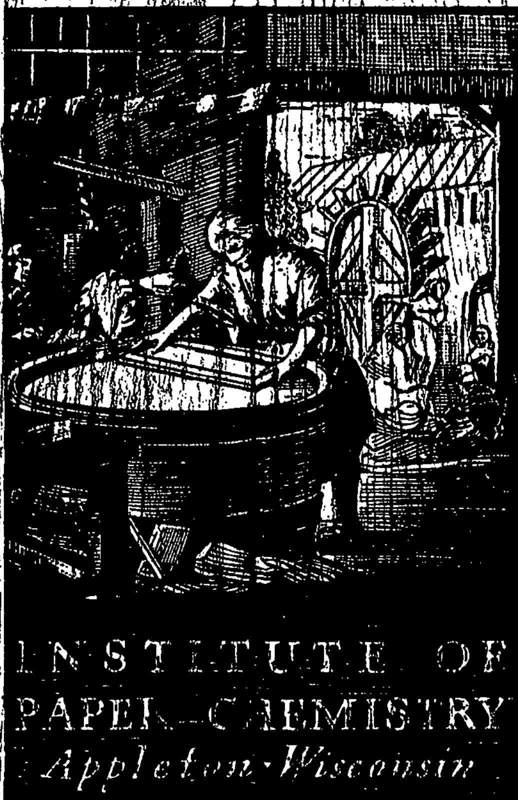

GROWTH AND NUTRIENT REQUIREMENTS OF HYBRIDS BETWEEN POPULUS CANESCENS AND POPULUS GRANDIDENTATA

Project 2412

Report Nine

A Progress Report

to

LOUIS W. AND MAUD HILL FAMILY FOUNDATION

September 11, 1968

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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COOPERATING ORGANIZATIONS

Investigations under way at The Institute of Paper Chemistry under Project 1800, sponsored by the Lake States Aspen Genetics and Tree Improvement Group, and Project 2412, sponsored by the Louis W. and Maud Hill Family Foundation, have been closely coordinated for the past five years to the mutual benefit of each group. With the exception of the progress report describing "Growth and Nutrient Requirements of Hybrids Between Populus canescens and Populus tremuloides," separate progress reports have been prepared which stressed the separate interests of the two cooperating organizations.

Again, as in the exception described above, the nature of the investigation being described is such that it is not feasible to provide separate descriptions of the study and the report that follows constitutes Progress Report Nine of Project 2412 and Progress Report Nineteen of Project 1800. The project cooperators for this combined report include the following organizations:

Project 2412

Louis W. and Maud Hill Family Foundation

Project 1800

American Can Company

Combined Paper Mills, Inc.

Kimberly-Clark Corporation

Nekoosa-Edwards Paper Company

The Northwest Paper Company

Owens-Illinois, Inc., Forest Products Division

The Procter & Gamble Company

St. Regis Paper Company

Scott Paper Company

Thilmany Pulp & Paper Company

indicating the uptake of certain elements influenced the uptake of other major nutrients. When estimates were made of the total amount of nutrient removed from the nutrient solutions, total uptake by the European gray poplar seedlings was approximately three times as great as that of the bigtooth aspen seedlings. Total nutrient uptake by the hybrids was intermediate between the two parent species.

INTRODUCTION

Land use trends, population increases, and increased per capita consumption of wood and paper products has generated considerable apprehension among forest managers regarding the future supply of raw material for the pulp and paper industry. With increasing pulpwood prices and the recent upswing in woods labor problems, more and more companies are considering the use of genetically improved species, mechanized harvesting systems, fertilization, irrigation, and other methods of intensive forest management as ways of meeting future raw material requirements.

As mentioned in earlier reports, there are a number of genetic and physiological implications, not the least of which is the need for the production of species that will do well on low-quality sites and will respond to improvements in soil fertility and soil moisture conditions. Equally important is the availability of rapidly growing species that have form and crown characteristics that make possible the production of high volume stands that will lend themselves to future mechanized harvesting operations. The report that follows describes work under way aimed at evaluating the nutrient requirements of several types of hybrids. The basic approach involves the use of sand culture techniques to compare the growth and nutrient requirements of aspen hybrids with comparable seedlings of the parent species. The work to date has investigated the nutrient requirements of hybrids produced by crossing Lake States quaking aspen (*Populus tremuloides*) and Lake States bigtooth aspen (*P. grandidentata*) with European gray poplar (*P. canescens*). Growth chamber space limitations made it necessary to subdivide the work into two investigations. Project 1800, Progress Report Seventeen, and Project 2412, Progress Report Seven (October, 1967) described work with hybrids between quaking aspen and European gray poplar. The investigation described in the report that follows evaluates the nutrient requirements of hybrids between bigtooth aspen and European gray poplar.

RELATED STUDIES

Although the nutrient requirements of aspen hybrids have not been investigated previously, considerable information on closely related species is available in the literature to guide the interpretation of results. Of general interest is the work of Keller (1) who placed the minimum soil requirements of northern hardwoods at 0.2% for total nitrogen, 35 p.p.m. and 75 p.p.m. for phosphorus (P_2O_5) and potassium (K_2O) and 4 meq./100 g. and 0.5 meq./100 g. for calcium and magnesium. Wilde and Patzer (2) suggest similar but somewhat higher levels of nutrients for hardwood nursery soils. Courtois, et al. (3) in investigating chlorotic symptoms in P. nigra and P. alba in arid soils indicated that with increasing levels of P the availability of iron (Fe) was reduced and this resulted in a reduction in chlorophyll synthesis. Meidin (4), working with potassium level in the leaves of Populus x robusta, reported that levels of less than 1% K in the leaves indicated K deficiencies. Similarly, Walker (5), in investigating foliar analysis as a method of indicating K deficient soils, found that P. tremuloides growing on unfertilized low K soils had levels of K in the leaves of less than 0.75% while on fertilized plots the level in the leaves was greater than 1%.

Of particular interest is the work of Shumakov (6) who pointed out that aspen assimilates three to four times as much N, five times as much Ca, and four times as much P as pine. Further, the author's experimental data indicated that cultivated poplars enriched the soil in humus and assimilated bases, such as Ca and Mg, but depleted the soil of N. Other Russian work by Slukhai (7) with poplar indicates that N, P, and K fertilization reduces the transpiration coefficient and results in more economical utilization of soil moisture. Voigt, et al. (8) investigating the effect of soil characteristics on the growth of quaking aspen in northern Minnesota state that the average annual growth of aspen on soils with high levels of Ca, Mg, K, and N was four times greater than on soils of low fertility. Foliar analyses showed a close relation between soil fertility and the presence of Ca, Mg, and K in the leaves. Average values of N, P, K, Ca, and Mg in tissue and soils were presented for the rapid, medium, and slow-growing aspen stands.

Satoo in sand culture work with P. davidiana (9) and Betula tauschii (10), demonstrated the influence of the absence of N, P, and K on growth. The absence of nitrogen was most serious in the work with P. davidiana and the work with birch indicated double the normal nutrient level was the level optimum for cultivation. Recently, Phares (11), working with cottonwood and using sand culture techniques, demonstrated that optimum growth occurred at nitrogen levels near 100 p.p.m., phosphorus at 18-25 p.p.m., and potassium at about 120 p.p.m.

METHODS AND MATERIALS

The study described was established to obtain information regarding the growth and nutritional requirements of hybrids between bigtooth aspen and European gray poplar. The information gained is to be used in determining sites suitable for growing the hybrids and predicting the relative growth advantage of these hybrids. The approach used was to grow appropriate types of seedlings in sand culture and compare the growth and nutrient uptake of the hybrids with the growth of seedlings of the parent species.

EXPERIMENTAL PROCEDURES

Previous progress reports describe the sand culture technique that was devised to be run in the Biology Section growth chamber. Figure 1 presents a view of the growth chamber and aspen experimental materials a few days prior to harvest. Basically, the system employs growth containers containing silica sand. These containers are attached to pressurized carboys containing the nutrient solutions. A time clock activates a valve on a compressed air line which in turn causes the solutions to be pumped into the growth containers. After five minutes the valve closes and the solution drains back into the carboys. The test seedlings are grown in the sand on this periodically fluctuating nutrient solution. One basic unit consists of a pressurized carboy and three growth containers. Each growth container is a replication and each treatment is replicated a total of six times. For each additional treatment, two additional basic units are added (two carboys with three growth containers attached).

The overall plan for the entire study consisted of running a series of five interrelated growth experiments. Light, temperature, day length, and relative humidity were held constant in each of the five "growth chamber trials" while the level of a different soil nutrient was varied. Seed from four experimental crosses was used as a source of plant material. The progeny groups were started in the sand-filled growth containers and the growth and nutritional status of the seedlings were measured after forty days. As previously mentioned, the types of hybrid aspen to be investigated using this procedure were crosses between bigtooth aspen (G) and European gray poplar (Ca). Table I lists the parentage of the four progeny groups. It should be noted that experimental Material 2, cross XG-Ca-43-66, involves a bigtooth aspen as the female parent while the experimental Material 3, XCa-G-27-66, is the reciprocal cross and involves a gray poplar as the female parent.

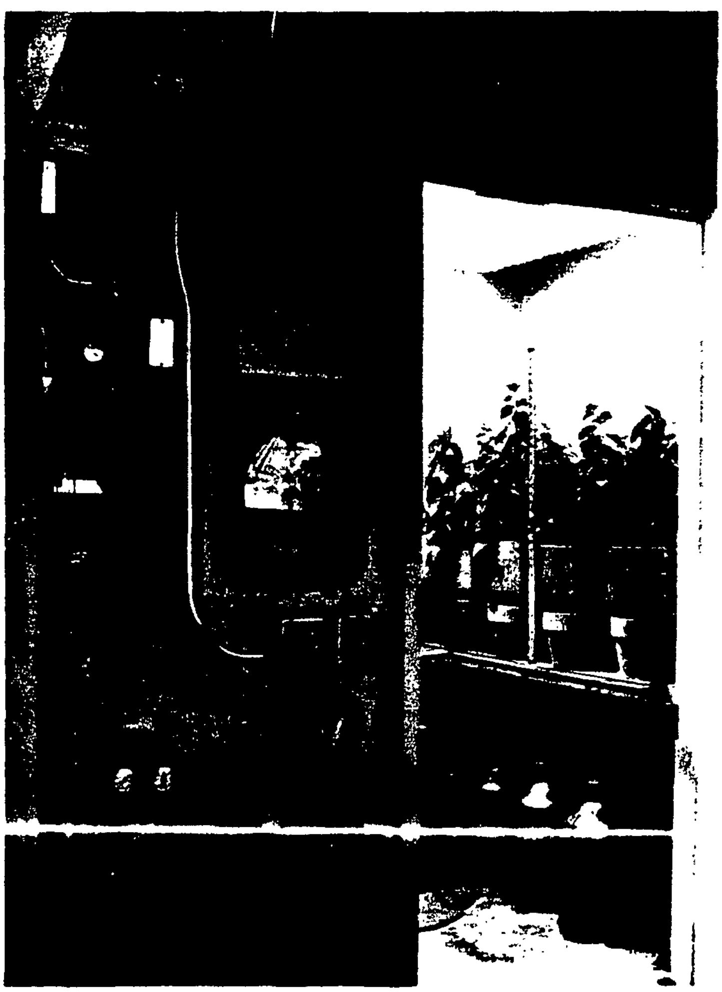

Figure 1. A View of the I.P.C. Growth Chamber Showing the Control Instruments (Left) and the Growth Containers Above and the Nutrient Carboys Below (Right). The Aspen Seedlings Shown Were Seeded 35 Days Earlier

TABLE I

PARENTAGE OF TEST TREES

Material Number	Type of Cross	Cross Number[a]	Parent Trees (female x male)
1	G x G	XG-0-55-66 XG-0-57-66	50-50 mixture of open-pollinated seed from G-8-66 and G-7-66
2	G x Ca	XG-Ca-43-66	G-22-60 x Ca-1-62
3	Ca x G	XCa-G-27-66	Ca-2 x G-2-66
4	Ca x Ca	XCa-28-66	Ca-2 x Ca-1-65

[a] X = cross, Ca = *P. canescens*, G = *P. grandidentata*, O = open-pollinated, the numbers indicate the cross number and the year the cross was completed.

Olson's (12) combination of required elements was used in making up the nutrient solution used in this study. The levels used by Olson were modified to meet the requirements of this investigation.[1] Nitrogen was the element varied in the first growth chamber run with levels of 29, 50, 75, 105, 131, and 158 p.p.m. being employed. The above nitrogen levels were run in combination with the level of the other essential nutrients listed in Table II under Olson's modified solution. A similar procedure was used in each growth chamber trial with a different element being varied. Table II presents the composition of Olson's modified solution and the six levels of each element used when that element was being varied in a growth chamber trial.

[1] Olson's modified nutrient solution contained all elements used by Olson except that the levels used were 60% of the levels he recommended.

TABLE II

COMPOSITION OF NUTRIENT SOLUTIONS, P.P.M.

Nutrient	Olson's Modified[a]	Six Levels Used in Growth Chamber Trials 1	2	3	4	5	6
N	158	29	50	75	105	131	158
P	65	2	11	22	43	54	65
K	93	3	15	31	62	77	93
Ca	46	0	8	15	31	38	46
Mg	21	0	3	7	14	17	21

[a]Appropriate levels of micronutrients were added to the basic solutions.

Each of the growth containers contained four seedlings, one seedling of each of the four types of test materials. Growth on the complete nutrient solution was rapid, and at 40 days it was not unusual to have seedlings that were ten to twenty inches tall. After 40 days of growth, all surviving seedlings were washed from the growth containers and the green weight (fresh weight) obtained for the tops and the roots along with the ovendry weights of the tops.[2] Next, the ovendry tops from the six genetically similar seedlings grown on the same nutrient solution were combined and the tissue ground in a Wiley mill. This ground tissue was used in determining the levels of N, P, K, Ca, and Mg in the seedlings produced by the various nutrient solutions. The levels of the above essential nutrients were determined by the IPC Analytical Chemistry Group using standard procedures for plant tissue.[3] The only exception to the above procedures was that in the case of the nitrogen growth chamber trial the dry weight of the roots was also measured.

[2]The term green weight is used throughout the report and is synonomous with the commonly used term "fresh weight."

[3]Emission spectrographic techniques were used in determining P, K, Ca, and Mg. Nitrogen was determined using the standard Kjeldahl procedure.

Nutrient uptake was examined to determine if such information, when related to growth information, would provide evidence regarding differences between test materials in their nutrient requirements. Uptake data were also used to examine the influence that varying the level of one element has upon the uptake of the other elements.

GROWTH COMPARISONS

The ratios of the dry weight of the tops to the green weight of the tops were calculated for all experimental data. A comparison of this information indicated that there were no significant differences between types of materials in the five experimental runs or between the average treatment effects on the dry weight – green weight ratio. In view of the relatively constant dry weight – green weight ratios, the total green weight of the plant was selected as the growth figure to be used in comparing treatment effects. Total dry weight data were presented for the nitrogen growth chamber trial only and were used to illustrate the relationships that exist between green weight and dry weight data.

Analysis of variance procedures were used to investigate differences between treatments and differences between experimental materials in growth and nutrient uptake. When significant growth differences were obtained either between experimental materials or due to treatment effects, the differences were illustrated graphically.

RESULTS

NITROGEN GROWTH CHAMBER TRIAL

The nitrogen trial was completed using the procedures described in the preceding section. Six levels of nitrogen (29, 50, 75, 105, 131, and 158 p.p.m.) were employed and, as previously discussed, there were six replications of each treatment. Figures 2 and 3 illustrate the green weight and dry weight changes that resulted when the level of nitrogen was varied.[4] Appendix Table XV summarizes average green weight for the experimental trees produced for all five growth chamber trials with the data for the nitrogen trial, the first of the trials listed.

Analysis of variance calculations using green weights indicated that there were significant growth differences between treatments and between test materials in response to increasing levels of nitrogen. Appendix Table XVI summarizes the analysis of variance calculations for the five growth chamber trials. The growth response was quite variable with Material 1 (bigtooth aspen cross) responding very little to the increasing levels of nitrogen and Material 4 (European gray poplar) showing the greatest response. Growth of the two hybrid crosses was more variable than the parent species crosses and the growth rate was intermediate. The growth and response of the hybrids to nitrogen treatments tended to be similar to the maternal parent species cross, i.e., Materials 1 and 2 behaved similarly and somewhat differently than Materials 3 and 4.

Appendix Table XVII summarizes the dry weight data for the several trials and Appendix Table XVIII summarizes the analysis of variance calculations. Analysis

[4]Both green weight and dry weight data are presented because the nitrogen treatments apparently influenced this ratio. The green weight — dry weight ratio for the other experimental trials was fairly constant and only green weight data have been presented.

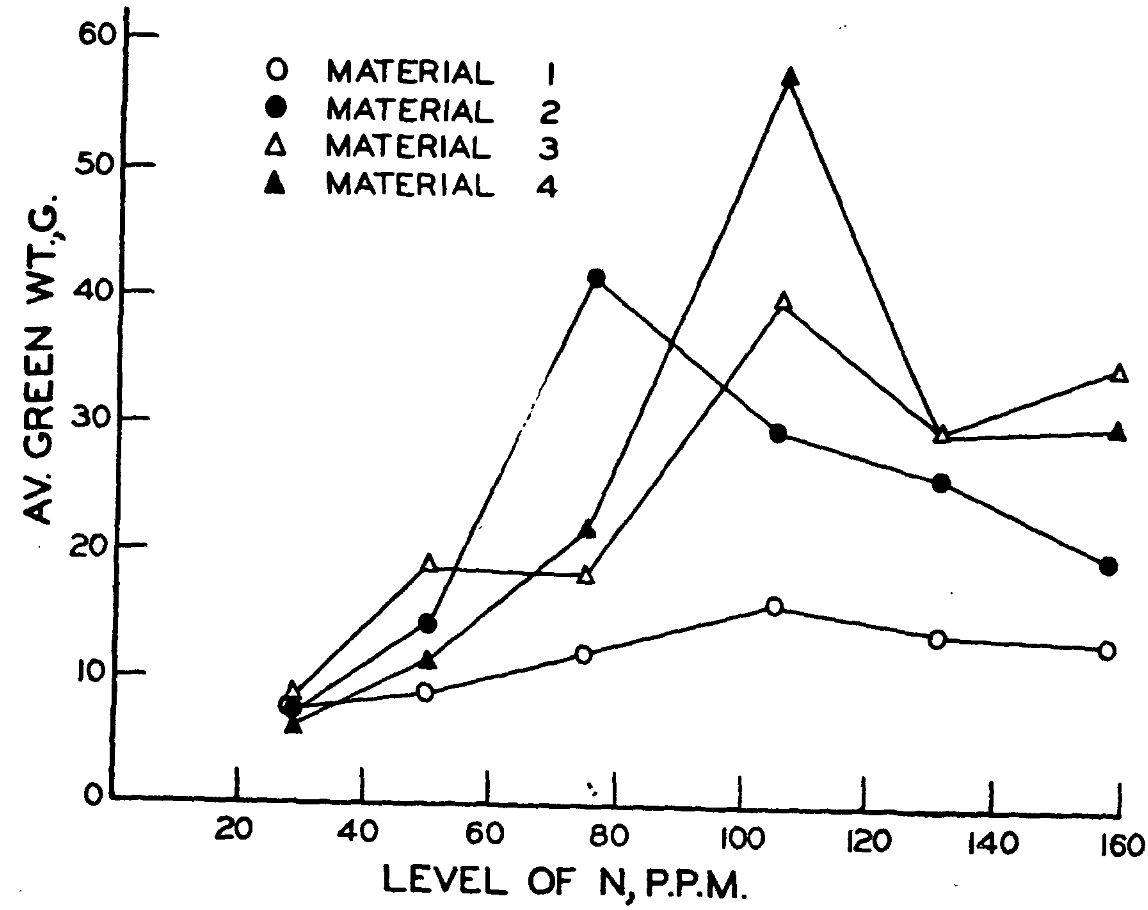

Figure 2. Differences in Average Green Weight of Trees Grown for Forty Days at Six Levels of Nitrogen

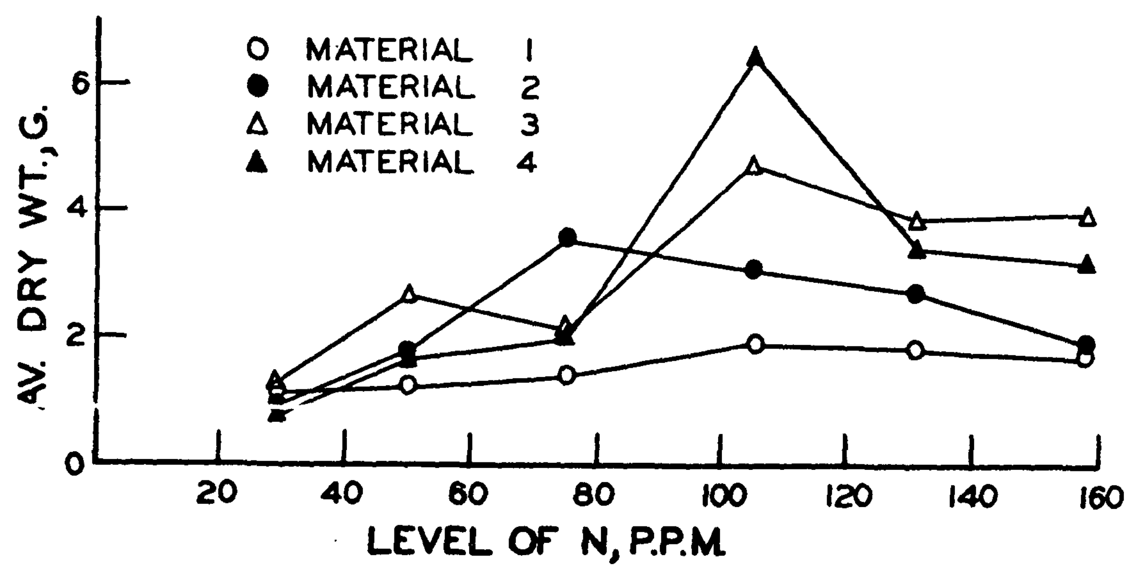

Figure 3. Differences in Average Dry Weight of Trees Grown for Forty Days at Six Levels of Nitrogen

of variance calculations on the dry weight data followed a trend similar to that of the green weight data and the discussion on nitrogen that follows applies to both green and dry weight data.

Looking at the overall growth data it appears that the levels of N above 105 p.p.m. failed to increase growth, and when Duncan's multiple range test was used to examine differences between treatment means, Treatment 4 quite consistently gave the best growth and Treatment 1 the poorest. In most instances growth differences between Treatments 1, 2, and 3 were not significant. Similarly, green weight growth differences between Treatments 5 and 6 were not significantly different. Growth differences between Treatments 1 and 4 appear to be the major cause of the significance between treatment results.

The nitrogen treatments not only influenced growth but also influenced the uptake of N, P, K, Ca, and Mg by the experimental tree seedlings. Figures 4, 5, and 6 illustrate the influence of N on the levels of the major essential elements in the tops of the experimental seedlings. Appendix Table XIX summarizes the results of the chemical analyses and Table III provides information on the analysis of variance calculations. These data indicate that there was increased nitrogen uptake as the level of nitrogen in the nutrient solution increased up to 105 p.p.m. Above the 105 p.p.m. treatment level the nitrogen in the tissue remained fairly constant. Uptake of P, Ca, and Mg followed a similar pattern with the uptake being low when nitrogen was low and increasing as nitrogen uptake increased. The same leveling-off trend at about 105 p.p.m. is also evident. Only in the case of Ca and Mg were there well-defined differences between materials in the uptake and, as Fig. 5 and 6 illustrate, the native bigtooth aspen (Material 1) had the lowest uptake, European gray poplar (Material 4) had the highest, and the two hybrids were

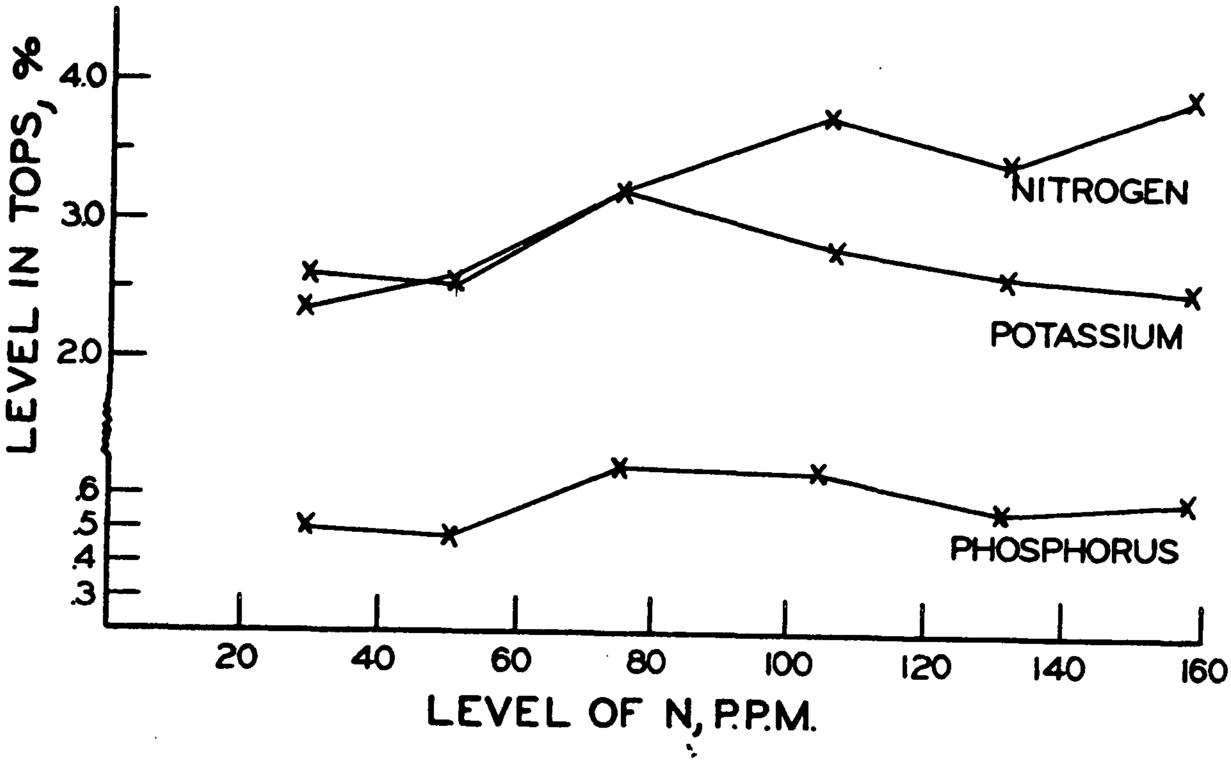

Figure 4. The Influence of Nitrogen Level on Nitrogen, Potassium, and Phosphorus Uptake. Data Plotted Are Combined Values for the Four Types of Experimental Materials

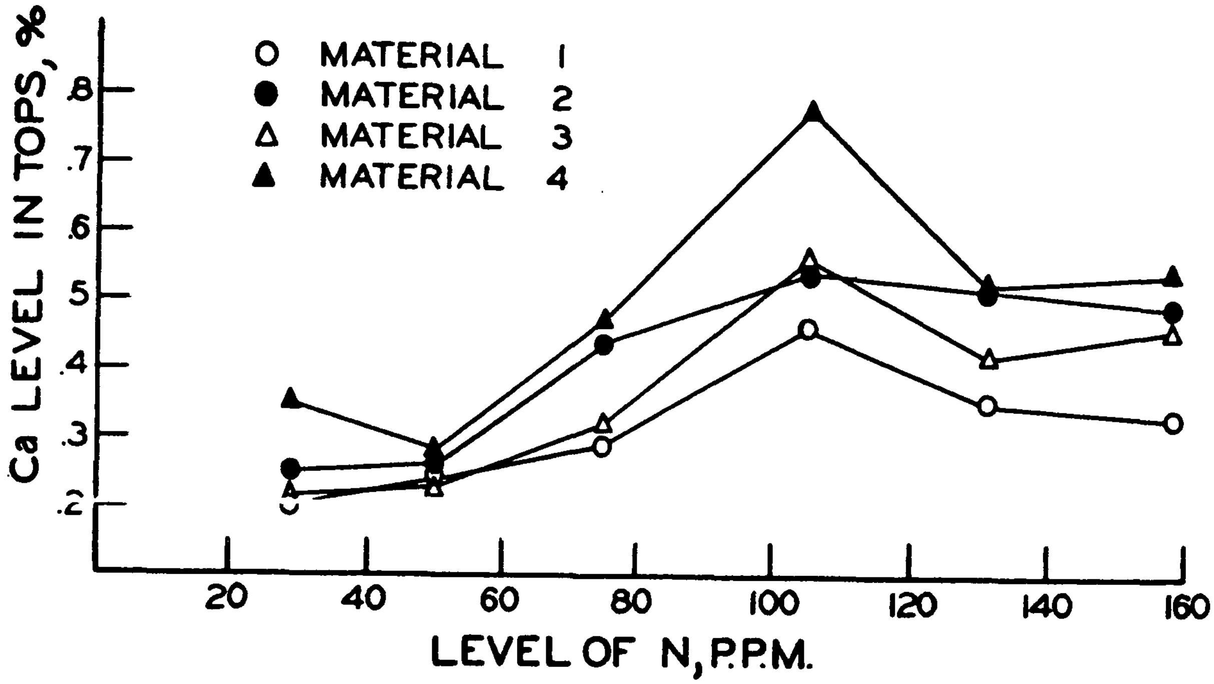

Figure 5. The Influence of Level of Nitrogen in the Nutrient Solution on Uptake of Calcium. Differences Between Experimental Materials are Statistically Significant

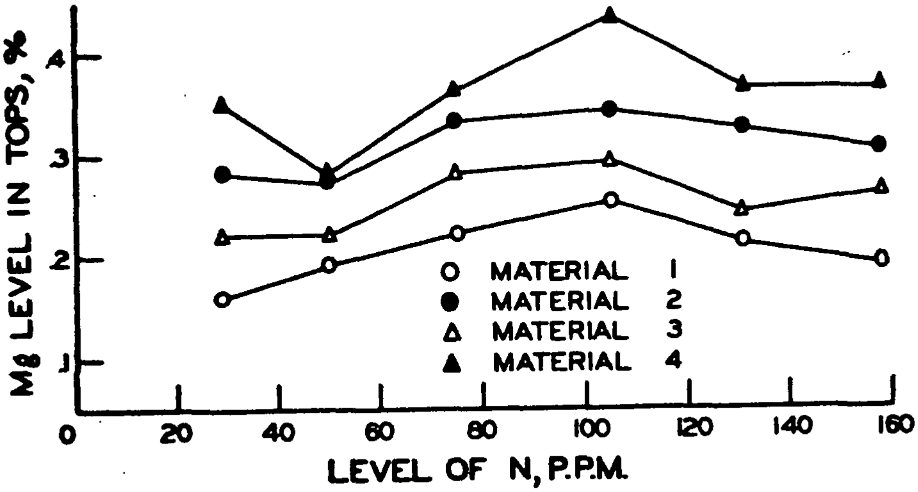

Figure 6. The Influence of Level of Nitrogen in the Nutrient Solution on Uptake of Magnesium. Differences Between Experimental Materials are Statistically Significant

TABLE III

ANALYSIS OF VARIANCE "F" VALUES FOR NITROGEN TRIAL
NUTRIENT LEVEL IN TISSUE

Element	Material[a]	Treatment[a]	Remarks
Nitrogen	4.79*	35.14**	Increasing uptake of N with increased supply in nutrient solution. Material 3 has low uptake, Materials 4 & 2 have high uptake.
Phosphorus	NS	16.23**	Phosphorus uptake is low at low nitrogen and increases to peak and drops off at higher levels of nitrogen.
Potassium	NS	12.7**	Trends same as phosphorus.
Calcium	14.1**	27.5**	Trends same as phosphorus with Material 1 having the lowest requirements, Material 4 the highest, and the hybrids intermediate in uptake.
Magnesium	51.9**	7.80**	Trends same as calcium in both treatments and materials.

[a]A double asterisk indicates the "F" values were significant at the 1% level, the single asterisk indicates significance at the 5% level, and the NS means the calculated "F" values were not significant.

intermediate. The high requirements of the European gray poplar and the very rapid growth of this material is in agreement with the results obtained in the earlier described growth chamber studies.

Differences between experimental materials in the level of nitrogen in the tops, when nitrogen was in adequate supply (levels greater than 105 p.p.m.) were not large. Average levels of N in the growth chamber tissue ranged from 4.00% for Material 3 to 4.31% for Material 2. The nitrogen level, obtained under growth chamber conditions, is higher than leaf sample information reported for aspen growing on good sites in Minnesota [1.85% (8)] and orchard-grown cherry leaves growing in Michigan [2.3-3.3% (13)]. The higher values reported are apparently related to the early uptake of N and the immature nature of the growth chamber leaf samples.

PHOSPHORUS GROWTH CHAMBER TRIAL

The phosphorus trial was established using the same experimental procedures and the same types of test materials as were used in the nitrogen trial. Phosphorus levels varied from 2 to 65 p.p.m. (2, 11, 22, 43, 54, and 65 p.p.m.) and the total green weight of the roots and tops and the dry weight of the tops were the measurement data taken to establish the growth response of the treatments. The dry weight — green weight ratios were not influenced by the phosphorus treatment.[5] Because the two types of data were so similar, only the total green weight growth data are presented.

Examination of the green weight data (Fig. 7 and Appendix Tables XV and XVI), using analysis of variance procedures, demonstrated that there were significant

[5] The one exception was the unusually high ratio which resulted at the very low level of phosphorus.

growth differences due to treatments and significant differences between the four types of experimental material in their response to the phosphorus treatments. All test materials grew slowly at the 2 p.p.m. level of phosphorus. Test Material 1, the bigtooth aspen cross, responded the least to increasing levels of phosphorus and test Materials 4 and 2 demonstrated the greatest response. Growth of the hybrids was intermediate between the two parent species with the growth curves for Materials 1 and 3 being similar and showing little growth response to P levels in excess of 11 p.p.m. The growth curves for test Materials 2 and 4 indicated slight decreases in growth resulting at treatment levels above 22 p.p.m.

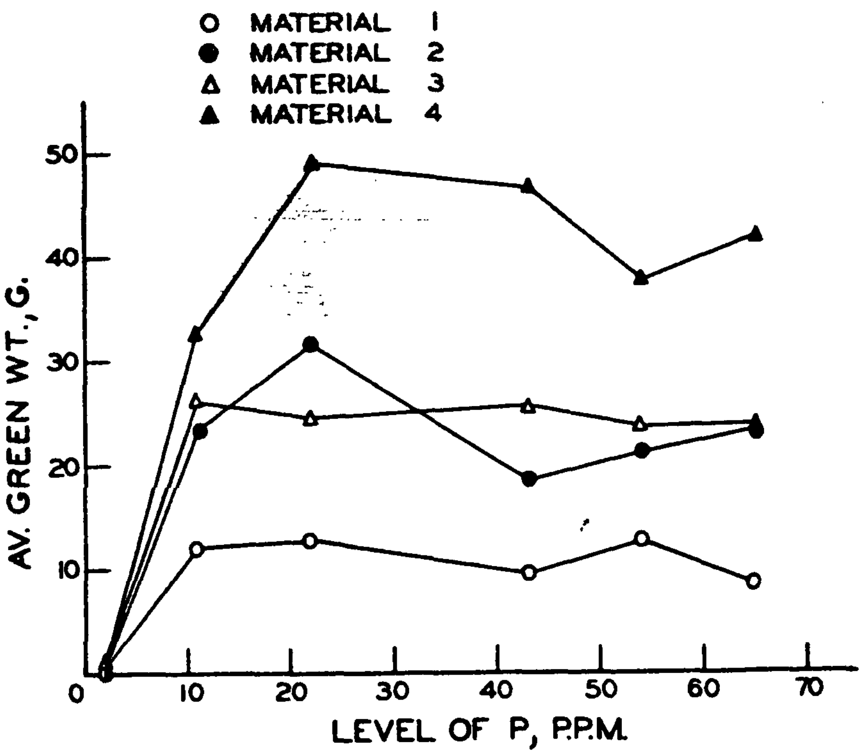

Figure 7. Differences in Average Green Weight of Trees Grown for Forty Days at Six Levels of Phosphorus

Table XX of the Appendix summarizes the chemical determinations made on the tops of the experimental trees grown in the phosphorus trial. Analysis of variance procedures were used to examine these data and Table IV summarizes the F test values obtained. The analysis of variance data indicates that increasing the level of phosphorus to 22 p.p.m. resulted in significant increases in the level of P in the tops of the seedlings. Above 22 p.p.m. the level in the tissue samples remained fairly constant. There was no significant difference between the four types of the experimental materials in phosphorus uptake. Figure 8 illustrates the trends described and also demonstrates the influence that increasing the level of P had on P, N, and K uptake. There was no significant difference between materials in P, N, and K uptake. (See between-material F values in Table IV.) Nitrogen uptake was highest at the low levels of P while the K uptake curve was very similar to that of P.

TABLE IV

ANALYSIS OF VARIANCE "F" VALUES FOR PHOSPHORUS TRIAL
NUTRIENT LEVEL IN TISSUE

Element	Material[a]	Treatment[a]	Remarks
Nitrogen	NS	2.97*	Slightly higher N uptake at lowest level of P.
Phosphorus	NS	22.6**	Increasing uptake with increasing level in solution.
Potassium	NS	6.67**	Low K uptake at two low levels of P.
Calcium	12.4**	NS	Low uptake of Ca by Material 1 and high uptake by Material 4. Hybrids usually intermediate.
Magnesium	16.9**	NS	Trend same as calcium.

[a]A double asterisk indicates the "F" values were significant at the 1% level, the single asterisk indicates significance at the 5% level and the NS means the calculated "F" values were not significant.

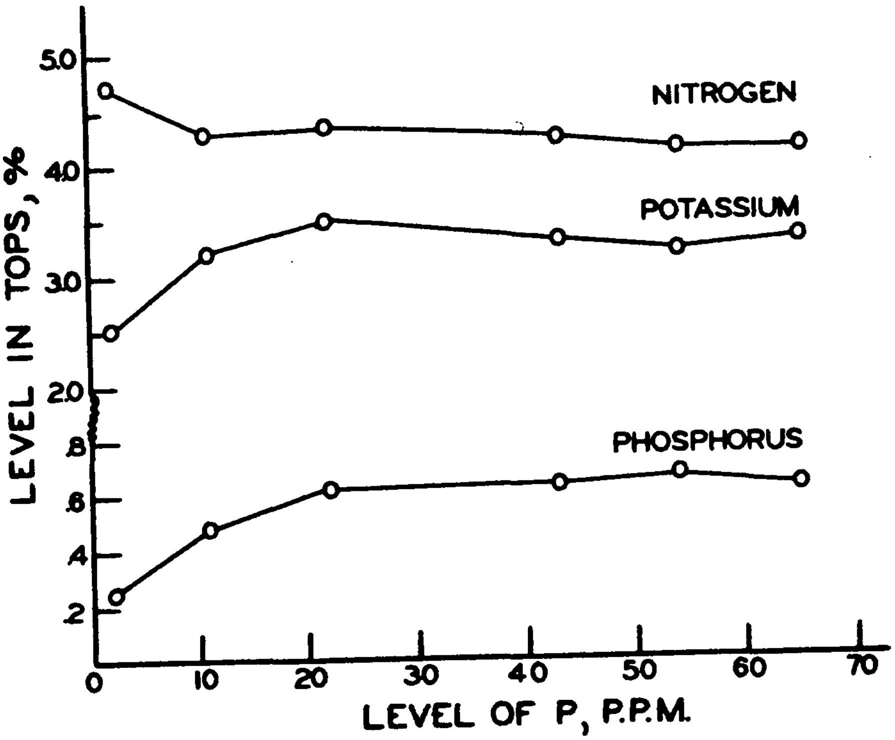

Figure 8. The Influence of Level of Phosphorus on Uptake of Nitrogen, Potassium and Phosphorus. Levels Shown are Average Values for the Four Types of Experimental Materials

The uptake of Ca and Mg was not affected by the phosphorus treatments and, as a result, no uptake curve is presented. There was, as in the nitrogen trial, significant differences between the four types of test materials in Ca and Mg uptake. Uptake was the least for Material 1, and greatest for Material 4. The two hybrids (Materials 2 and 3) were intermediate.

The phosphorus levels reported in Appendix Table XX are higher than reported for mature leaf samples of aspen growing on good sites [0.16% (8)] and orchard-grown cherry [0.23 0.33% (13)]. Early uptake and the immature nature of the growth chamber tissue samples are very likely major reasons for these differences. Examination of the growth response curve and the phosphorus nutrient uptake curve makes it clear that the lower levels of available P were adequately investigated.

POTASSIUM GROWTH CHAMBER TRIAL

Potassium levels were varied from 3 to 93 p.p.m. (3, 15, 31, 62, 77, and 93 p.p.m.) and the experimental design of the treatments was the same as described for previous trials. Figure 9 illustrates the response of the four test materials to increasing levels of potassium. When analysis of variance procedures were used, significant differences were obtained between test materials and between treatments for both the green weight and the dry weight growth data (see Appendix Tables XV, XVI, XVII, and XVIII). Growth was very slow at the low potassium levels and, although growth increases were obtained when the solutions contained up to 60 to 75 p.p.m., responses were not statistically significant above 31 p.p.m. The only exception was Material 4 which exhibited increased growth for K levels up to 62 p.p.m. Test Material 1 (bigtooth aspen) responded the least and Material 4 showed the greatest response to increasing levels of potassium.

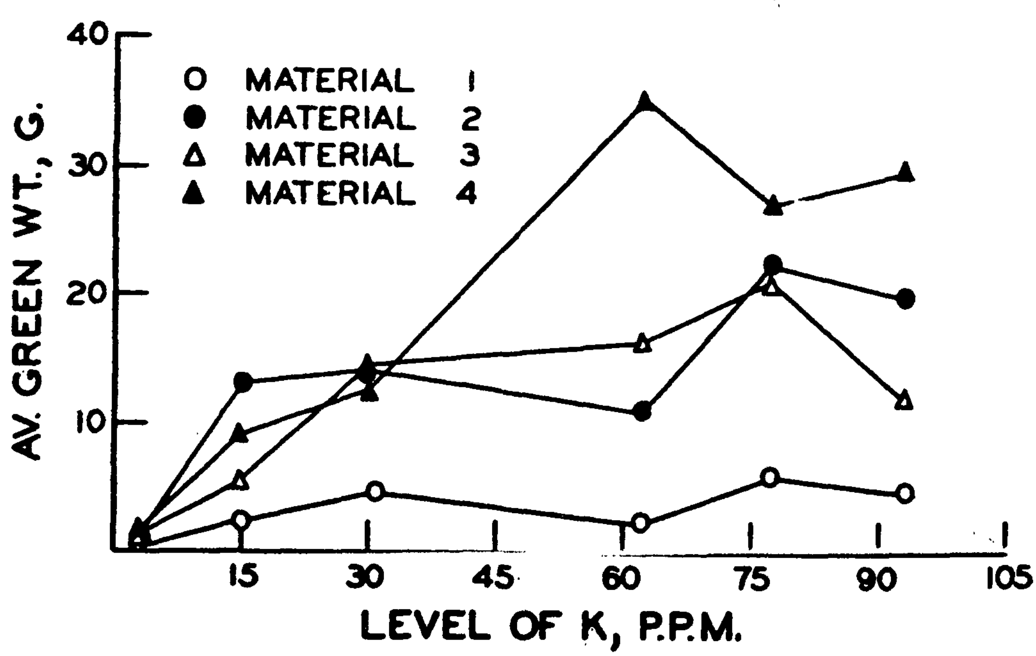

Figure 9. Differences in Average Green Weight of Trees Grown for Forty Days at Six Levels of Potassium

Appendix Table XXI summarizes the chemical analyses made on the samples from the tops of the seedlings grown at the several levels of potassium. Analysis of variance calculations was used to examine differences between treatments and differences between test materials in nutrient uptake. Table V summarizes the significant F values obtained. Differences obtained between test materials in potassium uptake were not statistically significant. These data also indicate that varying the level of K had no influence on the uptake of N or Ca, but did affect the levels of P, K, and Mg in the tops of the seedlings (see Fig. 10 and 11).

TABLE V

ANALYSIS OF VARIANCE "F" VALUES FOR POTASSIUM TRIAL
NUTRIENT LEVEL IN TISSUE

Element	Material[a]	Treatment[a]	Remarks
Nitrogen	5.33*	NS	Material 1 had the lowest uptake of N, Materials 2 & 4 the highest.
Phosphorus	NS	6.22**	High P uptake at low K treatment and moderate P uptake at high K
Potassium	NS	6.91**	K levels in tops increased with increasing levels in nutrient solution.
Calcium	26.0**	NS	Material 1 had the lowest Ca uptake, Material 4 greatest, hybrids intermediate.
Magnesium	22.3**	7.8**	Highest Mg uptake at low level of K. Differences between materials same as for Ca.

[a]A double asterisk indicates the "F" values were significant at the 1% level, the single asterisk indicates significance at the 5% level and the NS means the calculated "F" values were not significant.

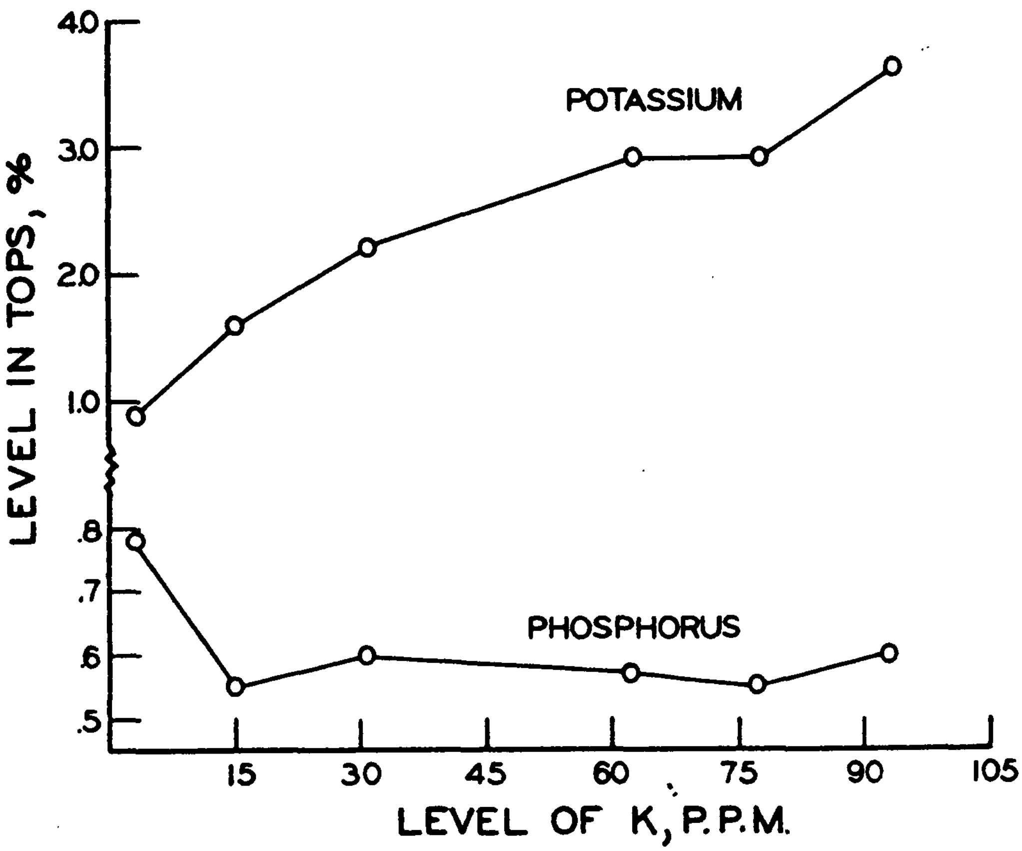

Figure 10. The Influence of Level of Potassium on Uptake of Potassium and Phosphorus. Levels Shown Are Average Values for the Four Types of Experimental Materials

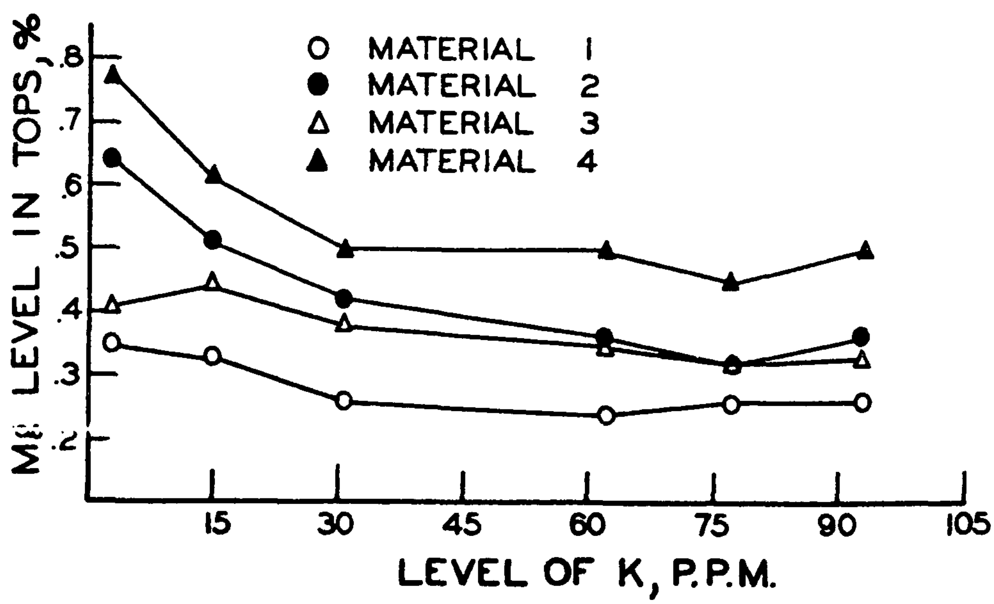

Figure 11. The Influence of Level of Potassium in the Nutrient Solution on Uptake of Magnesium. Differences Between Experimental Materials Are Statistically Significant

Uptake of P (Fig. 10) was high at the very lowest level of K (3 p.p.m.) and dropped to a normal level at K levels above 15 p.p.m. Also illustrated in Fig. 10 is the change in percent potassium which occurred with increasing K levels in the nutrient solution. Potassium tissue levels continued to increase well beyond the point where the treatment levels gave growth response. Earlier workers dealing with deficiency symptoms in trees suggested that low potassium resulted in high phosphorus concentration. The phosphorus in turn immobilized the iron in the plant and resulted in chlorotic leaves and reduced growth. The data obtained from the potassium growth chamber trial support the low K-high P theory.

Optimum levels of K in the nutrient solution appeared to be 62 to 77 p.p.m. Levels of K in the tissue, when growth was normal, varied from 2.8 to 3.1%. Growth of Materials 1, 2, and 3 increased only a minor amount when levels of potassium exceeded 31 p.p.m. Material 4 gave increased growth up to 62 p.p.m. The 2.8 to 3.1% potassium levels in the tissue are higher than reported (8, 13) for field-grown aspen (1.25%) and cherry (1.84%) growing at adequate nutrient levels.

Considerable information exists regarding levels of potassium in tree leaves when potassium is in low supply. Generally, levels of 0.7 to 1.0% or less indicate K-deficient growing conditions. Sucoff and Perala (14) reported 0.46-1.55% for young leaves and 0.20-0.70% for older leaves were indicative of potassium-deficient growing conditions for several species of hardwood. Gilbert (15) reports that when comparing leaf samples growing under high and low levels of potassium, calcium and magnesium uptake is inversely proportional to the level of K found in the leaves. The aspen data reported do not support this relationship, except in the instance where very low potassium resulted in higher than normal levels of magnesium (Fig. 11). One possible reason the inverse relationship has not been found is that the very high (above 90 p.p.m.) levels of potassium were not thoroughly investigated.

Also, levels of calcium in tree leaves have been shown to increase throughout the growing season and the immature nature of the sampled trees suggests they may not have grown long enough to reflect typical K and Ca ratios.

CALCIUM GROWTH CHAMBER TRIAL

Calcium levels were varied from 0 to 46 p.p.m. (0, 8, 15, 31, 38, and 46 p.p.m.) and the earlier described experimental design for handling treatments was followed. Figure 12 presents the growth response obtained as the level of calcium was increased. Some growth was obtained for all test materials at the zero level of calcium. However, little growth response occurred above 31 p.p.m., even though calcium uptake was greatest at the higher treatment levels. Response of Material 1 (bigtooth aspen) was quite different from the other three materials. Improved growth for Material 1 resulted when calcium was increased up to 15 p.p.m. and reduced growth occurred when calcium levels exceeded 31 p.p.m. Growth of Materials 2, 3, and 4 increased with increasing levels of calcium up to the 31 p.p.m. treatment level. No increase in growth resulted from calcium levels above 31 p.p.m. Again, as in the case of all the other growth chamber trials, growth of Material 1 was less than that of the other experimental materials.

Appendix Table XXII summarizes the results of the chemical analysis made on the tissue samples obtained from the calcium growth chamber trial. Table VI summarizes the F values obtained when these data were examined using analysis of variance procedures. Based upon these data it appears that varying the level of calcium influenced the uptake of N, K, Ca, and Mg. Only the level of phosphorus in the tissue sample was not affected by varying the level of calcium in the nutrient solution (Table VI).

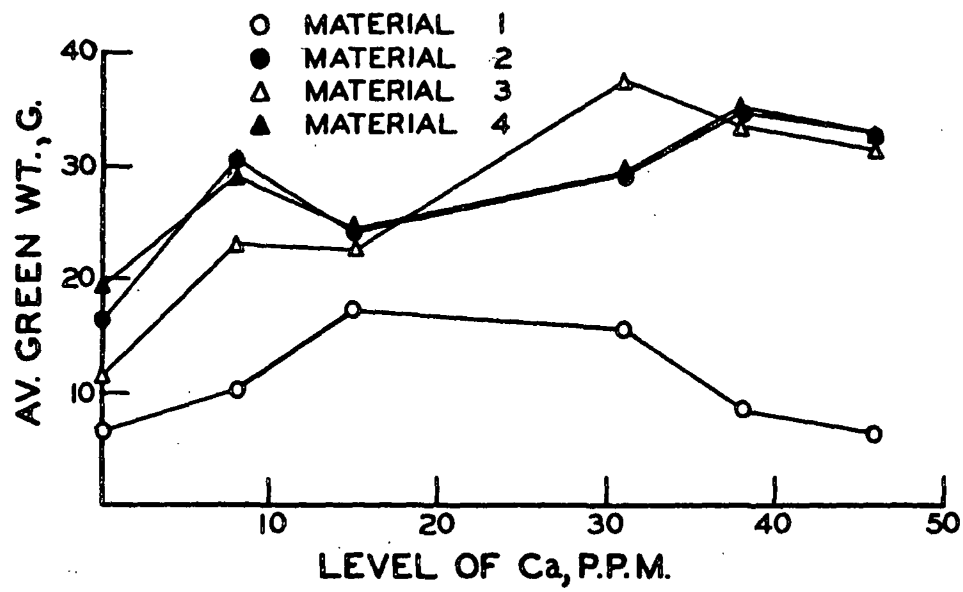

Figure 12. Differences in Average Green Weight of Trees Grown for Forty Days at Six Levels of Calcium

TABLE VI

ANALYSIS OF VARIANCE "F" VALUES FOR CALCIUM TRIAL
NUTRIENT LEVEL IN TISSUE

Element	Material[a]	Treatment[a]	Remarks
Nitrogen	6.36**	5.15**	Material 3 had lowest uptake and Material 2 the highest. The low and high levels of Ca gave greatest uptake and medium levels the lowest N uptake.
Phosphorus	3.74*	NS	Material 1 had the highest P uptake and Material 3 had the lowest.
Potassium	NS	7.33**	K uptake was lower at the higher levels of Ca
Calcium	5.15*	38.7**	Calcium uptake increased with increasing levels in the nutrient solution. Material 1 had lowest Ca uptake.
Magnesium	21.6**	12.4**	Magnesium uptake decreased with increasing levels of Ca in solution. Material 1 had lowest uptake and Material 4 the highest. The hybrids were intermediate.

[a] A double asterisk indicates the "F" values were significant at the 1% level, the single asterisk indicates significance at the 5% level and the NS means the calculated "F" values were not significant.

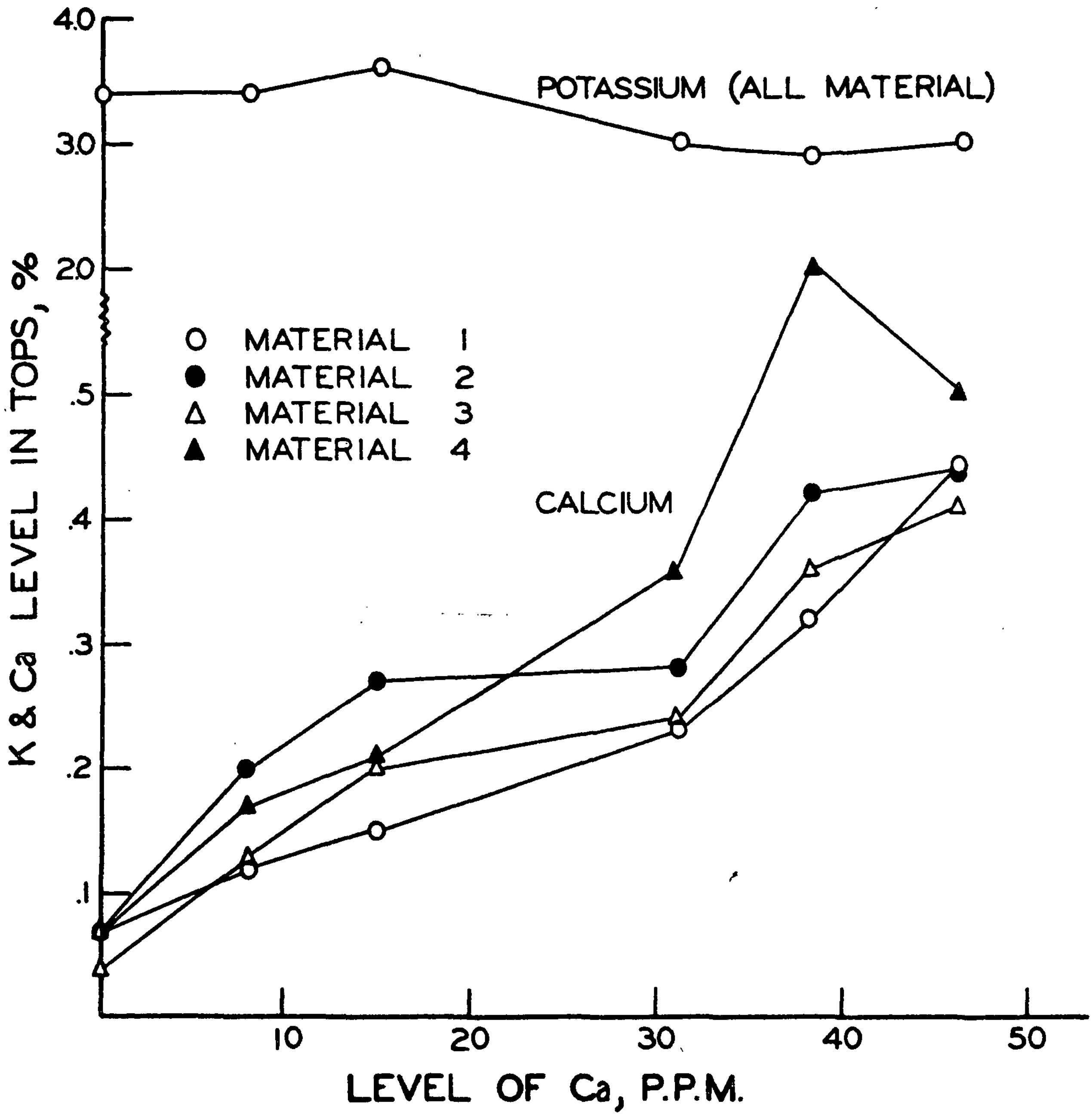

Figure 13. The Influence of Varying the Level of Calcium on the Uptake of K and Ca. There Were no Significant Differences Between Experimental Materials in K Uptake and the Levels Shown Are Average Values for the Four Types of Materials. Calcium Uptake Differed Significantly Between Materials

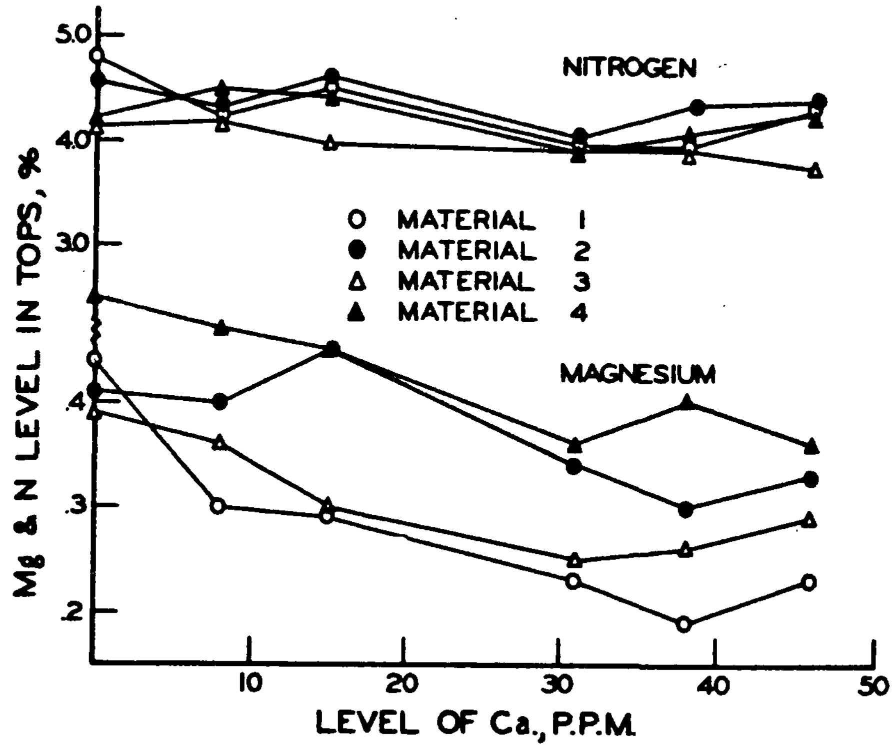

Figure 14. The Influence of Varying the Level of Calcium on the Uptake of Nitrogen and Magnesium. Uptake Differences Between Materials Were Statistically Significant

MAGNESIUM GROWTH CHAMBER TRIAL

The standard procedure for the arrangement of treatments was followed and the growth response of the four test materials followed a pattern that was quite similar to that obtained for calcium. Magnesium levels were varied from 0 to 21 p.p.m. (0, 3, 7, 14, 17, and 21 p.p.m.) and Fig. 15 illustrates the results obtained. All materials exhibited some growth at the zero level of magnesium and Materials 1 and 3 responded least to increasing levels of magnesium. Response for all materials was statistically significant. The overall magnesium growth response, although not clear-cut, suggests that no increased growth can be expected from magnesium levels above 14 p.p.m. It is also apparent that, when calcium is in adequate supply, nutrient solutions having between 3 and 7 p.p.m. Mg will give reasonable growth when Materials 1 and 2 are involved. Material 4 has the highest magnesium requirements.

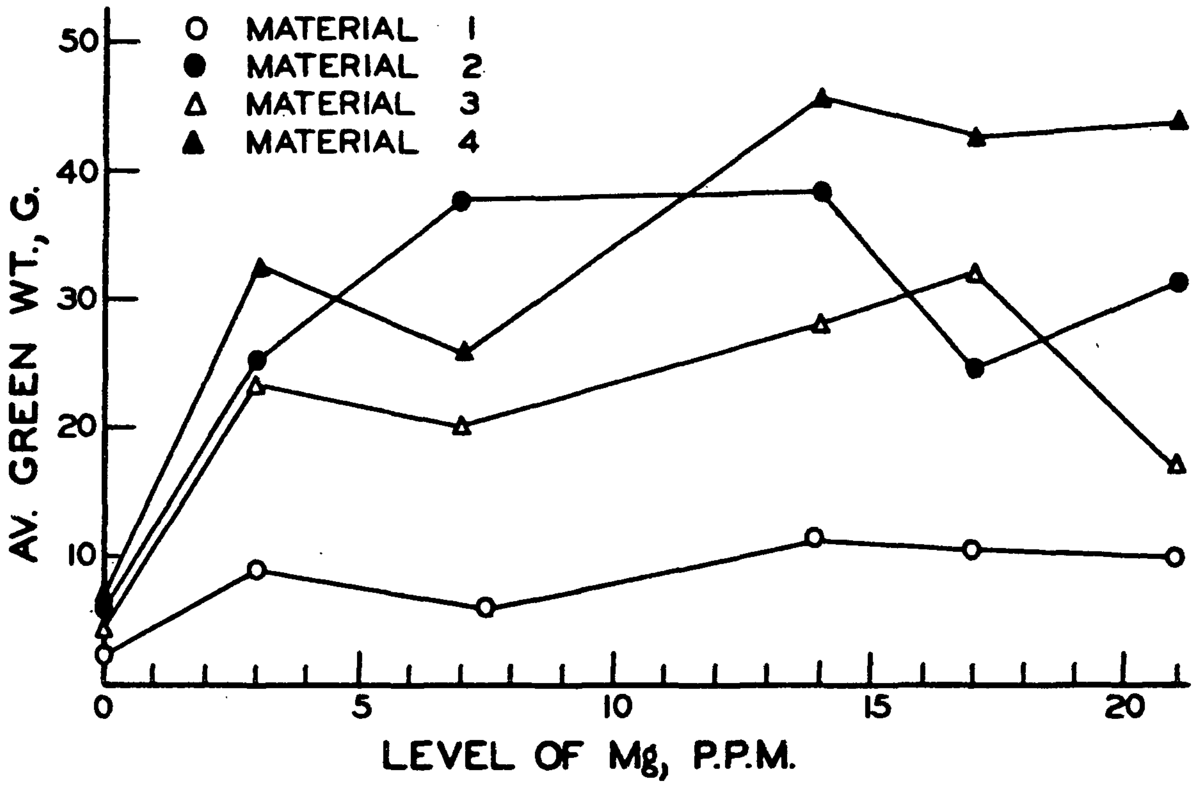

Figure 15. Differences in Average Green Weight of Trees Grown for Forty Days at Six Levels of Magnesium

Examination of the levels of the major elements in the tissue of the seedlings grown at varying levels of magnesium (Appendix Table XXIII) adds support to the observations reported in the previously described growth chamber trials. Analysis of variance procedures were used to compare treatment effects and Table VII summarizes the F values obtained. These results indicate that increasing the level of magnesium in the nutrient solution will result in increased magnesium uptake and, as might have been predicted from previous information on calcium uptake, will decrease the uptake of calcium. The Mg treatments, i.e., varying the level of Mg from 0 to 21 p.p.m., did not influence the uptake of N, P, or K (Table VII). Again, as in the other growth chamber runs, there were significant differences between the four types of experimental trees in their uptake of calcium and magnesium. Figure 16 illustrates the abovedescribed uptake trends.

TABLE VII

ANALYSIS OF VARIANCE "F" VALUES FOR MAGNESIUM TRIAL
NUTRIENT LEVEL IN TISSUE

Element	Material[a]	Treatment[a]	Remarks
Nitrogen	NS	NS	--
Phosphorus	4.61*	NS	Material 1 had slightly higher P uptake than the other materials.
Potassium	NS	NS	--
Calcium	28.4**	4.28*	High Ca uptake at low level of Mg. High uptake by Material 4, low by Material 1, and hybrids were intermediate.
Magnesium	10.8**	20.5**	High Mg uptake at low level of Mg. High uptake by Material 4, low uptake by Material 1, and the hybrids were intermediate.

[a] A double asterisk indicates the "F" values were significant at the 1% level, the single asterisk indicates significance at the 5% level and the NS means the calculated "F" values were not significant.

One additional relationship which should be pointed out is that in the N, P, and K growth chamber runs, no significant differences were found between the test materials in the uptake of phosphorus. When, however, calcium and magnesium were the elements being varied, experimental Material 1 (bigtooth aspen) quite consistently had higher levels of P in the tissue samples. How the above trend should be interpreted is not clear. Excessive levels of P in tissue have been reported to be associated with immobilization of iron and iron chlorosis.

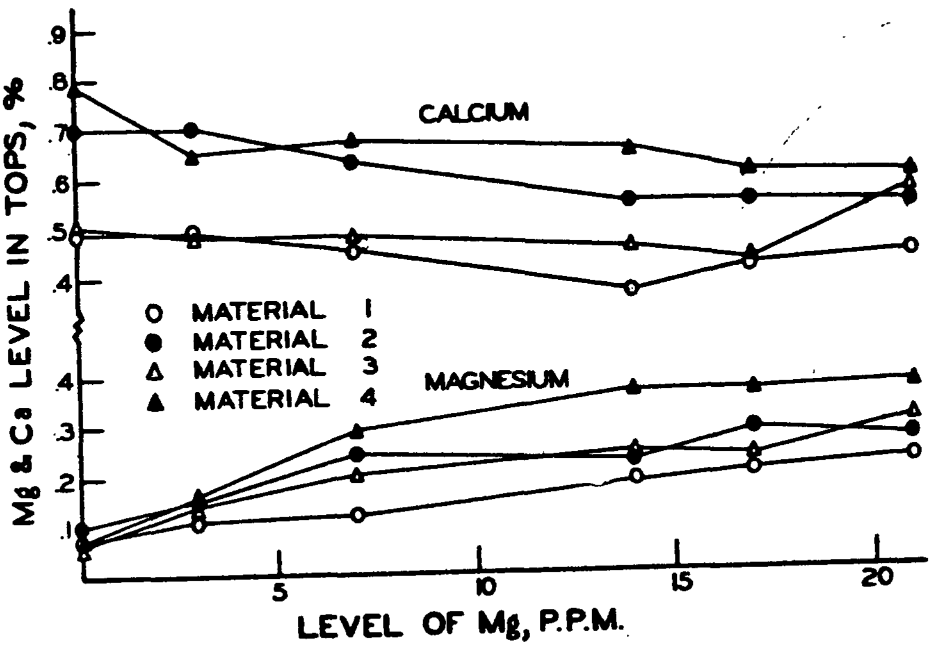

Figure 16. The Influence of Level of Magnesium on Levels of Ca and Mg in Tissue Samples of Populus Seedlings. Significant Between-Material Differences Existed in Levels of Ca and Mg

It is of interest to examine the level of magnesium in the several test materials when all elements were in adequate supply (Appendix Table XXIV). When this was done and related to growth response and to magnesium levels when magnesium was in low supply, it appears that a nutrient solution level of 14 to 21 p.p.m. should be used to obtain satisfactory growth. At these levels of magnesium, the average level in the tissue samples can be expected to vary from 0.20% for Material 1 to 0.36% for Material 4. This is in close agreement with levels reported for aspen, cherry, and yellow birch (8, 13, 17).

RELATED OBSERVATIONS

OPTIMUM NUTRIENT LEVELS

The objectives of the described sand culture studies included: (1) Determining what levels of the major nutrients should be used in sand culture studies with Populus, (2) Examining the levels of the various elements in the tops of the seedlings grown under so-called optimum conditions, (3) Determining differences between species and their hybrids in nutrient requirements. Previous sections of this report have discussed these points and the attempt here is to bring this information together in summary form and make some interpretation of the results. First, it should be pointed out that the so-called optimum levels discussed are for sand culture work and, although they may be similar, do not necessarily apply to natural soil systems. Second, the use of the technique of holding all nutrient levels except one constant and varying this single element will not give the same "optimum levels" as will be obtained from a well-designed factorial experiment. This latter type of design involves varying the level of several elements at the same time and requires a large amount of growth chamber space and increased numbers of uniform test materials, thus limiting the usefulness of this approach. Recent development of so-called "fractional factorial" designs which produce response surfaces appears to have considerable promise and the use of these designs is being investigated for future follow-up experimental work.

Based upon the growth response curves and the nutrient uptake information for the five experimental trials, it appears that there was little growth response or increased uptake at the three highest treatment levels (medium, medium high, and high). By tabulating nutrient levels in the tissue samples for treatments where all nutrients were considered to be adequate, data were obtained that provided an overall picture of N, P, K, Ca, and Mg levels in tissue samples. Additional information was also obtained regarding differences between species in nutrient uptake.[6] Table XXIV of the Appendix is a summary of this tabulation and Table VIII illustrates the F values obtained when analysis of variance procedures were used to examine the data. Based upon this analysis, it appears that there are significant differences between experimental test materials in the uptake (and very likely in the requirements) of N, Ca, and Mg. No differences in uptake of P and K were in evidence from this analysis. Statistically significant differences between experimental trials are interpreted to mean that relative uptake levels differ between experimental trials and in these instances the uptake very likely was being influenced by the nutrient that was being varied.

TABLE VIII

ANALYSIS OF VARIANCE "F" VALUES FOR NUTRIENT UPTAKE WHEN ALL LEVELS OF NUTRIENTS WERE IN ADEQUATE SUPPLY (TABLE XXIV)[a]

Nutrient Uptake Considered	Between Materials	Between Experimental Trials	Inter-action	Remarks
N	4.55**	21.3**	NS	Material 1 and Material 3 had the lowest uptake. Relative level of uptake varied between experimental trials.
P	NS	4.12**	NS	No difference between experimental materials in P requirement.
K	NS	11.0**	NS	No difference between experimental materials in K uptake.
Ca	24.6**	12.0**	NS	Significant difference between materials in uptake. Material 1 — lowest uptake, Material 4 — highest.
Mg	80.0**	12.4**	NS	Trends for Mg same as for Ca

[a]A single asterisk indicates significant at the 5% level, two asterisks significant at the 1% level and NS indicates the F value was not significant.

[6]It has been assumed that greater uptake is evidence that a particular species has higher requirements.

The combined data (Table VIII and XXIV) are in good agreement with the results obtained when the trials were examined on a trial-by-trial basis. Differences in Ca and Mg uptake by the tops of the trees were consistently demonstrated in all of the growth chamber trials. Uptake of potassium, on the other hand, did not differ between materials in any of the experimental runs. Nitrogen and phosphorus uptake was less well defined but there seems to be no question that there exist differences in nitrogen uptake and little, if any, difference in the phosphorus requirements for the four types of experimental trees.

Another use that can be made of the data available is to look at the total uptake by the tops of the trees when nutrient levels are near optimum. For example, in the nitrogen experimental run, best growth (both green and dry weight) was obtained for Materials 1, 3, and 4 at the 105 p.p.m. level of nitrogen and for Material 2 at 75 p.p.m. Using the total dry weight of the tops and the level of the several elements in the tissue when growth conditions were optimum, the total uptake data shown in Table IX were obtained. If the same procedure is repeated for each growth chamber run, the data in Table X are obtained. Using such a procedure will give some indication as to what might be expected in the way of total withdrawal from the soil when the various types of experimental materials are grown under near optimum growing conditions.

TABLE IX

TOTAL UPTAKE BY TOPS WHEN NITROGEN LEVEL WAS NEAR OPTIMUM

Test Material	Uptake of Elements, g.				
	N	P	K	Ca	Mg
1	0.43	0.07	0.32	0.05	0.03
2	0.79	0.14	0.65	0.09	0.07
3	0.97	0.15	0.76	0.16	0.08
4	1.54	0.26	1.11	0.30	0.17

TABLE X

NUTRIENT UPTAKE BY TOPS AT NEAR OPTIMUM GROWING CONDITIONS

Material	Experimental Run	Level of Elements, g.				
		N	P	K	Ca	Mg
1	N	0.43	0.07	0.32	0.05	0.03
	P	0.33	0.05	0.27	0.04	0.02
	K	0.14	0.02	0.09	0.01	0.01
	Ca	0.53	0.08	0.41	0.02	0.03
	Mg	0.31	0.06	0.23	0.03	0.01
2	N	0.79	0.14	0.65	0.09	0.07
	P	0.79	0.10	0.62	0.10	0.05
	K	0.50	0.06	0.35	0.06	0.04
	Ca	0.86	0.12	0.75	0.04	0.08
	Mg	0.92	0.12	0.62	0.13	0.05
3	N	0.97	0.15	0.76	0.16	0.08
	P	0.67	0.07	0.50	0.07	0.04
	K	0.58	0.07	0.37	0.08	0.04
	Ca	0.72	0.09	0.54	0.02	0.06
	Mg	0.70	0.10	0.47	0.07	0.04
4	N	1.54	0.26	1.11	0.30	0.17
	P	1.19	0.18	0.93	0.19	0.11
	K	1.03	0.12	0.62	0.17	0.11
	Ca	0.92	0.11	0.72	0.03	0.10
	Mg	1.19	0.17	0.87	0.18	0.10

The data when analyzed (Table XI) indicated that when the four types of materials were grown under optimum conditions for 40 days, Material 4 removed greater total amounts of nutrient from the solutions. Material 1 removed the least amount and the two hybrids were intermediate. Differences resulted from the combination of differences in growth and differences in the levels of the several elements in the plant tissue. Also interesting, from the genetics point of view, is that the uptake by the hybrids quite consistently demonstrated maternal influence. That is, the uptake of Material 2 is more nearly like Material 1 and the uptake of Material 3 is similar to Material 4.

TABLE XI

ANALYSIS OF VARIANCE "F" VALUES FOR TOTAL NUTRIENT UPTAKE BY TOPS WHEN NUTRIENT LEVELS WERE NEAR OPTIMUM[a]

Nutrient Uptake Considered	Between Materials	Between Trials	Remarks
N	31.6**	3.84*	Material 4 removed the greatest amount of nitrogen, Material 1 the least, and the hybrids were intermediate
P	15.3**	5.68**	Same trends as for N
K	32.5**	7.40**	Same trends as for N
Ca	9.9**	4.34*	Same trends as for N
Mg	46.2**	5.63**	Same trends as for N

[a]A double asterisk indicates the "F" values were significant at the 1% level, and the single asterisk indicates significance at the 5% level.

Just how this information should be interpreted in terms of differences in requirements between the four types of experimental materials is not entirely clear. One interpretation is that bigtooth aspen (Material 1), when grown under optimum conditions, will remove much less N, P, K, Ca, and Mg from the site and, therefore, has less total requirements. Also, it appears that Material 1 could be fertilized at lower rates and at less frequent intervals than the other materials being tested. It is also quite clear that where levels of calcium, magnesium, and nitrogen are involved, bigtooth aspen can be expected to respond less to fertilization than the European gray poplar (Material 4) or either of the two hybrids.

Differences between experimental materials in calcium and magnesium uptake followed a pattern that was to be expected. Not only did the total level of calcium and magnesium in the nutrient solution influence the uptake of these two elements, but the actual ratio of calcium to magnesium also influenced the uptake. Table XII illustrates the uptake data obtained when information from the calcium and magnesium experimental runs was tabulated according to the calcium and magnesium ratio. As reported by other workers and discussed earlier, calcium substitutes for magnesium when magnesium is in low supply and magnesium substitutes for calcium when calcium is in low supply.

TABLE XII

UPTAKE AT VARIOUS CALCIUM AND MAGNESIUM RATIOS[a]

Nutrient Solution Ca/Mg Ratio	Calcium Uptake, %	Magnesium Uptake, %
46	0.62	--
15.3	0.58	--
6.6	0.56	0.21
3.3	0.50	0.25
2.8	0.49	0.27
2.2	0.52	0.29
2.2	0.45	0.30
1.8	0.42	0.28
1.5	0.28	0.30
0.7	0.21	0.35
0.4	--	0.38
0	--	0.44

[a]Data presented only when Ca and/or Mg was considered to be in adequate supply. Uptake values are the average of the four experimental materials.

Table XIII summarizes the estimated optimum levels of the several nutrients with regard to the use in sand culture growth chamber studies and provides an approximate expected level of the various elements for tissue samples from the tops of 40-day-old trees grown under or near optimum conditions. No differences existed between experimental trees in the P and K requirements and only minor differences between materials in the N requirement. The _P. canescens_ "parent species" (Material 4) is believed to have the highest Mg and Ca requirements while the _P. grandidentata_ seedling (Material 1) apparently have the lowest requirements. The two hybrids were intermediate between the so-called "parent species." The requirement levels are based upon a comparison of levels giving optimum growth and also take into consideration the level of nutrient in the tissue. When total levels of nutrients removed from the nutrient solution are considered (using total update data in Table X) it appears that during early growth Material 4 will remove approximately three times as much N, P, K, Ca, and Mg from the soil as Material 1. The total uptake by the hybrids can be expected to be intermediate between the two parent species.

TABLE XIII

ESTIMATED OPTIMUM NUTRIENT SOLUTION LEVELS AND EXPECTED LEVELS IN TOPS OF SEEDLINGS[a]

Experimental Material	Nutrient Element				
	N	P	K	Ca	Mg
1. _P. grandidentata_ (G)	105(4.0)	22(0.65)	75(3.0)	15-20(0.40)	14-16(0.23)
2. G x Ca hybrid	75(4.3)	22(0.62)	75(3.0)	30-35(0.51)	14-16(0.31)
3. Ca x G hybrid	105(4.0)	22(0.58)	75(2.8)	30-35(0.47)	15-20(0.28)
4. _P. canescens_ (Ca)	105(4.1)	22(0.63)	65-75(2.9)	30-35(0.62)	15-20(0.4[illegible])

[a]Nutrient solution levels in p.p.m. and expected level in top of seedling expressed as % of dry weight.

It should be pointed out that the levels of nutrients in the tissue samples are based upon relatively young immature leaves and are quite different from values reported in the literature in which the data are based upon mature leaf samples. Calcium levels are lower and the N, P, and K levels are higher than reported for tissue samples from mature leaves in natural stands. The values for N, P, and K are in general agreement with sand culture work by McGee (16) and not greatly different from the levels of N, P, Ca, and Mg reported by Hoyle (17) for May leaf collections of yellow birch.

GROWTH DIFFERENCES BETWEEN EXPERIMENTAL MATERIALS

The overall growth potential of the four types of experimental trees is of interest. One method of getting a rough picture of the relative early growth of each material is to average or combine by test materials the growth data for all experimental trials and plot these averages over the relative level of the element being varied. This means, for example, averaging for experimental materials the green weight data for the very low level of potassium with the green weight data for the zero or very low level of the other growth chamber trials. Figure 17 illustrates the growth curves obtained. Growth differences at the low or very low levels are not very meaningful but at the higher nutrient levels they provide a fairly realistic picture of the differences between test materials. Test Material 4 quite consistently had higher average green weights than Materials 2 and 3. Growth of Material 1 was much lower than the other three materials and responded very little to increasing nutrient levels. Although dry weight information is not presented here, the differences between experimental materials in the dry weight of the tops were comparable to those shown in Fig. 17. The differences obtained at the higher nutrient levels were statistically significant with the exception that the growth of Materials 2 and 3 did not differ significantly. No evidence of hybrid vigor was exhibited by the two hybrids being tested.

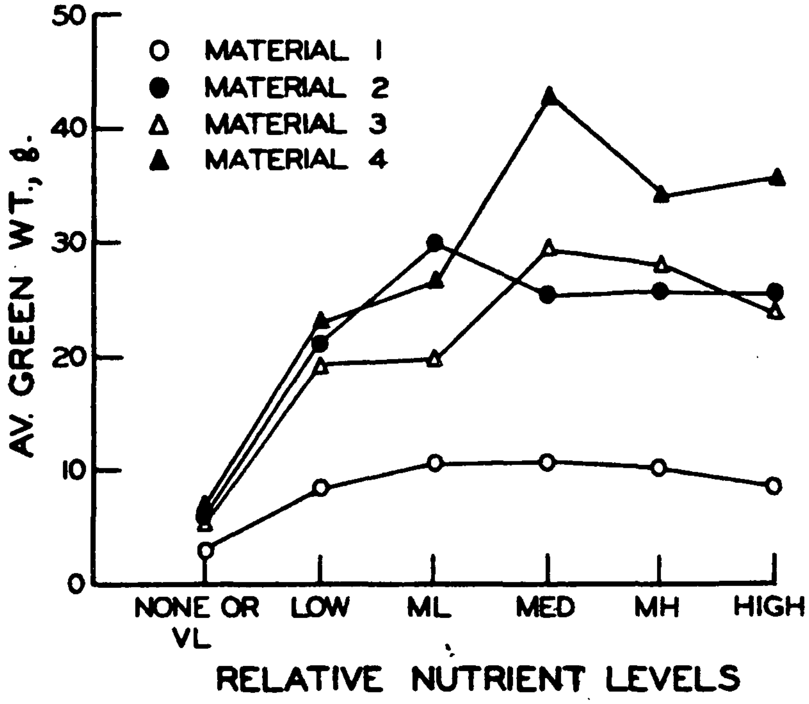

Figure 17. Differen-es in Green Weight of Trees Obtained by Averaging Data for all Trials and Plotting over Relative Nutrient Levels

TOP-ROOT RATIO

Top-root ratios (T-R R) provide some insight into the root development of a species and in some instances appear to be related to the ability of the species to do well on adverse sites. The tops and roots from each experimental material were handled in such a way that a ratio could be calculated for each treatment within each growth chamber trial. The top-root ratios were based on green weight values and varied considerably between treatments and between growth chamber runs. There appeared to be no well-defined pattern within growth chamber trials that was related to the level of the element being varied. Table XIV summarizes the ratios obtained by type of experimental material and by growth chamber trial.

TABLE XIV

TOP-ROOT RATIOS SUMMARIZED BY EXPERIMENTAL MATERIAL AND GROWTH CHAMBER RUN[a]

Growth Chamber Run	Experimental Test Material 1	2	3	4	Average
N	1.64	1.02	1.38	1.19	1.31
P	1.42	1.21	1.44	1.41	1.37
K	1.30	0.98	1.32	1.48	1.27
Ca	1.75	1.41	1.47	1.71	1.58
Mg	1.85	1.10	1.39	1.25	1.40
Av.	1.59	1.14	1.40	1.41	--

[a]Top-root ratios based upon all data except where, because of low nutrient levels, abnormal growth occurred.

Growth of all four test materials was abnormal at the zero and/or very low treatment levels and the top-root ratios from these treatments were excluded from the data in Table XIV. At the medium and high levels of each experimental trial, the T-R R were fairly constant and moderate differences were obtained between the types of experimental trees. Experimental Material 2 consistently had the lowest top-root ratio and was significantly different from the other three materials. Of the four types of materials tested, it appears that Material 2, because of its satisfactory growth rate and rapid root development (low top-root ratio) can be expected to be best suited to dry, sandy, adverse sites.

CONCLUSIONS

Results of the sand culture growth chamber comparisons between P. grandidentata, P. canescens, and hybrids between the two species revealed that significant growth differences existed between each of the experimental materials. Between-material differences also existed in the nutrient uptake (level in tissue samples) of N, Ca, and Mg and in the top-root ratios. The results also provided estimates of optimum nutrient solution levels for N, P, K, Ca, and Mg. Varying the level of the five major nutrients resulted in significant growth and nutrient uptake differences for the five major nutrient elements tested.

The treatment levels used adequately investigated the higher or near optimum conditions and provided satisfactory coverage at the lower treatment levels. Chemical determinations made on seedlings grown on adequate levels of all nutrients provided estimates of expected levels of N, P, K, Ca, and Mg for Populus seedlings growing under near optimum growing conditions.

Growth of Experimental Material 1 (bigtooth aspen parent species) was quite slow and typical of the early growth of this species when compared with its hybrids in field plantings. Not only did Experimental Material 1 grow slowly, but it failed to respond to increasing levels of the major nutrient elements being tested. Of the hybrids, Experimental Material 2 appeared to be the most promising. In addition to having a low top-root ratio, this hybrid did not have excessively high nutrient requirements and responded well to increasing levels of the five major nutrient elements.

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APPENDIX

TABLE XV

AVERAGE GREEN WEIGHTS (TOPS + ROOTS) IN GRAMS FOR THE EXPERIMENTAL TREES PRODUCED IN GROWTH CHAMBER STUDY

Growth Chamber Trial	Treatment No. and Level, p.p.m.	Experimental Materials			
		1	2	3	4
N	1 - 29	7.4	7.1	8.7	6.2
	2 - 50	8.5	14.1	18.5	11.1
	3 - 75	11.8	41.6	17.6	21.5
	4 - 105	15.8	29.7	40.0	57.7
	5 - 131	13.7	25.9	29.5	29.4
	6 - 158	13.0	19.6	34.8	30.1
P	1 - 2	0.2	0.1	0.8	0.9
	2 - 11	12.0	23.4	26.0	32.6
	3 - 22	12.8	31.5	24.4	48.8
	4 - 43	9.4	18.3	25.4	46.6
	5 - 54	12.6	21.0	23.4	37.6
	6 - 65	8.4	23.2	23.6	41.9
K	1 - 3	0.3	1.0	1.1	1.5
	2 - 15	2.4	13.2	5.4	9.3
	3 - 31	4.6	14.3	14.5	12.7
	4 - 62	2.2	11.0	16.3	35.1
	5 - 77	6.0	22.2	21.0	27.2
	6 - 93	4.8	19.8	12.0	29.9
Ca	1 - 0	6.5	16.5	12.4	19.4
	2 - 8	10.2	30.6	23.0	29.2
	3 - 15	17.2	24.0	22.5	24.1
	4 - 31	15.5	29.0	37.4	29.1
	5 - 38	8.5	34.6	33.6	35.0
	6 - 46	6.2	32.6	31.2	32.6
Mg	1 - 0	2.2	5.5	4.3	6.7
	2 - 3	8.8	25.3	23.4	32.6
	3 - 7	6.1	37.7	20.0	25.6
	4 - 14	11.3	38.4	27.9	45.5
	5 - 17	10.3	24.4	32.0	42.4
	6 - 21	9.9	31.3	16.8	43.5

TABLE XVI

SUMMARY OF ANALYSIS OF VARIANCE "F" TEST VALUES
FOR DIFFERENCES BETWEEN MATERIALS AND TREATMENTS
FOR GREEN WEIGHT (TOP + ROOTS) DATA

Source of Variation	D.F.	Significant "F" Test Values Tabulated by Expt. Trials[a]				
		N	P	K	Ca	Mg
Materials (M)	3	10.1**	19.5**	22.9**	14.1**	28.9**
Treatments (T)	5	15.4**	12.6**	16.3**	3.7**	14.3**
M x T	15	3.1**	NS	3.1**	NS	2.0*
Residual	120	--	--	--	--	--

[a]A double asterisk indicates the "F" values were significant at the 1% level, the single asterisk indicates significance at the 5% level and the NS means the calculated "F" values were not significant.

TABLE XVII

AVERAGE DRY WEIGHT OF TOPS IN GRAMS FOR THE EXPERIMENTAL TREES PRODUCED IN GROWTH CHAMBER STUDY

Growth Chamber Trial	Treatment No. and Level, p.p.m.	Experimental Materials 1	2	3	4
N	1 - 29	1.1	0.9	1.3	0.8
	2 - 50	1.2	1.8	2.7	1.7
	3 - 75	1.4	3.5	2.0	2.0
	4 - 105	1.9	3.0	4.7	6.4
	5 - 131	1.8	2.7	3.8	3.4
	6 - 158	1.7	1.9	3.9	3.2
P	1 - 2	0.05	0.02	0.1	0.1
	2 - 11	1.1	2.2	2.8	3.4
	3 - 22	1.3	2.9	2.6	4.7
	4 - 43	1.0	1.9	2.8	5.4
	5 - 54	1.4	2.1	2.6	4.5
	6 - 65	0.9	2.4	3.1	4.9
K	1 - 3	0.1	0.1	0.2	0.2
	2 - 15	0.3	1.3	0.7	1.1
	3 - 31	0.5	1.3	1.8	1.5
	4 - 62	0.3	1.0	1.6	3.6
	5 - 77	0.5	1.9	2.3	3.0
	6 - 93	0.4	1.6	1.2	2.8
Ca	1 - 0	0.5	1.6	1.4	2.1
	2 - 8	1.2	3.3	2.9	3.4
	3 - 15	2.0	2.6	2.6	2.9
	4 - 31	2.0	3.4	4.4	3.6
	5 - 38	1.1	3.4	3.9	4.0
	6 - 46	0.8	3.4	3.6	3.8
Mg	1 - 0	0.3	0.7	0.5	0.7
	2 - 3	1.1	2.6	2.8	3.5
	3 - 7	0.7	3.5	2.2	2.6
	4 - 14	1.3	3.5	2.8	4.7
	5 - 17	1.3	2.3	3.5	4.2
	6 - 21	1.1	3.0	1.8	4.8

TABLE XVIII

SUMMARY OF ANALYSIS OF VARIANCE "F" TEST VALUES FOR
DIFFERENCES BETWEEN MATERIALS AND TREATMENTS
DRY WEIGHT (TOPS) DATA

Source of Variation	D.F.	Significant "F" Test Values Tabulated by Expt. Trials[a]				
		N	P	K	Ca	Mg
Treatments	5	5.2**	9.6**	4.6**	8.1**	6.6**
Materials	3	3.8*	17.2**	7.8**	23.7**	12.8**
Error	15	--	--	--	--	--

[a] A double asterisk indicates the "F" values were significant at the 1% level, the single asterisk indicates significance at the 5% level.

TABLE XIX

NITROGEN TRIAL TISSUE ANALYSIS

Material	Treat. 1 29 p.p.m.	Treat. 2 50 p.p.m.	Treat. 3 75 p.p.m.	Treat. 4 105 p.p.m.	Treat. 5 131 p.p.m.	Treat. 6 158 p.p.m.
	Level of Nitrogen Applied					
			Nitrogen %[a]			
1	2.29	2.46	3.14	3.76	3.66	3.60
2	2.54	2.98	3.75	3.76	3.64	4.06
3	2.20	2.41	3.14	3.45	3.17	3.70
4	2.32	2.48	2.83	4.02	3.22	4.09
			Phosphorus %[a]			
1	0.43	0.46	0.67	0.69	0.59	0.60
2	0.49	0.49	0.68	0.69	0.58	0.62
3	0.48	0.42	0.64	0.56	0.54	0.56
4	0.60	0.49	0.71	0.68	0.50	0.59
			Magnesium %[a]			
1	0.16	0.19	0.22	0.25	0.21	0.19
2	0.28	0.27	0.33	0.34	0.32	0.30
3	0.22	0.22	0.28	0.29	0.24	0.26
4	0.37	0.26	0.36	0.43	0.36	0.36
			Calcium %[a]			
1	0.20	0.24	0.29	0.46	0.35	0.33
2	0.25	0.26	0.44	0.54	0.52	0.49
3	0.21	0.23	0.32	0.56	0.42	0.46
4	0.35	0.28	0.47	0.78	0.52	0.54
			Potassium %[a]			
1	2.4	2.4	3.3	2.8	2.6	2.6
2	2.5	2.6	3.1	2.6	2.7	2.6
3	2.6	2.4	3.3	2.7	2.5	2.4
4	2.9	2.5	3.0	2.9	2.6	2.5

[a]Level of element in tissue sample of tops expressed as % of dry weight.

TABLE XX

PHOSPHORUS TRIAL TISSUE ANALYSIS

Material	Level of Phosphorus Applied					
	Treat. 1 2 p.p.m.	Treat. 2 11 p.p.m.	Treat. 3 22 p.p.m.	Treat. 4 43 p.p.m.	Treat. 5 54 p.p.m.	Treat. 6 65 p.p.m.
			Nitrogen %[a]			
1	5.09	4.42	4.27	4.27	4.28	4.09
2	5.10	4.03	4.51	4.39	4.43	4.31
3	4.20	4.06	4.34	4.22	3.93	3.66
4	4.44	4.57	4.22	4.08	3.83	4.41
			Phosphorus %[a]			
1	0.25	0.54	0.62	0.73	0.64	0.65
2	0.27	0.50	0.59	0.60	0.57	0.60
3	0.24	0.40	0.60	0.62	0.55	0.56
4	0.23	0.50	0.65	0.58	0.86	0.69
			Magnesium %[a]			
1	0.29	0.22	0.25	0.26	0.25	0.26
2	0.34	0.30	0.31	0.36	0.28	0.30
3	0.26	0.23	0.28	0.31	0.25	0.23
4	0.38	0.40	0.40	0.30	0.42	0.43
			Calcium %[a]			
1	0.54	0.43	0.48	0.50	0.48	0.45
2	0.53	0.47	0.57	0.54	0.57	0.50
3	0.46	0.42	0.53	0.50	0.48	0.46
4	0.62	0.56	0.68	0.51	0.60	0.71
			Potassium %[a]			
1	2.7	3.0	3.4	3.0	3.2	3.4
2	2.4	3.1	3.5	3.5	3.2	3.5
3	2.3	3.0	3.8	3.4	3.0	2.8
4	2.7	3.8	3.3	3.3	3.3	3.4

[a]Level of element in tissue sample of tops expressed as % of dry weight.

TABLE XXI

POTASSIUM TRIAL TISSUE ANALYSIS

Material	Level of Potassium Applied					
	Treat. 1 3 p.p.m.	Treat. 2 15 p.p.m.	Treat. 3 31 p.p.m.	Treat. 4 62 p.p.m.	Treat. 5 77 p.p.m.	Treat. 6 93 p.p.m.
			Nitrogen %[a]			
1	4.89	4.26	4.19	4.02	4.38	4.16
2	6.14	4.82	5.03	5.02	4.41	5.04
3	4.99	4.62	4.40	4.76	4.23	5.04
4	5.64	5.32	4.53	4.78	4.46	4.97
			Phosphorus %[a]			
1	0.65	0.54	0.68	0.50	0.53	0.62
2	0.90	0.55	0.68	0.58	0.56	0.67
3	0.73	0.48	0.52	0.65	0.53	0.57
4	0.84	0.62	0.52	0.56	0.59	0.56
			Magnesium %[a]			
1	0.35	0.33	0.26	0.24	0.26	0.26
2	0.64	0.51	0.42	0.36	0.32	0.36
3	0.41	0.44	0.38	0.35	0.32	0.33
4	0.87	0.61	0.50	0.50	0.45	0.50
			Calcium %[a]			
1	0.38	0.43	0.37	0.35	0.42	0.50
2	0.65	0.61	0.71	0.55	0.54	0.50
3	0.45	0.52	0.52	0.51	0.61	0.54
4	0.85	0.71	0.62	0.78	0.74	0.87
			Potassium %[a]			
1	0.57	1.4	2.4	2.8	2.9	3.9
2	1.0	1.9	2.3	2.9	3.1	4.0
3	0.94	1.3	2.0	3.1	2.7	3.3
4	1.1	1.8	2.2	2.9	2.8	3.2

[a]Level of element in tissue sample of tops expressed as % of dry weight.

TABLE XXII

CALCIUM TRIAL TISSUE ANALYSIS

Material	Treat. 1 0 p.p.m.	Treat. 2 8 p.p.m.	Treat. 3 15 p.p.m.	Treat. 4 31 p.p.m.	Treat. 5 38 p.p.m.	Treat. 6 46 p.p.m.
	Level of Calcium Applied					
			Nitrogen %[a]			
1	4.79	4.21	4.49	3.94	3.94	4.29
2	4.57	4.32	4.61	4.03	4.33	4.37
3	4.13	4.18	3.96	3.90	3.90	3.75
4	4.23	4.50	4.41	3.89	4.07	4.26
			Phosphorus %[a]			
1	0.88	0.69	0.69	0.60	0.61	0.65
2	0.57	0.62	0.65	0.49	0.66	0.67
3	0.62	0.50	0.50	0.54	0.55	0.57
4	0.50	0.53	0.55	0.59	0.62	0.69
			Magnesium %[a]			
1	0.44	0.30	0.29	0.23	0.18	0.23
2	0.41	0.40	0.45	0.34	0.30	0.33
3	0.39	0.36	0.30	0.25	0.26	0.29
4	0.50	0.47	0.45	0.36	0.40	0.36
			Calcium %[a]			
1	0.07	0.12	0.15	0.23	0.32	0.44
2	0.07	0.20	0.27	0.28	0.42	0.44
3	0.04	0.13	0.20	0.24	0.36	0.41
4	0.07	0.17	0.21	0.36	0.60	0.50
			Potassium %[a]			
1	3.9	3.4	3.5	3.0	2.4	2.9
2	3.4	3.8	3.5	2.9	3.0	3.2
3	3.2	3.1	3.5	3.0	2.7	2.9
4	3.1	3.5	3.9	2.9	3.0	3.0

[a]Level of element in tissue sample of tops expressed as % of dry weight.

TABLE XXIII

MAGNESIUM TRIAL TISSUE ANALYSIS

Material	Level of Magnesium Applied					
	Treat. 1 0 p.p.m.	Treat. 2 3 p.p.m.	Treat. 3 7 p.p.m.	Treat. 4 14 p.p.m.	Treat. 5 17 p.p.m.	Treat. 6 21 p.p.m.
			Nitrogen %[a]			
1	3.23	4.31	3.78	3.96	4.16	4.10
2	4.12	4.03	4.42	4.54	4.14	4.19
3	3.73	4.05	4.12	4.20	3.97	4.21
4	4.12	3.92	4.18	4.24	4.11	3.63
			Phosphorus %[a]			
1	0.61	0.74	0.62	0.72	0.69	0.86
2	0.60	0.60	0.60	0.66	0.69	0.59
3	0.60	0.54	0.59	0.63	0.66	0.65
4	0.62	0.60	0.61	0.60	0.64	0.63
			Magnesium %[a]			
1	0.07	0.11	0.12	0.18	0.20	0.22
2	0.10	0.15	0.24	0.22	0.28	0.26
3	0.06	0.14	0.20	0.24	0.23	0.30
4	0.07	0.16	0.29	0.36	0.36	0.37
			Calcium %[a]			
1	0.49	0.49	0.45	0.36	0.41	0.43
2	0.70	0.70	0.63	0.54	0.54	0.53
3	0.50	0.48	0.48	0.45	0.42	0.56
4	0.79	0.65	0.67	0.65	0.60	0.59
			Potassium %[a]			
1	2.9	3.2	2.7	3.0	2.9	2.9
2	2.8	3.2	3.0	2.9	2.9	2.6
3	3.9	3.3	3.7	2.8	2.6	2.7
4	3.1	3.0	3.0	3.1	2.6	2.6

[a]Level of element in tissue sample of tops expressed as % of dry weight.

LEVEL OF NUTRIENTS IN TOPS OF EXPERIMENTAL TREES WHEN ALL NUTRIENTS WERE IN ADEQUATE SUPPLY

Test Material	N Trial[a]			P Trial[a]			K Trial[a]			Ca Trial[a]			Mg Trial[a]			Grand Average
N Levels in Normal Tissue, %																
1	3.76	3.66	3.60	4.27	4.28	4.09	4.02	4.38	4.16	3.94	3.94	4.29	3.96	4.16	4.10	4.04
2	3.76	3.64	4.06	4.39	4.43	4.31	5.02	4.41	5.04	4.03	4.33	4.37	4.54	4.14	4.19	4.31
3	3.45	3.17	3.70	4.22	3.93	3.66	4.76	4.23	5.04	3.90	3.90	3.75	4.20	3.97	4.21	4.01
4	4.02	3.22	4.09	4.08	3.83	4.41	4.78	4.46	4.97	3.89	4.07	4.26	4.24	4.11	3.63	4.14
P Levels in Normal Tissue, %																
1	0.69	0.59	0.60	0.73	0.64	0.65	0.50	0.53	0.62	0.60	0.61	0.65	0.72	0.69	0.86	0.65
2	0.69	0.58	0.62	0.60	0.57	0.60	0.58	0.56	0.67	0.49	0.66	0.67	0.66	0.69	0.59	0.62
3	0.56	0.54	0.56	0.62	0.55	0.56	0.65	0.53	0.57	0.54	0.55	0.57	0.63	0.66	0.65	0.58
4	0.68	0.50	0.59	0.58	0.86	0.69	0.56	0.59	0.56	0.59	0.62	0.69	0.60	0.64	0.63	0.63
K Levels in Normal Tissue, %																
1	2.8	2.6	2.6	3.0	3.2	3.4	2.8	2.9	3.9	3.0	2.4	2.9	3.0	2.9	2.9	3.0
2	2.6	2.7	2.6	3.5	3.2	3.5	2.9	3.1	4.0	2.9	3.0	3.2	2.9	2.9	2.6	3.0
3	2.7	2.5	2.4	3.4	3.0	2.8	3.1	2.7	3.3	3.0	2.7	2.9	2.8	2.6	2.7	2.8
4	2.9	2.6	2.5	3.3	3.3	3.4	2.9	2.8	3.2	2.9	3.0	3.0	3.1	2.6	2.6	2.9
Ca Levels in Normal Tissue, %																
1	0.46	0.35	0.33	0.50	0.48	0.45	0.35	0.42	0.50	0.23	0.32	0.44	0.36	0.41	0.43	0.40
2	0.54	0.52	0.49	0.54	0.57	0.50	0.55	0.54	0.53	0.28	0.42	0.44	0.54	0.54	0.59	0.51
3	0.56	0.42	0.46	0.50	0.48	0.46	0.51	0.61	0.54	0.24	0.36	0.41	0.45	0.42	0.56	0.47
4	0.78	0.52	0.54	0.51	0.60	0.71	0.78	0.74	0.87	0.36	0.60	0.50	0.65	0.60	0.59	0.62
Mg Levels in Normal Tissue, %																
1	0.25	0.21	0.19	0.26	0.25	0.26	0.24	0.26	0.26	0.23	0.18	0.23	0.18	0.20	0.22	0.23
2	0.34	0.32	0.30	0.36	0.28	0.30	0.36	0.32	0.36	0.34	0.30	0.33	0.22	0.28	0.26	0.31
3	0.29	0.24	0.26	0.31	0.25	0.23	0.35	0.32	0.33	0.25	0.26	0.29	0.24	0.23	0.30	0.28
4	0.43	0.36	0.36	0.30	0.42	0.43	0.50	0.45	0.50	0.36	0.40	0.36	0.36	0.36	0.37	0.40

[a] Level in tops of experimental trees growing at the three highest levels of the nutrient being varied.