AN ABSTRACT OF THE THESIS OF

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Title: The Concentration of Nutrients in the Tissue of Ten White Spruce Provenances Grown on an Acid and a Basic Soil

Abstract approved: Signature redacted for privacy.

Dr. D. P. Lavender

The experiment described in this paper was designed and carried out to study the ability of five provenances of white spruce of acid soil origin and five provenances of basic soil origin grown on an acid and a basic soil to utilize and respond to the five macro-nutrient elements N, P, K, Ca and Mg as determined by analysis of the plant tissue produced. The purpose was to determine if some of the variability found in the growth performance of this species may be related to differential concentrations of required nutrients in the plant tissue. The ten provenances were grown in the two soils in three split plots. Two plots were unfertilized and the third was fertilized. Nutrient content of seed and plant tissue was obtained for the five elements. Exchangeable K, Ca and Mg and available P were determined for the two soils. The concentrations of nutrients in the seed of the ten provenances are similar except for calcium which was double in the basic provenances. This appears to be luxury consumption. No relation-

ship was apparent between the concentrations of nutrients in the seed and the produced tissue. Analysis of variance revealed significant differences in concentrations of nutrients in the tissue between the soils (P, K, Ca and Mg) and with fertilization (P and K). The interaction of tree type X soil was highly significant for K. The well known K - Ca and K - Mg interactions are prominent. However, the basic provenances contain more K when grown on the basic soil than did the acid provenances. These same basic provenances contain less K on the acid soil than did the acid provenances. It appears that the basic provenance possesses an inherited ability to obtain required quantities of this element in the face of possible adverse quantities of Ca and Mg. Ca, Mg and P concentrations in the tissue appear to reflect the supply available in the soil. Growth of the ten provenances was generally poor on the basic soil. Further study with a range of soils is required to confirm if the apparent variation between acid and basic soil origin provenances was of genetic or soil origin.

The Concentration of Nutrients in the Tissue of Ten White Spruce Provenances Grown on an Acid and a Basic Soil

by

Roy C. A. Gilbert

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Typed by Laurel Brain for Roy C. A. Gilbert

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The preparation of this thesis has been spread over the course of eight years. Thanks to an extension of the time allotment by the Graduate School at Oregon State University the work is now complete.

The preparation of the paper has been fraught with difficulty including those of failure of sufficient plant material to grow until the fourth attempt, difficulty in obtaining analysis of tissue and soil and difficulty in obtaining a computer analysis of the data. All these problems are, of course, expected in research.

There are many people who have assisted in overcoming these difficulties to which I must make mention.

Mark J. Holst of Environment Canada, Chalk River, Ontario provided the thesis idea and the necessary white spruce seed.

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I must also pay tribute to my wife Audrey, with whom I spent an enjoyable year in Oregon. She has also borne with me through the last eight years of trial and error.

No acknowledgement would be complete without an acclaim for the typist who must wade through large volumes of unintelligable figures and prose. Mrs. Laurel Brain, who has been my secretary with the Ontario Department of lands and Forests, at Hespeler, Ontario for the past four years, completed this task most ably.

I would also like to thank my major Professor Dr. D. P. Lavender and my committee consisting of Dr. W. W. Chilcote and Dr. R. K. Hermann for their endeavours on my behalf.

As a final acknowledgement I would like to thank my employer, the Ontario Department of Lands and Forests, for their encouragement and the necessary time to complete the task.

I would also like to add a word of caution to anyone contemplating finishing a dissertation after they have left the friendly environs of the university and have taken up a full time job. One is inclined to feel that the task of producing the data and the required report in their spare time will be an easy one. This becomes almost impossible,

however, when compounded with the legitimate demands of the employer.

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INTRODUCTION

White spruce (*Picea glauca* (Moench) Voss) is the most important and widely distributed of the Canadian spruces and is perhaps the most important species found in the Boreal Forest of North America.

The species, a major component of the climax community of this forest region, is commonly found in association with red and black spruce (*Picea rubens* Sarg. and *Picea mariana* (Mill) B.S.P.), balsam fir (*Abies balsamea* (L.) Mill.), tamarack (*Larix laricina* (Du Roi) K. Koch), the aspens and poplars (*Populus tremuloides* Michx. and *grandidentata* Michx. and *Populus balsamifera* L.) and white birch (*Betula papyrifera* Marsh.). In the western mountains it may also be found with subalpine fir (*Abies lasiocarpa* (Hook.) Nutt) and Engelmann spruce (*Picea engelmannii* Perry). The species has a wide pH tolerance range, being found growing on soils with pH values as low as 4.5 to as high as 8.4. The "lime tolerance" must be qualified, however, since symptoms of chlorosis have occurred on heavily limed nursery soils (Fowells, 1965).

Within its native range, white spruce is found on a variety of podzolized soils of glacial, lacustrine, marine and alluvial origin. Textures vary from clays to sands.

White spruce attains its best growth on deep, moist but well drained sandy loam soils and on alluvial soils commonly found along rivers and streams or around swamp edges (Harlow and Harrar, 1958).

Under the most favourable conditions, individuals of this species may grow to a maximum of 120 feet in height and four feet in diameter. The average, however, is much less, being between 70 and 80 feet in height and 18 to 24 inches in diameter (Hosie, 1969).

The species is widely and extensively used for pulpwood because of its abundant and long fibers and for construction lumber because of its lightness, strength and stability.

White spruce is normally harvested by using some form of the clearcut system. Prior to the adoption of the more modern forest management systems now in use, large pure or nearly pure stands were clearcut with little or no provision for regeneration. Consequently, vast areas of potentially productive forest reverted to pioneer associations of white birch and the poplars or in some cases Jack pine (*Pinus banksiana* Lamb.). With time, the spruce species and balsam fir invade to eventually become a suppressed understory stand. Expensive stand conversion techniques are often required to eliminate the less desirable pioneer species.

With more recent concern for minimizing the time lag until complete re-establishment of the valuable spruces on cut over areas, strip clearcutting, with strips not more than two times tree height, is now a common practice.

Occasionally, for any one of several reasons, the clearcut strips fail to regenerate. It therefore becomes necessary to introduce seedlings or seed artificially. Artificial regeneration with white spruce in Ontario in 1969, for example, was carried out on approximately 36,500 acres using 25,545,000 tree seedlings and container grown stock called tubelings (O.D.L.F.).

White spruce is also being used extensively for reforestation in the eastern United States and in Canada outside its natural range. In much of this area the soils are not of granitic origin as are most of the soils in the Boreal Forest but rather are of limestone origin with basic (alkaline) pH reactions throughout the soil profile.

The experiment described in this paper was designed and carried out to study the ability of five provenances of white spruce of acid soil origin and five provenances of basic soil origin grown on an acid and a basic soil to utilize and respond to five macro-nutrient elements as determined by analysis of the plant tissue produced. The purpose is to establish if some of the variability found in the growth performance of white spruce may be related to differential concentrations of required nutrients in the plant tissue.

LITERATURE REVIEW

The importance of an adequate supply of the macronutrient elements nitrogen, phosphorus, potassium, calcium and magnesium for good plant growth has long been recognized in the field of agriculture. The role of good nutrition in the maintainance of specimen trees and shrubs has been studied in the fields of arboriculture and horticulture. Only recently, however, has an appreciation of the nutritional requirements of forest tree species for survival and development been pursued.

The physiological role of these elements in the growth of agricultural crops (Broyer and Stout, 1959; Brown, 1963) and tree species (Reuther, Embleton and Jones, 1959; Swan, 1971) has been discussed at some length.

Diagnostic techniques and services for the analysis of soil and tissue have been developed which have proven quite reliable and accurate and are now widely used in forestry, particularly in the diagnosis of nutrient deficiencies. One of the first and continuing uses of these techniques is in connection with the control of nursery stock quality through fertilization. Armson (1960; 1966) has studied and perfected a monitoring system of sampling and analysis for quality control in Ontario's Provincial Forest Nurseries.

Foliar analysis may well become one of the most convenient and accurate indicators of the nutrient status of plants (Swan, 1970). The correct interpretation of these analyses in terms of the intricate relationships between the nutrients available, plant growth and the concentration of the elements in the various tissues requires considerable study for at least the most economically valuable forest tree species (Swan, 1971).

Considerable work has been done in recent years on the problems of where to sample, which trees to sample and when to sample (Lowry, 1968; Lowry and Avard, 1968, 1969; Swan, 1970; Lavender and Carmichael, 1966).

The spruce species, being the most valuable of the Boreal Forest species, have commanded a considerable amount of attention in terms of their nutritional requirements.

Norway spruce (Picea abies (L.) Karst.), the major European spruce species, has been studied extensively in nutrient solutions (Ingestad, 1959) and sand cultures (Giertych, 1970) to determine "optimum" concentrations of the several essential elements. Sand culture experiments with North American Boreal spruces and Jack pine conducted by Swan (1970, 1971) have provided suggested standards for the evaluation of the results of foliar analysis for white, red and black spruce and Jack pine. Ingestad (1959, 1962) in particular has provided similiar standards for Norway spruce.

The North American spruces described appear to be provide with "optimum" levels of nitrogen for "good to very good growth" with concentrations between 1.50 and 2.80 % of dry weight (Table I).

Phosphorus concentrations in white, red, black and Norway spruce are very similar and range from .18 to .32 % of dry weight while potassium levels differ slightly ranging from .40 to 1.10 %. Calcium and magnesium requirements are also similar and range from .13 to .40 % and .08 to .25 % respectively.

Norway spruce appears to have somewhat higher requirements than the North American spruces for nitrogen and potassium (2.40 to 3.00 % and .90 to 1.60 % respectively), similar requirements for phosphorus and magnesium (.15 to .40 % and .12 to .18 %) but lower requirements for calcium (.04 to .30 %).

It should be noted that the above nutrient concentrations are for foliage only, while those in the text of this paper are for the tissue of the entire plant. The later values will be somewhat lower since roots and stems do not normally concentrate as high quantities of these elements as do needles.

The question of genetic control of nutrient uptake from various soils has been studied to some extent. Some authors suggest that the nutrient content of plant tissue is simply a function of the supply available in the root zone (Wells and Metz, 1963: Spurr, 1964), while others feel

TABLE I: OPTIMUM CONCENTRATION OF ELEMENTS IN THE FOLIAGE OF FOUR SPRUCE SPECIES (% DRY WEIGHT)

Species	Nutrient Elements				
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Norway spruce *	2.40 - 3.00	0.15 - 0.40	0.90 - 1.60	0.04 - 0.30	0.12 - 0.18
White spruce **	1.50 - 2.50	0.18 - 0.32	0.45 - 0.80	0.15 - 0.40	0.10 - 0.20
Red spruce **	0.60 - 2.80	0.18 - 0.28	0.40 - 1.10	0.12 - 0.30	0.08 - 0.17
Black spruce ***	1.50 - 2.50	0.18 - 0.30	0.40 - 0.80	0.15 - 0.40	0.12 - 0.25

* Ingestad, 1962

** Swan, 1971

*** Swan, 1970

that it is a species characteristic and that each species will pick up its particular requirements from the soil (Jenkinson, 1967; Bard, 1945; Phares, 1964).

MATERIAL AND METHODS

Seeds

White spruce seed was obtained from ten locations in Ontario and Quebec (Table II) (Figure 1). Seed weights and germination were determined at the time the cones were processed. The contents of the elements nitrogen, phosphorus, potassium, calcium and magnesium in the seed were determined for each provenance using the standard plant tissue analysis methods of the Soils Department, Oregon State University. (Dickenson, 1964).

Soil

An acid and a basic soil were required on which to grow the ten provenances. It was decided to obtain one of the soils from under one of the parent seed source trees and attempt to duplicate it as closely as possible with a basic soil of similar texture. Thus the acid soil was obtained from under the parent of provenance #2465 (Thessalon, Ontario). The basic soil was obtained from an abandoned agricultural field near New Hamburg, Ontario, based on information published in the Waterloo County Soil Survey (Anonymous, 1939). The soils were subjected to routine analysis by the University of Guelph Soil Testing Laboratory prior to the growth period to confirm the pH values.

The required amount of soil of the two types was

TABLE II: ORIGIN OF THE TEN WHITE SPRUCE PROVENANCES

Source	Place Name	Latitude	Longitude	Elevation
		Location		
From dolomitic limestone soil origin				
2438	Peterborough, Ont.	44°20'N	78°20'W	850'
2439	Southampton, Ont.	44°34'N	81°20'W	600'
2440	Napanee, Ont.	44°08'N	77°03'W	300'
2441	Cardinal, Ont.	44°41'N	75°28'W	290'
2442	Winchester, Ont.	45°07'N	75°21'W	250'
From granitic soil origin				
2460	Maynooth, Ont.	45°14'N	77°53'W	1,295'
2461	Sundridge, Ont.	45°33'N	79°30'W	1,150'
2465	Thessalon, Ont.	46°16'N	83°34'W	7-800'
2467	Miller Lake, Ont.	45°02'N	81°22'W	6-700'
2469	Aylmer Lake, P.Q.	46°59'N	71°22'W	1,000'

Figure 1: Location of Ten White Spruce Provenances from Ontario and Quebec

collected from the A horizon of the profiles, excluding the duff, humus and upper grass root zones.

The soils were not treated in any way prior to placement in the specially prepared wooden growth boxes (Figures 2 and 3). Each box measured 60 centimeters by 30 centimeters by 13 centimeters deep, inside dimensions, and contained approximately 20 liters of soil with an adequate allowance for watering space at the top of the box.

Soil samples were taken from the six boxes at the time of harvesting the required seedlings. An analysis of the soil was conducted to determine the exchangeable cations of potassium, calcium and magnesium and the total available phosphorus. No determination was made for nitrogen.

Seed Treatment

The seed of the ten provenances was stratified as recommended (U.S.D.A., 1948) by putting a number of seeds on wet paper towels, rolling them up and placing them in a standard refrigerator at approximately 3^{0}C. When stratification was completed the seeds were removed and placed in Petri dishes to germinate. The filter paper was wetted with de-mineralized water which contained N-trichloromethylmercapto-4-cyclohexene-1,2-carboximide (Captan) to discourage damping-off disease.

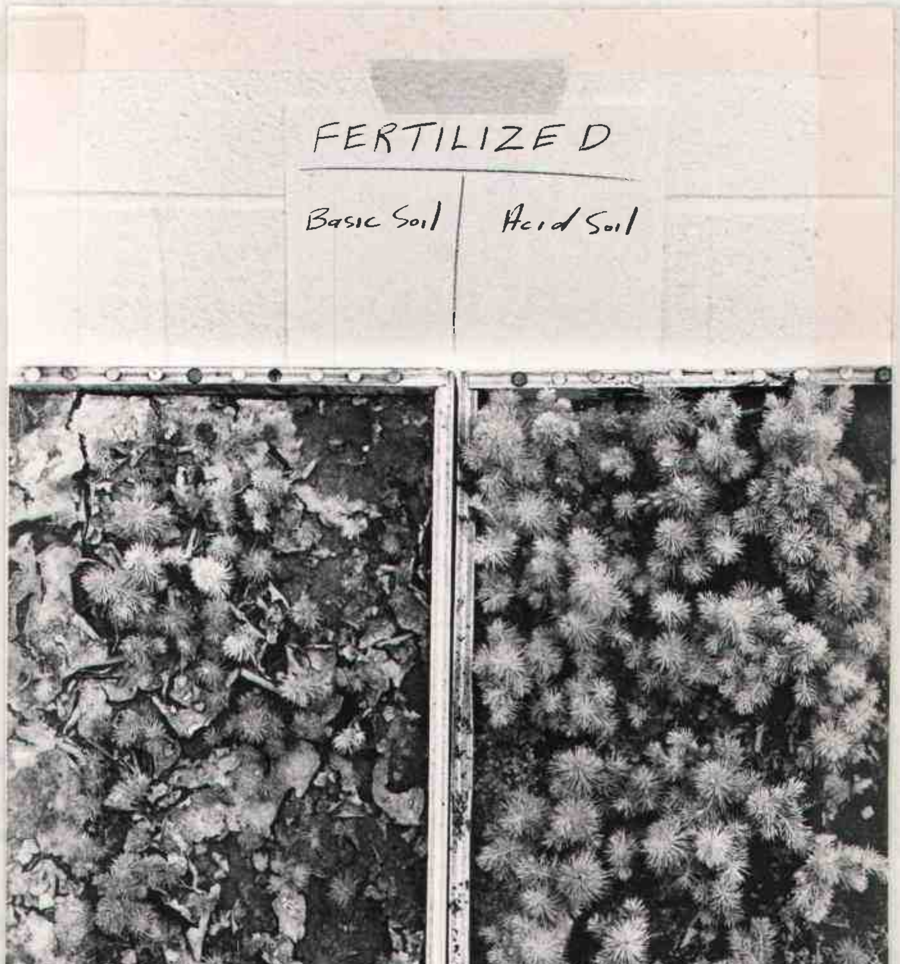
Figure 2: Ten White Spruce Provenances Growing on Two Soils (Acid and Basic) in a Split-plot Design Experiment

Left - Plot 2
Unfertilized
Left-Basic Right-Acid

Right - Plot 3
Fertilized
Left-Basic Right-Acid

Centre - Plot 1
Unfertilized
Left-Basic Right-Acid

Figure 3: Representitive Split-plot (Plot #3) with Ten White Spruce Provenances Growing on an Acid (right) and Basic (left) Soil at the Time of Harvest


FERTILIZED
Basic Soil
Acid Soil

After a germination period of ten days the seedlings were ready for planting in the prepared boxes of soil. It was evident at this time from observations of the Petri dishes that germination was not uniform among the ten provenances. The strongest germinants available were selected for transfer to the soil growth boxes.

Plantation

Three boxes of each soil, six in all, were sufficient to grow the germinants of the ten provenances on each of the two soils in three plots in a split-plot design (Cochran and Cox, 1957). The provenances were randomly assigned to each of the six soil boxes and the available germinants were planted in ten rows in sufficient numbers to assure a uniform stand of seedlings. Since the germination of three sources was poor, unstratified seed of these three provenances was added to the appropriate rows in an attempt to provide an adequate stand of harvestable tissue.

On two occasions through the 40 week growth period of the plantation the seedlings were thinned to allow adequate space for root and top development.

For the first five weeks of growth the plantation was watered with de-mineralized water with Captan added to discourage the establishment of disease, particularly damping-off. One split-plot was also treated with a complete soluble fertilizer[1] disolved in de-mineralized water, providing an apparently ample supply of the nutrients required by white spruce. The fertilizer treatment was continued at bi-weekly intervals for the entire growth period.

The remaining two split-plots were treated thereafter only with de-mineralized water. The water was applied to all three plots when the soil surface appeared dry, usually twice weekly.

Growth Conditions

The soil boxes were paired and placed in a controlled environment growth room where growth conditions were strictly regulated (Stoskopf et al, 1970).

The light source was provided by high intensity cool white fluorescent tubes, supplemented by incandescent bulbs. The light intensity at the soil surface was 8.5 milli-watts per cm^2 (approximately 25,000 lx), mostly in the 400 - 700 millimicron range. The photoperiod was timer controlled with a 16 hour light period and an eight hour dark period.

The temperature was also automatically controlled at 26.5°C during the light period and 22°C during the dark period. Humidity was automatically maintained at 70% at all times. The photoperiod and temperature provided are not necessarily those considered optimum for white spruce,

(1) C.I.L. Plant Grower (All soluble, concentrated) Analysis: N - 15%, P_2O_5 - 30%, K_2O - 15%, plus trace elements Mn, Zn, Cu, and Mb.

but were dictated by the major use of the growth room which was the production of experimental agricultural plants.

Harvest and Tissue Analysis

The seedlings were harvested as carefully as possible to minimize the loss of the small roots which had penetrated to and spread across the bottom of the growth boxes. The harvested tissue was washed, allowed to air dry and placed in clear plastic bags marked with tack colour, soil and plot number, for transport to the laboratory.

Survival rate, plant height and weight, root length or other measurements were not taken as they were not to be considered in the original experiment. Comments will be made concerning some of these values later in the text, however, based on some obvious differences as revealed in photographs (Figure 4,5 and 6) taken at the time of harvest.

The 59 harvested samples (one provided insufficient material for analysis) were allowed to air dry in the plastic bags, with the tops open wide. Prior to grinding the contents of the bags were further oven dried at 70^{o}C for four hours. Except for four samples from provenance #2438, all available plant material from each plot was ground in a Wiley laboratory mill in preparation for tissue analysis. A portion of the remaining four samples was also completely ground. Surplus material from these four samples was separated into roots and tops and ground individually.

The content, as a % of dry weight, of nitrogen,

Figure 4: Representative Seedlings of Ten White Spruce Provenances from Plot #1

Key

Symbol	Provenance No.	Location
Provenance from dolomitic limestone origin		
Pk	2438	Peterborough, Ont.
Gr	2439	Southampton, Ont.
Br	2440	Napanee, Ont.
G	2441	Cardinal, Ont.
Rd	2442	Winchester, Ont.
Provenances from granitic (acid) origin		
S	2460	Maynooth, Ont.
Bl	2461	Sundridge, Ont.
W	2465	Thessalon, Ont.
Bk	2467	Miller Lake, Ont.
Y	2469	Aylmer Lake, P.Q.

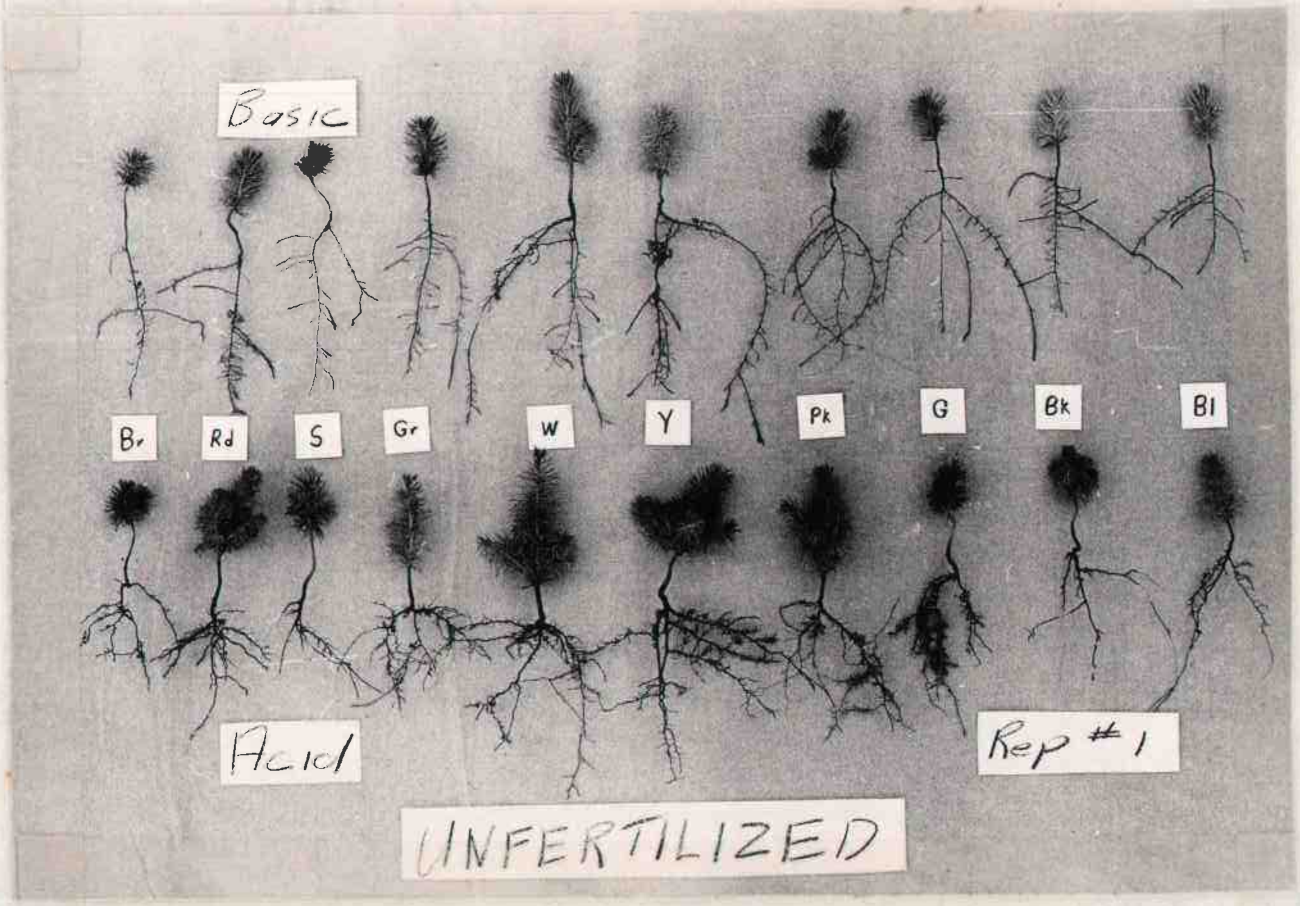

Basic
Br
Rd
S
Gr
W
Y
Pk
G
Bk
Bl
Acid
Rep #1
UNFERTILIZED

Figure 5: Representative Seedlings of Ten White Spruce Provenances from Plot #2

Key

Symbol	Provenance No.	Location
Provenances from dolomitic limestone origin		
Pk	2438	Peterborough, Ont.
Gr	2439	Southampton, Ont.
Br	2440	Napanee, Ont.
G	2441	Cardinal, Ont.
Rd	2442	Winchester, Ont.
Provenances from granitic (acid) origin		
S	2460	Maynooth, Ont.
Bl	2461	Sundridge, Ont.
W	2465	Thessalon, Ont.
Bk	2467	Miller Lake, Ont.
Y	2469	Aylmer Lake, P.Q.

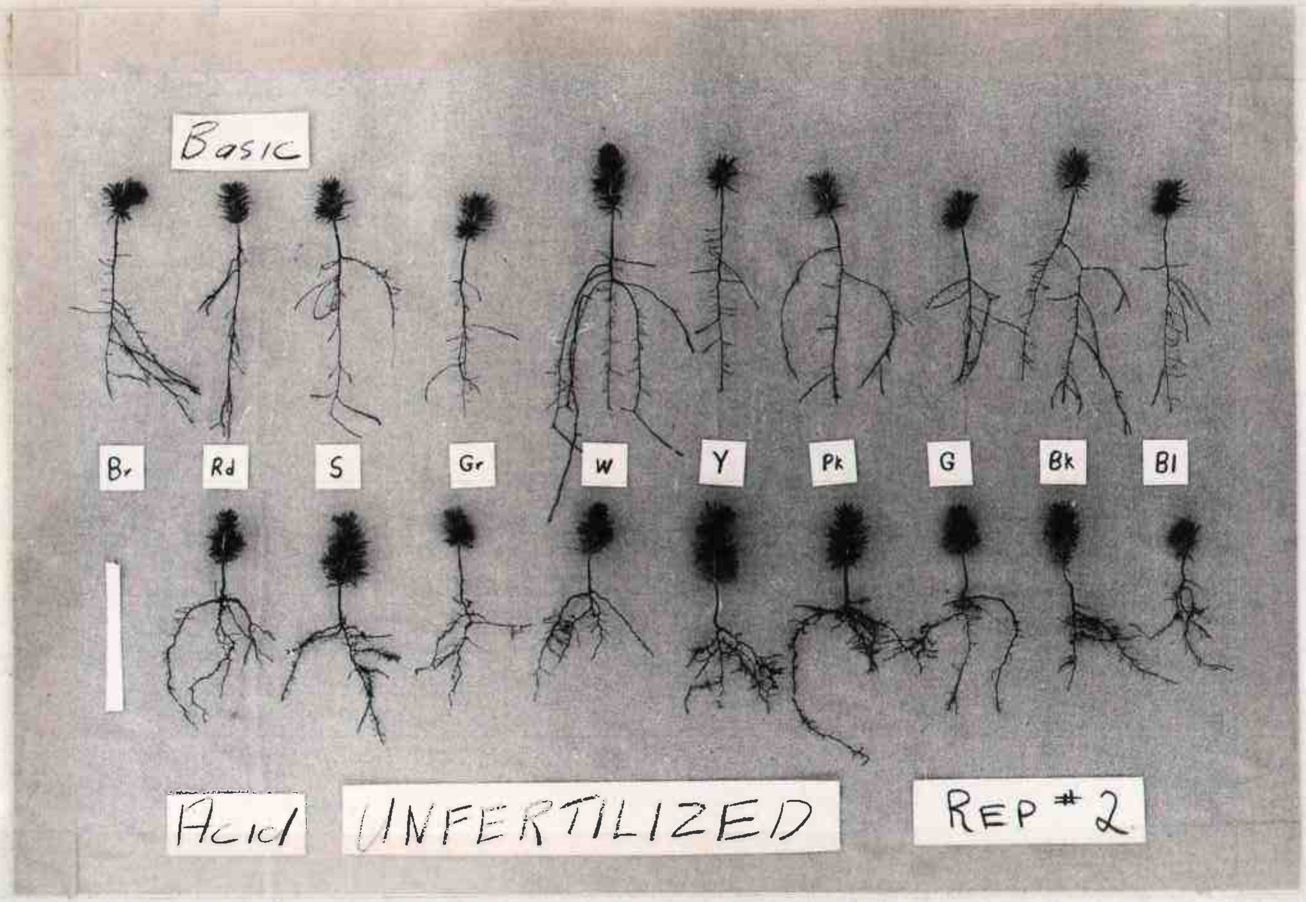
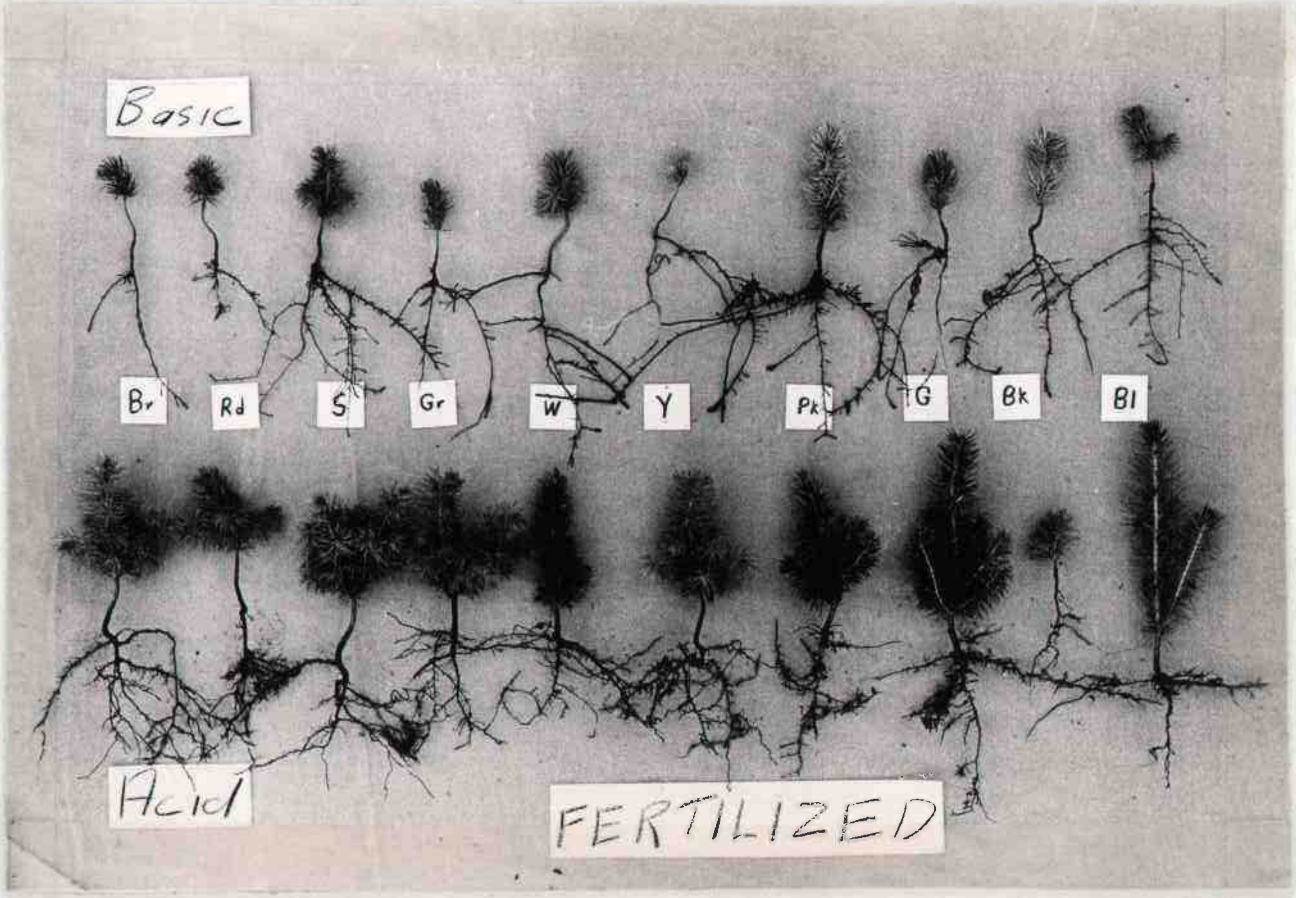

Basic
Br
Rd
S
Gr
W
Y
Pk
G
Bk
Bl
Acid
UNFERTILIZED
REP #2

Figure 6: Representative Seedlings of Ten White Spruce Provenances from Plot #3

Key

Symbol	Provenance No.	Location
Provenances from dolomitic limestone origin		
Pk	2438	Peterborough, Ont.
Gr	2439	Southampton, Ont.
Br	2440	Napanee, Ont.
G	2441	Cardinal, Ont.
Rd	2442	Winchester, Ont.
Provenances from granitic (acid) origin		
S	2460	Maynooth, Ont.
Bl	2461	Sundridge, Ont.
W	2465	Thessalon, Ont.
Bk	2467	Miller Lake, Ont.
Y	2469	Aylmer Lake, Ont.


Basic
Br
Rd
S
Gr
W
Y
Pk
G
Bk
Bl
Acid
FERTILIZED

phosphorus, potassium, calcium and magnesium was determined.

Tissue nitrogen was determined using the standard micro-Kjeldahl procedure (Cole and Parks, 1946). For phosphorus, potassium, calcium and magnesium, weighed tissue samples were dry ashed in a muffle furnace and the resultant ash brought into solution with dilute hydrochloric acid. Phosphorus was determined using the phospho-molybdate colorametric method and potassium, calcium and magnesium were determined using a Beckman model DU flame spectrophotometer. Calcium and magnesium values were later checked with a new atomic absorption system and found to be within acceptable limits.

Soil Analysis

Nitrogen was not determined. Available phosphorus was estimated colorametrically using the Bray and Kurtz (1945) dilute acid and ammonium fluoride extraction procedure. Potassium, calcium and magnesium were extracted with one Normal neutral ammonium acetate and exchangeable cations were determined with the Beckman model DU flame spectrophotometer.

Soil pH was measured in a one to five ratio soil/ water mixture. The methods of soil and tissue analysis used are the standard procedures of the Forest Soils Laboratory, Faculty of Forestry, University of Toronto.

Statistics

The plant tissue crop from one plot of provenance

#2440 was insufficient for tissue analysis. Thus for statistical analysis purposes the missing data procedure described by Steele and Torrie (1960) was used to fill the blanks. One figure for each of nitrogen, phosphorus, potassium, calcium and magnesium was calculated and inserted into the tissue nutrient content data.

Only the data provided by the nutrient analysis of the tissue were subjected to an analysis of variance of the split-plot type using the computer at the University of Guelph (Appendix 1).

A linear regression was calculated for the seed weight-germination relationship.

RESULTS

Seed Analysis

The average weight of the seed of the limestone provenances is considerably higher at 233 milligrams per 100 seed than that of the granitic provenances at 214 milligrams per 100 seeds. However, eliminating the very light seeded source #2465, the average weight of the four remaining granitic provenances is 230 milligrams per 100 seeds. The average germination of the granitic types at 80% is substantially higher than that of the limestone types at 65% (Table III).

Seed of two of the limestone origin provenances showed very poor germination (#2442 at 46% and #2440 at 53%).

The average content of nitrogen, phosphorus, potassium and magnesium in the seed of the limestone and granitic provenances are very similar. The average calcium content in the limestone provenances is almost double that of the granitic provenances (Table III). The largest variation appears in the three sources #2440, 2441 and 2442, with #2438 just slightly higher.

Soil Analysis

pH - The average pH of the two unfertilized acid soil plots was 6.68 (Table IV). The pH of the fertilized acid plot dropped through the growth period to 6.35.

The pH of the three basic plots was essentially the

TABLE III: CHARACTERISTICS OF THE SEED OF TEN WHITE SPRUCE PROVENANCES

Provenance	Seed Weight (100 seeds) (mg)	% Germination	Nutrient (% dry weight) Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
From dolomitic limestone soil origin							
2438	273	77	3.84	0.89	0.42	0.048	0.41
2439	241	76	3.97	0.86	0.42	0.038	0.43
2440	198	53	3.79	0.82	0.34	0.143	0.41
2441	224	71	4.09	0.81	0.32	0.057	0.33
2442	230	46	3.80	0.77	0.32	0.102	0.38
From granitic soil origin							
2460	245	93	3.92	0.83	0.32	0.039	0.36
2461	232	86	3.81	0.85	0.44	0.035	0.38
2465	149	68	4.21	0.87	0.32	0.047	0.36
2467	218	79	4.04	0.85	0.42	0.036	0.39
2469	226	74	4.22	0.76	0.35	0.040	0.34

TABLE IV: CHARACTERISTICS OF THE SOILS AFTER THE GROWTH PERIOD

Plot	Soil	Condition	pH	Exchange Cations (meq./100g.) Potassium	Calcium	Magnesium	Available Phosphorus (mg/100g.)
1	Acid	U	6.65	0.17	4.08	1.47	2.47
2	Acid	U	6.72	0.13	3.94	1.50	3.19
3	Acid	F	6.35	0.38	4.39	1.68	11.97
1	Basic	U	8.25	0.08	20.21	2.41	0.09
2	Basic	U	8.32	0.06	17.71	1.94	0.22
3	Basic	F	8.22	0.30	21.71	2.87	14.44

U - unfertilized

F - fertilized

same, averaging 8.26.

Phosphorus - The total available phosphorus was very low in the unfertilized basic soil averaging .15 milligrams per 100 grams of soil compared to an average of 2.83 milligrams per 100 grams in the unfertilized acid soil. The available phosphorus in the two fertilized plots was substantially increased from the unfertilized plots to 11.97 and 14.44 milligrams per 100 grams for the acid and basic soils respectively.

Potassium - The exchangeable potassium in the unfertilized basic soil was also very low averaging 0.07 milliequivalents per 100 grams of soil. The fertilized acid soil shows double the exchangeable potassium of the unfertilized acid soil. The fertilized basic soil shows four times the quantity of the unfertilized basic soil.

Magnesium - Magnesium averaged 1.48 milliequivalents per 100 grams of soil in the unfertilized acid soil and 1.68 milliequivalents per 100 grams in the fertilized acid soil. In the basic unfertilized soil there was an average of 2.17 milliequivalents per 100 grams and 2.87 milliequivalents per 100 grams in the fertilized basic soil.

The soluble fertilizer used in the watering operations did not contain magnesium.

Calcium - The greatest difference in the nutrient content of the two soils was in the exchangeable content of calcium. The unfertilized acid soil averaged 4.01 milliequivalents per 100 grams while the fertilized acid soil was slightly higher at 4.39 milliequivalents per 100 grams.

The analysis revealed an extremely high exchangeable content of calcium in the basic soil, averaging 19.46 milliequivalents per 100 grams in the unfertilized plots and 21.71 milliequivalents per 100 grams in the fertilized plot.

Again, the fertilizer used did not contain calcium.

Tissue Analysis

Nitrogen - The analysis of variance reveals no significant differences in the concentrations of nitrogen in the plant tissue either due to fertilization, soil, seed source or tree type.

Phosphorus - There were significant differences between the fertilized and unfertilized plots ($P > 1\%$) and between the soils ($P > 5\%$) in the concentrations of phosphorus (Table V).

The plants grown on acid unfertilized soil contained 50% more phosphorus than those grown on the basic unfertilized soil. When fertilizer was added the differential between the acid and basic soil was reduced to about 30%.

The increased concentrations of phosphorus in the tissue grown on the basic soil with the application of the high phosphorus analysis fertilizer was about 100%.

The increased concentrations of phosphorus with fertilization in the tissue grown on the acid soil was somewhat less pronounced, increasing approximately 68%.

TABLE V: PHOSPHORUS CONTENT IN THE TISSUE OF TEN WHITE SPRUCE PROVENANCES (% DRY WEIGHT)

SOIL	PLOT 1 (unfertilized)	2 (unfertilized)	3 (fertilized)	Mean **
Acid	0.080	0.072	0.128	0.093
Basic	0.053	0.044	0.100	0.066
Mean*	0.066	0.058	0.114	

* Difference between plots is significant at 1% level

** Difference between soils is significant at 5% level

Potassium - The largest number of significant differences appeared in the analysis of variance for potassium. There were differences between the unfertilized and fertilized plots, between the two soils and in the interactions of tree type X soils and seed source X soils. The potassium concentrations in the ten provenances on unfertilized and fertilized soils is shown graphically in Figures 7 and 8.

The potassium concentration is significantly higher (42%) in the tissue grown on the acid soil ($P > 1\%$)(Table VI). When fertilizer was added the differential between acid and basic soils was reduced to 23%.

The increased concentration with the application of fertilizer from unfertilized to fertilized basic soil plots was 70%. The increase with fertilizer on the acid soil from unfertilized to fertilized plots was somewhat less at 48%.

The tree type X soil interaction ($P > 1\%$) reveals that the five basic tree types concentrate more potassium in their tissue than do the five acid tree types on basic soil, but that the acid tree types concentrate more potassium than these same basic tree types on acid soil(Figure 9).

The soil X seed source interaction also significantly affects potassium concentration ($P > 5\%$). The soil X tree type interaction, however, accounts for most of the variability.

Calcium - Calcium concentrations in the tissue are not affected by the application of fertilizer, when the plants

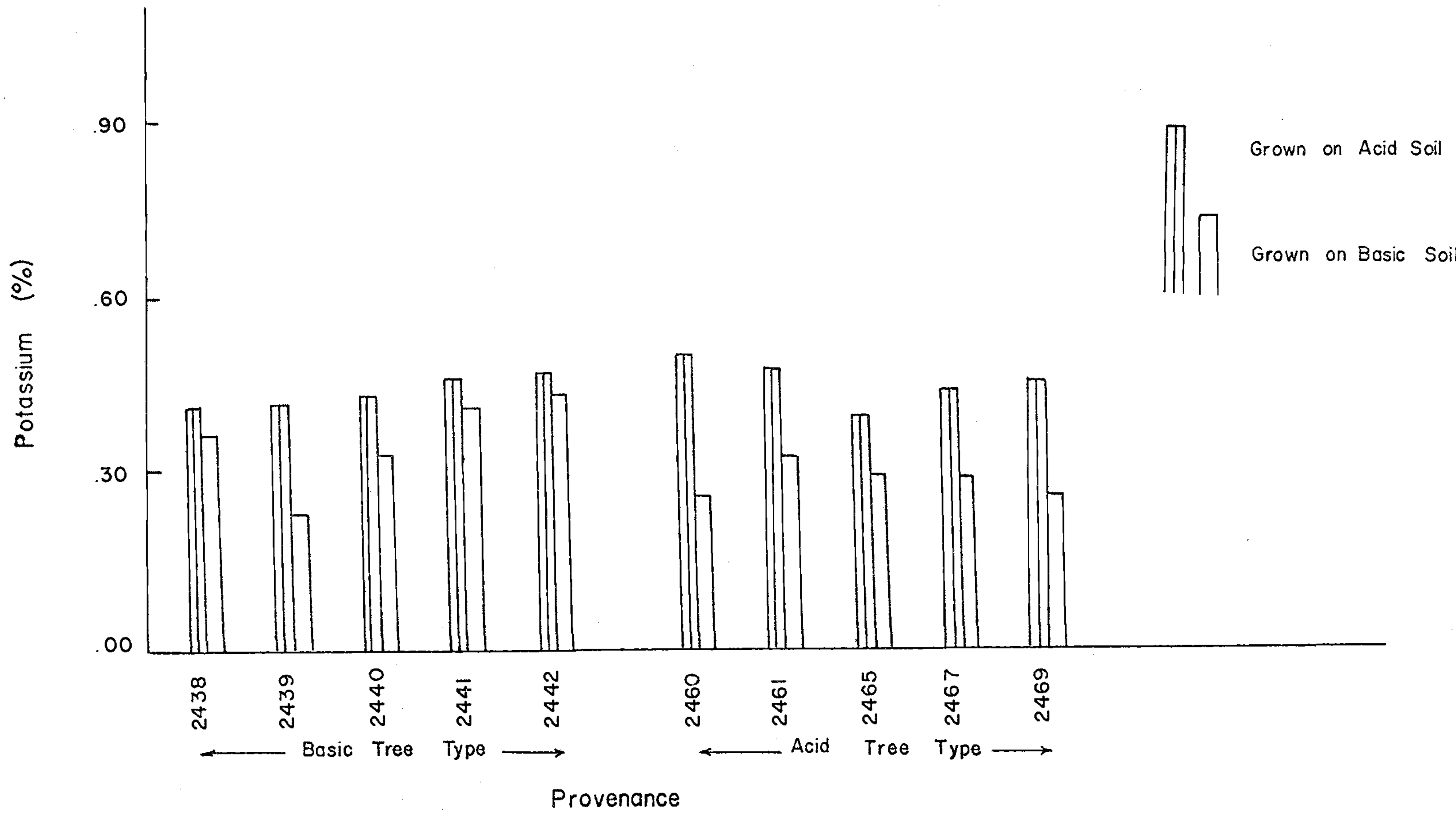


Figure 7: Content of Potassium in the Tissue of Ten White Spruce Provenances From the Unfertilized Plots (% Dry Matter)

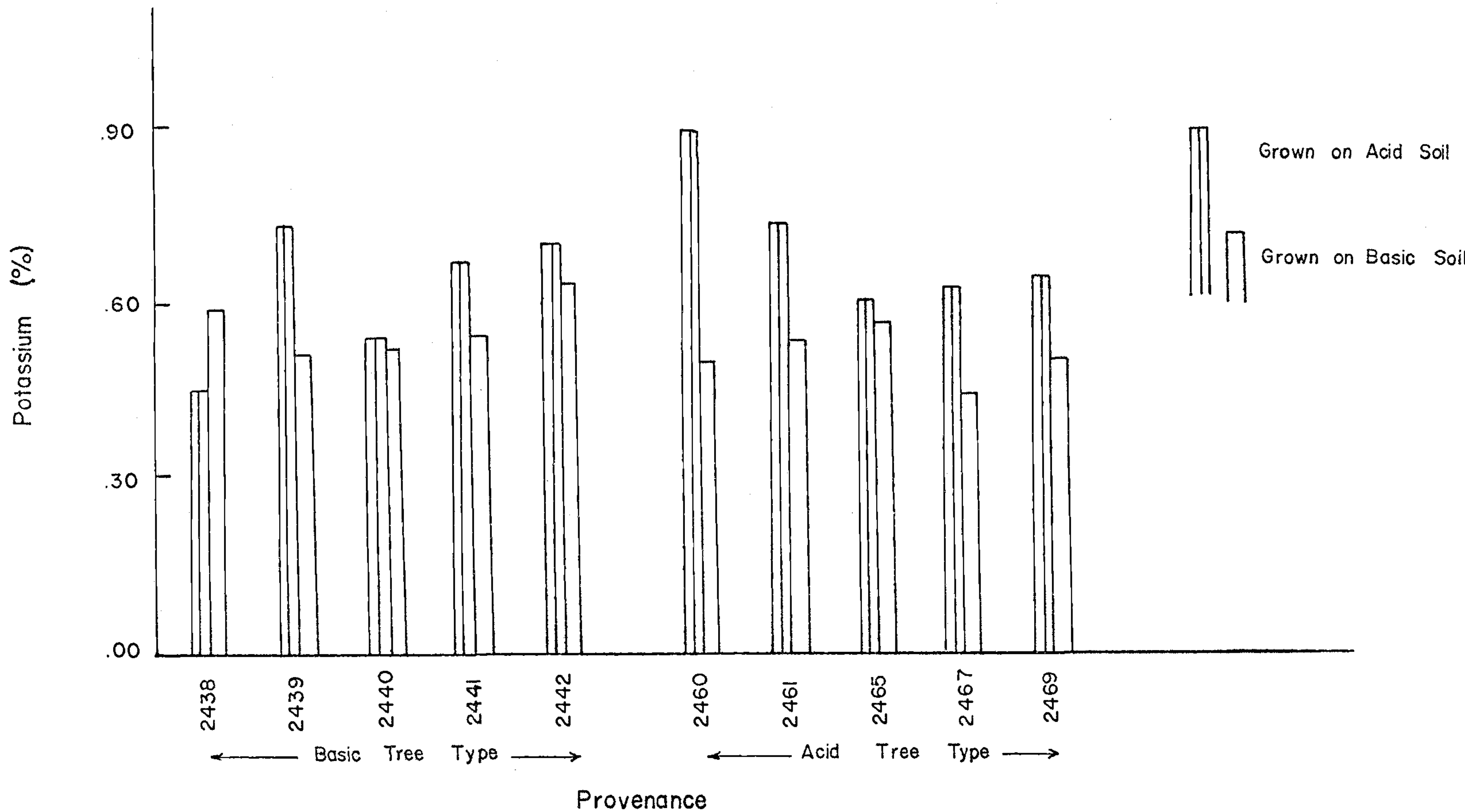


Figure 8: Content of Potassium in the Tissue of Ten White Spruce Provenances From the Fertilized Plot (% Dry Matter)

TABLE VI: POTASSIUM CONTENT IN THE TISSUE OF TEN WHITE SPRUCE PROVENANCES (% DRY WEIGHT)

SOIL	PLOT			
	1 (unfertilized)	2 (unfertilized)	3 (fertilized)	Mean*
Acid	0.436	0.466	0.667	0.520
Basic	0.288	0.348	0.541	0.392
Mean *	0.362	0.402	0.604	

* Difference between plots is significant at 1% level

** Difference between soils is significant at 5% level

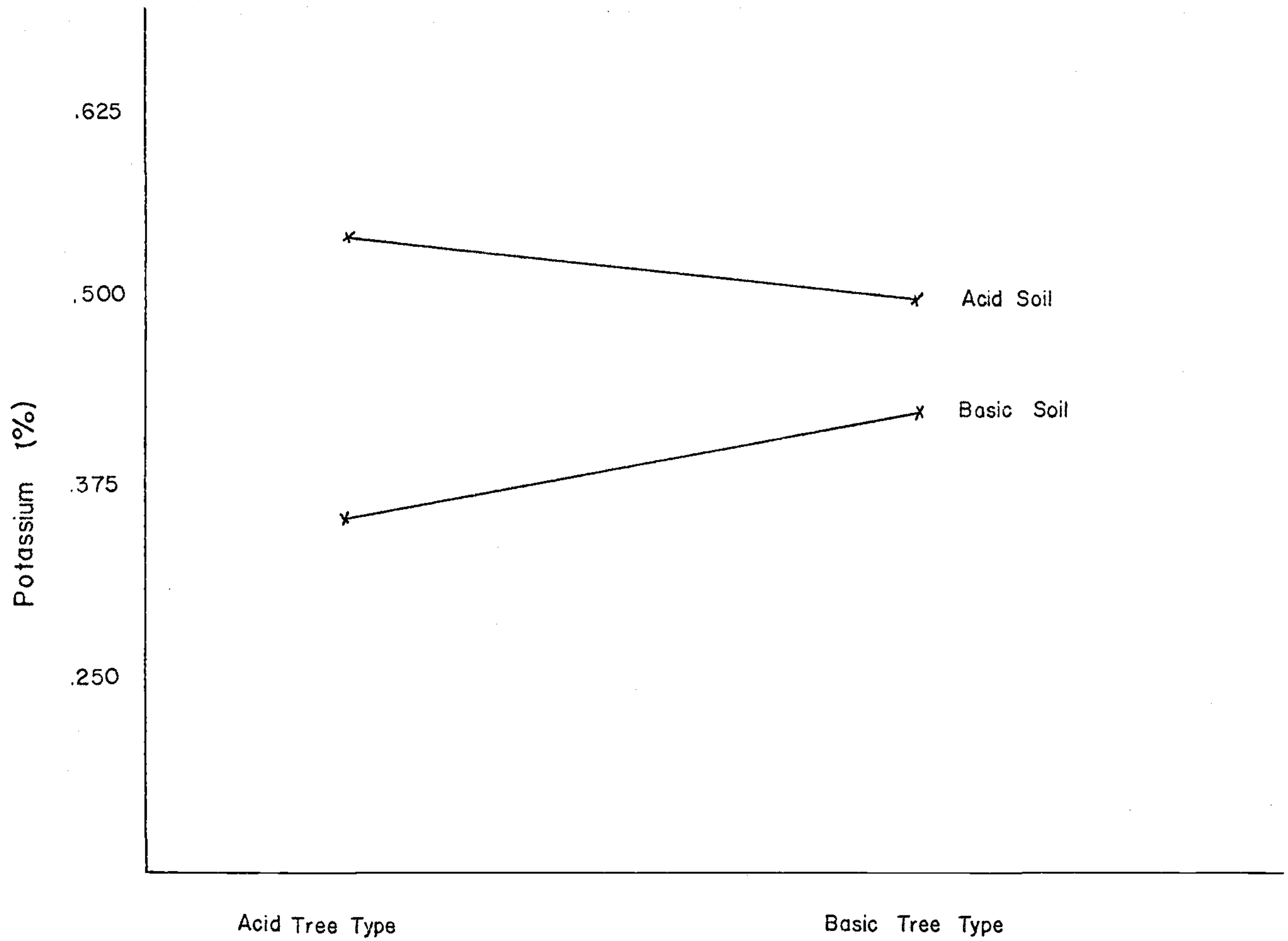


Figure 9: Uptake Response to Potassium of Two White Spruce Tree Types Grown on an Acid and a Basic Soil

are grown on either the acid or basic soil (Table VII). The concentrations of this element are significantly different ($P > 5\%$), however, in tissue grown on the two soils. Magnesium - There was no significant effect of fertilizer on the tissue concentrations of magnesium. The difference in concentration of this element was highly significant ($P > 1\%$) for the two soils, however (Table VIII).

There was also a significant difference in the mean concentration ($P > 5\%$) between the acid and basic tree types (Figure 10).

Stem and Root Analysis

Only one provenance (#2438) provided a sufficiently high quantity of tissue to separate roots and tops (above ground portion) for nutrient analysis. Of the four samples separated into parts, one came from each of the three acid soil plots and the fourth came from the fertilized basic plot.

The data provided by this analysis (Table IX) was too restricted to be considered further.

TABLE VII: CALCIUM CONTENT IN THE TISSUE OF TEN WHITE SPRUCE PROVENANCES (% DRY WEIGHT)

SOIL	PLOT 1 (unfertilized)	2 (unfertilized)	3 (fertilized)	Mean**
Acid	.364	.284	.361	.336
Basic	.763	.515	.585	.621
Mean	.563	.399	.473	

** Difference in soils is significant at 5% level

TABLE VIII: MAGNESIUM CONTENT IN THE TISSUE OF TEN WHITE SPRUCE PROVENANCES (% DRY WEIGHT)

SOIL	PLOT 1 (unfertilized)	PLOT 2 (unfertilized)	PLOT 3 (fertilized)	Mean*
Acid	.149	.144	.154	.150
Basic	.269	.245	.263	.259
Mean	.209	.196	.208	

* Difference in soils is significant at 1% level

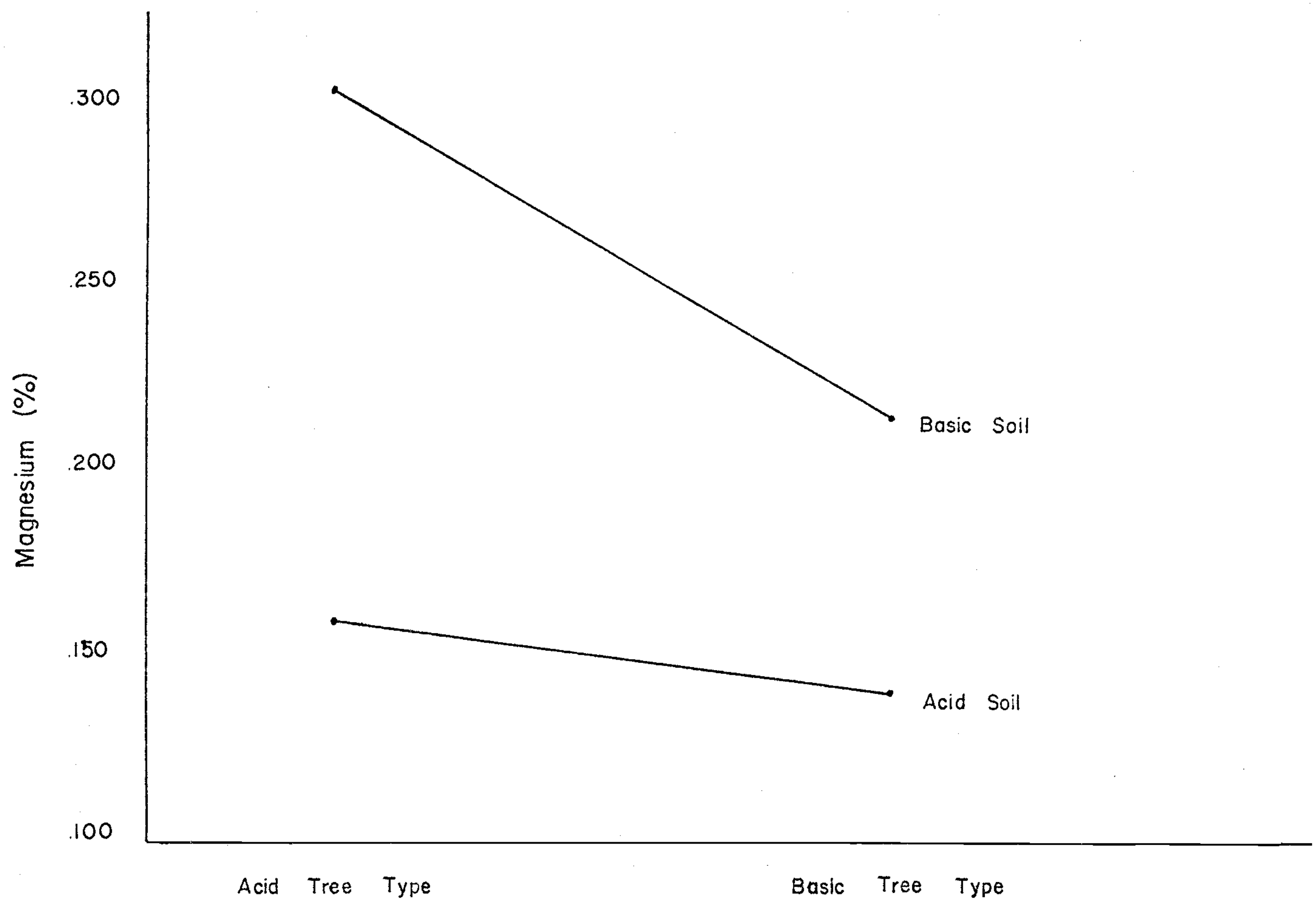


Figure 10: Uptake Response to Magnesium of Two White Spruce Tree Types Grown on an Acid and a Basic Soil

TABLE IX: NUTRIENT CONTENT OF TOP AND ROOT PORTION OF ONE WHITE SPRUCE PROVENANCE GROWN ON AN ACID AND A BASIC SOIL

	Soil	Condition	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Tops	Acid	U	0.91	.06	.44	.44	.19
	Acid	F	1.05	.05	.35	.45	.16
	Basic	F	1.06	.10	.51	.59	.25
Roots	Acid	U	1.15	.05	.12	.46	.11
	Acid	F	1.12	.10	.20	.24	.13
	Basic	F	1.50	.10	.22	1.16	.34

U - unfertilized

F - fertilized

DISCUSSION

In the process of natural regeneration the seed of white spruce, produced over the course of the previous growing season, drop to the ground and are stratified naturally over the winter months.

If conditions of soil moisture, light and temperature become favourable in the spring the new germinants will draw on the nutrients stored in the seed endosperm. The nutrient supply of the seed is a function of the soil and the inherited ability of the parent tree to utilize the available nutrients (Burger, 1972; Giertych, 1970).

When the new seedling has utilized all the nutrients incorporated in the seed from which it germinated, it must satisfy all future demands for required nutrients by absorbing these elements from the soil. Swan (1971) suggests that the external influence of nutrients becomes evident in sand culture experiments sometime after the 16th week of seedling growth.

It should be pointed out at this point that much of the work carried out to date concerning the nutrient status of forest trees, particularly the North American spruces, has been done primarily to establish "optimum" levels of the various nutrients (Swan, 1971; Lowry, 1968; Sucoff, 1962) usually with the goal of ultimately establishing fertilization standards based on foliar analysis.

The natural environment of species has not been studied extensively from the point of view of the possibilities of introducing or moving particularly efficient assimilators of the required nutrient elements to soils which are either deficient in or have excessive amounts of these elements.

Geographic variation in nutrient content of seed and tissue has been reported in Norway spruce and Scotch pine (*Pinus sylvestris* L.) (Giertych, 1970).

Seed Characteristics

The nutrient analysis of the seed of ten provenances of white spruce seed, five from basic soil origins and five from acid soil origins reveal no significant differences in the storage of the five macro-elements in terms of percent dry weight, except for calcium which was higher in three of the five basic origin provenances.

Converted to absolute quantities of the elements the average quantities of nitrogen, phosphorus, potassium and magnesium are very similar for the acid and basic provenances. Some variability creeps in, however, within the tree types. As might be expected the largest seed has the highest total content of the five elements, and the smallest seed the lowest total content. The other eight provenances, however, do not appear to fit a pattern. The total calcium content is more than double in the basic provenances (Table X).

TABLE X: TOTAL WEIGHT OF FIVE MACRO-NUTRIENT ELEMENTS IN THE SEED OF TEN WHITE SPRUCE PROVENANCES

Provenance	Weight of 100 Seeds (mg)	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
		Weight of Elements per Seed (Mg)				
From dolomitic limestone origin						
2438	273	.105	.024	.011	.0013	.011
2439	241	.072	.021	.010	.0009	.010
2440	198	.075	.016	.007	.0028	.008
2441	224	.092	.018	.007	.0013	.007
2442	230	.087	.018	.007	.0023	.009
From granitic (acid) origin						
2460	245	.096	.020	.008	.0010	.009
2461	232	.088	.020	.010	.0008	.009
2465	149	.063	.013	.005	.0007	.005
2467	218	.088	.019	.009	.0008	.009
2469	226	.095	.017	.008	.0009	.008
Average basic provenance		.086	.019	.008	.0017	.009
Average acid provenance		.086	.018	.008	.0008	.008
Average all provenances		.086	.0185	.008	.0013	.0085

Provenance #2438, with the heaviest seed, produced the largest amount of tissue as evidenced by a sufficient volume to segregate roots and tops for seperate additional analysis.

Increased seed germination with greater seed weight, though not strongly correlated in this study, is normal for spruce (Figure 11).

Giertych (1970) suggests that spruce races characterized by better growth are also characterized by heavier seed, although not consistently richer in any of the macro-elements. This is believed to be caused by provenance rather than progeny differences.

It would appear that the basic soil white spruce provenances take up and store larger quantities of calcium in their seed than do acid soil white spruce provenances. It is probable, however, that this is luxury consumption based entirely on availability in the soils on which the parent trees grow.

Soil

Differences in nutrient economy are associated with vegetation, flora and fauna and micro-environment (Nanda, 1965). Among the more important of these factors to the growth of forest trees might be the presence or absence of mycorrhizae-forming fungi. Although this symbiotic relationship between tree roots and fungi is exceedingly

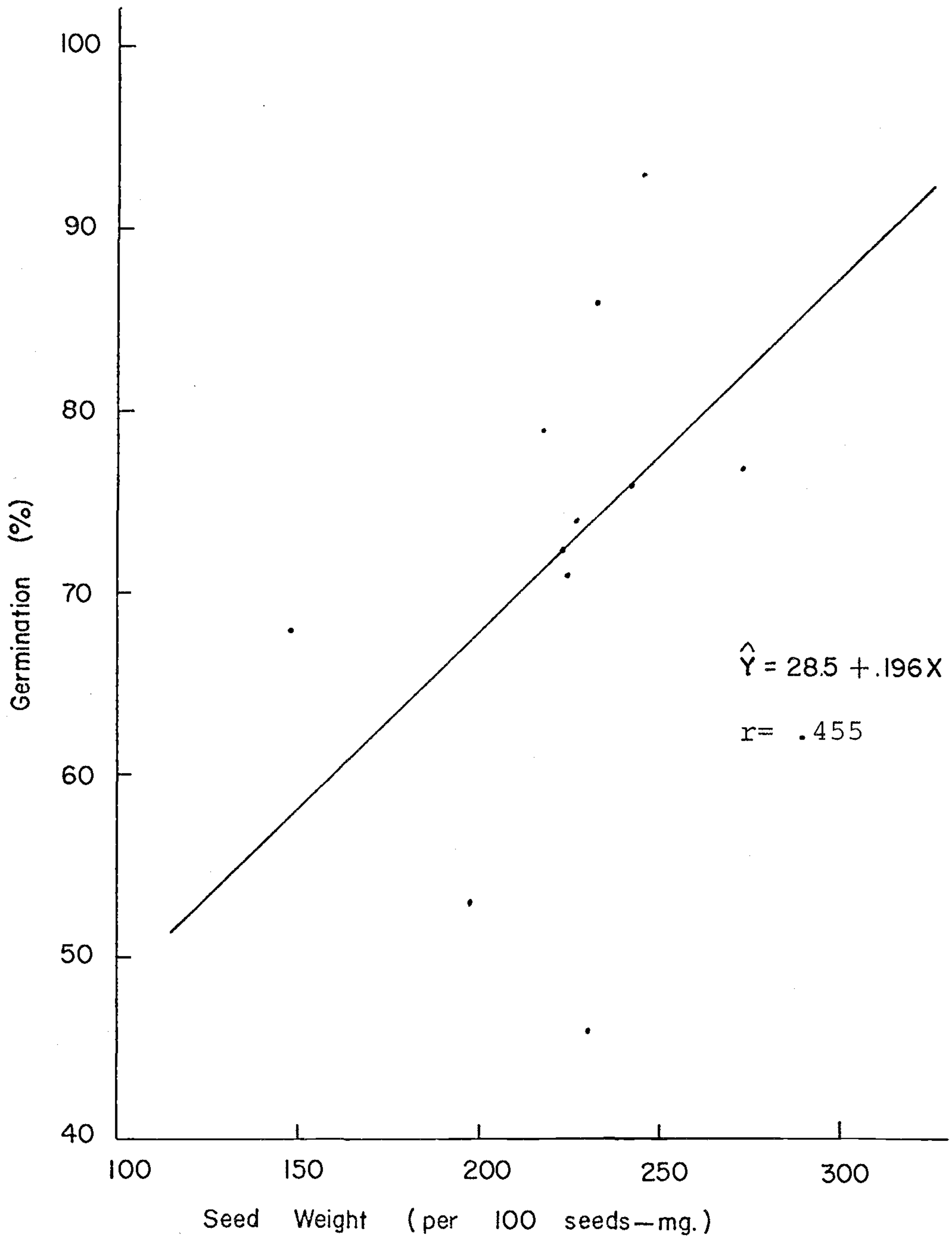


Figure 11: Correlation of Seed Weight and Germination Percent of Ten White Spruce Provenances

complex and as yet poorly understood, the importance of this factor cannot be denied.

Ingestad (1962) suggests that many workers claim mycorrhizae to be of great importance for the development of forest trees under nutrient deficiency and that his sand culture experiments may have yielded growth curves which are special cases within the sub-optimum nutrient range of Norway spruce. Hardwood seedlings grown from seed in three different soils grew much better on forest soils than on non-forest soils, mainly because of differences in soil fertility and microbiology (Phares, 1964). Jack pine seedlings grown in pot culture with various types of fertilization treatment show that only the seedlings grown in soil with humus from a healthy plantation incorporated into it developed mycorrhizae and only these were normal in growth and appearance (Spurr, 1964). Kramer and Kozolowski (1960) refer to pine seedlings growing normally on calcareous soil with pH 8.2 when mycorrhizae forming fungi were added to the soil in humus. They go on to summarize the function of these fungi in the nutrition of plants.

Reference to the photographs of the white spruce grown on the abandoned agricultural basic soil reveals a substantial effort of the plant roots to penetrate the largest possible soil area with little evidence of fine rootlets or nodules. The plants grown on the acid soil of forest origin show a fairly compact, well branched root system more characteristic of the root mass of healthy white spruce (Armson, 1960).

The root systems in the fertilized basic soil are somewhat better than those in the unfertilized basic soil in terms of numbers of rootlets and appear more compact in appearance but are far inferior to the comparable trees grown on the acid soil.

Similar to the root development, the top development on the basic soil is generally inferior to that on the acid soil. The fertilizer treatment does not improve the appearance appreciably.

With presumably adequate supplies of nitrogen, phosphorus and potassium available to all ten provenances grown on the fertilized basic soil the concentrations of these elements in the tissue was substantially lower than when grown on the fertilized acid soil. Nitrogen was slightly higher, but not significantly so.

Another possible explanation of the poor performance of the plants grown on the basic soil may be the influence of the high pH of this soil. Although white spruce is found on soils with pH values as high as 8.4, the trees growing on these soils are usually of very poor quality.

White and black spruce in Northern Ontario growing on soils with pH values over 8.0 are often only five to six feet in height and 80 to 100 years of age, with root systems which spread out over a zone of free calcium carbonate (Burger, 1972). Most authors working with the spruce species suggest soil pH values between four and five for "normal" growth.

A third possibility to explain the poor performance of the ten provenances when grown on the basic soil might be the tie up of phosphorus in the soil by magnesium and possibly calcium.

Nap (1969), in experiments with phosphorus and potassium fertilizers on a Fox series sandy loam texture soil suggests that large quantities of phosphorus added in fertilizer produces insoluble magnesium phosphate precipitates which are subsequently leached out, possibly creating magnesium deficiencies. Calcium is also known to make phosphorus less available, particularly at high pH values, producing low soluble calcium phosphates.

It seems unlikely that this has occurred in this case, however, since the tissue concentrations of phosphorus, although lower than the suggested optimum for the species (Table I) on both acid and basic soil, are not substantially lower on the fertilized basic soil than on the fertilized acid soil, with no reduction in the magnesium or calcium concentrations.

Relationship of Seed Nutrients and Tissue Nutrients

As suggested earlier the role of the seed nutrients diminishes, and perhaps disappears, after a short growth period. The quantity of the elements supplied by the seed would probably not sustain a thrifty seedling for very long. Armson (1960) reports dry weights per nursery grown white spruce seedlings of approximately 100 milligrams after about six months of growth. With a dry weight content of 2.00 % nitrogen for example, each seedling would contain approximately 2.0 milligrams of nitrogen in its tissue. The .105 milligrams of nitrogen found in the largest seed of the ten provenances in this study represents only about 5 % of the seedling total nitrogen.

Sources 2440, 2441 and 2442, which exhibit particularly high calcium contents in their seed, do not show comparably high concentrations in their tissues on either acid or basic soil, with or without fertilization.

A relationship of seed nutrients to tissue nutrients is not apparent for the other elements.

Relationship of Tissue Nutrients and Soil Nutrients

The interactions of potassium-magnesium and potassium-calcium are well known. Swans' (1971) data show that increasing concentrations of magnesium in nutrient solution and in the seedlings were associated with decreasing concentrations of potassium in the seedlings. Others have found that the concentration of potassium in the plant is reduced by adding magnesium to the soil and that in soils low in potassium this addition could lead to potassium deficiency.

A good supply of potassium intensified magnesium deficiency (Nap, 1969; Wells, 1970; Giertych, 1970) if the fertilizer applied were magnesium free. This has been explained on the grounds that the available magnesium of the soil was displaced by potassium and consequently washed out.

Similarly, high levels of calcium result in a significant decrease in the concentration of potassium (Wells, 1965). Voigt _et al_ (1958) suggest that the chlorotic appearance of Jack pine and white spruce seedlings in a forest nursery is caused by low levels of magnesium and calcium due to "antagonistic effects of potassium".

These interactions are evident in this experiment when comparing the unfertilized soils. Higher concentrations of calcium and magnesium by both tree types on the basic soil accompany lower concentrations of potassium (Figure 12 and 13).

The picture is somewhat confused when fertilizer is added, but generally the potassium concentration is higher and calcium and magnesium concentrations lower on both soils (Figure 14 and 15).

The basic tree types contained a higher percentage of potassium when grown on the basic soil than did the acid

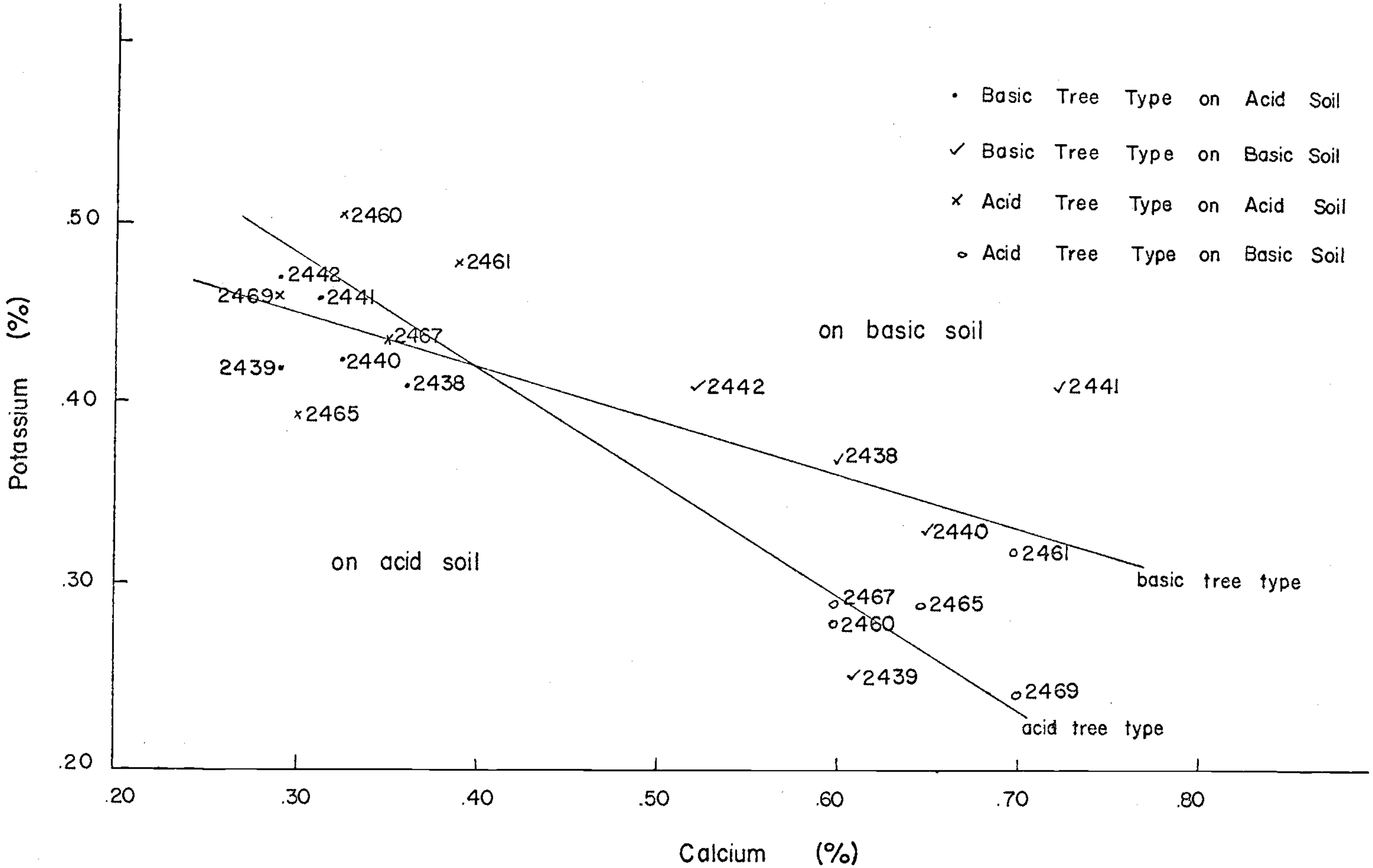


Figure 12: Potassium - Calcium Interrelationship in the Tissue of Ten White Spruce Provenances Grown on an Acid and a Basic Soil (Unfertilized)

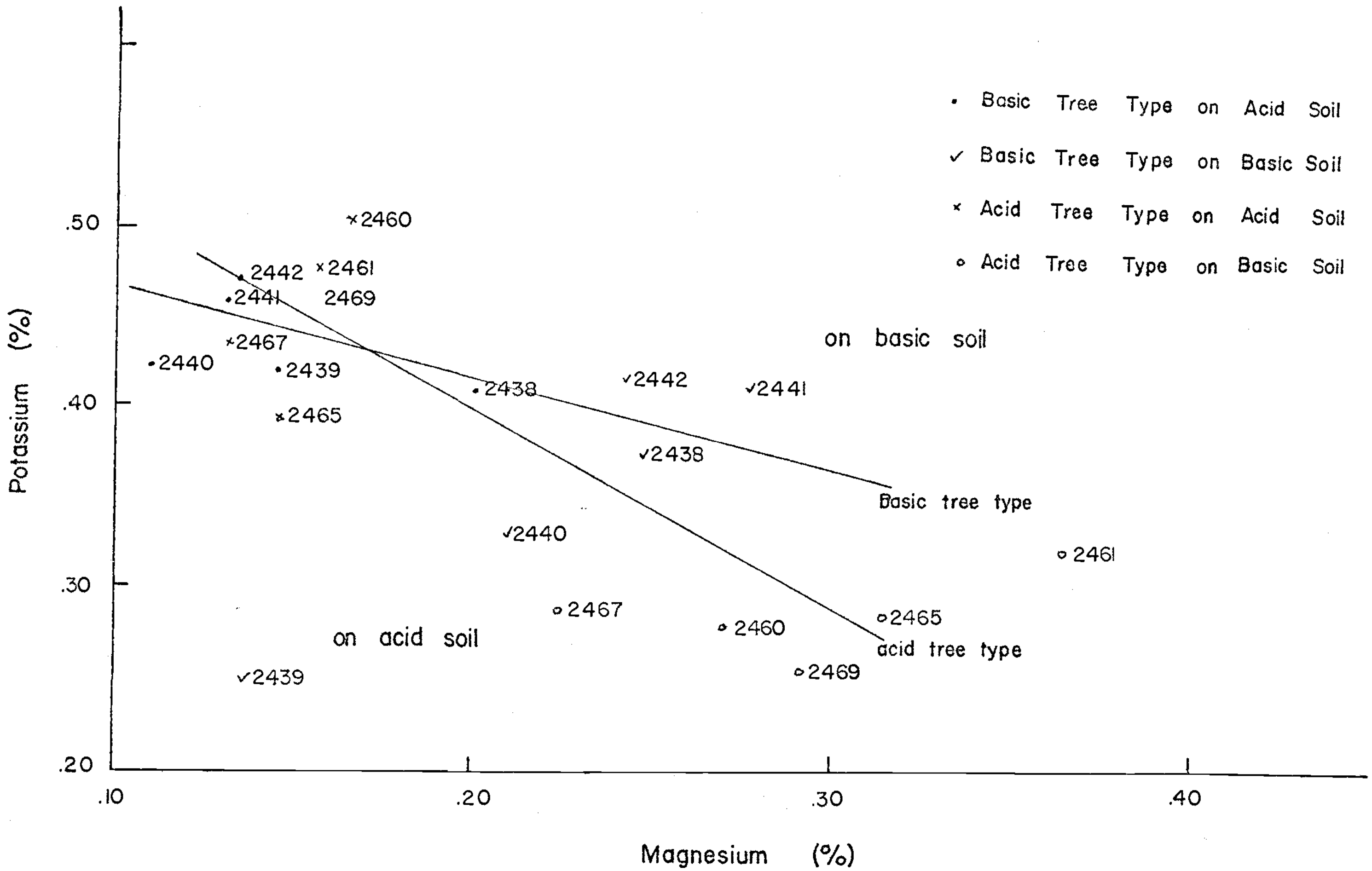


Figure 13: Potassium - Magnesium Interrelationship in the Tissue of Ten White Spruce Provenances Grown on an Acid and a Basic Soil (Unfertilized)

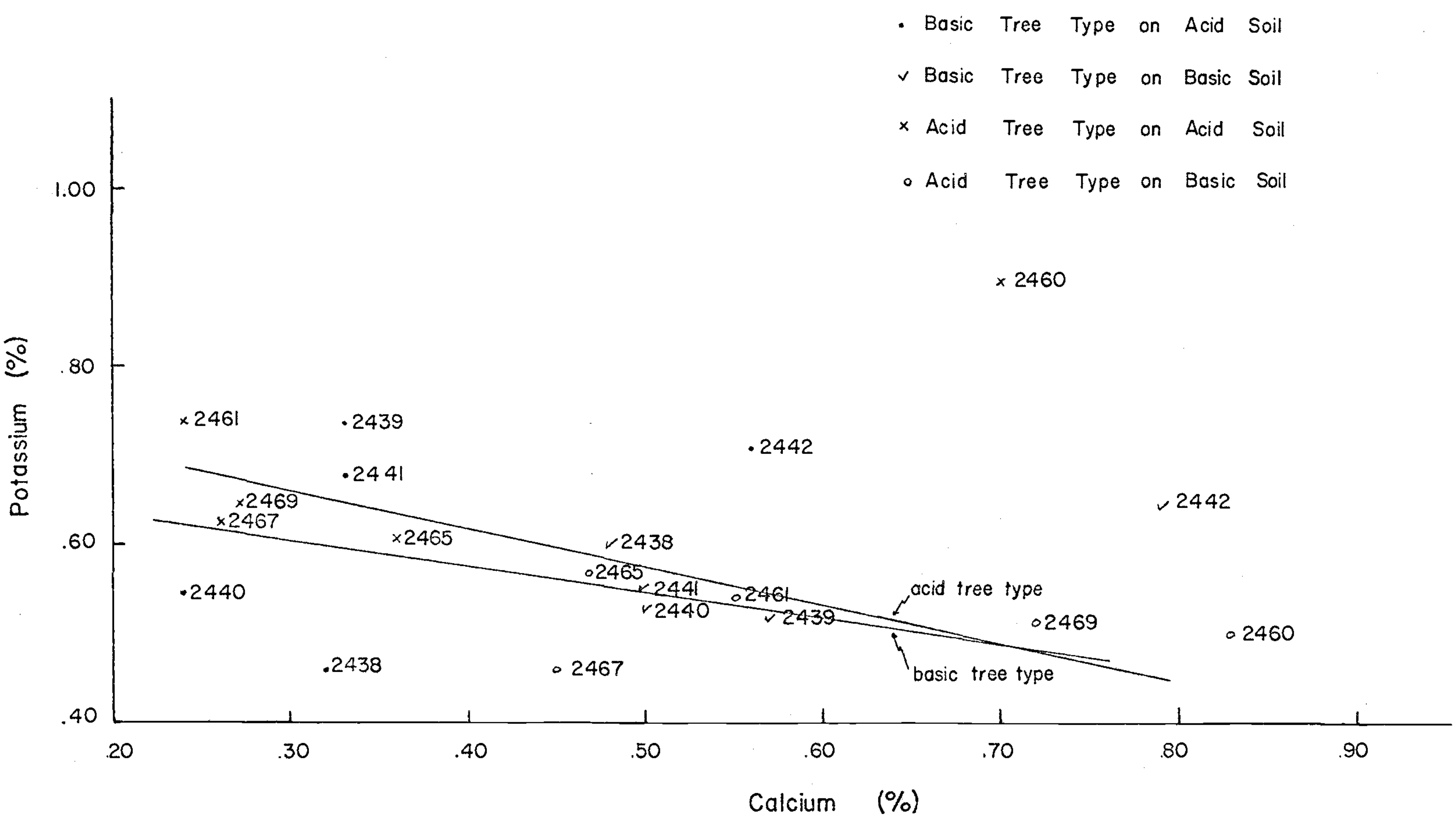


Figure 14: Potassium - Calcium Interrelationship in the Tissue of Ten White Spruce Provenances Grown on an Acid and a Basic Soil (Fertilized)

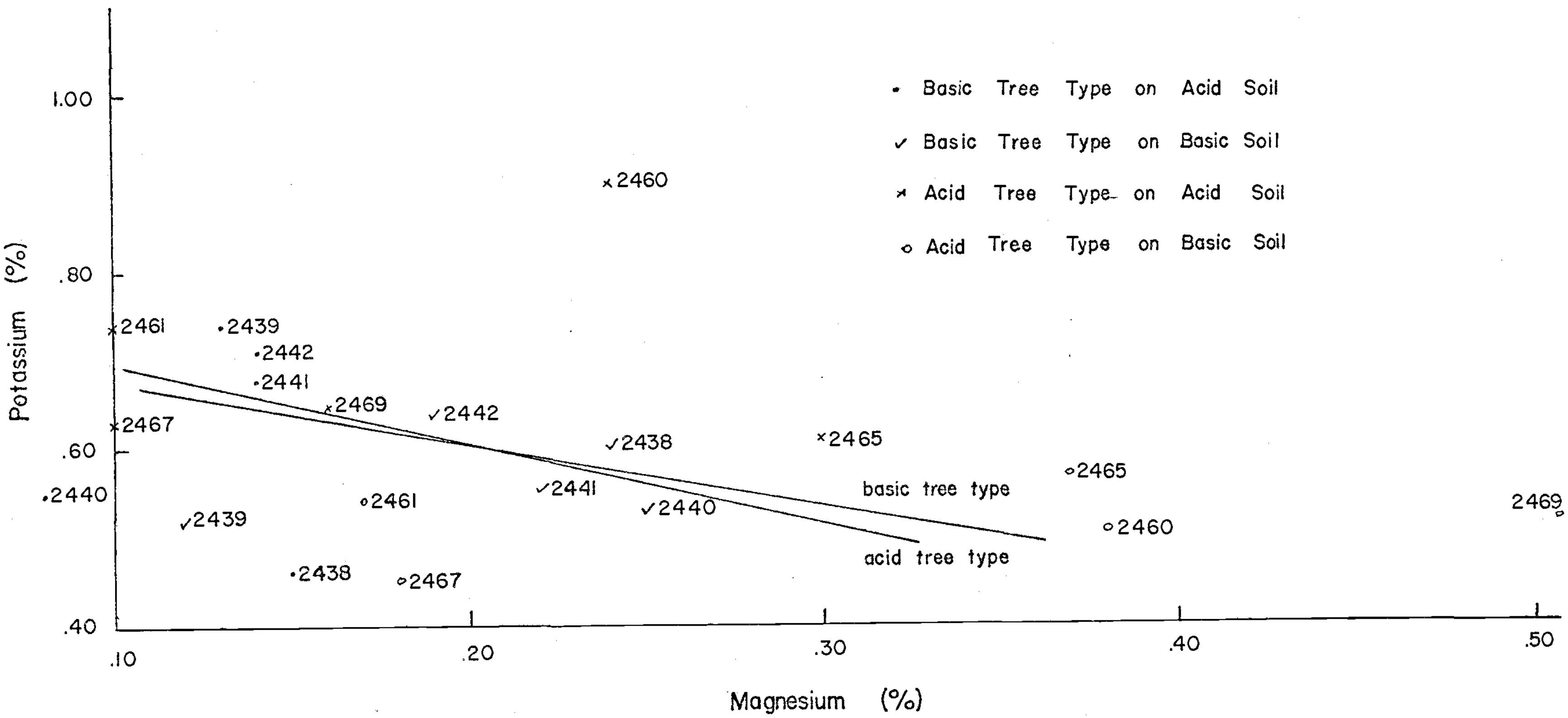


Figure 15: Potassium - Magnesium Interrelationship in the Tissue of Ten White Spruce Provenances Grown on an Acid and a Basic Soil (Fertilized)

tree types while the acid tree types contained a higher percentage when grown on the acid soil than did the basic tree types. The trends are clear and very similar on the unfertilized soils for both interactions.

It appears that the differences in the potassium-calcium and potassium-magnesium ratios may be due to inherited differences of the provenances.

Reduced concentration in the plant when the element is available may indicate a reduced requirement for the element to sustain growth.

Calcium is not particularly toxic to plants, which may explain the lack of significance in the concentration between the two tree types. A significantly higher concentration of this element from the basic soil is a response to the available supply.

Magnesium on the other hand is much more of a plant poison. Holst (1971) suggests that some white spruce provenances from high magnesium dolomitic limestone soils in Southern Ontario have developed a tolerance to high levels of this element by a system of low magnesium uptake which shows up as magnesium deficiency symptoms when they are planted on granitic soils with magnesium levels near 0.25 milliequivalents per 100 grams of soil.

The magnesium levels, averaging 1.55 milliequivalents per 100 grams in the acid soil used in this experiment, are apparently sufficiently high to exclude this response.

SUMMARY AND CONSLUSIONS

An experiment was established to study the concentration of nutrients in the tissue of ten white spruce provenances from basic and acid soil origins when grown on a basic and an acid soil. The purpose was to determine if some of the variability in performance within the species might be related to differential concentrations of required nutrients in the tissue of the plants.

Except for calcium, the concentrations of stored nutrients in the seed of ten white spruce provenances are very similar as a percent of dry weight. Three of the basic provenances show considerably higher concentrations of calcium as a percent of dry weight and four of the basic provenances show greater absolute quantities of calcium in their seed.

Evidence indicates that this excess is luxury consumption in some provenances beyond the genetically controlled nutritional requirement of the species. With regard to the data from this study, which does not include growth characteristics, there appears to be no relationship between the concentration of nutrients in the seed and in the tissue grown on the two soils further indicating that the seed storage of nutrients is an independent function.

The concentrations of phosphorus and potassium were significantly higher in the seedlings grown on the acid soil. The concentrations of these elements were significantly increased on both soils with fertilization.

Nitrogen concentration was essentially the same in plants grown on both soils with or without fertilizer. The concentrations of calcium and magnesium were significantly higher in the plants grown on the basic soil. Fertilization did not significantly affect the concentration of these elements in the tissue grown on either soil.

It is suggested that the pH of the basic soil is too high for good white spruce growth. It may also be that the pH of the acid soil is too high for optimum growth of this species.

The recognized interactions of potassium with calcium and/or magnesium is evident in the study. On the unfertilized soils the trends of this relationship were the same for potassium-calcium and potassium-magnesium i.e. the seedlings from acid soil origin provenances generally concentrated more potassium in their tissue on the acid soil than did the seedlings from basic soil origin provenances, but less potassium on the basic soil than did the seedlings from basic soil origin provenances. This relationship was less pronounced on the fertilized soils.

This would seem to indicate an ability of the basic soil provenance to pick up larger amounts of available potassium in the presence of possible adverse amounts of calcium and/or magnesium in the soil.

The one "basic" provenance which reacts consistently like an "acid" provenance is #2439, which also had a seed calcium concentration similar to the acid provenances. There are two possibilities to explain this. First, the soil on which it grew was mis-identified: this is a remote possibility since soil samples were obtained at the time of seed collection and later analyzed by Environment Canada (Holst, 1971). Secondly, the parent trees of this source were native to an acid soil and were introduced long ago to the basic soil site on which they now grow and have retained their "acid" provenance characteristics.

Further study will be required with these same provenances to confirm if the apparent variations between the acid and basic soil origin provenances are genetic or of soil origin.

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APPENDICES

Appendix 1: Analysis of Variance of Nitrogen as a Percent Dry Weight of Produced Tissue

Nitrogen

Source	d.f.	Mean Square	F
Plots	2	0.2339	2.166
Soils	1	1.1930	11.046
Error (a)	2	0.1080	
Seed Source	9	0.0102	0.356
Tree Type	1	0.0615	2.157
Seed Source X Tree Type 1	4	0.0062	0.217
Seed Source X Tree Type 2	4	0.0013	0.046
Soil X Seed Source	9	0.0109	0.381
Tree Type X Soil	1	0.0416	1.461
Soil X Seed Source within Tree Type 1	4	0.0024	0.084
Soil X Seed Source within Tree Type 2	4	0.0119	0.420
Error (b)	36	0.0285	
TOTAL	59		

Appendix 1: Analysis of Variance of Phosphorus as a Percent Dry Weight of Produced Tissue

Phosphorus

Source	d.f.	Mean Square	F
Plots	2	0.01822	112.500*
Soils	1	0.01124	68.750**
Error (a)	2	0.00016	
Seed Sources	9	0.00013	0.814
Tree Type	1	0.00008	0.498
Seed Source X Tree Type 1	4	0.00004	0.234
Seed Source X Tree Type 2	4	0.00023	1.414
Soil X Seed Source	9	0.00012	0.720
Tree Type X Soil	1	0.00008	0.498
Soil X Seed Source within Tree Type 1	4	0.00019	1.149
Soil X Seed Source within Tree Type 2	4	0.00006	0.347
Error (b)	36	0.000164	
TOTAL	59		

* Significant at the 1% level

** Significant at the 5% level

Appendix 1: Analysis of Variance of Potassium as a Percent Dry Weight of Produced Tissue

Potassium

Source	d.f.	Mean Square	F
Plots	2	0.337	168.50 *
Soils	1	0.243	121.50 *
Error (a)	2	0.002	
Seed Source	9	0.008	1.693
Tree Type	1	0.003	0.741
Seed Source X Tree Type 1	4	0.006	1.407
Seed Source X Tree Type 2	4	0.010	2.357
Soil X Seed Source	9	0.013	2.869 **
Tree Type X Soil	1	0.042	9.552 *
Soil X Seed Source within Tree Type 1	4	0.009	2.041
Soil X Seed Source within Tree Type 2	4	0.009	1.993
Error (b)	36	0.0045	
TOTAL	59		

* Significant at the 1% level

** Significant at the 5% level

Appendix 1: Analysis of Variance of Calcium as a Percent Dry Weight of Produced Tissue

Calcium

Source	d.f.	Mean Square	F
Plots	2	0.135	2.755
Soils	1	1.216	24.810 **
Error (a)	2	0.049	
Seed Source	9	0.0084	0.622
Tree Type	1	0.0068	0.502
Seed Source X Tree Type 1	4	0.0136	1.000
Seed Source X Tree Type 2	4	0.0025	0.183
Soil X Seed Source	9	0.0054	0.398
Tree Type X Soil	1	0.0009	0.066
Soil X Seed Source within Tree Type 1	4	0.0089	0.656
Soil X Seed Source within Tree Type 2	4	0.0030	0.221
Error (b)	36	0.0136	
TOTAL	59		

** Significant at the 5% level

Appendix 1: Analysis of Variance of Magnesium as a Percent Dry Weight of Produced Tissue

Magnesium

Source	d.f.	Mean Square	F
Plots	2	0.001	1.00
Soils	1	0.178	178.00 *
Error (a)	2	0.001	
Seed Source	9	0.013	1.820
Tree Type	1	0.043	6.829 **
Seed Source X Tree Type 1	4	0.010	1.615
Seed Source X Tree Type 2	4	0.006	0.883
Seed Source X Soil	9	0.005	0.861
Tree Type X Soil	1	0.017	2.687
Soil X Seed Source within Tree Type 1	4	0.003	0.475
Soil X Seed Source within Tree Type 2	4	0.005	0.715
Error (b)	36	0.006	
TOTAL	59		

* Significant at the 1% level

** Significant at the 5% level

Appendix 2: Nitrogen Content of Tissue of Ten White Spruce Provenances (% Dry Weight) Grown on an Acid and a Basic Soil

Provenance	Acid Soil Plot 1	Acid Soil Plot 2	Acid Soil Plot 3	Basic Soil Plot 1	Basic Soil Plot 2	Basic Soil Plot 3
From dolomitic limestone origin						
2438	1.25	1.54	1.55	1.12	1.20	1.28
2439	1.34	1.49	1.61	1.18	1.20	1.25
2440	1.32	1.53	1.44	1.21	1.14	1.38
2441	1.40	1.69	1.44	1.14	1.11	1.26
2442	1.14	1.47	1.47	1.30	1.19	1.28
From granitic (acid) origin						
2460	1.36	1.01	2.29	1.15	1.09	1.30
2461	1.28	1.81	1.61	1.17	1.09	1.56
2465	1.39	1.53	1.64	1.16	1.10	1.33
2467	1.38	1.75	1.63	1.30	1.06	1.26
2469	1.42	1.73	1.60	1.28	1.17	1.39

Appendix 2: Phosphorus Content of Tissue of Ten White Spruce Provenances (% Dry Weight) Grown on an Acid and a Basic Soil

Provenance	Acid Soil			Basic Soil		
	Plot			Plot		
	1	2	3	1	2	3
From dolomitic limestone origin						
2438	0.08	0.06	0.11	0.05	0.04	0.08
2439	0.08	0.08	0.13	0.06	0.05	0.11
2440	0.07	0.08	0.14	0.06	0.02	0.12
2441	0.08	0.07	0.13	0.04	0.04	0.08
2442	0.08	0.07	0.14	0.05	0.04	0.11
From granitic (acid) origin						
2460	0.08	0.07	0.15	0.05	0.05	0.08
2461	0.08	0.06	0.13	0.05	0.04	0.14
2465	0.07	0.08	0.11	0.05	0.05	0.11
2467	0.09	0.07	0.11	0.06	0.05	0.09
2469	0.09	0.08	0.13	0.06	0.06	0.08

Appendix 2: Potassium Content of Tissue of Ten White Spruce Provenances (% Dry Weight) Grown on an Acid and a Basic Soil

Provenance	Acid Soil			Basic Soil		
	Plot			Plot		
	1	2	3	1	2	3
From dolomitic limestone origin						
2438	0.42	0.40	0.46	0.29	0.46	0.60
2439	0.36	0.48	0.74	0.18	0.31	0.52
2440	0.45	0.40	0.55	0.31	0.35	0.53
2441	0.44	0.48	0.68	0.31	0.51	0.55
2442	0.53	0.41	0.71	0.33	0.50	0.64
From granitic (acid) origin						
2460	0.51	0.50	0.90	0.18	0.33	0.50
2461	0.42	0.54	0.74	0.37	0.27	0.54
2465	0.38	0.41	0.61	0.33	0.24	0.57
2467	0.44	0.43	0.63	0.31	0.27	0.45
2469	0.41	0.51	0.65	0.27	0.24	0.51

Appendix 2: Calcium Content of Tissue of Ten White Spruce Provenances (% Dry Weight) Grown on an Acid and a Basic Soil

Provenance	Acid Soil			Basic Soil		
	Plot			Plot		
	1	2	3	1	2	3
From dolomitic limestone origin						
2438	0.39	0.33	0.32	0.82	0.43	0.48
2439	0.28	0.30	0.33	0.66	0.56	0.57
2440	0.42	0.23	0.24	0.69	0.61	0.50
2441	0.40	0.22	0.33	1.01	0.43	0.50
2442	0.37	0.22	0.56	0.67	0.37	0.79
From granitic (acid) origin						
2460	0.33	0.32	0.70	0.74	0.47	0.83
2461	0.42	0.36	0.24	0.68	0.73	0.55
2465	0.32	0.28	0.36	0.77	0.54	0.47
2467	0.38	0.33	0.26	0.69	0.52	0.44
2469	0.33	0.25	0.27	0.90	0.49	0.72

Appendix 2: Magnesium Content of Tissue of Ten White Spruce Provenances (% Dry Weight) Grown on an Acid and a Basic Soil

Provenance	Acid Soil			Basic Soil		
	Plot			Plot		
	1	2	3	1	2	3
From dolomitic limestone origin						
2438	0.15	0.26	0.15	0.30	0.19	0.24
2439	0.13	0.16	0.13	0.12	0.15	0.12
2440	0.15	0.08	0.08	0.16	0.26	0.25
2441	0.13	0.13	0.14	0.36	0.19	0.22
2442	0.14	0.13	0.14	0.27	0.21	0.19
From granitic (Acid) origin						
2460	0.16	0.17	0.24	0.33	0.21	0.38
2461	0.15	0.16	0.10	0.19	0.54	0.17
2465	0.17	0.12	0.30	0.36	0.27	0.37
2467	0.11	0.15	0.10	0.22	0.23	0.18
2469	0.20	0.11	0.16	0.38	0.20	0.51