (In.)	Radial Growth 10 Yrs. (In.)	Height Growth Current Year (Ft.)	Height Growth 5 Years (Ft.)	Height Growth 10 Years (Ft.)	Site-Index (Stand) (Bull. 201)
77.3	1.40	1.05	*Not measured in first 88 samples taken.*		1.8	9.3	17.6	102
66.2	1.26	1.29			1.7	6.4	10.6	111
64.8	1.16	1.06			1.5	6.8	10.6	87
60.5	1.25	1.22			.9	4.4	9.3	101
69.1	1.49	1.32			1.3	5.0	9.0	101
59.6	1.34	1.34			1.0	5.3	9.8	101
72.9	1.32	1.16			1.3	10.0	15.3	113
80.2	1.61	1.31			2.4	12.6	22.0	94
42.2	1.21	1.28			1.2	3.9	6.5	106
67.3	1.31	1.32			1.0	10.7	16.3	121
75.2	1.45	1.33			2.1	9.8	16.9	121
47.2	1.71	1.19			1.3	5.9	11.7	124
52.0	1.40	1.27			2.0	11.4	21.2	114
59.2	1.25	1.19			2.2	11.2	17.7	120
55.6	1.32	1.16			1.6	9.1	17.2	140
59.1		.98			.9	6.3	13.3	140
72.3	1.27	1.21			1.0	7.3	17.5	116
72.1	1.52	1.28			2.4	12.3	24.3	121
51.0	1.59	1.31			1.8	5.2	11.3	130
62.9	1.68	1.20			2.3	12.4	21.6	134
63.9	1.36	1.34			3.4	12.7	23.5	133
78.5	1.27	1.30			1.1	8.1	14.2	135
48.7	1.39	1.53			1.2	11.3	22.0	132
70.7	1.34	1.33			1.7	8.6	17.3	134
69.6	1.31	1.48			1.9	10.1	20.0	134
57.4	1.25	1.34			1.8	7.8	16.5	134
65.6	1.15	1.19			1.5	9.3	19.4	144
46.4	1.34	1.24			1.5	10.1	21.1	134
82.6	1.53	1.24			3.2	15.3	27.4	121
78.1	1.50	1.19			1.9	13.0	26.7	117
79.1	1.60	1.25			2.9	12.6	26.0	114
57.6	1.53	1.29			2.3	12.6	27.0	134
66.3	1.43	1.08			1.8	8.6	13.2	139
62.8	1.30	1.23			.7	3.2	9.4	
44.9	1.50	1.31			2.2	10.7	20.5	136
58.9	1.30	1.36			3.5	12.8	22.8	
51.3	1.24	1.20			1.0	6.5	11.4	141
53.3	1.54	1.46			2.2	9.8	19.4	137
67.9	1.37	1.49			1.6	9.1	20.6	137
70.6	1.53	1.35			2.0	11.8	23.4	138
36.5	1.48	1.23			1.0	6.1	11.0	132
50.8	1.27	1.24			1.2	6.1	11.1	112
65.6	1.17	.98			.6	4.0	7.0	105
75.0	1.51	1.26	.9	1.8	3.1	14.7	30.9	123
63.7	1.57	1.39	.6	1.0	2.6	8.8	19.9	118
76.3	1.55	1.30	.8	1.8	3.1	13.9	24.3	131
81.1	1.26	1.31	1.0	2.0	2.4	12.5	26.1	118
66.0	1.35	1.55	.6	1.1	1.8	9.2	17.2	122

Table 55 (cont.)

Height (Ft.)	DBH (In.)	Stocking (Sq. Ft. B.A./Ac.)	Site (Tree)	Age (Yrs.)	Color Class	Needles per Inch	Needles Weight of 100 (Grms)	Needles Years
64.1	9.2	85	124	34		24.0	.657	4
57.2	11.3	90	111	34		36.0	.452	4
65.1	11.2	100	133	32		42.5	.640	4
70.0	9.7	85	129	36		16.9	.760	4
77.4	10.2	90	158	32		19.5	.706	4
81.8	12.0	90	134	41		32.3	.809	4
85.9	13.0	105	147	39		28.3	.585	5
68.2	12.6	110	114	40		31.1	.787	4
53.6	9.6	55	127	28		22.2	.780	4
62.9	9.3	70	133	31		25.5	.792	4
64.7	12.1	60	119	36		21.3	.595	4
70.5	10.5	120	112	43		22.7	.613	4
76.8	11.5	90	116	46		34.9	.453	4
61.8	9.4	85	114	36		23.1	.670	5
69.8	10.2	110	116	40		33.3	.657	5
62.4	10.4	115	112	37		17.7	.630	4
55.0	9.5	85	101	36		20.3	.684	4
85.9	15.3	90	141	41		17.5	.649	4
74.1	11.2	105	133	37		21.2	.680	4
77.3	10.1	95	132	39		23.1	.621	4
59.4	11.5	75	119	33		15.6	.620	4
76.2	11.1	115	130	39		21.7	.845	4
85.2	12.7	80	140	41		20.0	.796	4
68.2	10.0	75	126	36		21.5	.738	4
75.2	10.8	90	131	38		22.9	.794	4
76.5	13.3	60	131	39		39.4	.557	4
80.6	13.1	60	134	40		35.7	.730	4
90.9	13.0	140	138	46		21.3	.667	4
77.6	13.0	130	119	45		42.6	.470	5
65.1	11.4	100	111	39		30.3	.572	3
70.2	11.0	85	113	42		30.8	.700	
86.1	14.6	100	144	40		15.8	.671	4
75.9	12.7	110	130	39		18.0	.723	5
70.6	11.3	110	127	37		26.3	.490	4
101.8	20.4	140	121	69		28.0	.668	4
70.8	10.1	110	116	41		25.9	.523	4
73.3	10.0	130	118	42		19.3	.688	5
76.3	12.8	90	121	43		23.9	.591	2
94.1	14.1	120	143	46		32.0	.588	4
98.0	14.5	100	161	41		20.8	.592	4
82.2	10.8	150	121	48		36.4	.626	4
93.8	11.0	180	138	48		29.7	.638	5
86.4	11.3	180	117	55		33.2	.509	4
91.0	11.3	175	132	49		21.3	.571	6
92.8	14.2	130	134	49		37.2	.437	4
88.0	12.9	170	131	47		38.7	.384	4

Table 55

Green Crown (%)	First Whorl N%	Third Whorl N%	Radial Growth 5 Yrs. (In.)	Radial Growth 10 Yrs. (In.)	Height Growth Current Year (Ft.)	Height Growth 5 Years (Ft.)	Height Growth 10 Years (Ft.)	Site-Index (Stand) (Bull. 201)
66.5	1.39	1.40	.6	1.3	2.0	11.6	21.6	114
66.3	1.61	1.30	.8	1.7	2.6	11.6	20.2	121
76.0	1.40	1.49	.8	1.5	2.3	10.5	20.9	117
51.3	1.41	1.56	.7	1.4	1.0	8.9	19.6	122
74.8	1.42	1.39	.7	1.6	3.0	14.5	28.7	122
76.3	1.34	1.20	.6	1.2	2.1	10.4	19.3	125
80.2	1.28	1.21	.6	1.1	2.0	9.0	18.0	127
64.4	1.14	1.23	.6	1.2	1.5	8.6	14.7	122
81.9	1.59	1.31	1.2	2.3	3.3	15.2	30.2	117
79.5	1.66	1.45	1.1	2.1	2.9	15.5	28.1	116
81.0	1.47	1.21	1.1	2.2	3.3	10.6	19.2	108
63.4	1.61	1.49	.5	.8	1.9	8.4	15.6	132
52.1	1.24	1.25	.3	.6	.9	3.0	7.6	124
73.0	1.48	1.49	.7	1.3	2.7	11.0	18.2	137
67.9	1.51	1.40	1.0	1.3	1.9	9.1	16.3	127
76.6	1.73	1.33	.8	1.4	3.4	15.2	23.4	120
66.2	1.31	1.30	.6	1.2	2.0	10.1	19.8	122
66.7	1.34	1.14	1.1	1.7	3.0	12.2	20.3	134
80.2	1.37	1.23	.7	1.4	2.1	13.7	20.5	119
65.3	1.43	1.39	.7	1.3	3.0	13.5	25.3	124
74.6	1.54	1.58	1.1	2.2	3.0	12.9	22.8	109
55.2	1.48	1.35	.4	1.0	1.8	9.5	17.1	142
65.1	1.50	1.36	.7	1.3	3.1	12.5	26.7	123
70.1	1.42	1.26	.6	1.1	2.3	8.6	15.9	118
74.6	1.76	1.49	.6	1.1	2.0	11.2	19.6	123
83.0	1.13	1.26	.6	1.1	2.2	8.9	18.2	121
88.5	1.35	1.32	.5	1.4	2.5	12.4	25.5	121
55.6	1.65	1.52	.5	.7	1.8	9.1	19.9	128
54.4	1.05	1.23	.6	1.1	1.1	4.3	9.6	128
57.9	1.28	1.26	.6	1.2	1.8	8.1	13.9	121
70.1	1.36	1.29	.4	.5	1.5	5.7	10.2	123
75.7	1.49	1.56	.9	1.9	2.3	10.4	22.4	130
65.6	1.72	1.56	.6	1.3	3.0	13.7	25.0	118
32.4	1.34	1.36	.7	1.6	2.7	12.6	22.2	118
72.1	1.08	1.30	.6	1.2	1.6	6.6	12.7	131
	1.46	1.37	.6	1.1	1.9	10.0	18.1	126
40.7	1.28	1.40	.6	1.1	1.7	7.0	15.3	125
65.9	1.31		.7	1.4	1.8	6.5	15.9	111
61.7	1.48	1.36	.5	1.1	1.7	8.7	17.7	121
67.4	1.64	1.41	.4	1.2	2.0	12.8	24.0	148
30.9	1.10	1.32	.3	.6	1.3	5.7	11.5	131
	1.46	1.39	.5	.9	2.5	9.5	17.6	130
33.4	1.07	1.30	.4	.9	1.8	7.2	11.4	126
41.2	1.64	1.46	.5	.9	1.8	7.6	12.8	118
47.7	1.41	1.24	.6	1.3	2.0	9.0	15.4	124
59.8	1.35	1.21	.7	1.3	1.9	9.5	16.8	123

Table 56. TEST FOR SKEWNESS AND KURTOSIS IN FIGURES 10 - 15

Figure	Mean	Standard Deviation	Degree of Skewness	Degree of Kurtosis	Standard Error of Skewness	Standard Error of Kurtosis
10	1.4067	0.1806	0.2369	-0.3831	0.1777	0.3536
11	1.3235	0.1400	0.1361	0.0063	0.1777	0.3536
12	1.3867	0.1888	0.3019	-0.5861	0.2487	0.4926
13	1.4277	0.1673	0.1015	-0.3274	0.2487	0.4926
14	1.3170	0.1528	0.2380	-0.2248	0.2487	0.4926
15	1.3301	0.1262	0.0272	0.3563	0.2487	0.4926

Note: Original classes of 0.05 were multiplied by 20 for the above analysis.

Table 57. SIMPLE CORRELATION MATRIX OF ALL VARIABLES (188 samples)

Variable	1. Ht.	2. DBH	3. Stock	4. Site T.	5. Age	6. Color
1.	1.00000	0.76465	0.52388	0.62719	0.60088	-0.37464
2.	0.76465	1.00000	0.14686	0.55956	0.40704	-0.36112
3.	0.52388	0.14686	1.00000	-0.02540	0.69526	-0.16667
4.	0.62719	0.55956	-0.02540	1.00000	-0.19026	-0.27507
5.	0.60088	0.40704	0.69526	-0.19026	1.00000	-0.05238
6.	-0.37464	-0.36112	-0.16667	-0.27507	-0.05238	1.00000
7.	-0.02569	-0.08883	0.28511	-0.39693	0.36152	0.07124
8.	0.04036	0.13816	-0.26797	0.35509	-0.30797	-0.22063
9.	0.10403	0.02129	0.11213	-0.02340	0.10048	-0.22810
10.	-0.32961	-0.02458	-0.54345	0.20283	-0.61913	-0.00858
11.	-0.10876	-0.01964	-0.32907	0.30807	-0.45061	-0.06064
12.	0.13662	0.18428	-0.17830	0.30270	-0.14334	-0.20142
13.	-0.34730	-0.01487	-0.58756	0.26706	-0.65742	0.00000
14.	-0.32217	0.03867	-0.61278	0.33042	-0.67500	0.00000
15.	-0.05055	0.11478	-0.42181	0.41625	-0.45882	-0.05706
16.	-0.05296	0.08023	-0.45996	0.55515	-0.61852	-0.04520
17.	0.66341	0.57515	0.20560	0.71135	0.06665	-0.23518
18.	-0.03764	0.11719	-0.50342	0.60488	-0.65208	-0.05256

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Table 57 (cont.) SIMPLE CORRELATION MATRIX OF ALL VARIABLES (188 samples)

Variable	7. Ne-In	8. Wt.	9. Ndl.Yrs.	10. Grn.Crn.	11. Pct.N1	12. Pct.N3
1.	-0.02569	0.04036	0.10403	-0.32961	-0.10876	0.13662
2.	-0.08883	0.13816	0.02129	-0.02458	-0.01964	0.18428
3.	0.28511	-0.26797	0.11213	-0.65456	-0.32907	-0.17830
4.	-0.39693	0.35509	-0.02340	0.20283	0.30807	0.30270
5.	0.36152	-0.30797	0.10048	-0.61913	-0.45061	-0.14334
6.	0.07124	-0.22063	-0.22810	-0.00858	-0.06064	-0.20142
7.	1.00000	-0.54107	0.13564	-0.35060	-0.49188	-0.31633
8.	-0.54107	1.00000	-0.01721	0.34007	0.36459	0.33610
9.	0.13564	-0.01721	1.00000	-0.04682	-0.13874	-0.03176
10.	-0.35060	0.34007	-0.04682	1.00000	0.37939	0.05377
11.	-0.49188	0.36459	-0.13874	0.37939	1.00000	0.48537
12.	-0.31633	0.33610	-0.03176	0.05377	0.48537	1.00000
13.	-0.49775	0.39890	-0.02570	0.63748	0.41798	0.12014
14.	-0.53109	0.45094	-0.09982	0.65328	0.43514	0.16665
15.	-0.43632	0.38633	-0.08064	0.43039	0.51729	0.36482
16.	-0.56240	0.46374	-0.10056	0.55498	0.64321	0.35699
17.	-0.31178	0.21367	-0.05415	-0.00895	0.20003	0.27491
18.	-0.58019	0.47346	-0.15464	0.57877	0.62219	0.40028

continued on next page

Table 57 (cont.) SIMPLE CORRELATION MATRIX OF ALL VARIABLES (188 samples)

Variable	13. Diam. 5	14. Diam.10	15. Ht.Crt.	16. Ht. 5	17. Site.S	18. Ht. 10
1.	-0.34730	-0.32217	-0.05055	-0.05296	0.66341	-0.03764
2.	-0.01487	0.03867	0.11478	0.08023	0.57515	0.11719
3.	-0.58756	-0.61278	-0.42181	-0.45996	0.20560	-0.50342
4.	0.26706	0.33042	0.41625	0.55515	0.71135	0.60488
5.	-0.65742	-0.67500	-0.45882	-0.61852	0.06665	-0.65208
6.	0.00000	0.00000	-0.05706	-0.04520	-0.23518	-0.05256
7.	-0.49775	-0.53109	-0.43632	-0.56240	-0.31178	-0.58019
8.	0.39890	0.45094	0.38633	0.46374	0.21367	0.47346
9.	-0.02570	-0.09982	-0.08064	-0.10056	-0.05415	-0.15464
10.	0.63748	0.65328	0.43039	0.55498	-0.00895	0.57877
11.	0.41798	0.43514	0.51729	0.64321	0.20003	0.62219
12.	0.12014	0.16665	0.36482	0.35699	0.27491	0.40028
13.	1.00000	0.92073	0.60990	0.69667	0.08893	0.71793
14.	0.92073	1.00000	0.62630	0.74706	0.13041	0.79226
15.	0.60990	0.62630	1.00000	0.80426	0.16666	0.75221
16.	0.69667	0.74706	0.80426	1.00000	0.27551	0.93601
17.	0.08893	0.13041	0.16666	0.27551	1.00000	0.32777
18.	0.71793	0.79226	0.75221	0.93601	0.32777	1.00000

Table 58. VARIABLES WITH HIGHEST CORRELATION FROM SIMPLE CORRELATION MATRIX

First Variable	Second Variable	Correlation Coefficient
Leader Length	Ht. Growth (5 yrs.)	+ .8043
Radial Growth (10 yrs.)	Ht. Growth (10 yrs.)	+ .7923
Total Height	D.B.H.	+ .7646
Leader Length	Ht. Growth (10 yrs.)	+ .7522
Tree Site	Site-Index	+ .7113
Radial Growth (5 yrs.)	Ht. Growth (5 yrs.)	+ .6967
Stocking	Age	+ .6953
Total Height	Site=Index	+ .6634
Stocking	Green Crown (%)	+ .6546
Green Crown (%)	Radial Growth (10 yrs.)	+ .6534
N% 1st Whorl	Ht. Growth (5 yrs.)	+ .6432
N% 1st Whorl	Ht. Growth (10 yrs.)	+ .6229
Age	Green Crown (%)	- .6191
Age	Ht. Growth (5 yrs.)	- .6185
Total Height	Stocking	+ .6001

Table 59. SIMPLE REGRESSION OF FOLIAR NITROGEN AGAINST ALL VARIABLES (188 samples)

Independent Variable	Regression Equation	Multiple R	Standard Error of Estimate	F Value to Enter or Remove
	Stand Characteristics			
FIRST WHORL				
Site S	Y = 1.22 + .0013X	.1168	.2050	2.5703
Site T	Y = .971 + .0033X	.2544	.1996	12.8761
Age	Y = 1.980 - .0147X	.4390	.1855	44.4100
Stocking	Y = 1.617 - .0020X	.3283	.1950	22.4680
THIRD WHORL				
Site S	Y = 1.083 + .0018X	.1897	.1667	6.9422
Site T	Y = .954 + .0028X	.2604	.1641	13.5283
Age	Y = 1.448 - .0037X	.1337	.1685	3.3831
Stocking	Y = 1.364 - .0006X	.1113	.1689	2.3338
	Vigor Characteristics			
FIRST WHORL				
Ht Crt	Y = 1.086 + .1596X	.5003	.1787	62.1025
Ht 5	Y = 1.006 + .0408X	.5932	.1662	100.9853
Ht 10	Y = 1.035 + .0200X	.5659	.1702	87.6073
Rad 5	Y = 1.326 + .1511X	.2720	.1986	14.8616
Rad 10	Y = 1.325 + .0788X	.2798	.1981	15.7981
Wt	Y = 1.120 + .4385X	.3364	.1944	23.7308
DBH	Y = 1.428 - .0045X	.0514	.2061	0.4919
Ht	Y = 1.560 - .0024X	.1418	.2043	3.8170
THIRD WHORL				
Ht Crt	Y = 1.150 + .0800X	.3043	.1619	18.9786
Ht 5	Y = 1.126 + .0188X	.3313	.1604	22.9282
Ht 10	Y = 1.126 + .0100X	.3410	.1600	24.4742
Rad 5	Y = 1.248 + .1418X	.3101	.1616	19.7891
Rad 10	Y = 1.246 + .0741X	.3195	.1611	21.1386
Wt	Y = 1.164 + .2260X	.2105	.1662	8.6257
DBH	Y = 1.190 + .0100X	.1367	.1684	3.5403
Ht	Y = 1.185 + .0015X	.1067	.1690	2.1435
	Appearance Characteristics			
FIRST WHORL				
Ne-In	Y = 1.554 - .0063X	.2829	.1976	16.9819
Ndl Yrs	Y = 1.441 - .0150X	.0671	.2059	0.8417
Grn Crn	Y = 1.161 + .0036X	.2741	.1985	15.1143
THIRD WHORL				
Ne-In	Y = 1.400 - .0037X	.2071	.1663	8.3321
Ndl Yrs	Y = 1.243 + .0132X	.0720	.1695	0.9684
Grn Crn	Y = 1.289 + .0013X	.0124	.1700	0.0287

Table 60. SIMPLE REGRESSION OF FOLIAR NITROGEN AGAINST ALL VARIABLES (94 representative samples)

Independent Variable	Regression Equation	Multiple R	Standard Error of Estimate	F Value to Enter or Remove
	Stand Characteristics			
FIRST WHORL				
Site S	Y = .922 + .0037X	.2774	.1900	7.6687
Site T	Y = .838 + .0043X	.3561	.1838	13.3566
Age	Y = 2.011 - .0155X	.4847	.1720	28.2585
Stock	Y = 1.640 - .0022X	.4002	.1803	17.5450
THIRD WHORL				
Site S	Y = .852 + .0037X	.3496	.1460	12.8110
Site T	Y = .838 + .0038X	.3898	.1436	16.4801
Age	Y = 1.450 - .0037X	.1438	.1543	1.9424
Stocking	Y = 1.385 - .0007X	.1614	.1539	2.4606
	Vigor Characteristics			
FIRST WHORL				
Ht Crt	Y = 1.020 + .2071X	.5768	.1607	45.8697
Ht 5	Y = .929 + .0509X	.7573	.1285	123.7063
Ht 10	Y = .979 + .0239X	.7218	.1361	100.0415
Rad 5	Y = 1.308 + .1827X	.3472	.1845	12.6114
Rad 10	Y = 1.305 + .0971X	.3688	.1828	14.4860
Wt	Y = 1.157 + .3688X	.2994	.1877	9.0571
DBH	Y = 1.271 + .0093X	.1104	.1955	1.1352
Ht	Y = 1.461 - .0012X	.0771	.1961	0.5500
THIRD WHORL				
Ht Crt	Y = 1.067 + .1374X	.4830	.1365	27.9865
Ht 5	Y = 1.102 + .0227X	.4264	.1410	20.4479
Ht 10	Y = 1.103 + .0120X	.4561	.1388	24.1669
Rad 5	Y = 1.231 + .2002X	.4800	.1368	27.5416
Rad 10	Y = 1.230 + .1043X	.4996	.1351	30.6054
Wt	Y = 1.175 + .2162X	.2214	.1521	4.7417
DBH	Y = 1.102 + .0186X	.2798	.1497	7.8127
Ht	Y = 1.120 + .0024X	.1888	.1531	3.4011
	Appearance Characteristics			
FIRST WHORL				
Ne-In	Y = 1.633 - .0092X	.4697	.1736	26.0352
Ndl Yrs	Y = 1.506 - .0329X	.1611	.1941	2.4509
Grn Crn	Y = 1.043 + .0056X	.4450	.1761	22.7154
THIRD WHORL				
Ne-In	Y = 1.461 - .0056X	.3635	.1453	14.0109
Ndl Yrs	Y = 1.390 - .0218X	.1346	.1545	1.6985
Grn Crn	Y = 1.241 + .0009X	.0992	.1552	0.9143

Table 61. SIMPLE REGRESSION OF FOLIAR NITROGEN AGAINST ALL VARIABLES (94 random samples)

Independent Variable	Regression Equation	Multiple R	Standard Error of Estimate	F Value to Enter or Remove
	Stand Characteristics			
FIRST WHORL				
Site S	Y = 1.367 + .00018X	.0178	.2173	0.0293
Site T	Y = 1.120 + .0021X	.1535	.2148	2.2200
Age	Y = 1.949 - .0140X	.3945	.1997	16.9620
Stocking	Y = 1.588 - .0017X	.2521	.2104	6.2415
THIRD WHORL				
Site S	Y = 1.194 + .00084X	.0969	.1838	0.8724
Site T	Y = 1.059 + .0019X	.1594	.1823	2.3970
Age	Y = 1.452 - .0039X	.1289	.1831	1.5542
Stocking	Y = 1.343 - .0004X	.0693	.1842	0.4446
	Vigor Characteristics			
FIRST WHORL				
Ht Crt	Y = 1.110 + .1400X	.4549	.1936	24.0019
Ht 5	Y = 1.075 + .0325X	.4522	.1939	23.6457
Ht 10	Y = 1.094 + .0165X	.4220	.1971	19.9287
Rad 5	Y = 1.346 + .1177X	.2020	.2129	3.9135
Rad 10	Y = 1.347 + .0587X	.1961	.2132	3.6785
Wt	Y = 1.083 + .5062X	.3663	.2023	14.2544
DBH	Y = 1.600 - .0190X	.2072	.2127	4.1278
Ht	Y = 1.667 - .0037X	.2051	.2128	4.0408
THIRD WHORL				
Ht Crt	Y = 1.190 + .0536X	.2051	.1807	4.0390
Ht 5	Y = 1.140 + .0162X	.2657	.1780	6.9908
Ht 10	Y = 1.146 + .0083X	.2540	.1786	6.3445
Rad 5	Y = 1.266 + .0838X	.1692	.1820	2.7128
Rad 10	Y = 1.266 + .0423X	.1665	.1821	2.6244
Wt	Y = 1.150 + .2416X	.2059	.1807	4.0718
DBH	Y = 1.278 + .0016X	.0206	.1846	0.0390
Ht	Y = 1.253 + .0006X	.0374	.1845	0.1287
	Appearance Characteristics			
FIRST WHORL				
Ne-In	Y = 1.458 - .0025X	.1061	.2162	1.0478
Ndl Yrs	Y = 1.3591 + .0074X	.0301	.2173	0.0834
Grn Crn	Y = 1.290 + .0016X	.1134	.2160	1.1981
THIRD WHORL				
Ne-In	Y = 1.333 - .0014X	.0666	.1842	0.4101
Ndl Yrs	Y = 1.076 + .0543X	.2614	.1782	6.7473
Grn Crn	Y = 1.339 - .00069X	.0582	.1843	0.3128

Table 62. SIMPLE REGRESSION OF FOLIAR NITROGEN AGAINST ALL VARIABLES (49 representative samples)

Independent Variable	Regression Equation	Multiple R	Standard Error of Estimate	F Value to Enter or Remove
	Stand Characteristics			
FIRST WHORL				
Site S	Y = .937 + .0039X	.2423	.2169	2.9302
Site T	Y = .832 + .0046X	.3386	.2104	6.0844
Age	Y = 2.065 - .0163X	.5533	.1862	20.7346
Stocking	Y = 1.687 - .0026X	.4386	.2009	11.1978
THIRD WHORL				
Site S	Y = .846 + .0044X	.4227	.1341	10.2226
Site T	Y = .890 + .0039X	.4321	.1335	10.7886
Age	Y = 1.436 - .0016X	.0839	.1475	0.3332
Stocking	Y = 1.010 - .0011X	.1113	.1901	3.2212
	Vigor Characteristics			
FIRST WHORL				
Ht Crt	Y = 1.030 + .2000X	.5620	.1849	21.6939
Ht 5	Y = .911 + .0530X	.7882	.1376	77.0914
Ht 10	Y = .948 + .0250X	.7477	.1485	59.5994
Rad 5	Y = 1.107 + .4528X	.5152	.1916	16.9869
Rad 10	Y = 1.099 + .2351X	.5539	.1816	20.8070
Wt	Y = 1.122 + .4675X	.3831	.2065	8.0822
DBH	Y = 1.489 - .0080X	.0748	.2229	0.2643
Ht	Y = 1.651 - .0034X	.2036	.2189	2.0329
THIRD WHORL				
Ht Crt	Y = 1.190 + .0953X	.4094	.1350	9.4626
Ht 5	Y = 1.209 + .0172X	.3887	.1363	8.3670
Ht 10	Y = 1.226 + .0079X	.3579	.1382	6.9053
Rad 5	Y = 1.295 + .1142X	.1963	.1451	1.8833
Rad 10	Y = 1.275 + .0733X	.2608	.1429	3.4312
Wt	Y = 1.233 + .2278X	.2820	.1420	4.0603
DBH	Y = 1.227 + .0127X	.1788	.1456	1.5516
Ht	Y = 1.167 + .0028X	.2464	.1434	3.0384
	Appearance Characteristics			
FIRST WHORL				
Ne-In	Y = 1.703 - .0108X	.5269	.1900	18.0618
Ndl Yrs	Y = 1.423 - .0058X	.0197	.2235	0.0183
Grn Crn	Y = .963 + .0073X	.5493	.1868	20.3054
THIRD WHORL				
Ne-In	Y = 1.488 - .0042X	.3128	.1406	5.0972
Ndl Yrs	Y = 1.398 - .0071X	.0367	.1479	0.0634
Grn Crn	Y = 1.306 + .0011X	.1201	.1469	0.6874

Table 63. SIMPLE REGRESSION OF FOLIAR NITROGEN AGAINST ALL VARIABLES (51 random samples)

Independent Variable	Regression Equation	Multiple R	Standard Error of Estimate	F Value to Enter or Remove
Stand Characteristics				
FIRST WHORL				
Site S	Y = 1.548 - .0011X	.0446	.1765	0.0978
Site T	Y = 1.108 + .0024X	.1809	.1738	1.6570
Age	Y = 1.851 - .0108X	.4163	.1607	10.2715
Stocking	Y = 1.509 - .0009X	.1567	.1745	1.2335
THIRD WHORL				
Site S	Y = .606 + .0058X	.1968	.2177	1.9738
Site T	Y = 1.156 + .0013X	.0794	.2213	0.3106
Age	Y = 1.499 - .0043X	.1308	.2201	0.8526
Stocking	Y = 1.268 + .0006X	.0827	.2213	0.3371
Vigor Characteristics				
FIRST WHORL				
Ht Crt	Y = 1.105 + .1418X	.5081	.1522	17.0541
Ht 5	Y = 1.066 + .0344X	.5693	.1453	23.4974
Ht 10	Y = 1.087 + .01715X	.5205	.1509	18.2072
Rad 5	Y = 1.265 + .2267X	.2744	.1699	3.9908
Rad 10	Y = 1.279 + .1063X	.2506	.1711	3.2828
Wt	Y = 1.136 + .4439X	.2656	.1704	3.7193
DBH	Y = 1.719 - .0257X	.2909	.1691	4.5304
Ht	Y = 1.629 - .0028X	.1842	.1737	1.7204
THIRD WHORL				
Ht Crt	Y = 1.253 + .0340X	.0972	.2210	0.4670
Ht 5	Y = 1.146 + .0178X	.2350	.2158	2.8629
Ht 10	Y = 1.178 + .0078X	.1883	.2181	1.8003
Rad 5	Y = 1.160 + .0152X	.0512	.2122	1.2112
Rad 10	Y = 1.339 - .0086X	.0161	.2220	0.0128
Wt	Y = 1.094 + .3678X	.1751	.2186	1.5506
DBH	Y = 1.578 - .0213X	.1923	.2179	1.8819
Ht	Y = 1.416 - .0012X	.0609	.2216	0.1826
Appearance Characteristics				
FIRST WHORL				
Ne-In	Y = 1.734 - .0119X	.4951	.1535	15.9091
Ndl Yrs	Y = 1.292 + .0309X	.1433	.1750	1.0279
Grn Crn	Y = 1.325 + .0015X	.1559	.1745	1.2214
THIRD WHORL				
Ne-In	Y = 1.440 - .0042X	.1406	.2198	0.9887
Ndl Yrs	Y = .896 + .1065X	.3925	.2042	8.9247
Grn Crn	Y = 1.370 - .0007X	.0566	.2217	0.1575

Table 64. MULTIPLE REGRESSION OF FOLIAR NITROGEN AGAINST ALL OTHER VARIABLES

(All 188 samples)

	Independent Variables		Multiple R	Standard Error of Estimate	F Value to Remove or Enter
First Whorl	Ht 5	16	.5932	.1662	100.9853
	DBH	2	.6086	.1642	5.4325
	Wt	8	.6262	.1618	6.5881
	Ne-In	7	.6272	.1621	.3678
	Ht Crt	15	.6282	.1624	.3772
	Ndl Yrs	9	.6288	.1627	.2175
	Rad 5	13	.6293	.1631	.1870
	Grn Crn	10	.6297	.1634	.1768
	Stock	3	.6302	.1638	.1851
	Rad 10	14	.6306	.1642	.1547
	Ht 10	18	.6311	.1646	.1745
	Site T	4	.6314	.1650	.0918
	Site S	17	.6317	.1654	.1068
	Age	5	.6317	.1659	.0315
	Ht	1	.6323	.1663	.1984
Third Whorl	Ht 10	18	.3410	.1598	24.4742
	Grn Crn	10	.3862	.1572	7.1445
	Rad 10	14	.4262	.1546	7.3066
	Ndl Yrs	9	.4406	.1538	2.8408
	Site S	17	.4490	.1535	1.6977
	Wt	8	.4532	.1536	.8686
	Ne-In	7	.4571	.1537	.7965
	Stock	3	.4581	.1540	.2201
	Ht 5	16	.4590	.1544	.1877
	Site T	4	.4598	.1547	.1671
	DBH	2	.4611	.1551	.2609
	Ht	1	.4618	.1554	.1320

Table 65. MULTIPLE REGRESSION OF FOLIAR NITROGEN AGAINST ALL OTHER VARIABLES

(94 representative samples)

	Independent Variables		Multiple R	Standard Error of Estimate	F Value to Remove or Enter
First Whorl	Ht 5	16	.7573	.1284	123.7063
	Ne-In	7	.7608	.1283	1.1545
	Wt	8	.7636	.1284	.9199
	DBH	2	.7654	.1287	.5909
	Age	5	.7664	.1291	.3115
	Ht 10	18	.7678	.1296	.4773
	Rad 5	13	.7689	.1301	.3503
	Stock	3	.7712	.1303	.7395
	Ht	1	.7716	.1309	.1168
	Site T	4	.7806	.1294	2.9760
	Site S	17	.7809	.1301	.1162
	Ht Crt	15	.7811	.1309	.0573
	Rad 10	14	.7813	.1386	.0652
	Grn Crn	10	.7815	.1324	.0441
Third Whorl	Rad 10	14	.4996	.1351	30.6053
	Site T	4	.5901	.1266	13.7623
	Ne-In	7	.6094	.1250	3.3152
	Grn Crn	10	.6384	.1220	5.4300
	Ht Crt	15	.6537	.1206	3.0546
	Age	5	.6590	.1206	1.0625
	DBH	2	.6727	.1193	2.8591
	Rad 5	13	.6752	.1197	.5382
	Stock	3	.6771	.1201	.3983
	Ndl Yrs	9	.6789	.1205	.3666
	Site S	17	.6795	.1212	.1263
	Ht 10	18	.6798	.1219	.0590
	Ht 5	16	.6807	.1225	.1791
	Wt	8	.6809	.1232	.0481
	Ht	1	.6810	.1240	.0169

Table 66. MULTIPLE REGRESSION OF FOLIAR NITROGEN AGAINST ALL OTHER VARIABLES

(94 random samples)

	Independent Variables		Multiple R	Standard Error of Estimate	F Value to Remove or Enter
First Whorl	Ht Crt	15	.4549	.1936	24.0019
	Wt	8	.5141	.1875	7.1041
	DBH	2	.5721	.1803	8.4198
	Ht 5	16	.5798	.1801	1.1911
	Grn Crn	10	.5857	.1802	.9215
	Ne-In	7	.5913	.1803	.8855
	Stock	3	.5961	.1805	.7521
	Ndl Yrs	9	.5985	.1812	.3781
	Ht	1	.6000	.1820	.2499
	Site S	17	.6009	.1829	.1407
	Age	5	.6014	.1840	.0723
	Site T	4	.6023	.1849	.1397
	Rad 10	14	.6027	.1860	.0557
	Rad 5	13	.6054	.1867	.4027
	Ht 10	18	.6055	.1879	.0141
Third Whorl	Ht 5	16	.2657	.1780	6.9908
	Ndl Yrs	9	.3565	.1734	5.8902
	Grn Crn	10	.3836	.1724	2.1115
	Wt	8	.3957	.1724	.9978
	Stock	3	.4053	.1726	.8081
	Site S	17	.4096	.1732	.3704
	Ht 10	18	.4135	.1739	.3303
	Site T	4	.4172	.1746	.3122
	Ht Crt	15	.4184	.1755	.1095
	Rad 5	13	.4198	.1764	.1144
	Rad 10	14	.4245	.1771	.3969
	Ne-In	7	.4250	.1781	.0402
	Ht	1	.4251	.1792	.0128
	Age	5	.4254	.1803	.0213
	Site T	4	.4253	.1792	.0044

Table 67. MULTIPLE REGRESSION OF FOLIAR NITROGEN AGAINST ALL OTHER VARIABLES

(49 representative samples)

	Independent Variables		Multiple R	Standard Error of Estimate	F Value to Remove or Enter
First Whorl	Ht 5	16	.7882	.1376	77.0914
	Rad 5	13	.8025	.1349	2.9361
	Ht Crt	15	.8140	.1327	2.4799
	Wt	8	.8259	.1303	2.6965
	Ne-In	7	.8325	.1295	1.5441
	Ndl Yrs	9	.8387	.1288	1.4704
	Age	5	.8413	.1294	.5990
	Stock	3	.8434	.1302	.5026
	Site T	4	.8453	.1311	.4360
	Rad 10	14	.8474	.1320	.4831
	DBH	2	.8498	.1328	.5379
	Ht	1	.8506	.1343	.1857
	Site S	17	.8511	.1360	.1024
	Ht 10	18	.8515	.1378	.0901
	Grn Crn	10	.8517	.1398	.0236

Regression Equation:
Nitrogen Percent (First Whorl)
Y = .9055 + .0790(Ht 5) - .2470(Rad 5) - .1007(Ht Crt) + .1900(Wt)

	Independent Variables		Multiple R	Standard Error of Estimate	F Value to Remove or Enter
Third Whorl	Site T	4	.4321	.1335	10.7886
	Ht Crt	15	.4982	.1297	3.7613
	Age	5	.5106	.1300	.7663
	Ne-In	7	.5385	.1289	1.8078
	DBH	2	.5657	.1276	1.9012
	Wt	8	.5867	.1268	1.5487
	Site S	17	.5953	.1273	.6516
	Ht 5	16	.6010	.1282	.4250
	Rad 5	13	.6053	.1293	.3184
	Rad 10	14	.6151	.1298	.7273
	Ht 10	18	.6225	.1305	.5562
	Ndl Yrs	9	.6247	.1320	.1623
	Ht	1	.6254	.1338	.0467
	Stock	3	.6257	.1357	.0255

Table 68. MULTIPLE REGRESSION OF FOLIAR NITROGEN AGAINST ALL OTHER VARIABLES

(51 random samples)

	Independent Variables		Multiple R	Standard Error of Estimate	F Value to Remove or Enter
First Whorl	Ht 5	16	.5693	.1453	23.4974
	Ne-In	7	.6234	.1396	5.0629
	Rad 10	14	.6567	.1361	3.5290
	Rad 5	13	.6757	.1345	2.1334
	Age	5	.6865	.1341	1.2615
	Stock	3	.7017	.1328	1.8307
	Ht Crt	15	.7070	.1334	.6377
	Grn Crn	10	.7099	.1344	.3444
	Ht	1	.7110	.1358	.1303
	Site T	4	.7287	.1339	2.1706
	Ht 10	18	.7320	.1349	.4065
	DBH	2	.7329	.1365	.1092
	Wt	8	.7331	.1383	.0286
Third Whorl	Ndl Yrs	9	.3925	.2042	8.9247
	Wt	8	.4402	.2014	2.3637
	DBH	2	.4645	.2008	1.3173
	Site S	17	.4947	.1991	1.7658
	Ht 5	16	.5133	.1988	1.1453
	Rad 10	14	.5300	.1987	1.0648
	Ht Crt	15	.5415	.1993	.7516
	Ht	1	.5550	.1995	.8941
	Stock	3	.5598	.2011	.3250
	Site T	4	.5627	.2032	.1868
	Age	5	.5697	.2045	.4584
	Rad 5	13	.5715	.2069	.1151
	Grn Crn	10	.5730	.2094	.0975

Table 69. MULTIPLE REGRESSION OF FOLIAR NITROGEN AGAINST ALL OTHER VARIABLES EXCEPT HEIGHT GROWTH IN THE CURRENT YEAR

(49 representative samples)

	Independent Variables		Multiple R	Standard Error of Estimate	F Value to Enter or Remove
First Whorl	Ht 5	16	.7882	.1376	77.0913
	Rad 5	13	.8025	.1348	2.9361
	Wt	8	.8093	.1342	1.4391
	Ne-In	7	.8183	.1328	1.9458
	Ndl Yrs	9	.8238	.1325	1.2180
	Age	5	.8298	.132	1.3386
	Stock	3	.8323	.1327	.5554
	Site T	4	.8354	.1332	.6766
	Rad 10	14	.8378	.134	.5247
	DBH	2	.8415	.1343	.8110
	Site S	17	.8424	.1358	.1991
	Ht	1	.8429	.1375	.0997
	Ht 10	18	.8431	.1393	.0316
	Grn Crn	10	.8431	.1414	.0043
Third Whorl	Site T	4	.4321	.1335	10.7886
	Ht 5	16	.4862	.1307	2.9920
	Age	5	.5329	.1280	2.9934
	DBH	2	.5523	.1275	1.3337
	Ne-In	7	.5710	.1270	1.3384
	Wt	8	.5898	.1264	1.4095
	Site S	17	.5976	.1270	.5843
	Rad 5	13	.6014	.1282	.2874
	Rad 10	14	.6120	.1285	.8059
	Ht 10	18	.6204	.1291	.6393
	Ndl Yrs	9	.6226	.1305	.1629
	Ht	1	.6234	.1322	.0590
	Stock	3	.6236	.1341	.0151