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The nitrogen and phosphorus nutrition of white ash (Fraxinus Americana L.)

Glendon William Smalley
University of Tennessee

To the Graduate Council:

I am submitting herewith a dissertation written by Glendon William Smalley entitled "The nitrogen and phosphorus nutrition of white ash (Fraxinus Americana L.)." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Plant, Soil and Environmental Sciences.

M. E. Springer, Major Professor

We have read this dissertation and recommend its acceptance:

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

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We have read this dissertation and recommend its acceptance:

Frank W. Woods

J. W. Barrett

H. R. DeSelm

W. L. Parks

Accepted for the Council:

Hilton A. Smith

Vice Chancellor
Graduate Studies and Research

THE NITROGEN AND PHOSPHORUS NUTRITION OF WHITE ASH

(<u>FRAXINUS</u> <u>AMERICANA</u> L.)

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee

Glendon William Smalley

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ABSTRACT

The research reported here is the first endeavor to evaluate the adequacy of Cumberland Plateau and Highland Rim soils in middle Tennessee and northern Alabama for the satisfactory growth and development of white ash. It is part of a research program of the U. S. Forest Service aimed at determining site capability and species adaptability for the Plateau and Rim and providing silvicultural recommendations for the rehabilitation of forest lands.

In the first of two experiments seedlings were grown in pots of soil with N and P additions. Mixed A1 and A2 horizons from two representative forest soils (Hartsells and Bodine) were tested. The study was a split plot with three replications of each soil (major plots). Minor plots consisted of a complete factorial arrangement of four levels each of N as NH_4NO_3 (0, 168, 336, 504 kg/ha) and four levels of P as TSP (0, 112, 224, 336 kg/ha).

After one growing season growth and N, P, K, Ca, and Mg in the leaves of four seedings per pot were evaluated by ANOVA. Nitrogen and P main effects and their interactions were analyzed by generating linear, quadratic, and cubic components. Seedling biomass and foliar composition were correlated.

Seedling biomass and height were linearly and positively related to P-supply. The relation of root collar diameter and root/shoot ratio was quadratic and positive. N-supply had no significant effect on seedling growth. There was no interaction. Phosphorus appears to be

limiting in both soils. White ash seedlings should respond to larger increments of P. Foliar P concentration was 0.11% DW at the maximum rate applied.

Apparently soil pH (5.5) and Ca content (2 meq/100g) were also important factors. Biomass of seedlings grown in soils above these values were much larger than those grown in soils below these values.

Regardless of size, seedling biomass was composed of 70% roots, 14% stems, and 16% foliage. As biomass increased foliar N and K concentration decreased while Ca increased.

In Hartsells-grown seedlings, N-supply increased foliar N concentration and decreased P and Ca and P-supply decreased foliar N concentration and increased P and Ca. In Bodine-grown seedlings the only influence was an increase in P percent due to P-supply.

Added P increased the foliar content of all five elements from both soils except Mg from Bodine. Phosphorus and K foliar content in Hartsells-grown seedlings decreased and N content in Bodine-grown seedlings increased with N-supply.

In experiment-2 56 dominant and codominant white ash trees growing on eight broadly defined sites in reasonably well-stocked stands were measured for height (H), diameter (D), volume (V), and age. Nitrogen, P, K, Ca, and Mg were determined from foliage and topsoil samples. Tree, topsoil, and foliage data were evaluated by regression and correlation analyses. The effects of site were tested by univariate ANOVA. Variation of topsoil properties and foliar composition was expressed as coefficients of variation and sampling requirements were calculated for a precision of 10% at $p = 0.05$ and 0.01 levels.

Tree diameter, H, and V and topsoil properties were significantly related to site. Stand basal area and mean annual D, H, and V growth were not related to site. Foliar concentration of P, K, and Ca varied significantly with site.

Topsoil pH was the only measured soil property significantly correlated (inversely) with a growth variable (volume). The relationship was weak and no importance was made of it. No foliar composition variable was significantly correlated with growth. Multiple regressions relating growth to soil nutrients or foliar composition showed that soil N, Ca, and Mg explained 14% and foliar N, P, and K concentration explained 20% of the variation in H growth. The best soil or foliar predictors explained 12% or less of the variation in D and V growth.

Foliar P, Ca, and Mg concentration were significantly correlated with respective soil values, but less than 10% of the variation in concentration was explained by regression. Twelve, 21, 12, 10, and 36% of the variation in N, P, K, Ca, and Mg foliar concentration was accounted for by best multiple regressions employing soil elements as independent variables.

The lack of significant relationships between foliar concentration and tree growth made it impossible to evaluate the fertility status of the sampled trees with respect to experiment-1. Furthermore the lack of or weak correlation between tree growth and foliar composition and soil properties made it impossible to determine the adequacy of Plateau and Rim soils for the satisfactory growth of ash in natural stands. A reliable measure of response is a major problem confronting the forest scientist studying species which occur as scattered individuals on a wide range of sites in upland mixed hardwood forests.

TABLE OF CONTENTS

LIST OF TABLES

TABLE | PAGE

TABLE PAGE

LIST OF FIGURES

CHAPTER I

THE PROBLEM

A major concern in the study of site evaluation and species adaptability at the U. S. Forest Service Silviculture Laboratory, Sewanee, Tennessee, is the nutrient supplying capacity of representative forest soils of the Cumberland Plateau and Highland Rim. Specifically, we are interested in the relationship between 1) nutrient supply and tree growth, 2) nutrient supply and uptake, 3) uptake and growth, and 4) nutrient deficiencies and visual symptoms.

A variety of techniques are used in the study of tree nutrition. Sand culture and soil in pots are used to determine the independent effects and interactions of the macronutrients on seedlings of tree species. Subsequent studies in natural and planted stands will permit testing of nutrients and other environmental factors, to evaluate and delineate sites with similar productivity for selected species, and to assess the response of forest stands to supplemental nutrients.

White ash[1] is one of the hardwoods under study. It is the largest, most common, and most useful--but not the most widespread of the American ashes. It commonly grows on cool, moist positions below the Plateau escarpment and on the eastern and western portions of the Highland Rim. On the Plateau it occupies moist positions. Common

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[1]See Appendix A for scientific names of species mentioned.

associates are oaks, white basswood, yellow-poplar, black walnut, buckeye, hickories, cucumber, and black cherry.

There is little information on the nutrient requirements of white ash--none on the soils on which it is common in middle Tennessee and northern Alabama. Generally it grows on fertile soils with high nitrogen and moderate to high calcium. It is considered a nitrogen-demanding species. Information is necessary to evaluate the adequacy of Plateau and Highland Rim soils for the satisfactory growth and development of white ash.

Two separate but related experiments were performed. The first involved seedlings in pots of soil with N and P additions. Two representative soils were tested. The second experiment was concerned with relation between the growth of large trees in natural stands and soil and foliar levels. The relation of foliar levels to growth was evaluated in terms of the foliar levels obtained in experiment-1. Inferences were made regarding adequacy of the soils sampled in experiment-2 to meet the nutrient requirements of white ash, and the possibility of improving growth by additional N and P.

CHAPTER II

LITERATURE REVIEW

The importance of an adequate supply of minerals for good growth has been appreciated in agriculture and horticulture for many years but has been largely neglected in forestry until recently. In the United States diminishing acreages of commercial forest land and ever-increasing demands are changing this situation. As tree improvement programs supply better planting stock it will be necessary to provide a better environment if the growth potential of the genetically improved stock is to be realized (Bengtson, 1968b). While a few experiments date back as much as 40 years, a strong research effort to determine the specific mineral requirements of trees began only a decade or so ago (Ralston et al., 1958; McDermid, 1961; Bengtson, 1968a; Youngberg and Davey, 1970).

Reviews of progress and problems in forest tree nutrition have been prepared by Gessel (1962), Leyton (1957), and Stoeckeler and Arneman (1960). There are two extensive bibliographies on forest fertilization research (White and Leaf, 1957; Mustanoja and Leaf, 1965). Much of the information is from European research and a majority of research effort has been devoted to conifers.

I. NUTRIENT REQUIREMENTS OF FOREST TREE SPECIES

It is well established that trees, like other plants, require a balanced supply of 13 essential elements (the macronutrients--N, P, K, Ca, Mg, and S; and the micronutrients or trace elements--B, Cu, Zn, Fe, Mn, Mo, and Cl) for vigorous growth (Devlin, 1966; Kramer and Kozlowski, 1960). Also, it is common knowledge that some species may grow satisfactorily on relatively infertile soils. Consequently it has been concluded that trees have low mineral nutrient requirements. This is only partly true because trees seem to have a greater ability than many plants to extract nutrients, even from the poorest soils.

According to Rennie (1955) the uptake of P and K by three forest tree species groups in England was considerably lower than those for agricultural crops. Calcium uptake by hardwood forests was almost as much, pine one-fifth, and other conifers one-half as much as crops. He believed that a truer picture of nutrient requirements of agricultural crops and trees could be obtained by comparing uptake relative to the soil nutrient status. Using this approach he concluded that the nutrient demands of forest trees relative to the nutrient status of their sites were all greater than the nutrient demands of agricultural crops upon agricultural soils. However, Rennie failed to consider the different time intervals required to grow the various forest and agricultural crops. When his data are placed on a per annum basis only the demand for Ca by pine on afforested moor soils exceeds the demands by agricultural crops.

Results of tree nutrition research in Germany indicate that supplemental fertilization is necessary on most sites to obtain maximum wood yields (Mayer-Krapoll, 1956). For example, oak plantings require 50 to 60 kg N, 80 kg P_2O_5, 80 to 100 kg K_2O, and 40 to 50 kg CaO/ha. Only a part of these nutrients are supplied by the soil on an average forest site. In the colder portions of Europe the well-developed forest industry depends on a sustained yield from slow-growing forests. Since 1960 forest fertilization as an integral part of forest management has increased rapidly (Tamm, 1968).

Forest tree species exhibit varying degrees of growth response to differences in soil fertility. In general, hardwoods are more site-sensitive than conifers. Consequently, small changes in soil characteristics often result in large differences in the quantity and quality of wood produced and even in the species adapted to the site.

Forest tree nursery soil fertility standards have been established on the basis of soil fertility information from stands exhibiting acceptable growth rates (e.g., Wilde, 1958). In general, hardwood species require a moderate to high level of nursery soil fertility in comparison with less-exacting conifers. Hardwoods such as black walnut, white ash, white oak, yellow-poplar, sugar maple, and basswood require high fertility, whereas yellow birch, northern red oak, bigtooth aspen, and black cherry do well under moderate but stable soil fertility levels.

Mitchell and Chandler (1939) studied the N status of a wide variety of sites supporting hardwoods in northeastern United States. They were able to categorize tree species according to relative nitrogen demand. Northern, red, white, and chestnut oak, red maple and quaking aspen made satisfactory growth on relatively N-deficient soils; American beech, sugar maple, pignut hickory, and black gum were intermediate in their N requirements; and yellow-poplar, white ash, and basswood attained best growth only on sites with high N-supplying capacity.

Differences in mineral nutrient requirements have also been observed with fertilizer experiments. For example, McComb (1949) studied the nutrition of seedlings on an Iowa forest soil and three prairie soils and found N was deficient for the growth of green ash, American elm, and northern red oak. Black locust, a legume, responded to P but not to N.

A survey study in the Tennessee Valley indicated that the five-year basal area response to a single application of 336 kg N/ha on widely varying sites averaged about 30% for pines and 50% for hardwoods (Farmer _et al._, 1970a). Yellow-poplar was most responsive--101%. Hickories gained 79%, white oaks 77%, and red oaks 47%. The average duration of response was 4 to 5 years, but for some species, particularly white ash, the response may persist for 7 years (Chandler, 1943).

II. FOREST TREE NUTRITION RESEARCH METHODS

Tamm (1964) has reviewed the methods for the assessment of nutrient status and nutrient requirements, giving their advantages and drawbacks, and the nature of the information obtainable with each.

In general, three approaches have been used to evaluate the nutrient requirements of forest trees: soil analysis, foliar analysis, and fertilizer field trials. Each method has its limitations and all are useful in a coordinated research program.

The potential of soil and foliar analyses for assessing the nutrient status of forest stands and for predicting response to fertilization has been demonstrated (e.g., Wells, 1965). However, there is still some uncertainty and disagreement among researchers as to the best procedure to use for soil and foliage sampling and analysis (Kramer and Kozlowski, 1960; Phares, 1971a).

The development of the technique of foliar analysis has been reviewed by Ingestad (1962). Although foliar analysis has become a popular method for diagnosing the nutrient status of forest trees, this valuable tool must be further refined before it can be put to full and effective use. Correct interpretation of foliar analysis results requires a knowledge of the intricate relationships between nutrient supply, growth, and foliar composition.

Nutrition experiments can be classified into three categories: sand and solution culture, soil pot culture, and fertilizer trials in natural stands or plantations. Certainly field experimentation is the ultimate test. But this technique is often laborious and time consuming, especially using trees. More and more tree nutrition research is being conducted in greenhouses because there is greater control of environmental conditions, more complicated designs can be used, and results are obtained quicker and are generally easier to evaluate. Pot experiments have been used for diagnosing nutrient deficiencies, to obtain rough quantitative evaluation of fertilizer requirements and nutrient interactions, to evaluate fertilizer sources, and to study soil moisture-fertility relationships (Mead and Pritchett, 1971).

Sand culture techniques have yielded valuable information on deficiency symptoms and interactions between various nutrient elements as they affect the physiology and development of seedlings. However, the utility of the results for field fertilization prescriptions is questionable. The artificial environment, the inert rooting medium, and the extreme juvenility of the trees make extrapolation of results from sand culture to forest conditions very difficult (Tamm, 1964; Bengtson, 1968b; Mead and Pritchett, 1971).

Probably the use of soil pot cultures coupled with carefully evaluated field tests is a more efficient approach when the concern is with qualitative and/or rough quantitative evaluation of fertilizer requirements of a particular tree species--soil complex. In this procedure, the peculiar nutrient-supplying and nutrient-fixing potential of a particular soil, as well as its microbial components, are allowed to exert their often important influence (Bengtson, 1968b).

III. SOIL POT EXPERIMENTS

The growth response of cottonwood to various N, P, K, and lime additions to four bottomland soils common to the Midsouth was reported by Broadfoot and Ike (1968). On Sharkey clay and Adler silt loam there were no growth responses. However, uptake of some elements was increased. Lack of response was attributed to the relatively high fertility levels of the native soils. On Commerce silt loam there was a slight but statistical significant growth response from high N alone or in combination with K or P and K. Complete fertilizer and lime increased growth of seedlings on Bibb sandy loam but growth was poor even with amendments.

Lunt (1947) reported on a series of studies to determine the growth response of several conifers, southern red oak, sugar maple, white ash, and a hybrid poplar to N, P, and K alone and in various combinations with and without lime. Seedlings were grown in concrete frames filled with Cheshire loam soil and resting directly on natural subsoil. The growth of oak was reduced by the addition of lime. Response to other treatments was inconsistent but appeared to be greater on N-treated soil. In general, the foliar concentrations of the major elements were increased by additions of those elements. In oak leaves the SiO_2 concentration was considerably lower and P higher on limed than on unlimed soils. Maple showed a positive growth response to lime in most cases, and, in general, growth was increased by fertilizer treatment. White ash growth was increased by both N and lime. Foliar P concentration was increased by P fertilizer particularly in the absence of N; SiO_2 concentration was increased by lime and P; Ca by N (directly) and K (inversely); and Mg by lime (directly) and K (inversely). In both maple and ash a high concentration of K in the soil resulted in a lower foliar Ca concentration. Growth of the hybrid poplar was more uniform and the response greater than for other species. The N caused the greatest response, lime next, and P third. The effect of K was inconsistent.

Yellow-poplar has been the test species in three soil pot studies. Chapman (1933) followed the development of one-year-old seedlings potted in Clermont silt loam for 2 years. Soil was treated at the rate of 0, 22, 45, 112, 224, and 448 kg N/ha as NH_4NO_3. All rates produced growth responses. The N concentration of leaves, bark, wood, and roots increased to a maximum at the 448 kg rate. Maximum dry weight yield was attained at the 112 kg rate; for height growth it was the 45 kg rate. Root/shoot ratios decreased with increasing N-supply.

As a sequel to a sand culture experiment, Finn (1966a) studied the response of yellow-poplar seedlings to N, P, and K added to sandy, sandy loam, and clay loam soils. Uptake increased following fertilization, but growth response was small. Phosphorus applied to the sandy loam soil produced the most consistent response. Soil texture and associated physical properties were the more dominant growth factors--more so than soil fertility.

Auchmoody (1972) examined the growth of northern red oak seedlings in relation to all combinations of three levels of N (0, 224, 448 kg/ha), and P and K (0, 112, 224 kg/ha) supplied to forest soils (Barbour series) in gallon-size plastic pots. Nitrogen alone significantly increased seedling height and top dry weight but negatively affected root dry weight. There was no response to P or K applied singly or in combination with each other without N. Nitrogen and P applied together gave large increases in height and top dry weight above response obtained from N alone.

In Iowa nothern red oak seedlings were grown from seeds in pots of surface soils from two forest sites (Lindley and Clarksville series) and two old-field sites (Shelby and Clarksville series) (Phares, 1971a). The forest soils supplied more N and P and produced better growth than the non-forest soils. Results of fertilizer treatments applied as a 2^3 factorial series with applications of 100 kg N, 90 kg P, and 90 kg K, and as a rate series in which 0, 34, 100, 200, and 400 kg N/ha were added with 90 kg of P and K/ha indicated that all soils lacked sufficient N and P for maximum growth of red oak seedlings. Apparently there was sufficient K in the soils because additional K produced no growth response. At the 90 kg P/ha rate seedling dry weight increased 38% on forest soils and 62% on non-forest soils. There was a strong correlation between total seedling dry weight and foliar P concentration. The linear relationship indicated that more than 90 kg would be necessary to maximize seedling growth. Nitrogen stimulated growth only in combination with P. The optimum rate of N appeared to be between 100 and 200 kg/ha. Heavier rates depressed total dry weight and resulted in lower root/shoot ratios.

Foliar N concentration associated with maximum growth averaged 2.5% (2.2 to 2.7) on all soils. This agrees with Mitchell and Chandler's (1939) data from fast growing 40-year-old red oak trees of 2.46 to 2.57%. Apparently foliar N concentration of red oak does not vary much with age.

Phares (1971b) also studied the growth and nutrient uptake of red oak seedlings under conditions simulating a forest overstory. The tallest seedlings grew in 30% of full light; seedlings in full light had the greatest dry weight accumulation. Seedlings in full light had an average height of 25 cm, and those at 30 and 10% averaged 33 and 22 cm, respectively. Only seedlings in 30% or more light responded in height growth to an NPK fertilizer. Seedlings in 10% light accumulated nutrients but showed no growth response to fertilization. Thus, fertilization did not lower the minimum light requirements.

Black walnut seedlings grown from seed in Ames clay loam and Thurman sand were subjected to two soil moisture regimes (within 75% of field capacity and approximately a 20-day drying cycle from field capacity to near wilting point) and three fertility levels (0; N, P, K, at 153, 43, and 160 kg/ha applied 27 days after planting; and the same rate and time of application as above plus NPK at double these initial levels applied 30 days later) (Dickson, 1971). After four months all treatments had significantly affected growth and nutrient uptake. Seedling dry weight increased significantly with fertilization in both soils but only under the high moisture level. Fertilization at the low moisture level produced no gain in seedling dry weight. In fact, in the fertilized sandy soil at the low moisture level, root growth was significantly less than in the unfertilized soil. Even low rates of fertilization on the sandy soil were detrimental to walnut seedlings under low moisture level. Nitrogen was the element most responsible for the better growth at high moisture levels.

Combinations of N, P, and K with and without dolomitic limestone were added to five horizons (A2, B22, B23, B3, C) of a well-drained Hermon soil (Hoyle, 1970). Yellow birch seedlings (from seed) were grown in potted soils in a greenhouse for about four months under a 20-hour photo-period with supplemental incandescent light. Seedling growth in the A2 showed a primary response to P and a secondary response to N, while K, Ca, and Mg status seemed adequate. Primary P and secondary N responses were shown in the four subsoil horizons also, but, in addition, there were tertiary responses to K, Ca, and Mg. Growth equal to that in untreated humus was made by NP seedlings in the A2 and by NPK plus limestone seedlings in B22, B23, and B3. This maximum nutrient treatment greatly improved growth of seedlings in the C horizon but not up to levels found in humus. Tissue analyses further verified deficiencies of the macronutrients, and indicated possible toxic levels of Mn in leaves and Al in roots, and an amelioration of these conditions by adding dolomitic limestone.

The foliar N concentration of pedunculate and sessile oak seedlings grown in woodland conditions and in the greenhouse were of the same order (Newnham and Carlisle, 1969). Plants grown in the greenhouse had a significantly lower P concentration than those grown in the woodland. Results of this experiment and an associated sand culture experiment indicated that the typical soils of the oakwoods in the Southern Lake District of England had sufficient available N but insufficient available P for maximum growth of oak seedlings.

IV. FERTILIZER FIELD EXPERIMENTS

In the United States some of the earliest use of fertilizers was concentrated on correcting mineral deficiencies on adverse planting sites. Cummings (1941) applied 27 mixtures of an NPK fertilizer with supplements of dolomitic limestone or acid peat to three species--shortleaf pine, white ash, and yellow-poplar at the time of planting on oldfields and spoil banks from strip coal mining in the Central States. There was no marked superiority over untreated trees in height growth during the first two years, although differential responses of the three species to the individual nutrients were indicated.

In West Virginia a 4-12-4 fertilizer was placed 15 cm below the surface of an eroded DeKalb soil within reach of the roots of black locust and red pine (Holsoe, 1941). Despite the fertilizer placement weed growth was increased and only black locust was able to compete successfully. It was recommended that slow-growing intolerant species should not be fertilized when planting unless control of competition was planned.

In Indiana DenUyl (1944) placed a 2-12-6 fertilizer in the hole at the time of planting black locust on the compacted subsoil of Bedford silt loam which was deficient in nutrients. The fertilizer resulted in a marked increase in height, diameter, and root growth in comparison to the unfertilized. The effect was still evident after four years.

McComb (1949) applied N and P in loose and briquet form to planted black locust, green ash, American elm, and northern red oak seedlings. He concluded that under average eroded-field conditions in Iowa, fertilizer response of hardwood plantings will probably be small or nil. Exceptions might exist in areas completely devoid of surface soil and bare of any ground cover. Phosphorus fertilization of black locust was indicated for quick, complete coverage of gullied subsoil.

More recent tests have stressed soil-plant relations and stimulation of early growth for economic reasons on sites varying from very good to poor. In the Georgia Piedmont, one-year-old yellow-poplar seedlings fertilized with diammonium phosphate showed increases in height each year over unfertilized seedlings (Ike, 1962). After four years tree crowns on the most heavily fertilized plot (1,120 kg/ha) were closing. Control plots and those receiving only light fertilizer (0 to 560 kg/ha) were being invaded by volunteer sweetgum.

In the Ridge and Valley region of East Tennessee, three levels of N (0, 336, 672 kg/ha) and P (0, 168, 336 kg/ha) fertilizer were applied at the time of planting to run-of-the-bed 1-0 yellow-poplar seedlings (Farmer et al., 1970b). Nitrogen fertilizer was applied in holes near the trees by two methods: loose and in perforated bags. Phosphorus was applied loose in separate holes. Survival after five years was 56% and was not influenced by treatment. Both N and P stimulated growth during the first two years after planting but P was effective only in combination with N. During this period, loose application of N gave better results than bagged. After five years only N effects were statistically significant; mean height (2.2 m) of trees receiving 672 kg N/ha was 70% greater than controls. At nine years, control plants averaged 3.9 m while those fertilized with 672 kg N averaged 5.6 m, or 44% taller (Buckley and Farmer, 1974).

In the hilly upper Coastal Plain of northwest Alabama, Whipple and Moeck (1968) applied the equivalent of 112 kg N/ha in holes and 112 kg P/ha in a 61-cm circle around newly planted 1-0 yellow-poplar, sycamore, sweetgum and loblolly pine seedlings. The beneficial effect of fertilization on height growth was apparent the first growing season. Response varied greatly between species but not with slope position. Fertilized sycamore was tallest, yellow-poplar second, and sweetgum third. Fertilized pine grew less than any of the hardwoods fertilized or unfertilized. Fertilized yellow-poplar had the greatest increase in growth over the control with a 217% increase. Fertilized sycamore and sweetgum ranked second and third, respectively, 163 and 110%. On fertilized plots survival was better on lower slopes than on upper slopes or in bottoms. Unfertilized plots in the bottoms had as much and sometimes more competing vegetation than did fertilized plots on the slopes. Competition appeared to be a critical factor in the bottoms and to a lesser extent on the slopes.

Broadcast spring applications of N (NH_4NO_3) made the first growing season on an overflow bottomland pasture on the Oconee River floodplain in northeastern Georgia stimulated the growth of sycamore (A. F. Ike, Jr. and J. R. Saucier, 1969. Growth responses and wood properties of young sycamore (Platanus occidentalis L.) following fertilization. Agron. Abstr. p. 124). Simultaneous applications of P and K produced very small but measurable increases in height growth. After seven years with no additional treatments, height differences among fertilizer treatments became very small, but volume differences attributable to first-year fertilizer treatments persisted. Trees fertilized at age one with 336 kg N/ha produced 44.6 T dry wood/ha at age seven compared with 36.1 T/ha for trees receiving no N. There were no changes in wood properties associated with fertilizer additions.

In the first of two factorial field experiments, Kitzmiller (1972) annually applied four sources of N at rates of 112 and 224 kg/ha, and P (as superphosphate) at 56 and 112 kg/ha, from 1969 to 1971, to 20 families of sycamore from two Carolina provenances. The families were planted as 1-0 seedlings on a disked forest site in the Piedmont of North Carolina in 1969. Height and relative volume were significantly correlated with root collar diameter for all plants and treatments.

This correlation decreased during the three-year study period and decreased faster at high concentrations of N and P. No family x fertilizer interactions were detected, but there was significant variation among families for height and volume growth. Growth was significantly poorer when N was supplied as urea than as $NaNO_3$, NH_4NO_3 or $(NH_4)_2SO_4$. A significant growth response to P was not detected until after the third year, and volume was affected more than height. Foliar analyses indicated that unfertilized sycamore seedlings were severely deficient of N for satisfactory growth on the Piedmont ridge site. Nitrogen uptake and leaf production were greatly enhanced by the 224 kg/ha rate of N. The source of N had significantly affected foliage weight and foliar N concentration during the second growing season. Total N taken up in foliage was only one-half as great as from urea as from the other sources.

In the second experiment, N (NH_4NO_3) at 224, 448, and 672 kg/ha was applied in 1970 and 1971 to 48 families from five Georgia and North Carolina provenances. The families were planted as 1-0 seedlings on a bottomland site and an adjacent upland site (both of which had been disked and bedded) in the Virginia Piedmont in 1970. A single rate of P and K was applied to all plots in 1971. Height growth varied significantly among families on both sites. Also, there were significant, but weaker, family x site and family x fertilizer interactions. Each family was taller on the bottomland. Thus the family x site interactions were probably caused by soil moisture differences. The families most responsive to fertilization were not necessarily those most responsive to better site conditions. The foliage of seedlings receiving fertilizer had about three times greater dry weight and N content than those receiving no fertilizer. No additional dry weight response was obtained from adding N in excess of 224 kg/ha. Although N content did not increase significantly with additions of N greater than 224 kg/ha, the concentration of N in the foliage was directly proportional to levels of fertilizations. In contrast, the concentrations of K and Ca were inversely related. As N fertilization increased, the uptake of N by the trees proceeded more rapidly than production of leaf mass, resulting in higher average foliar concentration of N. Oppositely, the uptake of K and Ca did not keep pace with growth increases, which resulted in a "dilution effect."

Trees propogated from cuttings of 22 clones of cottonwood were grown under unfertilized and N fertilized conditions at TVA's nursery in Anderson County, Tennessee (Curlin, 1967). Fertilizer treatment consisted of 34 g of N/tree (NH_4NO_3) applied in perforated plastic bags buried 15 cm below the surface after rooting and apical elongation of the cuttings had begun. Large increases in growth resulted from fertilization. Mean diameter and height more than doubled and mean volume increased about nine-fold. A strong clone x fertilizer interaction was observed for diameter, height, and volume growth. Wood specific gravity was reduced by fertilization but no interaction between clones and fertilizer was noted for that character after two years.

The application of 6.72 T lime/ha to acid Coastal Plain bottoms produced a 17% increase in total height of a one-year-old cottonwood plantation.[2]

The use of 56-g packets of 19-5-17 fertilizer placed 20 cm deep and 30 cm from the seedlings in a Lapeer fine sandy loam in southcentral Wisconsin was tested by Attoe _et al_. (1970). The fertilizer treatments increased by 10 to more than 100% the rates of height and diameter growth of silver maple, white ash, sugar maple, and cottonwood.

Site preparation consisting of plowing and disking followed by chemical weed control for the first three years after planting were found to be necessary for the successful establishment of sugar maple, northern red oak, basswood, black locust, silver maple, and white ash plantations in southern Ontario (von Althen, 1973). White ash responded more readily to surface fertilization than any other species. After eight years height growth of ash seedlings on plots weeded and fertilized with N (336 kg/ha), P (179 kg), and K (179 kg) was double that of seedlings weeded but not fertilized.

Three levels each of N, P, K, and lime (0, 112, 448 kg/ha) were broadcast on a Clarksville cherty silt loam soil in east Tennessee which had been planted to one-year-old seedlings of American filbert, northern red oak, sugar maple, and white oak (Curlin, 1961). None of the fertilizer treatments influenced seedling survival. Nitrogen stimulated height growth of filbert during the first growing season; P had a like

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[2]From unpublished Minutes, Forestry Research Advisory Committee Meeting, Southern Hardwoods Laboratory, Stoneville, Miss., January 20, 1972.

effect on white oak the second and third seasons. None of the fertilizers affected the growth of red oak or maple.

In contrast to previous reports (Curlin, 1961; McComb, 1949) on N fertilization of planted northern red oak, distinct beneficial effects were observed in a test at an abandoned East Tennessee forest nursery characterized by a well-drained loam soil (Waynesboro) with a cover of fescue sod (Foster and Farmer, 1970; Buckley and Farmer, 1974). Applications of NH_4NO_3 were made during the first two years, and after the third growing season, all trees except controls received a commercial fertilizer (15-15-15) at a rate of 639 kg/ha. After four years, the combined effects of seedling selection and fertilization produced trees which averaged 1.7 m in height; controls averaged 0.7 m. Height differences due to these treatments have continued through eight years with the effect of fertilizer outweighing that of seedling size.

Ammonium nitrate and superphosphate were applied singly and in combination to a one-year-old black walnut plantation growing on Amana silty clay loam in Iowa (Finn, 1966b). Nitrogen was broadcast at 0, 321, 642, and 1,284 kg/ha and P at 0, 56, 112, and 224 kg/ha. Neither N or P increased the foliar concentrations of these elements. It was assumed that P was converted into insoluble compounds and made unavailable while N although available was not absorbed. Foliar analyses revealed a probable K deficiency. Black walnut trees growing 0.9 m or more per year should have foliar K concentrations of about 1.5%, but in the reported study K averaged about 0.9%. A probable K deficiency was further verified by the correlation of H growth with foliar K concentration. An additional study of P fertilizer placement in a one-year-old plantation was inconclusive. The single-furrow treatment resulted in a 50% gain in both height and diameter the first growing season, but the actual gains were 15 cm and 6 mm.

In Michigan seedlings were planted in fields and forest openings in conjunction with mulching, irrigation, and fertilization in an attempt to improve the establishment of black walnut (Schneider _et al_., 1970). Forest openings 9, 13.5, and 21 m wide were made in red pine and white pine plantations in both N-S and E-W directions. Mulch consisted of a 3 cm layer of wood chips 1 m in radius around the tree. Irrigation as 7.5 l/tree/wk. was applied from May to August. Fertilizer in 56-g slow release perforated plastic packets containing 11 g N, 2.5 g P, and 9.5 g K were placed 25 cm deep and 10 cm to the side of the tree.

Wind was a critical factor in the early establishment of walnut. Mulching and irrigation increased soil moisture, but did not compensate for lack of wind protection. Mulching increased the amount of exchangeable soil K. Fertilization did not significantly increase height and stem increment until the third growing season.

With one exception fertilizer experiments with seedling-to-sapling-size hardwoods have been located in the lower Mississippi River area. Blackmon (B. G. Blackmon, 1973. Response of eastern cottonwood plantations to fertilization: rates of nitrogen. Agron. Abstr. p. 137-138) applied five rates of N (0, 84, 168, 336, and 672 kg/ha from NH_4NO_3) to two old-field sites supporting low-vigor seven and ten-year old eastern cottonwood plantations. Both sites are in the Mississippi

River floodplain. Treatment effects were monitored over a two-year period. A quadratic growth response peaked at approximately 336 kg in the seven-year-old stand. In the 10-year-old stand, the response was linear, with best growth occurring at the highest rate. The largest volume responses were 150-200% greater than the unfertilized control. Foliar N increased significantly and was highly correlated with volume growth. Two years after fertilization, all treated plots maintained a growth advantage over the controls. However, this advantage had diminished considerably at the 84- and 168-kg rates. At the end of the second growing season, increased N in tree foliage and herbaceous vegetation could be detected only on plots treated with the higher rates of N.

On an old-field in the Mississippi River floodplain on which cottonwood had been planted six years before, application of 168 kg N/ha (NH_4NO_3) greatly increased tree growth in diameter, basal area, height, and total volume (B. G. Blackmon and E. H. White, 1971. Productivity of cottonwood plantations of old-field soils increased by nitrogen fertilization. Agron. Abstr. p. 117). Growth after application of 112 kg P/ha was no different from that on control plots, and P in combination with N was no better than N alone. Foliar concentrations of N in the upper and lower crowns were closely correlated with growth. Foliar P was poorly correlated with growth; however, r^2 values were higher for data from the lower crown. Best growth was made by trees with a foliar N concentration exceeding 2%.

Sycamore has shown no early response to lime or fertilizer on Coastal Plain soils. Microsite variations may be masking the response.[3]

Improved growth was still evident five years after vertical mulch and fertilizer (1,120 kg/ha of 13-13-13) was applied to a two-year-old yellow-poplar plantation on a severely eroded upland site (Memphis silty clay loam).[4] Mulch and fertilizer produced a height growth advantage of 45% (2.6 and 3.7 m). On two other sites not as severely eroded, the same treatments produced no significant increases in growth. Also, a broadcast application of the same rate of fertilizer produced only a slight height increase after four years.

Thirty-two fertilizer combinations were broadcast within circular milacre plots around understory dogwood trees in the understory of mixed pine-hardwood stands in east Tennessee (Curlin, 1962). These multi-aged stands were growing on the Clarksville-Fullerton-Dewey soil association. Nitrogen was applied as NH_4NO_3 at 0, 112, 336, 1,008 kg/ha; P as calcium metaphosphate and K as KCl were applied at 0, 336 kg/ha. Dolomitic limestone was applied at 0, 1,120 kg/ha. Average annual diameter growth per tree for all treatments was 12, 8, and 9 mm for the first, second and combined third and fourth growing seasons. The first season after fertilization diameter increased with increasing N-supply. Response was less pronounced the second season, and was not statistically significant for the third and fourth seasons. None of the other fertilizer treatments produced any noticeable growth response.

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[3] Ibid.

[4] Ibid.

Tests to measure the response of hardwood stands and plantations older than 10 years to fertilizer supplements have been conducted throughout eastern United States with a wide variety of species. Data from a fertilization experiment in 40-year-old heavily thinned mixed hardwood stands in New York indicated that P uptake by red maple was approximately twice as much as by northern red and chestnut oak growing on similar sites (Mitchell and Finn, 1935). The concentrations of foliar P increased with increasing rates of P fertilizer. Growth response was not studied.

Finn and Tyron (1942) compared the effects of leaf mold, sodium nitrate, and superphosphate on the growth of a 50-year-old northern red oak stand in New York. All treatments resulted in increased radial growth. The largest increase was obtained with 22.4 T of leaf mold/ha. Foliar N and P concentrations were closely correlated with growth. Trees making the best growth had the lowest foliar K concentration.

Mitchell and Chandler (1939) conducted a series of tests to determine the N nutrition of many hardwood species in New York forests. The N concentration of foliage varied with soil N. Within limits radial growth varied with soil N, thus foliar analysis provided a measure of site quality. A given species on variously fertilized plots approached maximum radial growth for the site at approximately the same relative N supply. Species were grouped according to their tolerance of N deficiency. These groups and the species in each were enumerated earlier (p. 5).

A single broadcast application of 22.4 T/ha of hydrated lime with and without varying rates of water soluble fertilizer containing N, P, K, Mg, and Zn was applied to a 75-year-old sugar maple stand (L. R. Auchmoody and H. C. Smith, 1971. Four year effects of fertilization and lime on mineral composition of sugar maple foliage. Agron. Abstr. p. 116). Foliar N, P, K, Ca, Mg, Mn, Zn, Cu, and Fe were monitored annually for four years in order to assess the effectiveness and longevity of nutrient treatments. N and Mg fertilization increased foliar concentrations during the first season, but had little effect in following years. Fertilization sharply increased Ca uptake from lime during the first season, but not thereafter. Concentrations of P, K, and micronutrients were unaffected by fertilization. Liming increased utilization of fertilizer N during the season of application, but had no lasting effects. Ca uptake, without fertilization, was not greatly affected by liming until the fourth season. However, Mg concentration was increased the first season and was maintained during the following three seasons. Mn levels declined during the third and fourth seasons, presumably from decreased Mn availability brought about by changes in soil pH.

Nitrogen, P, and Ca fertilizers were applied to a 50-year-old upland oak stand located on a DeKalb sandy loam soil in the Allegheny Plateau region of central Pennsylvania (Ward and Bowersox, 1970). Additions of 67 and 200 kg N/ha significantly increased the diameter growth of white and scarlet oaks. Addition of 1,120 kg Ca/ha also increased diameter growth of both species. Added P had no measurable influence. The combinations of N and Ca additions increased stand volume increment more than 40%. This increase in growth was associated with increased foliar N concentration and of litter following leaf fall. Nitrogen and Ca, but not P additions also increased the growth of understory browse plants such that the carrying capacity for white-tailed deer was substantially improved.

Various N, P, and K commercial fertilizers were broadcast at several rates to a 20-year-old slow-growing yellow-poplar plantation situated on Fox and Warsaw sandy loams in southwestern Michigan (Finn and White, 1966). Adding 376 kg N, 82 kg P, and 156 kg K/ha increased five-year height growth 100% and diameter growth 85%. Volume growth was increased over 200%. Leaf weight increased, color changed from a yellow-green to normal green, and leaf abscission was delayed by adding N. Height and density of weeds were greatly increased by adding N.

Vimmerstedt and Osmond (1970) made a single broadcast application of varying amounts of N, P, K, and Ca in a 6.1 m radius around individual 30-year-old yellow-poplar trees. The plantation was located in north central Ohio at the extreme southern edge of glaciation on Loudonville and Gilpin silt loams. The experimental design was a rotatable, central, composite with 31 treatment combinations. Exchangeable soil K increased with increased K applied. Applied N decreased the amount of exchangeable soil K after K fertilization. Foliar K concentration increased with applied K. High levels of N decreased foliar K. In the first year P fertilizer tended to raise foliar K of trees receiving low K and to lower foliar K at high K rates. There was a delayed response to Ca fertilization. In the second and third years 3,360 kg/ha did not result in any greater levels of exchangeable soil Ca than did 2,520 kg.

Exchangeable soil Ca was depressed as N rate increased. Foliar Ca did not show the effects of Ca fertilization until the third year. This effect was modified by K fertilization which depressed foliar Ca. Available soil P was linearly correlated with P rates of fertilization with a greater effect the second and third years. Foliar P was also higher in years two and three. Ammonium nitrate applications did not significantly affect total soil N. Foliar N increased as the rate of N fertilization increased with the greatest response in year two. P and Ca fertilization both affected foliar N. The only statistically significant effect of fertilizer on height growth was in year two when Ca depressed height growth. No treatment combination was clearly optimum for volume growth.

Five-year response (basal area growth) of pine and mixed hardwood stands to a single application of N (336 kg/ha) and P (74 kg/ha) fertilizers was studied in 37 tests throughout the Tennessee River Valley (Farmer et al., 1970a). Nitrogen effects were consistently positive, although highly variable among locations. Supplementing N with P produced a small additional mean response, but was not consistently effective. Responses during the fourth and fifth years after treatment were less than during the first three years. Hardwood species ranked according to their response measured in terms of growth as a percent increase over nonfertilized were: yellow-poplar, hickories, white oaks, and red oaks. Of the 37 tests, 10 hardwood stands which exhibited the best response to N during the first five years were remeasured after 10 years (Buckley and Farmer, 1974). There was a consistent decrease in response (basal area) during the second five-year period from 50% to about 20%.

Diameter and height growth were significantly increased in a 20-year-old sweetgum-water-willow oak stand by annual top-dressings of NH_4NO_3 and of complete NPK fertilizer (Broadfoot, 1966). For all species combined, 336 kg N produced a 65% increase in diameter growth and complete fertilizer produced a 44% increase in height growth. Nitrogen fertilization significantly increased N concentration of foliage of all species. Foliar P and K concentrations were not significantly affected. However P concentration of sweetgum decreased slightly as N was increased. Exchangeable K in the soil decreased with increasing N applied. A year after the last fertilizer application there were no differences in N or P content of the soil. With increasing N application, however, the K content of soil decreased.

Nitrogen (224 kg NH_4NO_3/ha), P (112 kg, superphosphate/ha), and K (112 kg muriate of potash/ha) were broadcast annually for five years in all combinations on a 19-year-old sweetgum plantation (Gilmore et al., 1971). The plantation was on the floodplain of Bay Creek, Pope County, Illinois, which was usually covered with floodwater two or three times each spring (Sharon and Belknap silt loams.

Nitrogen was the only single treatment that caused a growth response in basal area, diameter, or height. The NPK treatment was the only combination treatment producing a growth response, and this only for basal area.

V. SUMMARY

It is difficult to assess the results of hardwood fertilization because of varying rates, combinations, sources, soils, and species.

There are reports of primary growth responses by seedlings in pots of soil to N and secondary responses to P. On-the-other-hand, there are reports of primary responses to P with N secondary.

Results from experiments with newly planted seedlings are also conflicting. Nitrogen, NP, NPK, and NPK + lime either broadcast or in packets placed in the planting slit have all stimulated height and/or diameter growth of many hardwood species. Growth advantages have been detected up to eight years. In the only test of N sources, the response to urea was only one-half that from three inorganic sources.

In field fertilization trials with sapling-size and larger trees, N appears to be the key element. Growth of a variety of species from bottomland hardwoods to upland oaks and Appalachian hardwoods have been stimulated by supplemental N. But NP, NPK, and lime have also stimulated growth.

Reports of response to P alone are rare. Evidently natural hardwood stands of commercially valuable species are on better sites where P is adequate. Less fertile sites may be deficient in P for optimum hardwood growth.

Published accounts indicate diameter growth responses up to 85%, height to 100%, and volume in excess of 200%. In others, uptake has occurred but growth responses were nil.

White ash may require as much N as does yellow-poplar. Poplar seems to be more tolerant of heavy fertilizer applications than are many hardwoods and a balanced supply seems to increase poplar's resistance to high fertilizer salt concentrations. However, it does not necessarily follow that white ash will behave in a similar fashion just because its N requirement is the same. Typical sites may be deficient in P for optimum growth of white ash particularly in the seedling to sampling stage.

CHAPTER III

EXPERIMENT-1. SEEDLINGS IN POTS OF SOIL

I. SCOPE AND OBJECTIVES

In experiment-1, the response of white ash seedlings growing in mixed topsoil of two representative forest soils--one from the Cumberland Plateau derived from sandstone and one from the Highland Rim derived from cherty limestone--were tested. Objectives were:

1. To evaluate the ability of two forest soils to supply the nutrient requirements of white ash seedlings,
2. To determine the growth response of white ash seedlings to all combinations of four levels each of supplemental nitrogen and phosphorus,
3. To relate foliar concentrations and contents of N, P, K, Ca, and Mg to applied amounts of N and P, and
4. To relate seedling growth and development to foliar composition of N, P, K, Ca, and Mg.

II. METHODS AND PROCEDURES

Design and Analysis

The study was designed as a split plot experiment to permit a test of soils. This did not preclude an analysis of each soil sepaately. The three replications of the two soils constituted the major plots. Minor plots consisted of the complete factorial arrangement of four levels each of N and P supplements. Since each soil was obtained from three distinct locations, differences between soil locations were confounded with blocks.

Various expressions of seedling growth and foliar composition, both relative and absolute, of N, P, K, Ca, and Mg were evaluated by analysis of variance (ANOVA). Nitrogen and P main effects and their interaction were analyzed by generating the linear, quadratic, and cubic components. The format of the ANOVA is shown in Table 1. The null hypothesis of no differences in foliar composition or seedling growth due to N and P levels was rejected when observed differences exceeded the 0.05 level.

Relationships between seedling biomass and foliar composition were determined by using the combinatorial screening capabilities of REX (Grosenbaugh, 1967).

Soils

Thw two selected soils occupy extensive acreage and are major forest soils in Tennessee and Alabama, and perhaps Georgia and Kentucky. The Hartsells series is a member of the fine-loamy, siliceous, thermic family of Typic Hapludults. These soils have dark grayish brown to brown fine sandy loam or loam A horizons and yellowish brown B2t horizons of fine sandy clay loam or clay loam. Acid sandstone bedrock is at 0.5 to 1 m.

The Bodine series is a member of the loamy skeletal, siliceous, thermic family of Typic Paleudults. These soils have brownish surface soils and yellowish brown and/or strong brown loamy subsoils containing 35 to 90% by volume of chert fragments.

Table 1. Format of the Analysis of Variance of Experiment-1

Source of Variation	Degrees of Freedom
Major plots	(5)
Blocks	2
Soil (S)	1
Error I	2
Minor plots	(90)
Nitrogen (N)	3
Phosphorus (P)	3
N x P	9
N x S	3
P x S	3
N x P x S	9
Error II	60
Total	95

The potting medium consisted of mixed A1 and A2 horizons from forested sites near white ash trees of experiment-2. Each soil was obtained from three distinct locations in order to provide a stronger basis for the extrapolation of results. The soil sources and corresponding tree number in experiment-2 are shown in the following tabulation.

Soil and Source	Experiment-2 Tree Number
Hartsells	
Franklin-Marion State Forest	106
Five Points	101
Cape Cod	105
Bodine	
Cascade Springs	701
Jernigan	707
Mayes	706

The soil was screened through 1.3-cm mesh when collected to remove large stones and roots. After transporting to the Laboratory the soil was air-dried for a few days. The 10 kg (over dry basis) aliquots were weighed and the appropriate amount of fertilizer was thoroughly mixed with the soil before filling each 11.4-l glazed crock (pot). The fertilized potting media were incubated 30 to 37 days before sowing seed.

Properties of the soils used for potting media are summarized in Table 2. Bodine sources were more variable than Hartsells sources. There was little difference in pH and extractable bases of Hartsells sources. Organic matter, extractable P and total N of the Cape Cod source were somewhat greater than those from Franklin-Marion State Forest

Table 2. Chemical and Physical Properties of Mixed A1 and A2 Horizons Used in Potting Media--Experiment-1

Location and Block	pH	Extractable Bases K (meq/100g)	Extractable Bases Ca (meq/100g)	Extractable Bases Mg (meq/100g)	Total Acidity (meq/100g)	Extractable Al (meq/100g)	Extractable P (ppm)	Organic Matter (percent)	Total N (percent)	Coarse Material > 2 mm (percent)	Sand (percent)	Silt (percent)	Clay (percent)	Texture
						Hartsells								
Franklin-Marion State Forest-1	4.8	0.49	1.05	0.24	2.29	1.92	3.5	4.5	0.12	0.1	38	40	22	1
Five Points-2	4.9	0.53	1.10	0.16	1.89	1.57	3.5	4.8	0.12	1.0	50	30	20	1
Cape Cod-3	5.1	0.26	1.02	0.24	1.50	1.23	4.2	5.6	0.15	0.1	50	30	20	1
						Bodine								
Cascade Springs-1	4.6	0.56	1.20	0.30	1.54	1.16	11.6	4.6	0.14	15.5	18	56	26	sil
Jernigan-2	6.8	0.74	8.10	1.48	0.10	0.04	4.9	4.1	0.20	14.0	16	56	28	sicl
Mayes-3	5.8	0.53	3.69	0.72	0.25	0.13	5.8	4.2	0.16	7.7	20	54	26	sil

or Five Points. Topsoil from Franklin-Marion had less sand and more silt than Five Points or Cape Cod, but all were classified as loams.

There was good agreement between pH and extractable acidity and Al. The Jernigan and Mayes sources of Bodine had higher pH and base saturation and correspondingly lower extractable acidity and Al than the other four sources.

The location of the Jernigan source was farther downslope (lower elevation) and was probably an intergrade to Dellrose (fine-loamy, mixed, thermic Humic Hapludult). The Cascade Springs source had over 11 ppm of P which was twice the amount in Jernigan and Mayes. Organic matter was similar in all three sources of Bodine. A little less sand and more clay placed Jernigan topsoil in the silty clay loam category; Cascade Springs and Mayes topsoils were silt loams.

Nutrients

Both N and P were supplied as commercial fertilizer (Table 3).

Seed and Seedlings

Seed was collected in the Fall 1971 from a well-formed, reasonably vigorous, forest-grown tree in the vicinity of Sewanee. Seedlings would be half-sib progeny which would reduce the amount of variation in growth among individuals (Terman _et al._, 1970).

Twenty seeds were sown in each pot; the Bodine pots on 14 April 1972 and the Hartsells pots on 17 April. The pots were taken outside and placed in a shadehouse on 27 April after the threat of a late frost was apparently over. Germination was poor, averaging about 20%. All

Table 3. Sources and Rates of N and P--Experiment-1

Element	Source	Rate: Element (kg/ha)	Rate: Fertilizer (g/pot)
N	Ammonium nitrate, NH_4NO_3, 33.5-0-0	0	0
		168	2.24
		336	4.48
		504	6.72
P	Triple superphosphate, TSP, 0-46-0	0	0
		112	2.47
		224	4.94
		336	7.41

pots were thinned to four seedlings in late June. Seedlings grown in a sand-peat moss mixture were transplanted to a few pots in which only three seeds had germinated.

Physical Layout

Pots were placed on wooden benches aligned down the middle of the shadehouse. Each bench accommodated 16 pots or one block-soil combination. Soils were randomly assigned to each pair of benches. On each bench pots (N and P levels) were randomly assigned to one of 16 positions.

Experiment-1 was originally scheduled for termination about 15 September. Because of slow germination, this period was extended to allow more time for the seedlings to respond to nutrient regimes. Supplemental light consisting of a combination of incandescent and fluorescent bulbs was started on 21 August to produce a photoperiod of 15 hours (Fig. 1).

One month later the entire experiment was moved to the University of the South, Forestry Department, greenhouse. The 15-hour photoperiod was continued. Daytime temperature never exceeded 32°C and nighttime was never less than 16°C. Seedling growth was slow, no signs of fall coloration were observed.

Irrigation

All pots were hand-watered with deionized water as necessary to maintain soil moisture levels at no less than 70% of field capacity. Soil moisture status was monitored in each N_0P_0 pot with a six-inch

Figure 1. Layout of experiment-1 in the shadehouse. Supplemental light provided a 15-hour photoperiod after 21 August 1972.

tensiometer (Cat. No. 2700, Soilmoisture gage, Soilmoisture Equipment Corporation, Santa Barbara, California). This size extended about one-half the distance between the soil surface and the bottom of the pot.

Measurements

Experiment-1 was terminated in mid-December. After the leaves were detached, the seedlings were removed from the soil with care to recover as much of the root system as possible. Stem height and root collar diameter of each seedling were measured.

Each seedling was separated into root, stem, rachis-petioles, and leaf blades. Like parts were composited by pots and dried to constant weight at 70°C. Leaf blades were ground in a Wiley mill to pass a 20-mesh screen, placed in sealed glass jars, and stored at room temperature until analyzed.

Soil from each pot was thoroughly mixed. A 0.5 l sample was placed in cotton bags, air-dried, seived through a 2-mm screen, and stored for analysis.

CHAPTER IV

EXPERIMENT-2. TREES IN NATURAL STANDS

I. SCOPE AND OBJECTIVES

In experiment-2, the relationships between the growth of white ash trees in natural stands, their foliar composition, and the properties of the topsoils supporting them were determined. Objectives were:

1. To determine the relationships between sites and tree, soil, and foliage variables,
2. To compare tree growth with foliar N, P, K, Ca, and Mg,
3. To compare tree growth with soil N, P, K, Ca, and Mg,
4. To correlate foliar composition with soil nutrient levels, and
5. To evaluate foliar N and P levels in experiment-2 in relation to foliar N and P levels which produced the maximum response in experiment-1.

II. METHODS AND PROCEDURES

Design and Analysis

Experiment-2 consisted of 56 single-tree plots located on a limited portion of the Cumberland Plateau and Highland Rim in south central Tennessee and extreme northeastern Alabama (Fig. 2).

Univariate ANOVA were made on tree characteristics, topsoil properties, leaf weights and area, and foliar composition to provide an understanding of the effects of site.

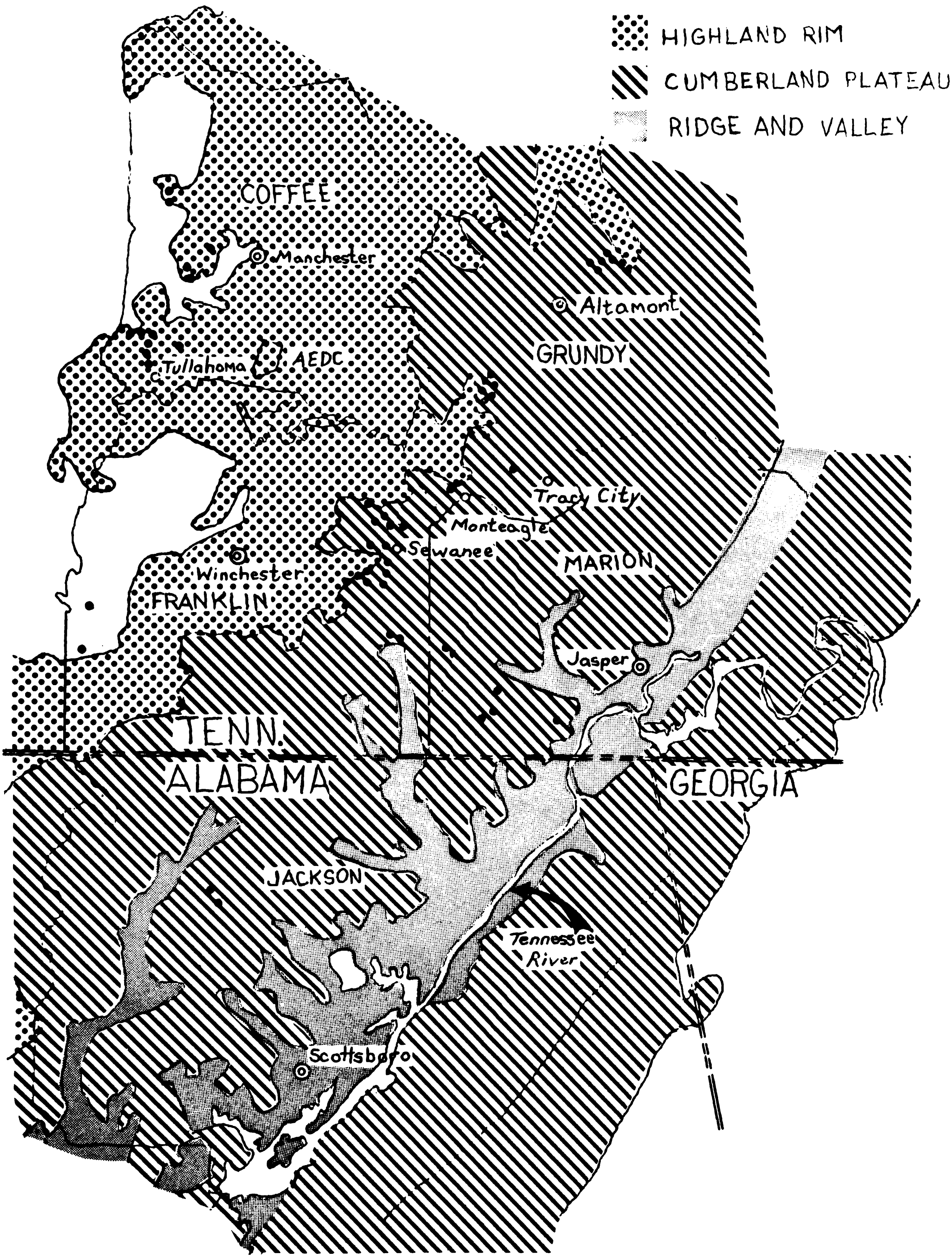

Figure 2. Distribution of white ash sample trees--experiment-2.

Relationships between tree growth, topsoil properties, and foliar composition were explored by regression and correlation analyses (Grosenbaugh, 1967). The 0.05 level of significance was preselected. Means in ANOVA were compared by Duncan's new multiple range test (Duncan, 1955; Harter, 1960).

Variation of topsoil properties and foliar composition was expressed as coefficients of variation. Sampling recommendations involved the calculation of numbers of trees required to estimate means of foliage and soil variables with a preselected precision of 10% at the 0.05 and 0.01 levels of probability.

Sites and Trees

Trees were selected to cover the natural range of sites of white ash. Trees were well-formed, in reasonably closed stands (basal area of trees > 8.9 cm d.b.h. $\geq$ 11.5 m^2/ha), free of visible scars and defects, and in dominant or codominant crown positions. The original plan called for sampling 40- to 60-year-old trees. Not enough could be found in this age bracket. Ages of sampled trees ranged from 37 to 98 years.

At each qualifying tree the following information was recorded:

1. elevation--from USGS topographic maps
2. aspect
3. slope gradient
4. topographic position
5. soil type
6. internal drainage
7. forest type

8. basal area--prism count of all trees > 11.4 cm d.b.h.
9. age--from core at 15 cm above ground.
10. total height
11. diameter breast height.

Seven trees were measured in each of the following eight site categories.

1. Plateau hollows above the escarpment.
2. Coves on the Plateau slopes.
3. Slopeland above 488 m elevation--north aspect.
4. Slopeland above 488 m elevation--south aspect.
5. Slopeland below 488 m elevation--north aspect.
6. Slopeland below 488 m elevation--south aspect.
7. Highland Rim slopes.
8. Highland Rim hollows and bottoms.

These sites were admittedly broad, but the basis for differentiation was biologically valid. Each represented a distinct, easily recognized segment of the landscape and was thought to have a distinct level of productivity.

The lack of suitable ash trees on the Plateau on sites other than hollows was attributable to discriminate cutting and easy accessibility. Sapling-size trees have been found on the Plateau uplands, few saw log-size. The 488-m elevation is the approximate boundary between soils with sandstone influence and those derived from limestone residuum. North aspects included all azimuths measured clockwise between 280 and 100°; south aspects from 100 to 280°. The Highland Rim slopes were on the break between the Highland Rim and the Nashville Basin, but above the arbitrary Chattanooga Shale boundary. White ash is not a component of the Highland Rim "Barrens" forests. All hollow sites were limited to areas not exceeding three vertical meters above the stream bottom.

Soil Sampling

A composite bulk sample of the combined A1 and A2 horizons was obtained from four pits located 2.4 to 3.7 m from each sample tree. The thickness of each horizon was measured.

Foliage Sampling

One branch originating in the upper third of the crown of the south side was shot out of each tree. Thirty-one trees were sampled in 1972. Sampling was terminated on 28 September due to the approaching onset of fall coloration and its attendant translocation of mobile elements. The remaining 25 trees were sampled in late August 1973. A 222 caliber rifle with a 4X scope was used to sever the limbs. Several types of bullets and loads were tested; none was superior to the others. The tough ash wood made it extremely difficult to make a clean break. Many limbs hinged down and then hung on lower limbs once they were severed.

About 25 reasonably perfect, mature leaves from outer twigs were obtained from each limb, placed in plastic bags, sealed, and transported to the Laboratory in styrafoam coolers. Leaflets were detached from the rachises, dried, ground in a Wiley mill to pass a 20-mesh screen, placed in sealed glass jars, and stored at room temperature until analyzed.

Blade area was determined by area/weight relations developed from 2.0 cm^2 plugs taken from every fifth leaflet.

CHAPTER V

LABORATORY PROCEDURES

I. PLANT TISSUE

Ground foliage was redried overnight at 70°C before taking subsamples for analysis.

Subsamples were analyzed for total N by the micro-Kjeldahl procedure (Bremner, 1965).

One-gram samples were ashed for four hours at 450°C. The ash was taken up in 5 ml of 2N HCl and diluted to 50 ml for analysis (Jackson, 1958). Aliquots of these solutions were analyzed for P by the vanado-molybdophosphoric yellow procedure (Olsen and Dean, 1965), K by flame emission spectrophotometry (Pratt, 1965), Ca and Mg by atomic absorption spectrophotometry using lanthanum oxide to suppress interferences at a final dilution of 1% w/v (Perkin-Elmer Instrument Division, 1968).

II. SOIL

Soil texture was determined by the hydrometer method (Bouyoucos, 1951).

Oxidizable organic matter was determined by the Walkley-Black method (USDA Soil Conservation Service, 1967).

Soil pH was measured with a glass electrode in a 1:1 soil-water mixture (Peech, 1965).

Potassium, Ca, and Mg were extracted from the soil with 1N neutral NH_4OAc. Potassium was determined by flame emission (Pratt, 1965) and

Ca and Mg by atomic absorption spectrophotometry using lanthanum oxide to suppress interferences at a final dilution of 1% w/v (Perkin-Elmer Instrument Division, 1968).

Total acidity and KCl-extractable Al were measured by titration (McLean, 1965).

Phosphorus was extracted with a dilute acid-fluoride solution (Bray No. 1) and determined by the molybdophosphoric blue procedure (Olsen and Dean, 1965).

Total N was determined by the macro-Kjeldahl procedure (Bremner, 1965).

CHAPTER VI

RESULTS AND DISCUSSION

I. EXPERIMENT-1

Seedling Growth

Seedling growth was expressed by eight variables. Six were expressions of biomass measured as oven-dry weight (DW) of four seedlings in grams per pot (roots, stems, foliage, shoots, total, and root/shoot ratio). Shoot biomass was the sum of stem and foliage; total biomass was the sum of root and shoot. The other two variables were seedling root collar diameter (mm) and height (cm); calculated as the mean of four seedlings in each pot.

Most biomass variables showed significant linear responses to P-supply while root/shoot ratio and root collar diameter showed quadratic responses to P (Table 4). There were no significant differences due to soil or N-supply, and no interactions.

To insure that the pooled data were not masking soil differences, a comparison was made of the error mean squares from the ANOVA of each soil. Some of these mean squares differed by as much as a factor of two. However, the results of the orthogonal partitions were the same as those for combined soils for all plant variables.

This comparison of individual soil ANOVA also revealed a significant block effect for six of eight growth variables of seedlings grown in Bodine topsoil. This probably reflects the confounded effect of soil

Table 4. Mean Squares Calculated for the Analysis of Growth Characteristics of White Ash Seedlings--Experiment-1

Source of Variation	d.f.	Biomass: Root	Stem	Foliage	Shoot	Total	Root/Shoot Ratio	Root Collar Diameter	Height
Block	2	497.24	29.02	19.92	95.74	1,017.29	1.72	13.31	117.73
Soil (S)	1	476.60	65.34	36.26	198.95	1,291.40	1.13	13.88	248.33
Error - I	2	152.30	17.07	8.33	49.21	359.62	2.50	2.48	39.78
Nitrogen (N)	3	46.32	2.25	1.87	7.53	86.82	0.42	0.10	8.41
Phosphorus (P)	3	1,014.66*	48.00*	53.83*	203.44*	2,125.41*	0.83*	19.08*	210.68*
Linear	1)	2,959.64*	139.75*	158.01*	594.96*	6,208.57*	0.94	54.20*	613.82*
Quadratic	1)	10.47	0.03	0.00	0.01	11.14	1.50*	2.57*	1.13
Cubic	1)	73.87	4.22	3.47	15.34	156.52	0.06	0.48	17.10
N X P	9	42.75	1.67	1.50	6.19	79.29	0.40	0.60	4.70
N X S	3	36.50	3.69	3.19	13.58	91.80	0.17	0.73	7.46
P X S	3	19.08	1.47	0.42	2.71	27.87	0.32	0.26	0.94
N X P X S	9	37.06	1.70	1.84	7.03	70.54	0.33	0.50	5.77
Error - II	60	39.30	2.02	1.70	7.18	76.90	0.29	0.58	6.80

*Significant at the 0.05 level.

source with blocks. The Hartsells soils were fairly similar; the Bodine more variable (Table 2, p. 35).

On the average, all parts of seedlings grown in Bodine topsoil were larger than those in Hartsells, but the differences were not significant.

	Soil	
Plant Part	Hartsells (g/pot)	Bodine (g/pot)
Roots	11.7	16.2
Stems	2.1	3.7
Foliage	2.5	3.7

The trends of biomass with respect to applied N and P are shown in Fig. 3. Each soil was graphed separately to facilitate later discussion of foliage composition. Root, stem, foliage, and total dry weight of seedlings receiving the equivalent of 336 kg P/ha weighed nearly five-times and two-times as much as those growing in Hartsells and Bodine, respectively, with no fertilizer.

The linear relationships indicated that the optimum level of applied P was greater than 336 kg/ha. White ash seedlings should respond to larger increments of P. A similar response plus a secondary response to N was reported by Phares (1971a) for northern red oak seedlings. Total biomass increased 38% at the maximum rate of 90 kg P/ha. Yellow birch seedlings grown in A2 soil of a Podzol (Hermon) showed a primary response to P and a secondary one to N (Hoyle, 1970). The rates were 1,351 kg P/ha and 231 kg N/ha. Finn (1966a) reported 34% and 20% increases in the biomass of two-year-old yellow-poplar seedlings

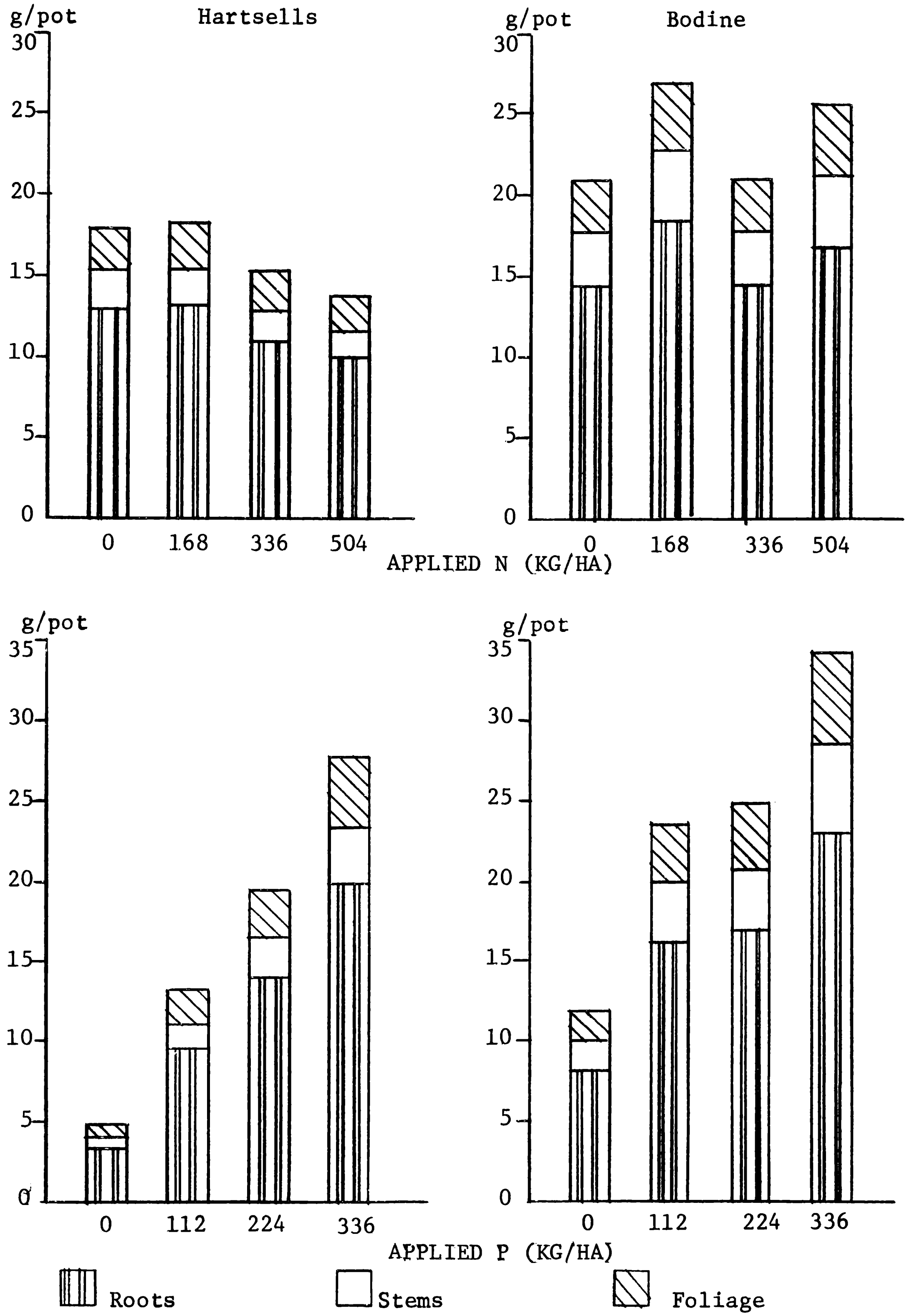

Figure 3. Effect of applied N and P on root, stem, and foliage biomass (DW) of white ash seedlings growing in Hartsells and Bodine topsoils--experiment-1.

on sandy (Spinks) and sandy loam (Conover) soils, respectively, from added P. The maximum rate applied was 266 kg/ha. In the only soil pot study with white ash, biomass was increased by N and lime but not P (Lunt, 1947).

Judging from past research with white ash and associated species, and the low levels of N in both soils, a response to N was expected. The lack of response to N in the face of a linear response to P and no interaction indicated that P was probably limiting in both soils; more so in Hartsells than in Bodine. A response to N may be possible when limiting P requirements are met.

It appears that fixation of P was not a problem even though pH of the three Hartsells soils and the Cascade Springs source of Bodine was less than 5.5. The depression and recovery of pH from NH_4NO_3 additions is fairly rapid. It was assumed that pH had risen to near non-fertilized levels by the end of the 30-day incubation period. Seedling roots showed no signs of necrosis.

The quadratic relationship of root/shoot ratio to P-levels is shown in Fig. 4. The dry weight of roots of unfertilized seedlings averaged slightly more than twice the weight of shoots. The addition of 112 and 224 kg P/ha increased root/shoot ratio from 2.0 to 2.4, but more P resulted in a decrease to 2.3 (Fig. 5). Root/shoot ratios of 2.0 or greater agreed with published values for one to three-year-old sessile and overcup oaks (Ovington and MacRae, 1960; Kozlowski, 1949) but exceeded the 1.25 ratio reported by Phares (1971b) for one-year-old northern red oak. Finn (1966a) reported ratios of four to five for

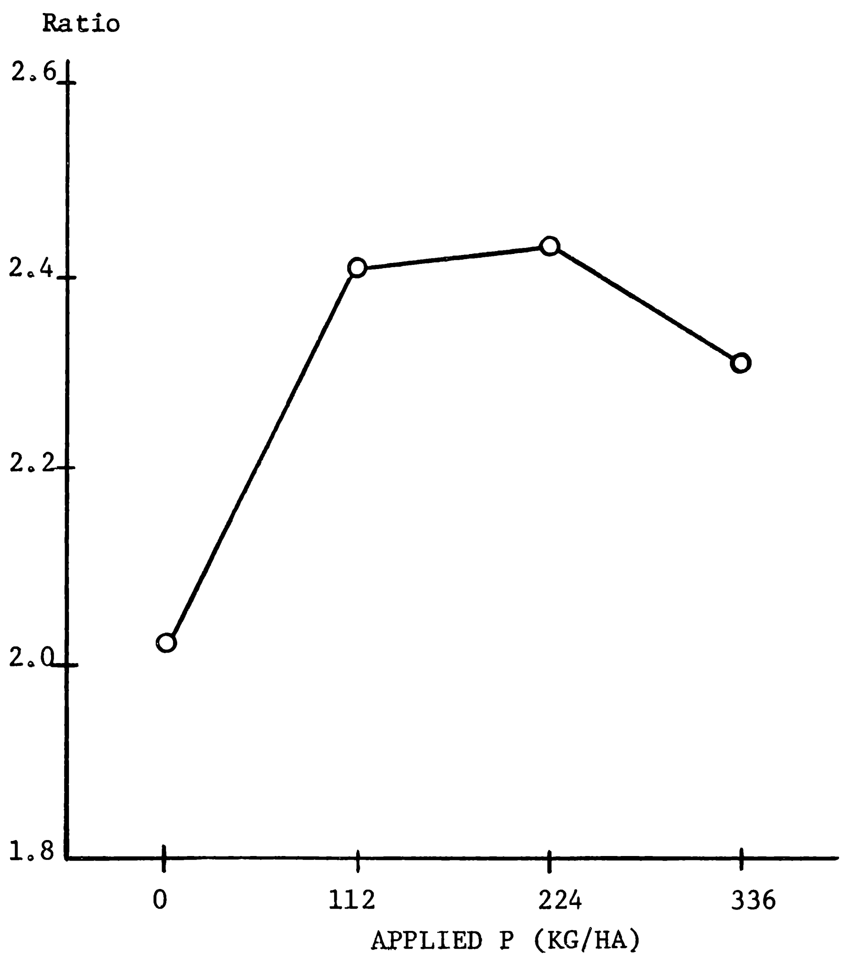

Figure 4. Mean root/shoot ratios of white ash seedlings with respect to applied P--experiment-1.

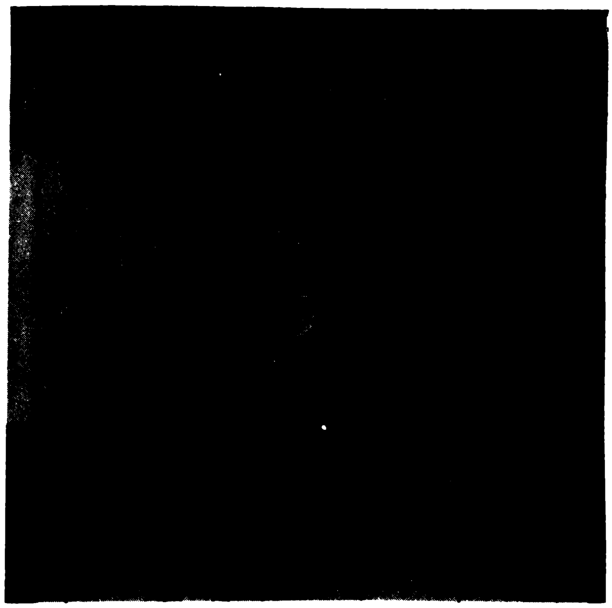

Figure 5. Seedlings with about average root/shoot ratio. They grew in Hartsells topsoil from the Franklin-Marion State Forest with the equivalent of 336 kg N and 224 kg P/ha. Dry weight of roots was 12.8 g, stems 2.5 g, and foliage 2.9 g. Root/shoot ratio was 2.4. Grid lines are 10 cm apart.

one-year-old yellow-poplar seedlings in a P fertilization test, but ratios did not differ significantly with P-supply.

Distribution of seedling biomass into roots, stems, and foliage was fairly constant regardless of seedling size. Roots comprised 70% of the total biomass, stems 14%, and foliage 16%. Each component of biomass was consistently related to the others as evidenced by the high coefficients of determination (r^2).

Regression	r^2
Stems on roots	.8634
Foliage on roots	.8821
Foliage on stems	.9291

The relations of root collar diameter and height to applied P are shown in Fig. 6. The highest level of P increased height 74% and diameter 69% over the size of non-fertilized seedlings. The linear trend of height also indicated that the optimum level of applied P was greater than 336 kg/ha. The curvilinear trend of diameter indicated that an optimum level was being approached. These results coupled with the linear trends of biomass indicated that gains in shoot biomass from additional increments of P would be due more to stem elongation than diameter growth.

Although the statistical design did not permit testing combinations of soil sources, inspection of the data revealed a greater seedling biomass on the Jernigan and Mayes sources of Bodine as compared with the other four sources. This comparison indicated that the biomass of white ash seedlings in soils with relatively high pH (> 5.5) and relatively

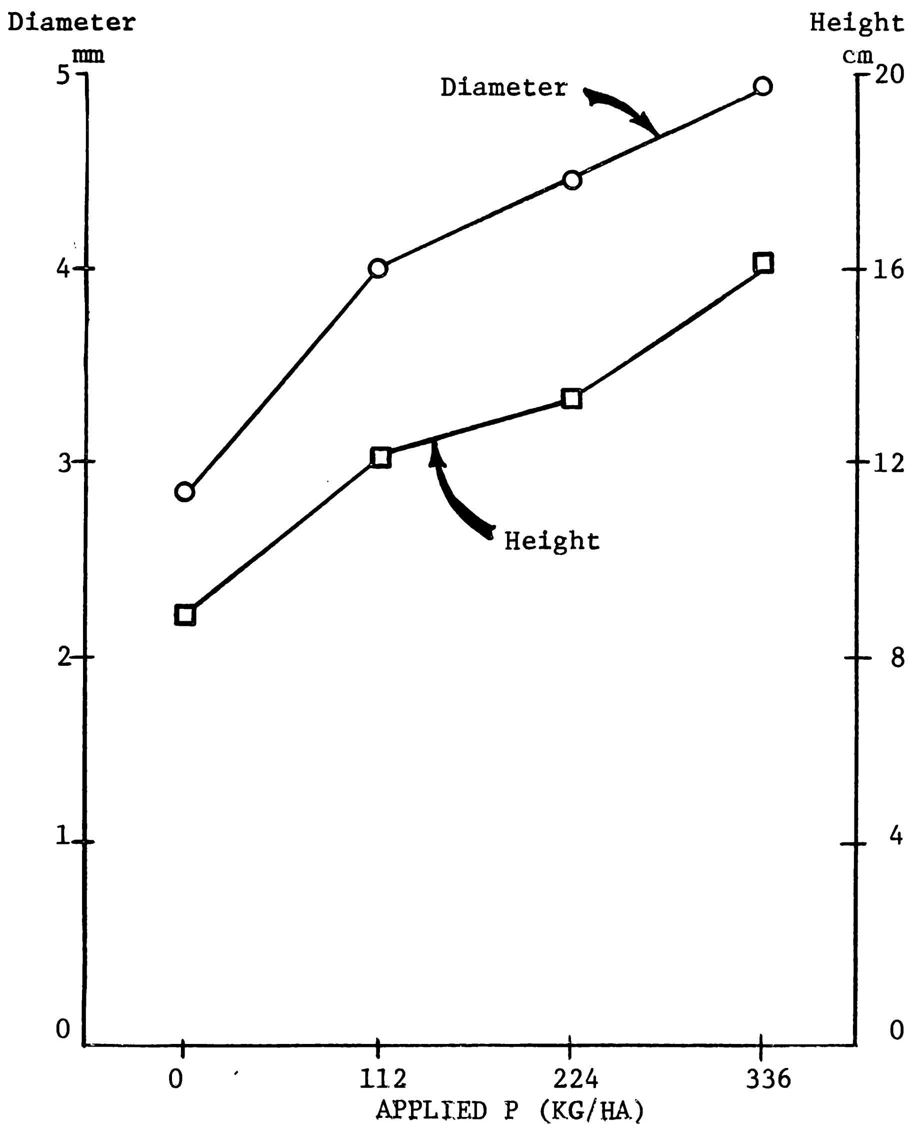

Figure 6. Effect of applied P on the mean root collar diameter and height of white ash seedlings--experiment-1.

high Ca (> 2 meq/100 g) was 1.8-times greater than the biomass of seedlings in soils with low pH (< 5.5) and low Ca (< 2 meq/100 g). Seedling biomass of the two groups averaged 28.4 g and 15.7 g/pot, respectively.

Foliar Composition

It was necessary to depart from the planned analysis of foliar composition data because there was not enough foliage from all pots to make determinations of all elements. There were two missing cells in the ANOVA in N analysis in each soil and six missing cells in the Hartsells and three in the Bodine in the P, K, Ca, and Mg analyses.

When disproportionality occurs in a replicated design, the analysis of the data becomes quite complicated. As a concession to reality and in view of the results of the plant growth variables, a simpler approach was taken. Each soil was analyzed separately ignoring blocks. The ANOVA became a completely randomized two-factor factorial with unequal replications (Table 5). This analysis involved the method of fitting constants and resulted in the calculation of adjusted sums of squares for main effects and the loss of error degrees of freedom equal to the number of missing cells (Steel and Torrie, 1960). The partition of main effects into linear, quadratic, and cubic components was performed as originally planned.

Foliar concentration (percent DW)--Hartsells. Nitrogen, P, and Ca concentrations responded significantly to N-supply (Table 6). Foliar N increased linearly, and P, and Ca decreased linearly with increasing N-supply (Figs. 7-11). Potassium and Mg were not significantly related to N-supply. However the linear response of Mg approached significance.

Table 5. Revised Format of the Analysis of Variance of Foliar Composition Data for Each Soil--Experiment-1

Source of Variation	Degrees of Freedom[1]
Nitrogen (N)	3
Phosphorus (P)	3
N X P	9
Error	26 to 30
Total	41 to 45

[1]Error and total degrees of freedom vary according to the number of missing cells.

Table 6. Mean Squares Calculated for the Analysis of Foliage Concentration (percent DW) of White Ash Seedlings Grown in Hartsells Topsoil--Experiment-1

Source of Variation	d.f.	N	P	K	Ca	Mg
Nitrogen (N)	3	2.483*	0.003*	0.024	0.800*	0.012
Linear	1)	7.410*	0.009*	0.057	2.336*	0.022
Quadratic	1)	0.029	0.001	0.014	0.062	0.014
Cubic	1)	0.009	0.000	0.000	0.002	0.001
Phosphorus (P)	3	0.592*	0.002	0.081	0.402	0.008
Linear	1)	1.615*	0.004*	0.231	1.200*	0.019
Quadratic	1)	0.160	0.002	0.004	0.004	0.003
Cubic	1)	0.000	0.000	0.009	0.002	0.002
N X P	9	0.120	0.000	0.052	0.042	0.001
Error[1]	(30 (26	0.148	0.001	0.076	0.180	0.006

[1]N Analysis based on 30 d.f.; all other elements on 26 d.f.
*Significant at the 0.05 level.

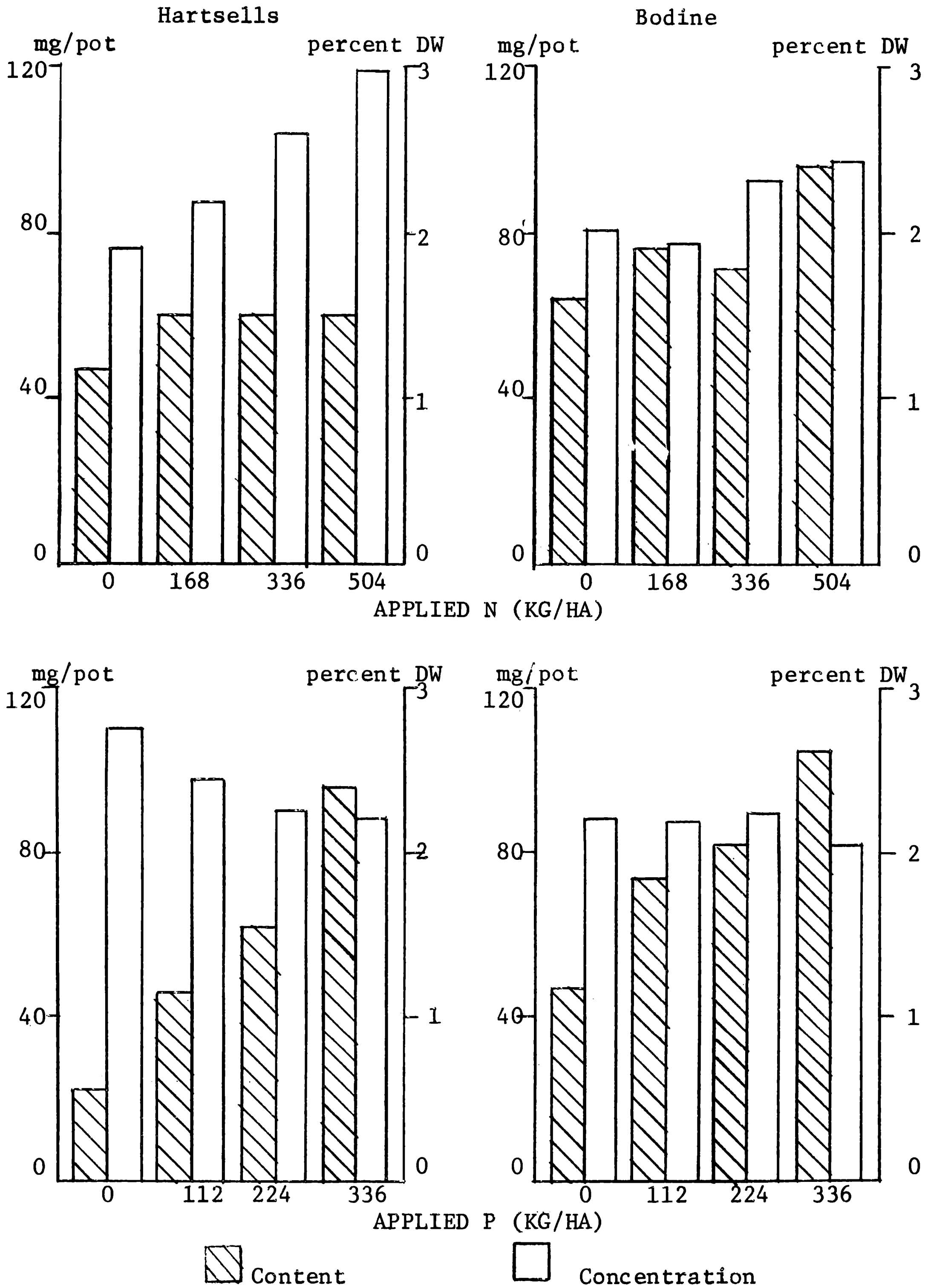

Figure 7. Effect of applied N and P on foliar N concentration (percent DW) and content (mg/pot) of white ash seedlings growing in Hartsells and Bodine topsoils--experiment-1.

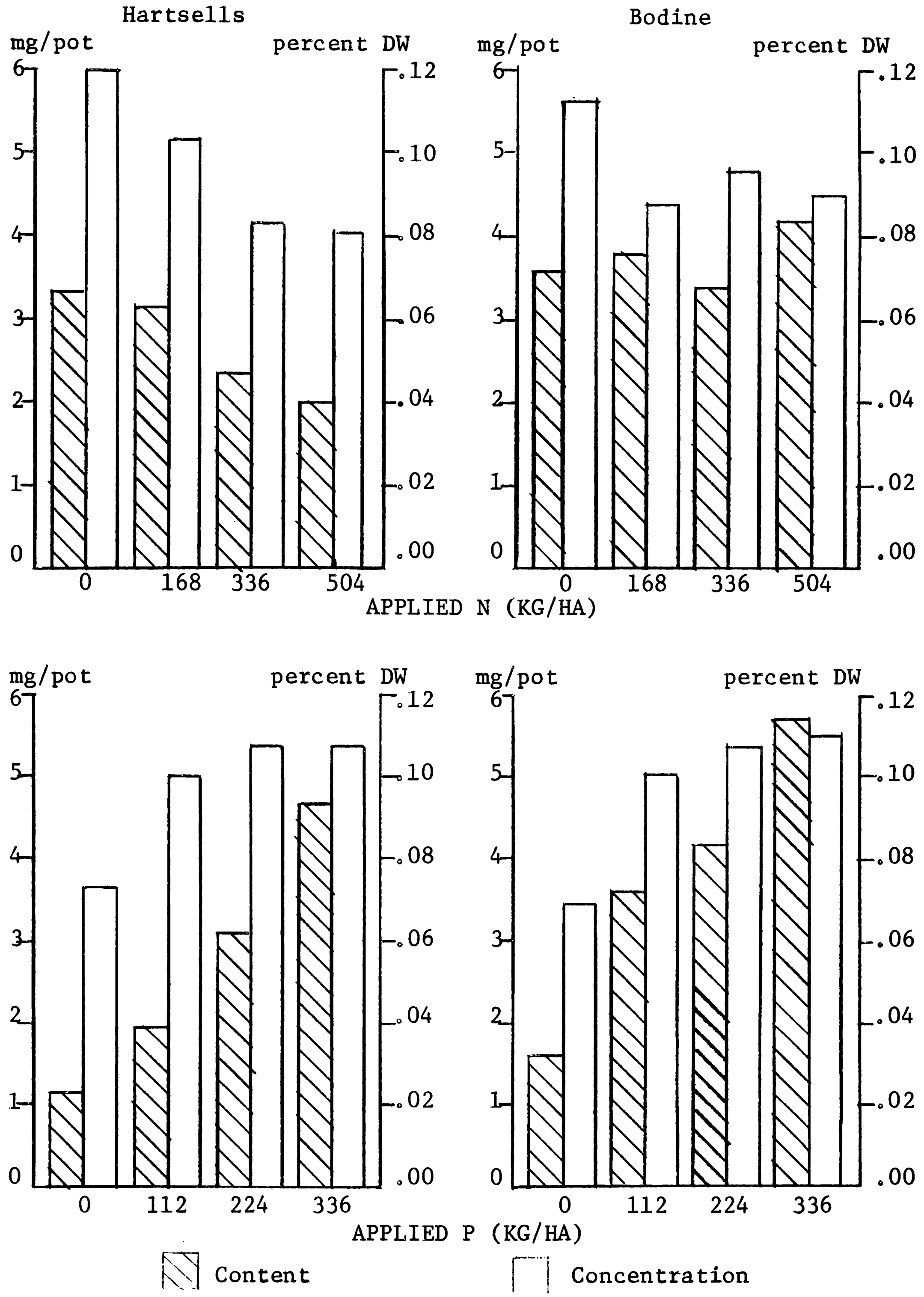

Figure 8. Effect of applied N and P on foliar P concentration (percent DW) and content (mg/pot) of white ash seedlings growing in Hartsells and Bodine topsoils--experiment-1.

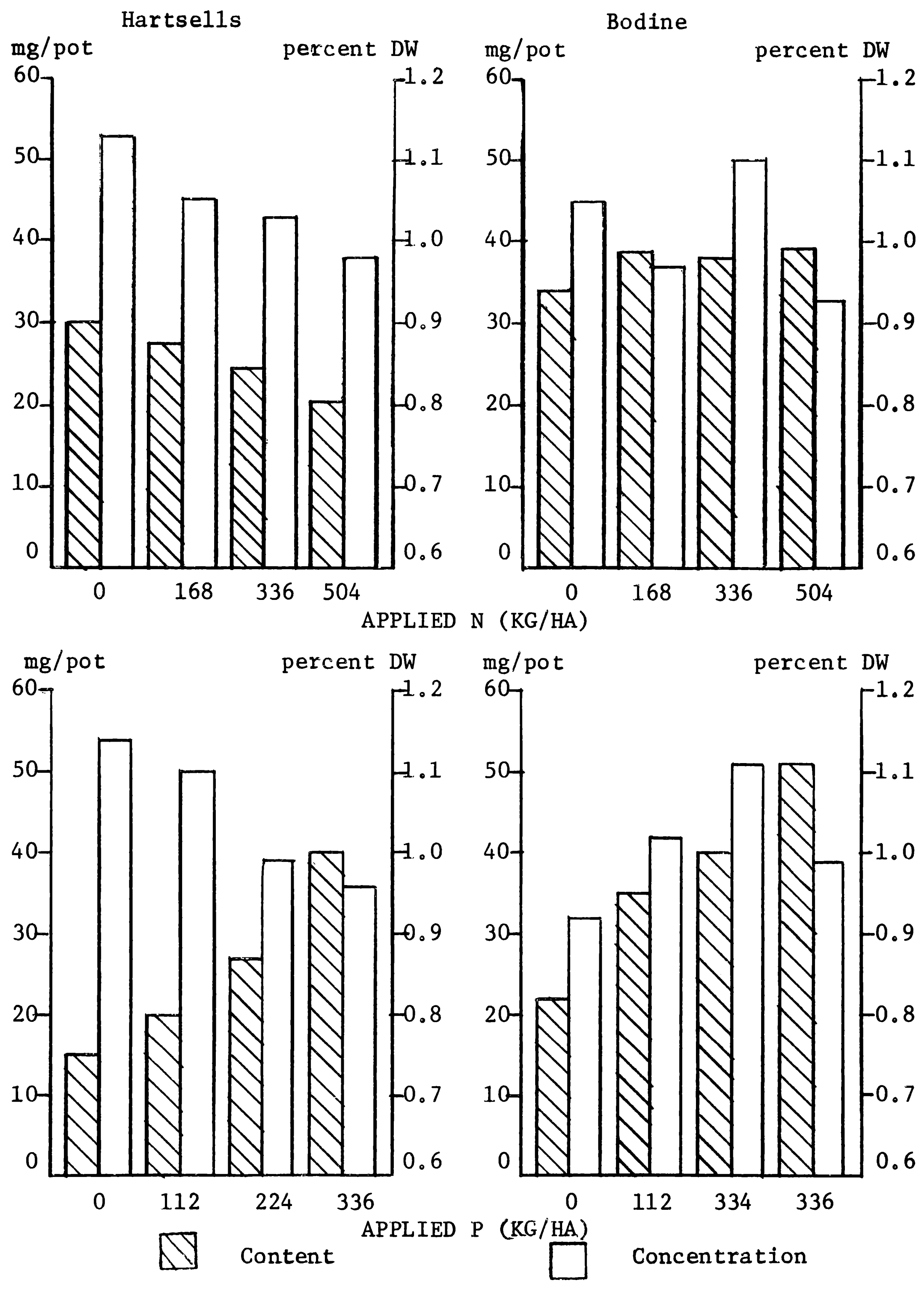

Figure 9. Effect of applied N and P on foliar K concentration (percent DW) and content (mg/pot) of white ash seedlings growing in Hartsells and Bodine topsoils--experiment-1.

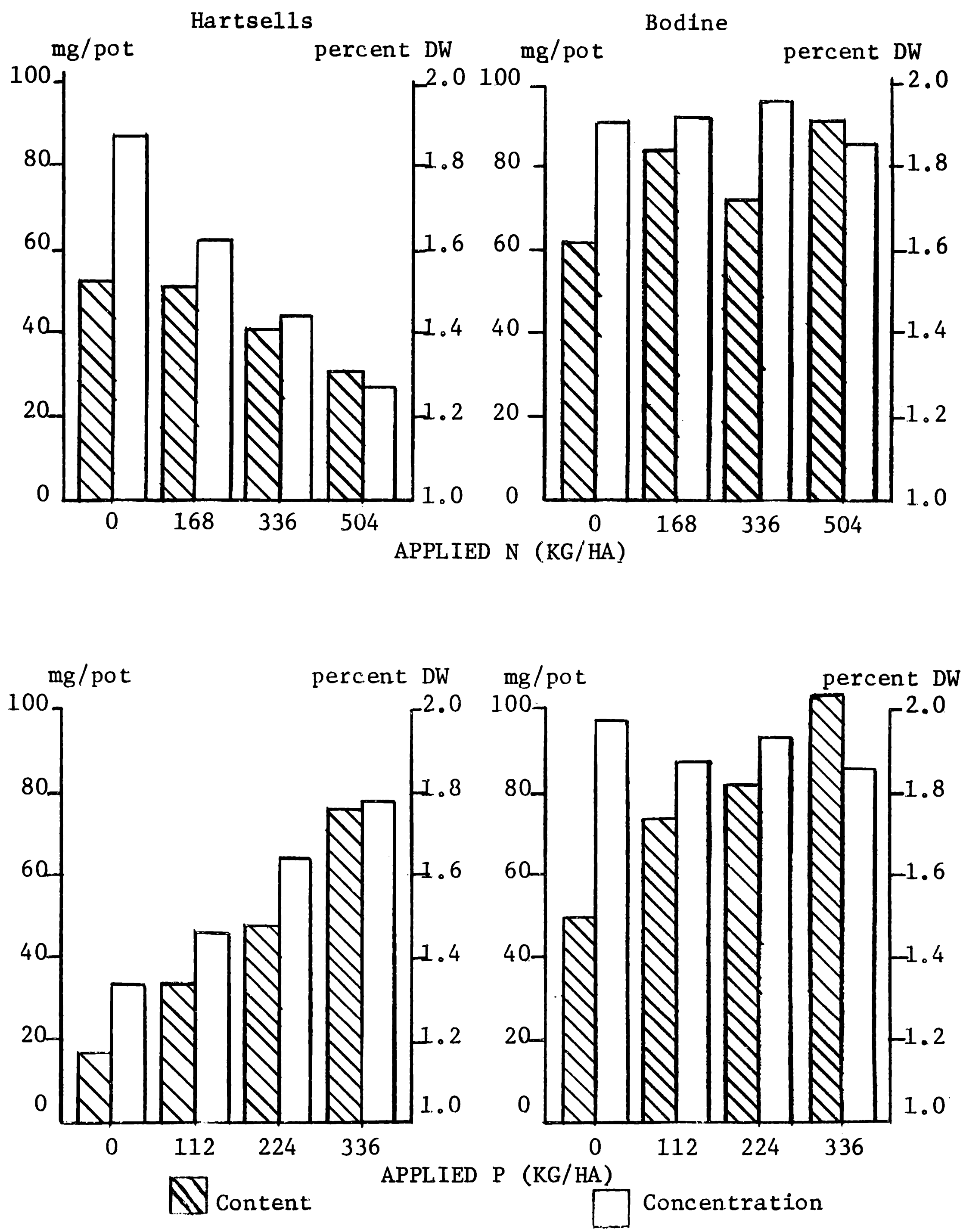

Figure 10. Effect of applied N and P on foliar Ca concentration (percent DW) and content (mg/pot) of white ash seedlings growing in Hartsells and Bodine topsoils--experiment-1.

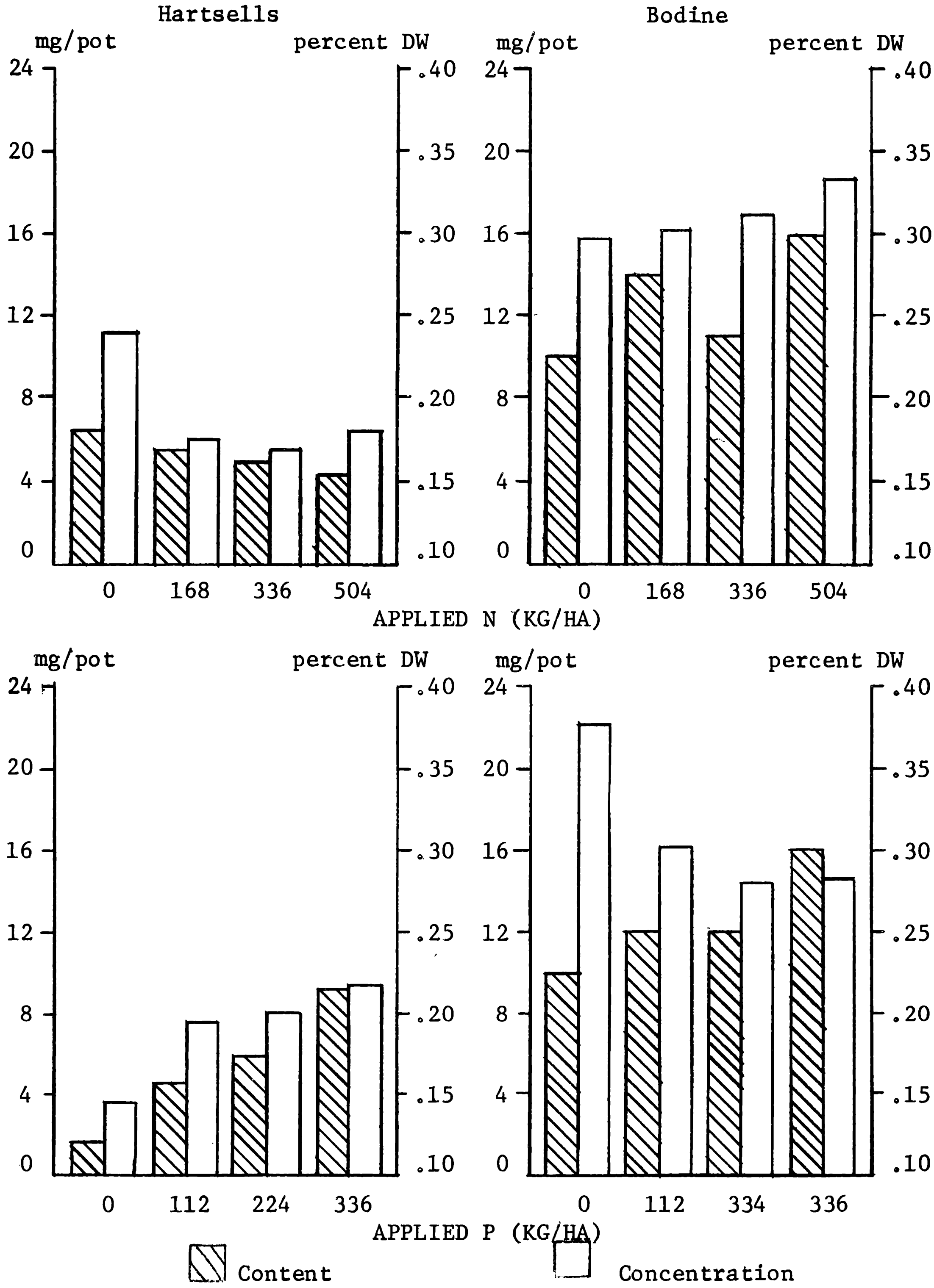

Figure 11. Effect of applied N and P on foliar Mg concentration (percent DW) and content (mg/pot) of white ash seedlings growing in Hartsells and Bodine topsoils--experiment-1.

Significant responses of foliar concentrations to P-supply were linear and opposite of responses to N-supply. Foliar N decreased, and P and Ca increased with increasing P-supply. Potassium and Mg were not significantly related to P-supply although the linear responses of K and Mg approached significance.

There was no significant interaction of N- and P-supplies for any foliar concentration variable.

Foliar content (mg/pot)--Hartsells. Absolute quantities of P and Ca were significantly related to N-supply (Table 7). They decreased linearly with N-supply (Figs. 7-11). All element contents were significantly related to P-supply in positive linear relationships.

Since foliar content is the product of foliage biomass and concentration, the effect of N- and P-supplies on foliar contents was understandable. Foliar biomass was strongly related to P-supply but not to N-supply (Fig. 3, p. 52). Thus foliar concentrations and contents were related to N-supply in a similar manner. On-the-other-hand the strong relation of foliage biomass to P-supply resulted in the significant relation of all content variables, even to the extent of showing significance where none existed or reversing the trends with foliar concentration.

There was no significant interaction of N- and P-supplies for any foliar content variable.

Foliar concentration (percent DW)--Bodine. In contrast to Hartsells, no foliar concentration variables of seedlings grown in Bodine topsoil were significantly related to N-supply, and only P was

Table 7. Mean Squares Calculated for the Analysis of Foliage Content (mg/pot) of White Ash Seedlings Grown in Hartsells Topsoil--Experiment-1[1]

Source of Variation	d.f.	N	P	K	Ca	Mg
Nitrogen (N)	3	519	3.85	122	1,130	9.4
Linear	1)	1,000	10.48*	332	3,004*	28.1
Quadratic	1)	511	0.50	28	372	0.0
Cubic	1)	46	0.57	6	12	0.1
Phosphorus (P)	3	10,194*	21.83*	1,098*	5,637*	84.4*
Linear	1)	29,828*	63.83*	3,026*	16,421*	242.8*
Quadratic	1)	397	1.65	266	342	1.2
Cubic	1)	357	0.00	2	147	9.0
N X P	9	732	1.06	96	149	2.9
Error[1]	(30 (26	600	1.92	92	524	10.3

[1]N analysis based on 30 d.f.; all other elements on 26 d.f.

*Significant at the 0.05 level.

significantly related to P-supply (Table 8 and Figs. 7-11). Foliar P concentration increased linearly with P-supply. The linear responses of foliar N and P concentrations to N-supply approached significance.

There was no significant interaction of N- and P-supplies for any foliar concentration variables.

Foliar content (mg/pot)--Bodine. Only foliar N content was significantly related to N-supply (Table 9). It increased linearly with N-supply. However P-supply significantly affected all foliar content variables except Mg. Foliar N, P, K, and Ca contents all increased with increasing P-supply (Figs 7-11).

There was no significant interaction of N- and P-supplies for any foliar content variables.

Growth-Foliar Composition Relationships

Biomass of seedlings grown in both soils was significantly correlated with foliar N, K, and Ca concentrations (Table 10). Biomass was inversely related to N and K and directly related to Ca. In seedlings grown in Hartsells biomass was also significantly positively related to foliar Mg concentration.

Biomass was significantly and positively correlated to the content of all elements. Foliar contents were better correlated with seedling biomass than were foliar concentrations. Best correlations were obtained with Ca content.

Multivariate expressions of seedling biomass as functions of foliar composition were also determined. The best (smallest relative mean square residual) equation for Hartsells included all five elements

Table 8. Mean Squares Calculated for the Analysis of Foliage Concentration (percent DW) of White Ash Seedlings Grown in Bodine Topsoil--Experiment-1[1]

Source of Variation	d.f.	N	P	K	Ca	Mg
Nitrogen (N)	3	0.528	0.001	0.076	0.026	0.002
Linear	1)	1.263	0.003	0.037	0.020	0.006
Quadratic	1)	0.057	0.001	0.029	0.035	0.001
Cubic	1)	0.264	0.001	0.162	0.022	0.000
Phosphorus (P)	3	0.089	0.004*	0.057	0.018	0.017
Linear	1)	0.118	0.008*	0.030	0.013	0.036
Quadratic	1)	0.086	0.002	0.122	0.005	0.014
Cubic	1)	0.063	0.000	0.020	0.034	0.000
N X P	9	0.175	0.001	0.049	0.091	0.004
Error[1]	(30 (29	0.338	0.001	0.094	0.357	0.019

[1]N analysis based on 30 d.f.; all other elements on 29 d.f.

*Significant at the 0.05 level.

Table 9. Mean Squares Calculated for the Analysis of Foliage Content (mg/pot) of White Ash Seedlings Grown in Bodine Topsoil--Experiment-1[1]

Source of Variation	d.f.	N	P	K	Ca	Mg
Nitrogen (N)	3	2,268	1.45	67	2,012	99.4
Linear	1)	4,958*	0.97	122	3,334	168.8
Quadratic	1)	514	1.46	39	0	2.1
Cubic	1)	1,332	1.91	39	2,704	127.4
Phosphorus (P)	3	6,085*	30.04*	1,447*	5,114	81.4
Linear	1)	17,662*	85.36*	4,230*	14,813*	205.4
Quadratic	1)	38	0.66	9	1	8.8
Cubic	1)	557	4.09	102	528	30.1
N X P	9	371	0.58	80	866	40.0
Error[1]	(30 (29	824	4.21	347	2,353	92.5

[1]N analysis based on 30 d.f.; all other elements on 29 d.f.

*Significant at the 0.05 level.

Table 10. Simple Correlation Coefficients (r)* Between Seedling Biomass and Foliar Composition--Experiment-1

Soil	Element	Concentration (Percent DW)	Content (mg/pot)
Hartsells	N	-0.514	0.766
	P	0.218	0.848
	K	-0.656	0.711
	Ca	0.544	0.936
	Mg	0.367	0.852
Bodine	N	-0.668	0.773
	P	-0.104	0.768
	K	-0.461	0.695
	Ca	0.329	0.919
	Mg	0.260	0.835

*For Hartsells: Significant r at 0.05 level = 0.304, at 0.01 level = 0.393. For Bodine: Significant r at 0.05 level = 0.294, at 0.01 level = 0.380.

expressed both as concentration and content (Table 11). The best equation for Bodine included N, P, K, and Mg concentrations, and N, P, Ca, and Mg contents. There was little gain in explained variation for equations containing all five elements. In no regressions were there discernible trends in residuals.

Biomass of seedlings grown in Hartsells was better correlated with foliar composition than biomass of seedlings grown in Bodine. Foliar element contents were much more effective in explaining variation in seedling biomass than were element concentrations.

Multiple regressions involving foliar element concentrations explained more of the variation in seedling biomass than any of the simple linear expressions (Tables 10 and 11). On-the-other-hand, simple linear regressions of biomass on foliar Ca content explained nearly as much of the variation in seedling biomass as explained by multiple regressions involving all five elements.

II. EXPERIMENT-2

Site Relations

Tree characteristics. Mensurational characteristics of the sampled white ash trees are shown in Table 12. Tree height, diameter, and merchantable stem volume were significantly related to site.

Trees on south Plateau slopes below 488 m were significantly shorter than those on all other sites. Trees in Plateau coves and on both Highland Rîm sites were tallest.

Trees on south Plateau slopes had the smallest mean diameter, shortest mean height, smallest volume. Those in Plateau hollows and

Table 11. Best Multiple Regressions Relating Seedling Biomass to Foliar Composition--Experiment-1

Soil	Independent Variables	Composition	R^2
Hartsells	N, P, K, Ca, Mg	Concentration	0.6863
	N, P, K, Ca, Mg	Content	0.9129
Bodine	N, P, K, Mg	Concentration	0.5420
	N, K, Ca, Mg	Content	0.8834

Table 12. Characteristics of White Ash Sample Trees--Experiment-2[1]

Site	Age (yrs)	Height (m)	Diameter (cm)	Merchantable Volume (dm^3)	Stand Basal Area (m^2/ha)	Mean Annual Increment Height (cm)	Mean Annual Increment Diameter (mm)	Mean Annual Increment Volume (dm^3)
1. Plateau	60	25 bcd[2]	34 bc	566 abc	17	46	6	11
hollows	37-90	22-27	28-38	368-736	14-22	30-61	3-9	3-17
2. Coves	59	29 e	35 bc	623 bc	18	52	6	11
	41-73	26-33	32-38	510-736	14-22	40-70	5-9	8-17
3. North slopes	64	25 bcd	32 abc	510 abc	24	43	5	8
above 488 m	44-80	20-29	27-38	340-764	16-32	37-67	3-9	6-17
4. South slopes	56	23 b	29 ab	425 ab	16	43	5	8
above 488 m	41-72	20-26	25-36	283-680	11-27	36-55	4-6	6-8
5. North slopes	60	25 bc	32 abc	510 abc	22	43	6	8
below 488 m	38-77	22-28	27-40	340-821	11-34	30-61	4-8	6-11
6. South slopes	58	20 a	26 a	311 a	17	36	5	6
below 488 m	46-89	14-22	21-33	113-538	14-25	24-46	4-7	3-8
7. Highland Rim	71	27 cde	37 c	793 c	19	40	5	11
slopes	55-93	24-33	29-52	396-1,557	16-25	30-43	4-7	6-23
8. Highland Rim	63	28 de	32 ab	510 abc	21	46	5	8
hollows and bottoms	43-98	24-33	22-41	198-878	16-38	34-58	4-6	6-14

[1]Upper value = average of seven trees; lower values = range among trees.

[2]Means in the same column and followed by the same letter are not significantly different at the 0.05 level of probability according to Duncan's multiple range test.

coves and on Highland Rim slopes had the largest mean diameters and volume.

Age, stand basal area, and mean annual growth rates were not significantly related to site. A wide range of age was sampled on all sites.

Stand basal area was a criterion for sample tree selection because it is a good indicator of competition and stocking. However, it was not expected to be significantly related to site because of its strong dependence on stand age, a wide point-to-point range, and the ease by which it can be altered by cutting. Stands with lowest average basal area occurred on south Plateau slopes while north Plateau slopes had the highest.

None of the three mean annual increments were significantly related to site. On the average, white ash trees in mixed upland forests grew at the annual rate of 0.4 m in height, 0.5 cm in diameter, and 8.5 dm^3 in merchantable stem volume. The mean annual diameter growth rate is about double the 0.26 cm rate of 50-year-old white ash trees in New York (Mitchell and Chandler, 1939). Their maximum rate of 0.45 cm nearly equaled the mean rate in Tennessee and Alabama. Note that trees on some sites were growing at annual rates in excess of 0.6 m in height, 0.8 cm in diameter, and 17 dm^3 in volume.

Soil properties. The mean and range of the chemical and physical properties of topsoils supporting white ash trees is shown in Table 13. All properties were significantly related to site despite considerable variation within sites.

Table 13. Properties of Topsoils Supporting White Ash Trees--Experiment-2[1]

Site	Thickness (cm)	pH	Extractable Bases K (meq/100g)	Extractable Bases Ca (meq/100g)	Extractable Bases Mg (meq/100g)	Extractable P (ppm)	Organic Matter (percent)	Total N (percent)	Sand (percent)	Silt (percent)	Clay (percent)
1. Plateau	33	5.1a[2]	.68 ab	1.84 a	.58a	12.8a	4.50 a	.19a	47 b	31 ab	22 ab
hollows	23-41	4.9-5.2	.45-.75	1.15-2.75	.37-.85	7.7-21.4	3.41-6.74	.14-.27	34-64	22-40	14-30
2. Coves	25	6.1 bcd	.72 ab	10.84 bc	1.37 ab	14.4 ab	8.52 ab	.34 ab	48 c	24 a	18 a
	8-51	5.2-7.0	.56-1.13	2.22-29.25	.43-4.25	9.9-18.3	4.48-22.31	.17-.91	38-70	16-32	14-22
3. North slopes	25	6.0 bcd	.96 c	11.54 bc	2.21 b	12.6 a	8.40 ab	.41 ab	41 b	33 b	26 b
above 488 m	13-61	5.3-6.7	.78-1.25	6.82-21.00	1.30-3.45	8.4-16.1	4.00-14.87	.20-.72	30-56	24-42	20-38
4. South slopes	23	6.5 d	.74 ab	18.63 c	1.81 b	14.6 ab	13.00 b	.51 b	48 c	26 a	16 a
above 488 m	8-46	5.8-7.0	.62-1.08	6.10-37.56	.65-3.62	10.8-24.2	3.93-29.45	.18-1.10	44-68	18-32	12-24
5. North slopes	23	6.1 bcd	.86 bc	11.44 bc	2.20 b	10.2 a	5.24 a	.21 a	41 b	31 ab	28 b
above 488 m	13-53	5.2-6.9	.59-1.01	4.36-24.55	.67-4.68	7.7-12.2	3.10-8.72	.12-.32	22-54	22-38	18-40
6. South slopes	25	6.4 cd	.68 ab	14.43 c	2.11 b	13.8 ab	5.22 a	.20 a	37 b	37 b	26 b
below 488 m	10-46	5.4-7.9	.44-.95	5.55-23.50	.67-3.92	8.8-28.4	3.02-8.00	.11-.31	22-52	26-48	12-38
7. Highland Rim	30	5.7 ab	.75 ab	4.57 ab	1.14 ab	19.3 b	4.06 a	.20 a	20 a	54 c	26 b
slopes	20-43	5.1-6.3	.60-.99	2.56-6.70	.79-1.33	10.5-29.8	3.80-4.47	.16-.23	16-24	52-58	24-28
8. Highland Rim	41	5.8 bc	.64 a	5.20 ab	1.31 ab	19.8 b	4.35 a	.21 a	18 a	56 c	26 b
hollows and bottoms	25-64	5.3-6.5	.42-.90	2.65-10.10	.73-2.13	13.0-27.0	2.29-7.61	.12-.37	12-28	52-62	20-30

[1]Upper value = average of seven locations; lower values = range among locations.

[2]Means in the same column and followed by the same letter are not significantly different at the 0.05 level of probability according to Duncan's multiple range test.

A distinct textural difference between Plateau and Highland Rim sites was obvious. Soil from Rim sites had significantly lower sand and higher silt fractions than Plateau soils.

Organic matter (OM) averaged less than 6% on five sites. Plateau coves and slopes above 488 m had very high OM. Soil sampling on these boulder-strewn sites was often limited to pockets between the rocks. No doubt these high levels of OM were responsible for the associated high N levels and possibly the extractable bases.

An average total N ranged from 0.2 to 0.5%, but at individual tree locations it ranged from 0.1 to 1.1%.

Soils on Highland Rim sites had signficantly higher P contents than Plateau hollows and north slopes.

Plateau coves and slopes had the greatest quantities of Ca and Mg but this was not a significant trend. South slopes averaged higher Ca than north slopes. On each aspect sites below 488 m (limestone-derived soils) had higher Ca and lower Mg contents than sites above 488 m (sandstone-derived soils). Highland Rim sites (cherty limestone-derived soils) had only one-half to one-third as much Ca as Plateau slopes. Plateau hollow soils were low in Ca.

Soil reaction corresponded well with Ca content. The pH of all sites was in the intermediate range and represented a satisfactory biological regime.

Leaf weight and area. Leaf weight and area characteristics are shown in Table 14. Blade dry weight should not be confused with leaf dry weight (includes rachis). The ranking of sites by leaf and blade

Table 14. Leaf Characteristics--Experiment-2[1]

Site	Leaf Dry Weight (g/leaf)	Blade Dry Weight (g/leaf)	Leaf Blade Area (cm^2/leaf)
1. Plateau hollows	2.56 1.45-4.14	2.22 1.25-3.57	249 171-400
2. Coves	2.53 1.50-3.88	2.21 1.33-3.41	241 150-355
3. North slopes above 488 m	2.74 1.61-3.91	2.32 1.31-3.24	306 221-399
4. South slopes above 488 m	2.92 1.97-4.00	2.52 1.75-3.49	312 198-421
5. North slopes below 488 m	2.77 1.99-3.90	2.38 1.66-3.34	284 203-363
6. South slopes below 488 m	2.08 1.32-3.31	1.79 1.15-2.88	205 133-379
7. Highland Rim slopes	2.96 2.04-3.73	2.61 1.77-3.30	266 187-328
8. Highland Rim hollows and bottoms	2.54 2.10-3.43	2.20 1.85-2.85	250 197-351

[1]Upper value = average of seven trees; lower values = range among trees.

dry weights were the same except Plateau coves and Highland Rim hollows and bottoms were reversed.

Leaf weight and area were not significantly related to site. A comparison of leaf and tree variables showed that large trees with relatively rapid volume growth had heavy leaves--least blade area per unit weight (Plateau hollows, coves, and Highland Rim sites).

Leaves on trees growing on south Plateau slopes below 488 m averaged 0.4 g less in dry weight than leaves from all other sites. Trees on south Plateau slopes above 488 m and Highland Rim slopes had the heaviest leaves.

Foliar concentration. Variability of topsoil characteristics was reflected in wide ranges in foliar composition. Phosphorus, K, and Ca concentrations varied significantly with site; N and Mg did not (Table 15). The foliar nutrient concentrations of trees on no one site or group of sites was distinctly higher or lower than the rest. At least three sites were in each non-significant group and all groups were overlapping.

Foliage of trees on Plateau slopes above 488 m had the highest K and Ca concentrations; south slopes above 488 m had the highest concentrations of P.

Trees in Plateau hollows averaged the lowest foliar Ca concentrations, and south slopes below 488 m had the lowest N, P, and Mg concentrations. Leaves of trees on both Highland Rim sites had low Ca concentrations, lower than Plateau slopes and coves.

Average N concentration of white ash foliage on these Plateau and Rim sites was 0.25% greater, P concentration was only one-half, and K

Table 15. White Ash Foliar Concentrations of N, P, K, Ca, and Mg in Late Summer--Experiment-2[1]

Site	N (Percent DW)	P (Percent DW)	K (Percent DW)	Ca (Percent DW)	Mg (Percent DW)
1. Plateau hollows	2.12	.13 bc[2]	1.28 bc	1.17 a	.31
	1.92-2.31	.13-.14	1.09-1.47	.92-1.66	.20-.41
2. Coves	1.97	.14 bc	1.11 ab	1.69 bcd	.30
	1.78-2.17	.11-.17	.83-1.42	1.12-2.50	.24-.41
3. North slopes above 488 m	2.07	.12 abc	1.40 c	1.80 cd	.36
	1.77-2.53	.10-.16	1.18-1.62	1.41-2.10	.22-.67
4. South slopes above 488 m	2.08	.14 c	1.31 bc	2.09 d	.30
	1.85-2.31	.11-.20	1.04-1.50	1.35-2.94	.14-.39
5. North slopes below 488 m	2.19	.12 ab	1.25 bc	1.66 bcd	.34
	1.77-2.71	.10-.13	1.07-1.47	1.26-2.38	.23-.52
6. South slopes below 488 m	1.91	.10 a	1.11 ab	1.64 bcd	.25
	1.67-2.03	.08-.12	.71-1.42	1.00-2.49	.17-.40
7. Highland Rim slopes	2.13	.14 bc	1.22 abc	1.29 ab	.30
	1.92-2.30	.11-.17	1.02-1.43	.95-1.77	.24-.36
8. Highland Rim hollows and bottoms	2.16	.13 bc	1.00 a	1.48 abc	.38
	1.87-2.45	.11-.16	.50-1.33	1.05-1.74	.32-.48

[1]Upper value = average of seven trees; lower values = range among trees.

[2]Means in the same column and followed by the same letter are not significantly different at the 0.05 level of probability according to Duncan's multiple range test.

concentration averaged 0.61% less than corresponding percentages reported by Mitchell and Chandler (1939) in ash trees growing in New Jersey, West Virginia, and New York.

Foliar content. Foliar content of P and Ca varied significantly with site, but N, K, and Mg did not (Table 16). With the exception of K ($p = 0.074$) these results were consistent with those for foliar concentration. However, there were changes in the rankings of the elements by sites between relative and absolute units.

Trees on south Plateau slopes above 488 m and Highland Rim slopes had the heaviest leaves and contained large amounts of N, P, K, and Ca. Trees on north Plateau slopes had heavy leaves and ranked high in content of all five elements.

Leaves of trees on south Plateau slopes below 488 m were the smallest and contained the least amounts of N, P, K, and Mg, and next to the lowest amount of Ca.

Growth Relations

Soil. The only significant relationship (inverse) was volume growth to topsoil pH (Table 17). The correlation coefficients for each site-growth-soil property combination ranged from positive to negative. There was no consistent relationship of tree growth to soil properties across all sites. This wide range of correlation on individual sites was responsible for the overall lack of correlation.

Although the correlations were weak, height growth was better correlated with soil factors than was diameter or volume growth.

Table 16. White Ash Foliar Contents of N, P, K, Ca, and Mg in Late Summer--Experiment-2[1]

Site	N (mg/leaf)	P (mg/leaf)	K (mg/leaf)	Ca (mg/leaf)	Mg (mg/leaf)
1. Plateau hollows	46.8 29.6-71.5	2.9 ab[2] 1.5-4.6	29.1 14.8-52.5	25.5 a 11.5-34.7	6.9 2.9-11.1
2. Coves	43.7 23.6-62.3	3.1 b 1.9-4.5	24.5 14.9-33.2	36.7 ab 23.4-65.6	6.5 4.1-8.5
3. North slopes above 488 m	48.0 32.2-82.0	2.9 ab 1.7-4.6	32.4 21.2-48.6	41.4 bc 27.5-60.3	8.1 2.9-14.7
4. South slopes above 488 m	52.6 35.6-76.5	3.5 b 2.1-4.2	32.9 18.2-46.8	51.8 c 27.3-75.4	7.4 4.4-11.2
5. North slopes below 488 m	51.6 37.9-76.9	2.8 ab 2.0-4.0	29.4 19.7-39.8	39.0 abc 26.3-58.5	8.6 3.8-15.9
6. South slopes below 488 m	34.4 20.7-55.3	1.9 a 1.2-3.5	19.6 14.4-39.8	30.9 ab 11.5-58.2	4.6 1.9-8.2
7. Highland Rim slopes	55.9 34.0-67.7	3.6 b 2.5-4.4	31.8 19.5-39.5	34.1 ab 17.0-47.8	7.8 4.2-10.9
8. Highland Rim hollows and bottoms	47.8 36.4-63.4	2.9 ab 2.0-4.2	22.7 8.9-38.0	32.7 ab 21.8-44.8	8.2 6.8-9.3

[1]Upper value = average of seven trees; lower values = range among trees.

[2]Means in the same column and followed by the same letter are not significantly different at the 0.05 level of probability according to Duncan's multiple range test.

Table 17. Simple Correlation Coefficients (r)[1] Between Tree Growth and Topsoil Variables--Experiment-2[2]

Soil Variable	Mean Annual Increment Diameter	Height	Volume
Sand	.113 -.755 to .542	.124 -.765 to .604	.021 -.524 to .705
Silt	-.091 -.669 to .717	-.094 -.561 to .651	.011 -.678 to .560
Clay	-.103 -.898 to .607	-.124 -.793 to .684	-.071 -.758 to .555
Organic matter	.183 -.402 to .698	.207 -.338 to .756	.080 -.348 to .763
pH	-.200 -.799 to .844	-.134 -.618 to .662	-.272 -.774 to .370
Total N	.171 -.559 to .681	.251 -.385 to .763	.092 -.326 to .707
Extractable P	.030 -.275 to .613	.019 -.499 to .456	.148 -.402 to .554
Extractable K	.071 -.580 to .638	.075 -.648 to .796	.030 -.524 to .572
Extractable Ca	.023 -.568 to .632	.015 -.380 to .670	-.097 -.504 to .682
Extractable Mg	.074 -.744 to .730	.102 -.765 to .789	-.049 -.802 to .722

[1]Significant r at 0.05 level = 0.264.

[2]Upper value = average of 56 trees growing on eight sites; lower values = range among sites.

Soil P was better correlated with volume growth than either height or diameter. Diameter and height growth were influenced more than volume growth by OM and N. Particle size distribution was better related to diameter and height growth than it was to volume growth.

Sand, OM, N, P, and K were all positively related to tree growth while the clay and pH relationships were negative. The relation of silt, Ca, and Mg to growth variables was mixed. The inverse relationship of pH and volume growth apparently contradicted the findings in experiment-1. However the relationship was weak. Less than 10% of the variation in growth was explained.

There were equal numbers of direct and inverse relationships between the three growth variables and soil pH for individual sites. More sampling of trees in each site is needed to provide a better definition of the relationships between soil physico-chemical properties and tree growth.

The best correlations of tree growth with soil variables occurred on Plateau coves and south Plateau slopes above 488 m.

Multiple regressions relating topsoil nutrients to the growth variables added little improvement in explained variation. In the best regression, 14% of the variation in height growth was explained by N, Ca, and Mg. Nitrogen and Ca were the most important elements related to diameter and volume growth, but these explained 10% or less of the variation in growth. Unit leaf weight was poorly related to soil nutrient levels (R^2 = 8% for best regression involving P, Ca, and Mg). Metz _et al_. (1966) reported that soil variables (including transformations and products) accounted for 35, 32, and 11% of the variation in height, diameter, and needle weight, respectively, of young loblolly pine.

Foliage. No foliage composition variable was significantly correlated with tree growth variables (Table 18). However, several elements approached significance: diameter growth on N concentration, height growth on N and P concentrations and contents, and volume growth on N and P contents.

Foliar N and P concentrations and contents were about equally correlated with growth variables. Considerable differences existed between the correlations of K, Ca, and Mg concentrations and contents with growth variables.

Correlation coefficients on individual sites ranged from positive to negative. No doubt this variability was responsible for the lack of correlation across all sites.

No one site was superior with respect to the correlation of foliar concentrations with diameter or height growth. The best correlation of N, P, K, and Mg concentrations with diameter growth occurred on the same sites as the best correlations of the same elements with volume growth.

The best correlation of tree growth with N, P, K, and Ca contents occurred on north Plateau slopes above 488 m.

Foliar contents were positively correlated with growth variables except volume growth on Ca content. This agrees with results from experiment-1. The direction of the correlations of growth variables

Table 18. Simple Correlation Coefficients (r)[1] Between Tree Growth and Foliar Composition Variables--Experiment-2[2]

Foliage Variable	Mean Annual Increment: Diameter	Mean Annual Increment: Height	Mean Annual Increment: Volume
Concentration - Percent DW			
N	.230 -.725 to .722	.257 -.535 to .716	.198 -.823 to .756
P	.152 -.404 to .753	.256 -.486 to .795	.210 -.338 to .675
K	-.120 -.785 to .365	-.148 -.638 to .365	-.082 -.823 to .359
Ca	-.061 -.472 to .654	-.054 -.984 to .703	-.130 -.592 to .513
Mg	-.045 -.667 to .949	.007 -.839 to .897	-.028 -.644 to .906
Content - mg/leaf			
N	.198 -.519 to .912	.241 -.560 to .874	.230 -.457 to .943
P	.164 -.557 to .856	.253 -.569 to .801	.230 -.535 to .843
K	.027 -.612 to .865	.058 -.602 to .800	.079 -.608 to .871
Ca	.043 -.177 to .895	.095 -.823 to .844	-.004 -.388 to .884
Mg	.027 -.724 to .698	.111 -.731 to .786	.042 -.529 to .566

[1]Significant r at 0.05 level = 0.264.

[2]Upper value = average of 56 trees growing on eight sites; lower values = range among sites.

with foliar N and P was positive for concentration and content. Direction for the other elements was mixed.

Multiple regressions relating growth variables with foliar composition were somewhat better than simple regressions. In best regressions involving concentration units, N, P, and K accounted for 12, 20 and 11% of the variation in diameter, height, and volume growth, respectively. Best regressions for foliar content were N and K for diameter growth (R^2 = 12%), N, P, and K for height growth (R^2 = 20%), and all five elements for volume growth (R^2 = 18%).

Foliage and Soil Relationships

Three related analyses were performed. Correlations among topsoil elements were examined first. Then a correlation analysis among foliar element composition provided insight into possible ion interactions. Lastly, a correlation analysis was used to determine the extent to which variability in the foliar composition of individual trees was associated with variations in the nutrient levels of the topsoil beneath.

There were significant correlations between total N in the topsoil and extractable K, Ca, and Mg (Table 19). The cations were significantly correlated with each other. Total N and Ca were correlated the best with 67% of the variation explained. There was a lack of correlation between P and the other topsoil elements.

A change in the concentration of any one element in the soil exerts an influence on others and, consequently, on elemental composition in the foliage. Although information about ion interactions in the nutrition of hardwoods is scarce, two reviews (Emmert, 1960; Smith,

Table 19. Simple Correlation Coefficients (r)* Between N, P, K, Ca, and Mg in the Topsoil--Experiment-2

Soil Element	N (Percent DW)	P (ppm)	K (meq/100g)	Ca (meq/100g)
P (ppm)	-0.009			
K (meq/100 g)	0.562	-0.096		
Ca (meq/100 g)	0.818	-0.148	0.489	
Mg (meq/100 g)	0.586	-0.121	0.608	0.743

*Significant r at 0.05 level = 0.264.

1962) indicate that antagonisms among K, Ca, and Mg are general for plants.

Only foliar percent K was significantly correlated with N and P (Table 20). On-the-other-hand, the content of each foliar element was significantly and positively correlated with each of the other elements. This was probably due to the constant influence of leaf blade dry weight in the calculation of foliar contents.

Foliar P, Ca, and Mg concentrations and P content were significantly correlated with respective soil values (Table 21). However, less than 10% of the variation in foliar composition was accounted for by regression. The indicated relationships, although statistically significant, were so poor that they would not influence sampling recommendations.

Although correlations were poor, foliar concentrations were better correlated with respective soil values than were foliar contents. Of all the elements N was correlated the poorest. There was no apparent relationship between the degree of correlation and site. No other soil elements were significantly correlated with foliar composition values.

Multiple regression analyses were made with the soil elements employed as independent variables for the prediction of foliar N, P, K, Ca, and Mg composition. As indicated by the coefficient of determination 12, 21, 12, 10, and 36% of the variation in N, P, K, Ca, and Mg percentage of the leaf blades, respectively, was accounted for by the best regressions on soil variables. Each regression involved the respective soil element plus one other, except the P regression which had three soil elements.

Table 20. Simple Correlation Coefficients (r)* Between Foliar N, P, K, Ca, and Mg Concentrations and Contents--Experiment-2

Foliar Composition	N	P	K	Ca
Concentration - Percent DW				
P	0.188			
K	0.292	0.321		
Ca	-0.033	0.080	0.150	
Mg	-0.049	-0.002	-0.191	0.000
Content - mg/leaf				
P	0.828			
K	0.859	0.823		
Ca	0.606	0.588	0.617	
Mg	0.602	0.541	0.507	0.414

*Significant r at 0.05 level = 0.264.

Table 21. Simple Correlation Coefficients (r)[1] Between Foliage Composition and Respective Topsoil Values--Experiment 2[2]

Foliage Composition	Soil N	Soil P	Soil K	Soil Ca	Soil Mg
Concentration	.057	.275	.232	.293	.300
(Percent DW)	-.470 to .604	-.294 to .811	-.669 to .490	-.332 to .452	-.242 to .783
Content	-.077	.280	.060	.088	.234
(mg/leaf)	-.598 to .545	-.442 to .813	-.801 to .287	-.508 to .127	-.581 to .884

[1]Significant r at 0.05 level = 0.264.

[2]Upper value = average of 56 trees growing on eight sites; lower values = range among sites.

Nine, 14, 6, and 38% of the variation in foliar contents of N, P, K, and Mg, respectively, was accounted for by best regressions. The regressions for N, P, and Mg involved the respective soil element plus two others. The regression predicting foliar K content involved N and Ca. Foliar Ca content was so poorly related to soil elements that the mean was the best measure.

Variation

Foliage. The coefficient of variation (CV) of 10.5% for foliar N concentration was the lowest of all foliar variables studied (Table 22). Largest coefficients were obtained for foliar contents (30% and greater).

Leaf weights and area were similar in their variability.

Coefficients of variation calculated for nutrient concentrations were less than the coefficients of respective nutrient contents. Coefficients calculated for P and K concentrations were similar (18-19%); those calculated for Ca and Mg concentrations were also similar (29-30%).

There was no apparent relationship between the magnitudes of the foliage variables and the coefficients of variation.

Coefficients calculated for foliar nutrients agree closely with those reported by Metz *et al.* (1966) from young loblolly pines on a relatively homogeneous Piedmont site. Leaf (1973) found foliar N concentration the least variable and K concentration the most variable of five elements determined in the foliage of a 35-year-old red pine plantation in New York.

Soil. Soil pH exhibited the least variation of any soil variable

Table 22. Mean, Range, and Coefficient of Variation of Foliage Variables (Combined Sites)--Experiment-2

Variable	Mean	Range	CV
Leaf weight (g/100 leaves)	263.8	131.6 - 414.4	27.0
Blade weight (g/100 leaves)	228.1	114.6 - 357.4	27.4
Blade area (cm^2/leaf)	264	133 - 421	28.1
Foliar N (percent DW)	2.08	1.67 - 2.71	10.5
Foliar P (percent DW)	0.13	0.08 - 0.20	17.8
Foliar K (percent DW)	1.21	0.50 - 1.62	18.8
Foliar Ca (percent DW)	1.60	0.92 - 2.94	28.8
Foliar Mg (percent DW)	0.32	0.14 - 0.67	29.8
Foliar N (mg/leaf)	47.6	20.7 - 82.0	30.1
Foliar P (mg/leaf)	2.9	1.2 - 4.6	32.6
Foliar K (mg/leaf)	27.8	8.9 - 52.5	35.4
Foliar Ca (mg/leaf)	36.5	11.5 - 75.4	38.5
Foliar Mg (mg/leaf)	7.3	1.9 - 15.9	39.4

studied. Coefficients of variation calculated for soil nutrients were greater than those of corresponding elements in the foliage (Table 23).

Variation of N, Ca, and Mg exceeded 70% while that of P and K was under 40%. In general, soil nutrients were more variable than soil separates or pH. This corroborates results from other forest soils (Alban, 1974; Ike and Clutter, 1968; Metz _et al_., 1966).

The magnitude of variability of soil characteristics could not be compared with other published data because of differing units of measure.

Sampling Recommendations

The calculated numbers of trees required to estimate means of foliage and soil variables within 10% at two levels of probability are given in Table 24. If estimates within 5% of the mean are desired, then the number of trees needed would be four times those shown.

In general, the numbers of samples needed to obtain a specified accuracy are less among foliage variables than among soil variables. Among soil variables, pH requires the minumum and Ca requires maximum numbers of samples. The minimum numbers of foliage samples are required for percent N and the maximum numbers are required for Mg content.

These sampling requirements for specific foliage and soil characteristics have limited practical value. Most often several elements or other properties are determined from each sample of leaves or soil. Therefore sampling requirements will be determined by the most variable characteristic of interest. When large numbers of samples are required to estimate extremely variable characteristics, the high cost involved usually necessitates an arbitrary reduction. This means accepting a

Table 23. Mean, Range, and Coefficient of Variation of Soil Variables (Combined Sites)--Experiment-2

Variable	Mean	Range	CV
Sand (percent DW)	40	12 - 70	41.6
Silt (percent DW)	37	16 - 62	34.9
Clay (percent DW)	23	12 - 40	29.6
Organic matter (percent DW)	6.66	2.29 - 29.45	79.0
pH	6.0	4.9 - 7.9	11.1
Total N (percent DW)	0.28	0.11 - 1.10	71.4
Extractable P (ppm)	15	8 - 30	38.8
Extractable K (meq/100 g)	0.75	0.42 - 1.25	24.0
Extractable Ca (meq/100 g)	9.82	1.15 - 37.56	86.8
Extractable Mg (meq/100 g)	1.59	0.37 - 4.68	69.8

Table 24. Numbers of Trees Required to Estimate Means of Foliage and Soil Variables Within 10% at 0.05 and 0.01 Levels of Probability

Characteristic	Level of Probability 0.05	0.01
Leaf weight	29	52
Blade weight	30	53
Blade area	32	56
Foliar concentration		
N	4	8
P	13	23
K	14	25
Ca	33	59
Mg	36	63
Foliar content		
N	36	64
P	43	76
K	50	89
Ca	60	106
Mg	62	110
Sand	69	123
Silt	49	87
Clay	35	62
Organic matter	250	444
pH	5	9
Total N	205	363
Extractable P	60	107
Extractable K	23	41
Extractable Ca	302	536
Extractable Mg	196	347

lower level of precision and/or a lower probability level. Since we are dealing with single tree plots it is not possible to achieve any trade offs between trees per plot and numbers of plots.

Variability might also be reduced by stratifying the population. For example, in this experiment sites were logical strata. Inspection of individual site means and CV's showed that soil from north and south Plateau slopes above 488 m and coves was very high in OM and N. Variability calculated for OM on these three sites was 74% and over 200 samples would be required to achieve the minimum prescribed precision. However the CV of the remaining sites was 31% and the required sample was 40. A similar reduction in the sample size required for soil N could be made using these same low-variability sites.

Evaluation

There was no basis for an evaluation of experiment-2 results with respect to experiment-1. None of the three growth variables in experiment-2 were significantly related to foliar element percentages. Thus it was not possible to contrast the concentrations associated with best growth in experiment-2 with its seedling counterpart in experiment-1.

As an alternative, foliar concentrations of experiment-2 trees averaged over all sites were compared with foliar concentrations of seedlings growing in topsoil which had received the equivalent of 336 kg P/ha (those with the best biomass growth).

Tree leaves averaged 0.13% less N than leaves of seedlings grown in Hartsells, but were about equal in N concentration to Bodine-grown seedlings. Trees on Plateau sites averaged less N than Hartsells-grown seedlings, but the range exceeded the seedling level on four of six Plateau sites. Trees on both Highland Rim sites averaged higher foliar N concentrations than Bodine-grown seedlings.

The concentration of P in tree foliage averaged 0.02% more than that in seedling leaves. Only on south slopes below 488 m was P concentration less than that in seedlings.

Potassium concentration in tree foliage averaged more than 0.2% greater than in seedling leaves, although individual trees in coves and Highland Rim hollows and bottoms, and on south slopes below 488 m, had less K than the seedlings.

The concentration of Ca in tree foliage was 0.22% less than the concentration in seedling leaves while the foliar Mg concentration in trees was 0.07% greater than it was in seedlings.

Mean concentrations in seedling leaves at the highest P rate were all within the range of concentrations recorded for trees growing in natural stands. No distinguishing differences were evident.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Two separate but related experiments were conducted as the initial effort to evaluate the adequacy of Cumberland Plateau and Highland Rim soils in middle Tennessee and northern Alabama for the satisfactory growth and development of white ash. The first consisted of seedlings in pots of soil (Hartsells and Bodine) with all combinations of four levels of N as NH_4NO_3 (0, 168, 336, 504 kg/ha) and four levels of P as TSP (0, 112, 224, 336 kg/ha).

Total biomass and height of seedlings were linearly and positively related to P-supply. The relation of root collar diameter and root/shoot ratio was quadratic and positive. N-supply had no significant effect on seedling growth and there was no interaction.

P-supply had a greater effect on seedlings grown in Hartsells than those grown in Bodine. Seedlings which received the highest rate of P had five and two times more biomass, respectively, than seedlings in non-fertilized soils. But Bodine-grown seedlings were larger than those grown in Hartsells.

Phosphorus in both soils appeared to be limiting the growth of white ash seedlings; more so in Hartsells than in Bodine. The highest rate of 336 kg/ha was not enough to satisfy this deficiency. White ash seedlings should respond to larger increments of P. Foliar concentration of P at the highest rate was 0.11% DW. Seedling height and root collar diameter responses indicated that projected gains in biomass from additional P would be due more to stem elongation than diameter growth. The N supplying capacity of these topsoils must be assumed to be adequate for the growth of white ash seedlings. Additional response may be possible from added N when the limiting supply of P is satisfied.

Although differences among soil sources could not be tested statistically, the data showed that the biomass of seedlings grown in Jernigan and Mayes sources of Bodine (Group I) averaged 28.4 g/pot while those grown in the three Hartsells sources and the Cascade Springs source of Bodine (Group II) averaged 15.7 g. Group I soils had relatively high pH (> 5.5) and Ca (> 2 meq/100 g). Group II had low pH (< 5.5) and Ca (< 2 meq/100 g). Biomass of seedlings in both groups increased with P-supply.

The partition of seedlings into roots, stems, and foliage was very consistent regardless of seedling size. Roots comprised 70%, stems 14%, and foliage 16% of the total biomass. Seedling biomass was significantly and positively related to foliar N, P, K, Ca, and Mg contents. However, as biomass increased the concentration of foliar N and K decreased while Ca increased.

Supplies of N and P had greater influence on the foliar composition of Hartsells-grown seedlings than on Bodine-grown ones. In the foliage of seedlings grown in Hartsells, N-supply increased the percent of foliar N and decreased P and Ca; P-supply decreased the percent of foliar N and increased P and Ca. In the foliage of seedlings grown in Bodine, the only influence was an increase in P concentration due to P-supply.

Added P significantly increased the foliar content of all five elements from both soils except Mg from Bodine. The foliar content of P and K in Hartsells-grown seedlings decreased and N content in Bodine-grown seedlings increased with N-supply.

The second experiment was an attempt to define relationships between the growth of white ash trees in natural stands and soil nutrient and foliar composition values. Fifty-six trees on eight broad sites were sampled. The delineation of these sites were supported by the significance of tree diameter, height, and volume, and topsoil characteristics with respect to site. However, mean annual increments were not related to site.

Variability of topsoil characteristics was reflected in wide ranges in foliar composition. Foliar concentrations of P, K, and Ca varied significantly with site. All topsoil and foliage variables varied considerably within sites. No site was distinctly different from all others for any one or group of variables.

Topsoil pH was the only soil property significantly correlated with a growth variable (volume). No foliage composition variable was significantly correlated with growth. Multiple regressions relating growth to soil nutrients or foliar composition showed that soil N, Ca, and Mg explained 14% and foliar N, P, and K explained 20% of the variation in height growth. The best soil or foliar predictors explained 12% or less of the variation in diameter and volume growth.

Foliar P, Ca, and Mg concentrations were significantly correlated with respective soil values. However, less than 10% of the variation in concentration was accounted for by regression. Twelve, 21, 12, 10, and 36% of the variation in N, P, K, Ca, and Mg foliar concentration was accounted for by multiple regressions employing soil elements as independent variables.

Soil elements were considerably more variable than foliar concentrations. Foliar contents were more variable than foliar concentrations. Measured soil physical properties were less variable than chemical properties. Trade offs between precision, cost, and stratification were deemed necessary when sampling soil and foliage composition of single-tree plots.

The lack of significant relationships between foliar concentrations and tree growth made it impossible to evaluate the fertility status of the sampled trees with respect to experiment-1 results. Alternatively, the foliar concentration of experiment-2 trees averaged over all sites were compared with the average foliar concentration of seedlings grown in topsoil which had received the equivalent of 336 kg P/ha (those with largest biomass). There were some small differences, but the concentration of elements in seedling leaves were all within the range of concentrations recorded in the leaves of trees growing in natural stands.

The lack of correlation might have been due to the choice of mean annual increments as measures of growth response. Mean annual increments are integrators of the tree's response to all environmental stresses during its lifetime. Trying to relate these integrated expressions of growth with point measures of soil and foliage characteristics may have been a futile endeavor.

Perhaps periodic growth in the recent past would be a more realistic measure of growth. However, only periodic diameter growth can be determined from once-measured hardwood trees. Periodic height and volume growth require repeated measurements. A reliable measure of response is a major problem confronting the forest scientist studying species which occur as scattered trees on a wide range of sites in the upland mixed hardwood forests.

It was concluded that two representative soils of the Cumberland Plateau and Highland Rim (Hartsells and Bodine) were deficient in P for the optimum growth of white ash seedlings. It appeared that soil pH (5.5) and Ca content (2 meq/100 g) were also critical. Biomass of seedlings grown in soils above these values were 1.8 times larger than those grown in soils below these levels.

The results were inconclusive regarding the adequacy of Plateau and Rim soils for the satisfactory growth and development of ash in natural stands. Neither foliar composition nor soil properties were strongly related to tree growth. The wide variation in growth rates both within and among sites can probably be attributed to the broadness of the sites, the wide range of ages, and the small numbers of samples.

South-facing lower Plateau slopes were obviously poor sites. Trees growing at 0.6 m per year in height occurred on nearly all sites. On the average, white ash trees in mixed upland forests grew at the annual rate of 0.4 m in height, 0.5 cm in diameter, and 8.5 dm^3 in merchantable stem volume.

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LITERATURE CITED

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APPENDICES

APPENDIX A

COMMON AND SCIENTIFIC NAMES

American beech	-	*Fagus grandifolia* Ehrh.
American elm	-	*Ulmus americana* L.
American filbert	-	*Corylus americana* Walt.
Basswood	-	*Tilia americana* L.
Bigtooth aspen	-	*Populus grandidentata* Michx.
Black cherry	-	*Prunus serotina* Ehrh.
Blackgum	-	*Nyssa svlvatica* Marsh.
Black locust	-	*Robinia pseudoacacia* L.
Black walnut	-	*Juglans nigra* L.
Buckeye	-	*Aesculus octandra* Marsh.
Chestnut oak	-	*Quercus prinus* L.
Cottonwood	-	*Populus deltoides* Bartr. var *deltoides*
Cucumber	-	*Magnolia acuminata* L.
Dogwood	-	*Cornus florida* L.
European white birch	-	*Betula verrucosa* Ehrh.
Green ash	-	*Fraxinum pennsylvanica* Marsh.
Loblolly pine	-	*Pinus taeda* L.
Northern red oak	-	*Quercus rubra* L.
Overcup oak	-	*Quercus lyrata* Walt.
Paper birch	-	*Betula papyrifera* Marsh.
Pendunculate oak	-	*Quercus robur* L.

Pignut hickory	-	_Carya glabra_ (Mill.) Sweet
Quaking aspen	-	_Populus tremuloides_ Michx.
Red maple	-	_Acer rubrum_ L.
Red pine	-	_Pinus resinosa_ Ait.
Scarlet oak	-	_Quercus coccinea_ Muenchh.
Sessile oak	-	_Quercus petraea_ (Mattuschka) Liebl.
Shortleaf pine	-	_Pinus echinata_ Mill.
Silver maple	-	_Acer saccharinum_ L.
Southern red oak	-	_Quercus falcata_ Michx. var. _falcata_
Sugar maple	-	_Acer saccharum_ Marsh.
Sweetgum	-	_Liquidambar styraciflua_ L.
Sycamore	-	_Plantanus occidentalis_ L.
Water oak	-	_Quercus nigra_ L.
White ash	-	_Fraxinum americana_ L.
White basswood	-	_Tilia heterophylla_ Vent.
White oak	-	_Quercus alba_ L.
White pine	-	_Pinus strobus_ L.
Willow oak	-	_Quercus phellos_ L.
Yellow birch	-	_Betula alleghaniensis_ Britton
Yellow-poplar	-	_Liriodendron tulipifera_ L.

Table 25. Root Biomass (Oven Dry Weight) of White Ash Seedlings--Experiment-1

		P Level									
		Hartsells					Bodine				
Block	N Level	0 (g/pot)	1 (g/pot)	2 (g/pot)	3 (g/pot)	Mean (g/pot)	0 (g/pot)	1 (g/pot)	2 (g/pot)	3 (g/pot)	Mean (g/pot)
I	0	0.5	13.0	13.1	23.9	12.6	2.6	8.5	13.8	23.0	12.0
	1	0.4	1.2	17.4	19.4	9.6	0.3	8.7	10.5	23.3	10.7
	2	0.2	1.8	11.4	14.3	6.9	0.3	13.3	6.9	22.4	10.7
	3	0.1	2.8	6.7	17.1	6.7	0.2	4.4	9.3	10.2	6.0
	Mean	0.3	4.7	12.2	18.7	9.0	0.8	8.7	10.1	19.7	9.8
I	0	12.3	5.2	21.6	14.7	13.4	12.4	17.1	16.7	20.4	16.6
	1	4.1	12.8	20.2	29.4	16.6	15.6	31.8	26.1	27.4	25.2
	2	0.8	3.2	18.8	8.0	7.7	12.3	25.3	23.7	9.8	17.8
	3	0.2	8.2	6.4	24.6	9.8	12.7	24.0	30.5	33.9	25.3
	Mean	4.4	7.4	16.8	19.2	11.9	13.2	24.5	24.2	22.9	21.2
III	0	5.0	18.0	5.2	22.6	12.7	12.3	9.0	24.6	12.1	14.5
	1	9.6	17.9	9.4	15.6	13.1	13.8	20.6	7.4	39.5	20.3
	2	2.6	21.7	21.6	26.5	18.1	10.8	22.1	10.4	17.0	15.1
	3	4.2	8.9	17.3	22.2	13.2	5.1	11.6	24.8	35.5	19.8
	Mean	5.4	16.6	13.4	21.7	14.3	10.5	15.8	16.8	26.5	17.4
Block mean	0	5.9	12.1	13.3	20.4	12.9	9.1	11.5	18.4	18.5	14.4
	1	4.7	10.6	15.7	21.5	13.1	9.9	20.4	14.7	30.1	18.8
	2	1.2	8.9	17.3	16.3	10.9	7.8	20.2	13.7	16.4	14.5
	3	1.5	6.6	10.1	21.3	9.9	6.0	13.3	21.5	27.2	17.0
	Mean	3.3	9.6	14.1	19.8	11.7	8.2	16.4	17.0	23.0	16.2

Table 26. Stem Biomass (Oven Dry Weight) of White Ash Seedlings--Experiment-1

		P Level									
		Hartsells					Bodine				
Block	N Level	0 (g/pot)	1 (g/pot)	2 (g/pot)	3 (g/pot)	Mean (g/pot)	0 (g/pot)	1 (g/pot)	2 (g/pot)	3 (g/pot)	Mean (g/pot)
I	0	0.1	2.9	3.0	4.7	2.7	0.4	2.4	2.9	5.5	2.8
	1	0.2	0.3	3.2	3.3	1.8	0.1	0.9	1.2	5.6	2.0
	2	0.1	0.3	2.5	3.4	1.6	0.1	1.7	1.6	4.2	1.9
	3	0.1	0.7	1.2	3.8	1.4	0.1	1.0	1.9	1.6	1.2
	Mean	0.1	1.0	2.5	3.8	1.9	0.2	1.5	1.9	4.2	2.0
II	0	2.8	1.1	4.6	2.7	2.8	2.6	4.4	3.3	6.8	4.3
	1	1.0	2.5	3.2	6.6	3.3	3.1	8.1	7.3	6.2	6.2
	2	0.1	0.6	3.1	1.7	1.4	2.6	4.8	5.4	3.0	4.0
	3	0.1	1.4	1.1	4.4	1.8	3.0	5.9	8.0	10.2	6.8
	Mean	1.0	1.4	3.0	3.8	2.3	2.8	5.8	6.0	6.6	5.3
III	0	0.9	3.1	0.8	3.0	2.0	2.3	1.9	3.8	3.3	2.8
	1	1.2	2.6	2.2	2.1	2.0	2.3	4.9	1.8	8.1	4.3
	2	0.3	3.0	3.2	3.8	2.6	2.9	5.0	2.8	4.0	3.7
	3	0.6	1.6	1.8	2.8	1.7	1.2	2.8	6.4	9.6	5.0
	Mean	0.8	2.6	2.0	2.9	2.1	2.2	3.6	3.7	6.2	3.9
Block mean	0	1.3	2.4	2.8	3.5	2.5	1.8	2.9	3.3	5.2	3.3
	1	0.8	1.8	2.9	4.0	2.4	1.8	4.6	3.4	6.6	4.1
	2	0.2	1.3	2.9	3.0	1.8	1.9	3.8	3.3	3.7	3.2
	3	0.3	1.2	1.4	3.7	1.6	1.4	3.2	5.4	7.1	4.3
	Mean	0.6	1.7	2.5	3.5	2.1	1.7	3.6	3.9	5.7	3.7

Table 27. Foliage Biomass (Oven Dry Weight) of White Ash Seedlings--Experiment-1

		P Level									
		Hartsells					Bodine				
Block	N Level	0 (g/pot)	1 (g/pot)	2 (g/pot)	3 (g/pot)	Mean (g/pot)	0 (g/pot)	1 (g/pot)	2 (g/pot)	3 (g/pot)	Mean (g/pot)
I	0	0.1	2.9	2.4	3.9	2.3	0.6	2.7	3.1	6.2	3.2
	1	0.2	0.3	3.6	4.2	2.1	0.1	1.4	2.2	5.9	2.4
	2	0.1	0.5	2.9	5.4	2.2	0.3	1.9	1.8	4.1	2.0
	3	0.1	1.3	1.6	5.2	2.0	0.1	1.1	2.3	2.8	1.6
	Mean	0.1	1.2	2.6	4.7	2.2	0.3	1.8	2.4	4.8	2.3
II	0	3.0	1.2	4.1	3.8	3.0	2.0	3.3	3.3	4.9	3.4
	1	1.3	2.9	3.6	6.7	3.6	3.2	7.4	5.9	5.3	5.4
	2	0.2	0.8	3.6	2.9	1.9	2.3	5.0	5.0	3.1	3.8
	3	0.1	1.6	1.6	5.2	2.1	2.9	5.8	8.0	9.2	6.5
	Mean	1.2	1.6	3.2	4.6	2.7	2.6	5.4	5.6	5.6	4.8
III	0	1.1	3.1	1.3	3.7	2.3	2.8	2.6	3.5	3.5	3.1
	1	1.8	3.3	3.1	3.1	2.8	2.6	4.6	2.0	7.9	4.3
	2	0.5	4.0	4.3	4.8	3.4	3.5	4.4	3.8	4.3	4.0
	3	0.9	1.9	2.6	3.5	2.2	1.9	3.1	6.8	8.8	5.2
	Mean	1.1	3.1	2.8	3.8	2.7	2.7	3.7	4.0	6.1	4.1
Block mean	0	1.4	2.4	2.6	3.8	2.6	1.8	2.9	3.3	4.9	3.2
	1	1.1	2.2	3.4	4.7	2.8	2.0	4.5	3.4	6.4	4.0
	2	0.3	1.8	3.6	4.4	2.5	2.0	3.8	3.5	3.8	3.3
	3	0.4	1.6	1.9	4.6	2.1	1.6	3.3	5.7	6.9	4.4
	Mean	0.8	2.0	2.9	4.4	2.5	1.8	3.6	4.0	5.5	3.7

Table 28. Root Collar Diameter of White Ash Seedlings (Mean of Four Seedlings Per Pot)--Experiment-1

		P Level									
		Hartsells					Bodine				
Block	N Level	0 (mm)	1 (mm)	2 (mm)	3 (mm)	Mean (mm)	0 (mm)	1 (mm)	2 (mm)	3 (mm)	Mean (mm)
I	0	1.2	3.9	3.7	4.4	3.3	2.2	4.4	4.6	5.0	4.0
	1	1.6	2.0	4.4	4.3	3.1	1.6	3.0	4.0	4.4	3.2
	2	1.3	2.3	4.4	4.4	3.1	1.4	3.4	3.6	5.8	3.6
	3	1.3	2.8	3.3	4.6	3.0	1.6	2.9	3.9	4.2	3.2
	Mean	1.4	2.8	4.0	4.4	3.1	1.7	3.4	4.0	4.8	3.5
II	0	3.9	3.1	4.4	4.6	4.0	4.1	3.7	4.8	4.7	4.3
	1	2.6	5.0	4.6	4.6	4.2	5.2	6.1	4.8	5.3	5.4
	2	1.8	2.5	4.5	4.2	3.2	4.7	4.8	5.5	4.7	4.9
	3	1.4	3.4	3.4	5.1	3.3	4.0	6.0	6.1	7.0	5.8
	Mean	2.4	3.5	4.2	4.6	3.7	4.5	5.2	5.3	5.4	5.1
III	0	3.2	4.7	3.1	4.8	4.0	3.8	4.0	5.0	4.2	4.2
	1	4.1	4.7	4.3	4.4	4.4	4.0	4.3	4.0	6.0	4.6
	2	2.7	4.6	5.9	4.9	4.5	4.5	5.4	5.0	5.1	5.0
	3	3.0	3.8	4.3	4.8	4.0	3.2	4.6	5.4	6.8	5.0
	Mean	3.2	4.4	4.4	4.7	4.2	3.9	4.6	4.8	5.5	4.7
Block mean	0	2.8	3.9	3.7	4.6	3.8	3.4	4.0	4.8	4.6	4.2
	1	2.8	3.9	4.4	4.4	3.9	3.6	4.5	4.3	5.2	4.4
	2	1.9	3.1	4.9	4.5	3.6	3.5	4.5	4.7	5.2	4.5
	3	1.9	3.3	3.7	4.8	3.4	2.9	4.5	5.1	6.0	4.6
	Mean	2.3	3.6	4.2	4.6	3.7	3.4	4.4	4.7	5.3	4.4

Table 29. Height of White Ash Seedlings (Mean of Four Seedlings Per Pot)--Experiment-1

		P Level									
		Hartsells					Bodine				
Block	N Level	0 (cm)	1 (cm)	2 (cm)	3 (cm)	Mean (cm)	0 (cm)	1 (cm)	2 (cm)	3 (cm)	Mean (cm)
I	0	4.9	12.2	11.7	17.2	11.5	8.6	12.6	15.7	17.2	13.5
	1	5.4	7.4	12.5	12.1	9.4	5.8	8.1	9.4	18.4	10.4
	2	5.7	6.7	12.5	14.1	9.8	5.5	9.8	11.3	15.8	10.6
	3	5.2	8.5	8.9	16.0	9.6	5.2	9.7	11.6	9.8	9.1
	Mean	5.3	8.7	11.4	14.8	10.0	6.3	10.0	12.0	15.3	10.9
II	0	13.2	8.2	14.2	14.0	12.4	13.4	15.6	13.7	18.2	15.2
	1	9.5	14.5	13.4	18.5	14.0	15.2	22.1	16.9	18.2	18.1
	2	4.7	9.2	12.6	12.0	9.6	14.0	14.6	18.1	15.8	15.6
	3	5.9	8.9	10.0	16.7	10.4	11.9	19.9	18.4	23.8	18.5
	Mean	8.3	10.2	12.5	15.3	11.6	13.6	18.0	16.8	19.0	16.9
III	0	9.3	15.3	10.7	14.5	12.4	13.6	10.5	15.0	13.6	13.2
	1	9.0	10.8	15.3	12.2	11.8	11.4	14.5	12.4	22.1	15.1
	2	6.0	12.4	12.1	12.4	10.7	13.8	15.0	14.6	17.0	15.1
	3	7.0	11.9	9.5	12.6	10.2	9.6	12.9	18.0	23.5	16.0
	Mean	7.8	12.6	11.9	12.9	11.3	12.1	13.2	15.0	19.0	14.8
Block mean	0	9.1	11.9	12.2	15.2	12.1	11.9	12.9	14.8	16.3	14.0
	1	8.0	10.9	13.7	14.2	11.7	10.8	14.9	12.9	19.6	14.5
	2	5.4	9.4	12.4	12.8	10.0	11.1	13.1	14.7	16.2	13.8
	3	6.0	9.8	9.5	15.1	10.1	8.9	14.2	16.0	19.0	14.5
	Mean	7.2	10.5	12.0	14.4	11.0	10.7	13.8	14.6	17.8	14.2

Table 30. Foliar N Concentration (Percent Dry Weight) of White Ash Seedlings--Experiment-1

		P Level									
	N	Hartsells					Bodine				
Block	Level	0	1	2	3	Mean	0	1	2	3	Mean
I	0	1.58	2.04	1.60	1.16	1.60	2.12	2.57	2.79	1.89	2.34
	1	2.58	1.72	1.61	2.20	2.03	-	2.24	2.67	2.20	2.37
	2	-	2.47	2.32	2.59	2.46	3.45	2.60	2.58	1.83	2.62
	3	-	3.08	3.17	2.57	2.94	-	2.77	3.13	3.33	3.08
	Mean	2.08	2.33	2.18	2.13	2.19	2.78	2.54	2.79	2.31	2.58
II	0	2.65	2.40	1.37	2.41	2.21	1.89	1.67	1.33	1.89	1.70
	1	2.67	2.32	2.46	1.71	2.29	1.64	1.53	1.84	1.53	1.64
	2	3.47	3.06	2.08	2.65	2.82	1.78	2.05	1.46	2.45	1.94
	3	3.78	3.09	3.34	2.59	3.20	2.18	1.90	1.63	1.79	1.88
	Mean	3.14	2.72	2.31	2.34	2.63	1.87	1.79	1.56	1.92	1.78
III	0	1.96	1.86	2.19	1.61	1.90	1.84	2.35	1.63	2.27	2.02
	1	2.34	1.88	2.36	2.41	2.25	1.70	2.01	2.91	1.25	1.97
	2	2.85	2.32	2.14	2.19	2.38	2.29	1.96	2.72	2.59	2.39
	3	2.76	3.06	2.54	2.43	2.70	3.24	2.62	2.22	1.55	2.41
	Mean	2.48	2.28	2.31	2.16	2.31	2.27	2.24	2.37	1.92	2.20
Block mean	0	2.06	2.10	1.72	1.73	1.90	1.95	2.20	1.92	2.02	2.02
	1	2.53	1.97	2.14	2.11	2.19	1.67	1.93	2.47	1.66	1.93
	2	3.16	2.62	2.18	2.48	2.61	2.51	2.20	2.25	2.29	2.31
	3	3.25	3.08	3.02	2.53	2.97	2.71	2.43	2.33	2.22	2.42
	Mean	2.75	2.44	2.26	2.21	2.42	2.21	2.19	2.24	2.05	2.17

Table 31. Foliar P Concentration (Percent Dry Weight) of White Ash Seedlings--Experiment-1

		P Level									
	N	Hartsells					Bodine				
Block	Level	0	1	2	3	Mean	0	1	2	3	Mean
I	0	-	0.12	0.13	0.12	0.12	0.11	0.15	0.16	0.11	0.13
	1	-	0.12	0.11	0.16	0.13	-	0.05	0.13	0.12	0.10
	2	-	0.08	0.08	0.11	0.09	-	0.06	0.11	0.11	0.09
	3	-	0.10	0.13	0.08	0.10	-	0.10	0.05	0.08	0.08
	Mean	-	0.10	0.11	0.12	0.11	0.11	0.09	0.11	0.10	0.10
II	0	0.16	0.14	0.13	0.12	0.14	0.07	0.14	0.07	0.12	0.10
	1	0.09	0.14	0.14	0.09	0.12	0.04	0.08	0.13	0.11	0.09
	2	-	0.08	0.10	0.10	0.09	0.06	0.11	0.08	0.19	0.11
	3	-	0.09	0.06	0.12	0.09	0.06	0.10	0.08	0.11	0.09
	Mean	0.12	0.11	0.11	0.11	0.11	0.06	0.11	0.09	0.13	0.10
III	0	0.07	0.10	0.13	0.11	0.10	0.06	0.12	0.10	0.14	0.10
	1	0.04	0.07	0.11	0.10	0.08	0.06	0.09	0.15	0.05	0.09
	2	0.06	0.08	0.08	0.10	0.08	0.06	0.09	0.12	0.10	0.09
	3	0.05	0.08	0.08	0.08	0.07	0.11	0.12	0.11	0.08	0.10
	Mean	0.06	0.08	0.10	0.10	0.08	0.07	0.10	0.12	0.09	0.10
Block mean	0	0.12	0.12	0.13	0.12	0.12	0.08	0.14	0.11	0.12	0.11
	1	0.06	0.11	0.12	0.12	0.10	0.05	0.07	0.14	0.09	0.09
	2	0.06	0.08	0.09	0.10	0.08	0.06	0.09	0.10	0.13	0.10
	3	0.05	0.09	0.09	0.09	0.08	0.08	0.11	0.08	0.09	0.09
	Mean	0.07	0.10	0.11	0.11	0.10	0.07	0.10	0.11	0.11	0.10

Table 32. Foliar K Concentration (Percent Dry Weight) of White Ash Seedlings--Experiment-1

Block	N Level	P Level: Hartsells 0	Hartsells 1	Hartsells 2	Hartsells 3	Hartsells Mean	Bodine 0	Bodine 1	Bodine 2	Bodine 3	Bodine Mean
I	0	-	1.18	1.05	1.18	1.14	0.94	1.40	1.45	1.04	1.21
	1	-	1.54	0.92	1.12	1.19	-	1.27	1.30	1.31	1.29
	2	-	1.14	1.27	1.04	1.15	-	0.96	1.79	0.89	1.21
	3	-	1.13	1.34	0.77	1.08	-	1.28	1.28	1.10	1.22
	Mean	-	1.25	1.14	1.03	1.14	0.94	1.23	1.46	1.08	1.23
II	0	1.54	1.28	0.86	1.12	1.20	1.38	1.09	0.97	1.15	1.15
	1	1.56	1.16	0.75	0.54	1.00	0.83	0.92	1.05	1.18	1.00
	2	-	1.10	0.56	1.32	0.99	1.08	1.13	1.29	1.36	1.22
	3	-	1.21	1.20	0.67	1.03	1.03	0.95	0.78	1.00	0.94
	Mean	1.55	1.19	0.84	0.91	1.06	1.08	1.02	1.02	1.17	1.07
III	0	1.14	0.94	1.23	0.72	1.01	0.73	0.95	0.51	1.02	0.80
	1	0.75	0.72	1.14	1.21	0.96	0.91	0.57	1.11	0.31	0.72
	2	1.17	0.67	0.74	1.00	0.90	0.65	0.92	1.09	1.11	0.94
	3	0.89	1.14	0.82	0.82	0.92	0.85	0.84	0.66	0.46	0.70
	Mean	0.99	0.87	0.98	0.94	0.94	0.78	0.82	0.84	0.72	0.79
Block mean	0	1.34	1.13	1.05	1.01	1.13	1.02	1.15	0.98	1.07	1.05
	1	1.16	1.14	0.94	0.96	1.05	0.87	0.92	1.15	0.93	0.97
	2	1.17	0.97	0.86	1.12	1.03	0.86	1.00	1.39	1.12	1.10
	3	0.89	1.16	1.12	0.75	0.98	0.94	1.02	0.91	0.85	0.93
	Mean	1.14	1.10	0.99	0.96	1.05	0.92	1.02	1.11	0.99	1.01

Table 33. Foliar Ca Concentration (Percent Dry Weight) of White Ash Seedlings--Experiment-1

		P Level									
	N	Hartsells					Bodine				
Block	Level	0	1	2	3	Mean	0	1	2	3	Mean
I	0	-	1.64	2.00	2.02	1.89	1.15	1.55	1.65	1.46	1.45
	1	-	0.88	1.70	2.02	1.53	-	0.95	1.37	1.37	1.23
	2	-	0.92	1.36	1.23	1.17	-	1.00	1.12	1.35	1.16
	3	-	1.35	1.05	1.24	1.21	-	1.05	0.85	1.07	0.99
	Mean	-	1.20	1.53	1.63	1.45	1.15	1.14	1.25	1.31	1.23
II	0	1.52	1.62	1.50	2.13	1.69	1.70	1.84	2.13	2.02	1.92
	1	1.06	1.62	1.67	1.56	1.48	1.67	1.70	2.07	2.00	1.86
	2	-	0.72	1.62	1.26	1.20	2.07	2.29	2.23	2.14	2.18
	3	-	0.85	1.01	1.22	1.03	2.07	2.11	1.97	1.99	2.04
	Mean	1.29	1.20	1.45	1.54	1.38	1.88	1.98	2.10	2.04	2.00
III	0	1.46	2.23	2.16	2.82	2.17	2.03	2.40	2.79	2.24	2.36
	1	1.63	2.10	1.84	1.97	1.88	2.37	2.75	2.39	2.35	2.46
	2	1.42	2.10	1.77	2.00	1.82	2.16	2.46	2.30	2.32	2.31
	3	1.06	1.47	2.05	1.87	1.61	2.15	2.52	2.42	1.97	2.26
	Mean	1.39	1.98	1.96	2.16	1.87	2.18	2.53	2.48	2.22	2.35
Block mean	0	1.49	1.83	1.89	2.32	1.88	1.63	1.93	2.19	1.91	1.91
	1	1.34	1.53	1.74	1.85	1.62	2.02	1.80	1.94	1.91	1.92
	2	1.42	1.25	1.58	1.50	1.44	2.12	1.92	1.88	1.94	1.96
	3	1.06	1.22	1.37	1.44	1.27	2.11	1.89	1.75	1.68	1.86
	Mean	1.33	1.46	1.64	1.78	1.55	1.97	1.88	1.94	1.86	1.91

Table 34. Foliar Mg Concentration (Percent Dry Weight) of White Ash Seedlings--Experiment-1

		P Level									
	N	Hartsells					Bodine				
Block	Level	0	1	2	3	Mean	0	1	2	3	Mean
I	0	-	0.25	0.22	0.19	0.22	0.20	0.16	0.22	0.22	0.20
	1	-	0.06	0.17	0.18	0.14	-	0.10	0.14	0.12	0.12
	2	-	0.12	0.10	0.19	0.14	-	0.13	0.10	0.15	0.13
	3	-	0.16	0.12	0.21	0.16	-	-.17	0.13	0.17	0.16
	Mean	-	0.15	0.15	0.19	0.16	0.20	0.14	0.15	0.16	0.15
II	0	0.10	0.19	0.19	0.23	0.18	0.27	0.41	0.39	0.22	0.32
	1	0.09	0.16	0.19	0.18	0.16	0.29	0.37	0.26	0.26	0.30
	2	-	0.14	0.18	0.20	0.17	0.33	0.24	0.32	0.44	0.33
	3	-	0.10	0.15	0.14	0.13	0.38	0.36	0.28	0.29	0.33
	Mean	0.10	0.15	0.18	0.19	0.16	0.32	0.34	0.31	0.30	0.32
III	0	0.22	0.35	0.32	0.41	0.32	0.43	0.29	0.38	0.37	0.37
	1	0.17	0.28	0.27	0.21	0.23	0.45	0.43	0.33	0.50	0.43
	2	0.13	0.26	0.24	0.19	0.20	0.50	0.51	0.36	0.24	0.40
	3	0.16	0.27	0.26	0.27	0.24	0.46	0.45	0.45	0.42	0.44
	Mean	0.17	0.29	0.27	0.27	0.25	0.46	0.42	0.38	0.38	0.41
Block mean	0	0.16	0.26	0.24	0.28	0.24	0.30	0.29	0.33	0.27	0.30
	1	0.13	0.17	0.21	0.19	0.17	0.37	0.30	0.24	0.29	0.30
	2	0.13	0.17	0.17	0.19	0.17	0.42	0.29	0.26	0.28	0.31
	3	0.16	0.18	0.18	0.21	0.18	0.42	0.33	0.29	0.29	0.33
	Mean	0.14	0.20	0.20	0.22	0.19	0.38	0.30	0.28	0.28	0.31

APPENDIX C

Table 35. Topsoil Thickness--Experiment-2

Tree No.	Site 1 (cm)	2 (cm)	3 (cm)	4 (cm)	5 (cm)	6 (cm)	7 (cm)	8 (cm)	All (cm)
1	30	23	18	15	13	46	23	25	
2	41	8	61	8	15	10	36	36	
3	28	15	13	46	53	25	20	84	
4	23	33	20	11	20	25	43	30	
5	41	51	25	30	25	10	33	36	
6	30	41	23	28	20	18	25	25	
7	30	13	23	25	20	36	30	43	
Mean	32	26	26	23	24	24	30	40	28
SD	6.7	15.9	15.9	13.2	13.5	13.3	8.0	20.5	14.1
CV	21.1	60.6	60.7	56.5	56.9	54.7	26.8	51.5	50.1

Table 36. Topsoil Sand Content--Experiment-2

Tree No.	Site 1 (percent)	2 (percent)	3 (percent)	4 (percent)	5 (percent)	6 (percent)	7 (percent)	8 (percent)	All (percent)
1	40	48	56	68	40	38	18	18	
2	34	66	48	54	30	34	20	18	
3	64	70	44	68	54	52	16	28	
4	40	58	34	54	54	36	22	16	
5	58	64	40	60	48	22	20	14	
6	42	64	30	60	36	38	24	12	
7	50	38	34	44	22	38	22	20	
Mean	47	58	41	58	40	37	20	18	40
SD	11	11	9	8	12	9	3	5	17
CV	23.2	19.6	22.4	14.6	30.1	23.8	13.3	28.7	41.5

Table 37. Topsoil Silt Content--Experiment-2

Tree No.	Site 1 (percent)	2 (percent)	3 (percent)	4 (percent)	5 (percent)	6 (percent)	7 (percent)	8 (percent)	All (percent)
1	40	32	24	20	30	40	58	52	
2	36	18	30	30	36	48	54	58	
3	22	16	36	18	22	36	56	52	
4	38	20	28	32	22	36	52	54	
5	22	24	36	26	34	40	54	62	
6	34	20	36	22	36	34	52	62	
7	28	40	42	32	38	26	54	54	
Mean	31	24	33	26	31	37	54	56	37
SD	7	7	6	5	7	7	2	4	13
CV	23.7	35.7	18.4	22.6	21.5	18.1	3.9	7.8	35.2

Table 38. Topsoil Clay Content--Experiment-2

Tree No.	Site 1 (percent)	2 (percent)	3 (percent)	4 (percent)	5 (percent)	6 (percent)	7 (percent)	8 (percent)	All (percent)
1	20	20	20	12	30	22	24	30	
2	30	16	22	16	34	18	26	24	
3	14	14	20	14	24	12	28	20	
4	22	22	38	14	24	28	26	30	
5	20	12	24	14	18	38	26	24	
6	24	16	34	18	28	28	24	26	
7	22	22	24	24	40	36	24	26	
Mean	22	17	26	16	28	26	25	26	23
SD	5	4	7	4	7	9	2	4	7
CV	22.2	22.7	27.4	25.0	25.6	36.1	5.9	13.8	29.2

Table 39. Topsoil pH--Experiment-2

Tree No.	Site 1	2	3	4	5	6	7	8	All
1	5.1	7.0	6.5	6.8	6.9	7.0	5.2	5.7	
2	4.9	6.1	5.6	6.8	5.2	5.4	6.3	5.8	
3	4.9	6.4	6.3	6.2	6.6	5.5	5.8	5.9	
4	5.5	6.2	5.7	7.0	5.9	7.1	5.1	5.8	
5	5.2	6.0	6.7	6.5	5.8	5.4	5.6	5.3	
6	5.2	5.2	5.3	6.3	6.4	6.5	5.9	5.4	
7	5.0	5.6	5.7	5.8	6.0	7.9	5.8	6.5	
Mean	5.1	6.1	6.0	6.5	6.1	6.4	5.7	5.8	6.0
SD	0.2	0.6	0.5	0.4	0.6	1.0	0.4	0.4	0.7
CV	4.1	9.4	8.8	6.4	9.3	15.5	7.3	6.8	11.1

Table 40. Topsoil Organic Matter--Experiment-2

	Site								
Tree No.	1 (percent DW)	2 (percent DW)	3 (percent DW)	4 (percent DW)	5 (percent DW)	6 (percent DW)	7 (percent DW)	8 (percent DW)	All (percent DW)
1	4.46	8.18	14.87	29.45	6.92	4.78	3.97	4.69	
2	6.74	22.31	8.74	22.98	3.98	5.11	3.84	4.06	
3	4.06	9.76	14.85	5.49	5.36	3.02	4.03	2.29	
4	4.01	5.78	5.34	15.71	3.45	8.00	4.47	4.34	
5	4.94	4.58	6.12	8.92	3.10	6.21	3.80	2.63	
6	3.41	4.48	4.00	4.48	8.72	5.28	4.02	4.84	
7	3.90	4.58	4.86	3.93	5.12	4.16	4.27	7.61	
Mean	4.50	8.52	8.40	12.99	5.24	5.22	4.06	4.35	6.66
SD	1.10	6.41	4.66	10.04	2.01	1.57	0.24	1.74	5.26
CV	24.3	75.2	55.4	77.3	38.5	30.2	5.8	40.1	78.9

Table 41. Topsoil Total N--Experiment-2

Tree No.	1 (percent DW)	2 (percent DW)	3 (percent DW)	4 (percent DW)	5 (percent DW)	6 (percent DW)	7 (percent DW)	8 (percent DW)	All (percent DW)
1	0.18	0.29	0.72	1.10	0.25	0.17	0.16	0.22	
2	0.27	0.91	0.43	0.86	0.18	0.16	0.21	0.21	
3	0.16	0.42	0.68	0.23	0.21	0.11	0.22	0.12	
4	0.18	0.24	0.27	0.62	0.16	0.31	0.23	0.23	
5	0.23	0.18	0.31	0.38	0.12	0.24	0.21	0.12	
6	0.14	0.17	0.20	0.18	0.32	0.23	0.18	0.22	
7	0.15	0.17	0.23	0.18	0.24	0.19	0.18	0.37	
Mean	0.19	0.34	0.40	0.51	0.21	0.20	0.20	0.21	0.28
SD	0.05	0.27	0.21	0.36	0.06	0.06	0.02	0.08	0.20
CV	25.0	78.5	52.8	71.8	31.2	32.2	12.8	39.5	72.6

Table 42. Topsoil Extractable P--Experiment-2

Tree No.	Site 1 (ppm)	2 (ppm)	3 (ppm)	4 (ppm)	5 (ppm)	6 (ppm)	7 (ppm)	8 (ppm)	All (ppm)
1	21.4	9.9	14.1	17.8	7.7	8.8	29.8	17.2	
2	7.7	16.8	9.1	11.9	12.2	13.3	11.6	22.0	
3	17.5	14.0	16.1	24.2	11.9	16.4	10.5	13.0	
4	13.0	18.2	14.0	12.1	9.8	28.4	15.0	27.0	
5	9.1	9.9	8.4	10.8	11.9	10.5	14.4	16.8	
6	10.5	18.3	13.4	15.0	8.8	9.8	27.0	21.0	
7	10.8	13.6	13.4	10.8	9.1	9.1	27.0	21.4	
Mean	12.8	14.4	12.6	14.6	10.2	13.8	19.3	19.8	14.7
SD	4.9	3.6	2.8	4.9	1.8	7.0	8.2	4.5	5.7
CV	38.2	24.8	22.3	33.5	17.6	50.9	42.7	22.9	38.8

Table 43. Topsoil Extractable K--Experiment-2

	Site								
Tree No.	1 (meq/ 100g)	2 (meq/ 100g)	3 (meq/ 100g)	4 (meq/ 100g)	5 (meq/ 100g)	6 (meq/ 100g)	7 (meq/ 100g)	8 (meq/ 100g)	All (meq/ 100g)
1	0.71	0.56	1.25	1.08	1.01	0.95	0.60	0.82	
2	0.75	1.13	0.78	0.71	0.88	0.48	0.68	0.59	
3	0.72	0.85	1.06	0.62	0.76	0.44	0.72	0.51	
4	0.71	0.63	0.95	0.74	0.88	0.72	0.65	0.69	
5	0.70	0.65	0.95	0.65	0.59	0.77	0.88	0.42	
6	0.45	0.61	0.90	0.72	1.00	0.75	0.99	0.56	
7	0.69	0.65	0.82	0.64	0.90	0.65	0.75	0.90	
Mean	0.68	0.72	0.96	0.74	0.86	0.68	0.75	0.64	0.75
SD	0.10	0.20	0.16	0.16	0.14	0.18	0.14	0.17	0.18
CV	15.0	27.6	16.5	21.4	16.9	25.9	18.2	26.8	23.7

Table 44. Topsoil Extractable Ca--Experiment-2

	Site								
	1	2	3	4	5	6	7	8	All
Tree No.	(meq/ 100g)	(meq/ 100g)	(meq/ 100g)	(meq/ 100g)	(meq/ 100g)	(meq/ 100g)	(meq/ 100g)	(meq/ 100g)	(meq/ 100g)
1	2.70	15.42	21.00	37.56	24.55	10.20	4.09	5.27	
2	1.70	29.25	7.83	35.24	4.60	9.00	6.70	4.95	
3	1.80	12.90	19.40	6.10	9.80	5.55	5.78	4.81	
4	2.75	7.27	7.02	24.30	8.90	20.00	2.56	5.00	
5	1.50	4.70	11.85	11.55	4.36	17.24	4.09	2.65	
6	1.15	2.22	6.90	6.43	16.35	15.57	4.76	3.65	
7	1.31	4.15	6.82	9.25	11.55	23.50	4.00	10.10	
Mean	1.84	10.84	11.54	18.63	11.44	14.44	4.57	5.20	9.82
SD	0.64	9.43	6.18	13.60	7.10	6.44	1.34	2.35	8.52
CV	34.7	87.0	53.6	73.0	62.0	44.6	29.4	45.2	86.8

Table 45. Topsoil Extractable Mg--Experiment-2

Tree No.	Site 1 (meq/100g)	2 (meq/100g)	3 (meq/100g)	4 (meq/100g)	5 (meq/100g)	6 (meq/100g)	7 (meq/100g)	8 (meq/100g)	All (meq/100g)
1	0.76	0.95	2.83	3.62	2.42	1.05	0.98	1.55	
2	0.50	4.25	1.30	2.62	1.83	0.95	1.20	1.32	
3	0.37	1.52	3.10	0.65	1.28	0.67	1.33	0.85	
4	0.85	0.87	3.45	2.71	0.95	2.51	0.79	1.29	
5	0.73	0.75	2.08	1.22	0.67	4.17	1.14	0.73	
6	0.37	0.43	1.42	0.83	3.58	1.52	1.29	1.28	
7	0.48	0.80	1.30	1.05	4.68	3.92	1.22	2.13	
Mean	0.58	1.37	2.21	1.81	2.20	2.11	1.14	1.31	1.59
SD	0.20	1.31	0.91	1.15	1.47	1.45	0.19	0.46	1.11
CV	33.9	96.0	41.3	63.5	66.8	68.5	16.7	35.3	69.8

Table 46. Leaf Weight (Blade + Rachis)--Experiment-2

Tree No.	Site 1 (g/100 leaves)	2 (g/100 leaves)	3 (g/100 leaves)	4 (g/100 leaves)	5 (g/100 leaves)	6 (g/100 leaves)	7 (g/100 leaves)	8 (g/100 leaves)	All (g/100 leaves)
1	239.0	150.1	161.3	238.0	248.6	158.5	321.8	222.0	
2	214.5	239.5	390.8	196.8	243.1	131.6	271.8	243.4	
3	174.6	265.6	293.9	241.6	198.9	240.4	203.8	209.5	
4	311.6	243.4	265.4	304.4	214.8	330.6	291.7	343.0	
5	145.3	388.1	232.5	374.2	285.7	148.0	320.8	301.9	
6	294.7	290.1	247.5	399.7	390.5	208.5	372.7	242.0	
7	414.4	192.4	328.4	291.7	355.6	239.7	290.2	216.9	
Mean	256.3	252.7	274.2	292.3	276.7	208.2	296.1	254.1	263.8
SD	91.8	75.6	73.2	74.2	71.9	69.5	52.1	49.8	71.3
CV	35.8	29.9	26.7	25.4	26.0	33.4	17.6	19.6	27.0

Table 47. Leaf Blade Weight--Experiment-2

	Site								
Tree No.	1 (g/100 leaves)	2 (g/100 leaves)	3 (g/100 leaves)	4 (g/100 leaves)	5 (g/100 leaves)	6 (g/100 leaves)	7 (g/100 leaves)	8 (g/100 leaves)	All (g/100 leaves)
1	212.2	132.7	130.8	202.0	213.9	133.7	294.3	194.6	
2	187.3	210.5	324.3	174.7	208.8	114.6	237.5	209.9	
3	146.7	227.6	258.4	202.6	166.3	209.4	177.2	185.1	
4	269.7	206.4	219.4	256.6	179.2	288.1	255.8	285.4	
5	125.3	340.6	196.5	321.7	253.9	124.2	278.2	264.0	
6	254.7	262.3	208.0	349.2	334.5	179.7	329.7	207.8	
7	357.4	168.1	288.4	257.0	306.1	204.2	253.0	193.3	
Mean	221.9	221.2	232.2	252.0	237.5	179.1	260.8	220.0	228.1
SD	79.6	67.0	64.1	64.9	63.6	61.5	47.9	34.8	71.3
CV	35.9	30.3	27.6	25.8	26.8	34.3	18.4	17.6	27.3

Table 48. Leaf Blade Area--Experiment-2

	Site								
Tree No.	1 (cm^2/leaf)	2 (cm^2/leaf)	3 (cm^2/leaf)	4 (cm^2/leaf)	5 (cm^2/leaf)	6 (cm^2/leaf)	7 (cm^2/leaf)	8 (cm^2/leaf)	All (cm^2/leaf)
1	224	150	221	265	208	152	328	208	
2	191	200	396	198	342	133	293	264	
3	171	309	270	321	270	232	187	197	
4	330	212	280	359	203	379	264	351	
5	146	355	293	326	278	161	274	309	
6	280	260	284	421	328	169	293	218	
7	400	200	399	292	363	212	222	200	
Mean	249	241	306	312	284	205	266	250	264
SD	92	71	66	71	63	84	48	60	74
CV	37	30	22	23	22	41	18	24	28.1

Table 49. Foliar N Concentration--Experiment-2

Tree No.	Site 1 (percent DW)	2 (percent DW)	3 (percent DW)	4 (percent DW)	5 (percent DW)	6 (percent DW)	7 (percent DW)	8 (percent DW)	All (percent DW)
1	2.30	1.78	2.46	2.31	1.77	1.87	2.30	1.87	
2	1.92	1.83	2.53	2.04	2.71	2.02	2.09	2.45	
3	2.02	2.17	1.86	1.85	2.44	2.01	1.92	2.17	
4	2.31	2.06	1.77	2.18	2.18	1.92	2.25	2.22	
5	2.31	1.83	1.86	2.06	1.99	1.67	2.20	2.27	
6	1.99	2.09	2.22	2.19	2.30	1.86	2.01	1.92	
7	2.00	2.06	1.81	1.95	1.94	2.03	2.16	2.24	
Mean	2.12	1.97	2.07	2.08	2.19	1.91	2.13	2.16	2.08
SD	0.18	0.16	0.32	0.16	0.32	0.13	0.13	0.20	0.22
CV	8.3	7.9	15.6	7.5	14.7	6.7	6.3	9.4	10.5

Table 50. Foliar P Concentration--Experiment-2

Tree No.	Site 1 (percent DW)	2 (percent DW)	3 (percent DW)	4 (percent DW)	5 (percent DW)	6 (percent DW)	7 (percent DW)	8 (percent DW)	All (percent DW)
1	0.13	0.14	0.13	0.20	0.12	0.12	0.12	0.14	
2	0.12	0.14	0.14	0.12	0.13	0.10	0.16	0.13	
3	0.12	0.14	0.11	0.19	0.12	0.10	0.14	0.11	
4	0.14	0.16	0.10	0.12	0.11	0.12	0.17	0.12	
5	0.12	0.11	0.11	0.11	0.10	0.10	0.11	0.16	
6	0.14	0.17	0.12	0.12	0.12	0.08	0.12	0.12	
7	0.13	0.12	0.16	0.14	0.12	0.11	0.16	0.13	
Mean	0.13	0.14	0.12	0.14	0.12	0.10	0.14	0.13	0.13
SD	0.01	0.02	0.02	0.04	0.01	0.01	0.02	0.02	0.02
CV	7.0	14.9	16.6	25.8	8.1	13.4	17.0	12.6	17.9

Table 51. Foliar K Concentration--Experiment-2

Tree No.	Site 1 (percent DW)	2 (percent DW)	3 (percent DW)	4 (percent DW)	5 (percent DW)	6 (percent DW)	7 (percent DW)	8 (percent DW)	All (percent DW)
1	1.33	1.12	1.62	1.50	1.12	1.35	1.07	0.98	
2	1.09	0.83	1.50	1.04	1.44	1.40	1.27	1.14	
3	1.15	1.42	1.20	1.38	1.47	0.71	1.10	0.50	
4	1.25	1.20	1.18	1.44	1.10	1.42	1.43	1.33	
5	1.18	1.03	1.48	1.11	1.38	1.25	1.42	1.19	
6	1.47	1.13	1.35	1.34	1.19	0.89	1.02	0.83	
7	1.47	1.02	1.49	1.34	1.07	0.77	1.26	1.04	
Mean	1.28	1.11	1.40	1.31	1.25	1.11	1.22	1.00	1.21
SD	0.15	0.18	0.16	0.17	0.17	0.31	0.16	0.27	0.23
CV	11.9	16.4	11.8	13.0	13.7	28.0	13.5	27.2	18.8

Table 52. Foliar Ca Concentration--Experiment-2

Tree No.	Site 1 (percent DW)	2 (percent DW)	3 (percent DW)	4 (percent DW)	5 (percent DW)	6 (percent DW)	7 (percent DW)	8 (percent DW)	All (percent DW)
1	1.18	1.76	2.10	1.35	1.46	1.56	1.20	1.74	
2	1.66	1.33	1.86	2.36	1.26	1.00	1.77	1.47	
3	1.21	1.93	1.54	2.25	2.38	2.49	0.96	1.30	
4	0.97	1.17	1.41	2.94	1.49	2.02	1.49	1.57	
5	0.92	1.12	1.93	1.68	1.66	1.83	1.23	1.56	
6	1.26	2.50	1.95	1.60	1.45	1.04	1.45	1.05	
7	0.97	2.00	1.83	2.45	1.91	1.58	0.95	1.68	
Mean	1.17	1.69	1.80	2.09	1.66	1.64	1.29	1.48	1.60
SD	0.26	0.51	0.24	0.56	0.38	0.53	0.30	0.24	0.46
CV	21.9	30.0	13.5	27.0	22.7	32.2	23.0	16.0	28.8

Table 53. Foliar Mg Concentration--Experiment-2

Tree No.	Site 1 (percent DW)	2 (percent DW)	3 (percent DW)	4 (percent DW)	5 (percent DW)	6 (percent DW)	7 (percent DW)	8 (percent DW)	All (percent DW)
1	0.32	0.31	0.22	0.22	0.27	0.20	0.30	0.48	
2	0.34	0.31	0.23	0.39	0.47	0.17	0.25	0.35	
3	0.20	0.24	0.24	0.39	0.23	0.27	0.24	0.37	
4	0.31	0.41	0.67	0.29	0.24	0.23	0.26	0.32	
5	0.41	0.24	0.45	0.14	0.26	0.31	0.33	0.32	
6	0.29	0.28	0.37	0.32	0.42	0.19	0.33	0.39	
7	0.31	0.34	0.32	0.36	0.52	0.40	0.36	0.43	
Mean	0.31	0.30	0.36	0.30	0.34	0.25	0.30	0.38	0.32
SD	0.06	0.06	0.16	0.09	0.12	0.08	0.05	0.06	0.09
CV	20.1	19.6	45.2	31.0	35.4	32.0	15.7	15.5	29.8

VITA

Glendon William Smalley was born in Bridgeton, N. J. on 13 January 1928. He attended elementary schools in that city and was graduated from Bridgeton High School in 1945; a recipient of the Rensselaer Polytechnic Institute Mathematics and Science Award.

He attended the University of Michigan and Catawba College. In September 1949 he entered Michigan State University from which he received a Bachelor of Science degree, with honor, in Forestry in June 1952 and a Master of Science degree in December 1956.

He enrolled in The Graduate School at The University of Tennessee in September 1968 under the Government Employees Training Act and received the Doctor of Philosophy degree with a major in Plant and Soil Science in June 1975.

He has spent his entire professional career with the United States Forest Service. From 1953-1956 he completed several assignments on the Sam Houston National Forest, Texas, and the Ouachita National Forest, Arkansas. Since 1957 he has been associated with the Southern Forest Experiment Station, first at Birmingham, Alabama, and for the past 12 years at the Silviculture Laboratory, Sewanee, Tennessee. He has authored or co-authored 19 publications. Most recent, teamed with Dr. R. L. Bailey, he produced a comprehensive set of models for predicting and projecting stand structure of old-field loblolly and shortleaf pine plantations in middle Tennessee, northern Alabama, and northwestern Georgia.

He is a member of the Society of American Foresters, American Society of Agronomy, Soil Science Society of America, and the Ecological Society of America. He is a Registered Forester in Alabama. He has been elected to Xi Sigma Pi, Gamma Sigma Delta, and Sigma Xi. He is listed in Who's Who in the South and Southwest and American Men and Women of Science. He is a Christmas tree grower and has been a Director of the Tennessee Christmas Tree Growers Association since its inception in 1971.

He is married to the former Mary Corner, of Huntsville, Texas. They have two children; a son, Glendon, Jr. is a junior at The University of Tennessee at Knoxville, and a daughter, Leslie, is a freshman at The University of the South.