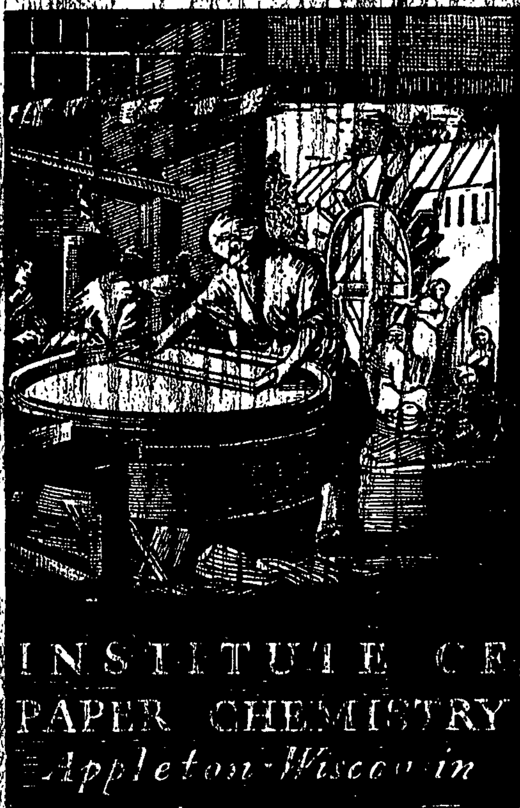


# GROWTH AND NUTRIENT REQUIREMENTS OF HYBRIDS BETWEEN POPULUS CANESCENS AND POPULUS TREMULOIDES

Project 2412

Report Seven

A Progress Report

to

LOUIS W. AND MAUD HILL FAMILY FOUNDATION

October 27, 1967

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. Despite the close relationship between the two projects, separate progress reports have been prepared which stress the separate interests of the two cooperating organizations.

The nature of the investigation being described in this report is such that it is not feasible to provide separate descriptions of the study and the report that follows constitutes Progress Report Seven of Project 2412 and Progress Report Seventeen 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

## INTRODUCTION

Statistics on forest land use indicate that, although the total acreage in forest is not changing greatly, the quality of the land available for forest production is decreasing. Forestry is also facing other interesting challenges. Population increases, projected increases in wood and paper consumption, and the recent upswing in woods labor problems have resulted in greater interest in the intensive management of forest land. More forest managers are looking closely at possibilities of using genetically improved species, mechanized harvesting, fertilization, irrigation, and other methods of intensive forest management as ways of meeting future raw material requirements.

There are a number of genetic and physiological implications, not the least of which is a 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 the work under way aimed at evaluating the nutrient requirements of several types of aspen 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 (P. 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. The first involves the evaluation of hybrids between quaking aspen and European gray poplar and is the subject of this report. The second investigation involves evaluating the growth and nutrient requirements of the hybrids between bigtooth aspen and European gray poplar and will be described in a January, 1968 report.

## 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 requirements of northern hardwoods at 0.2% for total nitrogen, 35 p.p.m. and 75 p.p.m. for P ($P_2O_5$) and K ($K_2O$) and 4 meq./100 g. and 0.5 meq./100 g. for Ca and Mg. 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 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 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 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.

# METHODS AND MATERIALS

The study described was established to obtain information regarding the growth and nutritional requirements of hybrids between quaking 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 the 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 the 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 material 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 four growth containers. Each growth container is a replication and the four containers make up a single treatment. For each additional treatment an additional basic unit is added.

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 full-sib progeny groups[1] 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 first type of hybrid aspen to be investigated using this procedure was the cross between quaking aspen (T) and European gray poplar (Ca). Table I lists the parentage of the four progeny groups used. It should be noted that Experimental Material Two, cross XT-Ca-35-65, involves a quaking aspen as the female parent while the Experimental Material Three, XCa-T-8-65, is the reciprocal cross and involves a gray poplar as the female parent.

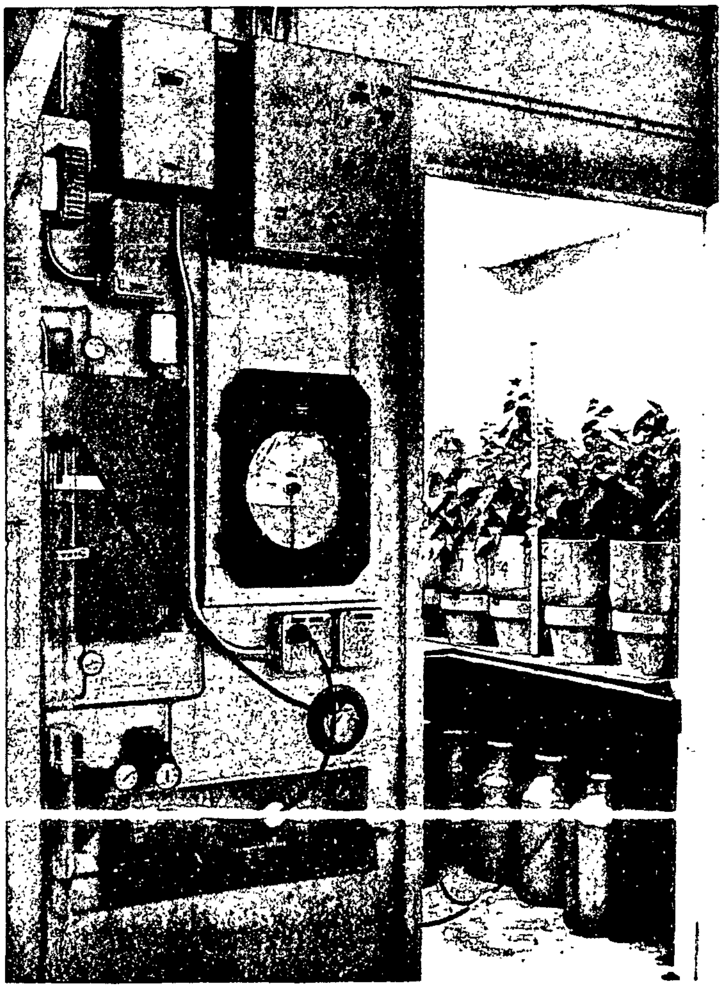

Figure 1. A View of the I.P.C. Growth Chamber Showing the Control Instruments (Left) and the Growth Containers Above and the Nutrient Carboys Below (Right). The Aspen Seedlings Shown Were Seeded 35 Days Earlier

[1] Full-sib progeny group is a progeny group in which all seedlings are brothers and sisters (have common parents).

TABLE I

PARENTAGE OF TEST TREES

| Material Number | Type of Cross | Cross Number[a] | Parent Trees (female x male) |
|---|---|---|---|
| 1 | T x T | XT-36-65 | T-12-58 x T-10-60 |
| 2 | T x Ca | XT-Ca-35-65 | T-12-58 x Ca-1-62 |
| 3 | Ca x T | XCa-T-8-65 | Ca-2 x XT-22-56, S-4 |
| 4 | Ca x Ca | XCa-34-65 | Ca-2 x Ca-1-62 |

[a] X = cross, Ca = P. canescens, T = P. tremuloides, the numbers indicate the cross number and year the cross was completed.

Olson's (11) combination of required elements was used in making up the nutrient solutions used in this study. The levels used by Olson were modified to meet the requirements of this investigation. Phosphorus was the element varied in the first growth chamber run with levels of 0, 22, 43, 54, and 65 p.p.m. being employed. One phosphorus series was run in combination with the low level of the other essential nutrients and a second series was run using a medium level of the other nutrients[2]. Both the "low series" and "medium series" were handled in a single growth chamber trial. A similar procedure was used in each growth chamber trial with a different element being varied. Table II presents the composition of Olson's low and Olson's medium solutions and the right half of the table presents the five levels of each element used when that element was being varied in a growth chamber trial.

[2] Olson's low was a nutrient solution in which all elements except the element being varied were supplied at a level equal to 40% of Olson's standard solution. Olson's medium was 60% of the standard solution.

TABLE II

COMPOSITION OF NUTRIENT SOLUTIONS IN P.P.M.

| Nutrient | Olson's Low[a] | Olson's Medium[a] | Five Levels Used in Growth Chamber Trials 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| N | 105 | 158 | 29 | 52 | 105 | 131 | 158 |
| P | 43 | 65 | 0 | 22 | 43 | 54 | 65 |
| K | 62 | 93 | 0 | 31 | 62 | 77 | 93 |
| Ca | 31 | 46 | 0 | 15 | 31 | 38 | 46 |
| Mg | 14 | 21 | 0 | 7 | 14 | 17 | 21 |

[a]Appropriate levels of micronutrients were included in 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 forty days it was not unusual to have seedlings that were 10 to 20 inches tall. After forty 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 weight of the tops.[3] Next the ovendried tops from the four 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 solution treatments. The levels of the above essential nutrients were determined by the I.P.C. Analytical Chemistry Group using standard procedures for plant tissue[4].

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

[4]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 was also used to examine the influence that varying the level of one element has on 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 was no significant difference between types of test 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 plants was selected as the growth figure to be used in comparing treatment effects. When such comparisons were made, considerable variation was encountered between individuals within progeny groups that had been treated alike. This, coupled with missing trees in some treatments, particularly treatments involving Experimental Material Two, resulted in reduced usefulness of the growth information. Analysis of variance procedures were used to investigate differences between treatments and differences between experimental materials in growth and nutrient uptake. Significant growth differences were not obtained between materials grown on Olson's low level when compared with Olson's medium level. This made it possible to combine the data for these two levels and handle the information as though one level had been used in which there were a greater number of replications.

## RESULTS

### NITROGEN GROWTH CHAMBER TRIAL

The nitrogen growth chamber run was handled as described previously. A total of ten treatments was employed. Five of the treatments involved nitrogen at 29, 52, 105, 131, and 158 p.p.m. used in combination with Olson's low level of essential nutrients (Table II). The other five treatments consisted of the above five levels of nitrogen used in combination with a medium level of the other essential elements. Results of the growth information for the four experimental materials are summarized in Fig. 2. As described under Growth Comparison, no statistically significant differences existed between the growth of the test trees on the two levels of Olson's solutions. Figure 2 illustrates the influence of varying levels of nitrogen on the average green weight of forty-day-old test trees. The data plotted are the combined average weight of the seedlings from the low and medium nutrient solutions. The green weight differences between the test materials are believed to be significant at the moderate levels of nitrogen. The nitrogen response curves indicate a rapid improvement in growth at the low nitrogen levels and growth reductions at the levels greater than 105 p.p.m. All test materials responded in a similar manner.

Appendix Table XII summarizes the nutrient levels found in the tops of the seedlings. An analysis of variance was used to examine these differences. Table III summarizes the significant F values obtained. As these data illustrate, there were no significant differences between the four types of test materials in the uptake N, P, K, or Ca. Mg uptake differences existed between the test materials with Experimental Material Four apparently having the highest magnesium uptake.

The significant treatment F values for N and Ca indicate that varying the level of N influences the uptake of both N and Ca. Figure 3 illustrates the changes in levels of N and Ca that resulted when the N levels were varied from 29 to 158 p.p.m. Since there was no significant difference between test materials in the N and Ca uptake, a single curve representing all test materials was used to illustrate the results obtained. The average values shown in Fig. 3 are in agreement with later nutrient uptake information for nitrogen.

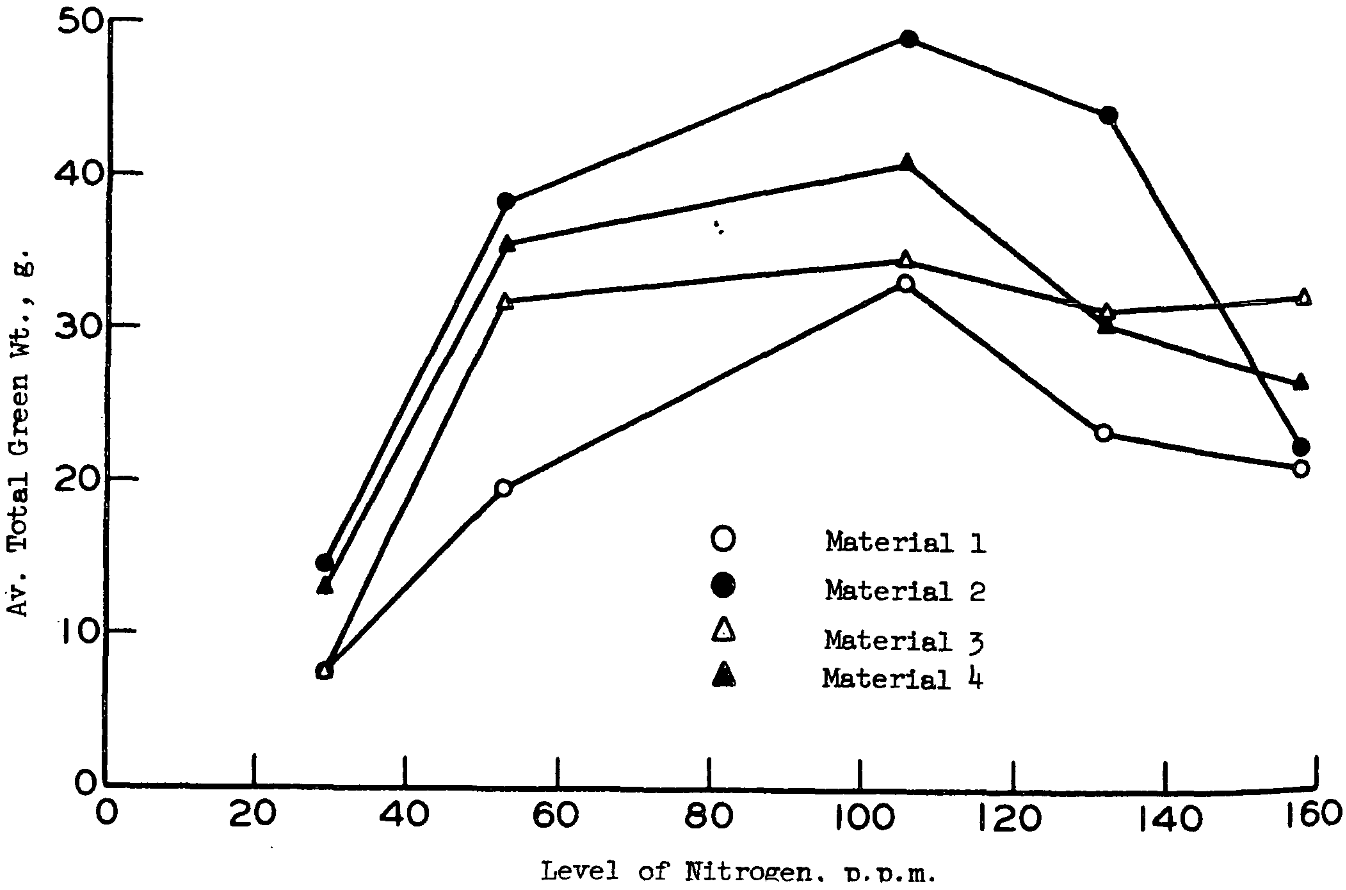


Figure 2. Differences in Average Green Weight of Trees Grown for Forty Days at Five Levels of Nitrogen

TABLE III

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

| Element | Between Treatments | Between Test Materials | Remarks |
|---|---|---|---|
| N | 72.3** | NS | N uptake increased as level of N in nutrient solution increased |
| P | NS | NS | None |
| K | NS | NS | None |
| Ca | 10.67** | NS | Low and high levels of N reduced Ca uptake |
| Mg | NS | 3.15* | Significant differences between materials in Mg uptake |

[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.

The growth curves and the uptake data indicate that no additional advantage was obtained from nitrogen levels above 105 p.p.m. It also appears that when levels of nitrogen in the tops drop below 4.0%, levels of nitrogen in the solutions are below optimum. Nitrogen levels above 105 p.p.m. apparently had an adverse effect on calcium uptake. Appendix Table XVII summarizes nitrogen levels obtained in the tops when all elements were in adequate supply. No significant differences were obtained between test materials or experimental runs when the nitrogen data in the above table were examined using analysis of variance procedures. This, then, suggests that the nitrogen level of 4.38% is a meaningful average for all materials when all elements are in adequate supply. This nitrogen level, obtained under growth chamber conditions, is higher than leaf sample information

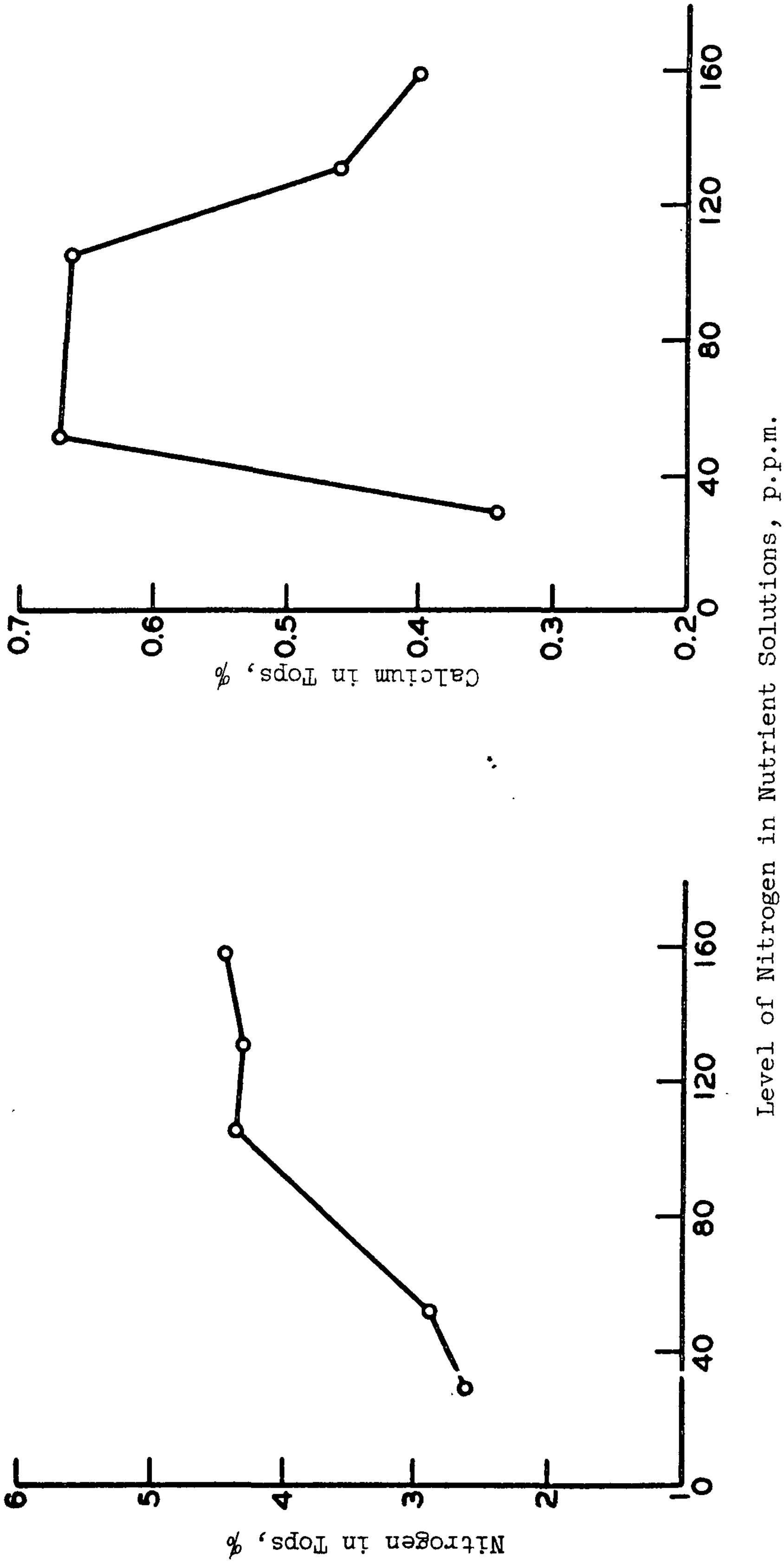


Figure 3. The Influence of Nitrogen Level on Nitrogen and Calcium Uptake. Data Plotted are Combined Values for the Four Types of Experimental Materials

reported for aspen growing on good sites in Minnesota (1.85%, 8) and orchard-grown cherry leaves growing in Michigan (2.3-3.3%, 12). The higher growth chamber values are apparently related to the early uptake of N and the immature nature of the growth chamber leaf samples.

PHOSPHORUS GROWTH CHAMBER TRIAL

The treatments in the phosphorus growth chamber trial were handled using a procedure similar to that described for nitrogen. Levels of phosphorus were varied from 0 to 65 p.p.m. Growth differences between Olson's low and Olson's medium levels were not significant. Figure 4 summarizes influence of the varying levels of P on seedling growth. No growth was obtained at the 0 level of P and growth of all test materials increased greatly as the result of the increase from 0 to 22 p.p.m. Increasing the levels of P above 22 p.p.m. failed to produce corresponding increases in growth. Missing trees in Experimental Material Two (T x Ca) contributed to the variability of the growth measurements for this material.

Table XIII of the Appendix summarizes the nutrient levels obtained in the tissue samples taken from the tops of the trees grown at the various phosphorus levels. Table IV summarizes the *F* values obtained when an analysis of variance was run on the nutrient uptake data. Varying the levels of phosphorus not only influenced the phosphorus in the tissue samples but also affected the levels of N, Ca, and Mg. Figures 5 and 6 illustrate the influence that varying the levels of P had on the level of P, N, Ca, and Mg in the tops of the experimental seedlings. Phosphorus and nitrogen uptake increased as the levels of phosphorus were increased while Mg and Ca levels were reduced at the high phosphorus levels. Data from this experimental trial also indicate that differences exist between materials in the accumulation of phosphorus, potassium, and magnesium (see the between test material

F values in Table IV). In most instances, Material Number One, quaking aspen, had the lowest uptake while Material Number Four, European gray poplar, had the highest uptake, with the hybrids being intermediate. When the nutrient uptake information was tabulated for those treatments in which nutrient levels of all nutrients were believed to be in adequate supply (Appendix Table XVII), the data further verified the high uptake of Material Number Four and the lower uptake of Materials One and Two.

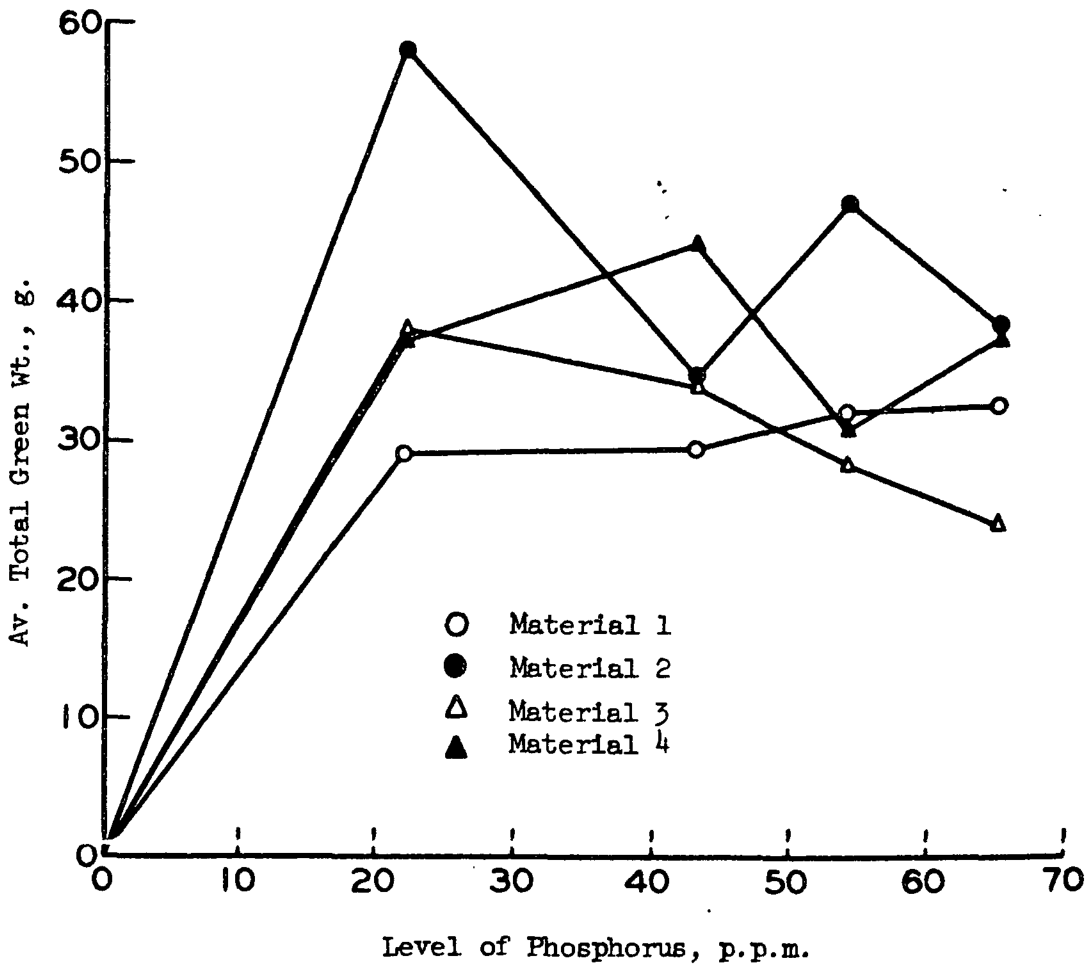


Figure 4. Differences in Average Green Weight of Trees Grown for Forty Days at Five Levels of Phosphorus

TABLE IV

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

| Element | Between Treatments | Between Test Materials | Remarks |
|---|---|---|---|
| N | 4.15* | NS | Highest N uptake at high P level |
| P | 9.10** | 11.38** | P uptake increased with increasing levels of P. Material 4 had highest uptake, Material 1 lowest and hybrids were intermediate |
| K | NS | 3.66* | Material 4 had highest uptake, Material 1 lowest and the hybrids were intermediate |
| Ca | 5.60** | NS | Ca uptake decreased with increasing levels of P |
| Mg | 3.49* | 5.48** | Mg uptake was similar to that of Ca. Material 4 had highest uptake, Material 1 lowest and the hybrids were intermediate |

[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.

The phosphorus levels reported in Appendix Table XVII 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%, 12). 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 not adequately investigated.

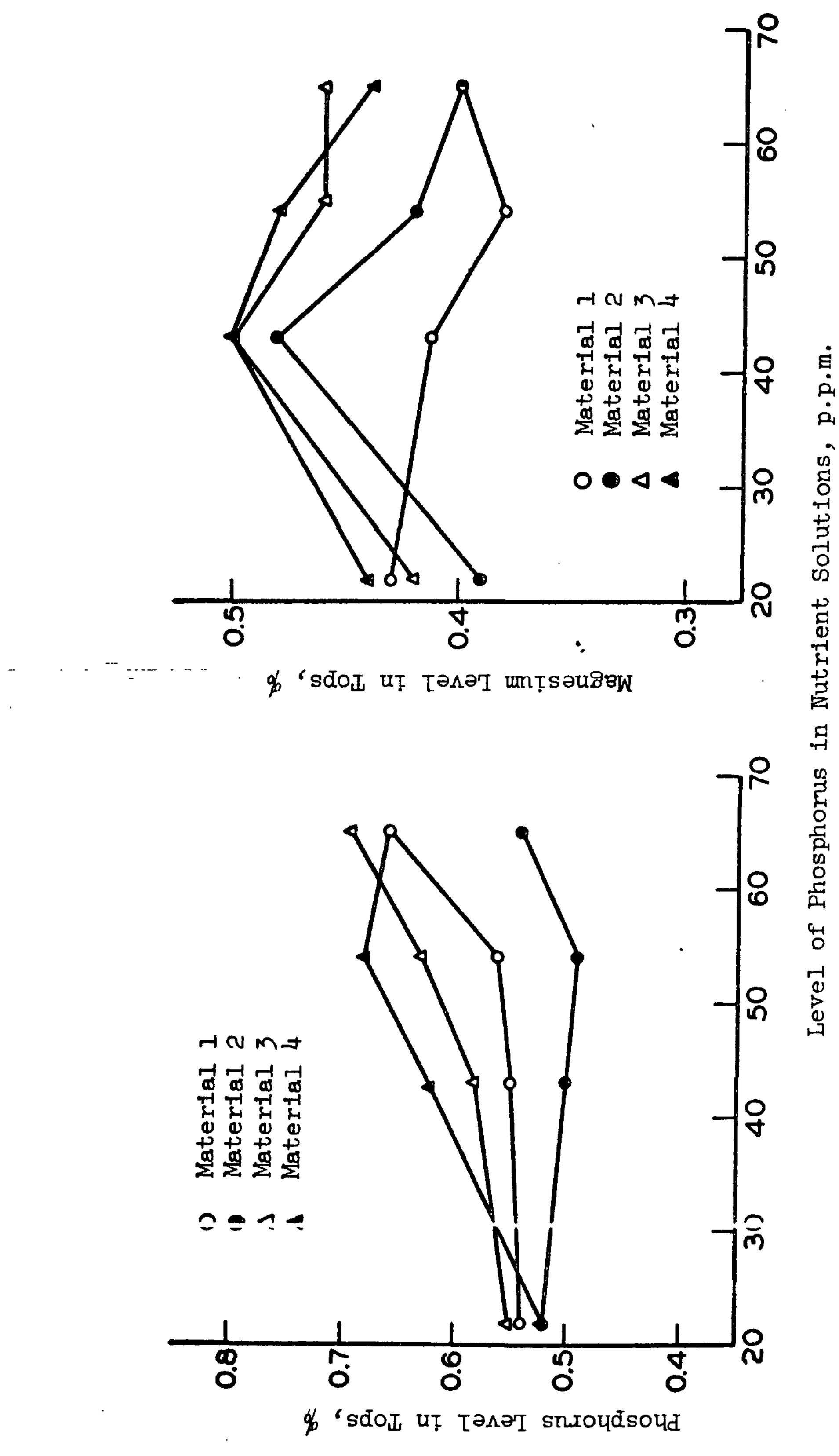


Figure 5. The Influence of Level of Phosphorus in the Nutrient Solution on Uptake of Phosphorus and Magnesium. Differences Between Experimental Materials are Statistically Significant

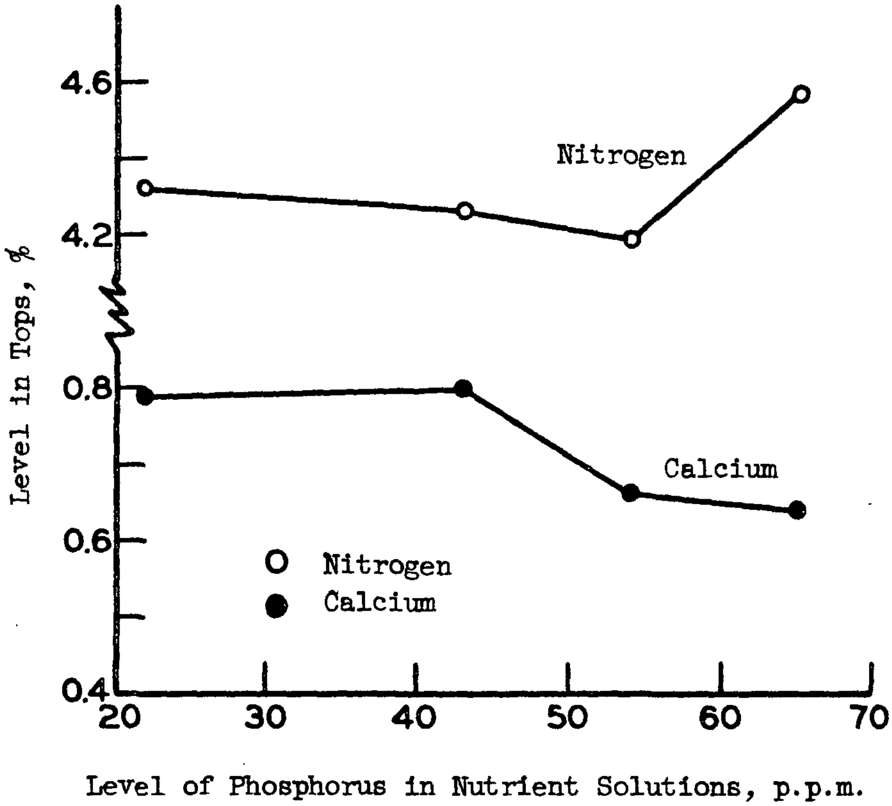


Figure 6. The Influence of Level of Phosphorus on Uptake of Nitrogen and Calcium. Levels Shown are Average Values for the Four Types of Experimental Materials

POTASSIUM GROWTH CHAMBER TRIALS

Potassium levels were varied from 0 to 93 p.p.m. and the experimental design of the treatments was the same as described for previous trials. Figure 7 illustrates the growth response of the four test materials. No measurable growth was obtained at the 0 level of potassium and the response of all four materials to increasing levels of potassium was statistically significant. At the highest level of potassium, response of Test Material Two (T x Ca) was greater than the other test materials. Little or no response was obtained from Materials One, Three, and Four at potassium levels above 62 p.p.m.

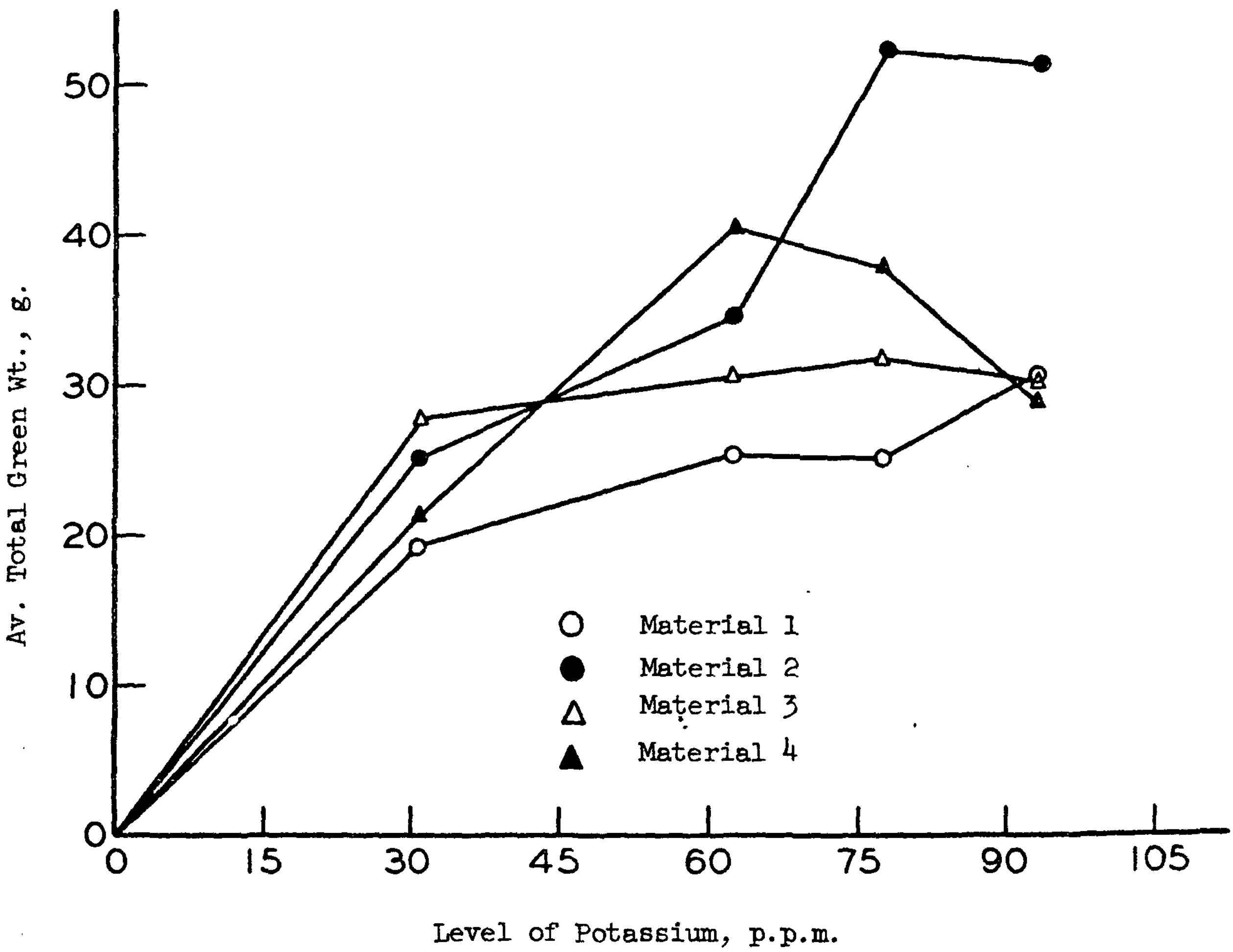


Figure 7. Differences in Average Green Weight of Trees Grown for Forty Days at Five Levels of Potassium

Appendix Table XIV summarizes the chemical analyses made on the samples from the tops of the seedlings grown at the several levels of potassium. An analysis of variance was used to examine differences between treatments and differences between test materials. Table V summarizes the significant F values obtained. These data indicate that varying the level of K has no influence on the uptake of N, P, or Mg, but does affect the uptake of K and Ca. As Fig. 8 indicates, the uptake of Ca and K increased as the level of K was increased. Looking at the differences between test materials, Table V results confirm the observations made in the other experimental trials and indicate that no significant difference exists between test materials in potassium uptake.

TABLE V

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

| Element | Between Treatments | Between Test Materials | Remarks |
|---|---|---|---|
| N | NS | NS | None |
| P | NS | 5.58** | Material 4 had highest uptake, Material 1 the lowest and hybrids intermediate |
| K | 20.2** | NS | K uptake increased as level in nutrient solution increased |
| Ca | 7.03** | 7.24** | Ca uptake increased as K increased from 31-77 p.p.m. Material 4 had highest uptake, Material 1 the lowest and hybrids intermediate |
| Mg | NS | 15.2** | Material 1 had the lowest uptake and other materials had similar levels |

[a]Two asterisks significant at the 1% level and NS indicates the F value was not significant.

The potassium picture for the materials used in this study seems fairly clear until one looks at the K uptake when all nutrients are in adequate supply. When this situation exists (Table XVII of the Appendix), there appears to be a rather clear-cut difference between experimental materials in K uptake. The average levels were highest for Material four, the lowest for Material One and the hybrid Materials Two and Three were intermediate. How these results should be interpreted is not readily apparent but it seems to indicate that when all nutrients are in good supply, between-material differences exist in potassium uptake. When the nutrient solutions had varying levels of N, K, Ca, or Mg, uptake was variable and the differences between materials were not significant. Optimum levels of K in the nutrient solution appear to be about 60 p.p.m. with levels of K in the tissue, when growth is normal, varying from 2.8 to 3.3% depending upon the type of test material involved. These values a e higher than reported (8, 12) for field grown aspen (1.29%) and cherry (1.0-1.84%) growing at adequate nutrient levels.

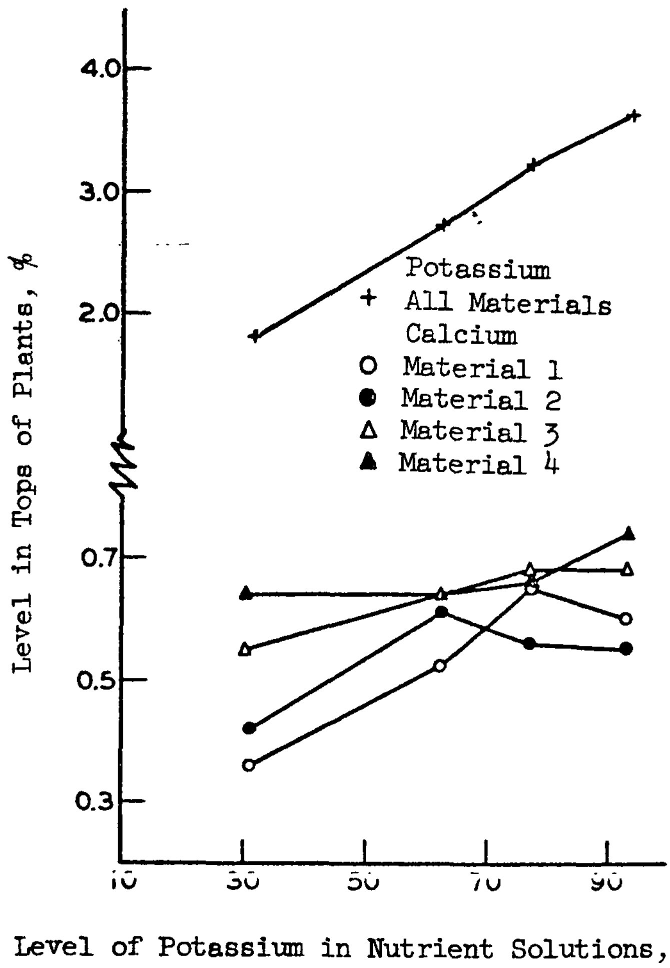


Figure 8. The Trends of Increasing Ca and K Uptake with Increasing Levels of K. Ca Uptake Differed Significantly Between Types of Test Materials. There was no Significant Difference Between Materials in K Uptake and a Single Average for all Materials is Presented

Considerable information exists regarding levels of K in tree leaves when K is in low supply. Generally, levels of 0.7-1.0% or less are considered indicative of K-deficient growing conditions. Gilbert (13) 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, apparently because neither the very high (above 90 p.p.m.) or very low (0-31 p.p.m.) levels of K were thoroughly investigated.

CALCIUM GROWTH CHAMBER TRIAL

Calcium levels were varied from 0 to 46 p.p.m. and the earlier described experimental design for handling treatments was followed. Figure 9 shows the growth response obtained as the level of calcium was increased. Some growth was obtained for all test materials at the 0 level of calcium. Response of the quaking aspen cross (Material One) to increasing levels of calcium was not statistically significant. The response of the other three materials was statistically significant. The average green weight of the four materials did not differ greatly at the highest level of calcium and again Experimental Material Two ranked high in average total green weight as was the case in all five experimental trials.

Appendix Table XV summarizes the results of the chemical analyses made on the tissue samples obtained from the calcium 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 had no influence on the uptake of N, P, or K but did affect Ca and Mg uptake. Increasing the calcium level in the nutrient solutions increased the level of calcium and decreased the level of magnesium. Figure 10 illustrates the magnitude of these trends and substantiates the commonly reported result that, at low levels of calcium, magnesium tends to substitute for calcium in certain physiological functions. It should also be noted that varying the level of calcium resulted in there being no significant between-material difference in uptake of either calcium or magnesium or any of the other elements being investigated. These results are not at all surprising in the case of N, K, and also seemed reasonable for Ca and Mg, considering the Ca and Mg substitution possibilities. Only in the case of P does it seem that there should exist between-material differences in phosphorus uptake despite the varying level of calcium.

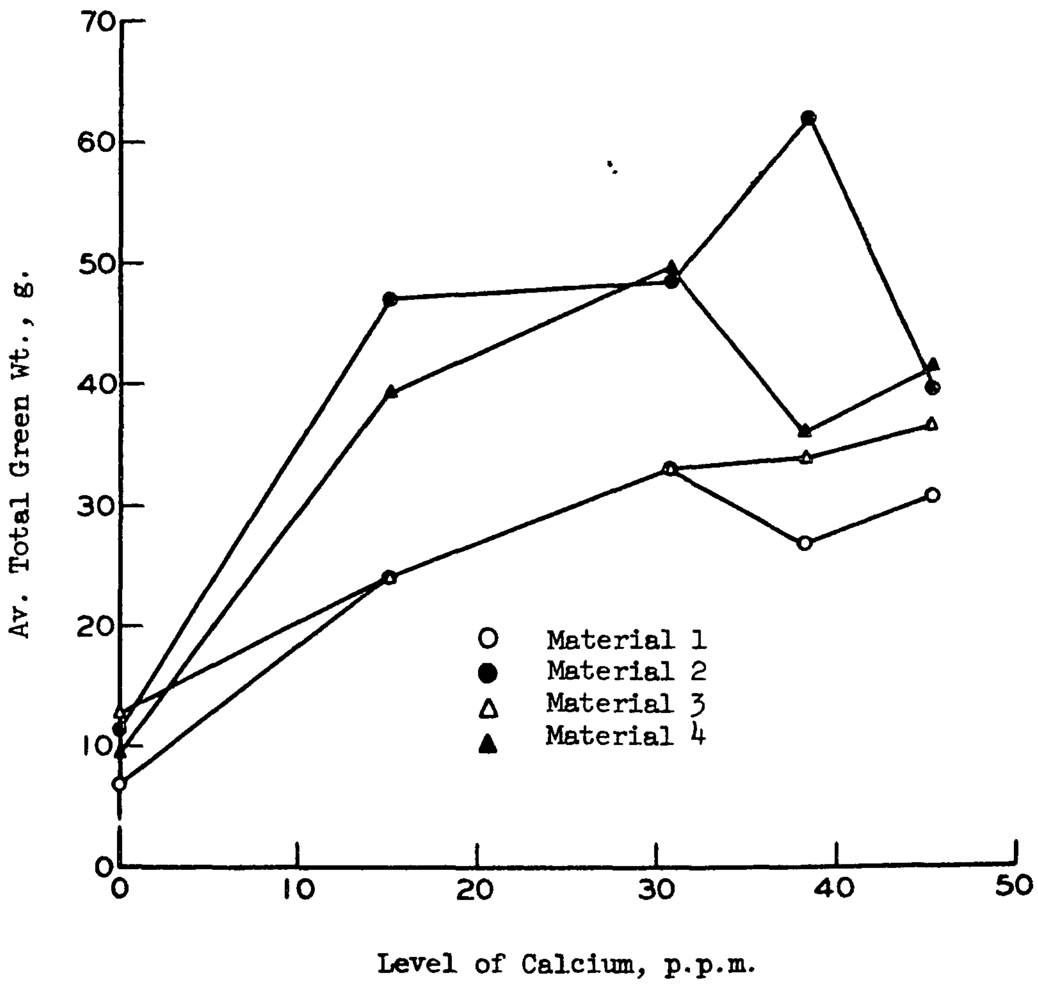


Figure 9. Differences in Average Green Weight of Trees Grown for Forty Days at Five Levels of Calcium

TABLE VI

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

| Element | Between Treatments | Between Test Materials | Remarks |
|---|---|---|---|
| N | NS | NS | None |
| P | NS | NS | None |
| K | NS | NS | None |
| Ca | 37.05** | NS | Increased uptake of Ca with increasing levels of Ca |
| Mg | 7.38** | NS | High level of Mg uptake at the lowest two levels of Ca |

[a]Two asterisks significant at the 1% level and NS indicates the F value was not significant.

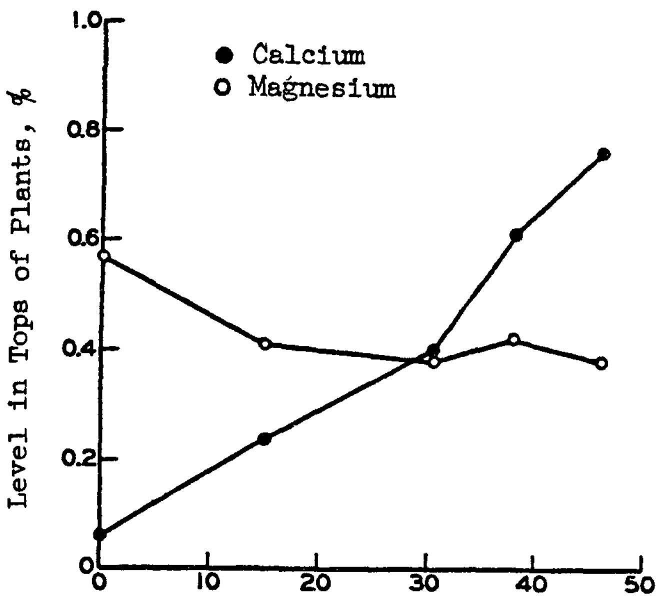


Figure 10. The Influence of Varying the Level of Calcium on the Uptake of Ca and Mg. There Were no Significant Differences Between Experimental Materials and the Levels Shown are Average Values for the Four Types of Materials

After examination of the growth response curves (Fig. 9) and the data in Table XV, the conclusion was reached that a nutrient solution level of 30-40 p.p.m. calcium would give satisfactory growth and at this level, the tissue samples of seedlings can be expected to average between 0.56 and 0.63% calcium. These levels of calcium are less than reported by other workers for field-grown aspen (2.4%), cherries (1.6-2.9%), and yellow birch (0.83-1.5%), (8, 12, 14) growing on adequate levels of soil nutrients. Hoyle (14) who sampled yellow birch leaves periodically from May to October pointed out that the total calcium level increased continually throughout the growing season. The immature nature of the leaf samples used apparently accounts for the levels of total calcium encountered.

MAGNESIUM GROWTH CHAMBER TRIAL

The standard procedure for the arrangement of treatments was followed and the response of the four test materials to varying levels of magnesium followed a pattern similar to that obtained for calcium. Figure 11 illustrates the results obtained. All test materials exhibited some growth at the zero level of Mg and Materials One and Three responded the least to increasing levels of Mg. Response for all materials was statistically significant. The overall magnesium growth response, although not clear-cut, suggests that a moderate increase in growth resulted when the level of Mg was increased from 14 to 17 and from 17 to 21 p.p.m.

Examination of the levels of the major elements in the tissue of the seedlings grown at varying levels of magnesium (Table XVI) adds support to the observation 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 levels of Mg in the nutrient solution resulted in increased Mg uptake and, as might have been predicted from previous information on calcium uptake, decreased the uptake of calcium. Phosphorus was also influenced by varying the levels of Mg with the high P uptake at low levels of Mg. Differences were also obtained between experimental materials in the uptake of phosphorus and calcium. Figure 12 illustrates the above-described trends.

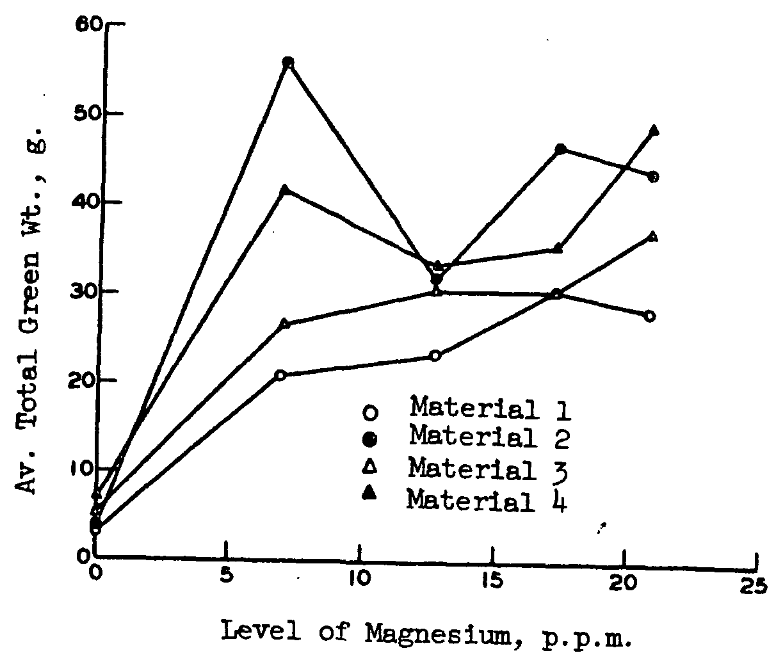


Figure 11. Differences in Average Green Weight of Trees Grown for Forty Days at Five Levels of Magnesium

TABLE VII

ANALYSIS OF VARIANCE "F" VALUES FOR MAGNESIUM TRIAL, NUTRIENT LEVEL IN TISSUE[a]

| Element | Between Treatments | Between Test Materials | Remarks |
|---|---|---|---|
| N | NS | NS | None |
| P | 6.93** | 8.46** | High P uptake at zero level of Mg. Material 4 had the highest uptake, Material 1 the lowest and the hybrids were intermediate |
| K | NS | NS | None |
| Ca | 41.8** | 5.29** | High Ca uptake at the none and low levels of Mg. Material 4 had the highest uptake, Material 1 the lowest and the hybrids were intermediate |
| Mg | 27.8** | NS | Mg uptake increased as level in nutrien solution increased. Variation between reps resulted in a NS value for expecte difference between materials |

[a]Two asterisks significant at the 1% level and NS indicates the F value was not significant.

It was also of interest to examine the level of magnesium in the several test materials when all elements were in adequate supply (Table XVII). When this was done and related to growth response and to magnesium levels when magnesium was in low supply, it appeared that a nutrient solution level of 18-20 p.p.m. was required for best growth. At this level of Mg, the average level in tissue samples can be expected to range from 0.36 to 0.45% depending upon the experimental material involved. These levels are in close agreement with levels reported for aspen, cherry, and yellow birch (8, 12, 14).

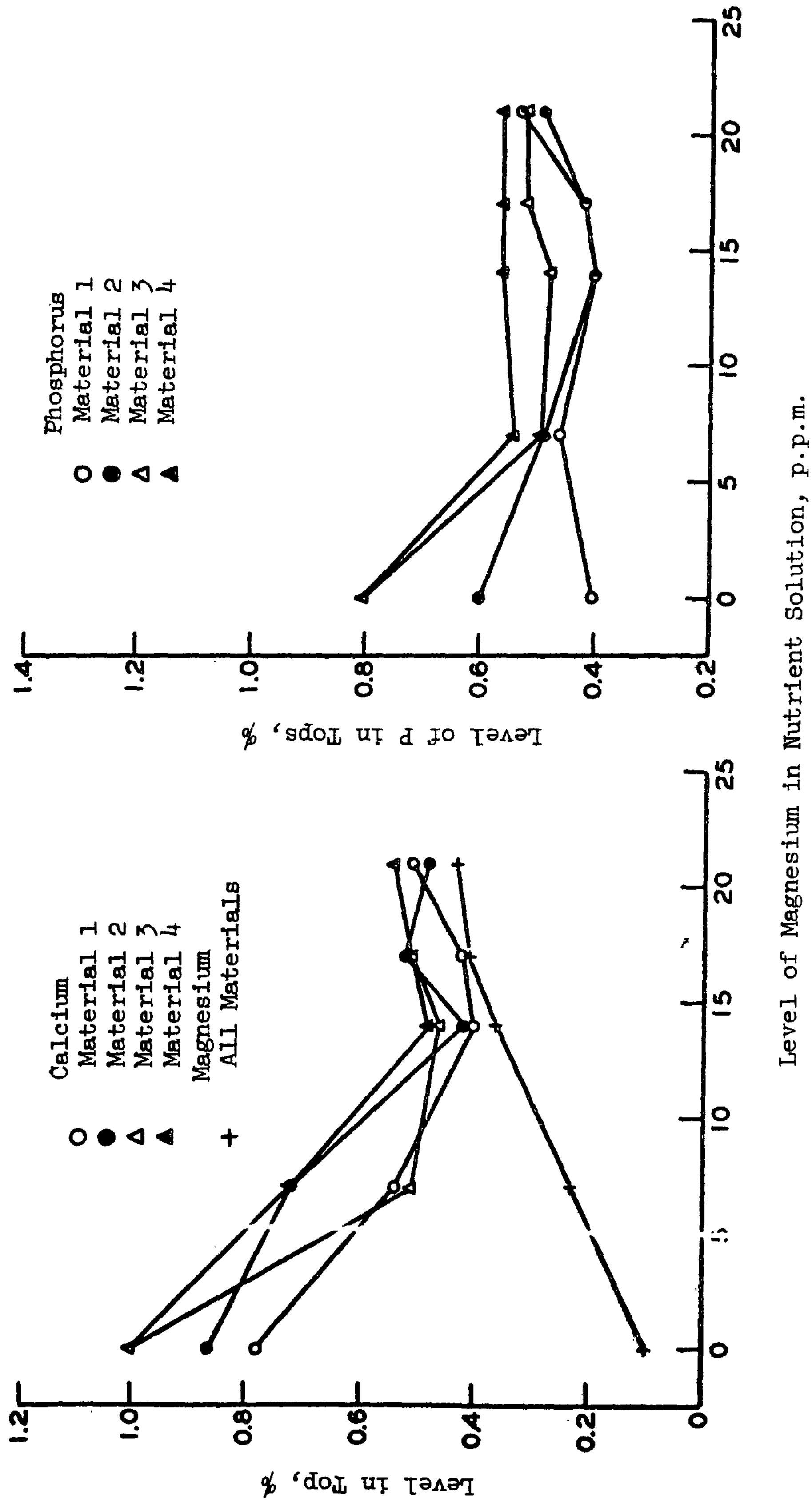


Figure 12. The Influence of Level of Magnesium on Levels of Ca, Mg, and P in Tissue Samples of *Populus* Seedlings. Significant Between-Material Differences Existed in Levels of Ca and P

## RELATED OBSERVATIONS

### OPTIMUM NUTRIENT LEVELS

One of the objectives of this study was to determine optimum levels of the major nutrients for use in sand culture studies of *Populus*. An additional objective was to examine the levels of the various elements in the tops of seedlings grown under "so-called" optimum conditions. A third objective was to determine if there exists differences between species and hybrids in their 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 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 large 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 where all nutrients were considered to be in adequate supply, 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[5]. Table XVII 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 the experimental test materials in the uptake (and very likely in the requirements) of P, K, and Mg. No differences in uptake of N and Ca were in evidence from this analysis. Statistically significant differences between experimental trials is interpreted to mean that relative uptake levels differed between experimental trials and in these instances the overall uptake very likely was being influenced by the nutrient being varied.

The combined data (Table XVII and Table VIII) are in general agreement with the results obtained when the trials were considered on a trial by trial basis. The one major exception is that when, on a trial by trial basis, the levels of potassium in the tissue were examined there were no differences between experimental materials in potassium uptake. However, when average values were used and all elements were in adequate supply, there turned out to be significant differences between experimental materials in potassium uptake. This anomaly apparently resulted because of fairly large differences between replications in the potassium trial and because of apparent abnormal K uptake that resulted when nutrient deficiencies were created as part of the treatments. Differences in K uptake apparently exist between experimental materials when all nutrients are in adequate supply.

---

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

TABLE VIII

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

| Nutrient Uptake Considered | Between Materials | Between Experimental Trials | Inter-action | Remarks |
|---|---|---|---|---|
| N | NS | NS | NS | No differences between materials or trials |
| P | 15.9** | 11.6** | NS | Material 4 had highest uptake, Materials 1 & 2 the lowest. Relative level of uptake varied between experimental trials |
| K | 6.34** | NS | NS | Material 4 – highest uptake, Material 1 lowest and hybrids were intermediate |
| Ca | NS | 6.94** | NS | No significant difference between materia but Ca uptake did vary between experiment· trials |
| Mg | 12.6** | 5.50* | NS | Material 4 – highest uptake, Material 1 lowest, and hybrids were intermediate |

[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.

Differences between experimental materials in Ca and Mg also were somewhat different than expected and apparently these differences resulted because of the influence the Ca – Mg ratio had on the uptake of these two elements. It appears that calcium substituted for magnesium when magnesium was in low supply and magnesium substituted for calcium when calcium was in low supply. In addition, the actual calcium – magnesium ratio also apparently influenced the uptake of these two elements (Table IX). The above factors influenced the nutrient levels in the experimental trees and modified the results obtained with regard to differences between materials.

TABLE IX

UPTAKE AT VARIOUS CALCIUM AND MAGNESIUM RATIOS[a]

| Nutrient Solution Ca/Mg Ratio | Calcium Uptake, % | Magnesium Uptake, % |
|---|---|---|
| 46 | 0.96 | -- |
| 30 | 0.86 | -- |
| 6.6 | 0.72 | -- |
| 4.4 | 0.58 | -- |
| 3.3 | 0.43 | 0.27 |
| 3.3 | 0.90 | 0.38 |
| 2.7 | 0.51 | 0.36 |
| 2.7 | 0.71 | 0.40 |
| 2.2 | 0.49 | 0.39 |
| 2.2 | 0.52 | 0.37 |
| 2.2 | 0.40 | 0.34 |
| 2.2 | 0.63 | 0.36 |
| 1.8 | 0.47 | 0.46 |
| 1.8 | 0.51 | 0.44 |
| 1.5 | 0.51 | 0.49 |
| 1.5 | 0.40 | 0.41 |
| 1.1 | -- | 0.42 |
| 0.7 | -- | 0.41 |
| 0.07 | -- | 0.46 |
| 0.05 | -- | 0.68 |

[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 X summarizes the estimated optimum levels of the several nutrients with regard to their 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 near optimum conditions. No differences existed between the experimental trees in the N, Ca requirements. The P. canescens "parent species" (Material Four) is believed to have the highest P, Mg, and K requirements while the P. tremuloides seedlings (Material One) apparently have the lowest requirements. The two hybrids were intermediate between the two so-called "parent species." It should be pointed out that the levels of nutrients in the tissue samples are based on 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 were in general agreement with sand culture work by McGee (14) and not greatly different in levels of N, P, Ca, and Mg from the values reported by Hoyle (15) 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 element being varied as part of the treatment. This means, for example, averaging for experimental materials the green weight data for the zero level of potassium with the green weight data for the zero or very low level of the other growth chamber trials. Figure 13 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 Materials Two and Four quite consistently had higher average green weights than Materials One and Three. 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. 13. The differences obtained were statistically significant and suggest that some measure of hybrid vigor was being exhibited by Experimental Material Two.

TABLE X

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

| Experimental Material | Nutrient Element | | | | |
|---|---|---|---|---|---|
| | N | P | K | Ca | Mg |
| 1. *P. tremuloides* (T) | 100 (4.3) | 22 (0.52) | 60 (2.8) | 30-40 (0.56) | 15-18 (0.36) |
| 2. T x Ca hybrid | 100 (4.4) | 22 (0.51) | 80 (3.1) | 30-40 (0.56) | 15-18 (0.41) |
| 3. Ca x T hybrid | 100 (4.4) | 42 (0.57) | 60 (3.0) | 30-40 (0.58) | 18-20 (0.41) |
| 4. *P. canescens* (Ca) | 100 (4.4) | 42 (0.60) | 60 (3.3) | 30-40 (0.63) | 18-20 (0.45) |

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

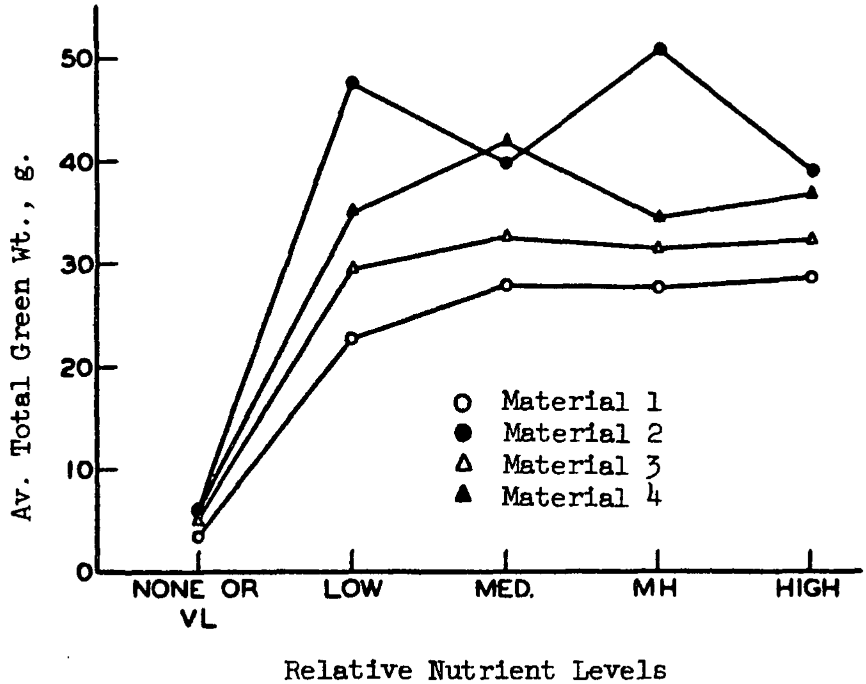


Figure 13. Differences in Green Weight of Trees Obtained by Averaging Data for All Trials and Plotting Over Relative Nutrient Levels

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. There appeared to be no well-defined pattern within growth chamber trials that was related to the level of the element being varied. Table XI summarizes the ratios obtained by the type of experimental material and by growth chamber trial.

TABLE XI

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

| Growth Chamber Run | Experimental Test Material 1 | 2 | 3 | 4 | Average |
|---|---|---|---|---|---|
| N | 1.33 | 1.08 | 1.42 | 1.41 | 1.31 |
| P | 1.09 | 1.00 | 1.54 | 1.32 | 1.24 |
| K | 1.20 | 0.92 | 1.31 | 1.22 | 1.16 |
| Ca | 1.15 | 0.98 | 1.31 | 1.40 | 1.21 |
| Mg | 1.50 | 1.16 | 1.62 | 1.35 | 1.41 |
| Av. | 1.25 | 1.03 | 1.44 | 1.34 | -- |

[a]Top-root ratios based upon all data except where, because of low nutrient levels, no growth occurred.

Growth of all four test materials was abnormal at the zero and/or very low treatment levels and the top-root ratios are not very meaningful in this instance. At the medium and high levels of each experimental trial, the T-R R were fairly constant and large differences were obtained between the types of experimental trees. Figure 14, which was drawn using the overall average top-root ratios, regardless of the nutrient element being varied, illustrates the differences obtained between the test materials.

When an analysis of variance was run on the data included in Table XVIII in the Appendix, with the none or very low treatment being excluded, the results indicated that there were significant T-R R differences between experimental materials and between growth chamber trials. The P, Ca, and K growth chamber trials produced the lowest ratios and the N and Mg trials had the highest T-R R.

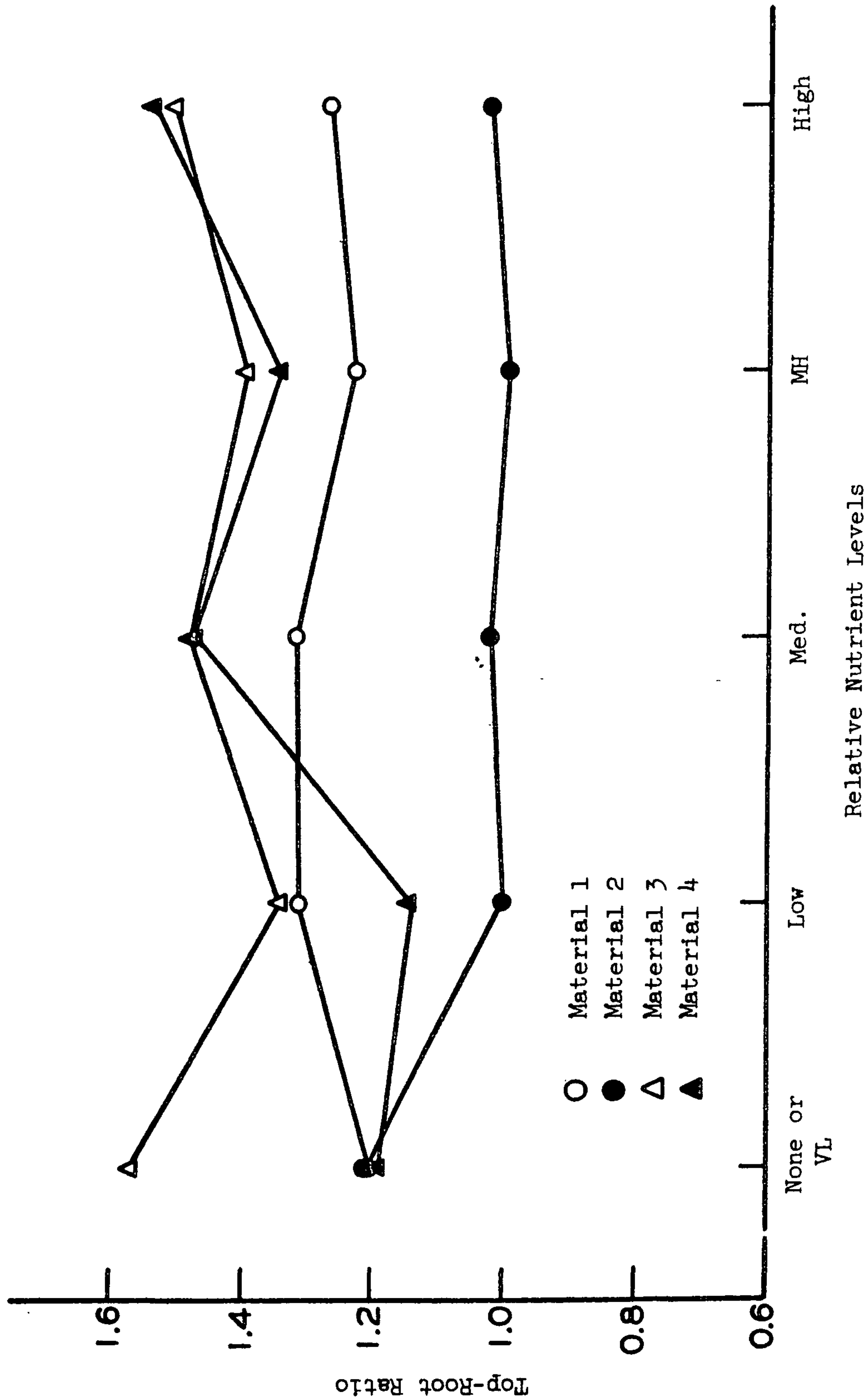


Figure 14. Top-Root Ratios Obtained by Averaging Data for all Trials. The Medium to High Nutrient Levels Give an Accurate Comparison of Differences Between Materials

The N and Mg growth chamber trials were the last two trials in the series. It appears that the T-R R may be in part influenced by the element being varied and in part by the gradual decrease in light intensity that occurred over the nine-month period that the experimental trials were under way.

The T-R R differences between experimental materials appear to be real. Of the two so-called "parent species," Test Material One had the lowest ratio and Material Four had the highest ratio. Of the two hybrid materials, Two, as might be expected, was most like Material One and consistently had the lowest top-root ratio. The T-R R of Materials Three and Four were very similar (see Table XI and Fig. 14).

## CONCLUSIONS

The results of the sand culture growth chamber comparisons between *P. tremuloides*, *P. canescens*, and hybrids between the two species revealed that significant growth differences existed between experimental materials. Between-material differences also existed in the nutrient uptake of K, Mg, and P 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 treatment differences in the uptake of all five elements. The treatment levels used adequately investigated the higher or near optimum conditions but failed to provide adequate coverage at the lower treatment levels. Chemical determinations made on seedlings grown on adequate levels of all nutrients provided estimates of the levels of N, P, K, Ca, and Mg for *Populus* seedlings growing under near optimum growing conditions.

Growth of Experimental Material Two (T x Ca hybrid) looks quite promising. This material exhibited hybrid vigor and had a low top-root ratio that seems to indicate it would do well on sandy dry sites. In addition, this hybrid did not have excessively high nutrient requirements and responded well to increasing levels of the five major nutrients tested.

## ACKNOWLEDGMENTS

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## APPENDIX

### TABLE XII

### NITROGEN TRIAL TISSUE ANALYSIS

| Material | Level of Nitrogen Applied<br>Treat. 1 & 6<br>29 p.p.m. | Treat. 2 & 7<br>52 p.p.m. | Treat. 3 & 8<br>105 p.p.m. | Treat. 4 & 9<br>131 p.p.m. | Treat. 5 & 10<br>158 p.p.m. |
|---|---|---|---|---|---|
| | | | Nitrogen, %[a] | | |
| 1 | 2.58 | 2.69 | 4.12 | 4.51 | 4.36 |
| 2 | 2.80 | 3.06 | 4.52 | 4.38 | 4.56 |
| 3 | 2.38 | 2.62 | 4.34 | 4.14 | 4.47 |
| 4 | 2.62 | 3.10 | 4.50 | 4.20 | 4.37 |
| | | | Phosphorus, %[a] | | |
| 1 | 0.46 | 0.36 | 0.48 | 0.52 | 0.47 |
| 2 | 0.44 | 0.46 | 0.52 | 0.50 | 0.53 |
| 3 | 0.46 | 0.41 | 0.53 | 0.50 | 0.56 |
| 4 | 0.56 | 0.47 | 0.54 | 0.58 | 0.54 |
| | | | Magnesium, %[a] | | |
| 1 | 0.39 | 0.34 | 0.37 | 0.35 | 0.31 |
| 2 | 0.34 | 0.42 | 0.37 | 0.43 | 0.38 |
| 3 | 0.32 | 0.38 | 0.36 | 0.38 | 0.38 |
| 4 | 0.42 | 0.40 | 0.47 | 0.40 | 0.39 |
| | | | Calcium, %[a] | | |
| 1 | 0.33 | 0.60 | 0.64 | 0.40 | 0.36 |
| 2 | 0.36 | 0.72 | 0.64 | 0.48 | 0.42 |
| 3 | 0.28 | 0.65 | 0.62 | 0.48 | 0.40 |
| 4 | 0.37 | 0.71 | 0.75 | 0.46 | 0.44 |
| | | | Potassium, %[a] | | |
| 1 | 3.5 | 2.6 | 2.8 | 2.8 | 2.4 |
| 2 | 3.1 | 3.2 | 3.6 | 3.0 | 2.7 |
| 3 | 3.3 | 3.6 | 3.2 | 2.6 | 3.1 |
| 4 | 3.6 | 3.4 | 3.2 | 3.0 | 3.5 |

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

## TABLE XIII

## PHOSPHORUS TRIAL TISSUE ANALYSIS

| Material | Level of Phosphorus Applied | | | | |
|---|---|---|---|---|---|
| | Treat. 1 & 6<br>0 p.p.m. | Treat. 2 & 7<br>22 p.p.m. | Treat. 3 & 8<br>43 p.p.m. | Treat. 4 & 9<br>54 p.p.m. | Treat. 5 & 10<br>65 p.p.m. |
| | | | Nitrogen, %[a] | | |
| 1 | | 4.48 | 4.22 | 4.24 | 4.70 |
| 2 | No growth | 4.16 | 4.24 | 4.08 | 4.29 |
| 3 | | 4.42 | 4.30 | 4.12 | 4.66 |
| 4 | | 4.24 | 4.29 | 4.32 | 4.58 |
| | | | Phosphorus, %[a] | | |
| 1 | | 0.54 | 0.55 | 0.56 | 0.66 |
| 2 | No growth | 0.52 | 0.50 | 0.48 | 0.54 |
| 3 | | 0.55 | 0.58 | 0.63 | 0.69 |
| 4 | | 0.52 | 0.62 | 0.68 | 0.66 |
| | | | Magnesium, %[a] | | |
| 1 | | 0.43 | 0.41 | 0.38 | 0.40 |
| 2 | No growth | 0.39 | 0.48 | 0.42 | 0.40 |
| 3 | | 0.42 | 0.50 | 0.46 | 0.46 |
| 4 | | 0.44 | 0.50 | 0.48 | 0.44 |
| | | | Calcium, %[a] | | |
| 1 | | 0.84 | 0.72 | 0.66 | 0.72 |
| 2 | | 0.77 | 0.77 | 0.64 | 0.61 |
| 3 | No growth | 0.78 | 0.85 | 0.62 | 0.60 |
| 4 | | 0.76 | 0.85 | 0.72 | 0.64 |
| | | | Potassium, %[a] | | |
| 1 | | 2.8 | 2.8 | 2.8 | 3.1 |
| 2 | No growth | 3.2 | 2.9 | 2.7 | 2.8 |
| 3 | | 2.8 | 2.9 | 3.1 | 3.2 |
| 4 | | 3.0 | 3.4 | 3.2 | 3.6 |

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

TABLE XIV

POTASSIUM TRIAL TISSUE ANALYSIS

| | Level of Potassium Applied | | | | |
|---|---|---|---|---|---|
| Material | Treat. 1 & 6 0 p.p.m. | Treat. 2 & 7 31 p.p.m. | Treat. 3 & 8 62 p.p.m. | Treat. 4 & 9 77 p.p.m. | Treat. 5 & 10 93 p.p.m. |
| | | | Nitrogen, %[a] | | |
| 1 | | 4.11 | 4.22 | 4.26 | 4.42 |
| 2 | No growth | 4.16 | 4.76 | 4.30 | 4.43 |
| 3 | | 4.26 | 4.33 | 4.32 | 4.68 |
| 4 | | 4.60 | 4.36 | 4.44 | 4.48 |
| | | | Phosphorus, %[a] | | |
| 1 | No growth | 0.44 | 0.53 | 0.54 | 0.55 |
| 2 | | 0.46 | 0.54 | 0.52 | 0.56 |
| 3 | | 0.48 | 0.56 | 0.58 | 0.64 |
| 4 | | 0.62 | 0.60 | 0.64 | 0.69 |
| | | | Magnesium, %[a] | | |
| 1 | | 0.30 | 0.34 | 0.38 | 0.37 |
| 2 | No growth | 0.46 | 0.44 | 0.40 | 0.43 |
| 3 | | 0.46 | 0.44 | 0.40 | 0.42 |
| 4 | | 0.55 | 0.46 | 0.48 | 0.49 |
| | | | Calcium, %[a] | | |
| 1 | | 0.36 | 0.52 | 0.65 | 0.60 |
| 2 | No growth | 0.42 | 0.61 | 0.56 | 0.55 |
| 3 | | 0.55 | 0.64 | 0.68 | 0.68 |
| 4 | | 0.64 | 0.64 | 0.66 | 0.74 |
| | | | Potassium, %[a] | | |
| 1 | | 1.4 | 2.6 | 3.0 | 3.4 |
| 2 | No growth | 2.0 | 3.0 | 3.0 | 3.8 |
| 3 | | 1.6 | 2.4 | 3.0 | 3.5 |
| 4 | | 2.0 | 2.7 | 3.6 | 3.7 |

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

TABLE XV

CALCIUM TRIAL TISSUE ANALYSIS

| Material | Level of Calcium Applied<br>Treat. 1 & 6<br>0 p.p.m. | Treat. 2 & 7<br>15 p.p.m. | Treat. 3 & 8<br>31 p.p.m. | Treat. 4 & 9<br>38 p.p.m. | Treat. 5 & 10<br>46 p.p.m. |
|---|---|---|---|---|---|
| | | | Nitrogen, %[a] | | |
| 1 | 5.05 | 4.06 | 4.37 | 4.36 | 4.37 |
| 2 | 4.76 | 4.22 | 4.54 | 4.66 | 4.51 |
| 3 | 4.20 | 4.08 | 4.54 | 4.37 | 4.38 |
| 4 | 4.20 | 4.24 | 4.42 | 4.36 | 4.48 |
| | | | Phosphorus, %[a] | | |
| 1 | 0.76 | 0.48 | 0.54 | 0.48 | 0.52 |
| 2 | 0.78 | 0.58 | 0.46 | 0.60 | 0.52 |
| 3 | 0.58 | 0.62 | 0.56 | 0.60 | 0.60 |
| 4 | 0.61 | 0.56 | 0.52 | 0.57 | 0.71 |
| | | | Magnesium, %[a] | | |
| 1 | 0.61 | 0.40 | 0.36 | 0.33 | 0.36 |
| 2 | 0.66 | 0.41 | 0.38 | 0.43 | 0.38 |
| 3 | 0.52 | 0.40 | 0.38 | 0.42 | 0.36 |
| 4 | 0.50 | 0.44 | 0.40 | 0.50 | 0.40 |
| | | | Calcium, %[a] | | |
| 1 | 0.08 | 0.26 | 0.40 | 0.56 | 0.77 |
| 2 | 0.08 | 0.23 | 0.41 | 0.59 | 0.74 |
| 3 | 0.04 | 0.22 | 0.36 | 0.60 | 0.73 |
| 4 | 0.06 | 0.24 | 0.44 | 0.70 | 0.82 |
| | | | Potassium, %[a] | | |
| 1 | 2.8 | 2.7 | 3.0 | 2.6 | 2.8 |
| 2 | 3.4 | 3.0 | 3.0 | 3.3 | 3.1 |
| 3 | 3.8 | 3.2 | 3.5 | 3.1 | 2.7 |
| 4 | 3.4 | 3.4 | 3.7 | 3.4 | 3.0 |

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

TABLE XVI

MAGNESIUM TRIAL TISSUE ANALYSIS

| | Level of Magnesium Applied | | | | |
|---|---|---|---|---|---|
| Material | Treat. 1 & 6<br>0 p.p.m. | Treat. 2 & 7<br>7 p.p.m. | Treat. 3 & 8<br>14 p.p.m. | Treat. 4 & 9<br>17 p.p.m. | Treat. 5 & 10<br>21 p.p.m. |
| | | | Nitrogen, %[a] | | |
| 1 | 3.94 | 4.10 | 4.02 | 4.28 | 4.62 |
| 2 | 4.01 | 4.54 | 4.02 | 4.50 | 4.53 |
| 3 | 4.53 | 4.18 | 4.49 | 4.35 | 4.44 |
| 4 | 4.73 | 4.41 | 4.32 | 4.27 | 4.55 |
| | | | Phosphorus, %[a] | | |
| 1 | 0.40 | 0.46 | 0.40 | 0.42 | 0.53 |
| 2 | 0.60 | 0.49 | 0.40 | 0.42 | 0.49 |
| 3 | 0.80 | 0.49 | 0.48 | 0.52 | 0.52 |
| 4 | 0.80 | 0.54 | 0.56 | 0.56 | 0.56 |
| | | | Magnesium, %[a] | | |
| 1 | 0.08 | 0.21 | 0.28 | 0.34 | 0.42 |
| 2 | 0.10 | 0.24 | 0.32 | 0.47 | 0.42 |
| 3 | 0.10 | 0.20 | 0.34 | 0.40 | 0.43 |
| 4 | 0.12 | 0.26 | 0.38 | 0.44 | 0.44 |
| | | | Calcium, %[a] | | |
| 1 | 0.78 | 0.54 | 0.40 | 0.42 | 0.51 |
| 2 | 0.86 | 0.72 | 0.42 | 0.52 | 0.48 |
| 3 | 1.00 | 0.51 | 0.46 | 0.51 | 0.54 |
| 4 | 1.00 | 0.72 | 0.48 | 0.51 | 0.54 |
| | | | Potassium, %[a] | | |
| 1 | 2.8 | 3.2 | 2.4 | 2.6 | 3.1 |
| 2 | 2.8 | 3.3 | 3.0 | 3.2 | 3.0 |
| 3 | 3.4 | 3.0 | 3.0 | 2.8 | 3.0 |
| 4 | 3.0 | 3.4 | 3.4 | 3.0 | 3.4 |

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

TABLE XVII

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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Mg Levels in Normal Tissue, %** | | | | | | | | | | | | | | | | |
| 1 | 0.37 | 0.35 | 0.31 | 0.41 | 0.38 | 0.40 | 0.34 | 0.38 | 0.37 | 0.36 | 0.33 | 0.36 | 0.28 | 0.34 | 0.43 | 0.36 |
| 2 | 0.37 | 0.43 | 0.38 | 0.48 | 0.42 | 0.40 | 0.44 | 0.40 | 0.43 | 0.38 | 0.43 | 0.38 | 0.32 | 0.47 | 0.42 | 0.41 |
| 3 | 0.36 | 0.38 | 0.38 | 0.50 | 0.46 | 0.46 | 0.44 | 0.40 | 0.42 | 0.38 | 0.42 | 0.36 | 0.34 | 0.40 | 0.43 | 0.41 |
| 4 | 0.47 | 0.40 | 0.39 | 0.50 | 0.48 | 0.44 | 0.46 | 0.48 | 0.49 | 0.40 | 0.50 | 0.40 | 0.39 | 0.44 | 0.44 | 0.45 |
| **Ca Levels in Normal Tissue, %** | | | | | | | | | | | | | | | | |
| 1 | 0.65 | 0.40 | 0.36 | 0.72 | 0.66 | 0.72 | 0.52 | 0.65 | 0.60 | 0.40 | 0.56 | 0.77 | 0.40 | 0.42 | 0.51 | 0.56 |
| 2 | 0.64 | 0.48 | 0.42 | 0.77 | 0.64 | 0.61 | 0.61 | 0.55 | 0.55 | 0.41 | 0.59 | 0.74 | 0.42 | 0.52 | 0.48 | 0.56 |
| 3 | 0.62 | 0.48 | 0.40 | 0.85 | 0.62 | 0.60 | 0.64 | 0.68 | 0.68 | 0.36 | 0.60 | 0.73 | 0.46 | 0.51 | 0.54 | 0.58 |
| 4 | 0.75 | 0.46 | 0.44 | 0.85 | 0.72 | 0.64 | 0.64 | 0.66 | 0.74 | 0.44 | 0.70 | 0.82 | 0.48 | 0.51 | 0.54 | 0.63 |
| **K Levels in Normal Tissue, %** | | | | | | | | | | | | | | | | |
| 1 | 2.8 | 2.8 | 2.4 | 2.8 | 2.8 | 3.1 | 2.6 | 3.0 | 3.4 | 3.0 | 2.6 | 2.8 | 2.4 | 2.6 | 3.1 | 2.8 |
| 2 | 3.6 | 3.0 | 2.7 | 2.9 | 2.7 | 2.8 | 3.0 | 3.0 | 3.8 | 3.0 | 3.3 | 3.1 | 3.0 | 3.2 | 3.0 | 3.1 |
| 3 | 3.2 | 2.6 | 3.1 | 2.9 | 3.1 | 3.2 | 2.4 | 3.0 | 3.5 | 3.5 | 3.1 | 2.7 | 3.0 | 2.8 | 3.0 | 3.0 |
| 4 | 3.2 | 3.0 | 3.5 | 3.4 | 3.2 | 3.6 | 2.7 | 3.6 | 3.7 | 3.7 | 3.4 | 3.0 | 3.4 | 3.0 | 3.4 | 3.3 |
| **N Levels in Normal Tissue, %** | | | | | | | | | | | | | | | | |
| 1 | 4.1 | 4.5 | 4.4 | 4.2 | 4.2 | 4.7 | 4.2 | 4.3 | 4.4 | 4.4 | 4.4 | 4.4 | 4.0 | 4.3 | 4.6 | 4.3 |
| 2 | 4.5 | 4.4 | 4.6 | 4.2 | 4.1 | 4.3 | 4.8 | 4.3 | 4.4 | 4.5 | 4.7 | 4.5 | 4.0 | 4.5 | 4.5 | 4.4 |
| 3 | 4.3 | 4.1 | 4.5 | 4.3 | 4.1 | 4.7 | 4.3 | 4.3 | 4.7 | 4.5 | 4.4 | 4.4 | 4.5 | 4.4 | 4.4 | 4.4 |
| 4 | 4.5 | 4.2 | 4.4 | 4.3 | 4.3 | 4.6 | 4.4 | 4.4 | 4.5 | 4.4 | 4.4 | 4.5 | 4.3 | 4.3 | 4.4 | 4.4 |
| **P Levels in Normal Tissue, %** | | | | | | | | | | | | | | | | |
| 1 | 0.48 | 0.52 | 0.47 | 0.55 | 0.56 | 0.66 | 0.53 | 0.54 | 0.55 | 0.54 | 0.48 | 0.52 | 0.40 | 0.42 | 0.53 | 0.52 |
| 2 | 0.52 | 0.50 | 0.53 | 0.50 | 0.48 | 0.54 | 0.54 | 0.52 | 0.56 | 0.46 | 0.60 | 0.52 | 0.40 | 0.42 | 0.49 | 0.51 |
| 3 | 0.53 | 0.50 | 0.56 | 0.58 | 0.63 | 0.69 | 0.56 | 0.58 | 0.64 | 0.56 | 0.60 | 0.60 | 0.48 | 0.52 | 0.52 | 0.57 |
| 4 | 0.54 | 0.58 | 0.54 | 0.62 | 0.68 | 0.66 | 0.60 | 0.64 | 0.69 | 0.52 | 0.57 | 0.71 | 0.56 | 0.56 | 0.56 | 0.60 |

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

TABLE XVIII

TOP-ROOT RATIOS[a]

| Growth Chamber Run | Experimental Test Material | | | |
| --- | --- | --- | --- | --- |
| | 1 | 2 | 3 | 4 |
| N | 1.15 | 1.34 | 1.46 | 0.98 |
| | 1.29 | 0.91 | 1.16 | 1.23 |
| | 1.30 | 1.18 | 1.78 | 2.00 |
| | 1.53 | 0.92 | 1.34 | 1.36 |
| | 1.40 | 1.04 | 1.38 | 1.48 |
| P | -- | -- | -- | -- |
| | 1.17 | 1.22 | 1.70 | 1.22 |
| | 1.16 | 0.90 | 1.41 | 1.14 |
| | 1.01 | 1.09 | 1.34 | 1.24 |
| | 1.01 | 0.80 | 1.68 | 1.68 |
| K | -- | -- | -- | -- |
| | 1.30 | 1.00 | 1.19 | 1.06 |
| | 1.12 | 0.98 | 1.28 | 1.08 |
| | 1.21 | 0.86 | 1.50 | 1.27 |
| | 1.18 | 0.86 | 1.30 | 1.47 |
| Ca | 0.70 | 0.98 | 1.64 | 1.65 |
| | 1.14 | 0.85 | 1.08 | 1.17 |
| | 1.50 | 0.98 | 1.32 | 1.59 |
| | 1.10 | 0.88 | 1.10 | 1.08 |
| | 1.32 | 1.20 | 1.42 | 1.50 |
| Mg | 1.76 | 1.30 | 1.60 | 0.93 |
| | 1.64 | 1.02 | 1.57 | 1.03 |
| | 1.46 | 1.06 | 1.59 | 1.54 |
| | 1.24 | 1.22 | 1.66 | 1.74 |
| | 1.40 | 1.22 | 1.70 | 1.51 |

[a]Values listed within each cell in the two-way table are the top-root ratios obtained for the none or very low, low, medium, medium high, and high level of the nutrient being varied.