A STUDY OF THE GROWTH OF DOUGLAS FIR
(PSEUDOTSUGA MENZIESII)
SEEDLINGS

by

MICHAIL SCHAEDLE
B.S.A., University of British Columbia, 1957

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE IN AGRICULTURE
in the Department
of
SOIL SCIENCE

We accept this thesis as conforming to the
required standard.

THE UNIVERSITY OF BRITISH COLUMBIA
April, 1959
ABSTRACT

The object of this work was to study the soil and nutrient requirements of Douglas fir seedlings in relation to their physiological development. For this purpose, fertilizer, irrigation, growth and nutrient uptake experiments were conducted at the Green Timbers Forest Nursery and the University of British Columbia.

The experimental sites were characterized by chemical and physical soil analysis. The N, P, K, Ca and Mg content of 0-0 and 1-0 seedlings was determined. Statistical methods of analysis were used to determine the significance of experimental results.

Douglas fir seedlings during the first year in the nursery (0-0) produced little dry matter and removed small amounts of nutrients from the soil. The application of 20 to 30 lbs. per acre of nitrogen increased the growth of 0-0 seedlings in 1957 and 1958. Fertilization with potassium decreased, and with phosphorus increased, the growth of 0-0 seedlings in 1957 but had no effect in 1958. Application of compost, mushroom manure and cow manure increased the growth of 0-0 Douglas fir seedlings. The fertilization of 0-0 seedlings with mineral fertilizers had no effect on their development in the subsequent year.

In the second year of growth (1-0), the dry matter production and the removal of nutrients from the soil by Douglas fir seedlings exceeded that of many agricultural crops. During the summer, 1-0 Douglas fir seedlings passed through at least one period of temporary
dormancy, but their growth was continuous throughout the summer. Nitrogen fertilization increased the length and dry weight of 1-0 seedlings. Application of 320 lb. N per acre decreased growth and resulted in damage to seedling tissues. High phosphorus application decreased the unfavourable effect of excessive nitrogen fertilization. The 1-0 seedlings did not respond to potassium fertilization. Phosphorus, however, increased the dry weight of the 1-0 seedlings when applied at a rate of 320 lb. P2O5 per acre. Late summer nitrogen applications resulted in very rapid seedling growth during autumn, however, dormancy was delayed and the seedlings were heavily damaged by frost. Nitrogen fertilization in September increased the frost resistance of dormant 1-0 seedlings.

Irrigation increased the height and weight of 1-0 Douglas fir seedlings. Heavy irrigation decreased the winter hardiness of the seedlings.

The duration and time of the dormant period was found to be influenced by fertilization and soil moisture conditions. Each seedling, however, had individual dormancy characteristics.
In presenting this thesis in partial fulfilment of the requirements for an advanced degree at the University of British Columbia, I agree that the Library shall make it freely available for reference and study. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the Head of my Department or by his representatives. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Department of Soil Science

The University of British Columbia, Vancouver 8, Canada.

Date April 15, 1959
TABLE OF CONTENTS

INTRODUCTION ................................................. 1

SOME FACTORS AFFECTING THE GROWTH AND DEVELOPMENT OF SEEDLINGS .................. 2

EXPERIMENTAL .................................................. 5

Climate ......................................................... 5

Nursery Management Practices .................. 5

Fertilization, Seeding and Irrigation of Experimental Plots .................. 6

Sampling Method ............................................. 8

Statistical Analysis ....................................... 9

Soil Analysis .................................................. 10

Plant Analysis ................................................ 11

EXPERIMENTS WITH DOUGLAS FIR SEEDLINGS ................. 20

Part A, Experiment 1. ....................................... 20

Part A, Experiment 2.1. ..................................... 26

Part A, Experiment 2.2. ..................................... 29

Part A, Experiment 3.1. ..................................... 30

Part A, Experiment 3.2. ..................................... 33

Part A, Experiment 4. ....................................... 35

Part A, Experiment 5. ....................................... 38

Part A, Experiment 6. ....................................... 42

Part A, Experiment 7. ....................................... 46
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part D, Experiment 8</td>
<td>19</td>
</tr>
<tr>
<td>Part E, Experiment 9</td>
<td>55</td>
</tr>
<tr>
<td>Experiment 10</td>
<td>59</td>
</tr>
<tr>
<td>Experiment 11</td>
<td>76</td>
</tr>
<tr>
<td>GENERAL DISCUSSION</td>
<td>83</td>
</tr>
<tr>
<td>Growth and Development of 0-0 Douglas fir Seedlings</td>
<td>83</td>
</tr>
<tr>
<td>Growth and Development of 1-0 Douglas fir Seedlings</td>
<td>84</td>
</tr>
<tr>
<td>Some Differences Between 0-0 and 1-0 Douglas Fir Seedlings</td>
<td>86</td>
</tr>
<tr>
<td>Dormancy of Douglas Fir Seedlings</td>
<td>87</td>
</tr>
<tr>
<td>SUMMARY</td>
<td>90</td>
</tr>
<tr>
<td>APPENDIX I</td>
<td>93</td>
</tr>
<tr>
<td>Tables</td>
<td>93</td>
</tr>
<tr>
<td>Climatic Data</td>
<td>141</td>
</tr>
<tr>
<td>APPENDIX II</td>
<td>143</td>
</tr>
<tr>
<td>Equation Used for the Calculation of the Integrated Mean Soil Moisture Tension</td>
<td>143</td>
</tr>
<tr>
<td>Statistical Analysis of a Partially Confounded 5 x 5 x 3 Factorial Experiment, Replicated Two Times</td>
<td>144</td>
</tr>
<tr>
<td>APPENDIX III</td>
<td>156</td>
</tr>
<tr>
<td>Plates</td>
<td>156</td>
</tr>
<tr>
<td>SELECTED BIBLIOGRAPHY</td>
<td>161</td>
</tr>
</tbody>
</table>
## LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>Part</th>
<th>Experiment</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A, 1</td>
<td>Nitrogen fertilization</td>
<td>Effect on length, dry weight, and stem diameter of 1-0 Douglas fir seedlings</td>
<td>22</td>
</tr>
<tr>
<td>2</td>
<td>A, 1</td>
<td>Nitrogen fertilization</td>
<td>Total uptake of nitrogen, phosphorus, potassium, calcium, and magnesium</td>
<td>23</td>
</tr>
<tr>
<td>3a</td>
<td>A, 1</td>
<td>Nitrogen fertilization</td>
<td>Concentration in 1-0 Douglas fir seedling, tops</td>
<td>24</td>
</tr>
<tr>
<td>3b</td>
<td>A, 1</td>
<td>Nitrogen fertilization</td>
<td>Concentration in 1-0 Douglas fir seedling, roots</td>
<td>24</td>
</tr>
<tr>
<td>4</td>
<td>A, 2a</td>
<td>Nitrogen fertilization</td>
<td>Effect of N, P, and K on length and dry weight of 0-0 Douglas fir seedlings</td>
<td>28</td>
</tr>
<tr>
<td>5</td>
<td>A, 3a</td>
<td>Nitrogen fertilization</td>
<td>Dry weight and length of tops of 0-0 (1957) Douglas fir seedlings</td>
<td>32</td>
</tr>
<tr>
<td>6</td>
<td>A, 3b</td>
<td>Nitrogen fertilization</td>
<td>Effect of fertilizer applications on growth in the following year</td>
<td>34</td>
</tr>
<tr>
<td>7</td>
<td>A, 4</td>
<td>Nitrogen fertilization</td>
<td>Effect of time of nitrogen application</td>
<td>37</td>
</tr>
<tr>
<td>8</td>
<td>A, 5</td>
<td>Nitrogen fertilization</td>
<td>Effect of N and P on length, dry weight, and stem diameter</td>
<td>41</td>
</tr>
<tr>
<td>9</td>
<td>A, 6</td>
<td>Nitrogen fertilization</td>
<td>Effect of time of fertilization on length, dry weight, and stem diameter</td>
<td>44</td>
</tr>
<tr>
<td>TABLE 10</td>
<td>Part A, Experiment 7: The effect of organic and mineral fertilizers on the length and dry weight of 0-0 Douglas fir seedlings.</td>
<td>48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TABLE 11</td>
<td>Part E, Experiment 9: The effect of soil moisture tension on the growth of 1-0 Douglas fir seedlings.</td>
<td>58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TABLE 12</td>
<td>Part D, Experiment 8: The effect of nitrogen and phosphorus fertilization on the length and dry weight of Douglas fir seedlings.</td>
<td>52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TABLE 13</td>
<td>Experiment 10: Total uptake of N, P, K, Ca and Mg by 0-0 and 1-0 Douglas fir seedlings.</td>
<td>61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TABLE 14</td>
<td>Experiment 10: Uptake of N, P, K, Ca and Mg by 1-0 Douglas fir seedlings during two periods in the growing season.</td>
<td>61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TABLE 15</td>
<td>Experiment 10: Total dry weight production of 0-0 and 1-0 Douglas fir seedlings</td>
<td>62</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TABLE 16</td>
<td>Experiment 11: Length, diameter of stem, and dry weight of 0-0 and 1-0 Douglas fir seedlings at the Green Timbers Nursery in 1957 and 1958.</td>
<td>77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TABLE 17</td>
<td>Experiment 11: The length and dry weight of Douglas fir seedlings from three locations in British Columbia.</td>
<td>77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TABLE 18</td>
<td>Experiment 11: Mineral composition of 0-0 and 1-0 Douglas fir seedling roots in 1957 and 1958.</td>
<td>78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TABLE 19</td>
<td>Experiment 11: Mineral composition of 0-0 and 1-0 Douglas fir seedling tops in 1957 and 1958.</td>
<td>79</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TABLE 20</td>
<td>Experiment 11: Amount of N, P, K, Ca and Mg removed from the soil by 0-0 and 1-0 seedlings, (based on 50 plants per square foot).</td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TABLE 21</td>
<td>Experiment 11: The amount of dry matter produced by 0-0 and 1-0 Douglas fir seedlings, (based on 50 plants per square foot).</td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FIGURE</td>
<td>Description</td>
<td>Page</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>The height and rate of elongation of Douglas fir seedling tops.</td>
<td>66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>The length and rate of elongation of Douglas fir seedling roots.</td>
<td>67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>The dry weight and rate of dry matter production of Douglas fir seedling tops</td>
<td>68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>The dry weight and rate of dry matter production of Douglas fir seedling roots</td>
<td>69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>The dry weight and rate of dry matter production of Douglas fir seedlings</td>
<td>70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>The rate of nitrogen uptake by Douglas fir seedlings.</td>
<td>71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>The rate of phosphorus uptake by Douglas fir seedlings.</td>
<td>72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>The rate of potassium uptake by Douglas fir seedlings.</td>
<td>73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>The rate of calcium uptake by Douglas fir seedlings.</td>
<td>74</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>The rate of magnesium uptake by Douglas fir seedlings.</td>
<td>75</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Dr. C. A. Rowles for his guidance and direction of the study. The author is indebted to Dr. J. S. Clark for the development of a critical scientific attitude and his untiring assistance in the study. The author wishes to thank Mr. R. H. Spilsbury, Research Division, British Columbia Forest Service, for his understanding and considerate organization of the project. For their help in the statistical analysis of the experiments, the author wishes to thank Mr. J. R. H. Dempster, Dr. S. W. Nash and Dr. J. C. Sawyer. The author wishes to thank Messrs. R. Phelps, J. Hoes, N. Sprout and Dr. J. D. Beaton for their practical help, suggestions, and criticism.

The author acknowledges the financial assistance of the Research Division, British Columbia Forest Service.
INTRODUCTION

During the past century, many studies have been made concerning the physiological characteristics and soil requirements of forest tree species of importance in Europe and the Eastern and Southern United States. However, only limited work of this type has been done for the tree species native to the north west coast of North America. This may be attributed to the fact that forest growth is normally very rapid and abundant in the Pacific North West and, therefore, the management practices used are usually extensive. However, forest management practices are becoming more intensive in the coastal area and the demand for more specific information is growing rapidly.

An important part of intensive forest management programs is the production of nursery stock for planting. The characteristics of the nursery seedlings depend, to a large extent, on the management practice followed in the nursery. The only adequate means of evaluating nursery management practices is to understand the factors affecting the growth and development of seedlings.

The object of this work was to study the soil and nutrient requirements of Douglas fir seedlings in relation to the physiological development of the young trees.
The mineral composition, the proportion and size of organs, and the structure and physiological nature of tissues of trees changes with age (66). A tree in the temperate and cold regions of the earth passes through an annual growth cycle, which can be divided into three parts. The growth period during the summer, the rest or dormant period during the winter, and transition periods during fall and spring. The immediate characteristic of a tree is, therefore, determined by the age of the tree and the time of observation.

It has been found that every species has a characteristic pattern of summer growth (8, 41, 47, 48, 51, 52, 55). Red pine, for example, completes practically all of its annual growth during May and June. Balsam fir, however, grows nearly all summer (48). The annual growth pattern of a species can be modified significantly by changes in the environment (52) within the limits of its hereditary potential (4).

The chemical composition of trees varies with species (66, 55), age (55, 33), tissue sampled (55) and the time of sampling (4, 5, 55, 65). The percent of most mineral elements in the tissue of a young tree decreases with age (34, 109). The new growth usually has a higher mineral content than the older tissue regardless of the age of the tree (34, 55, 109). During an annual growth cycle, the mineral concentration is usually lowest during the period of maximum
growth and increases again in the fall, winter and spring (5, 55). This general pattern can vary considerably with species, soil fertility, soil moisture, and the temperature and light conditions.

The effect of fertilizers on coniferous seedlings has been studied by numerous investigators. These studies were made to correct nutrient deficiencies (30, 53, 100), to increase the size and winter hardiness of the seedlings (10, 24, 44, 77, 111, 112), to study the utilization of nutrients (55, 104), and to determine the toxic effect of excess cations and anions (71, 92, 93). A summary of this work is found in the World Forestry Series Bulletin No. 2 (110).

It has been found that excess moisture decreases growth and may lower the winter hardiness of seedlings (11, 89). Lack of moisture on the other hand will limit growth (46), however, soil moisture deficiency in the early fall induces early cessation of growth and increases winter hardiness (90) and, therefore, may be desirable.

Temperature affects the chemical reactions in the plant and in the soil and has, therefore, a significant influence on the growth of young conifers. High temperatures decrease the growth of seedlings or, in extreme cases, may kill the seedlings (9, 42). The susceptibility to heat damage is especially high immediately after germination and decreases with age (37). Kramer (50) demonstrated that for Loblolly pine the seasonal height growth did not depend so much on the mean daily temperature as on the difference between day and night temperatures. Maximum growth was obtained with differences of
12 to 13 degrees centigrade between day and night temperatures.

Light affects conifers through the process of photosynthesis and the phenomena of photoperiodism. Coniferous species vary in the light intensity required for maximum photosynthesis and in the efficiency of photosynthesis at different light intensities (7, 22, 31, 32). The end and beginning of the dormant period is, to some extent, determined by the response of a tree to the length of the dark and light periods (20, 31, 32, 52, 61, 103). Because of this effect on the annual growth cycle, photoperiodism in some cases may determine the resistance of the seedlings to early fall frosts.

From the study of the literature, it was found that little of the information available regarding the growth and development of trees has been obtained with Douglas fir. Unquestionably, most of the factors considered above will affect Douglas fir in a similar manner as other tree species. Therefore, the interrelationship of soil fertility, soil moisture, temperature and light must be considered in the interpretation of any experiment with seedlings.
EXPERIMENTAL

CLIMATE

Climatic data for the Green Timbers Nursery and the University of British Columbia are found in the appendix I (Tables 11 and 12).

With exception of the heavy precipitation in July, the year 1957 can be considered to have been normal. On the other hand, 1958 was very unusual. The precipitation from April to September was considerably less than the 10 year average. The maximum temperature from May to September was approximately 10 degrees Fahrenheit above the 10 year average.

NURSERY MANAGEMENT PRACTICES

At the Green Timbers Nursery, the seedlings are grown in beds 4 feet wide and 50 feet long. Boards 4 to 5 inches high are erected along the beds to give support to the snow fencing used for shading in the summer and protection against frost and snow during the winter. The Douglas fir is seeded by hand broadcast in the latter part of May or the early part of June. During the first summer in the nursery, the seedlings are irrigated to keep the soil moist and the beds are shaded in hot sunny weather. In the fall, the beds
are covered with a rice hull mulch to a depth of 1 inch. This has been found to decrease frost heaving considerably. As an additional winter protection, the beds containing 0-0 seedlings are covered with the snow fence shades.

In the following spring, the 1-0 seedlings are root pruned at a depth of 5 to 6 inches in order to obtain short bushy root systems. The 1-0 seedlings normally are not irrigated but in the summer of 1958, it was necessary to apply some water to prevent seedling mortality.

FERTILIZATION, SEEDING AND IRRIGATION OF EXPERIMENTAL PLOTS

Fertilizer Materials

Ammonium nitrate was applied in solution. The containers for the NH₄NO₃ were tightly stoppered and fresh solutions prepared daily to eliminate losses of ammonia by volitalization.

Triple superphosphate and muriate of pot ash were applied in solid form. The commercial products were ground to a fine, relatively uniform, particle size and mixed with quartz sand to give sufficient material for uniform hand application.

Fertilizer Application and Seeding

After erection of the side boards, the seed beds were cultivated several times with a spring tooth harrow and leveled with
a wooden float. The organic and mineral fertilizers were applied to the plots and worked into the 6 inches of soil with a hoe. The plots were carefully levelled with a rake and watered to decrease the possibility of fertilizer injury. Shortly before seeding, the beds were compacted with a heavy roller to give a firm, fine seed bed. Seed was broadcasted by hand, rolled to press it into the soil and covered with 1/4 to 1/2 inch of loamy sand. All 1-0 seedlings were irrigated after the application of mineral fertilizer to remove fertilizer salts from the needles and to ensure that the fertilizer penetrated the rice hull mulch.

**Irrigation**

The experimental plots of 0-0 Douglas fir seedlings were irrigated in the normal course of the nursery management. In 1957, the moisture supply was apparently adequate up to the middle of August and the 1-0 seedlings grew vigorously without irrigation. In 1958 however, it was necessary to irrigate the 1-0 seedlings in June, July and August to prevent retardation of growth and loss of seedlings due to the lack of moisture. Since the water supply in the nursery was limited, the amount of water applied was governed by the amount of water available. During parts of July and August, 1958, the soil moisture supply was probably not adequate for the seedlings.
For the fertilizer experiments, the plot size was 4 by 8 feet but in the irrigation experiment, 4 by 16 feet plots were used. In all cases, the sampling area was 3 by 6 feet.

To obtain an unbiased sample for the analysis of variance, it was found more efficient to stratify the sample. This was done by subdividing the sample area into 18 square foot units. One or, in some experiments, two randomly selected seedlings were removed from each of the eighteen squares. To facilitate this random sampling, a 3 by 6 foot frame divided into 18 square foot units was placed over the plot leaving a margin of 0.5 foot on each side of the frame and one foot at each end. A small one foot square plastic frame divided into 1/100 square foot units was placed over a square in the large frame. A particular square in the small frame was selected with random numbers and the seedling growing closest to the centre of the small square was harvested. If no seedling was found directly below the small square, then the seedling closest to that square was lifted. The process was repeated with the 18 units in the large frame. The sampling procedure was satisfactory if the density of the seed beds was uniform.

After harvesting, the tops and roots were separated by cutting the seedlings close to the base of the stem. The length of tops was measured from the cut to the upper end of the terminal bud and the roots from the cut to the end of the longest root. The
diameter of the stem was measured 1 cm. above the cut. The tops and the roots were washed thoroughly to remove all soil; dried at 70°C for 48 hours; and then weighed to determine the dry weight.

STATISTICAL ANALYSIS

The statistical significance of the experimental results was tested by the analysis of variance. If the F test was found to be significant for a group of treatments, the LSD (least significant difference) test was applied to that group for the purpose of interpretation and discussion of the data. This eliminated to some extent the inaccuracy of the LSD test for the comparison of more than two means (28).

The analysis of variance of all randomized complete block experiments and of the $5 \times 5$ factorial experiment was conducted as suggested by Federer (27a).

The $3 \times 3 \times 3$ partially confounded factorial experiments were analysed by the method described by Kempthorne (40).

The analysis of variance of the $5 \times 5 \times 3$ partially confounded greenhouse experiment was developed by Dr. S. W. Nash, Department of Mathematics, University of British Columbia, and can be found in appendix II.
SOIL ANALYSIS

Chemical Analysis

Cation Exchange Capacity and Exchangeable Cations

The cation exchange capacity was determined using the ammonium acetate method (75).

The ammonium acetate extract was prepared for the analysis of Ca, Mg, and K, by the destruction of organic matter and acetate with aqua regia and subsequent dehydration of silica by evaporation with HCl (75).

Calcium and potassium were determined with the flame photometer. The versenate titration with Erichrome Block T indicator was used for the determination of Calcium plus magnesium.

Organic Matter

The organic matter content was determined by the wet combustion method described by Peach et al (75).

pH

The pH was measured with a glass electrode using a soil : water ratio of 1:1.

Adsorbed Phosphorus

Adsorbed phosphorus was extracted with 0.03 N ammonium
fluoride in 0.025 N HCl (15). The amount of phosphorus in the extract was found by the molybdenum blue method (23).

Physical Analysis

The hydrometer method (14) was used for the mechanical analysis of the soil samples. Organic matter was destroyed in three 100 g. samples with H2O2. One of the samples was used for the determination of the organic matter free dry weight of the soil. The other two samples were dispersed with a mechanical stirrer using sodium-hexametaphosphate as dispersing agent.

To determine the relation between soil moisture tension and moisture content, for the irrigation experiment, soil core samples were obtained from two locations. In each location quintuple samples were taken from 0 to 5, 5 to 10 and 10 to 15 inches.

The soil moisture content at 1/3 atmosphere tension was determined with a pressure pot (83) and the pressure membrane (84) was used for 1, 2, 4 and 6 atmospheres tension.

PLANT ANALYSIS

The analytical methods adopted for the analysis of Douglas fir tissue samples had to be modified considerably to permit rapid analysis with satisfactory precision and accuracy. The methods used are therefore described in detail.
The Determination of Nitrogen by the Modified Kjeldahl Method (39, 64, 74)

Reagents

1) Concentrated H_2SO_4 containing 33 g. of salicylic acid per liter.
2) NaOH containing 120 g. of Na_2S_2O_3·5H_2O per liter:
   Dissolve 3.0 kg. of technical NaOH (76%) in 3 l. of H_2O; allow the impurities to settle and siphon into 1.5 l. of H_2O containing 360 g. Na_2S_2O_3·5H_2O.
3) Catalyst:
   a) Prepare a mixture of CuSO_4·5H_2O, HgO and K_2SO_4 in the weight ratio 20:3:150.
   b) Selenium granules
4) Indicator:
   Methyl red - Methyl blue
   Mix 2 parts of 0.2% alcoholic methyl red with 1 part of 0.2% methyl blue.
5) Powdered Na_2S_2O_3·5H_2O
6) Boric acid solution:
   Dissolve 40 g. of boric acid in H_2O and make up to 1 liter.
7) Standard 0.1 N HCl
8) Standard NH_4Cl solution:
   Dissolve 0.382 g. NH_4Cl sublimed analytical grade in H_2O and dilute to 100 ml.

Procedure

Place 1 g. of dried 40 mesh plant material in an 800 ml.
Kjeldahl flask; add 35 ml. of concentrated H2SO4 containing salicylic acid. During the first hour, shake vigorously several times and allow to stand overnight. Add 5 g. of Na2S2O3.5H2O powder; heat gently for 5 minutes. Cool; add 20 g. of the catalyst mixture and 5 selenium grains. Increase the temperature until the mixture is boiling. Rotate the flask several times during the digestion period (about 2 hours). After the solution is clear, continue heating for 30 minutes. Cool the flask and add carefully 200 ml. of H2O; the water must be added before the solution in the flask solidifies.

Place 50 ml. of 1% boric acid into a 400-600 ml. erlenmeyer flask; add a few drops of indicator, and place the flask under the receiving tip of the distillation apparatus. To the Kjeldahl flask, add carefully 125 ml. of the concentrated NaOH mixture, pouring it down the side of the flask so that two layers are formed and no mixing takes place. Add a few granules of mossy zinc. Connect the flask to the apparatus and swirl rapidly. Distill over about 150-200 ml. of solution. Titrate the boric acid solution with standard 0.1 N HCl.

The Determination of Calcium, Magnesium, Potassium and Phosphorus in Plant Materials

Ashing and Preparation of Residue for Analysis

Reagents

1) Lithium Chloride:

1250 ppm Li. Dissolve 1.250 gm. of LiCl in H2O and
make up to 1 liter.

2) Concentrated HCl

3) Concentrated HNO3

4) 6 N HCl:
Dilute 500 ml. of concentrated HCl to 1 liter with H2O.

Procedure
Place 2 g. of dried finely ground plant sample in a 50 ml. erlenmeyer flask. Ash in a muffle furnace by increasing the temperature slowly to 500-550°C to avoid excessive smoke. Continue heating at 500-550°C for 6-10 hours. Remove beaker from the furnace; cool; add aqua regia and evaporate to dryness. Repeat the acid evaporation twice. Add 5 ml. of 6 N HCl; evaporate to dryness and dehydrate silica for 4 hours. Dissolve the residue in 3 ml. of 6 N HCl using a rubber policeman to ensure the complete dissolution of the soluble material. Add H2O and filter through filter paper into a 100 ml. volumetric flask. Add enough LiCl to produce a Li concentration of 25 ppm and make up to volume with H2O (Solution A). This solution was used for the determination of Ca, Mg, K and P.

Separation of Fe, Al and P (75)

Iron and aluminum were separated from an aliquot of solution A used for the flame photometric determination of calcium
and the versenate titration for Ca plus Mg. The removal of iron and aluminum prevented the fading of the Erichrome Block T indicator. It also eliminated the interference of Al in the flamephotometric determination of Ca as shown in the table below.

<table>
<thead>
<tr>
<th>Plant Part</th>
<th>Ca ppm Fe and Al not Removed</th>
<th>Ca ppm Fe and Al Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tops</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>80</td>
<td>110</td>
</tr>
<tr>
<td>b</td>
<td>40</td>
<td>53</td>
</tr>
<tr>
<td>Roots</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>25</td>
<td>65</td>
</tr>
<tr>
<td>b</td>
<td>12</td>
<td>14</td>
</tr>
</tbody>
</table>

**Reagents**

1) Ammonium chloride 25%:

Dissolve 250 g. of NH₄Cl in H₂O and make up to 1 liter.

2) Ammonium hydroxide approximately 1 N:

Dilute 66.6 ml. of concentrated NH₄OH to 1 liter with H₂O.

3) Methyl red

4) Lithium chloride:

125 ppm Li. Dilute 100 ml. of 1250 ppm Li to 1 liter with H₂O.
Procedure

Place 30 ml. of solution A in a centrifuge tube marked at 60 ml. Add 3 drops of methyl red, 10 ml. of NH₄Cl and 5 ml. of LiCl. Titrate with NH₄OH until yellow and then add 4 drops in excess. Make up to volume and then add 12 more drops of H₂O to compensate for evaporation during centrifuging and heating. Heat for 5 minutes at 95°C and centrifuge the hot mixture at 2500 rpm. Decant 30-40 ml. into an erlenmeyer flask and stopper tightly (Solution B).

Determination of Ca (98)

Reagents

1) Standard 2500 ppm Ca solution:
   Dissolve 6.250 gm. of CaCO₃ in 125 ml. of 3 N HCl and dilute to 1000 ml. with H₂O.

2) Standard 1250 ppm Li solution

3) Methyl red

Procedure

Prepare 5 standard solutions containing 0, 25, 50, 75, and 100 ppm Ca, 25 ppm Li, and the same concentration of NH₄Cl and methyl red as used for the Al, Fe, and P precipitation. Determine Ca with the Perkin-Elmer flame photometer using Solution B directly.
Determination of Mg (98, 76)

Reagents

1) Concentrated HCl

2) Concentrated HN03

3) 6 N HCl:
   Dilute 500 ml. of concentrated HCl to 1 liter with H2O.

4) 0.1 N HCl:
   Dilute 16.6 ml. of 6 N HCl to 1 liter with H2O.

5) Ammonium chloride - ammonium hydroxide buffer solution:
   Dissolve 67.5 g. of NH4Cl in 570 ml. of concentrated
   NH4OH and make to 1 liter with H2O.

6) Eriochrome Black T indicator:
   Dissolve 0.5 g. of Eriochrome Black T in 100 ml. of
   95% ethanol.

7) Sodium cyanide 10%:
   Dissolve 50 gm. of NaCN in 450 ml. of H2O.

8) Versenate approximately 0.01 N:
   Dissolve 2 g. of disodium dihydrogen ethylenediamine
tetraacetate and 0.05 gm. of MgCl2 in H2O and dilute
to 1 liter. Standardize against standard Ca solution.
Procedure

Place two 10 ml. aliquotes of Solution B in two 50 ml. erlenmeyer flasks. Evaporate to dryness; add aqua regia and evaporate again. Add 6 N HCl and evaporate to dryness. Dissolve the residue with 1-2 ml. of 0.1 N HCl and add 15-20 ml. of H2O. Add 3 ml. of NaCN, 2 ml. of buffer and 3-5 drops of Erichrome Black T indicator. Titrate with 0.01 N versenate. Determine the magnesium content by subtracting the amount of Ca determined with the flame photometer.

Determination of K (98)

Reagents

1) Standard 2500 ppm K solution:

Dissolve 4.766 g. of KCl in H2O and dilute to 1 liter with H2O.

2) Standard 1250 ppm Li solution

Procedure

Prepare 6 potassium standards containing 0, 25, 50, 100, 150 and 200 ppm K, and 25 ppm Li. Determine K with the Perkin-Elmer flame photometer using Solution A.

Determination of P (23)

Reagents

1) Molybdate solution 8.4%:
Dissolve 42 gm. of ammonium molybdate \((\text{NH}_4)_6\text{Mo}_7\text{O}_{24}.4\text{H}_2\text{O}\) in H2O and dilute to 500 ml.

2) Hydrochloric acid 9.8 N:
Dilute 816 ml. of concentrated HCl to 1 liter.

3) Stannous chloride (concentrated solution):
Dissolve 10 g. of SnCl2.2H2O in 75 ml. of concentrated HCl and store in brown bottle.

4) Standard phosphate solution 1 x 10^-4 M

5) Molybdate - HCl mixture:
Add 50 ml. of 8.4% molybdate solution to 100 ml. 9.8 N HCl.

6) Stannous chloride (dilute solution):
Add 1 ml. of concentrated SnCl2 solution to 19 ml. of H2O.

Procedure
Prepare 7 phosphorus standards, 0, 1, 6, 10, 20, 30, and 40 x 10^-6 M P, and develop color in the manner described below.

Take two 1 ml. aliquotes of solution A and place in two 125 ml. erlenmeyer flasks. Add 7½ ml. of H2O, 9 ml. of molybdate-HCl mixture and 15 drops of SnCl2 (dilute). Read percent transmittance on a colorimeter at 660 m.µ.1 minute after the addition of SnCl2.
During 1957 and 1958, a series of experiments was conducted with 0-0* and 1-0** Douglas fir seedlings at the Green Timbers Forest Nursery and the University of British Columbia.

Part A includes all fertilizer experiments with 0-0 and 1-0 Douglas fir seedlings at the Green Timbers Nursery.

PART A - EXPERIMENT 1

The application of nitrogen, phosphorus and potassium to 1-0 (1956)*** Douglas fir seedlings.

Location

Field No. 2, Green Timbers Forest Nursery

Experimental Design

Partially confounded 3 x 3 x 3 factorial experiment. A different second order interaction was confounded in each of the 4 replicates.

* 0-0 Less than one year old seedlings
** 1-0 Seedlings < 2, > 1 year old
*** (1956) Year of Seeding
Seed Source

U-22

Seed Crop: 1956

Origin: Cumberland, B.C.

Elevation: 800 Feet

Age of Trees: Second Growth

Date of Sowing

May 30-31, 1955

Fertilization

Fertilizers used: Ammonium nitrate

Triple superphosphate

Potassium chloride

Treatments:

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Amount of Fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>0 lb. per acre N</td>
</tr>
<tr>
<td>N1</td>
<td>21 lb. per acre N</td>
</tr>
<tr>
<td>N2</td>
<td>43 lb. per acre N</td>
</tr>
<tr>
<td>P0</td>
<td>0 lb. per acre P205</td>
</tr>
<tr>
<td>P1</td>
<td>32 lb. per acre P205</td>
</tr>
<tr>
<td>P2</td>
<td>97 lb. per acre P205</td>
</tr>
<tr>
<td>K0</td>
<td>0 lb. per acre K20</td>
</tr>
<tr>
<td>K1</td>
<td>21 lb. per acre K20</td>
</tr>
<tr>
<td>K2</td>
<td>86 lb. per acre K20</td>
</tr>
</tbody>
</table>

Date of fertilization: May 15, 1958
Remarks

A random sample of 18 plants was taken from each plot.

Results of soil analysis can be found in appendix table 1c.

Results

The experimental measurements and the analysis of variance tables are found in appendix table 1a and 1b.

Significant Treatments:

- Length of tops: nitrogen 1%
- Length of roots: nitrogen-phosphorus interaction 1%
- Diameter of stem: nitrogen 1%
- Dry weight of tops: nitrogen 1%
- Dry weight of roots: nitrogen 1%
- Total dry weight: nitrogen 1%

Table 1

Part A, Experiment 1: The effect of nitrogen fertilization on the length, dry weight, and stem diameter of 1-0 Douglas fir seedlings.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Length of Tops cm.*</th>
<th>Diameter of Stem mm.**</th>
<th>Dry Weight of Tops mg.***</th>
<th>Dry Weight of Roots mg.***</th>
<th>Total Dry Weight mg.***</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>17.0</td>
<td>2.28</td>
<td>732</td>
<td>323</td>
<td>1055</td>
</tr>
<tr>
<td>N1</td>
<td>20.1</td>
<td>2.39</td>
<td>979</td>
<td>309</td>
<td>1288</td>
</tr>
<tr>
<td>N2</td>
<td>21.6</td>
<td>2.58</td>
<td>1294</td>
<td>355</td>
<td>1649</td>
</tr>
<tr>
<td>Nsd</td>
<td>2.3</td>
<td>0.38</td>
<td>320</td>
<td>90</td>
<td>350</td>
</tr>
<tr>
<td>N5sd</td>
<td>3.0</td>
<td>0.13</td>
<td>420</td>
<td>120</td>
<td>460</td>
</tr>
</tbody>
</table>

* Individual Treatment

** Mean Level of Factor

*** Significant Differences at the 5% level.
Chemical Analysis of Seedlings

For analysis of variance tables see appendix tables ld and le.

Table 2


<table>
<thead>
<tr>
<th>Treatment</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>NoPoKo</td>
<td>12.90</td>
<td>1.46</td>
<td>4.19</td>
<td>2.29</td>
<td>0.85</td>
</tr>
<tr>
<td>NoPoK2</td>
<td>15.73</td>
<td>1.85</td>
<td>6.17</td>
<td>3.03</td>
<td>1.19</td>
</tr>
<tr>
<td>NoP2Ko</td>
<td>15.39</td>
<td>1.63</td>
<td>5.25</td>
<td>3.15</td>
<td>1.17</td>
</tr>
<tr>
<td>NoP2K2</td>
<td>13.05</td>
<td>1.57</td>
<td>5.24</td>
<td>2.49</td>
<td>0.88</td>
</tr>
<tr>
<td>N2PoKo</td>
<td>19.70</td>
<td>1.71</td>
<td>5.90</td>
<td>1.00</td>
<td>1.24</td>
</tr>
<tr>
<td>N2PoK2</td>
<td>15.15</td>
<td>1.78</td>
<td>6.00</td>
<td>2.88</td>
<td>0.92</td>
</tr>
<tr>
<td>N2P2Ko</td>
<td>18.50</td>
<td>2.00</td>
<td>6.12</td>
<td>3.83</td>
<td>1.61</td>
</tr>
<tr>
<td>N2P2K2</td>
<td>18.52</td>
<td>2.01</td>
<td>7.45</td>
<td>3.75</td>
<td>1.30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>NoPoKo</td>
<td>3.15</td>
<td>0.43</td>
<td>0.97</td>
<td>1.06</td>
<td>0.32</td>
</tr>
<tr>
<td>NoPoK2</td>
<td>3.12</td>
<td>0.40</td>
<td>0.98</td>
<td>0.82</td>
<td>0.28</td>
</tr>
<tr>
<td>NoP2Ko</td>
<td>2.78</td>
<td>0.41</td>
<td>0.87</td>
<td>0.88</td>
<td>0.28</td>
</tr>
<tr>
<td>N2PoKo</td>
<td>3.38</td>
<td>0.41</td>
<td>0.91</td>
<td>0.95</td>
<td>0.32</td>
</tr>
</tbody>
</table>
Table 3a

Part A, Experiment 1: The concentration of N, P, K, Ca and Mg in 1-0 Douglas fir seedling tops.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>N (mg.g.⁻¹)</th>
<th>P (mg.g.⁻¹)</th>
<th>K (mg.g.⁻¹)</th>
<th>Ca (mg.g.⁻¹)</th>
<th>Mg (mg.g.⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NoPoKo</td>
<td>17.58</td>
<td>1.99</td>
<td>5.72</td>
<td>3.13</td>
<td>1.16</td>
</tr>
<tr>
<td>NoPoK2</td>
<td>15.94</td>
<td>1.87</td>
<td>6.24</td>
<td>3.07</td>
<td>1.20</td>
</tr>
<tr>
<td>NoP2Ko</td>
<td>15.69</td>
<td>1.76</td>
<td>5.35</td>
<td>3.21</td>
<td>1.19</td>
</tr>
<tr>
<td>NoP2K2</td>
<td>16.14</td>
<td>1.94</td>
<td>6.49</td>
<td>3.08</td>
<td>1.09</td>
</tr>
<tr>
<td>N2PoKo</td>
<td>15.17</td>
<td>1.32</td>
<td>4.55</td>
<td>3.09</td>
<td>0.96</td>
</tr>
<tr>
<td>N2PoK2</td>
<td>14.64</td>
<td>1.38</td>
<td>5.78</td>
<td>2.78</td>
<td>0.89</td>
</tr>
<tr>
<td>N2P2Ko</td>
<td>14.36</td>
<td>1.55</td>
<td>4.75</td>
<td>2.97</td>
<td>1.25</td>
</tr>
<tr>
<td>N2P2K2</td>
<td>14.38</td>
<td>1.55</td>
<td>5.78</td>
<td>2.91</td>
<td>1.01</td>
</tr>
<tr>
<td>lsd 5%</td>
<td>1.41</td>
<td>0.36</td>
<td>1.12</td>
<td>not sig.</td>
<td>not sig.</td>
</tr>
</tbody>
</table>

Table 3b

Part A, Experiment 1: The concentration of N, P, K, Ca and Mg in 1-0 Douglas fir seedling roots.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>N (mg.g.⁻¹)</th>
<th>P (mg.g.⁻¹)</th>
<th>K (mg.g.⁻¹)</th>
<th>Ca (mg.g.⁻¹)</th>
<th>Mg (mg.g.⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NoPoKo</td>
<td>9.85</td>
<td>1.34</td>
<td>2.99</td>
<td>3.27</td>
<td>0.99</td>
</tr>
<tr>
<td>NoPoK2</td>
<td>10.11</td>
<td>1.29</td>
<td>3.19</td>
<td>2.64</td>
<td>0.91</td>
</tr>
<tr>
<td>NoP2Ko</td>
<td>9.39</td>
<td>1.39</td>
<td>2.94</td>
<td>2.99</td>
<td>0.93</td>
</tr>
<tr>
<td>N2PoKo</td>
<td>9.50</td>
<td>1.14</td>
<td>2.55</td>
<td>2.67</td>
<td>0.91</td>
</tr>
<tr>
<td>lsd 5%</td>
<td>not sig.</td>
<td>0.19</td>
<td>not sig.</td>
<td>0.86</td>
<td>not sig.</td>
</tr>
</tbody>
</table>

Observations

The needles of seedlings to which nitrogen was applied became green, compared with no nitrogen, 3 weeks after fertilization. The
green color began to fade in the low nitrogen treatments on July 1, 1957 and in the high nitrogen treatments around July 15, 1957. The appearance of seedlings fertilized with nitrogen was more vigorous than that of seedlings receiving no nitrogen.

Discussion

The application of nitrogen increased considerably the dry weight of tops and roots, the diameter of stem and the length of tops.

The percent nitrogen, phosphorus and potassium in the plants tops was decreased by nitrogen fertilization. The fertilized seedlings however, contained more nitrogen and potassium per plant top. The total amount of phosphorus in the plant shoots did not vary consistently with fertilizer treatment. Potassium fertilization increased the concentration of K in the plant tops.

The phosphorus and calcium concentration of the roots was significantly decreased by nitrogen and potassium fertilization. The total uptake of nutrients by the roots, however, was the same regardless of treatment.

The Ca and Mg concentrations as well as the total uptake of these elements was not affected by fertilization. The total content of N, P, K, Ca and Mg in the roots is only 1/3 to 1/6 of that of the tops.
PART A - EXPERIMENT 2.1

Application of nitrogen, phosphorus and potassium to 0-0 (1957) Douglas fir seedlings.

Location

Field No. 5, Green Timbers Forest Nursery

Experimental Design

Partially confounded 3 x 3 x 3 factorial experiment. A different second order interaction was confounded in each of the 4 replicates.

Seed Source

L-25

MacMillan Bloedel seed

No history

Date of Sowing

June 3-5, 1957

Fertilization

Fertilizer materials: Ammonium nitrate

Triple superphosphate

Potassium chloride
Treatments:

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Amount of Fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>0 lb. per acre N</td>
</tr>
<tr>
<td>N1</td>
<td>21 lb. per acre N</td>
</tr>
<tr>
<td>N2</td>
<td>43 lb. per acre N</td>
</tr>
<tr>
<td>Po</td>
<td>0 lb. per acre P2O5</td>
</tr>
<tr>
<td>P1</td>
<td>32 lb. per acre P2O5</td>
</tr>
<tr>
<td>P2</td>
<td>97 lb. per acre P2O5</td>
</tr>
<tr>
<td>Ko</td>
<td>0 lb. per acre K20</td>
</tr>
<tr>
<td>K1</td>
<td>21 lb. per acre K20</td>
</tr>
<tr>
<td>K2</td>
<td>86 lb. per acre K20</td>
</tr>
</tbody>
</table>

Date of fertilizer application: May 23, 1957

Remarks

A random sample of 18 plants was taken from each plot.
Results of soil analysis can be found in appendix table 2.1c.

Results

Details of experimental measurements and the analysis of variance tables are found in appendix table 2.1a and 2.1b.

Significant treatments:

Length of tops: nitrogen 1%
               potassium 1%
               phosphorus 5%

Dry weight of tops: nitrogen 1%
                    phosphorus 1%
                    potassium 1%
Table 4


Average per Plant

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Length of Tops</th>
<th>Dry Weight of Tops</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Individual</td>
<td>Mean Level</td>
</tr>
<tr>
<td></td>
<td>Treatment</td>
<td>of Factor</td>
</tr>
<tr>
<td>No</td>
<td>4.5</td>
<td>4.6</td>
</tr>
<tr>
<td>N1</td>
<td>4.9</td>
<td>4.8**</td>
</tr>
<tr>
<td>N2</td>
<td>4.8</td>
<td>4.8</td>
</tr>
<tr>
<td>Po</td>
<td>4.5</td>
<td>4.6</td>
</tr>
<tr>
<td>P1</td>
<td>4.9</td>
<td>4.8**</td>
</tr>
<tr>
<td>P2</td>
<td>4.5</td>
<td>4.9**</td>
</tr>
<tr>
<td>Ko</td>
<td>4.5</td>
<td>4.9</td>
</tr>
<tr>
<td>K1</td>
<td>4.7</td>
<td>4.7**</td>
</tr>
<tr>
<td>K2</td>
<td>4.2</td>
<td>4.5**</td>
</tr>
</tbody>
</table>

lsd 1%** 0.76 0.25 19.4 6.7
lsd 5%* 0.58 0.19 14.4 5.0

Observations

Plots fertilized with potassium appeared yellowish compared with all nitrogen fertilized plots. The application of nitrogen increased slightly the incidence of frost damage.

Discussion

The application of 20 lb. per acre of nitrogen or of 30 lb. per acre of phosphorus (P205) increased the length of tops and the dry weight of tops. Application of 40 lb. per acre of N or of 90 lb. per acre P205 produced no additional increase over the lower rates. Eighty lb. per acre of K20 decreased the length and dry weight of tops.
PART A - EXPERIMENT 2.2

Effect of fertilizer applications to 0-0 Douglas fir seedlings on the growth in the second year. (Plots of experiment 2.2 were resampled in 1958).

Results

Details of experimental measurements and analysis of variance tables are preserved in the appendix tables 2.2 a and b.

Significant Treatments:

Length of tops: nitrogen-phosphorus interaction 5%

Observations

All plots grew very poorly and did not reach the desired size for transplanting. The color of the foliage was yellowish throughout the year.

Discussion

The application of mineral fertilizers to 0-0 Douglas fir seedlings did not affect their development during the second summer in the nursery. The significant differences observed in the first year disappeared in the second summer. Mineral fertilizers appear to be leached or fixed completely in the year of application. The application of fertilizer to 1-0 seedlings appears essential for the production of suitable planting material under the present fertility status of the experimental area.
PART A - EXPERIMENT 3.1

The application of organic materials, nitrogen, phosphorus and potassium to 0-0 (1957) Douglas fir seedlings.

Location

Field No. 5, Green Timbers Forest Nursery

Experimental Design

Randomized complete block; replicated 6 times.

Seed Source

L-25

MacMillan Bloedel seed

No history

Date of Sowing

June 3-5, 1957

Fertilization

Fertilizers used:

- Ammonium nitrate
- Triple superphosphate
- Potassium chloride
- Calcium sulphate
- Magnesium sulphate
- Borax
- Cow manure
- U.B.C. compost
- Garden peat
- Fir sawdust
Treatments:

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Amount of Fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Manure</td>
<td>500 cubic feet per acre</td>
</tr>
<tr>
<td>2. Compost</td>
<td>750 cubic feet per acre</td>
</tr>
<tr>
<td>3. Peat &amp; N,P,K</td>
<td>2500 cubic feet per acre, 270 lbs. per acre N, 97 lbs. per acre P2O5, 43 lbs. per acre K2O</td>
</tr>
<tr>
<td>4. Sawdust &amp; N,P,K</td>
<td>1500 cubic feet per acre, 270 lbs. per acre N, 97 lbs. per acre P2O5, 43 lbs. per acre K2O</td>
</tr>
<tr>
<td>5. N, P, &amp; K</td>
<td>43 lbs. per acre N, 97 lbs. per acre P2O5, 43 lbs. per acre K2O</td>
</tr>
<tr>
<td>6. Control Ca + Mg + B</td>
<td></td>
</tr>
<tr>
<td>7. Control Ca + Mg + B</td>
<td></td>
</tr>
<tr>
<td>Broadcast</td>
<td></td>
</tr>
<tr>
<td>8. N,P,K Split Application</td>
<td>43 lbs. per acre N, 97 lbs. per acre P2O5, 43 lbs. per acre K2O</td>
</tr>
<tr>
<td>9. Control</td>
<td>none</td>
</tr>
</tbody>
</table>

All treatments except No. 9 received:
- 812 lbs. per acre calcium sulphate
- 270 lbs. per acre magnesium sulphate
- 10.8 lbs. per acre borax

Date of fertilization: The fertilizers were applied on May 23, 1957. For treatment 8, the fertilizer was split into two equal parts. The first fertilizer application was made May 23, 1957; the second on August 15, 1957.
**Observations**

The seedling density of the peat and sawdust plots was low, germination was delayed and the plants appeared small and dark green. Some of the plants in the sawdust plots showed necrotic spots on their needles. The split application of N, P, and K resulted in serious loss of seedlings from Fusarium top wilt.

**Discussion**

The peat and sawdust treatments decreased significantly the length and dry weight of the seedling tops. It is felt that this was the result of excessive nitrogen fertilization. Compost increased the dry weight of tops and manure, the length of tops. The mineral fertilizer applications produced no effect. This is in good agreement with the results in Part A, Experiment 2a. It was felt that row seeding was not advantageous due to crowding in the rows. Broadcast seeding resulted in better seedling distribution and produced sturdier seedlings.

**PART A - EXPERIMENT 3.2**

Effect of fertilizer application to 0-0 Douglas fir seedlings on the growth in the second year. (Plots of experiment 3a were resampled in 1958.)

**Remarks**

As a result of poor soil drainage in parts of the experimental area, one replicate was lost during the winter of
Remarks

All treatments except No. 7 were seeded in rows 4 inches apart. A random sample of 18 plants was taken from each plot. Results of soil analysis are found in the appendix table 3.1b.

Results:

The analysis of variance tables are found in the appendix table 3.1a.

Significant measurements:

Length of tops
Dry weight of tops

Table 5

Part A, Experiment 3a: Dry weight and length of tops of 0-0 (1957) Douglas fir seedlings.

Average per Plant

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Length of Tops</th>
<th>Dry Weight of Tops</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Compost</td>
<td>6.2**</td>
<td>115.0**</td>
</tr>
<tr>
<td>3. Peat &amp; N,K,P</td>
<td>3.9**</td>
<td>82.2**</td>
</tr>
<tr>
<td>4. Sawdust &amp; N,P,K</td>
<td>3.2**</td>
<td>62.3**</td>
</tr>
<tr>
<td>5. N, P, &amp; K</td>
<td>5.6</td>
<td>115.0</td>
</tr>
<tr>
<td>6. Control, Ca + Mg + B</td>
<td>5.4</td>
<td>108.4</td>
</tr>
<tr>
<td>7. Control, Ca + Mg + B</td>
<td>5.7</td>
<td>119.5</td>
</tr>
<tr>
<td>8. N,P,K, Split Application</td>
<td>5.2</td>
<td>108.4</td>
</tr>
<tr>
<td>9. Control</td>
<td>5.4</td>
<td>109.8</td>
</tr>
<tr>
<td>lsd 15**</td>
<td>0.68</td>
<td>15.0</td>
</tr>
<tr>
<td>5%</td>
<td>0.51</td>
<td>11.2</td>
</tr>
</tbody>
</table>
1957-1958. The experimental results represent therefore, means of 5 plots. Treatment No. 7 received 40 lb. per acre of nitrogen on June 2, 1958.

Results

The analysis of variance tables are found in appendix table 3.2a.

Significant measurements: Length of tops

Diameter

Dry weight of tops

Total dry weight

Table 6

Part A, Experiment 3b: The effect of fertilizer applications to 0-0 seedlings on their growth in the following year.

Average per Plant

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Length of Tops cm.</th>
<th>Length of Roots cm.</th>
<th>Diameter mm.</th>
<th>Dry Weight of Tops mg.</th>
<th>Dry Weight of Roots mg.</th>
<th>Total Dry Weight mg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Manure</td>
<td>15.58*</td>
<td>18.89</td>
<td>2.5*</td>
<td>832*</td>
<td>298</td>
<td>1131*</td>
</tr>
<tr>
<td>2 Compost</td>
<td>14.84</td>
<td>18.95</td>
<td>2.4</td>
<td>771</td>
<td>239</td>
<td>1010</td>
</tr>
<tr>
<td>3 Peat &amp; N,P,K</td>
<td>15.32</td>
<td>20.68</td>
<td>2.3</td>
<td>663</td>
<td>244</td>
<td>906</td>
</tr>
<tr>
<td>4 Sawdust &amp; N,P,K</td>
<td>12.46</td>
<td>18.85</td>
<td>2.1</td>
<td>583</td>
<td>248</td>
<td>831</td>
</tr>
<tr>
<td>5 N,P,K</td>
<td>11.60</td>
<td>18.65</td>
<td>2.4</td>
<td>724</td>
<td>228</td>
<td>951</td>
</tr>
<tr>
<td>6 Control</td>
<td>14.12</td>
<td>18.73</td>
<td>2.3</td>
<td>713</td>
<td>240</td>
<td>953</td>
</tr>
<tr>
<td>7 Control</td>
<td>16.38**</td>
<td>18.98</td>
<td>2.6**</td>
<td>973**</td>
<td>288</td>
<td>1261**</td>
</tr>
<tr>
<td>8 N,P,K Split Applctn</td>
<td>14.26</td>
<td>19.44</td>
<td>2.3</td>
<td>788</td>
<td>297</td>
<td>1086*</td>
</tr>
<tr>
<td>9 Control</td>
<td>13.70</td>
<td>18.92</td>
<td>2.2</td>
<td>633</td>
<td>227</td>
<td>849</td>
</tr>
</tbody>
</table>

1sd 2.48

5% 1.77

......
Observations

The application of nitrogen to 1-0 seedlings (treatment 7) produced the most uniform and vigorous seedlings. Plots treated with peat showed good color and vigorous growth. Seedlings fertilized with sawdust were yellowish and small.

Discussion

With exception of the manure treatment, application of organic and mineral fertilizers to 0-0 seedlings had no effect on the growth of the seedlings in the second year in the nursery.

The application of nitrogen to 1-0 seedlings (treatment 7) significantly increased the length of tops, stem diameter, dry weight of tops and total dry weight.

PART A - EXPERIMENT 4

Preliminary study of the effect of the time of fertilizer application on the development of 1-0 (1956) Douglas fir seedlings.

Location

Field No. 2, Green Timbers Forest Nursery

Experimental Design

One nursery bed per treatment; no replication.
Seed Source

U-22

Seed Crop: 1956

Origin: Cumberland, B.C.

Elevation: 800 Feet

Age of Trees: Second Growth

Date of Sowing

May 30-31, 1955

Fertilization

Fertilizers used: ammonium nitrate
calcium sulfate
magnesium sulfate
boron

Treatments:

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Amount of Fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Control</td>
<td>None</td>
</tr>
<tr>
<td>2. Nitrogen May 15</td>
<td>40 lb. per acre N</td>
</tr>
<tr>
<td>3. Nitrogen June 15</td>
<td>40 lb. per acre N</td>
</tr>
<tr>
<td>4. Nitrogen July 15</td>
<td>40 lb. per acre N</td>
</tr>
<tr>
<td>5. Nitrogen Aug. 15</td>
<td>40 lb. per acre N</td>
</tr>
<tr>
<td>6. Boron May 15</td>
<td>10 lb. per acre</td>
</tr>
<tr>
<td>7. CaSO₄ May 15</td>
<td>750 lb. per acre</td>
</tr>
<tr>
<td>8. MgSO₄ May 15</td>
<td>250 lb. per acre</td>
</tr>
</tbody>
</table>

Remarks

A random sample of 18 plants was taken from each plot.
The standard deviation and the standard error of the mean
was calculated for each measurement.
### Results

#### Table 7

Part A, Experiment 4: Effect of the time of nitrogen application on the dry weight, length, and stem diameter of 1-0 Douglas fir seedlings.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Length of Tops cm.</th>
<th>Length of Roots cm.</th>
<th>Diameter of Stem mm.</th>
<th>Dry Weight of Tops mg.</th>
<th>Dry Weight of Roots mg.</th>
<th>Total Dry Weight mg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Control</td>
<td>21.3</td>
<td>20.2</td>
<td>2.6</td>
<td>1210</td>
<td>388</td>
<td>1597</td>
</tr>
<tr>
<td>2 N May 15</td>
<td>26.0*</td>
<td>21.7</td>
<td>3.5**</td>
<td>1170</td>
<td>348</td>
<td>1518</td>
</tr>
<tr>
<td>3 N June 15</td>
<td>29.4**</td>
<td>27.0**</td>
<td>3.1*</td>
<td>2270**</td>
<td>604*</td>
<td>2874**</td>
</tr>
<tr>
<td>4 N July 15</td>
<td>26.1*</td>
<td>22.4</td>
<td>3.1*</td>
<td>1997*</td>
<td>545*</td>
<td>2542**</td>
</tr>
<tr>
<td>5 N Aug. 15</td>
<td>18.7</td>
<td>21.2*</td>
<td>3.0*</td>
<td>1168</td>
<td>437</td>
<td>1604</td>
</tr>
<tr>
<td>6 B May 15</td>
<td>18.4</td>
<td>19.9</td>
<td>2.4</td>
<td>882</td>
<td>303</td>
<td>1186</td>
</tr>
<tr>
<td>7 CaSO4 May 15</td>
<td>21.0</td>
<td>22.1</td>
<td>2.2</td>
<td>841</td>
<td>236</td>
<td>1077</td>
</tr>
<tr>
<td>8 MgSO4 May 15</td>
<td>19.9</td>
<td>21.8</td>
<td>2.3</td>
<td>844</td>
<td>268</td>
<td>1112</td>
</tr>
</tbody>
</table>

#### Observations

The plants in treatment 3 grew vigorously. The application of nitrogen in July induced the breaking of lateral and terminal buds. The plants did not stop growth in the fall and the young shoots were killed by a light frost in October. The vigorous growth of lateral shoots resulted in bushy plants. Seedlings to which nitrogen was applied in August had formed buds before the fertilizer application. Nearly all trees remained dormant after fertilization and appeared to be more frost resistant than any other treatment. Frost damage was limited to the few plants which broke dormancy.
Discussion

As the experimental treatments were not replicated, the results obtained must be interpreted with caution. The time of nitrogen application to 1-0 Douglas fir seedlings had a pronounced effect on the growth, dormancy, and frost resistance of the seedlings. It appears that early fall applications of nitrogen can increase the frost resistance of 1-0 seedlings, if the plants remain dormant after fertilization. Seedlings however, are easily damaged by light fall frost if the late nitrogen application results in the breaking of the buds or delays dormancy.

PART A - EXPERIMENT 5

Application of nitrogen and phosphorus to 1-0 (1957) Douglas fir seedlings.

Location

Field No. 5, Green Timbers Forest Nursery

Experimental Design

Partially confounded 5 x 5 factorial experiment replicated \( k \) times. The 16 degrees of freedom for the N, P, interaction were subdivided into 4 parts each having 4 degrees of freedom. Each of the 4 degrees of freedom was confounded in one of the replicates.
Seed Source

L-25

MacMillan Bloedel seed

No history

Date of Sowing

June 3-5, 1957

Fertilization

First year: 24 lb. per acre N

30 lb. per acre P2O5

120 lb. per acre K2O

Second year:

Fertilizers used: Ammonium nitrate

Triple superphosphate

Potassium chloride

Treatments:

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Amount of Fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>0 lb. per acre N</td>
</tr>
<tr>
<td>N1</td>
<td>40 lb. per acre N</td>
</tr>
<tr>
<td>N2</td>
<td>80 lb. per acre N</td>
</tr>
<tr>
<td>N3</td>
<td>160 lb. per acre N</td>
</tr>
<tr>
<td>N4</td>
<td>320 lb. per acre N</td>
</tr>
<tr>
<td>P0</td>
<td>0 lb. per acre P2O5</td>
</tr>
<tr>
<td>P1</td>
<td>40 lb. per acre P2O5</td>
</tr>
<tr>
<td>P2</td>
<td>80 lb. per acre P2O5</td>
</tr>
<tr>
<td>P3</td>
<td>160 lb. per acre P2O5</td>
</tr>
<tr>
<td>P4</td>
<td>320 lb. per acre P2O5</td>
</tr>
</tbody>
</table>

Date of fertilization: May 15, 1958
Remarks

A random sample of 18 plants was taken from each plot.

Results of soil analysis can be found in appendix table 5c.

Results

Details of experimental measurements and the analysis of variance tables are found in appendix tables 5a and 5b.

Significant treatments:

Length of tops: nitrogen 1%

nitrogen-phosphorus interaction 1%

Length of roots: nitrogen 5%

Diameter of stem: nitrogen 1%

Dry weight of tops: nitrogen 1%

Dry weight of roots: nitrogen 1%

phosphorus 1%

nitrogen-phosphorus interaction 1% and 5%

Total dry weight: nitrogen 1%

phosphorus 5%
### Table 8

Part A, Experiment 5: Effect of N and P on the length, dry weight and stem diameter of 1-0 Douglas fir seedlings.

**Average per Plant**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Length of Tops cm.</th>
<th>Length of Roots cm.</th>
<th>Diameter of Stem mm.</th>
<th>Dry Weight of Tops mg.</th>
<th>Dry Weight of Roots mg.</th>
<th>Total Dry Weight mg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>It* Mlf**</td>
<td>It Mlf</td>
<td>It Mlf</td>
<td>It Mlf</td>
<td>It Mlf</td>
<td>It Mlf</td>
<td>It Mlf</td>
</tr>
<tr>
<td>No</td>
<td>15.0 15.7</td>
<td>22.1 22.7</td>
<td>2.4 2.6</td>
<td>869 991</td>
<td>348 370</td>
<td>1217 1361</td>
</tr>
<tr>
<td>N1</td>
<td>19.0 18.4</td>
<td>24.0 23.9</td>
<td>2.9 2.9</td>
<td>1347 1289</td>
<td>474 463</td>
<td>1821 1744</td>
</tr>
<tr>
<td>N2</td>
<td>20.5 20.7</td>
<td>23.7 23.6</td>
<td>3.0 3.2</td>
<td>1159 1513</td>
<td>437 504</td>
<td>1946 2017</td>
</tr>
<tr>
<td>N3</td>
<td>19.4 18.8</td>
<td>22.1 23.2</td>
<td>3.0 3.1</td>
<td>1265 1432</td>
<td>483 518</td>
<td>1748 1951</td>
</tr>
<tr>
<td>N4</td>
<td>17.4 17.6</td>
<td>22.3 22.3</td>
<td>3.1 3.1</td>
<td>1329 1332</td>
<td>457 485</td>
<td>1786 1817</td>
</tr>
<tr>
<td>Po</td>
<td>not</td>
<td>not</td>
<td>not</td>
<td>not</td>
<td>not</td>
<td>348 450</td>
</tr>
<tr>
<td>P1</td>
<td>signif.</td>
<td>signif.</td>
<td>signif.</td>
<td>signif.</td>
<td>signif.</td>
<td>359 460</td>
</tr>
<tr>
<td>P2</td>
<td>ficant</td>
<td>ficant</td>
<td>ficant</td>
<td>ficant</td>
<td>ficant</td>
<td>365 436</td>
</tr>
<tr>
<td>P3</td>
<td>ficant</td>
<td>ficant</td>
<td>ficant</td>
<td>ficant</td>
<td>ficant</td>
<td>319 463</td>
</tr>
<tr>
<td>P4</td>
<td>ficant</td>
<td>ficant</td>
<td>ficant</td>
<td>ficant</td>
<td>ficant</td>
<td>457 524</td>
</tr>
</tbody>
</table>

**lsd** 1%: 2.3 1.0 3.4 1.5 0.5 0.2 492 220 166 52 592 261

* Individual Treatment

** Mean Level of Factor

**Observations**

The application of 320 lb. per acre of N damaged 1-0 Douglas fir seedlings. The seedlings remained small, became dormant early and had grayish curled needles. In few instances, the needles were dropped by the seedlings. In some cases, plants from plots to which 160 lb. per acre N was applied, showed similar excess nitrogen symptoms. The unfavourable effect of the high N applications was lessened by
high phosphorus fertilization. Seedlings that received 80 lb. per acre N and 160 or 320 lb. per acre P2O5 were very uniform in size and appeared to be exceptionally vigorous. The application of 40 lb. per acre N produced seedlings of good size and health. All seedlings which received no nitrogen remained small and yellowish. Photographs showing the nitrogen excess symptoms are found in the appendix plates 6, 7, and 8.

Discussion

Under the particular experimental conditions, nitrogen applications in excess of 80 lb. per acre did not increase the growth of seedlings but rather decreased it. Application of 40 lb. per acre N produced seedlings of "satisfactory" size and character for transplanting. The dry weight of roots and the total dry weight were increased by the application of 320 lb. per acre P2O5. The nitrogen phosphorus interaction was significant for the length of tops and dry weight of roots.

PART A - EXPERIMENT 6

The effect of the time of fertilizer application on the growth of 1-0 (1957) Douglas fir seedlings.

Location

Field No. 5, Green Timbers Forest Nursery

Experimental Design

Randomized complete block; replicated 6 times.
Seed Source

L-25

MacMillan Bloedel seed

No history

Date of Sowing

June 3-5, 1957

Fertilization

Fertilizer Materials: Ammonium nitrate
            Triple superphosphate
            Potassium chloride

Treatments:

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Amount of Fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 N May 16</td>
<td>40 lb. per acre N</td>
</tr>
<tr>
<td>2 N June 1</td>
<td>40 lb. per acre N</td>
</tr>
<tr>
<td>3 N July 1</td>
<td>40 lb. per acre N</td>
</tr>
<tr>
<td>4 N August 1</td>
<td>40 lb. per acre N</td>
</tr>
<tr>
<td>5 N August 15</td>
<td>40 lb. per acre N</td>
</tr>
<tr>
<td>6 N September 8</td>
<td>40 lb. per acre N</td>
</tr>
<tr>
<td>7 N May 16 &amp; Sept. 1</td>
<td>40 lb. per acre N</td>
</tr>
<tr>
<td>8 N May 16 &amp; Sept. 1</td>
<td>40 lb. per acre N</td>
</tr>
<tr>
<td>9 K September 1</td>
<td>60 lb. per acre K20</td>
</tr>
<tr>
<td>10 P September 1</td>
<td>80 lb. per acre P205</td>
</tr>
<tr>
<td>11 Control</td>
<td>None</td>
</tr>
<tr>
<td>12 N May 16 &amp; P Sept. 1</td>
<td>80 lb. per acre N</td>
</tr>
<tr>
<td></td>
<td>160 lb. per acre P205</td>
</tr>
</tbody>
</table>

Remarks

A random sample of 18 plants was taken from each plot.

Results of soil analysis can be found in the appendix table 6b.
Results

Analysis of variance table can be found in the appendix.

Table 6a.

Table 9

Part A, Experiment 6: Effect of the time of fertilization on the length, dry weight and stem diameter of 1-0 Douglas fir seedlings.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Length of Tops cm.</th>
<th>Length of Roots cm.</th>
<th>Diameter of Stem mm.</th>
<th>Dry Weight of Tops mg.</th>
<th>Dry Weight of Roots mg.</th>
<th>Total Dry Weight mg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 N May 16</td>
<td>20.25**</td>
<td>16.86</td>
<td>3.1**</td>
<td>1567**</td>
<td>655*</td>
<td>2222**</td>
</tr>
<tr>
<td>2 N June 1</td>
<td>18.64*</td>
<td>16.90</td>
<td>3.1**</td>
<td>1478**</td>
<td>647*</td>
<td>2125**</td>
</tr>
<tr>
<td>3 N July 1</td>
<td>20.58**</td>
<td>16.84</td>
<td>3.1**</td>
<td>1550**</td>
<td>590</td>
<td>2140**</td>
</tr>
<tr>
<td>4 N Aug. 1</td>
<td>20.15**</td>
<td>15.99</td>
<td>3.0*</td>
<td>1452*</td>
<td>500</td>
<td>1952*</td>
</tr>
<tr>
<td>5 N Aug. 15</td>
<td>19.32**</td>
<td>16.57</td>
<td>3.1**</td>
<td>1484**</td>
<td>599</td>
<td>2083**</td>
</tr>
<tr>
<td>6 N Sept 8</td>
<td>15.11</td>
<td>16.58</td>
<td>2.9</td>
<td>991</td>
<td>514</td>
<td>1505</td>
</tr>
<tr>
<td>7 N May 16 &amp;</td>
<td>19.24**</td>
<td>16.00</td>
<td>3.2**</td>
<td>1452*</td>
<td>686**</td>
<td>2138**</td>
</tr>
<tr>
<td>Sept. 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 N May 16 &amp;</td>
<td>21.39**</td>
<td>17.68</td>
<td>3.4**</td>
<td>1740**</td>
<td>770**</td>
<td>2510**</td>
</tr>
<tr>
<td>Sept. 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 K Sept 1</td>
<td>15.11</td>
<td>14.18</td>
<td>2.7</td>
<td>985</td>
<td>452</td>
<td>1437</td>
</tr>
<tr>
<td>10 P Sept 1</td>
<td>16.15</td>
<td>15.67</td>
<td>2.8</td>
<td>1111</td>
<td>538</td>
<td>1679</td>
</tr>
<tr>
<td>11 Control</td>
<td>15.95</td>
<td>15.45</td>
<td>2.7</td>
<td>1026</td>
<td>464</td>
<td>1490</td>
</tr>
<tr>
<td>12 N May 16 &amp;</td>
<td>19.46**</td>
<td>16.43</td>
<td>3.5**</td>
<td>1693**</td>
<td>748**</td>
<td>2441**</td>
</tr>
<tr>
<td>P Sept 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| lsd             | 3.24                | not                  | 0.39                 | 439                    | 209                     | 584                  |
| 5%*             | 2.14                 | sig.                 | 0.29                 | 331                    | 157                     | 439                  |

Observations

Application of nitrogen after June 1 resulted in vigorous growth 2 to 3 weeks after fertilization. The needles of the growing tips became spiral as can be seen in the appendix plates 3, 4 and 5. This spiral shape of the needles was found to be usually but not
necessarily associated with rapid growth. In December, trees in treatments 1, 2 and 3 showed very light frost damage but seedlings in treatment 4 and 5 were damaged severely. Treatments 7 and 8 produced plants that were dark green and sturdy, and had suffered the least frost damage of all N fertilized plots. The application of phosphorus in the fall induced apparently bud bursting. Trees in treatments 9, 10, 11 were small yellowish and not affected by frost.

Discussion

The applications of nitrogen on May 16, June 1, July 1, August 1 and August 15, all increased the length of tops, the stem diameter and the dry weight of tops approximately by the same amount. Considering only the size and dry weight of the seedlings, a treatment would appear equally effective but as mentioned under observations, the August applications delayed the termination of growth in the fall and resulted in heavy frost damage. It is felt, therefore, that nitrogen should not be applied later than June 1. This suggestion is supported further by the fact that only the early nitrogen applications produced a significant increase in root weight. A second application of nitrogen in September apparently induced frost hardiness. This is in agreement with last year's findings. Late applications of nitrogen may, under certain conditions, result in renewed growth and until the physiology of dormancy of Douglas fir is better understood, such a nursery practice would be dangerous. Late applications of phosphorus following spring nitrogen fertilization induced bud bursting. Late potassium and phosphorus fertilization had no effect on the size and weight and dormancy of the seedlings.
PART A - EXPERIMENT 7

The application of organic and mineral fertilizers to 0-0 Douglas fir seedlings.

Location

Field No. 4, Green Timbers Forest Nursery

Experimental Design

Randomized complete block; replicated 6 times.

Seed Source

SL-181

Seed Crop: 1957

Origin: Mount Baker National Park

Elevation: 2500 - 3500 Feet

Date of Sowing

May 29 to June 2, 1959

Fertilization

Fertilizers used: Compost
Mushroom manure
Sawdust
Peat
Calcium sulfate
Borax
Ammonium nitrate
Triple superphosphate
Potassium chloride
Treatments:

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Amount of Fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Compost</td>
<td>1750 cu. ft. per acre</td>
</tr>
<tr>
<td>2 Mushroom manure</td>
<td>1750 cu. ft. per acre</td>
</tr>
<tr>
<td>3 Sawdust plus</td>
<td>1750 cu. ft. per acre</td>
</tr>
<tr>
<td>4 Peat plus</td>
<td>1750 cu. ft. per acre</td>
</tr>
<tr>
<td>5 CaSO₄</td>
<td>1000 lb. per acre</td>
</tr>
<tr>
<td>6 MgSO₄</td>
<td>1000 lb. per acre</td>
</tr>
<tr>
<td>7 Borax</td>
<td>10 lb. per acre</td>
</tr>
<tr>
<td>8 N P</td>
<td>125 lb. per acre N</td>
</tr>
<tr>
<td>9 Peat</td>
<td>1750 cu. ft. per acre</td>
</tr>
<tr>
<td>10 Sawdust</td>
<td>1750 cu. ft. per acre</td>
</tr>
<tr>
<td>11 Nitrogen 15</td>
<td>15 lb. per acre N</td>
</tr>
<tr>
<td>12 Nitrogen 30</td>
<td>30 lb. per acre N</td>
</tr>
<tr>
<td>13 Nitrogen 60</td>
<td>60 lb. per acre N</td>
</tr>
<tr>
<td>14 Phosphorus 30</td>
<td>30 lb. per acre P2O5</td>
</tr>
<tr>
<td>15 Phosphorus 90</td>
<td>90 lb. per acre P2O5</td>
</tr>
<tr>
<td>16 Phosphorus 150</td>
<td>150 lb. per acre P2O5</td>
</tr>
<tr>
<td>17 Potassium 20</td>
<td>20 lb. per acre K₂O</td>
</tr>
<tr>
<td>18 Potassium 80</td>
<td>80 lb. per acre K₂O</td>
</tr>
<tr>
<td>19 Potassium 140</td>
<td>140 lb. per acre K₂O</td>
</tr>
<tr>
<td>20 Control</td>
<td>None</td>
</tr>
</tbody>
</table>

Date of fertilization: May 20, 1959

Remarks

A random sample of 36 plants was taken from each plot. Results of soil analysis can be found in the appendix table 7b. Results of chemical analysis of the organic fertilizers can be found in the appendix table 7a.

Results

Analysis of variance tables are found in the appendix
Significant Treatments:

Length of tops:
1. Compost 1%
4. Peat plus 5%
10. Sawdust 5%

Dry weight of tops:
1. Compost 1%
4. Peat plus 5%
7. Borax 5%
10. Sawdust 5%
12. Nitrogen 30 5%

Table 10


Average per Plant

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Length of Tops cm.</th>
<th>Dry Weight of Tops mg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Compost</td>
<td>5.29**</td>
<td>114.8**</td>
</tr>
<tr>
<td>2  Mushroom manure</td>
<td>4.48</td>
<td>90.3</td>
</tr>
<tr>
<td>3  Sawdust plus</td>
<td>4.23</td>
<td>85.2</td>
</tr>
<tr>
<td>4  Peat plus</td>
<td>4.99*</td>
<td>99.3*</td>
</tr>
<tr>
<td>5  CaSO4</td>
<td>4.43</td>
<td>84.5</td>
</tr>
<tr>
<td>6  MgSO4</td>
<td>4.75</td>
<td>91.9</td>
</tr>
<tr>
<td>7  Borax</td>
<td>4.82</td>
<td>97.9*</td>
</tr>
<tr>
<td>8  N + P</td>
<td>4.30</td>
<td>86.9</td>
</tr>
<tr>
<td>9  Peat</td>
<td>4.69</td>
<td>93.8</td>
</tr>
<tr>
<td>10  Sawdust</td>
<td>3.54*</td>
<td>57.9*</td>
</tr>
<tr>
<td>11  Nitrogen 15</td>
<td>4.19</td>
<td>79.1</td>
</tr>
<tr>
<td>12  Nitrogen 30</td>
<td>4.76</td>
<td>100.2*</td>
</tr>
<tr>
<td>13  Nitrogen 60</td>
<td>4.19</td>
<td>83.6</td>
</tr>
<tr>
<td>14  Phosphorus 30</td>
<td>4.64</td>
<td>91.3</td>
</tr>
<tr>
<td>15  Phosphorus 90</td>
<td>3.91</td>
<td>73.1</td>
</tr>
<tr>
<td>16  Phosphorus 150</td>
<td>4.19</td>
<td>78.6</td>
</tr>
<tr>
<td>17  Potassium 20</td>
<td>4.24</td>
<td>78.5</td>
</tr>
<tr>
<td>18  Potassium 80</td>
<td>4.36</td>
<td>83.2</td>
</tr>
<tr>
<td>19  Potassium 1h0</td>
<td>4.14</td>
<td>81.6</td>
</tr>
<tr>
<td>20  Control</td>
<td>4.35</td>
<td>76.7</td>
</tr>
</tbody>
</table>

lsd 1%** 0.85  26.8
lsd 5%* 0.64  20.3
Observations

The experimental plots were located close to a row of large deciduous trees. It was observed that plots close to the trees were poor, regardless of treatment. It is felt that this significantly decreased the sensitivity of the experiment.

Discussion

With exception of the 30 lb. per acre of nitrogen and 10 lb. per acre of borax, applications, all mineral fertilizer treatments had no effect on the growth of 0-0 seedlings. Peat with nitrogen and phosphorus increased the dry weight and length of tops. Peat alone and nitrogen and phosphorus alone, however, had no effect on the growth of the seedlings. Sawdust decreased the size and weight of the seedlings. The negative response was not observed when nitrogen and phosphorus were added with the sawdust. Compost was the best treatment as measured by the length and dry weight of tops.

PART D - EXPERIMENT 8

A greenhouse study of the effect of nitrogen, phosphorus and potassium on the growth and development of Douglas fir seedlings.

Location

Greenhouse at the University of British Columbia
Experimental Design

Partially confounded $5 \times 5 \times 3$ factorial experiment replicated 2 times.

Seed Source

Project 1, Experiment 1

BK - 2 - S: Shawnigan, B.C.

5631 A and 5631 B mixed

Date of Sowing

September 13, 1957

Fertilization

Fertilizer materials: Ammonium nitrate

Triple superphosphate

Potassium sulfate

Treatments:

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Amount of Fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>0 lb. per acre N</td>
</tr>
<tr>
<td>N1</td>
<td>40 lb. per acre N</td>
</tr>
<tr>
<td>N2</td>
<td>80 lb. per acre N</td>
</tr>
<tr>
<td>N3</td>
<td>160 lb. per acre N</td>
</tr>
<tr>
<td>N4</td>
<td>320 lb. per acre N</td>
</tr>
<tr>
<td>P0</td>
<td>0 lb. per acre P205</td>
</tr>
<tr>
<td>P1</td>
<td>40 lb. per acre P205</td>
</tr>
<tr>
<td>P2</td>
<td>80 lb. per acre P205</td>
</tr>
<tr>
<td>P3</td>
<td>160 lb. per acre P205</td>
</tr>
<tr>
<td>P4</td>
<td>320 lb. per acre P205</td>
</tr>
<tr>
<td>K0</td>
<td>0 lb. per acre K20</td>
</tr>
<tr>
<td>K1</td>
<td>60 lb. per acre K20</td>
</tr>
<tr>
<td>K2</td>
<td>120 lb. per acre K20</td>
</tr>
</tbody>
</table>
Date of fertilizer application: August 27, 1957

Remarks

The soil used in the experiment was collected from the surface 6 inches of Field No. 1, Green Timbers Forest Nursery. The seedlings were grown in 2 gallon glazed pots. The soil was steam sterilized, to decrease the possibility of damping off. The amount of fertilizer per pot was calculated on the assumption that the upper 6 inches of an acre contain 2 million pounds of over dry soil. Triple superphosphate was applied as a solid and mixed thoroughly with the soil. Nitrogen and potassium were added in solution to the surface of the crocks. To facilitate uniform distribution of the fertilizer, each pot was watered immediately with 1000 ml. of H2O.

Twelve seeds were sown in each pot. The pots were later thinned several times to prevent overcrowding. At harvest time, each pot contained 5 plants. The temperature in the greenhouse was maintained between 50 and 70 F during the winter months and 60-85 F during the summer. Artificial light was provided during the winter to extend the light period to 16 hours per day.

Results of soil analysis are found in the appendix table 8c.
Results

Details of experimental measurements and the analysis of variance tables are found in appendix tables 8a and 8b.

Significant treatments:

- Length of tops: nitrogen 1%
- Dry weight of tops: nitrogen 1%
- phosphorus 5%
- nitrogen-phosphorus interaction 1%
- Dry weight of roots: nitrogen 5%
- Total dry weight: nitrogen 1%
- phosphorus 5%

Table 12

Part D, Experiment 8: The effect of nitrogen and phosphorus fertilization on the length and dry weight of Douglas fir seedlings.

Average per Plant

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Length of Tops cm.</th>
<th>Dry Weight of Tops mg.</th>
<th>Dry Weight of Roots mg.</th>
<th>Total Dry Weight mg.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>It*</td>
<td>Mlf**</td>
<td>It</td>
<td>Mlf</td>
</tr>
<tr>
<td>No</td>
<td>18.60</td>
<td>18.37</td>
<td>1490</td>
<td>1404</td>
</tr>
<tr>
<td>N1</td>
<td>14.20</td>
<td>15.59</td>
<td>998</td>
<td>1080</td>
</tr>
<tr>
<td>N2</td>
<td>10.90</td>
<td>13.20</td>
<td>694</td>
<td>881</td>
</tr>
<tr>
<td>N3</td>
<td>10.60</td>
<td>11.21</td>
<td>692</td>
<td>711</td>
</tr>
<tr>
<td>N4</td>
<td>8.20</td>
<td>9.85</td>
<td>1410</td>
<td>583</td>
</tr>
<tr>
<td>P0</td>
<td>not</td>
<td></td>
<td>1490</td>
<td>818</td>
</tr>
<tr>
<td>P1</td>
<td>not</td>
<td></td>
<td>1186</td>
<td>895</td>
</tr>
<tr>
<td>P2</td>
<td>significant</td>
<td></td>
<td>1432</td>
<td>906</td>
</tr>
<tr>
<td>P3</td>
<td>1570</td>
<td>992</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P4</td>
<td>1356</td>
<td>1048</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1sd 1% 9.20 1.78 678 136 1312 265 1058 211
5% 6.90 1.35 312 102 992 199 796 159

* Individual Treatment
** Mean Level of Factor
Observations

Germination was uniform and very good throughout the experiment. During the first two months, 2 to 3 plants were lost per treatment as a result of damping off. It was noticed that the position of pots on the benches had a distinct effect on the growth of the seedlings. The location of the replicates and the pots within each replicate was therefore, changed each month. Two months after seeding, no differences were observed between treatments. All pots were thinned to 7-8 plants shortly after November 15, 1957.

Most of the seedlings became dormant in December. The high nitrogen treatments had a larger proportion of dormant seedlings. In spite of the artificial light, all seedlings became dormant at least once during the winter. The length of the dormant period varied from 2-3 weeks to 2-3 months. The high nitrogen treatments had the longest dormant period. Seedlings in the same crock, however, varied considerably in the length as well as time of the dormant period, indicating that dormancy is an individual characteristic of a seedling. Seedlings in all treatments did not appear healthy during the winter. In March practically all seedlings broke dormancy. The high nitrogen treatments formed large swollen buds which opened with difficulty and grew only for one or two weeks before becoming dormant again. Seedlings which had not received nitrogen or only 40 lb. per acre, formed normal buds and grew most satisfactorily. The incidence of Fusarium top wilt continued but was limited mainly to high nitrogen treatments. During June and July, 1958, the general appearance of all seedlings improved considerably. Growth in the unfertilized and low nitrogen treatments
was, in some cases 2-3 inches in one week. All high nitrogen treat-
ments remained small and spindly. Indeed, in some of these crocks,
the plants had a reddish-pink color and could be considered a complete loss.

The phenotype of seedlings grown in the greenhouse differed
from nursery seedlings. The development of side buds appeared retarded
giving rise to tall slim plants. Roots were long and unbranched.
Needles were long and sparsely spaced on the branches.

Photographs of some of the treatments are found in the ap­
pendix plates 9 and 10. The experiment was harvested on August 12
and 13, 1958.

Discussion

The application of nitrogen decreased considerably the weight,
and length of the seedlings. The soil must, therefore contain suf­
ficient nitrogen for seedling growth. In the field, however, the same
soil requires 40 to 80 lb. per acre of nitrogen to produce seedlings
of desirable size and color. Difference in the environmental con­
ditions in the nursery and in the field may account for the discrepancy.
In the greenhouse, the soil was maintained in a moist, warm condition
throughout the year. Rapid nitrification under these conditions could
account for the high available nitrogen content of the soil in the
greenhouse (87). Steam sterilization might also have resulted in an
increase in plant nutrients in the soil. In the field, the soil is
covered with an inch layer of rice hulls and it has been shown that
mulches decrease the amount of available nitrogen in the soil (3a).
The application of phosphorus increased the dry weight of the seedlings. A significant nitrogen phosphorus interaction was found for the dry weight of tops. High applications of phosphorus decreased the damaging effect of high nitrogen applications.

Despite of 16 hours of light per day, Douglas fir had a dormant period during the winter, regardless of fertilizer treatment. The dormant period was shortened or lengthened by fertilizer applications. The time of the dormant period as well as the duration of the dormant period appears to be a characteristic of each individual plant. This was shown by the fact that in one treatment, the plants would become dormant at different times and would remain dormant for different length of time. Although modified by the individual character of the plant, the overall effect of a fertilizer treatment was similar for all the plants within that treatment.

PART E - EXPERIMENT 9

The effect of different soil moisture tensions on the growth of 1-0 (1957) Douglas fir seedlings.

Location

Field No. 5, Green Timbers Forest Nursery

Experimental Design

Randomized complete block; replicated 6 times.
Seed Source

W-8

Seed Crop: 1956
Origin: Great Central Lake
Elevation: 1300 - 2100 Feet

Date of Sowing

May 31, 1957

Fertilisation

First year: 24 lb. per acre N
30 lb. per acre P205
120 lb. per acre K20

Second year: 80 lb. per acre N(NH4NO3)

Treatments: Maximum Tension 0.2 atm
Maximum Tension 0.75 atm
As dry as possible

Remarks

The irrigation system consisted of plastic pipe with Rain Bird Silver Spray half circle heads. Valves were installed at each sprinkler head to permit individual control. The rate of water delivery was 1.2 to 1.5 inches per hour which was slightly too high for the soil. The uniformity of water distribution was satisfactory. Tensionmeters were used for soil moisture tension measurements in treatment 1 and 2. The tension was measured at 5, 10 and 15 inches
depth three times a week. The moisture content of treatment 3 was measured gravimetrically. Duplicate moisture samples were taken weekly with a soil auger at a depth of 5, 10 and 15 inches. The experiment was started on June 1, 1958 and terminated on September 30, 1958. The rate of water removal from the different depths indicated that the roots did not withdraw moisture from deeper than 5 inches. The integrated mean soil moisture tension was calculated from 5 inch readings, using a modified form of the equation suggested by Taylor (95). Details of the modification are found in the appendix II.

Results of physical and chemical soil analysis are found in the appendix tables 9c, 9d and 9e. A random sample of 36 plants was taken from each plot.

Results

Analysis of variance tables are found in the appendix tables 9a and 9b.

Significant treatments:  

- Length of tops 1%
- Length of Roots 5%
- Dry weight of tops 1%
- Dry weight of roots 5%
- Total dry weight 1%
Table 11

Part E, Experiment 9: The effect of soil moisture tension on the growth of 1-0 Douglas fir seedlings.

Size and Weight of Seedling - Average per Plant

<table>
<thead>
<tr>
<th>Integrated Mean Soil Moisture Tension atm</th>
<th>Dry Weight of Tops g.</th>
<th>Dry Weight of Roots g.</th>
<th>Total Dry Weight g.</th>
<th>Length of Tops cm.</th>
<th>Length of Roots cm.</th>
<th>Diameter of Stem mm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 0.12</td>
<td>1.73</td>
<td>0.17</td>
<td>2.20</td>
<td>24.3</td>
<td>26.3</td>
<td>3.3</td>
</tr>
<tr>
<td>2. 0.33</td>
<td>1.59</td>
<td>0.51</td>
<td>2.11</td>
<td>22.6</td>
<td>25.6</td>
<td>3.0</td>
</tr>
<tr>
<td>3. 5.9</td>
<td>1.11</td>
<td>0.41</td>
<td>1.52</td>
<td>16.3</td>
<td>24.2</td>
<td>2.8</td>
</tr>
<tr>
<td>lsd 1%</td>
<td>0.46</td>
<td>0.10</td>
<td>0.52</td>
<td>5.20</td>
<td>2.30</td>
<td></td>
</tr>
<tr>
<td>lsd 5%</td>
<td>0.32</td>
<td>0.07</td>
<td>0.37</td>
<td>3.68</td>
<td>1.62</td>
<td></td>
</tr>
</tbody>
</table>

Observations

Seedlings in treatments 1 and 2 did not become semi-dormant during the summer but apparently grew continuously. Treatment 1 did not harden off in the fall and light frost damage was observed. Seedlings in treatment 3 suffered severely from lack of water. During the driest part of the summer, approximately 10% of the seedlings died in the plots. Most of the trees became dormant in July and did not commence growth again.

Discussion

During the summer, the moisture content of the dry plots (treatment 3) was below the wilting point for approximately one week. The development and growth of the seedlings might have been determined by this period of extremely low soil moisture tension. It is felt,
therefore, that the integrated soil moisture tension calculated for the dry plots might not be significant.

Irrigation increased the size and weight of 1-0 Douglas fir seedlings but did not increase the stem diameter. No significant differences in growth were found between seedlings grown at soil moisture tensions of 0.12 and 0.33 atmospheres (Table 11). The experiment has shown that seedling growth can be inhibited at the Green Timbers Forest Nursery by lack of water in dry summers. It was also observed that if the soil moisture tension was kept below 0.12 atmospheres throughout the growing season, dormancy was delayed and the seedlings were damaged by fall frost (11). It would be desirable to investigate the time at which irrigation should be stopped in the late summer to permit hardening off.

EXPERIMENT 10

The rate of growth and uptake of nutrients by 0-0 and 1-0 Douglas fir seedlings.

Introduction

It is impossible to discuss the nutrient requirements of Douglas fir satisfactorily without information regarding the rate of nutrient uptake during the period of growth under investigation. This experiment was conducted to obtain quantitative information with regard to the rate of growth and nutrient uptake by Douglas fir seedlings. For this purpose, a 250 square foot area was seeded with Douglas fir in 1957 on the agronomy farm of the University of British Columbia.
The plot was sampled at intervals of 6 to 3 weeks for two years. The length of tops, length of roots, dry weight of tops and the dry weight of roots of the seedlings was measured. The tops and roots were analyzed separately for N, P, K, Ca and Mg.

**Location**
University of British Columbia, Agronomy plots

**Experimental Design**
For the uptake experiment, seedlings were sown in four 64-square foot beds. To avoid extensive damage to the beds during sampling, relatively large blocks of seedlings were removed from each of the four beds. The number of seedlings in a sample varied with age. At 6 weeks, 100 seedlings were required to provide sufficient material for chemical analysis. The size of the sample decreased with age of the seedlings but was never less than 25 seedlings.

**Seed Source**
Unknown

**Date of Sowing**
June 4, 1957

**Fertilization**
40 lb. per acre N
Date of fertilization: July 20, 1957
Remarks

The plots were irrigated whenever it appeared necessary.

Results of soil analysis are found in the appendix table 10d.

Results

For details of experimental results, see appendix tables 10a, 10b, 10c and figures 1 to 10.

Table 13

Experiment 10: Total uptake of N, P, K, Ca and Mg by 0-0 and 1-0 Douglas fir seedlings.

Based on 50 Seedlings per Square Foot

<table>
<thead>
<tr>
<th>Age</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lb. per acre</td>
<td>lb. per acre</td>
<td>lb. per acre</td>
<td>lb. per acre</td>
<td>lb. per acre</td>
</tr>
<tr>
<td>0-0</td>
<td>19.4</td>
<td>1.42</td>
<td>4.4</td>
<td>3.3</td>
<td>0.83</td>
</tr>
<tr>
<td>1-0</td>
<td>225.0</td>
<td>38.20</td>
<td>126.0</td>
<td>63.2</td>
<td>21.20</td>
</tr>
</tbody>
</table>

Table 14

Experiment 10: Uptake of N, P, K, Ca and Mg by 1-0 Douglas fir seedlings during two periods in the growing season.

Based on 50 Seedlings per Square Foot

<table>
<thead>
<tr>
<th>Period</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lb. per to- acre</td>
<td>% of</td>
<td>lb. per to- acre</td>
<td>% of</td>
<td>lb. per to- acre</td>
</tr>
<tr>
<td>May 6 to Aug. 30/58</td>
<td>138.0</td>
<td>64</td>
<td>21.0</td>
<td>55</td>
<td>113.0</td>
</tr>
<tr>
<td>Aug. 31/58</td>
<td>59.5</td>
<td>26</td>
<td>8.1</td>
<td>21</td>
<td>41.4</td>
</tr>
</tbody>
</table>
Experiment 10: Total dry weight production of 0-0 and 1-0 Douglas fir seedlings.

Based on 50 Seedlings per Square Foot

<table>
<thead>
<tr>
<th>Age</th>
<th>Total Dry Weight</th>
<th>Dry Weight Produced</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lbs. per acre</td>
<td>lbs. per acre 1958</td>
<td></td>
</tr>
<tr>
<td>0-0</td>
<td>720</td>
<td>···</td>
<td>···</td>
</tr>
<tr>
<td>1-0</td>
<td>17,200</td>
<td>5,540</td>
<td>32</td>
</tr>
</tbody>
</table>

Discussion

Growth:

The elongation of 0-0 seedlings tops was completed by September 1, the date of the first sampling. The new top growth started in February but the rate of growth was slow until April 15. The rate of elongation increased rapidly between April 15 and May 15, remained constant for a month until June 10, and then reached a maximum between June 10 and July 1. In the late summer, the rate of height growth declined gradually and stopped in September.

The root elongation of 0-0 seedlings continued through the winter, but the rate of elongation was slow. The rate of root growth of 1-0 seedlings increased considerably after April 15 and reached a maximum rate between June 10 and July 1. The rate of growth declined slightly in July but increased again in August. In September, the length growth of roots virtually stopped.

The amount of dry matter produced and the total nutrient uptake were small during the first year in the nursery. The dry weight
increase of 2.5 tons per acre in August, 1958, represents 32% of the total growth of the seedlings. In the same month, the nutrient uptake of the seedlings was approximately equal to that of a grain crop.

The greater part of the increase in dry weight of 0-0 Douglas fir seedling tops occurred between July 18 and October 15, 1957. No weight increase of the tops was observed between November 9, 1957 and February 20, 1958. The weight of seedling tops began to increase again in early April. The rate of top dry matter production increased rapidly until June 10, then remained constant until August 2 and obtained its maximum value in August. The growth rate of 1-0 seedling tops decreased sharply in September; after October 4, no further growth was observed.

Between September 3, and November 3, the dry weight of 0-0 seedling roots increased considerably. No further dry weight increase was found until April 9, 1958. The increase in root weight of 1-0 seedlings was slow till July 1. In July the dry matter increase of the roots became very rapid and then decreased slightly during August and September. After October 4, no further weight increase could be observed.

It is seen from figures 3, 4, and 5 that the rate of total dry matter production increased uniformly from February to September. The rate of increase of top weight and root weight, however, was not uniform. The period of constant top growth coincides with the period of maximum root growth. In August, the rate of root growth decreased but top growth at the same time reached its maximum rate (35). The
reason for this inter-relation between top and root growth is not fully understood. In 0-0 and 1-0 Douglas fir seedlings, the periods of maximum elongation preceded maximum dry weight production.

Nutrient Composition and Uptake:

The nutrient content of the seedlings increased throughout the two years. The percent of N, P, K and Mg was higher in the tops than in the roots. The percent calcium was higher in the roots than in the tops. The percent Mg plus Ca was nearly the same in the roots and tops.

Nitrogen (Fig. 6):
The nitrogen concentration in young plants was higher than in older plants. During the active growing season the percent nitrogen in the plants decreased, but increased slightly in the fall. The rate of nitrogen uptake in June, July and August, 1958, appears to be directly related to root elongation.

Phosphorus (Fig. 7):
The phosphorus concentration in 0-0 and 1-0 Douglas fir seedlings showed the same trend as nitrogen. The rate of P uptake increased throughout the summer and reached a maximum value in September, a month after the period of maximum growth.

Potassium (Fig. 8):
The potassium concentration in the seedlings remained constant during the two years of sampling. The rate of uptake was
directly related to the amount of dry weight produced. The data also indicate that some K was lost to the soil by the plants in the late fall.

Calcium (Fig. 9):

The calcium concentration in the seedlings remained almost constant. The roots showed a small increase in the percent Ca in the fall. Calcium uptake was very rapid in July, August and September, the period of maximum increase in root weight.

Magnesium (Fig. 10):

The magnesium concentration in the tops was constant. In the roots, the Mg level fluctuated markedly. As shown by the rate of uptake curves, the total uptake by the plants in May, August and September was less than the increase in the tops. The magnesium concentration in the tops must have been maintained at a constant level by translocation from the roots to the tops. The total uptake of Mg was directly related to the rate of dry weight increase of the tops.
FIG 1  THE HEIGHT AND RATE OF ELONGATION OF DOUGLAS FIR SEEDLING TOPS
FIG. 2 THE LENGTH AND RATE OF ELONGATION OF DOUGLAS FIR SEEDLING ROOTS

LENGTH

DAY LENGTH

Length cm
or
Length Days

DAYS

50.00
40.00
30.00
20.00
10.00

50 160 240 320 400 480 560
FIG 3. THE DRY WEIGHT AND RATE OF DRY MATTER PRODUCTION OF DOUGLAS FIR SEEDLING TOPS

Weight mg

or

Weight x 100

Days

DAYS

1957
FIG 4. THE DRY WEIGHT AND RATE OF DRY MATTER PRODUCTION OF DOUGLAS FIR SEEDLING ROOTS.

- Weight
- Weight
- Days

Weight (mg) or Weight (mg/day) x 100

Days

0 150 210 520 100 450 950
FIG. 5 THE DRY WEIGHT AND RATE OF DRY MATTER PRODUCTION OF DOUGLAS FIR SEEDLINGS
FIG. 6 THE RATE OF NITROGEN UPTAKE BY DOUGLAS FIR SEEDLINGS

1957

ROOTS

TOPS

WHOLE PLANT

N
Days x 100

N/day

DAYS
FIG 7. THE RATE OF PHOSPHOROUS UPTAKE BY DOUGLAS FIR SEEDLINGS
FIG 8. THE RATE OF POTASSIUM UPTAKE BY DOUGLAS FIR SEEDLINGS

- ROOTS
- TOPS
- WHOLE PLANT

Days: 80, 160, 240, 320, 400, 480, 560

K days x 100
FIG. 9. THE RATE OF CALCIUM UPTAKE BY DOUGLAS FIR SEEDLINGS

1957

J J A S O N D J F M A M J J A S O N D

12.00

ROOTS

9.00

TOPS

6.00

WHOLE PLANT

3.00

Ca / days x 100

my/ day

DAYS

0 160 210 320 100 150 560
FIG 10 THE RATE OF MAGNESIUM UPTAKE BY DOUGLAS FIR SEEDLINGS

ROOTS

TOPS

WHOLE PLANT

DAYS

mg/day

Mg x 100

Days

80 160 210 320 400 480 560
EXPERIMENT II

The growth and chemical composition of Douglas fir seedlings from three locations in British Columbia.

Introduction

Douglas fir seedlings were collected in the fall of 1957 and 1958 at the Green Timbers Nursery, the University of British Columbia, and the University of British Columbia Forest at Haney, B.C. The seedlings from Haney were seeded naturally and grew under the usual field conditions. Seedlings from the University of British Columbia were irrigated during the summer of 1957 and 1958. Douglas fir seedlings from the Green Timbers Forest Nursery were irrigated as 0-0 seedlings in 1957 and 1958. The 1-0 seedlings in 1957 were not irrigated, however, in 1958 some water had to be applied to prevent extensive seedling mortality. The seedlings for this experiment were harvested in late September and October. The length of tops, length of roots, dry weight of tops, and dry weight of roots of the seedlings were determined, and the plant tissues analyzed for N, P, K, Ca and Mg. For the calculation of results on a per acre basis, it was assumed that the density of the seedlings was 50 plants per square foot.
### Results

#### Table 16

Experiment 11: Length, diameter of stem and dry weight of 0-0 and 1-0 Douglas fir seedlings at the Green Timbers Nursery in 1957 and 1958.

<table>
<thead>
<tr>
<th>Fertilizer Treatment</th>
<th>Length of Tops cm.</th>
<th>Diameter of Stem mm.</th>
<th>Dry Weight of Tops mg.</th>
<th>Dry Weight of Roots mg.</th>
<th>Total Dry Weight mg.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1-0 SEEDLINGS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1957 No N</td>
<td>17.1</td>
<td>2.3</td>
<td>842</td>
<td>301</td>
<td>1143</td>
</tr>
<tr>
<td>1958 No N</td>
<td>15.7</td>
<td>2.6</td>
<td>991</td>
<td>370</td>
<td>1361</td>
</tr>
<tr>
<td>1957 40 lb/acre N</td>
<td>21.4</td>
<td>2.7</td>
<td>1217</td>
<td>340</td>
<td>1557</td>
</tr>
<tr>
<td>1958 40 lb/acre N</td>
<td>18.4</td>
<td>2.9</td>
<td>1289</td>
<td>463</td>
<td>1744</td>
</tr>
<tr>
<td><strong>0-0 SEEDLINGS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1957 No N</td>
<td>4.6</td>
<td>not measured</td>
<td>87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1958 No N</td>
<td>4.4</td>
<td>not measured</td>
<td>77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1957 20 lb/acre N</td>
<td>4.9</td>
<td>measured</td>
<td>97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1958 30 lb/acre N</td>
<td>4.8</td>
<td>measured</td>
<td>100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Table 17

Experiment 11: The length and dry weight of Douglas fir seedlings from three locations in British Columbia.

<table>
<thead>
<tr>
<th>Origin</th>
<th>Length of Tops cm.</th>
<th>Length of Roots cm.</th>
<th>Dry Weight of Tops mg.</th>
<th>Dry Weight of Roots mg.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>0-0 SEEDLINGS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.B.C. Forest, Haney, B.C., 1957</td>
<td>3.3</td>
<td>12.8</td>
<td>39</td>
<td>24</td>
</tr>
<tr>
<td>University of British Columbia,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1957</td>
<td>4.4</td>
<td>13.8</td>
<td>77</td>
<td>35</td>
</tr>
<tr>
<td>Green Timbers Forest Nursery 1957</td>
<td>4.9</td>
<td>12.0</td>
<td>84</td>
<td>29</td>
</tr>
<tr>
<td>Green Timbers Forest Nursery 1958</td>
<td>7.1</td>
<td>16.6</td>
<td>117</td>
<td>59</td>
</tr>
<tr>
<td><strong>1-0 SEEDLINGS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.B.C. Forest, Haney, B.C., 1957</td>
<td>7.2</td>
<td>13.9</td>
<td>223</td>
<td>81</td>
</tr>
<tr>
<td>Green Timbers Nursery 1957</td>
<td>27.4</td>
<td>19.4</td>
<td>1982</td>
<td>438</td>
</tr>
<tr>
<td>Green Timbers Nursery 1958</td>
<td>20.0</td>
<td>23.8</td>
<td>1190</td>
<td>550</td>
</tr>
<tr>
<td>University of British Columbia</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1958</td>
<td>22.6</td>
<td>41.9</td>
<td>2610</td>
<td>1080</td>
</tr>
</tbody>
</table>
Table 18


<table>
<thead>
<tr>
<th>Origin</th>
<th>N</th>
<th></th>
<th>P</th>
<th></th>
<th>K</th>
<th></th>
<th>Ca</th>
<th></th>
<th>Mg</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>mg. lb/acre</td>
<td>%</td>
<td>mg. lb/acre</td>
<td>%</td>
<td>mg. lb/acre</td>
<td>%</td>
<td>mg. lb/acre</td>
<td>%</td>
<td>mg. lb/acre</td>
</tr>
<tr>
<td></td>
<td>plant</td>
<td></td>
<td>plant</td>
<td></td>
<td>plant</td>
<td></td>
<td>plant</td>
<td></td>
<td>plant</td>
<td></td>
</tr>
<tr>
<td>0-0 SEEDLINGS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.B.C. Forest, Haney, B.C. 1957</td>
<td>0.93</td>
<td>0.23</td>
<td>1.1</td>
<td>0.12</td>
<td>0.03</td>
<td>0.14</td>
<td>0.21</td>
<td>0.05</td>
<td>0.2</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>University of British Columbia 1957</td>
<td>1.95</td>
<td>0.68</td>
<td>3.4</td>
<td>0.15</td>
<td>0.05</td>
<td>0.24</td>
<td>0.63</td>
<td>0.22</td>
<td>1.1</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green Timbers Forest Nursery 1957</td>
<td>1.85</td>
<td>0.54</td>
<td>2.6</td>
<td>0.10</td>
<td>0.03</td>
<td>0.29</td>
<td>0.29</td>
<td>0.08</td>
<td>0.4</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green Timbers Forest Nursery 1958</td>
<td>0.93</td>
<td>0.55</td>
<td>2.6</td>
<td>0.10</td>
<td>0.06</td>
<td>0.29</td>
<td>0.35</td>
<td>0.20</td>
<td>1.0</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-0 SEEDLINGS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.B.C. Forest, Haney, B.C. 1957</td>
<td>2.13</td>
<td>1.75</td>
<td>8.5</td>
<td>0.15</td>
<td>0.12</td>
<td>0.58</td>
<td>0.32</td>
<td>0.26</td>
<td>1.3</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green Timbers Forest Nursery 1957</td>
<td>1.22</td>
<td>5.35</td>
<td>25.6</td>
<td>0.12</td>
<td>0.51</td>
<td>2.14</td>
<td>0.35</td>
<td>1.53</td>
<td>7.4</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green Timbers Forest Nursery 1958</td>
<td>0.88</td>
<td>4.85</td>
<td>23.3</td>
<td>0.09</td>
<td>0.48</td>
<td>2.30</td>
<td>0.43</td>
<td>2.47</td>
<td>11.8</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>University of British Columbia 1958</td>
<td>0.91</td>
<td>9.30</td>
<td>54.6</td>
<td>0.17</td>
<td>1.71</td>
<td>8.21</td>
<td>0.45</td>
<td>5.51</td>
<td>26.4</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* 50 plants per square foot</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* 50 plants per square foot
Table 19

Experiment 11: Mineral composition of 0-0 and 1-0 Douglas fir seedling tops in 1957 and 1958.

<table>
<thead>
<tr>
<th>Origin</th>
<th>N % plant</th>
<th>P lb/acre</th>
<th>K mg. plant</th>
<th>Ca lb/acre</th>
<th>Mg lb/acre</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>0-0 SEEDLINGS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.B.C. Forest, Haney, B.C. 1957</td>
<td>1.29</td>
<td>0.5</td>
<td>2.4</td>
<td>0.14</td>
<td>0.06</td>
</tr>
<tr>
<td>University of British Columbia 1957</td>
<td>2.77</td>
<td>2.1</td>
<td>10.6</td>
<td>0.15</td>
<td>0.11</td>
</tr>
<tr>
<td>Green Timbers Forest Nursery 1957</td>
<td>2.01</td>
<td>1.7</td>
<td>8.4</td>
<td>0.10</td>
<td>0.08</td>
</tr>
<tr>
<td>Green Timbers Forest Nursery 1958</td>
<td>1.40</td>
<td>1.6</td>
<td>7.9</td>
<td>0.09</td>
<td>0.10</td>
</tr>
<tr>
<td><strong>1-0 SEEDLINGS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.B.C. Forest, Haney, B.C. 1957</td>
<td>2.17</td>
<td>4.9</td>
<td>23.4</td>
<td>0.17</td>
<td>0.37</td>
</tr>
<tr>
<td>Green Timbers Forest Nursery 1957</td>
<td>1.60</td>
<td>31.8</td>
<td>153.0</td>
<td>0.13</td>
<td>2.48</td>
</tr>
<tr>
<td>Green Timbers Forest Nursery 1958</td>
<td>1.62</td>
<td>24.3</td>
<td>118.0</td>
<td>0.10</td>
<td>1.48</td>
</tr>
<tr>
<td>University of British Columbia 1958</td>
<td>1.40</td>
<td>35.5</td>
<td>170.0</td>
<td>0.21</td>
<td>6.22</td>
</tr>
</tbody>
</table>

* 50 plants per square foot
Table 20

Experiment 11: Amount of N, P, K, Ca and Mg removed from the soil by 0-0 and 1-0 seedlings, (based on 50 plants per square foot).

<table>
<thead>
<tr>
<th>Seedling Origin</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pounds per Acre</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>0-0 SEEDLINGS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.B.C. Forest, Haney, B.C. 1957</td>
<td>3.50</td>
<td>0.43</td>
<td>1.26</td>
<td>0.62</td>
<td>0.29</td>
</tr>
<tr>
<td>University of British Columbia 1957</td>
<td>13.86</td>
<td>0.77</td>
<td>4.04</td>
<td>2.31</td>
<td>0.57</td>
</tr>
<tr>
<td>Green Timbers Forest Nursery 1957</td>
<td>10.97</td>
<td>0.52</td>
<td>3.41</td>
<td>2.21</td>
<td>0.39</td>
</tr>
<tr>
<td><strong>1-0 SEEDLINGS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.B.C Forest, Haney, B.C. 1957</td>
<td>31.85</td>
<td>2.37</td>
<td>8.80</td>
<td>3.33</td>
<td>1.30</td>
</tr>
<tr>
<td>Green Timbers Forest Nursery 1957</td>
<td>178.60</td>
<td>14.34</td>
<td>84.16</td>
<td>33.10</td>
<td>11.03</td>
</tr>
<tr>
<td>Green Timbers Forest Nursery 1958</td>
<td>111.30</td>
<td>9.40</td>
<td>57.20</td>
<td>41.86</td>
<td>5.02</td>
</tr>
<tr>
<td>University of British Columbia 1958</td>
<td>214.60</td>
<td>38.11</td>
<td>125.10</td>
<td>63.00</td>
<td>21.97</td>
</tr>
</tbody>
</table>

Table 21

Experiment 11: The amount of dry matter produced by 0-0 and 1-0 Douglas fir seedlings, (based on 50 plants per square foot).

<table>
<thead>
<tr>
<th>Seedling Origin</th>
<th>0-0 Seedlings Dry Weight lb/acre</th>
<th>1-0 Seedlings Dry Weight lb/acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of British Columbia, 1958</td>
<td>720</td>
<td>17,200</td>
</tr>
<tr>
<td>Green Timbers Forest Nursery, 1958</td>
<td>850</td>
<td>9,850</td>
</tr>
<tr>
<td>Green Timbers Forest Nursery, 1957</td>
<td>560</td>
<td>11,750</td>
</tr>
<tr>
<td>U.B.C. Forest, Haney, B.C., 1957</td>
<td>300</td>
<td>1,480</td>
</tr>
</tbody>
</table>
Discussion

As can be seen from tables 17 to 20, the seedlings from Haney were the smallest. The amount of nutrients removed per acre was also comparatively small. The length and dry weight of 0-0 seedlings from the Green Timbers Nursery and the University of British Columbia were similar in 1957. In 1958, however, 0-0 seedlings from Green Timbers were considerably larger than in 1957.

The dry weight of tops and roots of 1-0 seedlings from the University of British Columbia in 1958 was twice that of seedlings from Green Timbers. In 1957, seedlings from Green Timbers were taller and heavier than in 1958 (Table 17). It might be of interest to note that seedlings grown in the experimental plots at Green Timbers were of similar length and weight in 1957 and 1958 (Table 16). The experimental plots of 1-0 seedlings were irrigated frequently in 1958 to avoid retarding growth due to lack of water. The small size of 1-0 seedlings at the Green Timbers Nursery in 1958 could, therefore, have been a result of soil moisture deficiency. The irrigation experiment (Experiment 9), conducted in 1958 with 1-0 seedlings, provides further evidence that the soil moisture conditions were not satisfactory for seedling growth in 1958. The total dry matter production of 1-0 Douglas fir seedlings varied considerably with the origin of the seedlings (Table 21). Naturally seeded plants from Haney produced only 1,480 lb. per acre dry matter, in contrast to seedlings at the University of British Columbia which produced 17,200 lb. per acre.
The removal of nutrients from the soil was generally parallel to the dry matter production (Table 20). The chemical composition of the seedlings (Tables 18 & 19) harvested in the fall was similar with exception of nitrogen. The percent nitrogen in the 1-0 seedlings decreased as the dry matter production of the seedlings increased.
The change from a seedling to a tree involves accretion and tissue development. The rate of development of a seedling is very rapid during the first year when the transition from a succulent to a woody plant occurs. This drastic change in the nature of seedling tissues as well as the relatively rapid production of new tissue results in significant changes in seedling physiology.

GROWTH AND DEVELOPMENT OF 0-0 DOUGLAS FIR SEEDLINGS

Immediately after germination, Douglas fir seedlings are small, succulent plants with few needles and a small shallow root system. The young plants can easily be destroyed by high temperatures (1, 37), lack of water in the surface soil (1, 37), frost (1), and mechanical injury.

At the Green Timbers Nursery and the University of British Columbia it was observed that 0-0 Douglas fir seedlings had two detectable growing periods during the summer. After germination, the seedling tops elongated about 3-4 cm. and formed 1 whorl of needles. During the same time, the roots grew straight downwards for approximately 10 cm. before forming lateral rootlets. The young plants then formed semi-permanent buds. It is felt that, should unfavourable
growing conditions prevail during this state of temporary dormancy, a seedling may become permanently dormant and not resume growth before next spring. Under the favourable growing conditions in the Gree Timbers Nursery and at the University of British Columbia, however, the seedling regularly resumed growth in late July and August. During this second period of visible growth, the 0-0 seedlings produced 1 to 5 whorls of needles depending on the growing conditions and the hereditary potential of the seedlings (47). Normally, the seedlings ceased to grow in the fall, but under unusually favourable soil conditions, the seedlings continued to grow until damaged by frost in autumn.

GROWTH AND DEVELOPMENT OF 1-0 DOUGLAS FIR SEEDLINGS

The 1-0 Douglas fir seedlings started growth in the late winter. During late spring, the seedlings formed semi-permanent buds, which were generally broken during the later part of the growing season. The length of the semi-dormant period depended on soil moisture, soil fertility and the origin of the seed. If the growing conditions are unfavourable due to lack of moisture or nitrogen, it is conceivable that plants may remain dormant till the next spring. The elongation of tops and roots and the dry weight increase did not cease with the formation of semi-permanent buds. The uptake study at the University of British Columbia (Experiment 10) showed clearly that growth continued throughout the summer whether or not buds were present.
Application of nitrogen to unfertilized 1-0 Douglas fir seedlings in July and August resulted in very rapid growth. Before the nitrogen application, the unfertilized seedlings were small and yellowish, but nevertheless by fall these seedlings attained the same size and weight as seedlings fertilized in May and June. This spectacular growth during the late summer could be the result of the stimulation of the second rapid growth period of Douglas fir seedlings by nitrogen fertilization. From this study, it would appear that the growth potential of a seedling could be utilized more fully by repeated timely nitrogen and complete fertilizer applications. Late summer nitrogen fertilization, however, may result in an extension of the growing season into autumn and increases the danger of frost damage.

It was found in Part A, Experiment 1 that the percent nitrogen and phosphorus in 1-0 seedlings was lower in plants fertilized with nitrogen, however, growth and nutrient uptake were increased by nitrogen fertilization. Chemical analysis of 1-0 seedlings from different locations (Experiment II) showed that the percent nitrogen was lower in plants which had produced more dry matter. The nutrient composition of a tree species is a function of total dry weight, age, available soil nutrients, and the time of sampling (55). The difference in mineral composition of seedlings from different sites tends to decrease in the fall. The sampling of seedlings in the fall for chemical analysis might, therefore, not be desirable if the data will be used for the comparison of site fertility. The concentration of
nutrients in the seedling during the period of summer growth will
be a much more significant indicator of the fertility of a soil.

**SOME DIFFERENCES BETWEEN 0-0 AND 1-0 DOUGLAS FIR SEEDLINGS**

The experiments conducted in 1957 and 1958 point up some
differences between 0-0 and 1-0 Douglas fir seedlings. The 0-0
seedlings produced 300 to 850 lb. per acre of dry matter compared
with 1,480 to 17,200 lb. per acre for 1-0 seedlings (Table 21).
The total nutrient uptake was directly related to the amount of dry
matter produced. The 0-0 seedlings removed very little nutrients
from the soil. This does not mean that they would grow satisfactorily
on soils low in available nutrients. The small root volume of
these seedlings requires that the necessary nutrients are present in
a small soil volume directly adjacent to the plant. In spite of the
high total nutrient uptake of 1-0 seedlings (Table 20), it is not
necessary that a nursery soil contain large quantities of so-called
"available" nutrients. It has been shown that coniferous seedlings
are able to utilize soil nutrients not available to some agricultural
crops (30, 104). For the interpretation of "available" soil nutrient
data, the relative scale applicable to conifer seedlings is still
unknown.

The optimum nitrogen application for 0-0 seedlings was
20 to 30 lb. per acre compared with 80 lb. per acre for 1-0 seedlings.
In Part A, Experiment 2, fertilization of 0-0 seedlings with K decreased and with P increased growth. In all other experiments with 0-0 seedlings, fertilization with phosphorus and potassium had no effect. The 1-0 seedlings responded favourably to high P applications but not to potassium fertilization. It has been shown by Mitchell (66) that young pine seedlings are adversely affected by nitrogen concentrations which were optimum for the growth of older seedlings.

The difference in response of 0-0 and 1-0 seedlings to mineral fertilization would indicate a similar physiological change with age for Douglas fir.

The growth of 0-0 seedlings can be decreased significantly or even stopped by excessive heat. The 1-0 Douglas fir seedlings, however, were found to be considerably more heat tolerant (1, 37).

**DORMANCY OF DOUGLAS FIR SEEDLINGS**

Dormancy is usually associated with the suspension of visible growth. Two types of dormancy are generally recognized (88):

"Temporary" dormancy - a state from which the plant resumes visible growth if the growing conditions become favourable;

"Permanent" dormancy - a condition from which the plant will resume growth only if a stimulus is provided in addition to an improvement in the environmental conditions.

There is no sharp distinction between the two types of
dormancy and plants pass usually through a period of temporary dormancy before entering permanent dormancy. In the state of permanent dormancy seedlings are frost resistant (85).

During the summer, 0-0 and 1-0 Douglas fir seedlings become temporarily dormant under normal nursery conditions. If the growing conditions were unfavourable, the seedlings entered permanent dormancy and resumed growth only in the next spring. If, however, moisture was adequate or provided by irrigation, and if nitrogen was applied on nitrogen deficient soils, growth was resumed vigorously after a very short rest period. The application of nitrogen to 1-0 seedlings up to August 15 induced breaking of the semi-dormant buds and resulted in renewed vigorous growth. In the fall, the 1-0 seedlings entered a state of temporary dormancy depending on the time of nitrogen fertilization. The later the fertilizer application, the later was the entry into the dormant state. Once temporary dormancy was broken Douglas fir seedlings required some undetermined amount of time before dormancy was possible again. This delay occurred even though the climatic factors, such as temperature, were unfavourable for further growth. If nitrogen fertilizer was applied in September, the majority of the seedlings did not break dormancy and it can be assumed that the seedlings were in the state of permanent dormancy. The comparison of 1957 and 1958 data shows that the pattern of dormancy was similar in both years but that the date at which plants became permanently dormant was different (51).

In 1957, non-irrigated 1-0 seedlings entered dormancy in the early summer and did not grow again in 1957. Seedlings irrigated
heavily (0.12 atm) grew vigourously nearly all summer but did not enter permanent dormancy early enough in the fall, so that there was some frost damage to terminal shoots. The 1-0 seedlings grown at an integrated mean soil moisture tension of 0.33 atmosphere also grew very well but hardened off early enough to avoid frost damage. The moisture conditions under which a seedling is grown, therefore, has considerable influence on the time at which dormancy occurs.

In the greenhouse, Douglas fir grown with a photoperiod of 16 hours entered temporary or permanent dormancy during the winter regardless of fertilizer treatment. The length of the dormant period depended on fertilizer treatment and some individual characteristic of the seedling.

During the summer, seedlings in the greenhouse became temporarily dormant. In fertilizer treatment favourable for growth, the dormant period often lasted only a few days. In the unfavourable treatments, primarily those with high nitrogen applications, the dormant period lasted as long as one month. Again the length of the dormant period depended to some extent on the individual characteristics of the plant.
SUMMARY

Experiments with 0-0 and 1-0 Douglas fir seedlings were conducted during 1957 and 1958.

Under the experimental conditions at the Green Timbers Nursery, the optimum rates of N fertilization for 0-0 and 1-0 seedlings were 20 and 80 lb. per acre N respectively. This indicated that 1-0 Douglas fir seedlings were able to tolerate and utilize higher N application than the younger stock. Application of 320 lb. per acre N to 1-0 seedlings resulted in decreased growth and damage to the plant tissues. A positive response to phosphorus applications reduced the unfavourable effect of excess nitrogen. The 1-0 Douglas fir seedlings did not respond to K fertilization.

The time of nitrogen application had a considerable influence on the growth habit of 1-0 seedlings. Spring applications resulted in rapid early growth and early dormancy in the fall. Late summer applications induced very rapid growth in the early fall, delayed dormancy and resulted in considerable frost damage. Nitrogen fertilization in September increased frost resistance if the seedlings remained dormant.

The application of fertilizers to 0-0 Douglas fir seedlings gave less consistent results than the experiments with 1-0 seedlings. Nitrogen applications of 20 to 30 lb. per acre increased the length and weight of seedlings. Phosphorus application increased the size
of seedlings in 1957 but had no effect in 1958. Potassium decreased
the size of seedlings in 1957 but did not influence the growth of
0-0 seedlings in 1958. Compost, mushroom manure and cow manure im-
proved the growth of 0-0 seedlings. The weight and length of the
seedlings was decreased by sawdust. Fertilization of 0-0 Douglas
fir seedlings had no effect on the growth of the seedlings in the
next growing season.

Irrigation increased the length and dry weight of 1-0
Douglas fir seedlings. Excess of moisture decreased the winter
hardiness of the seedlings.

The 0-0 Douglas fir seedlings produced little dry matter
and removed small amounts of nutrients from the soil. In the second
year of growth (1-0), the dry matter production and the removal of
soil nutrients at the University of British Columbia and the Green
Timbers Nursery exceeded that of many agricultural field crops.
The seedlings produced 8-5 tons dry matter per acre and removed 200-
160 lb. nitrogen per acre.

The growth of Douglas fir seedlings was continuous through-
out the summer even though the seedlings passed through at least one
period of temporary dormancy. The periods of rapid root or top
elongation were followed by very rapid dry weight increase of the
same plant part. Root and top growth appeared to be dominant at
different times during the summer.

The rate of nutrient uptake was generally parallel to the
rate of growth of the seedling. The percent N, P, and Ca in 1-0
seedlings was lower than in the 0-0 seedlings. The concentration of K and Mg appeared to remain constant during the two years of observation. In the roots, the percent N and K also decreased with age but P, Ca and Mg remained constant. The N and P concentration in the seedlings decreased during the periods of rapid growth and increased again during the fall and winter. In plants fertilized with nitrogen, the percent nitrogen, phosphorus, and potassium in the tops was less than in the unfertilized plants. The fertilized seedlings, however, contained more nitrogen and potassium per plant top. The total amount of phosphorus in the plant tops did not vary consistently with fertilizer treatments. Potassium fertilization increased the concentration of K in the plant tops. The phosphorus and calcium concentration of the roots was significantly decreased by nitrogen and potassium fertilization. The Ca and Mg concentration as well as the total uptake of these elements was not affected by N, P and K fertilization. The total uptake of N, P, K, Ca and Mg by the roots was only 1/3 to 1/6 of that of the tops.

It was observed that each seedling had individual dormancy characteristics. The length and the occurrence of the dormant periods was found to be influenced by fertilization and soil moisture conditions.
APPENDIX I

TABLE 1a.

Part A - Experiment 1. The effect of fertilization on the dry weight, length and diameter of 1-0 Douglas fir seedlings.

Average per plant

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Length of tops cm</th>
<th>Length of roots cm</th>
<th>Diameter of stems mm</th>
<th>Dry Weight of tops mg</th>
<th>Dry Weight of roots mg</th>
<th>Total Dry Weight mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>NoPoKo</td>
<td>17.0</td>
<td>21.0</td>
<td>2.3</td>
<td>732</td>
<td>323</td>
<td>1055</td>
</tr>
<tr>
<td>NoPoK1</td>
<td>16.7</td>
<td>20.6</td>
<td>2.2</td>
<td>799</td>
<td>314</td>
<td>1113</td>
</tr>
<tr>
<td>NoPoK2</td>
<td>17.7</td>
<td>18.9</td>
<td>2.3</td>
<td>989</td>
<td>309</td>
<td>1298</td>
</tr>
<tr>
<td>NoF1Ko</td>
<td>16.7</td>
<td>18.1</td>
<td>2.1</td>
<td>786</td>
<td>292</td>
<td>1078</td>
</tr>
<tr>
<td>NoF1K1</td>
<td>17.2</td>
<td>18.8</td>
<td>2.4</td>
<td>866</td>
<td>322</td>
<td>1188</td>
</tr>
<tr>
<td>NoF1K2</td>
<td>16.9</td>
<td>18.8</td>
<td>2.2</td>
<td>782</td>
<td>259</td>
<td>1041</td>
</tr>
<tr>
<td>NoF2Ko</td>
<td>19.5</td>
<td>18.5</td>
<td>2.4</td>
<td>981</td>
<td>295</td>
<td>1276</td>
</tr>
<tr>
<td>NoF2K1</td>
<td>16.4</td>
<td>17.2</td>
<td>2.3</td>
<td>793</td>
<td>271</td>
<td>1064</td>
</tr>
<tr>
<td>NoF2K2</td>
<td>16.3</td>
<td>17.7</td>
<td>2.3</td>
<td>809</td>
<td>298</td>
<td>1107</td>
</tr>
<tr>
<td>N1PoKo</td>
<td>20.1</td>
<td>18.4</td>
<td>2.5</td>
<td>979</td>
<td>309</td>
<td>1288</td>
</tr>
<tr>
<td>N1PoK1</td>
<td>20.3</td>
<td>19.2</td>
<td>2.5</td>
<td>1104</td>
<td>317</td>
<td>1421</td>
</tr>
<tr>
<td>N1PoK2</td>
<td>19.9</td>
<td>17.7</td>
<td>2.3</td>
<td>887</td>
<td>276</td>
<td>1163</td>
</tr>
<tr>
<td>N1F1Ko</td>
<td>19.1</td>
<td>19.1</td>
<td>2.3</td>
<td>886</td>
<td>297</td>
<td>1183</td>
</tr>
<tr>
<td>N1F1K1</td>
<td>17.8</td>
<td>16.9</td>
<td>2.3</td>
<td>937</td>
<td>323</td>
<td>1260</td>
</tr>
<tr>
<td>N1F1K2</td>
<td>20.5</td>
<td>17.8</td>
<td>2.4</td>
<td>1101</td>
<td>337</td>
<td>1438</td>
</tr>
<tr>
<td>N1F2Ko</td>
<td>20.5</td>
<td>18.6</td>
<td>2.5</td>
<td>1087</td>
<td>333</td>
<td>1420</td>
</tr>
<tr>
<td>N1F2K1</td>
<td>19.5</td>
<td>19.5</td>
<td>2.6</td>
<td>1108</td>
<td>368</td>
<td>1476</td>
</tr>
<tr>
<td>N1F2K2</td>
<td>20.7</td>
<td>19.2</td>
<td>2.5</td>
<td>1197</td>
<td>372</td>
<td>1569</td>
</tr>
<tr>
<td>N2PoKo</td>
<td>21.6</td>
<td>18.4</td>
<td>2.7</td>
<td>1294</td>
<td>355</td>
<td>1649</td>
</tr>
<tr>
<td>N2PoK1</td>
<td>20.6</td>
<td>18.9</td>
<td>2.6</td>
<td>1186</td>
<td>372</td>
<td>1558</td>
</tr>
<tr>
<td>N2PoK2</td>
<td>21.2</td>
<td>18.3</td>
<td>2.7</td>
<td>1034</td>
<td>286</td>
<td>1320</td>
</tr>
<tr>
<td>N2F1Ko</td>
<td>21.3</td>
<td>18.0</td>
<td>2.5</td>
<td>1076</td>
<td>299</td>
<td>1375</td>
</tr>
<tr>
<td>N2F1K1</td>
<td>21.2</td>
<td>19.1</td>
<td>2.6</td>
<td>1182</td>
<td>369</td>
<td>1551</td>
</tr>
<tr>
<td>N2F1K2</td>
<td>22.0</td>
<td>18.4</td>
<td>2.7</td>
<td>1368</td>
<td>394</td>
<td>1762</td>
</tr>
<tr>
<td>N2F2Ko</td>
<td>20.8</td>
<td>20.0</td>
<td>2.5</td>
<td>1288</td>
<td>364</td>
<td>1652</td>
</tr>
<tr>
<td>N2F2K1</td>
<td>21.7</td>
<td>19.5</td>
<td>2.6</td>
<td>1220</td>
<td>373</td>
<td>1593</td>
</tr>
<tr>
<td>N2F2K2</td>
<td>22.3</td>
<td>18.3</td>
<td>2.4</td>
<td>1285</td>
<td>344</td>
<td>1629</td>
</tr>
</tbody>
</table>
Table 1b.


<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2</td>
<td>333.0172</td>
<td>166.5086 **</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>2</td>
<td>5.8405</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>2</td>
<td>10.0066</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP</td>
<td>2</td>
<td>2.8205</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP2</td>
<td>2</td>
<td>2.7266</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NK</td>
<td>2</td>
<td>6.9572</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NK2</td>
<td>2</td>
<td>1.1772</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK</td>
<td>2</td>
<td>.9372</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK2</td>
<td>2</td>
<td>4.6672</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPK</td>
<td>2</td>
<td>2.4326</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPK2</td>
<td>2</td>
<td>5.4826</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP2K</td>
<td>2</td>
<td>1.6092</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP2K2</td>
<td>2</td>
<td>5.1444</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blocks</td>
<td>11</td>
<td>130.0908</td>
<td>17.2817 **</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>70</td>
<td>185.4721</td>
<td>2.6436</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>107</td>
<td>758.3900</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 1b (cont'd)

**Length of Roots.**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2</td>
<td>2.5146</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>2</td>
<td>8.5124</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>2</td>
<td>7.4346</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP</td>
<td>2</td>
<td>24.0813</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP2</td>
<td>2</td>
<td>13.6846</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NK</td>
<td>2</td>
<td>1.6502</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NK2</td>
<td>2</td>
<td>1.4068</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK</td>
<td>2</td>
<td>1.5680</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK2</td>
<td>2</td>
<td>4.9696</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NFK</td>
<td>2</td>
<td>7.0422</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NFK2</td>
<td>2</td>
<td>1.2847</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP2K</td>
<td>2</td>
<td>5.5680</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP2K2</td>
<td>2</td>
<td>3.7066</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blocks</td>
<td>11</td>
<td>132.6674</td>
<td></td>
<td>12.06 **</td>
</tr>
<tr>
<td>Error</td>
<td>70</td>
<td>211.9590</td>
<td></td>
<td>3.03</td>
</tr>
<tr>
<td>Total</td>
<td>107</td>
<td>426,9830</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**TABLE 1b (cont'd)**

**Dry weight of roots.**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2</td>
<td>16.1791</td>
<td>8.09 **</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>2</td>
<td>1.9979</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>2</td>
<td>2.4601</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP</td>
<td>2〈4</td>
<td>5.1814</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP2</td>
<td>2〈4</td>
<td>2.0693</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NK</td>
<td>2〈4</td>
<td>1.5839</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NK2</td>
<td>2〈4</td>
<td>0.948</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FK</td>
<td>2〈4</td>
<td>0.9480</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FK2</td>
<td>2〈4</td>
<td>5.1911</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPK</td>
<td>2〈8</td>
<td>1.6463</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPK2</td>
<td>2〈8</td>
<td>0.6543</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP2K</td>
<td>2〈8</td>
<td>1.6603</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP2K2</td>
<td>2〈8</td>
<td>0.6197</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Block</td>
<td>11</td>
<td>42.9936</td>
<td>3.91 **</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>70</td>
<td>99.8078</td>
<td>1.43</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>107</td>
<td>183.0880</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 1b (cont'd)

**Total dry weight**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2</td>
<td>1078.2729</td>
<td>539.14</td>
<td>**</td>
</tr>
<tr>
<td>P</td>
<td>2</td>
<td>80.1276</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>2</td>
<td>9.3141</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP</td>
<td>4</td>
<td>44.3612</td>
<td>6.5812</td>
<td></td>
</tr>
<tr>
<td>NP2</td>
<td>2</td>
<td>44.3612</td>
<td>6.5812</td>
<td></td>
</tr>
<tr>
<td>NK</td>
<td>4</td>
<td>9.5137</td>
<td>4.4684</td>
<td></td>
</tr>
<tr>
<td>NK2</td>
<td>2</td>
<td>9.5137</td>
<td>4.4684</td>
<td></td>
</tr>
<tr>
<td>PK</td>
<td>4</td>
<td>8.4459</td>
<td>2.1117</td>
<td></td>
</tr>
<tr>
<td>PK2</td>
<td>2</td>
<td>2.1117</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPK</td>
<td>4</td>
<td>42.1026</td>
<td>10.5256</td>
<td></td>
</tr>
<tr>
<td>NPK2</td>
<td>8</td>
<td>55.0611</td>
<td>6.8826</td>
<td></td>
</tr>
<tr>
<td>NP2K</td>
<td>2</td>
<td>9.5137</td>
<td>4.4684</td>
<td></td>
</tr>
<tr>
<td>NP2K2</td>
<td>2</td>
<td>9.5137</td>
<td>4.4684</td>
<td></td>
</tr>
<tr>
<td>Blocks</td>
<td>11</td>
<td>754.4246</td>
<td>68.58</td>
<td>**</td>
</tr>
<tr>
<td>Error</td>
<td>70</td>
<td>1397.0074</td>
<td>19.94</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>107</td>
<td>3589.7594</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 1b (cont'd)

#### Diameter of tops

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2</td>
<td>1.5958</td>
<td></td>
<td>.7979 **</td>
</tr>
<tr>
<td>P</td>
<td>2</td>
<td>.0391</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>2</td>
<td>.0230</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP</td>
<td>2</td>
<td>.1293</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP2</td>
<td>2</td>
<td>.3358</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NK</td>
<td>2</td>
<td>.0002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NK2</td>
<td>2</td>
<td>.0013</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK</td>
<td>2</td>
<td>.1013</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK2</td>
<td>2</td>
<td>.0186</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPK</td>
<td>2</td>
<td>.0089</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPK2</td>
<td>2</td>
<td>.0622</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP2K</td>
<td>2</td>
<td>.3025</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP2K2</td>
<td>2</td>
<td>.0536</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blocks</td>
<td>11</td>
<td>9.4611</td>
<td></td>
<td>.860 **</td>
</tr>
<tr>
<td>Error</td>
<td>70</td>
<td>5.1880</td>
<td></td>
<td>.0741</td>
</tr>
<tr>
<td>Total</td>
<td>107</td>
<td>17.3211</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**TABLE 1b (cont'd)**

**Dry weight of tops**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2</td>
<td>832.6</td>
<td></td>
<td>416.3 **</td>
</tr>
<tr>
<td>P</td>
<td>2</td>
<td>59.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>2</td>
<td>10.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP</td>
<td>2</td>
<td>24.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP2</td>
<td>2</td>
<td>7.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NK</td>
<td>2</td>
<td>9.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NK2</td>
<td>2</td>
<td>5.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK</td>
<td>2</td>
<td>12.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK2</td>
<td>2</td>
<td>61.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPK</td>
<td>2</td>
<td>27.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPK2</td>
<td>2</td>
<td>30.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP2K</td>
<td>2</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP2K2</td>
<td>2</td>
<td>0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blocks</td>
<td>11</td>
<td>623.6</td>
<td></td>
<td>56.69 **</td>
</tr>
<tr>
<td>Error</td>
<td>70</td>
<td>1147.1</td>
<td></td>
<td>16.38</td>
</tr>
<tr>
<td>Total</td>
<td>107</td>
<td>2852.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 1c

Part A. Experiment 1. Chemical and physical analysis of check plot soil samples

<table>
<thead>
<tr>
<th>Check Plot</th>
<th>Depth Ins.</th>
<th>pH</th>
<th>Organic Matter %</th>
<th>Total N mg/g</th>
<th>Exch. P lb/acre</th>
<th>Exch. CAP me/100g</th>
<th>Exchangeable cations me/100g</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0 - 6</td>
<td>5.2</td>
<td>8.6</td>
<td>21.2</td>
<td>21.8</td>
<td>0.81</td>
<td>0.12</td>
<td>0.31</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>5.2</td>
<td>7.7</td>
<td>37.2</td>
<td>21.5</td>
<td>0.81</td>
<td>0.24</td>
<td>0.16</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>5.2</td>
<td>8.1</td>
<td>44.3</td>
<td>21.2</td>
<td>1.19</td>
<td>0.43</td>
<td>0.28</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>5.3</td>
<td>7.9</td>
<td>56.5</td>
<td>20.8</td>
<td>1.16</td>
<td>0.18</td>
<td>0.28</td>
</tr>
</tbody>
</table>

### TABLE 1d.

Part A. Experiment 1. Chemical analysis of tops; analysis of variance tables

#### Nitrogen

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>7</td>
<td>33.5</td>
<td>4.78</td>
<td>9.86 **</td>
</tr>
<tr>
<td>Replica</td>
<td>3</td>
<td>5.8</td>
<td>1.94</td>
<td>4.00</td>
</tr>
<tr>
<td>Error</td>
<td>21</td>
<td>10.2</td>
<td>.49</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>49.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Phosphorous

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>7</td>
<td>1.7</td>
<td>.25</td>
<td>7.22 **</td>
</tr>
<tr>
<td>Replica</td>
<td>3</td>
<td>.7</td>
<td>.23</td>
<td>6.55</td>
</tr>
<tr>
<td>Error</td>
<td>21</td>
<td>.7</td>
<td>.03</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>3.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 1d (cont'd)

#### Potassium

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>7</td>
<td>12.6</td>
<td>1.80</td>
<td>5.89 **</td>
</tr>
<tr>
<td>Replica</td>
<td>3</td>
<td>3.8</td>
<td>1.27</td>
<td>4.15</td>
</tr>
<tr>
<td>Error</td>
<td>21</td>
<td>6.4</td>
<td>.31</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>22.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Calcium

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>7</td>
<td>.5</td>
<td>.07</td>
<td>2.15</td>
</tr>
<tr>
<td>Replica</td>
<td>3</td>
<td>1.4</td>
<td>.46</td>
<td>13.41</td>
</tr>
<tr>
<td>Error</td>
<td>21</td>
<td>.7</td>
<td>.03</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>2.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Magnesium

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>7</td>
<td>.4</td>
<td>.06</td>
<td>.79</td>
</tr>
<tr>
<td>Replica</td>
<td>3</td>
<td>.2</td>
<td>.05</td>
<td>.67</td>
</tr>
<tr>
<td>Error</td>
<td>21</td>
<td>1.7</td>
<td>.08</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>2.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 1e.

**Part A. Experiment 1. Chemical analysis of roots: analysis of variance tables**

#### Nitrogen

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>3.</td>
<td>1.2</td>
<td>.40</td>
<td>.59</td>
</tr>
<tr>
<td>Replica</td>
<td>3.</td>
<td>2.6</td>
<td>.86</td>
<td>1.28</td>
</tr>
<tr>
<td>Error</td>
<td>9.</td>
<td>6.1</td>
<td>.67</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>15.</td>
<td>9.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Phosphorous

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>3.</td>
<td>.15</td>
<td>.05</td>
<td>19.50 **</td>
</tr>
<tr>
<td>Replica</td>
<td>3.</td>
<td>.09</td>
<td>.03</td>
<td>11.75</td>
</tr>
<tr>
<td>Error</td>
<td>9.</td>
<td>.06</td>
<td>.0066</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>15.</td>
<td>.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Potassium

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>3.</td>
<td>.9</td>
<td>.28</td>
<td>.47</td>
</tr>
<tr>
<td>Replica</td>
<td>3.</td>
<td>3.2</td>
<td>1.08</td>
<td>1.79</td>
</tr>
<tr>
<td>Error</td>
<td>9.</td>
<td>5.4</td>
<td>.60</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>15.</td>
<td>9.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Calcium

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>3.</td>
<td>1.1</td>
<td>.35</td>
<td>2.59</td>
</tr>
<tr>
<td>Replica</td>
<td>3.</td>
<td>2.9</td>
<td>.98</td>
<td>7.23</td>
</tr>
<tr>
<td>Error</td>
<td>9.</td>
<td>1.2</td>
<td>.14</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>15.</td>
<td>5.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Source of Variation</td>
<td>df</td>
<td>Sum of Squares</td>
<td>Mean Squares</td>
<td>F</td>
</tr>
<tr>
<td>---------------------</td>
<td>----</td>
<td>----------------</td>
<td>--------------</td>
<td>-------</td>
</tr>
<tr>
<td>Treatment</td>
<td>3</td>
<td>.0</td>
<td>.01</td>
<td>.23</td>
</tr>
<tr>
<td>Replica</td>
<td>3</td>
<td>.1</td>
<td>.04</td>
<td>1.39</td>
</tr>
<tr>
<td>Error</td>
<td>9</td>
<td>.2</td>
<td>.03</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 2.Ia.

Part A: Experiment 2,1. The effect of fertilizers on the dry weight and length of tops of 0-0 Douglas fir seedlings. Average per Plant.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Length of Tops cm</th>
<th>Dry Weight of Tops mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>NoPoKo</td>
<td>4.5</td>
<td>90</td>
</tr>
<tr>
<td>NoPoK1</td>
<td>4.7</td>
<td>102</td>
</tr>
<tr>
<td>NoPoK2</td>
<td>4.2</td>
<td>91</td>
</tr>
<tr>
<td>NoPlKo</td>
<td>4.9</td>
<td>105</td>
</tr>
<tr>
<td>NoPlK1</td>
<td>4.5</td>
<td>98</td>
</tr>
<tr>
<td>NoPlK2</td>
<td>4.4</td>
<td>95</td>
</tr>
<tr>
<td>NoP2Ko</td>
<td>4.5</td>
<td>98</td>
</tr>
<tr>
<td>NoP2K1</td>
<td>4.5</td>
<td>97</td>
</tr>
<tr>
<td>NoP2K2</td>
<td>4.7</td>
<td>98</td>
</tr>
<tr>
<td>N1PoKo</td>
<td>4.9</td>
<td>109</td>
</tr>
<tr>
<td>N1PoK1</td>
<td>4.6</td>
<td>97</td>
</tr>
<tr>
<td>N1PoK2</td>
<td>5.0</td>
<td>101</td>
</tr>
<tr>
<td>N1P1Ko</td>
<td>5.1</td>
<td>111</td>
</tr>
<tr>
<td>N1P1K1</td>
<td>5.0</td>
<td>105</td>
</tr>
<tr>
<td>N1P1K2</td>
<td>4.6</td>
<td>98</td>
</tr>
<tr>
<td>N1P2K0</td>
<td>5.6</td>
<td>122</td>
</tr>
<tr>
<td>N1P2K1</td>
<td>4.9</td>
<td>1114</td>
</tr>
<tr>
<td>N1P2K2</td>
<td>4.8</td>
<td>107</td>
</tr>
<tr>
<td>N2PoKo</td>
<td>4.8</td>
<td>107</td>
</tr>
<tr>
<td>N2PoK1</td>
<td>4.5</td>
<td>95</td>
</tr>
<tr>
<td>N2PoK2</td>
<td>4.6</td>
<td>100</td>
</tr>
<tr>
<td>N2PlKo</td>
<td>5.1</td>
<td>118</td>
</tr>
<tr>
<td>N2PlK1</td>
<td>5.1</td>
<td>114</td>
</tr>
<tr>
<td>N2PlK2</td>
<td>4.6</td>
<td>106</td>
</tr>
<tr>
<td>N2P2Ko</td>
<td>5.2</td>
<td>112</td>
</tr>
<tr>
<td>N2P2K1</td>
<td>5.4</td>
<td>123</td>
</tr>
<tr>
<td>N2P2K2</td>
<td>4.6</td>
<td>96</td>
</tr>
</tbody>
</table>
TABLE 2. Ib.

Part A: Experiment 2,1. Analysis of variance tables.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2</td>
<td>2.4679</td>
<td>1.2339</td>
<td>**</td>
</tr>
<tr>
<td>P</td>
<td>2</td>
<td>1.6990</td>
<td>.8495</td>
<td>*</td>
</tr>
<tr>
<td>K</td>
<td>2</td>
<td>2.9513</td>
<td>1.2256</td>
<td>**</td>
</tr>
<tr>
<td>NP</td>
<td>2</td>
<td>.3946</td>
<td>.0802</td>
<td></td>
</tr>
<tr>
<td>NP2</td>
<td>2</td>
<td>.0052</td>
<td>.5690</td>
<td></td>
</tr>
<tr>
<td>NK</td>
<td>2</td>
<td>.1013</td>
<td>.0985</td>
<td></td>
</tr>
<tr>
<td>NK2</td>
<td>2</td>
<td>.4467</td>
<td>.0277</td>
<td></td>
</tr>
<tr>
<td>PK</td>
<td>2</td>
<td>.1202</td>
<td>.8267</td>
<td></td>
</tr>
<tr>
<td>PK2</td>
<td>2</td>
<td>.5690</td>
<td>.0277</td>
<td></td>
</tr>
<tr>
<td>Ca+Mg+B</td>
<td>1</td>
<td>7.79</td>
<td>7.79</td>
<td>**</td>
</tr>
<tr>
<td>Blocks</td>
<td>11</td>
<td>9.4185</td>
<td>.8562</td>
<td>**</td>
</tr>
<tr>
<td>Error</td>
<td>70</td>
<td>11.4184</td>
<td>.1631</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>107</td>
<td>30.1252</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 2. lb (cont'd)

#### Dry Weight of Tops.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2</td>
<td>.7776</td>
<td>.3888 **</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>2</td>
<td>.4254</td>
<td>.2127 **</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>2</td>
<td>.5560</td>
<td>.2780 **</td>
<td></td>
</tr>
<tr>
<td>NP</td>
<td>2(___)</td>
<td>.1675</td>
<td>.0965</td>
<td></td>
</tr>
<tr>
<td>NP2</td>
<td>2(___)</td>
<td>.0195</td>
<td>.0965</td>
<td></td>
</tr>
<tr>
<td>NK</td>
<td>2(___)</td>
<td>.0021</td>
<td>.0965</td>
<td></td>
</tr>
<tr>
<td>NK2</td>
<td>2(___)</td>
<td>.1931</td>
<td>.0965</td>
<td></td>
</tr>
<tr>
<td>PK</td>
<td>2(___)</td>
<td>.0137</td>
<td>.0965</td>
<td></td>
</tr>
<tr>
<td>PK2</td>
<td>2(___)</td>
<td>.1384</td>
<td>.0965</td>
<td></td>
</tr>
<tr>
<td>NPK</td>
<td>2(___)</td>
<td>.0759</td>
<td>.0965</td>
<td></td>
</tr>
<tr>
<td>NPK2</td>
<td>2(___)</td>
<td>.0226</td>
<td>.0965</td>
<td></td>
</tr>
<tr>
<td>NP2K</td>
<td>2(___)</td>
<td>.0864</td>
<td>.0965</td>
<td></td>
</tr>
<tr>
<td>NP2K2</td>
<td>2(___)</td>
<td>.1417</td>
<td>.0965</td>
<td></td>
</tr>
<tr>
<td>Ca+Mg+B</td>
<td>1</td>
<td>.8303</td>
<td>.8303 **</td>
<td></td>
</tr>
<tr>
<td>Blocks</td>
<td>11</td>
<td>1.8328</td>
<td>.172 **</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>70</td>
<td>2.3830</td>
<td>.034</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>107</td>
<td>6.8957</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 2. Ic

#### Part A: Experiment 2,1. Chemical and physical analysis of check plot soil samples

<table>
<thead>
<tr>
<th>Check Plot Depth</th>
<th>pH</th>
<th>Organic Matter %</th>
<th>Total N mg/g</th>
<th>Exch. P lb/acre</th>
<th>Exch. CAP me/100g</th>
<th>Exchangeable Cations me/100g</th>
</tr>
</thead>
<tbody>
<tr>
<td>1957</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 0 - 8</td>
<td>5.3</td>
<td>9.4(___)</td>
<td>31.3</td>
<td>21.8</td>
<td>4.66</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>5.2</td>
<td>9.3(___)</td>
<td>21.2</td>
<td>23.8</td>
<td>3.79</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5.1</td>
<td>8.8(___)</td>
<td>24.8</td>
<td>27.6</td>
<td>3.24</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>5.2</td>
<td>9.1(___)</td>
<td>26.5</td>
<td>27.2</td>
<td>4.36</td>
<td></td>
</tr>
</tbody>
</table>
TABLE 2. IIa

Part A: Experiment 2, 2.1-0 (1957). The effect of fertilizer applications to 0-0 seedlings, on their, dry weight, length and stem diameter during the next summer.

Average per Plant

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Length of Tops cm</th>
<th>Length of roots cm</th>
<th>Diameter of stem</th>
<th>Dry Weight of Tops mg</th>
<th>Dry Weight of roots mg</th>
<th>Total Dry Weight mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>NoPlKo</td>
<td>13.33</td>
<td>20.38</td>
<td>2.3</td>
<td>696</td>
<td>311</td>
<td>1007</td>
</tr>
<tr>
<td>NoPoK1</td>
<td>14.57</td>
<td>20.38</td>
<td>2.3</td>
<td>736</td>
<td>331</td>
<td>1067</td>
</tr>
<tr>
<td>NoPoK2</td>
<td>12.62</td>
<td>19.01</td>
<td>2.2</td>
<td>609</td>
<td>256</td>
<td>865</td>
</tr>
<tr>
<td>NoPlKo</td>
<td>13.34</td>
<td>20.57</td>
<td>2.3</td>
<td>783</td>
<td>336</td>
<td>1119</td>
</tr>
<tr>
<td>NoPlK1</td>
<td>13.97</td>
<td>22.04</td>
<td>2.8</td>
<td>832</td>
<td>368</td>
<td>1200</td>
</tr>
<tr>
<td>NoPlK2</td>
<td>13.26</td>
<td>21.08</td>
<td>2.7</td>
<td>812</td>
<td>377</td>
<td>1189</td>
</tr>
<tr>
<td>NoP2Ko</td>
<td>13.74</td>
<td>19.99</td>
<td>2.2</td>
<td>694</td>
<td>307</td>
<td>1001</td>
</tr>
<tr>
<td>NoP2K1</td>
<td>12.50</td>
<td>19.28</td>
<td>2.4</td>
<td>782</td>
<td>363</td>
<td>1175</td>
</tr>
<tr>
<td>NoP2K2</td>
<td>12.80</td>
<td>21.44</td>
<td>2.4</td>
<td>708</td>
<td>335</td>
<td>1043</td>
</tr>
<tr>
<td>NLPoKo</td>
<td>14.27</td>
<td>21.49</td>
<td>2.5</td>
<td>887</td>
<td>408</td>
<td>1295</td>
</tr>
<tr>
<td>NLPoK1</td>
<td>12.48</td>
<td>22.21</td>
<td>2.2</td>
<td>753</td>
<td>312</td>
<td>1065</td>
</tr>
<tr>
<td>NLPoK2</td>
<td>12.55</td>
<td>21.68</td>
<td>2.4</td>
<td>737</td>
<td>340</td>
<td>1077</td>
</tr>
<tr>
<td>NLPlKo</td>
<td>14.65</td>
<td>20.36</td>
<td>2.4</td>
<td>863</td>
<td>373</td>
<td>1236</td>
</tr>
<tr>
<td>NLPlK1</td>
<td>14.37</td>
<td>20.79</td>
<td>2.1</td>
<td>755</td>
<td>348</td>
<td>1103</td>
</tr>
<tr>
<td>NLPlK2</td>
<td>13.20</td>
<td>19.82</td>
<td>2.2</td>
<td>777</td>
<td>353</td>
<td>1130</td>
</tr>
<tr>
<td>NLPlK2</td>
<td>13.92</td>
<td>20.27</td>
<td>2.3</td>
<td>873</td>
<td>407</td>
<td>1280</td>
</tr>
<tr>
<td>NLPlK1</td>
<td>14.00</td>
<td>21.57</td>
<td>2.3</td>
<td>724</td>
<td>313</td>
<td>1037</td>
</tr>
<tr>
<td>NLPlK2</td>
<td>14.38</td>
<td>22.36</td>
<td>2.4</td>
<td>901</td>
<td>398</td>
<td>1299</td>
</tr>
<tr>
<td>N2P2Ko</td>
<td>13.56</td>
<td>20.60</td>
<td>2.3</td>
<td>733</td>
<td>348</td>
<td>1081</td>
</tr>
<tr>
<td>N2P2K1</td>
<td>13.37</td>
<td>21.22</td>
<td>2.4</td>
<td>755</td>
<td>309</td>
<td>1067</td>
</tr>
<tr>
<td>N2P2Ko</td>
<td>14.49</td>
<td>22.73</td>
<td>2.4</td>
<td>897</td>
<td>384</td>
<td>1281</td>
</tr>
<tr>
<td>N2P2K1</td>
<td>13.50</td>
<td>19.25</td>
<td>2.3</td>
<td>826</td>
<td>367</td>
<td>1193</td>
</tr>
<tr>
<td>N2P1Ko</td>
<td>13.54</td>
<td>20.33</td>
<td>2.3</td>
<td>722</td>
<td>342</td>
<td>1064</td>
</tr>
<tr>
<td>N2P1K1</td>
<td>12.72</td>
<td>22.52</td>
<td>2.3</td>
<td>722</td>
<td>354</td>
<td>1076</td>
</tr>
<tr>
<td>N2P2K2</td>
<td>14.21</td>
<td>20.87</td>
<td>2.3</td>
<td>812</td>
<td>383</td>
<td>1195</td>
</tr>
<tr>
<td>N2P2K1</td>
<td>13.78</td>
<td>21.01</td>
<td>2.4</td>
<td>918</td>
<td>431</td>
<td>1349</td>
</tr>
<tr>
<td>N2P2K2</td>
<td>14.02</td>
<td>20.00</td>
<td>2.4</td>
<td>832</td>
<td>364</td>
<td>1196</td>
</tr>
</tbody>
</table>
TABLE 2, IIb.


<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sums of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2</td>
<td>1.74</td>
<td>.87</td>
<td>.7</td>
</tr>
<tr>
<td>P</td>
<td>2</td>
<td>2.21</td>
<td>1.11</td>
<td>.9</td>
</tr>
<tr>
<td>K</td>
<td>2</td>
<td>4.92</td>
<td>2.46</td>
<td>1.9</td>
</tr>
<tr>
<td>NP</td>
<td>2</td>
<td>.73</td>
<td>.36</td>
<td>.3</td>
</tr>
<tr>
<td>NP&quot;</td>
<td>2</td>
<td>8.79</td>
<td>4.39</td>
<td>3.4*</td>
</tr>
<tr>
<td>NK</td>
<td>2</td>
<td>7.68</td>
<td>3.84</td>
<td>3.0</td>
</tr>
<tr>
<td>NK&quot;</td>
<td>2</td>
<td>.38</td>
<td>.19</td>
<td>.1</td>
</tr>
<tr>
<td>PK</td>
<td>2</td>
<td>.84</td>
<td>.42</td>
<td>.3</td>
</tr>
<tr>
<td>PK&quot;</td>
<td>2</td>
<td>1.70</td>
<td>.85</td>
<td>.7</td>
</tr>
<tr>
<td>NPK</td>
<td>2</td>
<td>2.37</td>
<td>1.18</td>
<td>.9</td>
</tr>
<tr>
<td>NP&quot;K</td>
<td>2</td>
<td>1.00</td>
<td>.50</td>
<td>.4</td>
</tr>
<tr>
<td>NP&quot;&quot;K</td>
<td>2</td>
<td>3.78</td>
<td>1.89</td>
<td>1.5</td>
</tr>
<tr>
<td>NPK&quot;</td>
<td>2</td>
<td>1.85</td>
<td>.92</td>
<td>.7</td>
</tr>
<tr>
<td>Block</td>
<td>11</td>
<td>80.16</td>
<td>7.29</td>
<td>5.7**</td>
</tr>
<tr>
<td>Error</td>
<td>70</td>
<td>89.95</td>
<td>1.28</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>107</td>
<td>208.09</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 2 IIb (cont'd)

Length of roots

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2.</td>
<td>9.57</td>
<td>4.78</td>
<td>1.3</td>
</tr>
<tr>
<td>P</td>
<td>2.</td>
<td>2.45</td>
<td>1.23</td>
<td>.3</td>
</tr>
<tr>
<td>K</td>
<td>2.</td>
<td>11.08</td>
<td>5.54</td>
<td>1.5</td>
</tr>
<tr>
<td>NP</td>
<td>2.</td>
<td>6.96</td>
<td>3.48</td>
<td>1.0</td>
</tr>
<tr>
<td>NP&quot;</td>
<td>2.</td>
<td>21.76</td>
<td>10.88</td>
<td>3.0</td>
</tr>
<tr>
<td>NK</td>
<td>2.</td>
<td>1.15</td>
<td>.57</td>
<td>.2</td>
</tr>
<tr>
<td>NK&quot;</td>
<td>2.</td>
<td>6.00</td>
<td>3.00</td>
<td>.8</td>
</tr>
<tr>
<td>PK</td>
<td>2.</td>
<td>.00</td>
<td>.00</td>
<td>.0</td>
</tr>
<tr>
<td>PK&quot;</td>
<td>2.</td>
<td>3.71</td>
<td>1.86</td>
<td>.5</td>
</tr>
<tr>
<td>NPK</td>
<td>2.</td>
<td>4.40</td>
<td>2.20</td>
<td>.6</td>
</tr>
<tr>
<td>NP&quot;K</td>
<td>2.</td>
<td>6.48</td>
<td>3.24</td>
<td>.9</td>
</tr>
<tr>
<td>NP&quot;K&quot;</td>
<td>2.</td>
<td>16.94</td>
<td>8.47</td>
<td>2.4</td>
</tr>
<tr>
<td>NPK&quot;</td>
<td>2.</td>
<td>2.15</td>
<td>1.07</td>
<td>.3</td>
</tr>
<tr>
<td>Block</td>
<td>11.</td>
<td>257.20</td>
<td>23.38</td>
<td>6.5 **</td>
</tr>
<tr>
<td>Error</td>
<td>70.</td>
<td>250.29</td>
<td>3.57</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>107.</td>
<td>600.12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 2, IIb (cont'd)

Diameter of Stem

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2.</td>
<td>2.35</td>
<td>1.18</td>
<td>.2</td>
</tr>
<tr>
<td>P</td>
<td>2.</td>
<td>3.18</td>
<td>1.59</td>
<td>.3</td>
</tr>
<tr>
<td>K</td>
<td>2.</td>
<td>1.46</td>
<td>.73</td>
<td>.1</td>
</tr>
<tr>
<td>NP</td>
<td>2.</td>
<td>17.57</td>
<td>8.79</td>
<td>1.7</td>
</tr>
<tr>
<td>NP&quot;</td>
<td>2.</td>
<td>17.02</td>
<td>8.51</td>
<td>1.7</td>
</tr>
<tr>
<td>NK</td>
<td>2.</td>
<td>13.46</td>
<td>6.73</td>
<td>1.3</td>
</tr>
<tr>
<td>NK&quot;</td>
<td>2.</td>
<td>15.02</td>
<td>7.51</td>
<td>1.5</td>
</tr>
<tr>
<td>PK</td>
<td>2.</td>
<td>1.79</td>
<td>.89</td>
<td>.2</td>
</tr>
<tr>
<td>PK&quot;</td>
<td>2.</td>
<td>10.35</td>
<td>5.18</td>
<td>1.0</td>
</tr>
<tr>
<td>NPK</td>
<td>2.</td>
<td>2.25</td>
<td>1.12</td>
<td>.2</td>
</tr>
<tr>
<td>NF&quot;K&quot;</td>
<td>2.</td>
<td>2.54</td>
<td>1.27</td>
<td>.3</td>
</tr>
<tr>
<td>NF&quot;K</td>
<td>2.</td>
<td>8.29</td>
<td>4.14</td>
<td>.8</td>
</tr>
<tr>
<td>NFK&quot;</td>
<td>2.</td>
<td>.29</td>
<td>.14</td>
<td>.0</td>
</tr>
<tr>
<td>Block</td>
<td>11.</td>
<td>433.18</td>
<td>39.38</td>
<td>7.8</td>
</tr>
<tr>
<td>Error</td>
<td>70.</td>
<td>355.54</td>
<td>5.08</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>107.</td>
<td>884.30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 2, IIb (cont'd)

Dry weight of Tops

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2.</td>
<td>33.48</td>
<td>16.74</td>
<td>2.8</td>
</tr>
<tr>
<td>P</td>
<td>2.</td>
<td>14.57</td>
<td>7.28</td>
<td>1.2</td>
</tr>
<tr>
<td>K</td>
<td>2.</td>
<td>3.19</td>
<td>1.59</td>
<td>.3</td>
</tr>
<tr>
<td>NP</td>
<td>2.</td>
<td>23.68</td>
<td>11.84</td>
<td>2.0</td>
</tr>
<tr>
<td>NP&quot;</td>
<td>2.</td>
<td>17.14</td>
<td>8.57</td>
<td>1.5</td>
</tr>
<tr>
<td>NK</td>
<td>2.</td>
<td>34.86</td>
<td>17.43</td>
<td>3.0</td>
</tr>
<tr>
<td>NK&quot;</td>
<td>2.</td>
<td>7.66</td>
<td>3.83</td>
<td>.6</td>
</tr>
<tr>
<td>PK</td>
<td>2.</td>
<td>3.68</td>
<td>1.84</td>
<td>.3</td>
</tr>
<tr>
<td>PK&quot;</td>
<td>2.</td>
<td>3.11</td>
<td>1.55</td>
<td>.3</td>
</tr>
<tr>
<td>NPK</td>
<td>2.</td>
<td>2.82</td>
<td>1.41</td>
<td>.2</td>
</tr>
<tr>
<td>NP&quot;K&quot;</td>
<td>2.</td>
<td>11.90</td>
<td>5.95</td>
<td>1.0</td>
</tr>
<tr>
<td>NP&quot;K</td>
<td>2.</td>
<td>8.57</td>
<td>4.28</td>
<td>.7</td>
</tr>
<tr>
<td>NPK&quot;</td>
<td>2.</td>
<td>9.32</td>
<td>4.66</td>
<td>.8</td>
</tr>
<tr>
<td>Block</td>
<td>11.</td>
<td>210.65</td>
<td>19.15</td>
<td>3.3**</td>
</tr>
<tr>
<td>Error</td>
<td>70.</td>
<td>411.06</td>
<td>5.87</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>107.</td>
<td>795.67</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 2, IIb (cont’d)

Dry Weight of Roots

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2</td>
<td>7.71</td>
<td>3.86</td>
<td>2.5</td>
</tr>
<tr>
<td>P</td>
<td>2</td>
<td>7.04</td>
<td>3.52</td>
<td>2.3</td>
</tr>
<tr>
<td>K</td>
<td>2</td>
<td>1.09</td>
<td>0.54</td>
<td>0.3</td>
</tr>
<tr>
<td>NP</td>
<td>2</td>
<td>4.78</td>
<td>2.39</td>
<td>1.6</td>
</tr>
<tr>
<td>NP&quot;</td>
<td>2</td>
<td>1.01</td>
<td>0.50</td>
<td>0.3</td>
</tr>
<tr>
<td>NK</td>
<td>2</td>
<td>7.50</td>
<td>3.75</td>
<td>2.5</td>
</tr>
<tr>
<td>NK&quot;</td>
<td>2</td>
<td>4.41</td>
<td>2.21</td>
<td>1.4</td>
</tr>
<tr>
<td>PK</td>
<td>2</td>
<td>1.56</td>
<td>0.78</td>
<td>0.5</td>
</tr>
<tr>
<td>PK&quot;</td>
<td>2</td>
<td>0.61</td>
<td>0.30</td>
<td>0.2</td>
</tr>
<tr>
<td>NPK</td>
<td>2</td>
<td>0.08</td>
<td>0.04</td>
<td>0.0</td>
</tr>
<tr>
<td>NP&quot;K</td>
<td>2</td>
<td>1.12</td>
<td>156.00</td>
<td>0.4</td>
</tr>
<tr>
<td>NP&quot;K</td>
<td>2</td>
<td>0.67</td>
<td>0.34</td>
<td>0.2</td>
</tr>
<tr>
<td>NPK&quot;</td>
<td>2</td>
<td>1.59</td>
<td>0.79</td>
<td>0.5</td>
</tr>
<tr>
<td>Block</td>
<td>11</td>
<td>125.32</td>
<td>11.39</td>
<td>7.5 **</td>
</tr>
<tr>
<td>Error</td>
<td>70</td>
<td>106.63</td>
<td>1.52</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>107</td>
<td>271.12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 2. IIfb (cont'd)

**Total Dry Weight**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2.</td>
<td>72.02</td>
<td>36.01</td>
<td>2.9</td>
</tr>
<tr>
<td>P</td>
<td>2.</td>
<td>42.29</td>
<td>21.14</td>
<td>1.7</td>
</tr>
<tr>
<td>K</td>
<td>2.</td>
<td>7.72</td>
<td>3.86</td>
<td>.3</td>
</tr>
<tr>
<td>NP</td>
<td>2.</td>
<td>49.40</td>
<td>24.70</td>
<td>2.0</td>
</tr>
<tr>
<td>NP&quot;</td>
<td>2.</td>
<td>25.99</td>
<td>13.00</td>
<td>1.0</td>
</tr>
<tr>
<td>NK</td>
<td>2.</td>
<td>75.37</td>
<td>37.68</td>
<td>3.0</td>
</tr>
<tr>
<td>NK&quot;</td>
<td>2.</td>
<td>23.90</td>
<td>11.95</td>
<td>1.0</td>
</tr>
<tr>
<td>PK</td>
<td>2.</td>
<td>5.11</td>
<td>2.55</td>
<td>.2</td>
</tr>
<tr>
<td>PK&quot;</td>
<td>2.</td>
<td>5.11</td>
<td>2.55</td>
<td>.2</td>
</tr>
<tr>
<td>NPK</td>
<td>2.</td>
<td>3.77</td>
<td>1.89</td>
<td>.1</td>
</tr>
<tr>
<td>NP&quot;K&quot;</td>
<td>2.</td>
<td>16.55</td>
<td>8.27</td>
<td>.7</td>
</tr>
<tr>
<td>NP&quot;K&quot;</td>
<td>2.</td>
<td>13.28</td>
<td>6.64</td>
<td>.5</td>
</tr>
<tr>
<td>NPK&quot;</td>
<td>2.</td>
<td>18.35</td>
<td>9.18</td>
<td>.7</td>
</tr>
<tr>
<td>Block</td>
<td>11.</td>
<td>592.89</td>
<td>53.90</td>
<td>**</td>
</tr>
<tr>
<td>Error</td>
<td>70.</td>
<td>862.15</td>
<td>12.32</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>107.</td>
<td>1813.92</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 2. IIc

Part A. Experiment 2, 2. Chemical and Physical analysis of check plot soil samples.

<table>
<thead>
<tr>
<th>Check Plot 1958</th>
<th>Depth Ins.</th>
<th>pH</th>
<th>Organic Matter %</th>
<th>Total N mg/g</th>
<th>Exch. P lb/acre</th>
<th>Exch. CAP me/100g</th>
<th>Exchangeable Cations me/100g</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 - 8</td>
<td>5.6</td>
<td>8.5</td>
<td>29.4</td>
<td></td>
<td></td>
<td>4.43 0.16 0.22</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>&quot;</td>
<td>5.5</td>
<td>9.2</td>
<td>20.0</td>
<td></td>
<td></td>
<td>3.68 0.22 0.19</td>
<td>34.6</td>
</tr>
<tr>
<td>3</td>
<td>&quot;</td>
<td>5.5</td>
<td>8.1</td>
<td>25.3</td>
<td></td>
<td></td>
<td>2.43 0.30 0.19</td>
<td>33.0</td>
</tr>
<tr>
<td>4</td>
<td>&quot;</td>
<td>5.6</td>
<td>8.4</td>
<td>22.6</td>
<td></td>
<td></td>
<td>3.24 0.09 0.24</td>
<td>32.4</td>
</tr>
</tbody>
</table>
TABLE 3. Ia


**Dry weight of tops.**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>9</td>
<td>7.046</td>
<td>.783 **</td>
</tr>
<tr>
<td>Replica</td>
<td>5</td>
<td>0.172</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>39</td>
<td>1.169</td>
<td>0.030</td>
</tr>
<tr>
<td>Total</td>
<td>57</td>
<td>8.387</td>
<td></td>
</tr>
</tbody>
</table>

**Length of tops**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>9</td>
<td>45.450</td>
<td>5.050 **</td>
</tr>
<tr>
<td>Replica</td>
<td>5</td>
<td>0.075</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>39</td>
<td>7.350</td>
<td>.188</td>
</tr>
<tr>
<td>Total</td>
<td>53</td>
<td>52.875</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 3. Ib

Part A: Experiment 3, 1. Chemical and physical analysis of check plot soil samples.

<table>
<thead>
<tr>
<th>Check Plot 1957</th>
<th>Depth Ins.</th>
<th>pH</th>
<th>Organic Matter %</th>
<th>Total N mg/g</th>
<th>Exch. P lb/acre</th>
<th>Exch. CAP me/100g</th>
<th>Exchangeable Cations me/100g</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ca</td>
</tr>
<tr>
<td>1</td>
<td>0 - 8</td>
<td>5.3</td>
<td>9.7</td>
<td>3.91</td>
<td>21.2</td>
<td>25.8</td>
<td>3.73</td>
</tr>
<tr>
<td>2</td>
<td>&quot;</td>
<td>5.1</td>
<td>10.5</td>
<td></td>
<td>24.8</td>
<td>29.0</td>
<td>3.19</td>
</tr>
<tr>
<td>3</td>
<td>&quot;</td>
<td>5.2</td>
<td>10.2</td>
<td></td>
<td>21.2</td>
<td>31.6</td>
<td>3.73</td>
</tr>
<tr>
<td>4</td>
<td>&quot;</td>
<td>5.2</td>
<td>9.4</td>
<td></td>
<td>36.6</td>
<td>28.0</td>
<td>3.24</td>
</tr>
<tr>
<td>5</td>
<td>&quot;</td>
<td>5.3</td>
<td>9.5</td>
<td></td>
<td>26.5</td>
<td>27.0</td>
<td>2.97</td>
</tr>
<tr>
<td>6</td>
<td>&quot;</td>
<td>5.1</td>
<td>9.5</td>
<td></td>
<td>26.5</td>
<td>28.4</td>
<td>3.08</td>
</tr>
</tbody>
</table>
TABLE 3. IIa


<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>8</td>
<td>11.3</td>
<td>1.413</td>
<td>1.11</td>
</tr>
<tr>
<td>Replica</td>
<td>4</td>
<td>1.7</td>
<td>.417</td>
<td>.33</td>
</tr>
<tr>
<td>Error</td>
<td>32</td>
<td>40.6</td>
<td>1.270</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>44</td>
<td>53.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>8</td>
<td>254.7</td>
<td>31.831</td>
<td>2.99*</td>
</tr>
<tr>
<td>Replica</td>
<td>4</td>
<td>17.8</td>
<td>4.448</td>
<td>.42</td>
</tr>
<tr>
<td>Error</td>
<td>32</td>
<td>340.2</td>
<td>10.630</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>44</td>
<td>612.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>8</td>
<td>86.3</td>
<td>10.788</td>
<td>3.40**</td>
</tr>
<tr>
<td>Replica</td>
<td>4</td>
<td>26.5</td>
<td>6.633</td>
<td>2.09</td>
</tr>
<tr>
<td>Error</td>
<td>32</td>
<td>101.5</td>
<td>3.170</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>44</td>
<td>214.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 3. IIa (cont'd)

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry weight of tops</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment</td>
<td>8</td>
<td>176.5</td>
<td>22.058</td>
<td>3.95 **</td>
</tr>
<tr>
<td>Replica</td>
<td>4</td>
<td>13.0</td>
<td>3.241</td>
<td>.58</td>
</tr>
<tr>
<td>Error</td>
<td>32</td>
<td>178.9</td>
<td>5.591</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>44</td>
<td>368.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length of tops</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment</td>
<td>8</td>
<td>52.0</td>
<td>6.506</td>
<td>2.45 **</td>
</tr>
<tr>
<td>Replica</td>
<td>4</td>
<td>23.5</td>
<td>5.881</td>
<td>3.12</td>
</tr>
<tr>
<td>Error</td>
<td>32</td>
<td>60.3</td>
<td>1.884</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>44</td>
<td>135.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length of roots</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment</td>
<td>8</td>
<td>15.6</td>
<td>1.954</td>
<td>.68</td>
</tr>
<tr>
<td>Replica</td>
<td>4</td>
<td>2.6</td>
<td>.645</td>
<td>.22</td>
</tr>
<tr>
<td>Error</td>
<td>32</td>
<td>92.3</td>
<td>2.884</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>44</td>
<td>110.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 3. IIb

**Part A Experiment 3, 2. Chemical and physical analysis of check plots soil samples.**

<table>
<thead>
<tr>
<th>Check Plots</th>
<th>Depth Ins.</th>
<th>pH</th>
<th>Organic Matter %</th>
<th>Total N mg/g</th>
<th>Exch. P lb/acre</th>
<th>Exch. CAP me/100g</th>
<th>Exchangeable Cations me/100g</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 - 8</td>
<td>5.5</td>
<td>9.1</td>
<td>26.6</td>
<td>3.06</td>
<td>0.13</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>&quot;</td>
<td>4.8</td>
<td>9.8</td>
<td>26.6</td>
<td>2.56</td>
<td>0.18</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>&quot;</td>
<td>5.0</td>
<td>9.3</td>
<td>28.0</td>
<td>3.00</td>
<td>0.23</td>
<td>0.24</td>
<td>35.1</td>
</tr>
<tr>
<td>4</td>
<td>&quot;</td>
<td>5.3</td>
<td>9.1</td>
<td>24.0</td>
<td>3.24</td>
<td>0.34</td>
<td>0.19</td>
<td>33.0</td>
</tr>
<tr>
<td>5</td>
<td>&quot;</td>
<td>5.4</td>
<td>8.8</td>
<td>24.0</td>
<td>2.31</td>
<td>0.15</td>
<td>0.27</td>
<td>31.9</td>
</tr>
<tr>
<td>6</td>
<td>&quot;</td>
<td>5.4</td>
<td>9.5</td>
<td>20.0</td>
<td>2.35</td>
<td>0.24</td>
<td>0.22</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 3. IIc

**Part A Experiment 3, 2. Analysis of organic fertilizers.**

<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>Organic Matter %</th>
<th>Total N mg/g</th>
<th>Exch. P lb/acre</th>
<th>Exch. CAP me/100g</th>
<th>Exchangeable Cations me/100g</th>
<th>Ca</th>
<th>Mg</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compost</td>
<td>6.4</td>
<td>9.8</td>
<td>6.36</td>
<td>373.0</td>
<td>25.83</td>
<td>14.23</td>
<td>8.22</td>
<td>1.83</td>
<td></td>
</tr>
<tr>
<td>Mushroom Manure</td>
<td>6.8</td>
<td>14.5</td>
<td>16.71</td>
<td>266.4</td>
<td>25.09</td>
<td>42.43</td>
<td>14.57</td>
<td>15.84</td>
<td></td>
</tr>
<tr>
<td>Peat</td>
<td>4.2</td>
<td>12.33</td>
<td>33.3</td>
<td>31.91</td>
<td>6.85</td>
<td>5.91</td>
<td>0.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sawdust</td>
<td>1</td>
<td>0.51</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 5a.
Part A. Experiment 5. The effect of fertilization on the dry weight, length and stem diameter of 1-0 Douglas fir seedlings

Average per plant

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Length of Tops cm</th>
<th>Length of Roots cm</th>
<th>Diameter of stem mm</th>
<th>Dry Weight of tops mg</th>
<th>Dry Weight of roots mg</th>
<th>Total Dry Weight mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>NoPo</td>
<td>15.03</td>
<td>22.11</td>
<td>2.4</td>
<td>869</td>
<td>348</td>
<td>1217</td>
</tr>
<tr>
<td>NoP1</td>
<td>15.68</td>
<td>22.73</td>
<td>2.7</td>
<td>936</td>
<td>359</td>
<td>1295</td>
</tr>
<tr>
<td>NoP2</td>
<td>16.58</td>
<td>23.14</td>
<td>2.8</td>
<td>1072</td>
<td>365</td>
<td>1437</td>
</tr>
<tr>
<td>NoP3</td>
<td>15.88</td>
<td>22.93</td>
<td>2.6</td>
<td>904</td>
<td>319</td>
<td>1223</td>
</tr>
<tr>
<td>NoP4</td>
<td>15.18</td>
<td>22.42</td>
<td>2.6</td>
<td>1174</td>
<td>457</td>
<td>1631</td>
</tr>
<tr>
<td>N1Po</td>
<td>18.96</td>
<td>23.97</td>
<td>2.9</td>
<td>1347</td>
<td>474</td>
<td>1821</td>
</tr>
<tr>
<td>N1P1</td>
<td>18.85</td>
<td>22.63</td>
<td>2.9</td>
<td>1175</td>
<td>422</td>
<td>1597</td>
</tr>
<tr>
<td>N1P2</td>
<td>19.22</td>
<td>23.17</td>
<td>2.9</td>
<td>1313</td>
<td>409</td>
<td>1722</td>
</tr>
<tr>
<td>N1P3</td>
<td>16.81</td>
<td>25.40</td>
<td>2.8</td>
<td>1158</td>
<td>469</td>
<td>1627</td>
</tr>
<tr>
<td>N1P4</td>
<td>19.43</td>
<td>24.39</td>
<td>3.2</td>
<td>1454</td>
<td>498</td>
<td>1952</td>
</tr>
<tr>
<td>N2Po</td>
<td>20.53</td>
<td>23.71</td>
<td>3.0</td>
<td>1459</td>
<td>487</td>
<td>1946</td>
</tr>
<tr>
<td>N2P1</td>
<td>19.79</td>
<td>22.69</td>
<td>3.3</td>
<td>1489</td>
<td>511</td>
<td>2000</td>
</tr>
<tr>
<td>N2P2</td>
<td>20.18</td>
<td>23.78</td>
<td>3.3</td>
<td>1538</td>
<td>511</td>
<td>2049</td>
</tr>
<tr>
<td>N2P3</td>
<td>20.99</td>
<td>24.92</td>
<td>3.2</td>
<td>1660</td>
<td>527</td>
<td>2187</td>
</tr>
<tr>
<td>N2P4</td>
<td>21.86</td>
<td>22.85</td>
<td>3.3</td>
<td>1570</td>
<td>485</td>
<td>2055</td>
</tr>
<tr>
<td>N3Po</td>
<td>18.43</td>
<td>22.08</td>
<td>3.0</td>
<td>1265</td>
<td>483</td>
<td>1748</td>
</tr>
<tr>
<td>N3P1</td>
<td>17.99</td>
<td>24.58</td>
<td>3.0</td>
<td>1440</td>
<td>516</td>
<td>1956</td>
</tr>
<tr>
<td>N3P2</td>
<td>17.91</td>
<td>22.47</td>
<td>3.1</td>
<td>1315</td>
<td>482</td>
<td>1797</td>
</tr>
<tr>
<td>N3P3</td>
<td>19.70</td>
<td>23.05</td>
<td>3.1</td>
<td>1556</td>
<td>568</td>
<td>2124</td>
</tr>
<tr>
<td>N3P4</td>
<td>20.05</td>
<td>23.68</td>
<td>3.3</td>
<td>1588</td>
<td>559</td>
<td>2147</td>
</tr>
<tr>
<td>N4Po</td>
<td>17.41</td>
<td>22.33</td>
<td>3.1</td>
<td>1329</td>
<td>457</td>
<td>1786</td>
</tr>
<tr>
<td>N4P1</td>
<td>17.36</td>
<td>22.24</td>
<td>3.1</td>
<td>1347</td>
<td>475</td>
<td>1815</td>
</tr>
<tr>
<td>N4P2</td>
<td>15.74</td>
<td>21.71</td>
<td>3.1</td>
<td>1138</td>
<td>432</td>
<td>1570</td>
</tr>
<tr>
<td>N4P3</td>
<td>18.01</td>
<td>21.93</td>
<td>3.1</td>
<td>1348</td>
<td>491</td>
<td>1839</td>
</tr>
<tr>
<td>N4P4</td>
<td>17.79</td>
<td>23.42</td>
<td>3.1</td>
<td>1504</td>
<td>569</td>
<td>2073</td>
</tr>
</tbody>
</table>

### Length of tops

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>4</td>
<td>279.05</td>
<td>69.76</td>
<td>54.7**</td>
</tr>
<tr>
<td>P</td>
<td>4</td>
<td>12.07</td>
<td>3.01</td>
<td></td>
</tr>
<tr>
<td>NP1</td>
<td>4</td>
<td>8.10</td>
<td>2.03</td>
<td></td>
</tr>
<tr>
<td>NP2</td>
<td>4</td>
<td>10.34</td>
<td>2.57</td>
<td></td>
</tr>
<tr>
<td>NP3</td>
<td>4</td>
<td>13.00</td>
<td>3.25</td>
<td>2.52</td>
</tr>
<tr>
<td>NP4</td>
<td>4</td>
<td>29.80</td>
<td>7.43</td>
<td>5.76**</td>
</tr>
<tr>
<td>Blocks</td>
<td>19</td>
<td>215.76</td>
<td>11.36</td>
<td>8.80**</td>
</tr>
<tr>
<td>Error</td>
<td>56</td>
<td>72.49</td>
<td>1.29</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>99</td>
<td>527.61</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 5b (cont'd)

Dry Weight of Roots

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>4</td>
<td>127.91</td>
<td>31.98</td>
<td>26.00 **</td>
</tr>
<tr>
<td>P</td>
<td>4</td>
<td>21.69</td>
<td>5.42</td>
<td>4.40 **</td>
</tr>
<tr>
<td>NP1</td>
<td>4</td>
<td>3.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP2</td>
<td>4</td>
<td>8.52</td>
<td>2.13</td>
<td></td>
</tr>
<tr>
<td>NP3</td>
<td>4</td>
<td>12.92</td>
<td>3.23</td>
<td>2.63 *</td>
</tr>
<tr>
<td>NP4</td>
<td>4</td>
<td>25.84</td>
<td>6.46</td>
<td>5.25 **</td>
</tr>
<tr>
<td>Blocks</td>
<td>19</td>
<td>46.15</td>
<td>2.45</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>56</td>
<td>68.78</td>
<td>1.23</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>99</td>
<td>315.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total Dry Weight

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>4</td>
<td>1830.88</td>
<td>457.72</td>
<td>14.70 **</td>
</tr>
<tr>
<td>P</td>
<td>4</td>
<td>356.28</td>
<td>89.07</td>
<td>2.86 *</td>
</tr>
<tr>
<td>NP1</td>
<td>4</td>
<td>63.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP2</td>
<td>4</td>
<td>98.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP3</td>
<td>4</td>
<td>93.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP4</td>
<td>4</td>
<td>24.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blocks</td>
<td>19</td>
<td>1108.61</td>
<td>58.34</td>
<td>1.86 *</td>
</tr>
<tr>
<td>Error</td>
<td>56</td>
<td>1743.08</td>
<td>31.13</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>99</td>
<td>5318.16</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Diameter of tops

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>4</td>
<td>4.01</td>
<td>1.00</td>
<td>13.5 **</td>
</tr>
<tr>
<td>P</td>
<td>4</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP1</td>
<td>4</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP2</td>
<td>4</td>
<td>0.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP3</td>
<td>4</td>
<td>0.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP4</td>
<td>4</td>
<td>0.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blocks</td>
<td>19</td>
<td>2.32</td>
<td>0.122</td>
<td>1.64</td>
</tr>
<tr>
<td>Error</td>
<td>56</td>
<td>4.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>99</td>
<td>11.26</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 5b (cont'd)

**Dry Weight of Tops.**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>4</td>
<td>1113.95</td>
<td>278.49</td>
<td>12.51 **</td>
</tr>
<tr>
<td>P</td>
<td>4</td>
<td>176.79</td>
<td>44.20</td>
<td>2.00</td>
</tr>
<tr>
<td>NP1</td>
<td>4</td>
<td>47.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP2</td>
<td>4</td>
<td>39.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP3</td>
<td>4</td>
<td>48.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP4</td>
<td>4</td>
<td>17.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blocks</td>
<td>19</td>
<td>483.74</td>
<td>25.46</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>56</td>
<td>1246.46</td>
<td>22.25</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>99</td>
<td>3171.02</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 5c.

**Part A. Experiment 5. Chemical and physical analysis of check plot soil samples.**

<table>
<thead>
<tr>
<th>Check Plot</th>
<th>Depth Ins.</th>
<th>pH</th>
<th>Organic Matter %</th>
<th>Total N mg/gm</th>
<th>Exch. P lb/acre</th>
<th>Exch. CAP me/100g</th>
<th>Exchangeable Cations me/100g</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sand</td>
</tr>
<tr>
<td>1</td>
<td>0 - 6</td>
<td>5.4</td>
<td>8.3</td>
<td>35.9</td>
<td>24.4</td>
<td>1.74</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0 - 6</td>
<td>5.5</td>
<td>8.4</td>
<td>3.61</td>
<td>57.3</td>
<td>23.4</td>
<td>2.50 0.29 0.22</td>
<td>37.8</td>
</tr>
<tr>
<td>3</td>
<td>0 - 6</td>
<td>5.4</td>
<td>9.5</td>
<td>30.6</td>
<td>25.1</td>
<td>1.80</td>
<td>0.16 0.30</td>
<td>29.0</td>
</tr>
<tr>
<td>4</td>
<td>0 - 6</td>
<td>5.3</td>
<td>8.9</td>
<td>30.6</td>
<td>25.1</td>
<td>1.80</td>
<td>0.16 0.34</td>
<td>33.2</td>
</tr>
</tbody>
</table>
### TABLE 6a.

**Part A. Experiment 6. Analysis of variance tables.**

#### Total dry weight

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>11</td>
<td>2902.8</td>
<td>263.886</td>
<td>5.63**</td>
</tr>
<tr>
<td>Replica</td>
<td>5</td>
<td>579.1</td>
<td>115.818</td>
<td>2.47*</td>
</tr>
<tr>
<td>Error</td>
<td>55</td>
<td>2576.4</td>
<td>46.843</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>71</td>
<td>6058.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Dry weight of roots

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>11</td>
<td>243.1</td>
<td>22.096</td>
<td>3.68**</td>
</tr>
<tr>
<td>Replica</td>
<td>5</td>
<td>83.4</td>
<td>16.682</td>
<td>2.78*</td>
</tr>
<tr>
<td>Error</td>
<td>55</td>
<td>330.1</td>
<td>6.002</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>71</td>
<td>656.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Dry weight of tops

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>11</td>
<td>1582.0</td>
<td>143.818</td>
<td>5.82**</td>
</tr>
<tr>
<td>Replica</td>
<td>5</td>
<td>288.0</td>
<td>57.599</td>
<td>2.33</td>
</tr>
<tr>
<td>Error</td>
<td>55</td>
<td>1357.5</td>
<td>24.682</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>71</td>
<td>3227.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Diameter of stem

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>11</td>
<td>417.3</td>
<td>37.934</td>
<td>5.83**</td>
</tr>
<tr>
<td>Replica</td>
<td>5</td>
<td>154.9</td>
<td>30.988</td>
<td>4.76**</td>
</tr>
<tr>
<td>Error</td>
<td>55</td>
<td>357.7</td>
<td>6.503</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>71</td>
<td>929.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 6a (cont'd)

Length of roots

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>11</td>
<td>52.9</td>
<td>4.809</td>
<td>1.06</td>
</tr>
<tr>
<td>Replica</td>
<td>5</td>
<td>27.8</td>
<td>5.553</td>
<td>1.23</td>
</tr>
<tr>
<td>Error</td>
<td>55</td>
<td>24.84</td>
<td>4.516</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>71</td>
<td>329.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Length of tops

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>11</td>
<td>327.8</td>
<td>29.803</td>
<td>6.66**</td>
</tr>
<tr>
<td>Replica</td>
<td>5</td>
<td>163.8</td>
<td>32.768</td>
<td>7.32**</td>
</tr>
<tr>
<td>Error</td>
<td>55</td>
<td>246.2</td>
<td>4.476</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>71</td>
<td>737.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TABLE 6b.

Part A. Experiment 6. Chemical and physical analysis of check plot soil samples.

<table>
<thead>
<tr>
<th>Check Plot</th>
<th>Depth Ins.</th>
<th>pH</th>
<th>Organic Matter %</th>
<th>Total N mg/gm</th>
<th>Exch P lb/acre</th>
<th>Exch Ca mg/100g</th>
<th>Exchangeable Cations me/100g</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sand</td>
</tr>
<tr>
<td>1</td>
<td>0-6</td>
<td>5.5</td>
<td>8.9</td>
<td>75.9</td>
<td>21.98</td>
<td>2.68</td>
<td>0.18</td>
<td>0.42</td>
</tr>
<tr>
<td>2</td>
<td>&quot;</td>
<td>5.3</td>
<td>8.6</td>
<td>79.9</td>
<td>23.00</td>
<td>2.43</td>
<td>0.33</td>
<td>0.34</td>
</tr>
<tr>
<td>3</td>
<td>&quot;</td>
<td>5.6</td>
<td>8.2</td>
<td>51.9</td>
<td>22.72</td>
<td>2.31</td>
<td>0.37</td>
<td>0.34</td>
</tr>
<tr>
<td>4</td>
<td>&quot;</td>
<td>5.3</td>
<td>9.7</td>
<td>54.61</td>
<td>26.13</td>
<td>2.01</td>
<td>0.22</td>
<td>0.38</td>
</tr>
<tr>
<td>5</td>
<td>&quot;</td>
<td>5.4</td>
<td>8.7</td>
<td>58.60</td>
<td>23.40</td>
<td>2.00</td>
<td>0.21</td>
<td>0.35</td>
</tr>
<tr>
<td>6</td>
<td>&quot;</td>
<td>5.4</td>
<td>9.3</td>
<td>49.30</td>
<td>25.24</td>
<td>2.31</td>
<td>0.13</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Percent

<table>
<thead>
<tr>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>36.2</td>
<td>31.0</td>
<td>32.8</td>
</tr>
</tbody>
</table>
TABLE 7a.


<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>19</td>
<td>17.65</td>
<td>.9289</td>
<td>2.98 **</td>
</tr>
<tr>
<td>Replica</td>
<td>5</td>
<td>3.78</td>
<td>.7561</td>
<td>2.42 *</td>
</tr>
<tr>
<td>Error</td>
<td>95</td>
<td>29.63</td>
<td>.3119</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>119</td>
<td>51.06</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>19</td>
<td>21.52</td>
<td>1.1324</td>
<td>2.76 **</td>
</tr>
<tr>
<td>Replica</td>
<td>5</td>
<td>5.28</td>
<td>1.0560</td>
<td>2.58 *</td>
</tr>
<tr>
<td>Error</td>
<td>95</td>
<td>38.90</td>
<td>.4095</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>119</td>
<td>65.70</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TABLE 7b.

Part A. Experiment 7. Chemical and Physical analysis of check plot soil samples.

<table>
<thead>
<tr>
<th>Check Plot</th>
<th>Depth Ins.</th>
<th>pH</th>
<th>Organic Matter %</th>
<th>Total N mg/gm</th>
<th>Exch. P lb/acre</th>
<th>Exch. Ca mg/100g</th>
<th>Exch. Mg me/100g</th>
<th>Exchangeable Caions, me/100g</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sand</td>
</tr>
<tr>
<td>1</td>
<td>0 - 6</td>
<td>6.0</td>
<td>7.4%</td>
<td>.346</td>
<td>20.56</td>
<td>4.31</td>
<td>0.64</td>
<td>0.45</td>
<td>32.3</td>
</tr>
<tr>
<td>2</td>
<td>&quot;</td>
<td>5.9</td>
<td>7.4%</td>
<td>36.0</td>
<td>20.77</td>
<td>4.37</td>
<td>0.36</td>
<td>0.27</td>
<td>32.0</td>
</tr>
<tr>
<td>3</td>
<td>&quot;</td>
<td>5.9</td>
<td>7.1%</td>
<td>41.3</td>
<td>20.32</td>
<td>4.00</td>
<td>0.51</td>
<td>0.32</td>
<td>35.7</td>
</tr>
<tr>
<td>4</td>
<td>&quot;</td>
<td>5.8</td>
<td>7.5%</td>
<td>48.0</td>
<td>21.51</td>
<td>3.87</td>
<td>0.46</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>&quot;</td>
<td>6.0</td>
<td>8.1%</td>
<td>50.6</td>
<td>23.26</td>
<td>4.56</td>
<td>0.54</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>&quot;</td>
<td>5.8</td>
<td>7.3%</td>
<td>36.0</td>
<td>21.77</td>
<td>4.62</td>
<td>0.49</td>
<td>0.30</td>
<td></td>
</tr>
</tbody>
</table>
Part D. Experiment 8. The effect of fertilization on dry weight, length and stem diameter of Douglas fir seedlings in the greenhouse.

Average per plant

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Length of tops cm</th>
<th>Length of roots cm</th>
<th>Diameter of stem mm</th>
<th>Dry Weight of tops mgm</th>
<th>Dry Weight of roots mgm</th>
<th>Total Dry Weight mgm</th>
</tr>
</thead>
<tbody>
<tr>
<td>NoPoK</td>
<td>18.60</td>
<td>47.3</td>
<td>2.9</td>
<td>1490</td>
<td>888</td>
<td>2378</td>
</tr>
<tr>
<td>NoP1Ko</td>
<td>14.20</td>
<td>51.1</td>
<td>2.6</td>
<td>1186</td>
<td>858</td>
<td>2044</td>
</tr>
<tr>
<td>NoP2Ko</td>
<td>18.50</td>
<td>48.2</td>
<td>3.1</td>
<td>1432</td>
<td>1004</td>
<td>2436</td>
</tr>
<tr>
<td>NoP3Ko</td>
<td>20.00</td>
<td>42.3</td>
<td>3.2</td>
<td>1570</td>
<td>866</td>
<td>2436</td>
</tr>
<tr>
<td>NoP4Ko</td>
<td>17.20</td>
<td>51.7</td>
<td>3.3</td>
<td>1356</td>
<td>858</td>
<td>2214</td>
</tr>
<tr>
<td>NoPoK1</td>
<td>16.55</td>
<td>46.4</td>
<td>2.9</td>
<td>1222</td>
<td>736</td>
<td>1958</td>
</tr>
<tr>
<td>NoP1K1</td>
<td>20.70</td>
<td>51.9</td>
<td>3.1</td>
<td>1438</td>
<td>1082</td>
<td>2620</td>
</tr>
<tr>
<td>NoP2K1</td>
<td>18.60</td>
<td>48.0</td>
<td>2.8</td>
<td>1406</td>
<td>1004</td>
<td>2410</td>
</tr>
<tr>
<td>NoP3K1</td>
<td>18.50</td>
<td>43.4</td>
<td>2.9</td>
<td>1398</td>
<td>798</td>
<td>2196</td>
</tr>
<tr>
<td>NoP4K1</td>
<td>16.60</td>
<td>46.8</td>
<td>2.9</td>
<td>1408</td>
<td>892</td>
<td>2300</td>
</tr>
<tr>
<td>NoPoK2</td>
<td>22.20</td>
<td>41.3</td>
<td>3.0</td>
<td>1348</td>
<td>712</td>
<td>2060</td>
</tr>
<tr>
<td>NoP1K2</td>
<td>18.70</td>
<td>47.8</td>
<td>3.2</td>
<td>1383</td>
<td>860</td>
<td>2213</td>
</tr>
<tr>
<td>NoP2K2</td>
<td>15.70</td>
<td>52.5</td>
<td>2.8</td>
<td>1340</td>
<td>786</td>
<td>2126</td>
</tr>
<tr>
<td>NoP3K2</td>
<td>24.00</td>
<td>57.9</td>
<td>2.9</td>
<td>1848</td>
<td>1138</td>
<td>2986</td>
</tr>
<tr>
<td>NoP4K2</td>
<td>18.50</td>
<td>53.4</td>
<td>2.9</td>
<td>1240</td>
<td>832</td>
<td>2072</td>
</tr>
<tr>
<td>N1P0Ko</td>
<td>14.20</td>
<td>45.7</td>
<td>2.7</td>
<td>998</td>
<td>740</td>
<td>1738</td>
</tr>
<tr>
<td>N1P1Ko</td>
<td>17.50</td>
<td>49.2</td>
<td>3.1</td>
<td>1360</td>
<td>942</td>
<td>2302</td>
</tr>
<tr>
<td>N1P2Ko</td>
<td>17.40</td>
<td>51.3</td>
<td>3.1</td>
<td>1315</td>
<td>962</td>
<td>2177</td>
</tr>
<tr>
<td>N1P3Ko</td>
<td>18.70</td>
<td>51.9</td>
<td>3.0</td>
<td>1378</td>
<td>956</td>
<td>2334</td>
</tr>
<tr>
<td>N1P4Ko</td>
<td>20.90</td>
<td>52.3</td>
<td>3.1</td>
<td>1586</td>
<td>920</td>
<td>2506</td>
</tr>
<tr>
<td>N1PoK1</td>
<td>12.50</td>
<td>48.9</td>
<td>2.6</td>
<td>766</td>
<td>792</td>
<td>1558</td>
</tr>
<tr>
<td>N1P1K1</td>
<td>14.60</td>
<td>54.0</td>
<td>2.9</td>
<td>910</td>
<td>804</td>
<td>1714</td>
</tr>
<tr>
<td>N1P2K1</td>
<td>12.30</td>
<td>42.4</td>
<td>2.8</td>
<td>824</td>
<td>734</td>
<td>1558</td>
</tr>
<tr>
<td>N1P3K1</td>
<td>16.90</td>
<td>53.5</td>
<td>2.8</td>
<td>910</td>
<td>876</td>
<td>1786</td>
</tr>
<tr>
<td>N1P4K1</td>
<td>17.80</td>
<td>52.5</td>
<td>2.9</td>
<td>1262</td>
<td>914</td>
<td>2176</td>
</tr>
<tr>
<td>N1PoK2</td>
<td>11.90</td>
<td>45.4</td>
<td>2.5</td>
<td>776</td>
<td>662</td>
<td>1446</td>
</tr>
<tr>
<td>N1P1K2</td>
<td>13.90</td>
<td>46.3</td>
<td>2.5</td>
<td>866</td>
<td>770</td>
<td>1636</td>
</tr>
<tr>
<td>Treatment</td>
<td>Length of tops cm</td>
<td>Length of roots cm</td>
<td>Diameter of stem mm</td>
<td>Dry Weight of tops mgm</td>
<td>Dry Weight of roots mgm</td>
<td>Total Dry Weight mgm</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------------</td>
<td>--------------------</td>
<td>---------------------</td>
<td>------------------------</td>
<td>-------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>N1P2K2</td>
<td>14.00</td>
<td>52.3</td>
<td>2.7</td>
<td>942</td>
<td>716</td>
<td>1658</td>
</tr>
<tr>
<td>N1P3K2</td>
<td>15.20</td>
<td>43.0</td>
<td>2.7</td>
<td>1056</td>
<td>842</td>
<td>1898</td>
</tr>
<tr>
<td>N1P4K2</td>
<td>16.40</td>
<td>41.3</td>
<td>2.8</td>
<td>1252</td>
<td>840</td>
<td>2092</td>
</tr>
<tr>
<td>N2PoKo</td>
<td>10.90</td>
<td>46.4</td>
<td>2.2</td>
<td>694</td>
<td>478</td>
<td>1172</td>
</tr>
<tr>
<td>N2P1Ko</td>
<td>13.80</td>
<td>40.7</td>
<td>2.5</td>
<td>814</td>
<td>714</td>
<td>1528</td>
</tr>
<tr>
<td>N2P2Ko</td>
<td>17.70</td>
<td>39.7</td>
<td>2.8</td>
<td>846</td>
<td>678</td>
<td>1524</td>
</tr>
<tr>
<td>N2P3Ko</td>
<td>17.40</td>
<td>48.0</td>
<td>2.9</td>
<td>1214</td>
<td>820</td>
<td>2034</td>
</tr>
<tr>
<td>N2P4Ko</td>
<td>16.60</td>
<td>49.8</td>
<td>3.0</td>
<td>1228</td>
<td>948</td>
<td>2176</td>
</tr>
<tr>
<td>N2PoK1</td>
<td>12.50</td>
<td>43.5</td>
<td>2.9</td>
<td>804</td>
<td>656</td>
<td>1460</td>
</tr>
<tr>
<td>N2P1K1</td>
<td>16.70</td>
<td>40.2</td>
<td>2.7</td>
<td>980</td>
<td>716</td>
<td>1696</td>
</tr>
<tr>
<td>N2P2K1</td>
<td>11.50</td>
<td>41.9</td>
<td>2.6</td>
<td>902</td>
<td>554</td>
<td>1456</td>
</tr>
<tr>
<td>N2P3K1</td>
<td>12.50</td>
<td>45.1</td>
<td>2.8</td>
<td>912</td>
<td>732</td>
<td>1644</td>
</tr>
<tr>
<td>N2P4K1</td>
<td>11.00</td>
<td>47.4</td>
<td>2.6</td>
<td>604</td>
<td>508</td>
<td>1112</td>
</tr>
<tr>
<td>N2PoK2</td>
<td>11.80</td>
<td>40.7</td>
<td>2.4</td>
<td>740</td>
<td>586</td>
<td>1326</td>
</tr>
<tr>
<td>N2F1K2</td>
<td>11.00</td>
<td>45.1</td>
<td>2.5</td>
<td>678</td>
<td>582</td>
<td>1260</td>
</tr>
<tr>
<td>N2P2K2</td>
<td>12.80</td>
<td>42.5</td>
<td>3.0</td>
<td>828</td>
<td>720</td>
<td>1548</td>
</tr>
<tr>
<td>N2P3K2</td>
<td>13.80</td>
<td>42.3</td>
<td>2.7</td>
<td>906</td>
<td>740</td>
<td>1646</td>
</tr>
<tr>
<td>N2P4K2</td>
<td>13.60</td>
<td>52.9</td>
<td>2.9</td>
<td>1072</td>
<td>920</td>
<td>1992</td>
</tr>
<tr>
<td>N3PoKo</td>
<td>10.60</td>
<td>49.1</td>
<td>2.5</td>
<td>692</td>
<td>578</td>
<td>1270</td>
</tr>
<tr>
<td>N3P1Ko</td>
<td>11.70</td>
<td>47.9</td>
<td>2.9</td>
<td>772</td>
<td>866</td>
<td>1638</td>
</tr>
<tr>
<td>N3P2Ko</td>
<td>10.50</td>
<td>42.6</td>
<td>2.1</td>
<td>628</td>
<td>480</td>
<td>1108</td>
</tr>
<tr>
<td>N3P3Ko</td>
<td>9.65</td>
<td>40.8</td>
<td>2.3</td>
<td>572</td>
<td>498</td>
<td>1070</td>
</tr>
<tr>
<td>N3P4Ko</td>
<td>14.35</td>
<td>41.8</td>
<td>2.7</td>
<td>1002</td>
<td>586</td>
<td>1659</td>
</tr>
<tr>
<td>N3PoK1</td>
<td>11.70</td>
<td>37.6</td>
<td>2.6</td>
<td>1020</td>
<td>566</td>
<td>1586</td>
</tr>
<tr>
<td>N3P1K1</td>
<td>13.10</td>
<td>45.3</td>
<td>3.0</td>
<td>826</td>
<td>758</td>
<td>1584</td>
</tr>
<tr>
<td>N3P2K1</td>
<td>9.70</td>
<td>49.0</td>
<td>2.3</td>
<td>608</td>
<td>654</td>
<td>1262</td>
</tr>
<tr>
<td>N3P3K1</td>
<td>9.90</td>
<td>43.3</td>
<td>2.5</td>
<td>650</td>
<td>508</td>
<td>1158</td>
</tr>
<tr>
<td>N3P4K1</td>
<td>12.40</td>
<td>44.5</td>
<td>2.8</td>
<td>794</td>
<td>694</td>
<td>1488</td>
</tr>
<tr>
<td>N3PoK2</td>
<td>10.40</td>
<td>48.0</td>
<td>2.2</td>
<td>634</td>
<td>464</td>
<td>1098</td>
</tr>
<tr>
<td>N3P4K2</td>
<td>9.60</td>
<td>42.3</td>
<td>2.4</td>
<td>614</td>
<td>588</td>
<td>1200</td>
</tr>
<tr>
<td>Treatment</td>
<td>Length of tops cm</td>
<td>Length of roots cm</td>
<td>Diameter of stem mm</td>
<td>Dry Weight of tops mgm</td>
<td>Dry Weight of roots mgm</td>
<td>Total Dry Weight mgm</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------------</td>
<td>--------------------</td>
<td>---------------------</td>
<td>-----------------------</td>
<td>------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>N3P2K2</td>
<td>13.30</td>
<td>42.4</td>
<td>2.6</td>
<td>830</td>
<td>796</td>
<td>1626</td>
</tr>
<tr>
<td>N3P3K2</td>
<td>10.00</td>
<td>44.5</td>
<td>2.5</td>
<td>662</td>
<td>736</td>
<td>1398</td>
</tr>
<tr>
<td>N3P4K2</td>
<td>11.30</td>
<td>45.6</td>
<td>2.7</td>
<td>804</td>
<td>728</td>
<td>1432</td>
</tr>
<tr>
<td>N4PoKo</td>
<td>8.20</td>
<td>38.9</td>
<td>2.0</td>
<td>440</td>
<td>346</td>
<td>786</td>
</tr>
<tr>
<td>N4P1Ko</td>
<td>7.70</td>
<td>43.9</td>
<td>2.2</td>
<td>459</td>
<td>437</td>
<td>896</td>
</tr>
<tr>
<td>N4P2Ko</td>
<td>8.90</td>
<td>39.0</td>
<td>2.1</td>
<td>476</td>
<td>420</td>
<td>896</td>
</tr>
<tr>
<td>N4P3Ko</td>
<td>11.20</td>
<td>38.0</td>
<td>3.0</td>
<td>750</td>
<td>696</td>
<td>1046</td>
</tr>
<tr>
<td>N4P4Ko</td>
<td>11.60</td>
<td>42.1</td>
<td>2.7</td>
<td>646</td>
<td>544</td>
<td>1180</td>
</tr>
<tr>
<td>N4PoK1</td>
<td>8.20</td>
<td>43.4</td>
<td>2.5</td>
<td>450</td>
<td>438</td>
<td>880</td>
</tr>
<tr>
<td>N4P1K1</td>
<td>9.80</td>
<td>43.1</td>
<td>2.3</td>
<td>600</td>
<td>496</td>
<td>1096</td>
</tr>
<tr>
<td>N4P2K1</td>
<td>9.90</td>
<td>39.8</td>
<td>2.2</td>
<td>668</td>
<td>518</td>
<td>1186</td>
</tr>
<tr>
<td>N4P3K1</td>
<td>8.50</td>
<td>36.4</td>
<td>2.1</td>
<td>436</td>
<td>334</td>
<td>770</td>
</tr>
<tr>
<td>N4P4K1</td>
<td>13.20</td>
<td>46.8</td>
<td>2.5</td>
<td>762</td>
<td>588</td>
<td>1350</td>
</tr>
<tr>
<td>N4PoK2</td>
<td>10.50</td>
<td>42.8</td>
<td>2.8</td>
<td>642</td>
<td>630</td>
<td>1272</td>
</tr>
<tr>
<td>N4P1K2</td>
<td>9.90</td>
<td>39.8</td>
<td>2.3</td>
<td>540</td>
<td>456</td>
<td>996</td>
</tr>
<tr>
<td>N4P2K2</td>
<td>9.40</td>
<td>44.3</td>
<td>2.4</td>
<td>547</td>
<td>450</td>
<td>997</td>
</tr>
<tr>
<td>N4P3K2</td>
<td>10.20</td>
<td>53.3</td>
<td>2.9</td>
<td>624</td>
<td>535</td>
<td>1159</td>
</tr>
<tr>
<td>N4P4K2</td>
<td>10.10</td>
<td>43.2</td>
<td>2.7</td>
<td>700</td>
<td>598</td>
<td>1298</td>
</tr>
</tbody>
</table>
### TABLE 8b.

**Part D. Experiment 8. Analysis of variance table.**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length of tops</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Replication</td>
<td>1</td>
<td>19.66</td>
<td>19.66</td>
<td>1.73</td>
</tr>
<tr>
<td>Blocks within reps.</td>
<td>8</td>
<td>35.96</td>
<td>4.50</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>4</td>
<td>1398.11</td>
<td>349.52</td>
<td>30.88**</td>
</tr>
<tr>
<td>P</td>
<td>4</td>
<td>89.24</td>
<td>22.31</td>
<td>1.97</td>
</tr>
<tr>
<td>K</td>
<td>2</td>
<td>9.65</td>
<td>4.83</td>
<td></td>
</tr>
<tr>
<td>PK</td>
<td>8</td>
<td>91.65</td>
<td>11.46</td>
<td></td>
</tr>
<tr>
<td>NK</td>
<td>8</td>
<td>84.01</td>
<td>10.50</td>
<td></td>
</tr>
<tr>
<td>NP conf.</td>
<td>16</td>
<td>146.14</td>
<td>9.13</td>
<td></td>
</tr>
<tr>
<td>NPK</td>
<td>32</td>
<td>109.46</td>
<td>3.42</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>66</td>
<td>747.18</td>
<td>11.32</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>149</td>
<td>2731.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Length of roots</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reps.</td>
<td>1</td>
<td>140.55</td>
<td>140.6</td>
<td>2.14</td>
</tr>
<tr>
<td>Blocks</td>
<td>8</td>
<td>200.34</td>
<td>25.0</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>4</td>
<td>3.78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>4</td>
<td>155.72</td>
<td>13.9</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>2</td>
<td>13.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK</td>
<td>8</td>
<td>207.23</td>
<td>25.9</td>
<td></td>
</tr>
<tr>
<td>NK</td>
<td>8</td>
<td>300.13</td>
<td>37.5</td>
<td></td>
</tr>
<tr>
<td>NF (conf)</td>
<td>16</td>
<td>151.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPK</td>
<td>32</td>
<td>1326.70</td>
<td>41.4</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>66</td>
<td>4346.2</td>
<td>65.8</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>149</td>
<td>6845.2</td>
<td>95</td>
<td></td>
</tr>
</tbody>
</table>
TABLE 8b (cont'd)

Diameter of tops

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reps.</td>
<td>1</td>
<td>.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blocks</td>
<td>8</td>
<td>.57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>4</td>
<td>5.18</td>
<td>1.29</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>4</td>
<td>1.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>2</td>
<td>.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK</td>
<td>8</td>
<td>1.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NK</td>
<td>8</td>
<td>1.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP (Conf)</td>
<td>16</td>
<td>5.70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPK &quot;</td>
<td>32</td>
<td>2.47</td>
<td>17.72</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>66</td>
<td>382.6</td>
<td>5.7</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>149</td>
<td>400.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dry weight of tops

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reps.</td>
<td>1</td>
<td>.2480</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blocks</td>
<td>8</td>
<td>6.1923</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>4</td>
<td>304.5753</td>
<td>76.14</td>
<td>46.42**</td>
</tr>
<tr>
<td>P</td>
<td>4</td>
<td>19.5055</td>
<td>4.88</td>
<td>2.97*</td>
</tr>
<tr>
<td>K</td>
<td>2</td>
<td>6.4805</td>
<td>3.24</td>
<td></td>
</tr>
<tr>
<td>PK</td>
<td>8</td>
<td>9.1160</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NK</td>
<td>8</td>
<td>20.4286</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP (conf.)</td>
<td>16</td>
<td>190.7644</td>
<td>11.92</td>
<td>7.26**</td>
</tr>
<tr>
<td>NPK &quot;</td>
<td>32</td>
<td>37.6843</td>
<td>594.9949</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>66</td>
<td>108.36</td>
<td>1.64</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>149</td>
<td>703.36</td>
<td>4.72</td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 8b (cont'd)

#### Dry Weight of roots

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reps</td>
<td>1</td>
<td>.5186</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blocks</td>
<td>8</td>
<td>1.3783</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>4</td>
<td>72.7607</td>
<td>18.1901</td>
<td>2.94 *</td>
</tr>
<tr>
<td>P</td>
<td>4</td>
<td>9.0091</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>2</td>
<td>.5356</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK</td>
<td>8</td>
<td>5.5607</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NK</td>
<td>8</td>
<td>4.2508</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP (Conf.)</td>
<td>16</td>
<td>7.4969</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPK &quot;</td>
<td>32</td>
<td>22.4432</td>
<td>123.9539</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>66</td>
<td>.407.26</td>
<td>6.17</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>149</td>
<td>531.22</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Total Dry Weight

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reps</td>
<td>1</td>
<td>5.6425</td>
<td>5.6425</td>
<td></td>
</tr>
<tr>
<td>Blocks</td>
<td>8</td>
<td>11.7917</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>4</td>
<td>691.8118</td>
<td>172.9529</td>
<td>43.7202 **</td>
</tr>
<tr>
<td>P</td>
<td>4</td>
<td>47.0435</td>
<td>11.7608</td>
<td>2.9729</td>
</tr>
<tr>
<td>K</td>
<td>2</td>
<td>7.3169</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK</td>
<td>8</td>
<td>26.7822</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NK</td>
<td>8</td>
<td>39.5118</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP(Conf)</td>
<td>16</td>
<td>34.8054</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPK &quot;</td>
<td>32</td>
<td>117.7997</td>
<td>3.6849</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>66</td>
<td>261.0926</td>
<td>3.9559</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>149</td>
<td>1243.5981</td>
<td>8.3462</td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 8c.

Part D. Experiment 8. Chemical and physical analysis of soil.

<table>
<thead>
<tr>
<th>Depth Inc.</th>
<th>pH</th>
<th>Organic Matter %</th>
<th>Total N mg/g</th>
<th>Exch. P lb/acre</th>
<th>Exch. CAP mS/100g</th>
<th>Exchangeable Cations me/100g Ca</th>
<th>Mg</th>
<th>K</th>
<th>Percent Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.7</td>
<td>9.1</td>
<td>3.65</td>
<td>10.8</td>
<td>23.7</td>
<td>1.19</td>
<td>0.80</td>
<td>0.23</td>
<td></td>
<td>38.7</td>
<td>33.3</td>
<td>28.0</td>
</tr>
</tbody>
</table>
TABLE 9a

Part E. Experiment 9. Effect of different soil moisture tensions on the dry weight, length and stem diameter of 1-0 Douglas fir seedlings.

<table>
<thead>
<tr>
<th>Plot No.</th>
<th>Integrated Tension atm.</th>
<th>Average Per Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L 0.2</td>
<td>L 0.7</td>
</tr>
<tr>
<td></td>
<td>Tops gr</td>
<td>Roots gr</td>
</tr>
<tr>
<td>----------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>1</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.34</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>0.31</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4.4</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>4.9</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>6.3</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>3.8</td>
<td></td>
</tr>
</tbody>
</table>

Diameter mm

#### Length of tops.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>2</td>
<td>213.3</td>
<td>106.65</td>
<td>13.23</td>
</tr>
<tr>
<td>Replica</td>
<td>5</td>
<td>7.7</td>
<td>1.53</td>
<td>.19</td>
</tr>
<tr>
<td>Error</td>
<td>10</td>
<td>80.6</td>
<td>8.06</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>17</td>
<td>301.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Length of roots.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>2</td>
<td>13.5</td>
<td>6.77</td>
<td>4.34</td>
</tr>
<tr>
<td>Replica</td>
<td>5</td>
<td>7.0</td>
<td>1.40</td>
<td>.89</td>
</tr>
<tr>
<td>Error</td>
<td>10</td>
<td>15.6</td>
<td>1.56</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>17</td>
<td>36.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Diameter of stem.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>2</td>
<td>.6</td>
<td>.28</td>
<td>3.52</td>
</tr>
<tr>
<td>Replica</td>
<td>5</td>
<td>.9</td>
<td>.17</td>
<td>2.13</td>
</tr>
<tr>
<td>Error</td>
<td>10</td>
<td>.8</td>
<td>.08</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>17</td>
<td>2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Source of Variation</td>
<td>df</td>
<td>Sum of Squares</td>
<td>Mean Squares</td>
<td>F</td>
</tr>
<tr>
<td>---------------------</td>
<td>----</td>
<td>----------------</td>
<td>--------------</td>
<td>-----</td>
</tr>
<tr>
<td>Treatment</td>
<td>2</td>
<td>1667.9</td>
<td>833.94</td>
<td>10.28</td>
</tr>
<tr>
<td>Replica</td>
<td>5</td>
<td>1360.4</td>
<td>272.08</td>
<td>3.35</td>
</tr>
<tr>
<td>Error</td>
<td>10</td>
<td>811.0</td>
<td>81.10</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>17</td>
<td>3839.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dry weight of roots

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>2</td>
<td>41.7</td>
<td>20.85</td>
<td>5.68</td>
</tr>
<tr>
<td>Replica</td>
<td>5</td>
<td>181.8</td>
<td>36.36</td>
<td>9.90</td>
</tr>
<tr>
<td>Error</td>
<td>10</td>
<td>36.7</td>
<td>3.67</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>17</td>
<td>260.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total dry weight

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>2</td>
<td>2109.1</td>
<td>1054.5</td>
<td>10.06</td>
</tr>
<tr>
<td>Replica</td>
<td>5</td>
<td>2523.1</td>
<td>504.6</td>
<td>4.81</td>
</tr>
<tr>
<td>Error</td>
<td>10</td>
<td>1048.1</td>
<td>104.8</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>17</td>
<td>5680</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 9c

Part E. Experiment 9. Some physical properties of the soil used in the irrigation experiment.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Apparent Density</th>
<th>Total Pore Space</th>
<th>Macro Pore Space</th>
<th>Micro Pore Space</th>
<th>Percent moisture at different soil moisture tensions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40 cm 80 cm 1/3 atm 1 atm 2 atm 4 atm 6 atm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 ins</td>
<td>0.84 67.2 24.2 43.0</td>
<td>50.8 47.1 40.1 29.8 25.8 21.6 19.81</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 ins</td>
<td>0.90 66.2 10.1 56.1</td>
<td>55.8 53.1 52.7 31.4 25.4 24.6 21.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 ins</td>
<td>1.04 58.8 9.6 79.2</td>
<td>46.9 43.2 36.2 27.6 22.8 21.6 15.41</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth</th>
<th>Apparent Density</th>
<th>Total Pore Space</th>
<th>Macro Pore Space</th>
<th>Micro Pore Space</th>
<th>Percent moisture at different soil moisture tensions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40 cm 80 cm 1/3 atm 1 atm 2 atm 4 atm 6 atm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 ins</td>
<td>0.90 65.6 18.8 46.8</td>
<td>51.2 47.4 41.5 31.5 25.1 24.3 21.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 ins</td>
<td>1.00 63.9 4.2 59.7</td>
<td>60.0 56.9 51.8 29.5 24.4 22.9 20.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 ins</td>
<td>1.22 41.9 5.4 35.5</td>
<td>41.9 38.8 31.9 20.5 16.9 15.7 13.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

AVERAGE OF TWO SITES

<table>
<thead>
<tr>
<th>Depth</th>
<th>Apparent Density</th>
<th>Total Pore Space</th>
<th>Macro Pore Space</th>
<th>Micro Pore Space</th>
<th>Percent moisture at different soil moisture tensions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40 cm 80 cm 1/3 atm 1 atm 2 atm 4 atm 6 atm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 ins</td>
<td>0.87 66.4 21.5 44.9</td>
<td>51.0 47.3 40.8 30.7 25.5 23.0 20.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 ins</td>
<td>0.95 65.1 7.2 57.9</td>
<td>57.9 55.0 52.3 30.5 24.9 23.8 21.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 ins</td>
<td>1.13 50.4 7.5 42.4</td>
<td>44.4 41.0 33.8 24.1 19.9 18.2 14.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 9d.

**Part E. Experiment 9. Chemical analysis of check plot soil samples.**

<table>
<thead>
<tr>
<th>Check Plot</th>
<th>Depth Ins.</th>
<th>pH</th>
<th>Organic Matter %</th>
<th>Total N mg/g</th>
<th>Exchangeable P lb/acre</th>
<th>Exchangeable CAP me/100g</th>
<th>Cations me/100g</th>
<th>Ca</th>
<th>Mg</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 - 6</td>
<td>4.9</td>
<td>8.2</td>
<td>21.3</td>
<td>24.17</td>
<td>1.81</td>
<td>0.39</td>
<td>0.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>&quot;</td>
<td>4.8</td>
<td>8.5</td>
<td>30.6</td>
<td>23.52</td>
<td>1.93</td>
<td>0.35</td>
<td>0.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>&quot;</td>
<td>4.7</td>
<td>8.6</td>
<td>25.3</td>
<td>24.46</td>
<td>2.24</td>
<td>0.25</td>
<td>0.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>&quot;</td>
<td>4.8</td>
<td>8.4</td>
<td>22.6</td>
<td>25.08</td>
<td>2.06</td>
<td>0.64</td>
<td>0.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>&quot;</td>
<td>4.8</td>
<td>8.0</td>
<td>36.0</td>
<td>20.25</td>
<td>1.43</td>
<td>0.30</td>
<td>0.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>&quot;</td>
<td>4.9</td>
<td>8.7</td>
<td>25.3</td>
<td>23.00</td>
<td>2.31</td>
<td>0.32</td>
<td>0.32</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 9e.

**Part E. Experiment 9. Mechanical analysis of soil samples.**

<table>
<thead>
<tr>
<th>Site</th>
<th>Depth Inches</th>
<th>Sand %</th>
<th>Silt %</th>
<th>Clay %</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>5</td>
<td>45.0</td>
<td>26.7</td>
<td>28.3</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>37.4</td>
<td>31.2</td>
<td>31.4</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>43.6</td>
<td>29.5</td>
<td>26.9</td>
</tr>
<tr>
<td>II</td>
<td>5</td>
<td>36.8</td>
<td>35.0</td>
<td>28.2</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>38.4</td>
<td>32.6</td>
<td>29.0</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>42.3</td>
<td>37.4</td>
<td>20.3</td>
</tr>
</tbody>
</table>
Experiment 10. Dry weight and length of Douglas fir seedlings.

Average per seedling.

<table>
<thead>
<tr>
<th>Date of Sampling</th>
<th>Days Since June 4, 1957</th>
<th>Mgm</th>
<th>Cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Wt. of tops</td>
<td>Wt. of roots</td>
</tr>
<tr>
<td>June 4, 1957</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>July 18, 1957</td>
<td>44</td>
<td>13</td>
<td>52</td>
</tr>
<tr>
<td>Sept. 4, 1957</td>
<td>92</td>
<td>52</td>
<td>77</td>
</tr>
<tr>
<td>Oct. 5, 1957</td>
<td>123</td>
<td>86</td>
<td>86</td>
</tr>
<tr>
<td>Nov. 9, 1957</td>
<td>157</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>Dec. 18, 1957</td>
<td>197</td>
<td>89</td>
<td>89</td>
</tr>
<tr>
<td>Feb. 18, 1958</td>
<td>257</td>
<td>127</td>
<td>127</td>
</tr>
<tr>
<td>Apr. 9, 1958</td>
<td>307</td>
<td>240</td>
<td>240</td>
</tr>
<tr>
<td>May 6, 1958</td>
<td>334</td>
<td>356</td>
<td>356</td>
</tr>
<tr>
<td>May 19, 1958</td>
<td>347</td>
<td>645</td>
<td>645</td>
</tr>
<tr>
<td>June 10, 1958</td>
<td>369</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>July 1, 1958</td>
<td>390</td>
<td>1560</td>
<td>1560</td>
</tr>
<tr>
<td>Aug. 2, 1958</td>
<td>422</td>
<td>2390</td>
<td>2390</td>
</tr>
<tr>
<td>Aug. 30, 1958</td>
<td>450</td>
<td>2610</td>
<td>2610</td>
</tr>
<tr>
<td>Oct. 4, 1958</td>
<td>484</td>
<td>2520</td>
<td>2520</td>
</tr>
<tr>
<td>Nov. 6, 1958</td>
<td>516</td>
<td>2550</td>
<td>2550</td>
</tr>
<tr>
<td>Dec. 15, 1958</td>
<td>555</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date of Sampling</th>
<th>N (mg/plant)</th>
<th>N (%)</th>
<th>P (mg/plant)</th>
<th>P (%)</th>
<th>K (mg/plant)</th>
<th>K (%)</th>
<th>Ca (mg/plant)</th>
<th>Ca (%)</th>
<th>Mg (mg/plant)</th>
<th>Mg (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 4, 1957</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>July 18, 1957</td>
<td>0.484</td>
<td>3.73</td>
<td>0.064</td>
<td>0.49</td>
<td>0.111</td>
<td>0.85</td>
<td>0.022</td>
<td>0.17</td>
<td>0.030</td>
<td>0.23</td>
</tr>
<tr>
<td>Sept. 4, 1957</td>
<td>1.100</td>
<td>2.12</td>
<td>0.046</td>
<td>0.09</td>
<td>0.413</td>
<td>0.80</td>
<td>0.228</td>
<td>0.44</td>
<td>0.056</td>
<td>0.11</td>
</tr>
<tr>
<td>Oct. 5, 1957</td>
<td>2.136</td>
<td>2.77</td>
<td>0.113</td>
<td>0.15</td>
<td>0.608</td>
<td>0.80</td>
<td>0.392</td>
<td>0.51</td>
<td>0.082</td>
<td>0.11</td>
</tr>
<tr>
<td>Nov. 9, 1957</td>
<td>2.590</td>
<td>3.01</td>
<td>0.148</td>
<td>0.17</td>
<td>0.611</td>
<td>0.71</td>
<td>0.485</td>
<td>0.56</td>
<td>0.110</td>
<td>0.13</td>
</tr>
<tr>
<td>Dec. 18, 1957</td>
<td>2.723</td>
<td>3.02</td>
<td>0.195</td>
<td>0.22</td>
<td>0.585</td>
<td>0.65</td>
<td>0.410</td>
<td>0.47</td>
<td>0.112</td>
<td>0.13</td>
</tr>
<tr>
<td>Feb. 18, 1958</td>
<td>2.718</td>
<td>3.05</td>
<td>0.186</td>
<td>0.21</td>
<td>0.547</td>
<td>0.62</td>
<td>0.480</td>
<td>0.54</td>
<td>0.119</td>
<td>0.13</td>
</tr>
<tr>
<td>Apr. 9, 1958</td>
<td>4.056</td>
<td>3.19</td>
<td>0.485</td>
<td>0.38</td>
<td>0.972</td>
<td>0.77</td>
<td>0.610</td>
<td>0.48</td>
<td>0.198</td>
<td>0.16</td>
</tr>
<tr>
<td>May, 6, 1958</td>
<td>6.254</td>
<td>2.61</td>
<td>0.770</td>
<td>0.32</td>
<td>2.376</td>
<td>0.99</td>
<td>0.835</td>
<td>0.35</td>
<td>0.297</td>
<td>0.12</td>
</tr>
<tr>
<td>May 19, 1958</td>
<td>7.230</td>
<td>2.03</td>
<td>0.925</td>
<td>0.26</td>
<td>3.916</td>
<td>1.10</td>
<td>1.025</td>
<td>0.29</td>
<td>0.477</td>
<td>0.13</td>
</tr>
<tr>
<td>June 10, 1958</td>
<td>10.48</td>
<td>1.63</td>
<td>1.316</td>
<td>0.20</td>
<td>5.579</td>
<td>0.87</td>
<td>2.218</td>
<td>0.34</td>
<td>0.877</td>
<td>0.14</td>
</tr>
<tr>
<td>July 1, 1958</td>
<td>15.69</td>
<td>1.57</td>
<td>2.040</td>
<td>0.20</td>
<td>9.400</td>
<td>0.94</td>
<td>3.300</td>
<td>0.33</td>
<td>1.220</td>
<td>0.12</td>
</tr>
<tr>
<td>Aug. 2, 1958</td>
<td>19.28</td>
<td>1.24</td>
<td>2.808</td>
<td>0.18</td>
<td>14.35</td>
<td>0.92</td>
<td>4.992</td>
<td>0.32</td>
<td>2.278</td>
<td>0.15</td>
</tr>
<tr>
<td>Aug. 30, 1958</td>
<td>30.83</td>
<td>1.29</td>
<td>4.302</td>
<td>0.18</td>
<td>21.98</td>
<td>0.92</td>
<td>7.170</td>
<td>0.30</td>
<td>3.489</td>
<td>0.15</td>
</tr>
<tr>
<td>Oct. 4, 1958</td>
<td>32.80</td>
<td>1.26</td>
<td>7.099</td>
<td>0.27</td>
<td>22.97</td>
<td>0.88</td>
<td>9.135</td>
<td>0.35</td>
<td>4.124</td>
<td>0.16</td>
</tr>
<tr>
<td>Nov. 6, 1958</td>
<td>34.20</td>
<td>1.36</td>
<td>6.149</td>
<td>0.24</td>
<td>23.94</td>
<td>0.95</td>
<td>8.064</td>
<td>0.32</td>
<td>3.679</td>
<td>0.15</td>
</tr>
<tr>
<td>Dec. 15, 1958</td>
<td>35.47</td>
<td>1.39</td>
<td>6.222</td>
<td>0.24</td>
<td>20.55</td>
<td>0.81</td>
<td>8.415</td>
<td>0.33</td>
<td>3.723</td>
<td>0.15</td>
</tr>
</tbody>
</table>
### TABLE 10c.


<table>
<thead>
<tr>
<th>Date of Sampling</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg/Plant</td>
<td>%</td>
<td>mg/Plant</td>
<td>%</td>
<td>mg/Plant</td>
</tr>
<tr>
<td>June 4, 1957</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>July 18, 1957</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sept. 4, 1957</td>
<td>0.290</td>
<td>1.53</td>
<td>0.025</td>
<td>0.13</td>
<td>0.161</td>
</tr>
<tr>
<td>Oct. 5, 1957</td>
<td>0.681</td>
<td>1.95</td>
<td>0.054</td>
<td>0.15</td>
<td>0.219</td>
</tr>
<tr>
<td>Nov. 9, 1957</td>
<td>1.119</td>
<td>2.07</td>
<td>0.114</td>
<td>0.21</td>
<td>0.419</td>
</tr>
<tr>
<td>Dec. 18, 1957</td>
<td>1.315</td>
<td>2.23</td>
<td>0.099</td>
<td>0.17</td>
<td>0.330</td>
</tr>
<tr>
<td>Feb. 18, 1958</td>
<td>1.589</td>
<td>2.52</td>
<td>0.146</td>
<td>0.23</td>
<td>0.393</td>
</tr>
<tr>
<td>Apr. 9, 1958</td>
<td>1.918</td>
<td>2.59</td>
<td>0.179</td>
<td>0.24</td>
<td>0.540</td>
</tr>
<tr>
<td>May 6, 1958</td>
<td>1.884</td>
<td>2.33</td>
<td>0.160</td>
<td>0.20</td>
<td>0.591</td>
</tr>
<tr>
<td>May 19, 1958</td>
<td>1.664</td>
<td>1.81</td>
<td>0.169</td>
<td>0.18</td>
<td>0.742</td>
</tr>
<tr>
<td>June 10, 1958</td>
<td>2.324</td>
<td>1.47</td>
<td>0.212</td>
<td>0.15</td>
<td>1.106</td>
</tr>
<tr>
<td>July 1, 1958</td>
<td>3.267</td>
<td>1.49</td>
<td>0.306</td>
<td>0.14</td>
<td>1.342</td>
</tr>
<tr>
<td>Aug. 2, 1958</td>
<td>5.170</td>
<td>0.91</td>
<td>0.861</td>
<td>0.15</td>
<td>3.648</td>
</tr>
<tr>
<td>Aug. 30, 1958</td>
<td>5.988</td>
<td>0.76</td>
<td>1.011</td>
<td>0.13</td>
<td>4.582</td>
</tr>
<tr>
<td>Oct. 4, 1958</td>
<td>8.564</td>
<td>0.79</td>
<td>1.630</td>
<td>0.15</td>
<td>5.616</td>
</tr>
<tr>
<td>Nov. 6, 1958</td>
<td>9.680</td>
<td>0.97</td>
<td>1.860</td>
<td>0.19</td>
<td>5.400</td>
</tr>
<tr>
<td>Dec. 15, 1958</td>
<td>9.300</td>
<td>0.91</td>
<td>1.713</td>
<td>0.17</td>
<td>5.508</td>
</tr>
</tbody>
</table>

### TABLE 10d.

Experiment 10. Chemical and physical analysis of the soil

<table>
<thead>
<tr>
<th>Depth Ins.</th>
<th>pH</th>
<th>Organic Matter %</th>
<th>Total N mg/g</th>
<th>Exch-Exch</th>
<th>Exch</th>
<th>Exchangeable Cations me/100g</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>P lb/acre</td>
<td>CAP me/100g</td>
<td>Ca</td>
<td>Mg</td>
</tr>
<tr>
<td>0-8</td>
<td>5.9</td>
<td>6.1</td>
<td>2.49</td>
<td>110.6</td>
<td>11.05</td>
<td>3.68</td>
<td>0.25</td>
</tr>
</tbody>
</table>
TABLE II.

Monthly Precipitation and Mean Maximum and Minimum Temperatures at the Green Timbers Forest Nursery.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1956</td>
<td>8.04</td>
<td>4.90</td>
<td>5.06</td>
<td>4.30</td>
<td>0.42</td>
<td>6.91</td>
<td>0.56</td>
<td>2.01</td>
<td>3.79</td>
<td>13.02</td>
<td>4.54</td>
<td>8.63</td>
</tr>
<tr>
<td>1957</td>
<td>2.97</td>
<td>5.88</td>
<td>6.49</td>
<td>3.90</td>
<td>1.59</td>
<td>3.69</td>
<td>3.29</td>
<td>2.09</td>
<td>1.42</td>
<td>3.29</td>
<td>4.61</td>
<td>14.93</td>
</tr>
<tr>
<td>1958</td>
<td>11.35</td>
<td>3.40</td>
<td>2.70</td>
<td>2.91</td>
<td>1.50</td>
<td>1.97</td>
<td>0.00</td>
<td>1.88</td>
<td>1.75</td>
<td>7.18</td>
<td>9.55</td>
<td>9.56</td>
</tr>
<tr>
<td>10 year Average</td>
<td>8.26</td>
<td>6.18</td>
<td>5.65</td>
<td>3.43</td>
<td>2.19</td>
<td>3.00</td>
<td>1.77</td>
<td>2.13</td>
<td>2.64</td>
<td>6.98</td>
<td>9.46</td>
<td>8.97</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1956</td>
<td>39.1</td>
<td>36.8</td>
<td>46.2</td>
<td>5.71</td>
<td>65.4</td>
<td>59.7</td>
<td>75.1</td>
<td>71.3</td>
<td>62.7</td>
<td>54.3</td>
<td>44.7</td>
<td>39.9</td>
</tr>
<tr>
<td>1957</td>
<td>32.6</td>
<td>39.5</td>
<td>47.5</td>
<td>5.45</td>
<td>65.1</td>
<td>65.9</td>
<td>67.1</td>
<td>70.1</td>
<td>72.1</td>
<td>56.4</td>
<td>46.2</td>
<td>40.0</td>
</tr>
<tr>
<td>1958</td>
<td>44.1</td>
<td>48.3</td>
<td>49.9</td>
<td>56.7</td>
<td>69.4</td>
<td>72.0</td>
<td>80.9</td>
<td>76.2</td>
<td>66.4</td>
<td>56.5</td>
<td>47.6</td>
<td>44.8</td>
</tr>
<tr>
<td>10 year Average</td>
<td>35.7</td>
<td>40.5</td>
<td>45.0</td>
<td>52.6</td>
<td>60.7</td>
<td>63.1</td>
<td>69.3</td>
<td>69.5</td>
<td>65.3</td>
<td>54.2</td>
<td>45.3</td>
<td>43.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1956</td>
<td>29.7</td>
<td>27.1</td>
<td>30.5</td>
<td>34.9</td>
<td>40.7</td>
<td>45.7</td>
<td>50.7</td>
<td>50.5</td>
<td>44.6</td>
<td>41.3</td>
<td>32.1</td>
<td>32.6</td>
</tr>
<tr>
<td>1957</td>
<td>18.7</td>
<td>26.9</td>
<td>34.1</td>
<td>38.2</td>
<td>46.5</td>
<td>47.4</td>
<td>48.5</td>
<td>50.4</td>
<td>47.5</td>
<td>37.8</td>
<td>32.5</td>
<td>33.9</td>
</tr>
<tr>
<td>1958</td>
<td>35.1</td>
<td>37.1</td>
<td>32.0</td>
<td>36.1</td>
<td>44.0</td>
<td>53.3</td>
<td>54.9</td>
<td>51.5</td>
<td>47.3</td>
<td>41.6</td>
<td>32.6</td>
<td>35.1</td>
</tr>
<tr>
<td>10 year Average</td>
<td>24.9</td>
<td>29.1</td>
<td>30.2</td>
<td>34.5</td>
<td>40.5</td>
<td>45.4</td>
<td>48.5</td>
<td>48.7</td>
<td>44.5</td>
<td>39.2</td>
<td>33.7</td>
<td>34.0</td>
</tr>
</tbody>
</table>
TABLE 12.

Monthly Precipitation and Mean Maximum and Minimum Temperatures at the University of British Columbia.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1957</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>68.3</td>
<td>55.9</td>
<td>46.5</td>
<td>46.2</td>
</tr>
<tr>
<td>1958</td>
<td>46.7</td>
<td>49.9</td>
<td>49.7</td>
<td>54.6</td>
<td>65.6</td>
<td>69.4</td>
<td>75.5</td>
<td>72.0</td>
<td>62.9</td>
<td>56.1</td>
<td>47.0</td>
<td>45.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1957</td>
<td>39.3</td>
<td>41.5</td>
<td>38.7</td>
<td>41.9</td>
<td>51.2</td>
<td>57.3</td>
<td>60.7</td>
<td>57.6</td>
<td>52.5</td>
<td>46.2</td>
<td>37.3</td>
<td>38.5</td>
</tr>
<tr>
<td>1958</td>
<td>44.9</td>
<td>54.6</td>
<td>44.9</td>
<td>54.6</td>
<td>52.5</td>
<td>46.2</td>
<td>38.8</td>
<td>37.9</td>
<td>38.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1957</td>
<td>1.16</td>
<td>3.24</td>
<td>3.67</td>
<td>6.72</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1958</td>
<td>1.86</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Maximum Temperature, °F

Minimum Temperature, °F

Precipitation, inches
Equation used for the calculation of the "Integrated Mean Soil Moisture Tension".

Taylor (95) proposed the following equation for the calculation of the mean integrated soil moisture tension.

\[
T_{pm} = \frac{\sum_{i=0}^{m} \sum_{j=0}^{l} (d_{i+1} - d_{i}) T_{ij}}{\sum_{i=0}^{m} \sum_{j=1}^{l} (d_{i+1} - d_{i})}
\]

\[
l = \text{number of depth.}
\]
\[
m = \text{number of times readings were taken}
\]
\[
j = \text{single time}
\]
\[
T_{ij} = \text{moisture tension at time } i \text{ and depth } j
\]
\[
d_{i} = \text{day of the year observation } i \text{ was made}
\]

In above equation the seasonal mean value is calculated using the maximum value of the interval \( d_{i+1} - d_{i} \).

Under most practical conditions this is not justified and McNab Miller (63) has proposed the use of the mean soil moisture tension of a measurement interval \( d_{i+1} - d_{i} \) in the equation. This suggestion was adopted in this study.

\[
T_{pm} = \frac{\sum_{i=0}^{m} \sum_{j=0}^{l} \left( \frac{T_{i+1}j + T_{ij}}{2} \right) (d_{i+1} - d_{i})}{\sum_{i=0}^{m} \sum_{j=1}^{l} (d_{i+1} - d_{i})}
\]
Statistical analysis of a partially confounded 5 x 5 x 3 factorial experiment, replicated two times.

Levels of N → 0, 40, 80, 160, 320 lbs/acre
Levels of P → 0, 40, 80, 160, 320 lbs/acre
Levels of K → 0, 60, 120 lbs/acre

Each replicate is subdivided into 5 blocks. The NP and NPK effects are partially confounded.

Let $u_{ijkm}$ denote the observation in the mth block of the lth replication which has the ith level of N, the jth level of P, the kth level of K.

\[ i = 0, 1, 2, 3, 4 \quad l = 1, 2 \]
\[ j = 0, 1, 2, 3, 4 \quad m = 0, 1, 2, 3, 4 \]
\[ k = 0, 1, 2 \]

Use $\sum$ with the appropriate subscript to denote sums.

The sum is over any subscript which has been replaced by a dot.
<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>Sum of Squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replications</td>
<td>1</td>
<td>$S^2$</td>
</tr>
<tr>
<td>Blocks within replications</td>
<td>8</td>
<td>$S_{m(1)}^{21}$</td>
</tr>
<tr>
<td>N</td>
<td>4</td>
<td>$S_i^2$</td>
</tr>
<tr>
<td>P</td>
<td>4</td>
<td>$S_j^2$</td>
</tr>
<tr>
<td>K</td>
<td>2</td>
<td>$S_k^2$</td>
</tr>
<tr>
<td>PK</td>
<td>8</td>
<td>$S_{jk}^2$</td>
</tr>
<tr>
<td>NK</td>
<td>8</td>
<td>$S_{ik}^2$</td>
</tr>
<tr>
<td>NP (partially confounded)</td>
<td>16</td>
<td>$S_{ij}^2$</td>
</tr>
<tr>
<td>NPK (partially confounded)</td>
<td>32</td>
<td>$S_{ijk}^2$</td>
</tr>
<tr>
<td>Error</td>
<td>66</td>
<td>$S_o^2$</td>
</tr>
<tr>
<td>Total</td>
<td>149</td>
<td>$S^2$</td>
</tr>
</tbody>
</table>

The first 7 sums of squares and the total sum of squares can be computed in the usual way as in non confounded experiments.

\[
S^2 = \sum_{i} \sum_{j} \sum_{k} \sum_{l} \sum_{m} u_{ijklm} - \frac{1}{150} + 2 \ldots
\]

\[
S_1^2 = \frac{1}{75} \sum_{1}^{2} \ldots 1. - \frac{1}{150} + 2 \ldots
\]

\[
S_{m(1)}^2 = \frac{1}{15} \sum_{1}^{m} \sum_{l}^{2} \ldots l. - \frac{1}{75} 1 + 2 \ldots 1.
\]
\[ s^2_{ij} = \frac{1}{30} i + 2 \cdot i \ldots - \frac{1}{150} + 2 \ldots \]

\[ s^2_{jk} = \frac{1}{10} j + k + 2 \cdot jk\ldots - \frac{1}{30} j + 2 \cdot j \ldots - \frac{1}{50} k + 2 \ldots \]

\[ s^2_{ik} = \frac{1}{10} i + k + 2 \cdot i.k\ldots - \frac{1}{30} i + 2 \cdot i \ldots - \frac{1}{50} k + 2 \ldots \]

\[ s^2_{ijk} \]

\[ s^2_{ikj} \] confounded will be stated later.

A sum of squares with several degrees of freedom can be broken up into component sums of squares, each with 1 degree of freedom. In our case NP has 16 degrees of freedom so that a total of 16 components exist. We shall break the NP sum of squares into 4 components each having 4 degrees of freedom i.e. consisting of 5 sums or "levels".

The 4 components are denoted W, X, Y, Z.

Wo, W1, W2, W3, W4 are the 5 "levels" of W similarly Xo, X1, X2, X3, X4 are r "levels" of X etc.
The levels of W, X, Y, Z can be derived formally by the following method.

<table>
<thead>
<tr>
<th></th>
<th>No</th>
<th>N1</th>
<th>N2</th>
<th>N3</th>
<th>N4</th>
</tr>
</thead>
<tbody>
<tr>
<td>P0</td>
<td>(1111)</td>
<td>(2222)</td>
<td>(3333)</td>
<td>(4444)</td>
<td>(5555)</td>
</tr>
<tr>
<td>P1</td>
<td>(2345)</td>
<td>(3451)</td>
<td>(4512)</td>
<td>(5123)</td>
<td>(1234)</td>
</tr>
<tr>
<td>P2</td>
<td>(3524)</td>
<td>(4135)</td>
<td>(5421)</td>
<td>(1352)</td>
<td>(2413)</td>
</tr>
<tr>
<td>P3</td>
<td>(4253)</td>
<td>(5314)</td>
<td>(1425)</td>
<td>(2531)</td>
<td>(3142)</td>
</tr>
<tr>
<td>P4</td>
<td>(5432)</td>
<td>(1543)</td>
<td>(2154)</td>
<td>(3215)</td>
<td>(4321)</td>
</tr>
</tbody>
</table>

W:  
00 + 14 + 23 + 32 + 41 \(w_0\)
01 + 10 + 24 + 33 + 42 \(w_1\)
02 + 11 + 20 + 34 + 43 \(w_2\)
03 + 12 + 21 + 30 + 44 \(w_3\)
04 + 13 + 22 + 31 + 40 \(w_4\)

The symbols 00 = NoPo and 14 = N1P1 etc. the order NP is always the same.

In the table above the number 1, 2, 3, 4, 5, refer to levels of W, X, Y, Z.

In each bracket the first digit refers to W the second to X the third to Y and the fourth to Z.

It is therefore possible to derive all levels of all components from the table.
Let denote the sum of the observations in the 1th replication which have the kth level of K and one of the ij combinations of NP which constitute W

\[ Y : \quad y_0 + y_1 + y_2 + y_3 + y_4 \]
\[ X : \quad x_0 + x_1 + x_2 + x_3 + x_4 \]
\[ Z : \quad z_0 + z_1 + z_2 + z_3 + z_4 \]

Let \( W_{hkl} \) denote the sum of the observations in the 1th replication which have the kth level of K and one of the ij combinations of NP which constitute \( W_h \).

Suppose we have 5 levels of some component such as W or X. There are 4 independent contrast and a corresponding 4 degrees of freedom.
Let $w_k$ stand for $w_{hk1}$

The contrasts are

Divisor

linear $A_1 = -2w_0 - w_1 + w_2 + 2w_3 + 2w_4$ 

10

quadratic $A_2 = 2w_0 - w_1 - 2w_2 - w_3 + 2w_4$ 

14

cubic $A_3 = -w_0 + 2w_1 - 2w_2 + w_3 + w_4$ 

10

quartic $A_4 = w_0 - 4w_1 + 6w_2 - 4w_3 + w_4$ 

70

Other sets of independent contrast are possible.

If we use $W_{0kl} \ldots W_{4kl}$, then we would denote the contrasts by $a_{1kl} \ldots a_{4kl}$, $k$ and $l$ have the same meaning as before.

The corresponding contrasts for $X_h$ be denoted by $b_1, \ldots, b_4$.

The 4 degrees of freedom corresponding to $W$ are confounded with blocks in the first replication but not in the second.

The 4 degrees of freedom corresponding to $X$ are confounded with blocks in the second replication but not in the first.

The 4 degrees of freedom corresponding to $Y$ and the 4 corresponding to $Z$ are not confounded at all.

One could get $S_{ij}^2$ for NP by calculating the component squares for $Y$ and $Z$ from both replications that for $W$ from the second replication that for $X$ from the first replication. One would follow such a scheme if the confounding was balanced, but where $W, X$ are partially confounded, $Y, Z$, are not, it is probably simpler to compute the NP sum of squares as if no sub-division into block existed, subtract from it the $W$ and $X$ contribution for both replications together then add the $W$ con-
tribution from replication 2\(^1\), the X contribution from replication 1.

Sum of squares for NP when blocks are disregarded.

\[
S_{NP}^2 = \frac{1}{6} \sum_{i=1}^{30} \sum_{j=1}^{2} i \cdot j \cdot S_{ij} - \frac{1}{30} \sum_{i=1}^{30} i \cdot S_{i.} - \frac{1}{30} \sum_{j=1}^{2} j \cdot S_{.j} + \frac{1}{150} \sum_{i=1}^{30} \sum_{j=1}^{2} i \cdot j \cdot S_{ij} = S_{W..}^2 + S_{X..}^2 + S_{Y..}^2 + S_{Z..}^2
\]

Sum of squares for W and X over both replications are:

\[
S_{W..}^2 = \frac{1}{30} \left[ \frac{1}{10} a_{1..}^2 + \frac{1}{14} a_{2..}^2 + \frac{1}{10} a_{3..}^2 + \frac{1}{70} a_{4..}^2 \right]
= \frac{1}{2100} \left[ 7a_{1..}^2 + 5a_{2..}^2 + 7a_{3..}^2 + a_{4..}^2 \right]
S_{X..}^2 = \frac{1}{2100} \left[ 7b_{1..}^2 + 5b_{2..}^2 + 7b_{3..}^2 + b_{4..}^2 \right]
\]

Sum of squares of W in replication 2 is

\[
S_{W,2}^2 = \frac{1}{15} \left[ \frac{1}{10} a_{1,2}^2 + \frac{1}{14} a_{2,2}^2 + \frac{1}{10} a_{3,2}^2 + \frac{1}{70} a_{4,2}^2 \right]
= \frac{1}{1050} \left[ 7a_{1,2}^2 + 5a_{2,2}^2 + 7a_{3,2}^2 + a_{4,2}^2 \right]
\]

Sum of squares for X in replication 1 is

\[
S_{X,1}^2 = \frac{1}{1050} \left[ 7b_{1,1}^2 + 5b_{2,1}^2 + 7b_{3,1}^2 + b_{4,1}^2 \right]
\]

Then

\[
S_{ij}^2 = S_{NP}^2 - S_{W..}^2 - S_{X..}^2 + S_{W,2}^2 + S_{X,1}^2
= S_{W,2}^2 + S_{X,1}^2 + S_{Y..}^2 + S_{Z..}^2
\]
Derivation of the NPK effect.

The NP interaction was made up of 16 independent contrasts, 4 each for W, X, Y, Z. The K effect with 3 levels gives 2 contrasts.

The 32 contrasts for the NPK interaction can be found formally by multiplying the 16 for NP by the 2 for K.

The two independent contrasts for K are:

\[
\begin{align*}
\text{linear} & \quad \text{linear} \quad K = -K_0 + \frac{K_2}{2} \\
\text{quadratic} & \quad K_0 - 2K_1 + \frac{K_2}{6}
\end{align*}
\]

The formal product linear Wx linear K is:

\[
\begin{align*}
\text{linear Wx linear K} & = (-2W_0 - W_1 + W_3 + 2W_4) (-K_0 + K_2) \\
& = -(\text{linear W for K at 0 level}) + (\text{linear W for K at 2 level}) \\
& = -a_{101} + a_{121}
\end{align*}
\]

When listing the 16 contrast in the interaction of K with W and X the third subscript 1 or the dot replacing it will be omitted. There are 16 other contrasts in the interaction of K with Y and Z which are needed not needed for the particular method of analysis selected.

<table>
<thead>
<tr>
<th>Divisor</th>
</tr>
</thead>
<tbody>
<tr>
<td>linear Wx linear K</td>
</tr>
<tr>
<td>quadratic Wx linear K</td>
</tr>
<tr>
<td>cubic Wx linear K</td>
</tr>
<tr>
<td>quartic Wx linear K</td>
</tr>
<tr>
<td>linear Wx quadratic K</td>
</tr>
<tr>
<td>quadratic Wx quadratic K</td>
</tr>
<tr>
<td>cubic Wx quadratic K</td>
</tr>
<tr>
<td>quartic Wx quadratic K</td>
</tr>
</tbody>
</table>
The corresponding contrast for $X K$ denoted by $d$ can be obtained by replacing the a's by b's.

Sum of squares for NPK when blocks are disregarded is:

$$S^2_{NPK} = \frac{1}{2} \sum_{i} \sum_{j} \sum_{k} e_{ijk}^2 - \frac{1}{6} \sum_{i} \sum_{j} e_{ij}^2 - \frac{1}{10} \sum_{i} \sum_{k} e_{i,k}^2$$

$$= \frac{1}{10} \sum_{j} \sum_{k} e_{jk}^2 + \frac{1}{30} \sum_{i} \sum_{j} e_{i,j}^2 + \frac{1}{30} \sum_{j} \sum_{i} e_{i,j}^2 + \frac{1}{50} \sum_{k} \sum_{i} e_{i,k}^2$$

$$= S^2_{wk} + S^2_{xk} + S^2_{yk} + S^2_{zk}$$

Sum of squares for WK and XK over both replications are:

$$S^2_{wk} = \frac{1}{10} \left[ \frac{1}{20} c_{11}^2 + \frac{1}{28} c_{21}^2 + \frac{1}{20} c_{31}^2 + \frac{1}{140} c_{12}^2 + \frac{1}{60} c_{12}^2 + \frac{1}{84} c_{22}^2 + \frac{1}{60} c_{32}^2 + \frac{1}{420} c_{42}^2 \right]$$

$$= \frac{1}{4200} \left[ 21c_{11}^2 + 15c_{21}^2 + 21c_{31}^2 + 3c_{41}^2 + 7c_{12}^2 + 5c_{22}^2 + 7c_{32}^2 + c_{42}^2 \right]$$

$$S^2_{XK} = \frac{1}{4200} \left[ 21d_{11}^2 + 15d_{21}^2 + 21d_{31}^2 + 3d_{41}^2 + 7d_{12}^2 + 5d_{22}^2 + 7d_{32}^2 + d_{42}^2 \right]$$
Sum of squares for WK in replication 2 is.

\[ S_{wk2}^2 = \frac{1}{5} \left[ \frac{1}{20} c_{112}^2 + \frac{1}{28} c_{211}^2 + \frac{1}{20} c_{312}^2 + \frac{1}{140} c_{412}^2 + \frac{1}{60} c_{122}^2 \\
+ \frac{1}{84} c_{222}^2 + \frac{1}{60} c_{312}^2 + \frac{1}{420} c_{422}^2 \right] \]

\[ = \frac{1}{2100} \left[ 21c_{112}^2 + 15c_{211}^2 + 21c_{312}^2 + 3c_{412}^2 + 7c_{222}^2 + 7c_{322}^2 \\
+ c_{422}^2 \right] \]

Sum of squares for XK in replication 1 is

\[ S_{xk1}^2 = \frac{1}{2100} \left[ 21d_{111}^2 + 15d_{211}^2 + 21d_{311}^2 + 3d_{411}^2 + 7d_{221}^2 + 7d_{321}^2 + d_{421}^2 \right] \]

Then

\[ S_{ijklm}^2 = S_{NPK}^2 - S_{wk}^2 - S_{yk}^2 + S_{wk2}^2 + S_{xk1}^2 \]

\[ S_{ijk}^2 = S_{wk2}^2 + S_{xk1}^2 + S_{yk}^2 + S_{zk}^2. \]

<table>
<thead>
<tr>
<th>Sum to calculate</th>
<th>No. of such terms</th>
<th>No. of items involved</th>
<th>Sum of Squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>( U_{ijklm} )</td>
<td>150</td>
<td>1</td>
<td>( \frac{1}{10} \Sigma U_{ijklm} )</td>
</tr>
<tr>
<td>( t_{ijk} )</td>
<td>75</td>
<td>2</td>
<td>( \frac{1}{2} \Sigma t_{ijk} )</td>
</tr>
<tr>
<td>( t_{ij} )</td>
<td>25</td>
<td>6</td>
<td>( \frac{1}{6} \Sigma t_{ij} )</td>
</tr>
<tr>
<td>( t_{i.k} )</td>
<td>15</td>
<td>10</td>
<td>( \frac{1}{10} \Sigma t_{i.k} )</td>
</tr>
<tr>
<td>( t_{i.j} )</td>
<td>15</td>
<td>10</td>
<td>( \frac{1}{10} \Sigma t_{i.j} )</td>
</tr>
<tr>
<td>( t_{i....} )</td>
<td>5</td>
<td>30</td>
<td>( \frac{1}{30} \Sigma t_{i....} )</td>
</tr>
<tr>
<td>Sums to calculate</td>
<td>No. of such terms</td>
<td>No. of items involved</td>
<td>Sum of Squares</td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------------</td>
<td>-----------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>( \dagger) (j)…</td>
<td>5</td>
<td>30</td>
<td>(\frac{1}{30} \ j^2 ) (\dagger) (j)…</td>
</tr>
<tr>
<td>( \dagger) (k)…</td>
<td>3</td>
<td>50</td>
<td>(\frac{1}{50} \ k^2 ) (\dagger) (k)…</td>
</tr>
<tr>
<td>( \dagger) (lm)</td>
<td>10</td>
<td>15</td>
<td>(\frac{1}{15} \ l \ m^2 ) (\dagger) (lm)</td>
</tr>
<tr>
<td>( \dagger) (l)…</td>
<td>2</td>
<td>75</td>
<td>(\frac{1}{75} \ l^2 ) (\dagger) (l)…</td>
</tr>
<tr>
<td>( \dagger) (\ldots)</td>
<td>1</td>
<td>150</td>
<td>(\frac{1}{150} \ \ldots^2)</td>
</tr>
</tbody>
</table>

| \(w_{hl}\) | 30                | 5                     | \(\ldots\) |
| \(w_{hk}\) | 15                | 10                    | \(\ldots\) |
| \(w_{h,l}\) | 10                | 15                    | \(\ldots\) |
| \(w_{h..}\) | 5                 | 30                    | \(\ldots\) |

Similarly for \(x_{hl}\), \(x_{hk}\), \(x_{h,l}\), \(x_{h..}\).

From the above \(w\)'s one computes the \(a\)'s.
From the \(x\)'s one computes the \(b\)'s.
From the \(a\)'s and \(b\)'s one can then calculate the respective \(c\)'s and \(d\)'s.

In the greenhouse experiment conducted with Douglas fir it was assumed that the treatments were arranged as shown in the above table for Rep. I and Rep II. The variation in light intensity in the greenhouse space available made necessary a monthly rotation of treatments in a replica and of the complete replica.
Arrangement of treatments in replicates and blocks. Blocks are denoted as a, b, ..., e; replicates as I, II, ..., VIII.

<table>
<thead>
<tr>
<th>Rep I</th>
<th>Rep II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level</td>
<td>Blocks</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>Ia</td>
</tr>
<tr>
<td>0</td>
<td>Wo</td>
</tr>
<tr>
<td>1</td>
<td>W1</td>
</tr>
<tr>
<td>2</td>
<td>W2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rep III</th>
<th>Rep IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level</td>
<td>Blocks</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>IIIa</td>
</tr>
<tr>
<td>0</td>
<td>Yo</td>
</tr>
<tr>
<td>1</td>
<td>Y1</td>
</tr>
<tr>
<td>2</td>
<td>Y3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rep V</th>
<th>Rep VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level</td>
<td>Blocks</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>Va</td>
</tr>
<tr>
<td>0</td>
<td>Wo</td>
</tr>
<tr>
<td>1</td>
<td>W1</td>
</tr>
<tr>
<td>2</td>
<td>W2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rep VII</th>
<th>Rep VIII</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level</td>
<td>Blocks</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>VIIa</td>
</tr>
<tr>
<td>0</td>
<td>Yo</td>
</tr>
<tr>
<td>1</td>
<td>Y1</td>
</tr>
<tr>
<td>2</td>
<td>Y2</td>
</tr>
</tbody>
</table>
Plate 1. Effect of nitrogen fertilization on 1-0 Douglas fir seedlings. Dark green plate received Nitrogen June 15, 1957

Plate 2. The appearance of the plots in plate 1 on August 2, 1957.
Plate 3. The appearance in the fall of unfertilized 1 - 0 Douglas fir seedlings

Plate 4. The appearance in the fall of 1 - 0 Douglas fir seedlings fertilized with 40 lb per acre N on May 15, 1957.
Plate 5. The appearance in the fall of 1 - 0 Douglas fir seedlings fertilized with 40 lb per acre N on August 1, 1957

Plate 6. The appearance in the fall of 1 - 0 Douglas fir seedlings fertilized with 80 lb per acre N on May 15, 1957
Plate 7. Nitrogen damage in plots of 1 - 0 Douglas fir seedlings fertilized with 160 lb N. per acre

Plate 8. Nitrogen damage caused by the application of 320 lb N. per acre to 1 - 0 Douglas fir seedlings.
Plate 9. Nitrogen damage caused by the application of 320 lb per acre N to Douglas fir seedlings in the greenhouse.

SELECTED BIBLIOGRAPHY


86. Romaine, J.D. When fertilizing, consider plant-food content of crops. Better Crops with Plant Food, 1940.


