1971

Effect of fertilization on Larix occidentalis in western Montana

William Elwood Chord
The University of Montana

Recommended Citation

Chord, William Elwood, "Effect of fertilization on Larix occidentalis in western Montana" (1971). *Graduate Student Theses, Dissertations, & Professional Papers*. 2156.
https://scholarworks.umt.edu/etd/2156

THE EFFECT OF FERTILIZATION ON LARIX OCCIDENTALIS IN WESTERN MONTANA

By

William E. Chord Jr.

B.S., University of Montana, 1968

Presented in partial fulfillment of the requirements
for the degree of

Master of Science in Forestry

UNIVERSITY OF MONTANA

1971

Approved by:

Mark J. Behan
Chairman, Board of Examiners

John M. Stewart
Dean, Graduate School

June 1, 1971
Date

6-3-71

ACKNOWLEDGMENTS

I wish to thank Dr. George Blake, my major advisor, and Dr. Mark Behan, my thesis advisor, for their valuable assistance and guidance during this study.

Special thanks also to Dr. Robert Wambach, my other committee member. Additionally, I wish to thank Wyman Schmidt of the Intermountain Forest and Range Experiment Station for his help and information.

Thanks also goes to Ronald McCracken and Jack Schmidt, who helped with the field work.

I also wish to acknowledge the financial support provided for this study from U. S. Forest Cooperative Agreement FS-INT-1204 and from McIntire Stennis funds allotted to the School of Forestry.

And last but definitely not least I wish to thank my wife Pat, whose help and encouragement made the completion of this study possible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

Chapter 1

INTRODUCTION

As the world population increases, so does the demand for wood products. This demand is accompanied by the removal of more timberland for agriculture, highways, and other man-made items. Consequently, the land manager should plan to produce more wood per acre if he intends to keep up with the demand.

There have been substantial investments of time and money in research devoted to discovering silvicultural practices that will increase the yield per acre. A large amount of this research is being conducted in forest fertilization. The results of fertilizer experiments have been so favorable that some countries of the world are undertaking extensive fertilization programs. One company in Sweden fertilized 150,000 acres in 1966 (Hagner, 1967) and fertilization of additional acreages has been planned for future years.

In the United States, most fertilizer experimentation has been on plantations in the East, Southeast, New England, and in the Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. Mensiesii) regions on the

West Coast.

In the Rocky Mountain region, one of the more important commercial species is western larch (Larix occidentalis, Nutt). According to "Timber Trends," a report by the U.S. Forest Service (1965), western larch is the major species found on 3.5 million acres in the U.S. The volume of western larch cut in the Rocky Mountain region is second only to Douglas-fir (Roe et al., manuscript pending).

Very little fertilization work has been done on western larch except for some preliminary work and a field study started under a cooperative agreement between the Intermountain Forest and Range Experiment Station and the University of Montana (Behan, 1967a, 1967b, 1968; Behan and Friedrich, 1967).

OBJECTIVES

A cooperative field study to determine the response of young western larch to fertilization was started in 1966. The foliar tests and growth responses were to be checked in 1971, five years later (FS-INT-1204-541 study plan, 1966, by Behan and Schmidt). A need existed to check for responses before the five-year period was up; therefore, this study was started in 1968 with the following objectives:

1. To determine if increases in foliar nutrient

concentrations can be detected after fertilization.

2. To determine if larch responds to fertilization by increasing diameter and height growth as soon as the second year following fertilization.

3. To determine if a relationship exists between foliar nutrient content and growth.

Chapter 2

LITERATURE REVIEW

The concept of a nutritional requirement for forest trees was recognized as early as 1873, when Fichê and Grandeau compared data on *Pinus pinaster*, Ait. and demonstrated that poor growth was associated with a high calcium and low potassium content (Leyton, 1948). However, it was not until the last few decades that research on nutrients and fertilization developed to any great extent.

Much of the early mineral nutrition research was done in Europe. In most cases, there was a definite response when various minerals were added to the soil. In Belgium, basic slag was applied and a growth response occurred that persisted over a 50-year period (Tamm, date unknown). In the Netherlands, phosphorus and potassium produced the greatest growth response, while in Great Britain nitrogen appeared to be a limiting nutrient (Tamm, date unknown).

Most of the nutrient work up to the present has been concerned with the three major minerals, nitrogen, phosphorus, and potassium.

In New Zealand, Will (1957), working with Monterey pine (Pinus radiata, D. Don), found that the mineral content varies from place to place in a tree. The amount of calcium, potassium, and phosphorus in the foliage increases towards the base of the tree while the nitrogen content decreases. Will also noted a growth response in height and diameter.

Tamm (1964) found that nitrogen gave a height growth response in spruce but phosphorus and potassium did not.

Much of the fertilizer research done in the Pacific Northwest has been on Douglas-fir. Beaton et al. (1964) found that the nitrogen content of Douglas-fir needles was higher after fertilization. They found that the phosphorus content remained relatively stable after fertilization rather than dropping. In a second study Beaton et al. (1965), using foliar analysis on Douglas-fir, found that the foliar nutrient concentrations were similar to their earlier tests. Although they had not planned to take growth response, they found that there was a definite increase in height growth. Gessel et al. (1965) found that the diameter and height growth of Douglas-fir was increased after fertilization with nitrogen.

Research in larch nutrition has been limited almost exclusively to Japanese larch (Larix leptolepis, mun). Edwards (1961) found that regardless of whether phosphorus was applied as basic slag or mineral, the growth response of Japanese larch was the same.

Van Goor (1953) determined the foliar nitrogen content of Japanese larch seedlings and found that increased foliar nitrogen content was associated with decreased phosphorus content and vice-versa. Van Goor found that the soil had an important influence on the nutrient uptake. If the soils were low in nitrogen and phosphorus, a small amount of each will result in a growth increase. If a large amount of nitrogen was added to a soil rich in nitrogen, growth rates decreased. In all soils the absorption of phosphorus was decreased by the addition of nitrogen; however, if the soils were already rich in nitrogen and phosphorus, a slight growth increase did occur. Van Goor concluded an N/P ratio exists at which optimum growth occurs. The best growth occurs at an N/P ratio of 4-5. Values on either side of this optimum will result in a growth decrease.

In 1957, Kurakina worked with Japanese larch seedlings and found that it was the nutrient ratio that was important for growth and not the amount of any single nutrient. He observed that the best seedling growth occurred when nitrogen, phosphorus, and potassium fertilizers were added in the ratio 1:2:1, respectively. The amount added was not as important as having the proper ratio.

Jung and Riechle (1966) found that nitrogen increased the height and diameter growth of Japanese larch seedlings grown in pots. Phosphorus and potassium had little effect, but the utilization of these nutrients improved with increased nitrogen application.

Leyton (1956) found a significant linear correlation between the height growth of Japanese larch and its foliar mineral content. Under the conditions of his experiment he found that both nitrogen and potassium prompted increases in height growth. Leyton did not observe any phosphorus responses. He attributed this to the high amount of phosphorus contained in the soil.

In another study, Leyton (1957) treated eight-year-old Japanese larch with three levels (0, 2, and 4 ounces per tree) of ammonium nitrate. This treatment was combined factorially with the same amount of potassium sulfate.

Height growth increased with increased nitrogen fertilization until an optimum of slightly more than two ounces nitrogen per tree was applied. Nitrogen applications above this optimum resulted in a growth decrease. He also found that nitrogen had an antagonistic effect on phosphorus uptake and that the N/P ratios strongly "affected" the growth response. N/P ratios of 3-8 gave an estimate of height growth with a standard error of ± 7.7 centimeters. The maximum growth increment was obtained with an N/P ratio of 12.6. Maximum growth was also obtained with an N/K ratio of 2.4 and a K/P ratio of 5.4.

In both studies the soils were high in phosphorus and no positive response was observed. To confirm this, phosphorus was added in 1956 to the trees treated in 1955. The phosphorus concentration did not increase after treatment; in fact, the nitrogen fertilizers still had a depressing influence on the foliar phosphorus content.

A second trial was set up at a location lower in soil phosphorus. Nitrogen and phosphorus were applied in the same factorial design as the other study, with similar results.

From his studies, Leyton found that the optimum nitrogen concentrations were 2.8% and higher concentrations resulted in decreased height growth.

Kawada (1964) gives a preliminary report on the growth of two-year-old Japanese larch. Each tree was treated with 15 grams of fertilizer containing nitrogen, phosphorus, and potassium. Kawada found that treated trees on poor sites had growth equal to trees on superior sites.

A laboratory study (Behan, 1967a, 1967b) has demonstrated deficiency symptoms of western larch for specific nutrients. Using pot cultures, Behan was able to get foliar symptoms that may be used in the field for diagnostic purposes.

Behan and Friedrich (1967) conducted a field study to determine the effects of season and crown position on foliar nutrient content and found that the best time to collect foliar samples was in August when nutrient contents stabilize. Nutrient concentrations are greatest in the upper part of the crown; therefore, samples should be collected from the upper portion of the tree crown.

Chapter 3

EXPERIMENTAL DESIGN AND METHODS

FERTILIZER PLOT ESTABLISHMENT AND DESIGN

A series of fertilizer plots were set out in the fall of 1966 throughout western Montana. The plots were selected to represent a selection of typical larch growing sites. (See Appendix C for description of plot locations.) At each of the locations there were from two to six treatments, including controls, with each treatment being replicated three times.

The amount of fertilizer applied was based on standard exploratory rates: urea at 300 pounds nitrogen per acre, treble super-phosphate at a rate equal to 200 pounds P_2O_5 (phosphorus pentoxide) per acre, and potassium chloride at the equivalent of 200 pounds K_2O (potassium oxide) per acre.

Each treatment was replicated three times.

The six treatments were as follows:

$N_0P_0K_0$ - Control
$N_3P_0K_0$ - 300 pounds N
$N_3P_2K_0$ - 300 pounds N, 200 pounds P_2O_5
$N_0P_2K_2$ - 200 pounds P_2O_5, 200 pounds K_2O

$N_3P_0K_2$ - 300 pounds N, 200 pounds K_2O

$N_3P_2K_2$ - 300 pounds N, 200 pounds P_2O_5, 200 pounds K_2O

The subscripts refer to the hundreds of pounds per acre applied.

The treatments at each location were as follows:

1. Those having all six treatments:

    Lower Cottonwood
    Rice Ridge
    Clearwater
    Coram Experimental Forest
    Murray Creek
    Trout Lake (thinned)
    Skid Creek

2. Those having three treatments, $N_0P_0K_0$, $N_3P_0K_0$, and $N_3P_2K_2$

    Barber Creek
    Margaret Creek
    Buckhorn Creek

3. Cottonwood Lake has treatments $N_0P_0K_0$ and $N_3P_2K_2$.

SAMPLE COLLECTION AND PREPARATION

During July and August of 1968 all of the experimental plots were visited to inspect the plots and to select the sample trees. Five sample trees per plot were chosen from the dominant or codominant trees present on each plot. In some cases we were unable to get five sample trees per plot due to the lack of trees or homogeneity of the trees. In these cases a partial sample was used.

Each tree chosen was marked with a permanent aluminum tag inscribed with a code number giving the location, treatment, replication, and tree number within the plot. The complete code is described within Appendix A. This gives a permanent record for further use.

In August of 1968, foliar samples were collected by obtaining the south-facing branch of the third whorl. This branch consisted of the leader formed in 1968, which supported only juvenile leaves, and branch segments formed in 1966 and 1967. The needles on these segments develop from the spur shoots and were used for the foliar samples.

Each branch was then measured to determine each year's lateral branch growth. Also, the number of spurs for each year was counted and recorded. The needles from the 1967 branch growth were removed and combined into a composite foliar sample. This composite sample from the five trees on each plot was placed in an oven at 70°C. and dried for 48 hours. Immediately after drying the samples were weighed to obtain sample weight. After drying, the samples were ground using a Wiley Mill, to pass a 40-mesh screen. The samples were then put into baby food jars and set aside for foliar analysis.

The growth data was collected beginning in September of 1968. This consisted of total height, height of last three years, terminal leader growth, diameter, and the radial increment.

Height growth was measured to the nearest decimeter. The terminal growth for each year was measured to the nearest centimeter by using a meter stick attached to a pole and taking the reading with binoculars. The accuracy of this method was tested several times and the readings were reproducible. Diameter was measured using a 1/100th of an inch diameter tape and these measurements were converted to centimeters by use of a table.

Cores were taken with a ¼-inch increment borer at breast height (4.5 ft.) unless the tree was too small; then it was taken at 2 feet. At the time of collection, each core was put into a straw marked with the tree code and placed into a plastic vial containing the cores for each plot. At the time of measurement all the cores were soaked in water so that the moisture content would be constant.

The diameter cores were measured using a dendrochronometer. Each year's growth was measured to the nearest 1/100th of a millimeter. The annual increment for each year was measured back to 1961 where possible.

Foliar samples were prepared for analysis of phosphorus and potassium by the wet ash technique described by Behan and Kinraide (1969). One gram of the composite foliar samples was used for this purpose. Phosphorus and potassium were determined using the vanadomolydbophosphoric yellow color method (Jackson, 1958) and a Beckman Du-2 flame spectrophotometer (Behan and Kinraide, 1969).

The foliar samples were analyzed for nitrogen using the semi-micro Kjeldahl method (Bradstreet, 1964).

Chapter 4

RESULTS

FOLIAR NUTRIENT CONTENT

The data obtained from the foliar tests has been displayed and arranged into general site classes: poor, medium, and good. (See Fig. 1, pp. 16-24.)

There appears to be a relationship between the various treatments and foliar mineral content. Where nitrogen was applied, there appears to be an increase in foliar nitrogen concentration, except for Skid Creek. This is similar to the findings of other investigators (Leyton, 1956, 1957; Tamm, 1954; Gessel et al., 1965).

At Skid Creek the N treatment had a nitrogen concentration of 1.90% versus a control of 1.96%. This whole location showed relatively little response to treatment which may mean it already has sufficient nutrients. Skid Creek also has a grass understory which may be utilizing the fertilizer.

The effect of phosphorus seems to be the same as other investigators (Leyton, 1956, 1957; Van Goor, 1953) have observed in that nitrogen and phosphorus fertilizer has an antagonistic effect on the foliar nutrient content

FIGURE 1

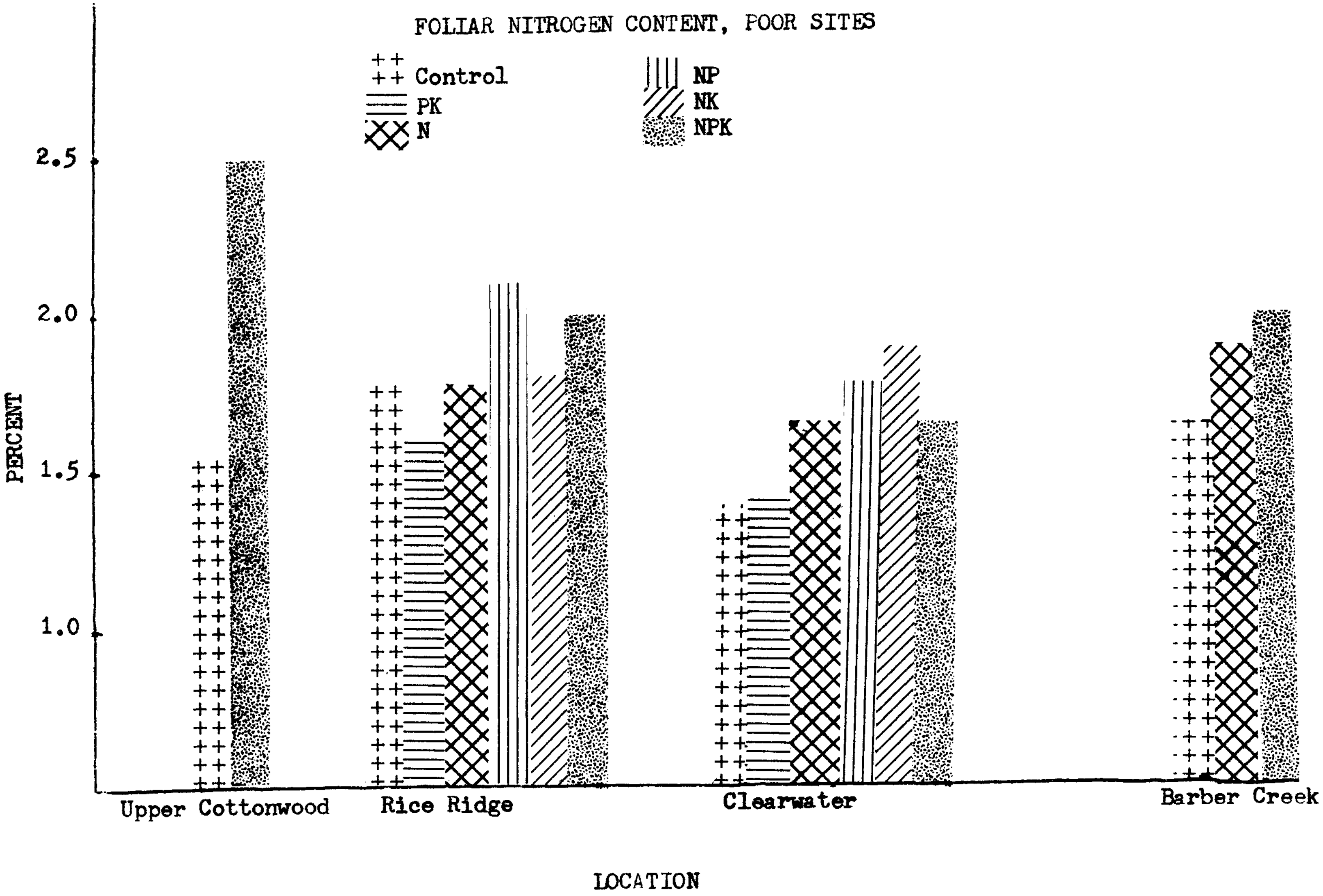

FOLIAR NITROGEN CONTENT, POOR SITES

FIGURE 1 Continued

FOLIAR PHOSPHORUS CONTENT, POOR SITES

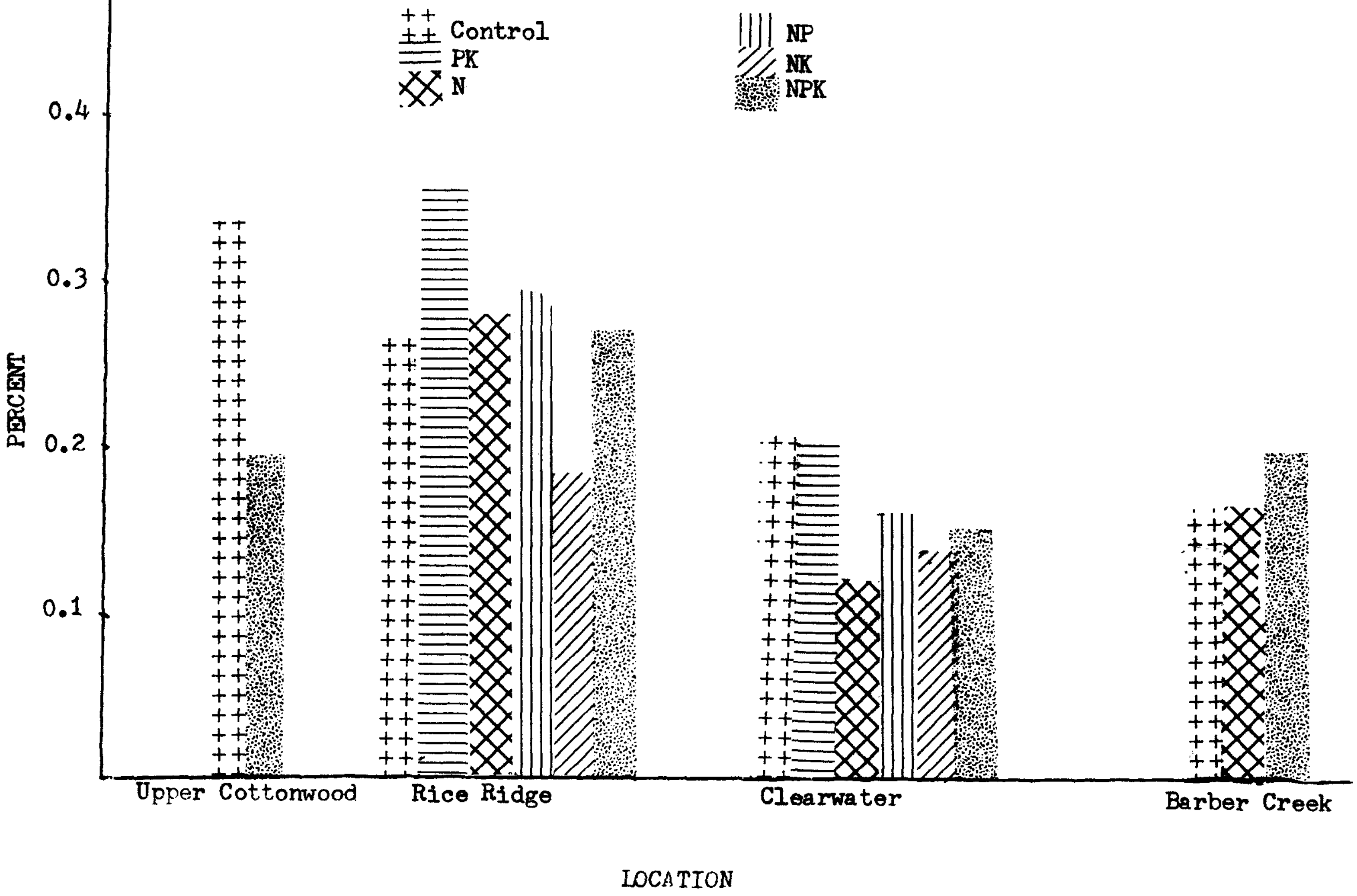
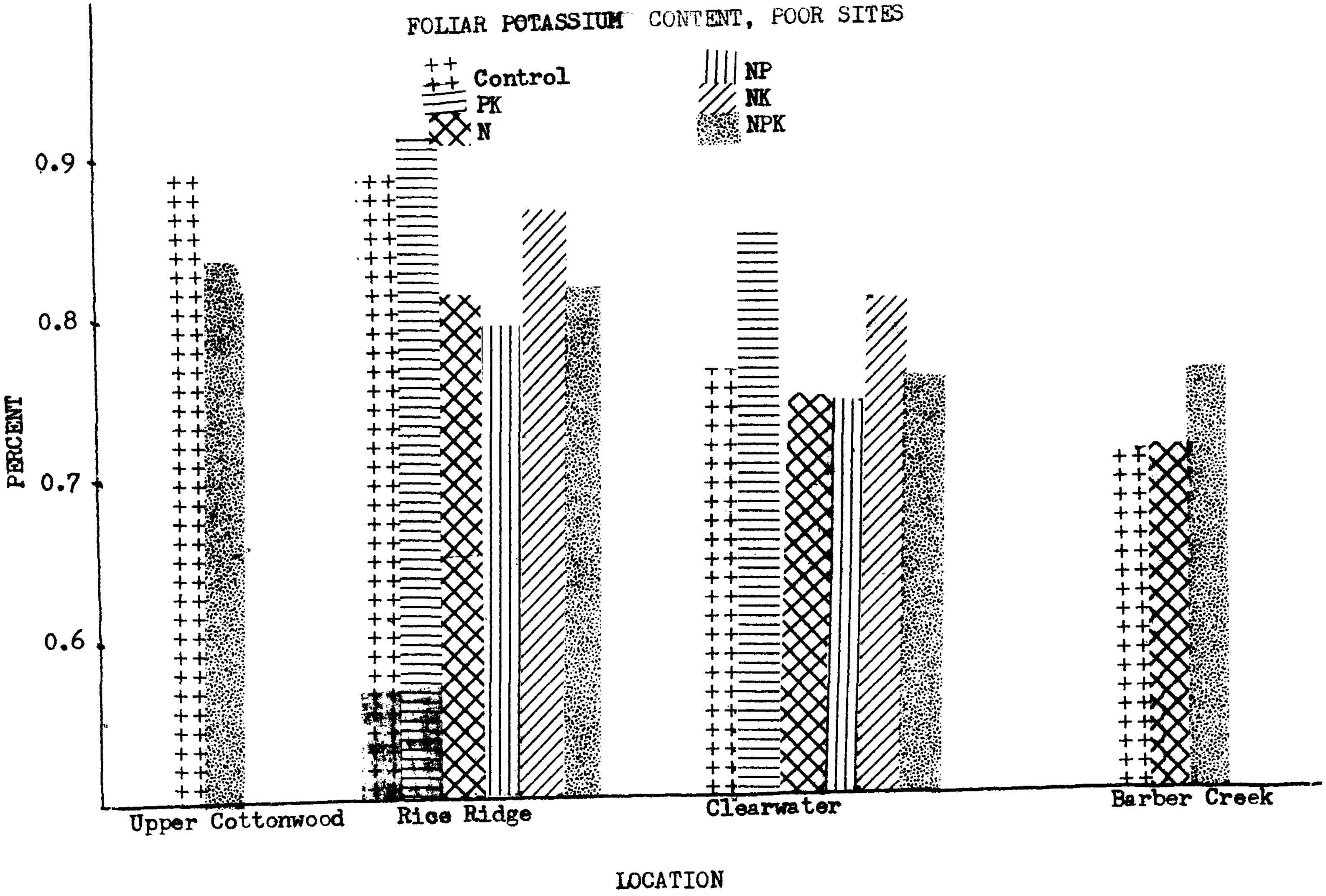


FIGURE 1 Continued



FOLIAR POTASSIUM CONTENT, POOR SITES

FIGURE 1 Continued

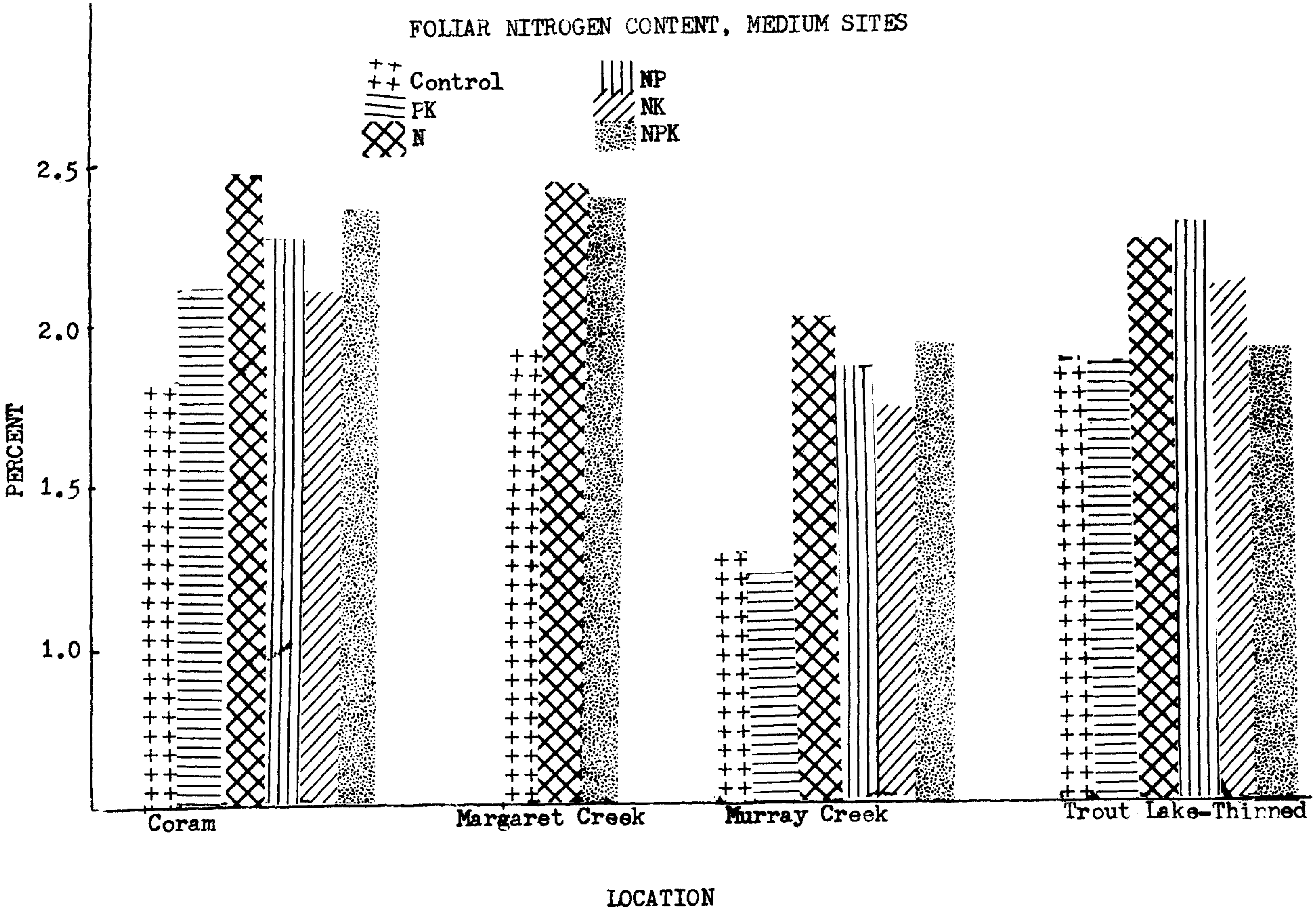

FOLIAR NITROGEN CONTENT, MEDIUM SITES

FIGURE 1 Continued

FOLIAR PHOSPHORUS CONTENT, MEDIUM SITES

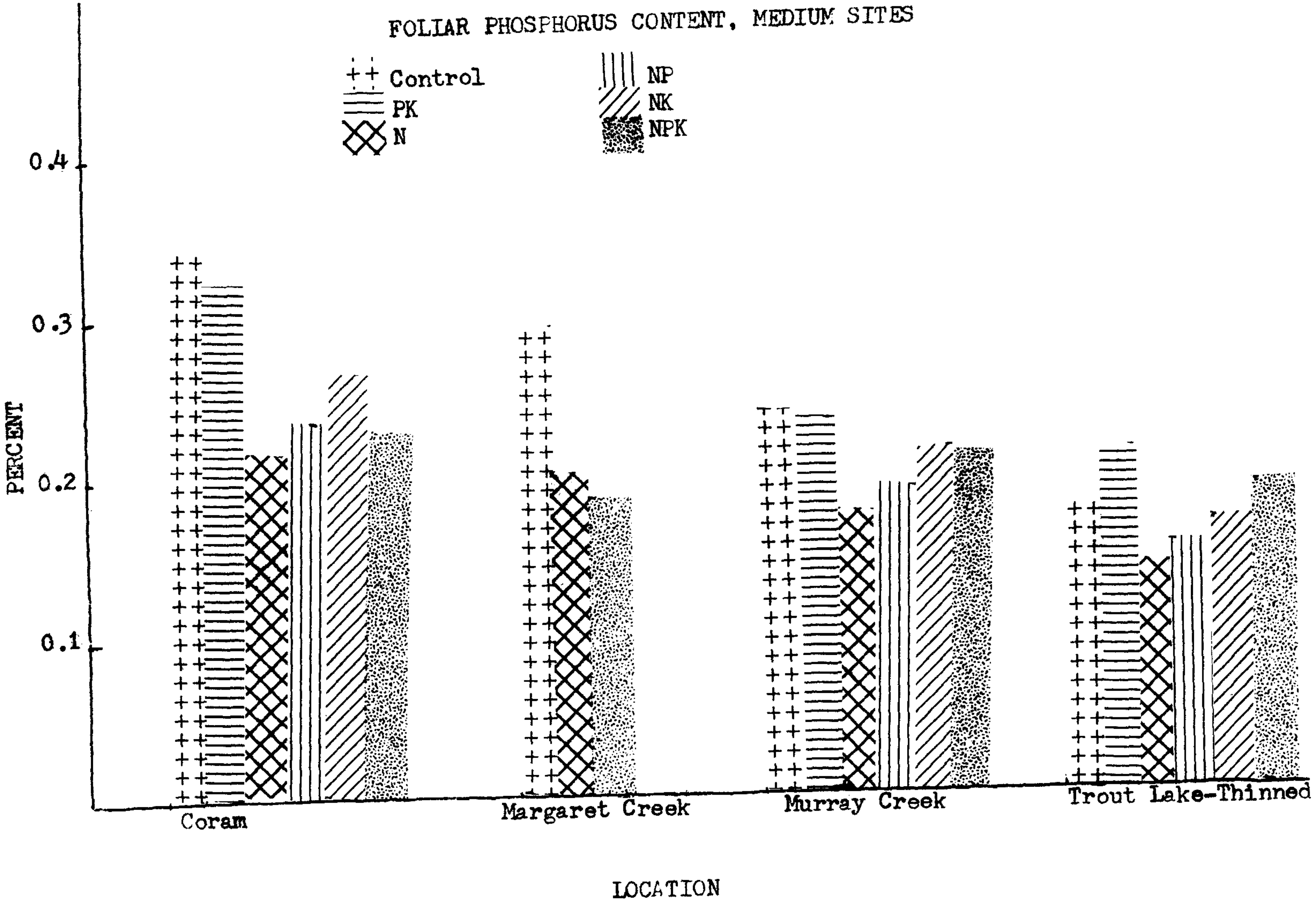
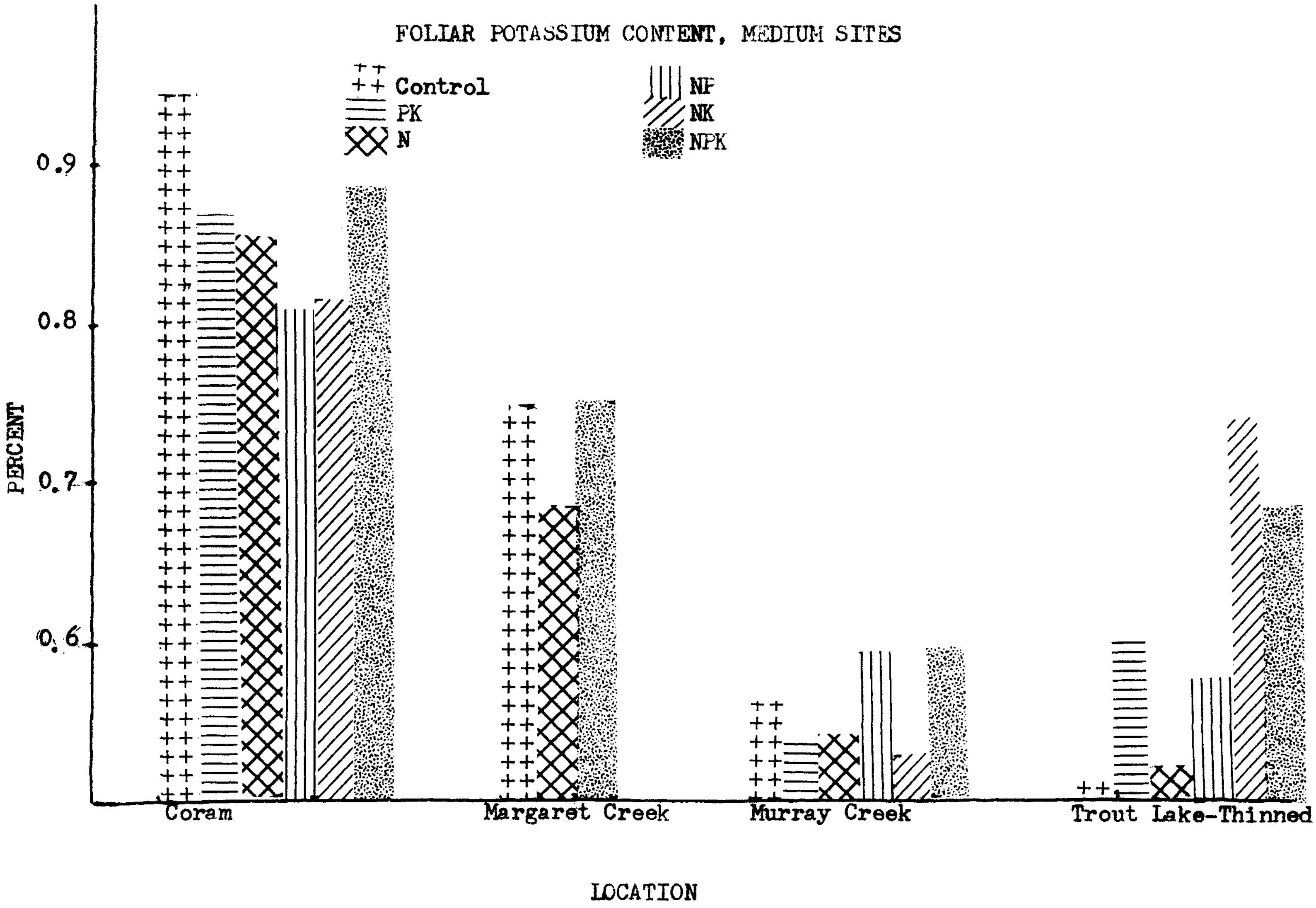


FIGURE 1 Continued



FOLIAR POTASSIUM CONTENT, MEDIUM SITES

FIGURE 1 Continued

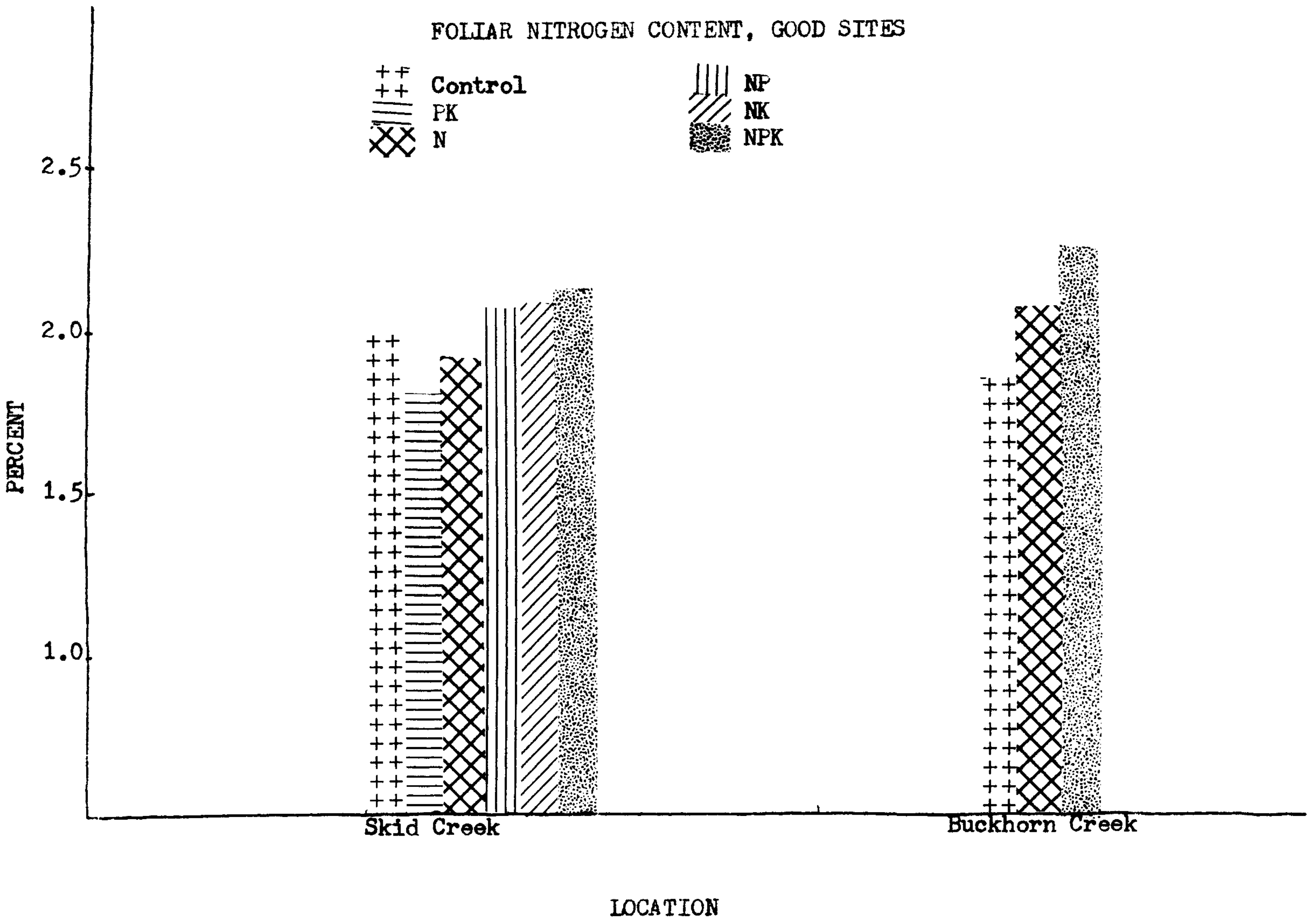


FIGURE 1 Continued

FOLIAR PHOSPHORUS CONTENT, GOOD SITES

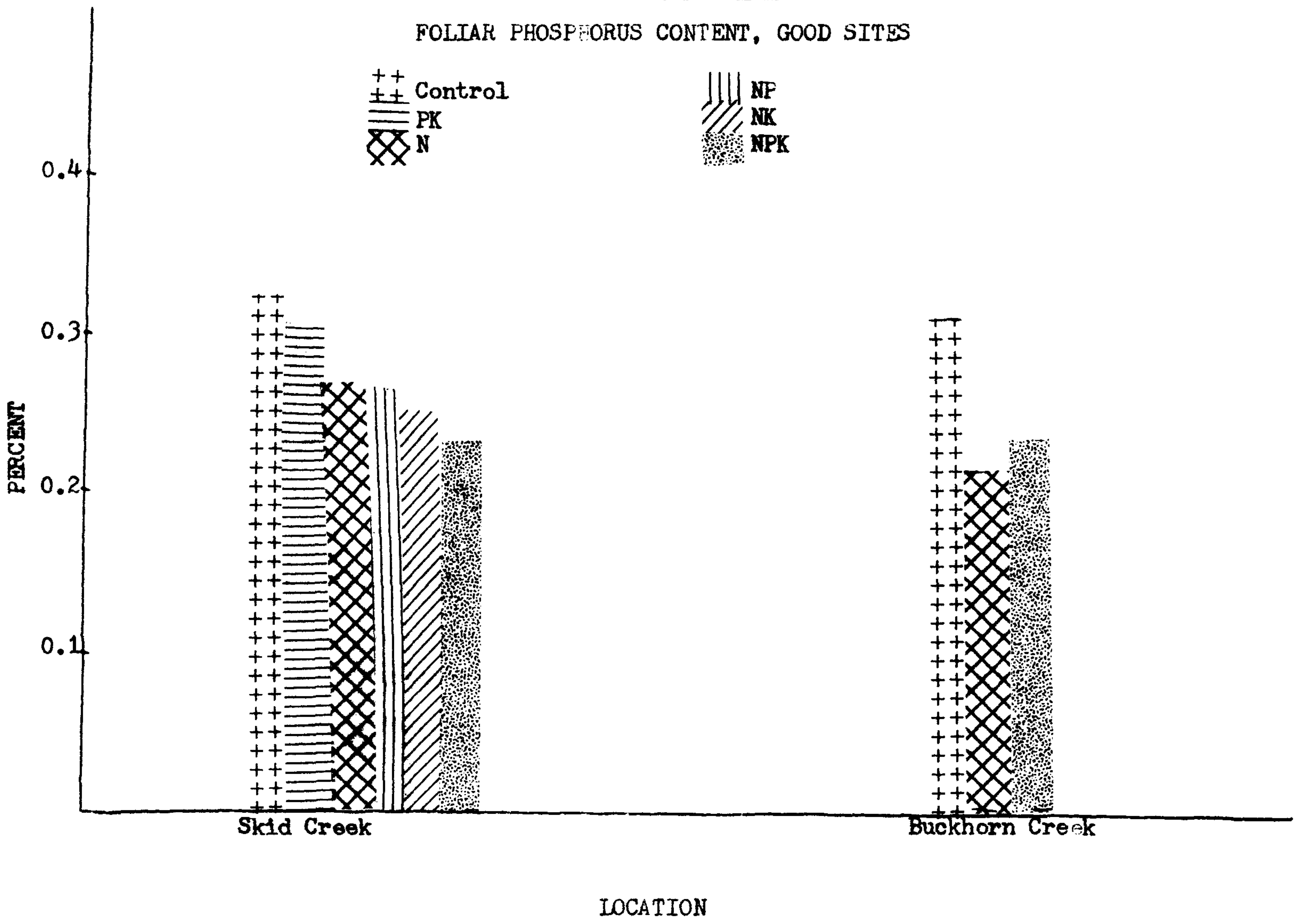
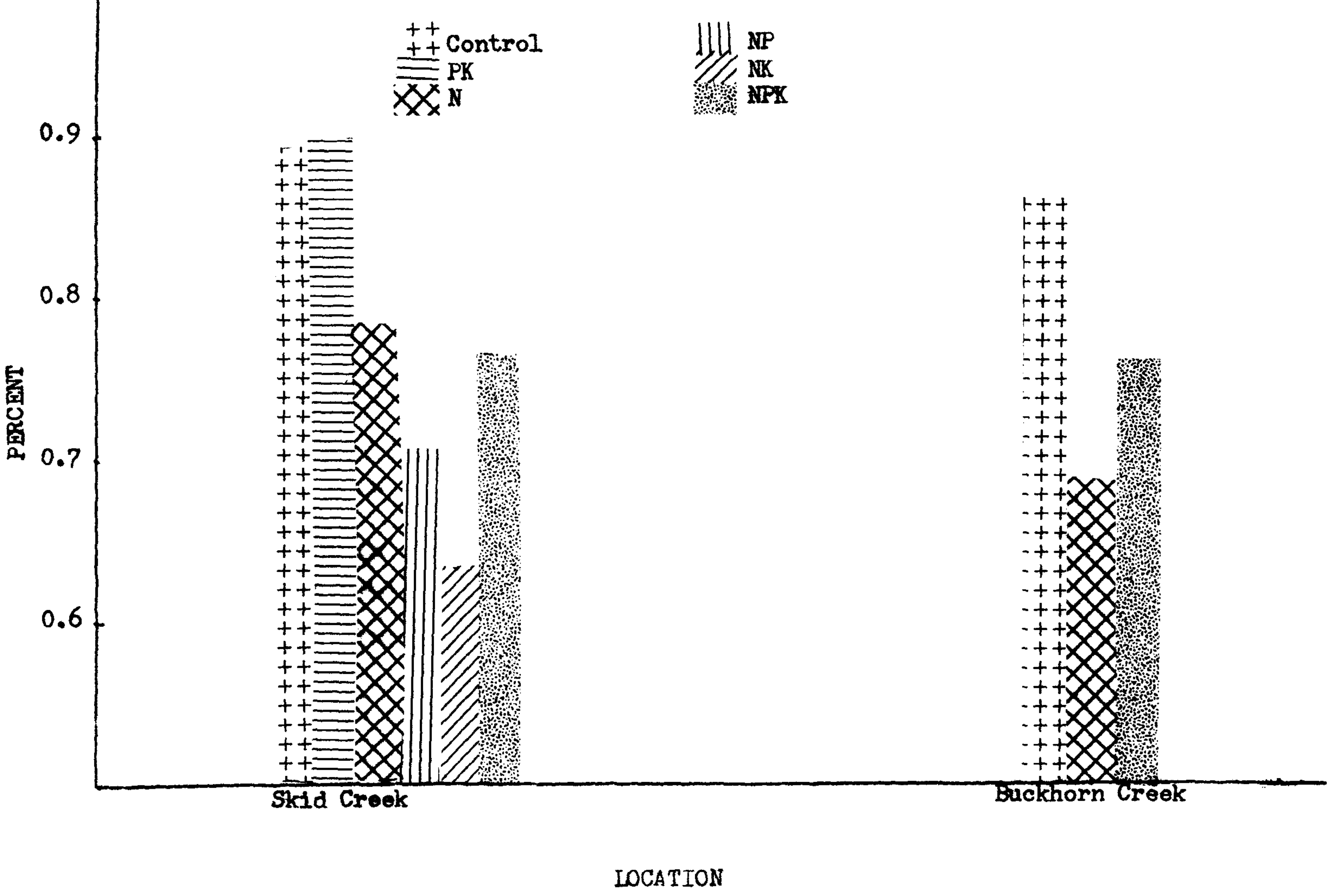


FIGURE 1 Continued

FOLIAR POTASSIUM CONTENT, GOOD SITES



of each other. In almost all instances the PK treatment resulted in an increase in phosphorus content, while the treatment containing nitrogen resulted in a decrease of phosphorus content, regardless of whether phosphorus was also applied.

The potassium data shows many of the same characteristics as the phosphorus data, but location seems to play a greater part. The poorer sites seemed to show very little change either way in potassium content. This would indicate that these areas are not deficient in potassium. At the medium sites we see the greatest potassium effect. Two of the sites, Trout Lake and Murray Creek, had an unusually low foliar potassium content compared to the other sites. While the content at Murray Creek remained low and fairly constant, Trout Lake showed a substantial increase where nitrogen and potassium were applied. Murray Creek is a stand of older trees which could explain the low unchanging potassium content. Murray Creek also has a heavy understory of shrubs, which may affect the foliar nutrient content by absorbing a portion of the applied fertilizer. The increase at Trout Lake would indicate a deficiency of potassium. However, for the increase to occur it appears necessary for nitrogen to be applied with potassium. The heavy grass understory at Trout Lake may have also affected the foliar nutrient content in a manner similar to Murray Creek.

An analysis of variance was run to determine if the responses were significant. Because some of the locations have all six treatments applied and some of them only three, two different analyses were run. One was a 6X7 factorial (six treatments and seven locations); the other 3X10 (three treatments and ten locations). The results of each were then compared to see if they supported each other.

The analysis of variance used is a two-way classification with repeated measurements (Dixon and Massey, 1957). The two variables were treatment and location with the replication of treatment used as the repeated measurements.

Table 2 shows the results of the analysis of variance. Checking the F ratio at 95% significance, we find that there is a significant fertilizer treatment response of foliar nutrient content for all three nutrients involved. A Student-Newman-Keuls Test (SNK) (C. E. Gates, 1959) using the 95% level was run on each set of nutrient means to see which treatments were actually giving the significant response.

Foliar nitrogen concentrations in all treatments except PK are greater than the control. This is expected as no nitrogen was added to increase the nitrogen foliar concentration. It would seem that potassium is having some effect on the nitrogen content. The nitrogen concentration is lower where potassium has been added than where nitrogen alone or nitrogen and phosphorus has been applied. This would indicate that potassium may be intereacting with nitrogen to some extent. The SNK test for three treatments are all significantly different.

Table 1. Results of Foliar Nutrient SNK Test Treatment

Foliar mineral	Fertilizers Applied					
	NP	N	NK	NPK	PK	Control
%N	2.42	2.40	2.37	2.25	1.99	1.98
%P	PK 0.317	Control 0.305	NP 0.245	NPK 0.236	N 0.232	NP 0.230
%K	PK 0.880	NK 0.872	Control 0.871	NPK 0.867	N 0.824	NP 0.823
Foliar mineral		N		NPK		Control
%N		2.08		2.01		1.73
%P		Control 0.266		NPK 0.204		N 0.198
%K		Control 0.754		NPK 0.747		N 0.702

Line denotes treatment differences are not significant at 95% level.

All means were significant at the 95% level.

Table 2. Statistical Analysis of Foliar Nutrient Data Using 6X7 and 3X10 Factorial

Foliar Nitrogen Content - 6X7

Source	Sum of squares	df	Mean square	F ratio
Location	4.482	6	.747	11.672*
Treatment	3.293	5	.659	10.297*
Interaction	3.351	30	.112	9.750*
Subtotal	11.126	41		
Within groups	5.387	84	0.064	
Total	16.513	124		

Foliar Phosphorus Content - 6X7

Source	Sum of squares	df	Mean square	F ratio
Location	3.7821	9	0.4202	6.271*
Treatment	3.1725	2	1.0862	16.211*
Interaction	2.0464	18	0.1136	1.695
Subtotal	8.001	29		
Within groups	3.991	60		
Total	11.992	89		

Foliar Potassium Content - 6X7

Source	Sum of squares	df	Mean square	F ratio
Location	0.234	6	0.039	19.50*
Treatment	0.117	5	0.023	11.50*
Interaction	0.073	30	0.002	1.00
Subtotal	0.424	41		
Within groups	0.182	84		
Total	0.606	125		

*Denotes significance at 95%.

Table 2 (Continued)

Foliar Nitrogen Content - 3X10

Source	Sum of squares	df	Mean square	F ratio
Location	0.127	9	0.014	14.00*
Treatment	0.086	2	0.043	4.30*
Interaction	0.046	18	0.003	3.00*
Subtotal	0.259	41		
Within groups	0.081	60	0.001	
Total	0.340	89		

Foliar Phosphorus Content - 3X10

Source	Sum of squares	df	Mean square	F ratio
Location	1.451	6	0.242	80.500*
Treatment	0.051	5	0.010	2.500*
Interaction	0.256	30	0.009	
Subtotal	1.750	41		
Within groups	.376	84		
Total	2.134	125		

Foliar Potassium Content - 3X10

Source	Sum of squares	df	Mean square	F ratio
Location	0.795	9	0.088	14.66*
Treatment	0.047	2	0.024	4.00*
Interaction	0.009	18	0.009	1.50
Subtotal	0.996	29		
Within groups	0.330	60	0.006	
Total	1.326	89		

All foliar phosphorus concentrations were significant from the control. The NPK, NK, and N treatments are not significant from each other; however, they are significantly lower than the control or PK treatment. The PK treatment is the only treatment significantly higher than the control, which reinforces the antagonistic effect of nitrogen fertilization on foliar phosphorus observed by others (Leyton, 1957; Kurankina, 1957).

The SNK test on three means shows that the N and NPK treatments are significantly lower than the control.

The foliar potassium content for six treatments shows there are significant differences but no real pattern is apparent. The PK treatment is significantly higher but the NK treatment was not significant from control. The NPK, N, and NP treatments were significant from the control but had a lower concentration. Again, testing three means the results were the same.

In summary two conclusions can be made:

1. Foliar nitrogen content increased when nitrogen was applied.

2. Where foliar nitrogen increased significantly, foliar phosphorus decreased. This was attributed to an antagonism between nitrogen and phosphorus.

GROWTH RESPONSE

One objective of this study was to determine if there was a growth response. Originally height and diameter growth were to be checked. Height growth was not used due to the complexity of obtaining accurate data because many of the trees had terminal leader damage caused by the spruce budworm (Schmidt and Fellin).

With the exception of three locations, there was a growth increase in mean radial increment on the treated plots versus the untreated plots. At the locations where this was not true, two of the locations, Clearwater and Murray Creek, had the PK treatment, showing less growth than the control. The other location, Barber Creek, had a nitrogen-only treatment showing less growth than the control.

An analysis of variance was run for each location using the data for radial increment. There were only two locations that showed a significant treatment response. The two locations are Upper Cottonwood and Murray Creek.

When growth responses were combined for all locations, no significant results of the treatments on growth were detected. However, when the radial increment was converted to a percent of the control, significant responses were obtained (see Table 3). This conversion eliminates variation due to locations.

Table 3. Percent Radial Increment Increase

Location	Control	PK
02 Upper Cottonwood	100	----
03 Rice Ridge	100	100.0
04 Clearwater	100	90.0
05 Barber Creek	100	----
06 Coram	100	112.0
07 Margaret Creek	100	----
08 Murray Creek	100	92.0
09 Trout Lake--Thinned	100	125.0
11 Skid Creek	100	107.0
12 Buckhorn Creek	100	----
Mean		X=104.3
Variance		144.88
Standard Deviation		12.3
Coefficient of Variation		11.6%
95% Confidence Interval		9.6
95% Confidence Limits		94.7 -113.9

N	NP	NK	NPK
----	----	----	161.0
129.0	131.0	134.0	120.0
112.0	131.0	156.0	144.0
100.0	----	----	119.0
154.0	135.0	117.0	136.0
127.0	----	----	121.0
141.0	164.0	145.0	149.0
118.0	119.0	142.0	129.0
108.0	132.0	110.0	135.0
106.0	----	----	109.0
X=121.6	X=135.3	X=134.0	X=133.3
278.3	189.55	55.6	211.4
16.7	13.76	15.989	14.5
13.7%	10.1%	12.0%	10.9%
10.9	11.0	12.8	8.9
110.7-132.5	124.3-146.3	121.2-146.8	124.4-142.2

To determine significance, an analysis of variance similar to the foliar content analysis was run. Two separate analyses were made. One was a 6X6 factorial (6 treatments and 6 locations), while the other was a 3X8 (3 treatments and 6 locations). Table 4 shows the results.

Using the data from Table 4, we can compute the 95% confidence intervals. At the 95% level all treatments are above the control with the exception of the PK treatment.

Table 4. Statistical Analysis of Percent Radial Increment Increase Using 6X6 and 3X8 Factorial

6X6

Source	Sum of squares	df	Mean square	F ratio
Location	904.00	5	180.80	0.997
Treatment	8203.00	5	1650.60	9.101*
Residual	4534.00	25	181.36	
Total	13651.00	35		

3X8

Source	Sum of squares	df	Mean square	F ratio
Location	1841.00	7	236.00	2.271
Treatment	3637.00	2	1818.50	15.706*
Residual	1621.00	14	115.78	
Total	7099.00	23		

*Denotes significance of 99%.

Assuming that the treatments whose confidence intervals (from Table 3) do not overlap indicate significant growth response, we can calculate the percentage of radial increment increase as follows: N, 21.6; NK, 34.0; NP, 35.3; PK, 4.3; and NPK, 33.3.

Although the PK treatment showed a slight radial increment increase, the confidence interval overlapped the control. All the other treatments had non-overlapping confidence intervals greater than the control. However, some treatment intervals overlapped each other.

As before, nitrogen played the dominant role. Treatments containing nitrogen were the ones with the greatest response.

RELATIONSHIP OF FOLIAR CONTENT AND GROWTH

An objective of this study was to determine if a relationship existed between foliar nutrient content and growth. In this study, radial growth increments were used since height growth was unavailable because of reasons cited earlier.

A plot of foliar nutrient content versus growth illustrated a clear relationship in only a few cases. When plotting percent radial increment increase versus the N/P ratio two locations, Clearwater and Murray Creek, had similar patterns. Both of these areas have older trees, which could indicate that there are differences in fertilization effects dependent on age. However, for purposes of this study all locations were lumped together.

After obtaining a visual idea of the relationships, the linear correlation coefficients were computed to determine if there were statistical relationships.

The relationship and correlation coefficients of the better graphs are summarized in the following table.

Table 5. Correlation of Growth and Foliar Nutrient

Actual mean increment vs N/P ratio	0.4073
Percent radial increment vs N/P ratio	0.4985
Actual mean increment vs percentage N	0.6797
Percent radial increment vs percentage N	0.7089

The correlation coefficients show that the percent radial increment increase versus percent N has the best coefficient. Computing the confidence interval for 0.7089 at the 95% level, we get an in interval of 0.53-0.82. This indicates that the correlation between percent growth increase and percent N content would not be good in all cases; however, it does indicate a trend. Due to the lack of visual evidence from graphic data presentation and low correlation coefficient, no further attempt was made to determine a relationship.

Chapter 5

DISCUSSION

The original fertilization study was started in 1966. This was the first field study conducted on western larch in Montana, and it was designed primarily as an exploratory study.

A significant foliar nutrient content response did occur with fertilization. In addition, the responses were similar to what other research has shown. Foliar nitrogen increased in almost all cases where nitrogen was applied. Increased nitrogen content resulted in a decrease of phosphorus content (Leyton, 1956, 1967). The decrease in phosphorus and some potassium content could be due to the large amount of nitrogen absorbed in relation to phosphorus and potassium. These results help confirm that foliar nutrient ratios (rather than percentages) are likely to be the most sensitive guide to fertilizer applications (Leyton, 1957; Van Goor, 1953; Kurankina, 1957).

Leyton (1957) found that the optimum value of nitrogen content for Japanese larch was 2.85%. The highest value for this study was 2.46%. Western larch either has a lower optimum, or the optimum was not being reached. If the optimum is not being reached, it could be due to the ratio of nitrogen fertilizer to other fertilizers applied. There may also be some limiting factor such as moisture that may have limited the uptake of nutrients, since 1967 was a drought year compared to 1966. The 1968 radial increment on the control plots was approximately 70% of the 1966 increment. The nutrient may not have been utilized due to the lack of moisture.

The radial increment data was first analyzed by location. There were only two locations that showed a significant growth response. One reason could be the time lag between the uptake of nutrients and conversion to growth. The study has shown that the nutrient content of the trees was increased in most cases.

A tree responds to fertilization by absorbing the fertilizer and increasing the foliar nutrient content. After nutrient uptake, an increase in crown or crown photosynthetic efficiency needs to occur before an increment increase will become apparent. Because of the short time between treatment and sampling, the growth increase may not have occurred yet.

Another factor may be the amount of variation observed in the plots during collection of data. There was variation between trees within the plots as well as between the plots. This lack of homogeneity between plots may overshadow any growth response that occurs, unless an analysis is used that will take this variation into account.

The analysis of all locations using percent radial increment increase showed a significant growth response. Percent radial increment increase occurred for all treatments with the exception of one, the PK treatment. Research has shown that nitrogen is the nutrient most related to growth response (Leyton, 1957a; Tamm, 1964); therefore, the lack of response from the PK treatment would be expected.

Based on percent radial increment increase, a growth response to fertilization is occurring. However, a better analysis of growth response can be made when the data is collected again in 1971. At that time, data will be available to determine the extent of natural growth variations.

The last objective of this study was to determine if a correlation could be established between foliar nutrient content and growth. Leyton (1957), using Japanese larch, found that height response could be interpreted directly in terms of nitrogen concentration in the foliage. Additionally, the nutrient ratios of N/P, N/K, and P/K could be used to interpret growth data. The correlation coefficients developed from this study using the various factors ranged from 0.4070 to 0.7089. The correlation that showed the best relationship was percent radial increment increase related to nitrogen content.

The coefficients may improve when the data is collected at a later time, if there is a time lag factor. It will take more study to determine how accurately growth response can be predicted using foliar nutrient content.

Chapter 6

SUMMARY

A study to deermine the effect of fertilization on western larch was started in the fall of 1966. In 1968, measurements were obtained to determine whether responses could be detected as soon as two years after fertilization.

The following responses were observed:

1. Foliar nutrient content had significant changes after fertilization.

2. An increase in percent radial increment growth occurred.

3. A correlation between foliar nutrient content and growth increment was obtained.

The study has shown that western larch is responding to fertilization. Although responses are occurring, it will require more research to determine if the responses will continue or become economically important.

LITERATURE CITED

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

———, I. MacRae, and R. C. Speer.
1965. Foliar analysis of Douglas-fir from aerial forest fertilization trails on Vancouver Island, British Columbia. Paper presented at Fourth California Forest Soil Fertility Conference, Redding, California, May 10-11.

Behan, M. J.
1967a. A diagnosis of mineral deficiency in western larch by visual symptoms. University of Montana Forest and Range Experiment Station Bulletin. In press.

———.
1967b. The relationship between growth and foliar mineral composition in western larch (*Larix occidentalis*, Nutt.) grown in sand cultures. Manuscript pending publication.

———, and W. Friedrich.
1967. The effect of season and crown position on the foliar mineral content of western larch (*Larix occidentalis*, Nutt.) Manuscript publication.

———.
1968. Fertilization in western larch forests. Montana Forest and Conservation Experiment Station, School of Forestry, University of Montana, Note 6.

———, and T. Kinraide.
1970. Rapid wet ash digestion of coniferous foliage for analysis of potassium, phosphorus, calcium and magnesium. Montana Forest and Conservation Experiment Station Bulletin 39, Sept. 1970.

Bradstreet, R. B.
1964. The Kjeldahl method for organic nitrogen. Chemical Rubber Co. Publications.

Dixon, W. J., and F. J. Massey.
1957. Introduction to statistical analysis. McGraw-Hill, 1957, (155-62).

Edwards, M. V.
1961. Effects of different forms and amounts of basic slag and mineral phosphate on the growth of Japanese larch planted on blanket bog. Rep. For. Res. (London), 1958-1959: 111. (From Forestry Abstracts No. 1786, 1961).

Gessel, S. P., T. N. Stoate, and K. J. Turnbull.
1965. The growth behavior of Douglas-fir with nitrogenous fertilizer in western Washington. College of Forestry, Institute of Forest Products, University of Washington Research Bulletin No. 1.

Hagner, S., J. Saraste, B. Joharsson, and A. Ahgren.
Timber production by forest fertilization. Vukesfranställning genom skögsgodsling Särtrych ur Sveriges Skogsnardsförbonds Trdshrift, Häfte 2, 1966.

Jackson, M. L.
1958. Soil Chemical Analysis. Prentice-Hall.

Jung, J., and G. Riechle.
Long-term fertilization studies with forest plants in pots. Forstwiss Chl. 85 (3/4), 1966, (107-20). (Abstract only.) (For. Abstract No. 27).

Kawada, H.
1964. A fertilizer treatment on young larch forests on wet podzolized soils. On effects of fertilizer on growth of larch and composition of needles. For. Exp. Station Bulletin. Meguro, Tokyo No. 162, 1964, (143-62). (Abstract only). (For. Abstract No. 26).

Kurankina, L. I.
1957. Effect of fertilizer on growth and development of larch seedlings. Botanicheskii Zhurnal, 42(1): 68-72.

Leyton, L.
1948. Mineral nutrient relationships of forest trees. From Forestry Abstracts 9: 399-408.

________.
1956. The relationships between the growth and mineral composition of the foliage of Japanese larch (*Larix leptolepis*, Mun.) Plant and Soil 7: 167-177.

Leyton, L.
1957. The relationships between the growth and mineral composition of the foliage of Japanese larch II. Evidence from Manurial trails. Plant and Soil 9: 31-48.

Schmidt, W. D., and D. G. Fellin.
Effect of spruce budworm on western larch height growth and form. Manuscript in preparation.

Tamm, C. O.
Unknown. Forest fertilization in Europe. Its research and practices. Forest Fertilization--a new era. Hand book by the American Potash Institute.

________.
1964. Growth and nutrient concentrations of spruce on various levels of nitrogen fertilization. Plant Analysis and Fertilizer Problems IV. Edited by C. Bould, P. Prevot, and J. R. Mogness. W. F. Humphrey Press Inc.

U. S. Dept. of Agriculture.
1965. Timber trends in the United States. U. S. Dept. of Agriculture Forest Resource Rep. 17, 235pp. illus.

Van Goor, C. P.
1953. The influence of nitrogen on the growth of Japanese larch (Larix leptolepis, Mun.). Plant and Soil V., No. 1.

Will, G. M.
1957. Variations in the mineral content of radiata pine needles with age and positioning tree crown. New Zealand.

Zahner, R.
1959. Fertilizer trials with loblolly pine in southern Arkansas. Journal Forestry, 57: 812-816.

APPENDIX A

MARKING AND IDENTIFICATION

Each sample tree will have a five-digit code number attached to it. Each digit will identify the tree as follows:

1st and 2nd Digit	Location
01	Lower Cottonwood Lakes
02	Upper Cottonwood
03	Rice Ridge
04	Upper Clearwater
05	Barber Creek
06	Coram Experimental Forest
07	Margaret Creek
08	Murray Creek
09	Trout Lake--thinned
10	Trout Lake--unthinned
11	Skid Creek
12	Buckhorn Creek

3rd Digit	
1	Rep 1
2	Rep 2
3	Rep 3

4th Digit	Treatment	Color Code
1	A-$N_3P_2K_0$	Orange
2	B-$N_3P_0K_0$	Blue
3	C-$N_3P_0K_2$	Red
4	D-$N_0P_0K_0$	White
5	E-$N_0P_2K_2$	Yellow
6	F-$N_3P_2K_2$	Green

5th Digit	Tree Number
1	1
2	2
3	3
4	4
5	5

Example: 01234 = Lower Cottonwood Lakes, Rep 2, Treatment C-$N_3P_0K_2$, tree No. 4.

The original study used alfameric to designate treatment.

APPENDIX B

Table 6. Data Summary

Location	Treatment	Mean Radial Increment	% Increase Radial Increment	%N	%P	%K	N/P Ratio	N/K Ratio	K/P Ratio
02 Upper Cottonwood	Control	1.711	100	1.59	.315	.887	5.11	1.80	2.84
	NPK	2.758	161	2.48	.195	.835	12.50	2.96	4.27
03 Rice Ridge	Control	1.78	100	1.74	.264	.830	7.07	2.11	3.25
	PK	1.78	100	1.61	.353	.890	4.77	1.82	2.63
	N	2.31	129	1.77	.274	.810	6.72	2.19	3.03
	NP	2.34	131	2.08	.291	.832	8.37	2.66	3.03
	NK	2.39	134	1.81	.185	.862	10.25	2.11	4.76
	NPK	2.32	130	1.99	.266	.816	7.54	2.47	5.09
04 Clearwater	Control	1.21	100	1.32	.206	.768	6.85	1.81	3.75
	PK	1.09	90	1.43	.204	.845	7.05	1.69	4.16
	N	1.36	112	1.64	.127	.782	12.70	2.13	6.15
	NP	1.57	144	1.64	.147	.760	11.32	2.17	5.26
	NK	1.89	156	1.90	.138	.810	13.70	2.38	6.07
	NPK	1.74	144	1.64	.147	.760	11.32	2.17	5.26
05 Barber Creek	Control	2.085	100	1.64	.231	.712	7.23	2.31	3.11
	N	2.079	99	1.90	.166	.712	12.04	2.67	4.53
	NPK	2.494	119	1.99	.196	.760	10.59	2.63	4.04

Table 6 (Continued)

Location	Treatment	Mean Radial Increment	% Increase Radial Increment	%N	%P	%K	N/P Ratio	N/K Ratio	K/P Ratio
06 Coram	Control	2.45	100	1.81	.337	.940	5.52	1.92	2.84
	PK	3.001	122	2.11	.318	.868	7.54	2.48	2.88
	N	3.788	154	2.46	.198	.810	13.01	3.17	4.13
	NP	3.309	135	2.24	.236	.803	9.53	2.82	3.40
	NK	2.883	117	2.09	.266	.815	8.20	2.63	3.09
	NPK	3.359	136	2.33	.228	.858	10.20	2.72	3.76
07 Margaret Creek	Control	3.357	100	1.93	.291	.748	6.65	2.59	2.58
	N	4.290	127	2.42	.213	.683	11.52	5.57	3.27
	NPK	4.051	121	2.38	.187	.748	12.91	3.21	4.07
08 Murray Creek	Control	1.958	100	1.28	.236	.560	5.52	2.30	2.40
	PK	1.805	92	1.22	.231	.540	5.33	2.30	2.33
	N	2.544	141	2.00	.171	.541	11.73	3.72	3.16
	NP	3.209	164	1.83	.193	.595	10.04	3.14	2.15
	NK	2.834	145	1.71	.212	.533	8.85	3.25	2.83
	NPK	2.928	149	1.93	.214	.596	4.04	3.25	2.83
09 Trout Lake--Thinned	Control	3.245	100	1.85	.176	.516	10.63	3.61	2.75

Table 6 (Continued)

Location	Treatment	Mean Radial Increment	% Increase Radial Increment	%N	%P	%K	N/P Ratio	N/K Ratio	K/P Ratio
Trout Lake (Cont'd.)	PK	4.055	125	1.88	.212	.613	8.94	3.14	2.87
	N	3.831	118	2.22	.147	.520	15.24	3.98	3.73
	NP	3.876	119	2.28	.155	.578	14.83	3.98	3.73
	NK	4.625	142	2.11	.163	.740	13.02	2.94	4.55
	NPK	4.197	129	1.91	.187	.683	10.27	2.80	3.70
11 Skid Creek	Control	2.657	100	1.96	.326	.888	6.03	2.21	2.74
	PK	2.861	107	1.80	.304	.898	6.02	2.04	2.96
	N	2.876	108	1.90	.269	.783	7.54	2.52	3.00
	NP	3.503	132	2.04	.263	.706	7.78	2.90	2.70
	NK	2.934	110	2.08	.252	.631	8.43	2.66	3.16
	NPK	3.598	135	2.12	.228	.763	9.37	2.77	3.53
12 Buckhorn Creek	Control	2.137	100	1.85	.309	.853	2.09	2.22	2.77
	N	2.281	106	2.07	.209	.683	9.87	3.03	3.27
	NPK	2.324	109	2.37	.231	.765	10.72	3.27	3.28

APPENDIX C

PLOT DESCRIPTIONS

01 Lower Cottonwood Lakes

- T 16N R 14W Sec. 3 PM
- Epx: NE
- Slope: 15%
- Elevation: 4900 MSl
- Age: 14
- Ht: 1.2-3.9M
- Site Index: 65
- Density: Thinned to 12X12, 1966
- Soil:
  - Class: Cryokrept
  - Landform: Bench (Till)
  - Parent Rock: Argillite-Quartzite
- Vegetation:
  - Alpine fir: (*Abies lasiocarpa*)
  - Engelmann spruce (*Picea engelmanii*)
  - Douglas fir (*Pseudotsuga mensiesii*)
  - Lodgepole pine (*Pinus contorta*)
  - Western larch (*Larix occidentalis*)
  - Quaking aspen (*Populus tremuloides*)
  - Willow (*Salix* spp.)
  - Cottonwood (*Populus* spp.)
  - Pachystima (*Pachystima myrsinites*)
  - Ceanothus (*Ceanothus velutinus*)
  - Menziesia (*Menziesia glabella*)
  - Beargrass (*Xerophyllum tenax*)
  - Oregon grape (*Mahonia repens*)
  - Ribes (*Ribes* spp.)
  - Serviceberry (*Amelanchier alnifolia*)
  - Huckleberry (*Vaccinium membranaceum*)
  - Dwarf huckleberry (*Vaccinium membranaceum*)

02 Upper Cottonwood

- T 16N R 14W Sec. 4 PM
- Exp: NW
- Slope: 18%
- Elevation: 5200 MSl
- Age: 14
- Ht: 2.0-4.0M
- Site Index: 60
- Density: 6946 stem/acre
- Soil:
  - Class: Cryoboralf
  - Landform: Valley Bench (Till)
  - Parent Rock: Argillite-Quartzite

Upper Cottonwood (Cont'd.)

Vegetation:
  Western larch
  Alpine fir
  Engelmann spruce
  Douglas fir
  Pachystima
  Huckleberry
  Serviceberry
  Beargrass
  Willow

03 Rice Ridge

T 17N R 15W Sec. 26 PMM
Exp: S and SW
Slope: 10 and 20%
Elevation: 4860 MSl and 4900 MSL[*]
Age: 20
Ht: 2.0-7.4M
Site Index: 70
Density: 35511 stem/acre
Soil:
  Class: Typic Cryoboralf
  Landform: Valley Bench (Till)
  Parent Rock: Argillite-Quartzite
Vegetation:
  Western larch
  Douglas fir
  Ponderosa pine (*Pinus ponderosa*)
  Engelmann spruce
  Alpine fir
  Snowberry (*Symphoricarpos albus*)
  Serviceberry
  Kinnikinnick (*Archtostaphylos uva-ursi*)
  Spiraea (*Spiraea* spp.)
  Beargrass
  Ceanothus
  Pachystima
  Oregon grape
  Mountain maple (*Acer glabrum*)

04 Upper Clearwater

T 19N R 16W Sec. 26 PPM
Exp: SSW
Slope: 10%

---

[*] The plots were located on two distinct areas.

Upper Clearwater (Cont'd.)

Elevation: 4425 MSl
Age: 62
Ht: 12.5-22.2M
Site Index: 60
Density: Thinned to 13' X 14', 1962
Soil:
  Class: Cryoboralf
  Landform: Valley Bench (Till)
  Parent Rock: Argillite-Quartzite
Vegetation:
  Western larch
  Douglas fir
  Ponderosa pine
  Lodgepole pine
  Engelmann spruce
  Beargrass
  Kinnikinnick
  Huckleberry
  Oregon grape
  Spiraea
  Pachystima
  Juniper (*Juniperus horizontalis*)

05 Barber Creek

T 20N R 16W Sec. 28 PMM
Exp: W
Slope: 18%
Elevation: 4050 MSl
Age: 13
Ht: 2.9-5.3M
Site Index: 80
Density: 3635/acre
Soil:
  Class: Typic Vitrandept
  Landform: Valley Bench (Till)
  Parent Rock: Argillite-Quartzite
Vegetation:
  Western larch
  Douglas fir
  Ponderosa pine
  Lodgepole pine
  Engelmann spruce
  Alpine fir
  Snowberry
  Pinegrass (*Calamagrostis rubescens*)
  Serviceberry
  Kinnikinnick
  Oregon grape

Barber Creek (Cont'd.)

Vegetation (Cont'd.):
  Mountain maple
  Willow
  Spiraea
  Wild rose (*Rosa woodsii*)

06 Coram Experimental Forest

T 30N R 18W Sec. 6 PMM
Exp:
Slope:
Elevation:
Age: 16
Ht: 3.2-8.0M
Site Index: 50-55
Density: 905 stem/acre
Soil:
  Class: Typic Vitrandept
  Landform: Valley slope (Till)
  Parent rock: Argillite-Quartzite
Vegetation:
  Western larch
  Engelmann spruce
  Alpine fir
  Western white pine (*Pinus monticola*)
  Pachystima
  Willow
  Huckleberry
  Serviceberry
  Cottonwood
  Thimbleberry (*Rubus parviflorus*)
  Fireweed (*Epilobium angustifolium*)
  Beargrass
  Spiraea

07 Margaret Creek

T 30N R 18W Sec. 11 PMM
Exp: NNW
Slope: 17%
Elevation: 4175 MSl
Age: 15
Ht: 3.4=6.1M
Site Index: Not available
Density: Thinned to 12' X 12', 1962
Soil:
  Class: Typic Vitrandept
  Landform: Valley slope (Till)
  Parent rock: Argillite-Quartzite

Margaret Creek (Cont'd.)

Vegetation:
- Western larch
- Engelmann spruce
- Alpine fir
- Western white pine
- Pachystima
- Willow
- Huckleberry
- Twinflower (*Linnaea borealis* var. *americana*)
- Yew (*Taxus brevifolia*)
- Mountain maple
- Fireweed
- Alder (*Alnus* spp.)

08 Murray Creek

T 29N R 17W Sec. 29 PMM
Exp: N
Slope: 15%
Elevation: 3775 MSL
Age: 37
Ht: 3.4-6.1M
Site Index:
Density: Thinned to 10' X 10', 1962
Soil:
- Class: Typic Vitrandept
- Landform: Bench (Till slope)
- Parent Rock: Argillite Quartzite

Vegetation:
- Western larch
- Alpine fir
- Engelmann spruce
- Pachystima
- Willow
- Twinflower
- Alder
- Mountain maple
- Spiraea

09 Trout Lake--Thinned

T 28N R 17W Sec. 22 PMM
Exp: NNW
Slope: 5-10%
Elevation: 3970 MSL
Age: 15
Ht: 3.2-7.4M
Site Index:
Density: Thinned to 9' X 9', 1962

Trout Lake-Thinned (Cont'd.)

Soil:
  Class: Typic Vitrandept
  Landform: Glacial outwash terrace
  Parent Rock: Argillite-Quartzite
Vegetation:
  Alpine fir
  Engelmann spruce
  Western larch
  Western white pine
  Huckleberry
  Pachystima
  Beargrass
  Pinegrass
  Spiraea
  Broken fern (*Pteridium aquilinum* var. *pubescens*)

11 Skid Creek

T 34N R 27W Sec. 29 PMM
Exp: ESE
Slope: 15-20%
Elevation: 4600 MSL
Age: 12
Ht: 2.4-5.5M
Site Index: 90
Density: 6835 stem/acre
Soil:
  Class: Typic Cryandept
  Landform: Glacial Lacustrine-Bench
  Parent Rock: Argillite-Quartzite
Vegetation:
  Alpine fir
  Engelmann spruce
  Western white pine
  Western larch
  Pachystima
  Thimbleberry
  Ribes
  Huckleberry
  Spiraea
  Strawflower (*Anaphalis margaritacea*)

12 Buckhorn Creek

T 34N R 27W Sec. 14 PMM
Exp: NNE
Slope: 20-25%
Elevation: 4460 MSL
Age: 12

Buckhorn Creek (Cont'd.)

Ht: 3.1-6.5M
Site Index: 90
Density: 6835 stem/acre
Soil:
  Class: Typic Cryandept
  Landform: Valley slope (Till)
  Parent Rock: Argillite-Quartzite
Vegetation:
  Alpine fir
  Engelmann spruce
  Western larch
  Dwarf huckleberry
  Pinegrass
  Buffaloberry (*Shepherdia canadensis*)
  Pachystima
  Spiraea
  Menziesia
  Twinflower