SOME FACTORS AFFECTING DOUGLAS-FIR SEEDLING GROWTH AND ESTABLISHMENT

by

JAMES RODNEY HOWLAND

A THESIS

submitted to

OREGON STATE UNIVERSITY

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1962

ACKNOWLEDGEMENTS

Many persons have played a role in shaping my thoughts and actions associated with the studies in this thesis. Be the role accidental or intentional I am indebted to all these people.

To Dr. William K. Ferrell, an extremely knowledgeable and understanding individual, I owe special thanks for patience and guidance.

Without the financial assistance provided by the South Santiam Fellowship I would not have been able to embark upon a graduate program. My thanks to the sponsors of the South Santiam Fellowship.

It is also very much appreciated that greenhouse facilities and access to McDonald Forest were made available for use in conducting research for this thesis.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF TABLES

SOME FACTORS AFFECTING DOUGLAS-FIR SEEDLING GROWTH AND ESTABLISHMENT

INTRODUCTION

The regeneration of many forest tree species, including Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, is a very difficult task. Failure of natural and/or artificial regeneration represents a cost to our forest economy. The cost of one attempt is frequently so high that no further effort is expended to correct the failure. These complete or partial failures have been attributed to a variety of causes. One important group of causes associated with the failure of regeneration is the impact of environmental factors present at the site. It has been stated that site is not one factor and not all factors, but is the sum of all effective factors among which usually one or more are dominant (15, p. 10). Furthermore, many environmental factors are not static. A factor may be important during one period and completely absent in another period; therefore, one should not become preoccupied with a single environmental factor.

The problem of regeneration is very complex and a complete understanding is often prevented by a multiplicity of interactions of the factors affecting regeneration. Some of the more important factors are harvesting methods, environment, genetic constitution, and regeneration methods. For purposes of simplicity the two basic factors affecting regeneration can be thought of as genetic constitution and the environment of the individual seedling. All other factors can be considered as modifications of these two factors. Harvesting methods and regeneration methods are modifications of environment through human action. Much remains to be learned about what form these modifications may take and how they can be used to good advantage to obtain the most satisfactory regeneration. Less than adequate knowledge of the effect of harvesting and regeneration methods on regeneration and incomplete knowledge of environment and genetic constitution are unavoidable, but the continuation of this situation is inexcusable.

Often the regeneration objective is stated as a minimum percentage of milacre plots occupied by one or more seedlings of satisfactory vigor. However, it is felt that this minimum level of stocking has only nominal meaning in either biological or economic terms. Considering our present level of knowledge in either the biology or economics of regeneration it would be meaningless to have inflexible regeneration objectives. However, effort to set forth meaningful regeneration objectives should be continuous and in the direction of stating these objectives in terms of environment-genetic combinations which will best satisfy our predicted economic needs.

Much of the difficulty in regeneration of Douglas-fir arises from the large amount of variation in environment and possibly genotypes. Isaac (17, p. 105) states, "Conditions within the Douglas-fir type are so varied that simple, specific rules cannot be set forth for securing regeneration over large areas, either in management of young stands or the harvesting of over-mature virgin forests." However, Isaac and others through research and observation have come to identify many of the key factors which determine the character of regeneration. Some of these key factors are: excess and lack of heat, low levels of light, animal depredation, moisture stress in the atmosphere and in the soil, genetic differences, and availability of seed. These same factors are couched in a wide array of terms some of which are: topographic aspect, slope, slash classes, burn intensity classes, elevation, maximum and minimum temperatures, competition, soil moisture, drought, precipitation, seed source, relative humidity, etc. It is necessary to use many of the forementioned terms to describe the feasibility of obtaining regeneration because they are usually more obvious and easily recognized than inherent differences in physiological activity between seedlings and subtle differences in physical forces which affect physiological activity. However, they do not always reflect the basic relationship between a seedling (genotype) and its environment. Some of the broader terms represent a conglomerate of basic relationships. For example, topographic aspect could represent variations in light, heat, and moisture. Since many of the factors operating in an environment are interrelated and since they vary through time and space it is doubtful that a completely accurate assessment is possible for a given area and for a given period of time. Even more unlikely is a prediction of future magnitudes and variations in these factors.

It is improbable that a general prescription will ever be effective in curing all the ills of regeneration. This is due not only to variation in environment in both time and space and to variation in physiological requirements within and between individuals through time, but to change in what we consider optimum regeneration from an economic point-of-view. We are, therefore, forced to rely on inference based on experimental results under roughly comparable conditions and on observations in issuing a prescription for a specific regeneration ill.

This thesis is concerned with variation between groups of seedlings and variations in environment. Any inference drawn is applicable, with caution, to the area of McDonald Forest. McDonald Forest is the source of study materials and the area in which the field plots are located. McDonald Forest, judging from its irregular terrain and its gross physiognomic differences in vegetation, is a good area to study variation in environments. To aid in the interpretation of regeneration problems on McDonald Forest a portion of this thesis is devoted to the study of localized ecotypic variation within Douglas-fir as well as environmental variation.

Two studies are presented. They are presented separately for purposes of clarity. The two studies are related to the extent that they both are concerned with the further understanding of the factors affecting the establishment and growth of Douglas-fir seedlings.

Study I was conducted under greenhouse conditions using four well-defined seed sources, a relatively uniform aerial environment, and two undisturbed soil series as the root medium. The seedlings were grown and observed for a period of three months. The purpose of the study was to test variation between known seed sources in their adaptability to soil differences. Study II was conducted on four field plots selected on the basis of soil series and topographic aspect. Planting stock of 2-0 Douglas-fir were transplanted to the field plots and observed for approximately one year. This study was concerned primarily with studying the interaction between planting date and field environment. The Aiken and Dixonville soil series were common to both studies.

"The mere recording of the frequency and abundance of reproduction is of little silvicultural value, but the reasons for its presence or absence are of the highest value." (55, p. 325) It is hoped that this sage advice was heeded in the following studies by the author of the thesis.

STUDY I

REVIEW OF LITERATURE

Environmental factors have an association with the genetic makeup of trees occupying a particular environment. Past features of the environment have left their mark on existing trees through the process of natural selection and evolution. The current nature of environmental factors will have an effect on the genetic character of trees that will subsequently exist. Therefore, the subject of ecotypic variation cannot be discussed adequately without mentioning environmental factors for they are inseparable subjects.

Ecotypic Variation

In recent years there has been a marked surge in the attention given to the role in forest regeneration activities of genetic variation. Much of this attention has been directed toward the eventual objective of bringing together a genotype and environment which will result in the production of a phenotype that will best suit our economic needs. To date most of the research has been concentrated on the detection of ecotypic variation throughout a wide portion of a species range. Variation in height growth, phenology, frost resistance, disease resistance, and wood properties have received much of the attention (16, 28, 35, 45, 59, 63). In spite of all this activity there is much to be learned about where ecotypic variation exists, and to what extent (63, p. 808).

Information provided by studies on ecotypic variation has given some indication of the necessity of defining the limits of a seed source for a species to be used in regeneration. However, the materials for most of the studies of ecotypic variation have been collected from areas too large to give evidence of localized ecotypic variation. Assuming that different environments exert differences in type and magnitude of selection pressures, it should be possible to find genetic differences within small areas if there are marked differences in environments within short distances.

One rule-of-thumb for establishment of seed collection zones, which seems to be fairly widely used, is that the area of seed collection should be within 100 miles and should not be over 1000 feet higher or lower in elevation than the area to be planted. Because we know very little about the variation and suitability of various seed source areas we have to adopt some kind of arbitrary standard. Studies in Douglas-fir indicate that there is considerable variation throughout the range of this species, but too little is known about this variation to turn it to practical use.

Munger and Morris (33, p. 39-40) in a study initiated in 1912 and summarized in 1936 found that there were apparent genetic differences between trees from 13 seed source areas in western Washington and Oregon, Ching and Bever (8, p. 16) in a study of plants from 14 seed source areas found that a preliminary analysis showed a distinct correlation between height growth in the second year after sowing and geographic location. The seed source areas for Ching and Bever's study extended from 42 degrees 20 minutes North to 49 degrees 10 minutes North on the west side of the Cascade Range. Irgens-Moller (16, p. 28) has demonstrated that there is variation in date of bud-bursting in Douglas-fir on the basis of response to temperature and photoperiod. He also used materials from widely separated locales, so the question of ecotypic variation within a small portion of the Douglas-fir range still remains an open question.

Squillace and Bingham (50, p. 32) conclude from the results of their study on localized ecotypic variation in Pinus monticola Dougl. that where highly variable topography is present, infiltration of genes from trees on adjacent sites is reduced because of differences in selection pressure due to wide variation in environment within very short distances. Two areas from which seed was collected in the study by Squillace and Bingham were within one-half mile of each other; seedlings from these areas exhibited differences in rate of height growth when grown in a common environment. Douglas-fir, in much of its range, occurs on similarly broken terrain. Since topography is irregular throughout much of the range of Douglas-fir, it does not seem unreasonable to expect that microclimate and other environmental factor differences are associated with the process of natural selection.

Environment

Studies on factors affecting natural regeneration of Douglas-fir cite many factors which influence the stocking percentage on clearcuts, but for purposes of simplicity they can all be put into three broad categories of climatic, edaphic, and biotic factors. Of these three categories, climatic and edaphic factors are especially pertinent to this study.

Isaac (17, p. 28, 45-46) states that local variations in climate have a very profound effect on regeneration of Douglas-fir. There may be more difference to the individual seedling between a north and a south slope than between the climate of the coast and the Cascade region. As regards growth potentialities, climate is a very important element of site quality. In reference to early survival of seedlings he cites temperature, especially surface soil temperature, as being the most critical environmental factor. The work of other researchers tends to confirm this conclusion. The literature is replete with accounts of the influence of factors directly related to climate on the survival and growth of Douglas-fir seedlings and trees.

Silen (47, p. 92-141) found that a few weeks old seedlings treated for 60 minutes at 123 degrees Fahrenheit usually show a discoloration or lesion at soil surface on the hypocotyl. Mortality rose sharply at 125 degrees Fahrenheit. It was found that 90 per cent of the south slopes had surface temperatures reaching 125 degrees Fahrenheit during the summer. Silen concludes that heat flow in calories rather than temperature as such is the best measure of expected mortality of Douglas-fir seedlings.

Other studies on factors affecting the natural regeneration of Douglas-fir on clearcuts give evidence that exposure has an influence on the per cent stocking (2, 16, 22, 25). The higher stocking percentages were found on northerly exposures and lower stocking percentages were found on southerly exposures. The other exposures were intermediate in stocking. In terms of site class, Urie (57, p. 14) found that north and east aspects were superior to south and west slopes. Variability was greater on the south and west aspects; all the site V stands were on the south slopes or level ground. Heavy cover classes of competing vegetation and medium to extreme burn intensities were found to be associated with low levels of stocking (2, p. 35; 25, p. 26). The differential effect of exposure on stocking is probably a reflection of the direct influence of the environmental factors of heat, frost, and moisture stress. The direct effect of differences in burn intensity and cover classes is also probably through the factors of heat, frost, and moisture, plus light, soil nutrition, and soil structure.

Drought, a complex phenomenon in itself, is considered to be of importance in some parts of the Douglas-fir range. In the Willamette Valley Foothills, Youngberg (66, p. 843) has found that when moisture tension in the soil goes above the 1 atmosphere level the rate of mortality of Douglas-fir seedlings is very rapid. In his study the one atmosphere moisture level was reached early in the summer. Griffith (13, p. 18) found that on the University of British Columbia Forest available soil moisture in the B horizon was the most significant variable affecting the growth of

Douglas-fir. Carmean (5, p. 335) found that in southwestern Washington site quality of Douglas-fir increases with an increase in precipitation especially summer precipitation. Although it may not always be clear as to what factors are operating in the phenomenon of drought and to what intensity, it can be said that climate always has a role and in many cases a dominant role.

Studies of ecotypic variation have concentrated on response to the aerial environment or the total environment. In a search of the literature no studies were found on adaptive response to the soil environment alone. There is no question that the soil environment varies widely. The role of the soil environment differences in ecotypic differentiation is poorly understood.

Soil differences may be suitable for the testing of ecotypic differentiation for the following reasons: (1) Soil is influenced by all other variables in the environment including the vegetation. (2) Many soil characteristics such as texture and structure are more stable than biotic or climatic factors. Photoperiod, being the most stable of environmental factors, is a noteworthy exception.

It is, therefore, felt that some features of the soil may act with a more constant selection pressure. Of course, it is to be remembered that differences in vegetative response may be difficult to attribute to soil differences alone, unless all other variables are held constant and this is usually impractical or impossible.

Most studies of ecotypic variation have used measurements on the aerial portions of seedlings because it is the aerial portion which most concerns commercial forestry. Other reasons for not devoting more attention to the roots are: It is more difficult to obtain measurements of the roots without seriously injuring the seedling, altering the environment, or even sacrificing the study materials. Also, since the plant functions as a unit the roots reflect variations in the aerial environment and it is difficult to distinguish response to aerial environment from response to the soil environment. Richardson (42, p. 437) found that in Acer saccharinum L., changes in night temperatures caused changes in shoot photosynthate production which in turn resulted in changes in rate of root elongation within 15 hours. Perhaps the roots reflect the aerial environment or the total environment as well as the shoot. However, the roots if for no other reason than their direct contact with the soil should be the most sensitive indicators of variation in the soil environment.

The principal objectives of this study were:

(1) To test for the presence or absence of localized ecotypic variation with respect to root characteristics in Douglas-fir seedlings reared from seed collected on areas within the confines of McDonald Forest.

(2) To test for differential adaptation by these seed sources to two soil series in a reasonably uniform aerial environment.

(3) To test the value of root characteristics as useful indicators of ecotypic variation.

METHODS AND MATERIALS

The experimental portion of the study was begun on December 24, 1959. Seed for the experiment was collected from four areas on McDonald Forest. The seed from these four seed sources are hereafter identified by two capital letters. The first capital letter indicates whether the seed was collected from a south or north slope. The second capital letter indicates the relative altitudinal position of the two slope classes; L indicating low elevation and H indicating high elevation. Seed collected on the area with a north aspect and at an elevation of 300 feet were labelled NL. Seed collected on the area with a north aspect and at an elevation of 1050 feet were labelled NH. Seed collected on the area with a south aspect and at an elevation of 700 feet were labelled SL. Seed collected on the area with a south aspect and at an elevation of 1450 feet were labelled SH.

Soils

The soil used in this study is from the Aiken and Dixonville soil series and was collected from two soil pits located on McDonald Forest under the direction of Dr. William K. Ferrell. Youngberg and Dyrness (67, p. 1) describe these soils as having developed on residuum from basic igneous rock. They have developed under grass, grass-oak, and Douglas-fir cover and are primarily in the reddish brown latosol great soil group. The Aiken series is the most productive from the standpoint of Douglas-fir site quality, averaging site III and small areas of site II on lower north slopes and some site IV on the shallower phases found on McDonald Forest. The deeper, less stony phases of the Dixonville average site IV and the shallower, stonier phases that are timbered fall in low site IV and V. Urie (57, p. 78-81) gives the following differences between Aiken and Dixonville: "Dixonville soils are differentiated from the Aiken series on the basis of higher pH, more blocky structure of the B horizon, and generally shallow rocky subsoils. Subsoil colors are usually less red than in Aiken. The Aiken series includes soils of a wide range of characteristics from shallow rocky soils with fractured basalt fragments common in the subsoil to deep, clayey soils with moderate B development." He also states that the forested soils of the Oregon Coast Range have been differentiated into soil series but they are not yet clearly defined. Sabhasri and Ferrell (44, p. 78-88) concluded that the Dixonville soil series and the environment in which it occurs on McDonald Forest is more favorable to shrub growth than is the Aiken series under its environmental conditions. However, they found variation in response within and between individual shrub species to Aiken and Dixonville soils in per cent cover, age, and height growth.

Twenty-four blocks, twelve each of Aiken and Dixonville, were placed, undisturbed, in square, plywood boxes during the summer of 1959. These boxes had a capacity of one cubic foot. The sides of the boxes were lined with polyethylene to reduce water loss through evaporation. The top one-foot of the soil was taken intact following the removal of the undecomposed organic material. The strong structure and plasticity of the soil made it possible to obtain a relatively undisturbed block of soil.

Subsequent to the removal of the soil blocks the soil adjacent to the pits was described. The Aiken soil pit is situated on a ridge at an elevation of 1200 feet. The area which has been logged has since become occupied by pole-sized big leaf maple Acer macrophyllum Pursh. The overstory is very dense approaching 100 per cent cover. The pit is located next to the road and as a result of side-light a heavy cover of herbs, grasses, and shrubs occupy the understory. The predominant understory species are thimbleberry, Rubus parviflorus Nutt. and bracken fern, Pteridium aquilinum (L.) Kuhn var. pubescens

Underw. The soil was moist when sampled.

A_1	0-3"	Dark reddish brown(5YR 3/4) moist, clay loam, strong fine crumb, friable, sticky, and slightly plastic, lower boundary abrupt and wavy.
A_3	3-10"	Dark reddish brown(5YR 3/3) moist, clay loam, strong fine to medium granular, friable, sticky, and slightly plastic, lower boundary gradual and wavy.
B_1	10-12"	Dark reddish brown(5YR 3/4) moist, clay, moderate fine subangular, friable, sticky, and plastic.

Only the top twelve inches of the soil profile was described because soil below the 12-inch level was not used in the study.

The Dixonville soil pit is situated on a 30 per cent slope with a south aspect and convex slope. The soil pit is within 100 feet of a ridge top and at an elevation of 1400 feet. The overstory is comprised of mature, medium-stocked Douglas-fir and scattered decadent Oregon white oak. This stand adjoins an open, grass-occupied area, which has been planted to ponderosa pine, Pinus ponderosa Law. The stand appears to be encroaching upon the park-like area. The understory is comprised of a light cover of grasses and herbs. Judging from the relative vigor of the grasses and the herbs, the grasses are gradually giving way to the herbs. The soil was moist when sampled.

A_1	0-3"	Dark brown(10YR 3/4) moist, silty clay loam, strong fine to very fine sub-angular blocky, firm, sticky, and plastic, lower boundary abrupt and irregular.
A_3	3-6"	Dark brown(10YR 3/3) moist, silty clay loam, strong fine sub-angular blocky, firm, sticky, and plastic, lower boundary abrupt and irregular.
B_2	6-12"	Dark brown(10YR 3/4) moist, silty clay loam, strong fine to medium sub-angular blocky, very firm, sticky, and very plastic.

Bulk densities of the soil bordering the soil pits were determined in hopes that they would aid in establishing a relationship between bulk density and root penetration. Urie (57, p. 39) found that scatter-diagrams indicate a decrease in site index values with an increase in bulk density of the subsoil horizons. In a separate regression analysis, he found that this relationship was significant for non-stony soils of the basalt parent material group which includes Aiken and Dixonville series. It was thought that there might be a differential resistance to root penetration between Aiken and Dixonville soils. The rate of root penetration by the roots could be an important factor in areas of summer drought.

Samples for determination of bulk density were collected approximately one foot from the edge of the soil pits. Twelve undisturbed samples were collected at each soil pit, six each from the 0-2 inch level and six from the 6-8 inch level. The samples were oven-dried at a temperature of 105 degrees centigrade for a period of 50 hours and the data are reported in Table 8.

Treatment of Soil Blocks

The twelve boxes of each soil series were left outside the greenhouse until early November. Then the boxes were arranged on a bench in three rows of eight each in such a fashion that a box containing a given soil series was not joined on any side by a box containing the same soil series. This arrangement provided for cancelling the effect of differences in greenhouse climate that may have been present from one end or side of the plot to the other end or side. There was an airspace of three inches between any two boxes; it was hoped that this would tend to equalize the temperature throughout the plot and within the boxes of soil. If the boxes had been touching there may have been a gradient in temperature and/or moisture from plot extremities to the plot center.

The period between placing the boxes in the greenhouse and the time of planting provided an opportunity for temperature and moisture within the soil to become stabilized. The stabilization period also provided favorable conditions for the germination of "weed" seeds and the sprouting of some plant roots. These germinates and sprouts were removed to reduce the weed problem following planting of the Douglas-fir seed.

The surface of the soil in the boxes was not level at the time of collection. The soil was leveled, loose organic debris removed, and cultivated to a depth of approximately one-fourth inch on all boxes. Cultivation and removal of organic debris was done to facilitate planting of the Douglas-fir seed; otherwise difficulties would have been encountered during planting. Cultivating should have had little influence on the results of the study since roots did not occupy the upper one-fourth inch of soil. This may be due to the fact that the soil surface dried out very rapidly even though watering was frequent.

Seed Source

Seed source means different things to different people. Seed source has connotations not only of locality where the seed was collected, but also of a distinct genetic identity. The Society of American Foresters (49, p. 19) defines seed source as "usually, the locality where a seed lot was collected. Synonymous with geographic race, provided the latter has been demonstrated." In this study seed source means specifically the locality where the seed lot was collected.

The description for each area used as a seed source is presented in Table 1. This table lists only gross differences; no attempt was made to describe subtle differences of environment. The stage of succession existing of the respective areas differs, no doubt, but exact placement of each stand in the proper place in the successional pattern is difficult and was not attempted. The south slope areas are probably in an earlier stage of succession than the north slope areas as indicated by the proximity of open areas occupied by grasses and the occurrence of Oregon white oaks, *Quercus garryana* Dougl. on the fringes of these south slope stands. It is generally held that north slopes in the Willamette Valley are more amenable to the establishment of Douglas-fir than are the south slopes; therefore, Douglas-fir has in all likelihood occupied the north slopes for a longer period of time than the south slopes.

Treatment of Seed and Planting

The seed for this study was collected in the fall of 1959 under the direction of Dr. William K. Ferrell. Following extraction from the cones the seed was stored in glass jars at room temperature and low humidity. The storage

Table 1. Description of seed source areas. Additional comments on areas are found in the text.

Characteristic	Areas NL	NH	SL	SH
Aspect	north	north	south	south
Elevation	300 feet	1050 feet	700 feet	1450 feet
Slope (per cent)	17	30	25	35
Slope direction	N25E	N10W	S30W	S20E
Soil series	Aiken	Aiken	Dixonville	Dixonville
Soil depth	36 inches, plus	36 inches, plus	12-18 inches to broken basalt	18 inches to broken basalt
Average height of dominants	67 feet	118 feet	64 feet	42 feet
Average age of dominants	36 years	92 years	38 years	26 years
Stocking(normal) in basal area	98 sq.ft.	250 sq.ft.	70 sq.ft.	16 sq.ft.
Stocking(this stand) in basal area	60 sq.ft.	110 sq.ft.	70 sq.ft.	20 sq.ft.

Table 1. Description of seed source areas. Additional comments on areas are found in the text. (Cont'd)

Characteristic	Areas			
	NL	NH	SL	SH
Per cent stocking	61	44	100	125
Site Index	130	120	110	110
Site Class	III	IV	IV	IV
Type of understory	grass, shrubs herbs	hophorn-beam, maple grass	fern, grass	grass
Density of understory	very light	heavy	medium	very heavy
Age composition	unevenaged	evenaged	unevenaged	evenaged

of the seed at room temperature and low humidity was followed by stratification of a portion of each seed lot. The seed was placed between layers of moistened paper toweling and placed in open, plastic bags. The moist stratification of the seed at temperatures just above freezing was continued for a period of three weeks. Following stratification, the seed lots were placed in open petri dishes and covered loosely by a piece of polyethylene and provided continuous light. Within four days most of the seeds had radicle emergence. To arrest growth until the preparations for planting were completed, the seeds were placed in storage at a temperature of 35 degrees Fahrenheit for eight days. The seed was then planted.

Only seeds that had a radicle emergence of at least one-fourth-inch were planted. Some of the radicles were as long as three-fourths-inch, but these were few in occurrence. The seed was planted at a depty of one-fourth to one-half inch. There were 16 uniformly distributed seed spots in each of the soil blocks; four each per seed lot. The selection of seed spots was done by random draw. A record was kept as to the exact location of all the replicates for all four seed lots in all 24 soil blocks. Three seeds from seed lots NH, SH, and SL were planted per seed spot. Only two seeds from seed lot NL were planted because an insufficient number of seeds had germinated to plant three. Approximately the same amount of seed from all four seed lots was stratified; the reason for the difference in the amount of germinated seed in the NL seed lot from the other seed lots was not apparent.

Investigations in Dr. Irgens-Moller's laboratory (personal correspondence) on the same seed sources have shown that unstratified seed from the south aspects germinated more quickly than seed from the north aspects, but when stratified this difference disappeared. It was thought that seed weight might give some hint on the difference in rate of germination, but no clear relationship was demonstrated. The NL seeds were intermediate in weight. Dr. Irgens-Moller reports that the 1000-seed weight for these seed lots, as determined by one of his students, is as follows: (personal correspondence)

1000-seed Weight	Seed Lot
10.10 grams	NH
10.30 "	NL
11.83 "	SL
12.29 "	SH

Lavender (23, p. 5) demonstrated in his study that in Douglas-fir there is a decrease in germinative vigor with a decrease in seed size and that there is no correlation between seed size and weight and size of resulting seedling. Righter (43, p. 134) found that seed weight in genus *Pinus* is correlated with seedling size but not with inherent vigor.

Some of the possible explanations for the difference in rate of germination between NL and the other seed lots are: (1) The storage and treatment may have had a differential effect on the seed lots. (2) There could have been a difference in maturity of the seed lots at the time of collection. (3) There could have been more selfing in the NL seed lot and consequently, more empty seed coats and decreased viability. (4) The NL seed lot may have been genetically inferior in germinative capacity.

Light Source and Photoperiod

During the stabilization period six fluorescent units containing warm-daylight lamps were suspended above the surface of the soil blocks at a distance of 15 inches. The lights were automatically turned on at 6 a.m. and turned off at 8 p.m. Pacific Standard Time. This provided a 14 hour photoperiod throughout the duration of the study. Irgens-Moller (16, p. 81) found that bud-bursting of Douglas-fir seedlings originating in the Corvallis area were influenced very little by duration of photoperiod. Temperature rather than photoperiod might be the critical factor in the growth of seedlings from the Corvallis area. In this study only the duration of the photoperiod was controlled; minimum light intensity was measured, but maximum light intensities were not known.

The study was conducted during that time of the year when days are shortest and since the growth of the seedlings was vigorous and rapid the fluorescent lights must have provided light in excess of the threshold value for photoperiod. Table 2 gives the light intensity at the soil surface as measured in the complete absence of solar radiation. The center row of the boxes had a consistently higher light intensity from the fluorescent lights than did the outer rows. The reverse was true when solar light was present because of the shading by the light units. Most likely light levels did not have a differential effect on the rows of soil blocks. If there was a differential effect it would have been cancelled in the statistical analysis.

Temperature and Relative Humidity

Temperature was recorded with an Autolite Thermograph which gave a continuous temperature reading at plot center throughout the duration of the study. Temperature recordings served the purpose of indicating whether temperatures approached injurious levels. Minimum temperatures were kept up by greenhouse radiators while the maximum

Table 2. Light intensities in foot candles at the surface of the soil blocks as measured in the absence of solar radiation and with a Weston Illumination Meter, Model 756 (quartz filter).

Box Number	Light Intensity	
	Center of box	Range within box
I	380	260-430
II	470	390-510
III	330	210-420
IV	420	300-490
V	530	500-540
VI	380	260-450
VII	380	260-440
VIII	500	480-530
IX	340	260-440
X	400	280-480
XI	520	480-520
XII	380	270-470
XIII	390	290-450
XIV	510	490-510
XV	390	270-430
XVI	360	260-440
XVII	480	450-490
XVIII	370	260-440
XIX	330	240-390
XX	420	410-440
XXI	330	250-390
XXII	300	190-380
XXIII	390	340-400
XXIV	300	180-380

Minimum light intensity measured = 180
Maximum light intensity measured = 540

Mean light intensity for centers of Aiken soil blocks = 400.8
Mean light intensity for centers of Dixonville soil blocks = 399.2

temperatures were reduced by increasing greenhouse ventilation. The minimum temperatures were never lower than 40 degrees Fahrenheit and the maximum temperature exceeded 100 degrees for brief periods on two days. Diurnal temperatures were strongly influenced by the intensity of solar radiation.

A hygrothermograph was placed on a bench adjacent to the bench on which the study was being conducted from February 9 through February 17. As was expected relative humidity varied directly with temperature. The minimum relative humidity during this period was 35 per cent; the maximum was 80 per cent. Moisture stress should not have reached injurious levels because of watering during warm weather. There was no evidence of wilting or heat lesions even on the warmest days.

Soil Moisture

Watering was done on the basis of the dryness of the surface soil as indicated by color of the soil surface. Sufficient water was applied at each watering to bring the soil moisture up to field capacity. Excessive water could not accumulate because of the good drainage allowed by the boxes and the small mass of the soil blocks. The degree of wetness of the Dixonville soil was shown by an obvious change in the color of the soil surface. The longest period between waterings was five days which should not have been long enough period to allow the soil moisture to approach the permanent wilting point. Admittedly, the need for water and the amount of water supplied was done subjectively, but it is doubtful that this had any effect on the results of the study; all soil blocks were watered at the same time and given sufficient water to bring all the soil blocks to field capacity.

Mortality

Within one week following planting of the seed a few seed coats appeared above the soil surface; however, it was two weeks before most of the seed spots had signs of shoot emergence. During this period there was damping-off and slug-caused mortality. To reduce the incidence of mortality caused by damping-off and slugs, Arasan and slug bait were applied to the soil surface on all soil blocks. At the time of application, seed spot mortality was 12.6 per cent. One month following planting the mortality of seed spots was 14.1 per cent.

Although it appeared that slugs and damping-off fungi were the principal causes of mortality other factors had a role. Attempts to catalog causes of mortality were abandoned because of the difficulty in determining the specific causes of mortality for individual seedlings. With the passage of time it appeared that damping-off and slug damage ceased altogether and other causes became dominant. Perhaps inherent weakness of individual seedlings became more important.

Thinning

On January 29, a little over one month following planting, the seed spots having more than one seedling were thinned to one seedling. By this time most of the seedlings had a couple of whorls of secondary needles and were growing rapidly. The seed spots were thinned of the least vigorous seedlings when there was a noticeable difference in vigor. Thinning was accomplished with a scissors by clipping the seedlings to be removed off at the surface of the soil. The only treatment the seedlings received after being thinned was periodic watering and the occasional removal of a weed. The seed spots were thinned in order that all seed spots would have only one seedling; thereby eliminating the possibility of differences due to the number of seedlings occupying a seed spot.

Removal

At the time of planting two boxes, with one glass side and containing representatives of the soils and seed, were placed next to the study plot. These boxes were used as guides in the timing of removal of the seedlings from the study boxes. It was hoped that root development could be observed through the glass, but for some reason the roots could not be observed.

On March 11, the seedlings from one of the glass-sided boxes were removed. At this time the deepest penetration of the primary roots was eight inches. It was decided not to remove the seedlings from the study boxes. The objective was to allow maximum development of the seedlings in the study boxes, but to remove them before the roots reached the bottom of the boxes. Abnormalities might have resulted if the roots were allowed to reach the bottom.

On March 22, the remaining glass-sided box was taken apart to check the progress of root development. It was found that the longest primary extended to a depth of 10 inches. The decision was made to remove the seedlings in the main boxes.

The seedlings in the study boxes were removed on March 23 and March 24. One side of the box was removed and the seedlings were removed by directing a stream of water on the soil block with a garden hose. In this manner all the seedlings were removed from the soil blocks. Following removal the remaining soil attached to the roots was removed and the seedlings were wrapped in damp cloth and placed in a refrigerator until measurements were taken. Considerable difficulty was encountered during removal because of the compactness of the soil and the intertwining of grass and shrub roots within the soil. On some of the seedlings part of the root system was lost during the removal. Only the shoots were used in the analysis when the root system was damaged in removal.

Measurements

Number of surviving seedlings, length of primary root, total length of lateral roots, number of growing root tips, and number of laterals were recorded soon after removal and prior to obtaining dry weight. To obtain shoot and root dry weight the shoot was severed from the root system at the ground line which was easily determined by observing the change in color of the stem from green to light brown. The dissected seedlings were placed in individual containers and oven-dried at 106 degrees centigrade for a period of 50 hours.

To obtain an index of root form the length of the laterals was divided by the length of the primary. Also obtained were root/shoot ratios. This was done by dividing the dry weight of the root system by the dry weight of the shoot.

In obtaining the length of laterals and the number of laterals, those laterals under one-fourth inch in length were excluded because they were few in number and difficult to measure. To determine the number of actively growing root tips, color difference between the turgid zone and the suberized zone and the length of the turgid zone were used as the criteria. The turgid zone was cream to white in color while the suberized zone was brown in color. Root tips with a turgid zone of less than two millimeters in length were not considered to be actively growing. It was not difficult to distinguish root activity on this basis and there were very few marginal root tips. The demarcation between active growth of root tips and arrested growth was almost always readily apparent.

Statistical Analysis

Analysis of variance was used to determine the significance of differences within the data. Averages of combinations of two or three boxes were used because some individual boxes had a seed source or seed sources missing through mortality. A combination of three boxes was used in the analysis of root data and the root/shoot ratios. It was not possible to use a combination of two boxes for analysis of root data because of the loss of usable root systems during removal. A combination of two boxes was used in the analysis of shoot measurements and survival. With the three box combination an attempt was made to cancel out differences, if there were any, due to position in the plot by combining two boxes from the outside rows with a box from the center row. In the case of the two box combinations this was not possible since there were three rows, but no two boxes from the same row were combined.

Where significant differences were indicated by the analysis of variance for a particular measurement the linear combination test was used to determine what seed source or seed sources were significantly different from the other seed sources within a soil (26, p. 221-233).

RESULTS

The mean values for the characteristics measured were computed by soils (Tables 3 and 4), between all seed sources (Tables 5 and 6), and for each seedling characteristic within a soil (Table 7).

The length of the laterals/length of primary ratio was significantly greater in the Aiken soil than in the Dixonville soil (Table 7) and was the only characteristic for all seed sources showing significant difference between the soils. There were significant differences between seed sources in shoot weight, number of laterals, and root/shoot ratio on both soils (Tables 5 and 6). There were no significant differences between seed sources in shoot length, length of primary root, root dry weight, number of actively growing root tips, survival, and length of laterals/length of primary ratio in either soil. In Aiken soil there were significant differences between seed sources in length of laterals, but no significant differences in Dixonville soil.

There were obvious differences between boxes in the vigor of the shoot growth, but due to the need to use combinations of two or three boxes in the analysis these differences are not apparent. The differences were probably due to differences in productivity between individual boxes of soil. Also, differences in aerial environment may have played a role in the differences in vigor. That there were differences in aerial environment throughout the plot is supported by the observation of differences in the rate of drying of the soil surface. The soil surface remained more moist on the three boxes closest to the greenhouse wall than the other boxes. The reason for this difference in rate of soil surface drying is probably in some way related to the microclimate of the greenhouse.

The bulk densities for the respective levels of the Aiken soil were consistently lower than the bulk densities of the Dixonville soil (Table 9). These findings are comparable to those of Youngberg and Dyrness (67, table 2), but with slightly lower overall values.

In general, based on observation and mean values, it can be said that the Aiken soil produced more vigorous and healthy Douglas-fir seedlings than Dixonville soil under the conditions of this study.

Table 3. Mean values for root and shoot characteristics on Aiken soil series.

Characteristic	Seed Source			
	NL	NH	SL	SH
Shoot length (inches)	1.89	1.94	2.04	1.90
Shoot dry weight (milligrams)	61.9	55.6	66.1	55.2
Length of primary root (inches)	6.18	5.43	5.04	5.06
Length of lateral roots (inches)	5.02	3.98	6.50	4.88
Number of lateral roots	8.9	6.3	9.9	7.8
Root dry weight (milligrams)	27.4	21.7	29.3	23.5
Number of actively growing root tips	8.9	7.8	8.6	7.6
Root/shoot ratio	.47	.35	.45	.45
Length of laterals/length of primary root	.84	.72	1.34	.93

Table 4. Mean values for root and shoot characteristics on Dixonville soil.

Characteristic	Seed Source			
	NL	NH	SL	SH
Shoot length (inches)	1.80	1.80	1.75	1.83
Shoot dry weight (milligrams)	51.6	47.5	50.2	54.4
Length of primary root (inches)	5.32	5.67	4.80	5.84
Length of lateral roots (inches)	4.05	2.70	2.75	4.12
Number of lateral roots	8.8	6.1	5.7	7.0
Root dry weight (milligrams)	29.5	25.9	22.0	30.2
Number of actively growing root tips	9.3	7.1	6.9	7.0
Root/shoot ratio	.58	.53	.46	.58
Length of laterals/length of primary root	.78	.49	.60	.73

Table 5. Statistical comparison of mean values for root and shoot characteristics on Aiken soil series (*, significant at 5% level and ns, non-significant.

	Comparison made					
Characteristic	SH vs. SL	SH vs. NH	SH vs. NL	SL vs. NH	SL vs. NL	NH vs. NL
Shoot length (inches)	ns	ns	ns	ns	ns	ns
Shoot dry weight (milligrams)	*	ns	ns	*	ns	ns
Length of primary root (inches)	ns	ns	ns	ns	ns	ns
Length of lateral roots (inches)	*	ns	ns	*	ns	ns
Number of lateral roots	ns	ns	ns	*	ns	ns
Root dry weight (milligrams)	ns	ns	ns	ns	ns	ns
Number of actively growing root tips	ns	ns	ns	ns	ns	ns
Root/shoot ratio	ns	*	ns	*	ns	*
Length of laterals/ length of primary root	ns	ns	ns	ns	ns	ns

Table 6. Statistical comparison of mean values for root and shoot characteristics on Dixonville soil series (*, significant at 5% level and ns, non-significant)

Characteristic	SH vs. SL	SH vs. NH	SH vs. NL	SL vs. NH	SL vs. NL	NH vs. NL
	Comparison made					
Shoot length (inches)	ns	ns	ns	ns	ns	ns
Shoot dry weight (milligrams)	ns	*	ns	ns	ns	ns
Length of primary root (inches)	ns	ns	ns	ns	ns	ns
Length of lateral roots (inches)	ns	ns	ns	ns	ns	ns
Number of lateral roots	ns	ns	ns	ns	*	ns
Root dry weight (milligrams)	ns	ns	ns	ns	ns	ns
Number of actively growing root tips	ns	ns	ns	ns	ns	ns
Root/shoot ratio	*	ns	ns	ns	*	ns
Length of laterals /length of primary root	ns	ns	ns	ns	ns	ns

Table 7. Mean values by soil for root and shoot characteristics with the four seed sources combined

Characteristic	Soil: Aiken	Soil: Dixonville
Shoot length (inches)	1.94	1.80
Shoot dry weight (milligrams)	59.7	50.9
Length of primary root (inches)	5.43	5.41
Length of lateral roots (inches)	5.10	3.40
Number of laterals over 1/4 inch in length	8.2	6.9
Root dry weight (milligrams)	25.5	26.9
Root/shoot ratio	.43	.54
Number of actively growing root tips over 2 mm in length	8.2	7.6
Length of laterals /length of primary root	.96 *	.65 *

* Significantly different at the 5 per cent level.

Table 8. Bulk densities of samples by soil series and position in soil profile taken from the site used for collection of undisturbed soil blocks used in the study (values in grams per cubic centimeter).

Sample	Sample Source			
	Aiken 0-2"	Aiken 6-8"	Dixonville 0-2"	Dixonville 6-8"
1	0.73	1.03	0.94	1.23
2	0.79	1.05	0.95	1.06
3	0.85	0.95	0.98	1.25
4	0.79	1.14	0.93	1.12
5	0.76	1.07	0.98	1.09
6	0.83	0.94	0.89	1.16
mean	0.79	1.03	0.94	1.15
range	0.12	0.20	0.09	0.19

DISCUSSION

The statistical analysis gives evidence of differential adaptation for some of the seedling characteristics measured within Aiken and Dixonville soils, but these differences were not the same on the two soil types. What environmental factor or factors are associated with the differential responses is not evident. Observation of general vigor during the course of the study leads to the conclusion that there was not only considerable variation within a soil, but also within some individual blocks of soil. Variation of soil characteristics, principally variation in resistance to root penetration and expansion within a block of soil, was apparently the cause of variation in the vigor of the seedlings. This observation is indirectly supported by the statistical analysis which failed to show significance in some cases when group means seem to indicate considerable difference. If too large, variation within a group would cancel out any statistical significance between groups of seedlings.

Based on group means, Aiken soil blocks, in general, were the most productive. Seedlings grown in Aiken soil had heavier shoots and roots than did seedlings grown in Dixonville soil although variation was large.

There were inconsistencies between the two soils for a given seedling characteristic especially for seedlings of the SL seed source in relation to the seedlings from the other three seed sources. The seedlings of NH, NL, and SH seed sources have a comparatively uniform relationship of mean values for the various characteristics measured on both the soils. The SL seedlings, however, had a complete reversal in their relative position with the other seed sources between the two soils. On Aiken soil the SL seedlings had the longest shoots and roots, and a comparatively high root/shoot ratio. On the Dixonville soil the reverse was true. Perhaps the switch in position of relative growth rate occurs when the genetic potential of the SL seedlings for high growth rate is present, but is in some way controlled, so that it is expressed only under certain environmental conditions. Or to put it another way -- the SL seedlings when grown in an environment which eliminates fast-growing, succulent seedlings have an environment sensitive, genetically-controlled mechanism which results in a slower-growing, more hardy seedling. Sabhasri and Ferrell (44, p. 81 and 83) in a study on brush species occurring in small openings of and in Douglas-fir stands of the Willamette Foothills found a similar reversal in response of shrub cover and height growth of certain species to Aiken and Dixonville soils.

It is possible that the response of a seedling to a given environmental factor is conditioned by other factors in the environment. The combination of the Aiken soil and greenhouse climate could be more ideal for the expression of genetic differences between seed sources than the combination of Dixonville soil and greenhouse climate.

There are several possible explanations for the variation in the study results. A few of the more obvious reasons will be mentioned. The seed used to rear the test seedlings was collected from open-pollinated cones, thus there almost certainly exists genetic heterogeneity. How much genetic heterogeneity contributes to variation within a seed source is indeterminable because the seed from several trees on a seed source area were mixed together; consequently, some meaning is lost from the results. Other workers have pondered a similar problem when values for individual seed lots varied considerably even within areas possibly because of inherent individual tree variation. Theoretically it is possible to have nearly as much variation within progeny from a single parent tree as among progenies from several parent trees (46, p. 28). A better experimental method would have been to identify the seed from each parent tree on each seed source area.

The soil blocks do not truly represent the in-the-field soil environment. Although the soil blocks were removed intact from the soil mass in the field, their small mass makes them somewhat artificial. Differences in mass would have an influence on the character and rate of movement of soil liquids and gases. The small mass of the soil blocks may have resulted in "border effect" extending throughout the soil block. Because soil moisture was artificially maintained, to near field capacity, it could be expected to depart from the soil moisture typically occurring during the growing season in the field. Assuming that low levels of moisture had an important role as a selection force in the McDonald Forest area in the evolution of the existing genotypes then it may have been better to maintain a lower level of soil moisture in the study. This would be especially true if low soil moisture levels have had a differential influence between seed source areas.

The same can be said for the greenhouse climate with its semi-controlled light and temperature being less rigorous than the field serial environment. It all adds up to the fact that differential responses in an artificial environment cannot be taken as absolute proof of a similar response under field conditions.

There are a great variety of characteristics that could be used to detect ecotypic variation and the ones used in this study may or may not have been the most sensitive. The determining of the most sensitive measure of ecotypic variation would be a study in itself. Root characteristics did not demonstrate any greater sensitivity to environment in comparing seed sources than did the shoot characteristics. In fact it was a combination of root dry weight and shoot dry weight in the form of a ratio which proved to be the most snesitive indicator of ecotypic variation in this study. Sine the roots and the shoot are reciprocally dependent on each other, it would be expected that there is a balance between them which is optimum for survival and growth of the seedling. For example, Richardson (41, p. 781) concludes that any change in the environment of the shoot which causes a change in the rate of photosynthesis has a commensurate effect on the rate of root growth. Vinokur (58, p. 273) states that soil temperature affects intensity of photosynthesis and rate of flow of "plastic" substances from leaves. He further states that heating of roots involves an increased flow to them of these substances from leaves which in turn intensifies the process of photosynthesis and is apparently one of the basic causes of the sharp increases in growth of roots and surface organs. In another study Merritt (32, p. 1513) found that the basic pattern of root growth of red pine, *Pinus resinosa* Ait., is inherently controlled, but environmental variations produced quantitative changes in root growth and influenced the timing of events.

When obtainable, the root/shoot ratio because it reflects both the differences in soil and aerial environment through direct contact of the respective parts should have some advantages over a measure taken from the roots or shoot alone.

Root form (length of laterals/length of primary) was the only measure used which demonstrated significant differences between soils, but there were no significant differences between seed sources with this variable. It is felt that the difference in root form between Aiken and Dixonville soils is primarily a reflection of differences in physical characteristics of the two soils. Aiken has a lower percentage of clay, lower bulk densities, and weaker ped structure than Dixonville soil; thus Aiken is more friable and offers less resistance to lateral development. Also, Aiken with a higher level of potassium, nitrogen, and organic matter is the more fertile of the two soils (67, table 1). Urie (57, p. 39) found that with a decrease in bulk density of the subsoil there was an increase in site index. Carmean (5, p. 334) found that as soil compaction (soil consistence) increased, site quality decreased in southwestern Washington. He concluded that soil compaction restricts root development because of poor aeration and internal drainage. Haasis (14, p. 302) attributes variation in root form of ponderosa pine to soil texture and structure. Physical differences have also been considered as important in root distribution and growth (29, p. 52). The mean value of the four combined seed sources for length of laterals/length of primary ratio was 0.97 for seedlings grown in Aiken and 0.65 in Dixonville.

The results of this study agree with the observations of Youngberg and Dyrness (67, table 2) that Aiken soils are more productive than Dixonville soils in terms of the growth of Douglas-fir. Productivity was judged by root and shoot weight of seedlings in this study and on the basis of height-age relations in their study. However, why Aiken soils are more productive has not been completely elucidated in either study.

Lower fertility and greater physical resistance of the Dixonville soil results in a narrower range of expression of differences in growth rate of shoots and roots; certainly genetic differences between the four seed sources were less evident (Tables 5 and 6). Lower productivity was indicated by lower mean values for shoot length, shoot weight, root length, and root weight of the seedlings from all four seed sources in Dixonville when compared with all the seedlings grown in Aiken.

Youngberg (66, p. 844) in discussing differences in reaction of Douglas-fir seedlings to soil moisture stress on Aiken and Climax soils suggests that these differences may be due to environmental factors other than soil moisture or physiological differences between lots of nursery stock used. It would seem that a difference in root form, resulting from differences in resistance to root expansion, could be an explanation of this difference in reaction to soil moisture stress. This would result in differences of the amount and placement of absorbing surface capable of sustaining the seedling. Also under conditions of high moisture stress a difference in root/shoot ratios might result in a differential reaction to the stress. In terms of survival the ratio could have an import effect under drought conditions, assuming that equal weights of shoot have equal stress for moisture on roots which have an equal capacity to supply moisture per unit of weight.

Very likely drought conditions vary considerably between the four areas used as seed sources in this study. Expected would be an increase in moisture stress on the seedling with a decrease in elevation and with an increase in incidence of solar radiation. Using expected differences in incident solar radiation and temperature as influenced by elevation and aspect of the areas from which the seed was collected could be ranked according to expected intensity of drought. SL would have the highest intensity, SH second highest, NL third highest, and NH would have the lowest expected intensity of drought. The analysis of root/shoot ratios and length of laterals/length of primary, in part, confirm the logic of ranking the four areas according to expected intensity of drought. Grouping the seedlings grown in both soils; SL has the greatest length of laterals/length of primary ratio, SH second highest, NL third highest, and NH the lowest. For root/shoot ratios NL had the highest, SH second highest, SL third highest, and NH had the lowest.

Other results of the study tend to support the ranking of the seed source areas. In Aiken soil, SL seedlings had significantly greater number of and length of laterals than did NH seedlings and significantly greater length of laterals than SH seedlings. It should not be too illogical to expect greater numbers of and greater length of laterals to make a seedling more drought resistant. On the other hand, in Dixonville soil SL seedlings had the least number of laterals and the shortest in length.

The results of this study do not in themselves solve any problems in regeneration, but they should aid in guiding future research in the problems of regeneration. The practical application of the results is that they provide further evidence that there is one best combination of genotype and environment which is most likely to produce the desired results. The possibility exists that these combinations of genotype and environment are more important than is often realized because there is greater diversity of genotypes and environments than is generally believed.

SUMMARY AND CONCLUSIONS

On the basis of the results of this study there is evidence of localized ecotypic variation in Douglas-fir found on McDonald Forest. It is believed that there is a close association between the occurrence of localized ecotypic variation and irregular terrain. Irregular terrain represents discontinuity in environment.

The evidence that there is genetic differences between trees on areas within relatively short distances suggests that the respective environments have exhibited differences in kind and/or magnitude of selection forces.

Under the soil conditions of the study the results indicate that the soil had a role in the expression of ecotypic variation. Taking all ecotypes together, however, root form is the only characteristic studied which differed significantly between Aiken and Dixonville soils. The differences in root form appear to be independent of seed source under the study conditions.

The statistical analysis shows no significant differences, with the forementioned exception, between soils; but between the group means of the seed sources there are seemingly large differences for some of the characteristics which demonstrated no significant differences. It is possible that these differences could be of importance in assessing regeneration problems on the two soils.

Root characteristics of seedlings have as much promise as shoot characteristics for use as indicators of ecotypic variation. Roots have the advantage of being in direct contact with the soil environment and because the roots and surface organs are reciprocally independent, roots reflect the influence of the total environment.

The ratio of root to shoot in terms of dry weight was the most sensitive measure used in this study. The results of the statistical analysis, in part, confirm an expected pattern of drought on McDonald Forest. The seedlings grown from seed collected at a high elevation and on a north slope, an environment which should be less droughty, had seedlings with smaller roots in proportion to the shoots than seedlings from lower elevations and south slopes, a more droughty environment.

STUDY II

INTRODUCTION

The requirements of forest regeneration can be summarized as follows: A seedling will survive if it has its physiological requirements, which are determined by the genetic makeup of the seedling, satisfied by the environment in which it is properly established.

Proper establishment, over which foresters should have considerable control, is far from being well defined or understood. One of the more elusive aspects is the time of establishment. Proof that there is nominal appreciation of an optimum period for successful planting, which may be short in duration and vary from year to year in timing, is evidenced by a recommendation by a committee of esteemed foresters (61, p. 44-45). "The choice of planting season is naturally during the period when stock is dormant, which is from late September to late April. The season of planting should be chosen to fit the area to be reforested and this is principally guided by weather conditions as reflected by soil moisture and temperature."

Planting date is that period when the combination of environment, in which the planting stock is to be planted, and the physiological status of the planting stock is such that the probability of survival is highest. Therefore, planting date is more complex than is implied by dormancy, level of soil moisture, time of year, and soil temperature.

LITERATURE REVIEW

If dormancy (cessation of all growth) is a prerequisite for successful planting then, for at least some species, there is no period throughout the year when we can plant with assurance of success. There appears to be a relationship between the level of growth activity of roots or the regenerative power of roots and the likelihood of the seedlings surviving transplanting, but what this relationship is has thus far eluded researchers. Of the species studied there are differences in pattern of growth between the roots and the surface organs. The relationship with surface organs and the level and periodicity of physiological activity of subsurface organs should have some influence on timing of lifting and planting.

It has been found that shortleaf, Pinus echinata Mill., and loblolly pine, Pinus taeda L., made recordable root growth during every eight-day period for two years (56, p. 149). There were, however, two marked periods of semidormancy from December 1 to March and from the end of June through August, under greenhouse conditions. Roots of ponderosa pine in one study had root growth during every month of the year (53, p. 330). Like shortleaf and loblolly pines, ponderosa pine manifested a distinct periodicity of root growth under greenhouse conditions. The transplanted ponderosa pine seedlings had no root elongation or root initiation when transplanted in July or August. Root elongation was evident only on ponderosa pine seedlings transplanted from December to June; however, the greatest activity was in the spring immediately before the terminal bud broke. Reed (40, p. 65) in another study on the roots of shortleaf and loblolly pines concludes that although it was impossible to establish an exact mathematical relationship between root growth and either temperature or soil moisture, the evidence indicates that deficient soil moisture may limit growth of roots during summer months, and low soil temperatures may have a like effect on root growth during the winter months. Stevens (51, p. 68) concludes that there is no evidence that a winter rest period is inherited or necessary for the roots of eastern white pine, Pinus strobus L.

In transplanting, the regeneration of new roots to replace those lost in the process may be critical factor in the survival of the seedling. Wilcox (62, p. 233) found that the period of most active root regeneration of noble fir, Abies procera Rehd., was from June 1 to September 1. In a few seedlings there was an additional earlier period in February and March. In a California study using Douglas-fir, it was found that when transplanted greatest root regeneration occurred from the middle of November to the middle of March. This period coincided with the planting dates having the highest percentage of survival of field planted 2- and 3-year-old Douglas-fir (52, p. 15).

During the removal of Douglas-fir seedlings for this study it was noted that at the Oregon State Nursery near Corvallis the roots of Douglas-fir seedlings never appeared to be completely dormant. A majority of the root tips were creamy white in color and turgid in appearance, throughout the winter. These same seedlings manifested a marked increase in root elongation just prior to bud-burst.

There is some indication that seedlings of at least some species have lower rates of survival if they are transplanted following initiation of bud-burst. Simon (48, p. 450) from the results of his study concludes that there is evidence that lifting Engelmann spruce, _Picea engelmannii_ Parry, two weeks and lodgepole pine, _Pinus contorta_ Dougl., four weeks after the beginning of bud-swelling impaired the capacity of the seedlings to survive. Storage had a more marked effect on Engelmann spruce and lodgepole pine following the inception of bud-swelling.

For some species there are incongruities in the results for a given planting date from year to year. Krygier (20, p. 8-10) found that there were conflicting results when comparing fall planting with spring planting of Port-Orford-cedar, Chamaecyparis lawsoniana (A. Murr.) Parl., outside its native range. He also found that in a given year the survival rate for the fall planting showed significant differences between exposures on which the plantings were made. The spring planting showed a significant difference in survival by exposure. Perhaps an early frost accounted for the differences by exposure in the fall planting.

Chapman (7, p. 826) working with shortleaf pine demonstrated in his study that spring-planted stock was much superior to fall-planted stock in survival rate. He also found that while top and root pruning or top pruning alone markedly increased the survival rate of spring-planted stock, the differences were not as great as they were with fall-planted stock. The reaction of fall-planted stock to pruning might be an indication that the tops have a greater dependence on the roots for sustenance through the period of "dormancy" than during periods of active top growth. During the late fall months conditions such as incomplete contact with the soil, shock due to differences in soil temperature between nursery and field soils, or any other aspects of the environment which could disrupt the physiological balance between roots and top could possibly be deleterious to the extent of impairing chances of survival. In the spring the aerial and soil environment, being more amenable to growth activities of both tops and roots, offset the effects of mechanical damage to the roots during transplanting and the time required to adjust to the new environment.

Limstrom (27, p. 50) recommends that planting strip-mined land be done anytime from the last week in February to the middle of March in the central states. This period most likely coincides with the time just prior to or during the initial stages of spring growth of the roots and/or tops.

That different classes of planting stock can act differently to obscure the importance of planting date is brought out in a study made by Cooper, Schopmeyer, and McGregor (10, p. 29). When they used 1-0 wildling sand pine, Pinus clausa (Engelm.) Sarg., they found that uniformly poor survival resulted from monthly plantings in October through February. Using nursery stock and planting in November and December the data indicated that the seedlings planted in December had significantly less mortality than the seedlings planted in November. These findings could be an indication that the nursery stock had not sufficiently "hardened off" in November to withstand transplanting as well as the more "hardened off" stock planted in December.

Walters and Soos (60, p. 6-12) who used Douglas-fir and Scots pine, *Pinus sylvestris* L., in a planting date study conclude that generalizations about planting dates are risky. The differences between rates of mortality by planting date were considerably less in 1959 than in 1958. 1959 had more summer precipitation, lower summer temperatures, and a shorter duration of days between rainfall than in 1958. In summary they infer from their data that fall-plantings are in general preferable to spring-plantings. To a small degree their results are negated by using different-aged planting stock in successive years. Also, planting was done from April through November; thus no test was made of late winter and early spring plantings which may be the most successful.

All possible references have not been included. However, those that have been reviewed should point out that the seemingly definitive phrase, planting date, has many ramifications and implications which deserve further research and observation. It is recognized that factors not related to planting date can be of equal or greater importance in the effect on survival and growth of seedlings than planting date, but it is also apparent that there is a period of time which is optimum for planting and it may be of relatively short duration and vary in timing from year to year.

PURPOSE

Regeneration on south slopes in particular has been an especially difficult proposition in the foothills of the Willamette Valley (2, p. 11-12; 25, P. 20-21). Other exposures present their problems but southern exposures present the greatest challenge to those responsible for the establishment of Douglas-fir. This study is primarily concerned with the determination of the best planting date, but to give more depth and possible elucidation, exposure and soils were combined with planting date for study. This makes the study a test of physiological status (planting date), soil, and exposure. Another criterion in selection of the study plots was the lack of sufficient stocking of Douglas-fir.

METHODS AND MATERIALS

The study area consisted of 4 plots located on McDonald Forest. On each of these plots 5 sub-plots were located, each representing a different planting date. The planting stock was 2-0 Douglas-fir grown at the Oregon State Nursery, Corvallis, Oregon, from seed collected on McDonald Forest. Forty seedlings were planted at each plot on five planting dates making a total of 800 seedlings used in the study. The planting dates were November 21, 1959; December 23, 1959; January 30, 1960; February 27, 1960; and April 2, 1960.

The seedlings were removed from the nursery beds by shovel; special effort was taken to avoid damage to the roots during removal. All abnormally large and all abnormally small seedlings were discarded; other than this gross grading, no other attempt was made to grade the seedlings. The roots were not pruned. However, in the process of removal a few of the smaller roots were sometimes severed. Within a few hours following lifting the seedlings were planted to prevent dessication or undue exposure. During the interval between lifting and planting, which did not exceed six hours, the seedlings were packed in moistened sawdust.

Prior to planting the plots were cleared of all vegetation which would overhang the seedlings. The ground was not scalped for this would have been but temporary relief without some other treatment. The planting was done with a planting bar. Care was taken to plant all seedlings in the same manner and without air pockets around the roots. The seedlings were planted with a spacing interval of 1.5 feet. The small spacing interval was used to reduce the amount of area the plot covered, thereby reducing the probability of the effects of site differences influencing the results.

Location of the plots was done on the basis of soil type and topographic aspect. The factors of soil and aspect were considered to be important in regeneration. That they are gross features representing a myriad of variables is admitted, but the objective was to see if these gross features could be used as a means of identifying potential difficulties in regeneration. More insight on the differences between the plots can be gleaned from the descriptions given in Table 9. Hereafter the four plots are identified by two capital letters: ND for the plot having a north aspect and Dixonville soil; NA for the plot having a north aspect and Aiken soil; SD for the plot having a south aspect and Dixonville soil; and SA for the plot having a south aspect and Aiken soil.

Table 9. Description of the plots used in Study II.

Characteristic	Plot ND	SD	NA	SA
Aspect	north	south	north	south
Soil series	Dixonville	Dixonville	Aiken	Aiken
Elevation (ft.)	1000	1500	1300	1400
Slope (per cent)	15	25	50	20
Soil depth	very deep	shallow	deep	shallow
Soil plasticity	very plastic	very plastic	friable	slightly plastic
Presence of rock fragments in upper 1 foot of soil	none	a few large	none	moderate numbers of large
Soil color	dark grey	black	reddish brown	reddish brown
Soil texture	silty clay loam	silty clay loam	clay loam	clay loam
Predominant ground cover	shrubs	grass	herbs	grass
Density of ground cover	very heavy	very heavy	medium	very heavy
Gross appearance	logged and slash burned	park-like opening	logged and slash burned	recently logged

RESULTS

The plots were examined and data collected on May 22, 1960, July 14, 1960 and November 26, 1960. The examination on May 22, 1960 was done by the author; Dr. William K. Ferrell made the examinations on the other two dates. The number of dead or missing seedlings was recorded for the respective planting dates on each plot as was the number of seedlings frost-damaged or browsed.

On the first examination there was little difference in mortality by planting site or by planting date (Table 10). However, on the last two examinations it became very apparent that planting site had a very significant impact on mortality. The south slope plots had a much higher rate of mortality than the north slope plots. Differences in rate of mortality by planting date were smaller. The number of seedlings that died between examinations varied considerably by planting date, but on the two south slope plots attrition was continuous with the passage of time. On the north slope plots attrition was sporadic and was possibly due to chance.

A chi-square test was used to compare number of dead or missing seedlings on the SA plot on the second and third examinations (Table 13). The November, January, and February plantings had significantly less mortality than the December and April plantings at the time of the second examination. At the time of the third examination the February planting had significantly less mortality than the other planting dates.

On the first examination it was found that on the plots with a south aspect there was a considerable amount of frost injury, 58.0 per cent in aggregate (Table 11). Those seedlings which were planted in November had the least amount of frost injury and those which were planted in April had the greatest amount of frost injury. The frost injury was only on the current year's growth; therefore, the frost was not, in itself, a killing frost. It is not known how much frost contributed to the total mortality.

To compare the number of frost-injured seedlings on the two south slope plots a chi-square test was used (Table 13). On the SA plot the November and December plantings had significantly less frost injury than the other plantings. The February planting had significantly less frost injury than the April planting. Other comparisons of frost injury by planting date showed no significant differences on the SA plot. On the SD plot the November planting had significantly less frost injury than the other planting dates. The January planting had significantly less frost injury than the April planting. All other comparisons of frost injury by planting date were not significantly different on the SD plot.

On the first examination a count was made of the seedlings that had been browsed by deer; no apparent browsing followed the first examination. Deer browsing had been observed to occur before all the seedlings had been planted. One possible explanation for the difference in amount of browsing between the April planting and the other plantings is that the Douglas-fir may have been largely replaced in the diet by other plant species by April. As in the case of frost injury and total mortality the plots on the south slopes suffered the greatest amount of deer browsing. Browsing appeared to be predominantly of the branch tips. Position, palatability, and/or nutrition were very likely the reasons branch tips were browsed. Also, it was observed that a very small number of the seedlings were pulled from the ground by the deer. These seedlings were counted as dead.

Table 10. Accumulative number of dead or missing seedlings by planting date and planting site.

Planting date	Planting Site ND	SD	NA	SA	Total
	First Examination (May 22, 1960)				
11/21/59	2	1	0	1	4
12/23/59	0	0	0	2	2
1/30/60	0	0	0	0	0
2/27/60	0	0	1	0	1
4/2/60	0	0	0	0	0
	Second Examination (July 14, 1960)				
11/21/59	2	34	1	9	46
12/23/59	0	30	0	35	65
1/30/60	1	12	0	7	20
2/27/60	1	6	1	1	9
4/2/60	0	9	0	24	33
	Third Examination (November 26, 1960)				
11/21/59	4	40	3	33	80
12/23/59	0	40	2	37	79
1/30/60	1	39	0	34	74
2/27/60	1	38	5	21	65
4/2/60	0	40	4	36	80
Total	6	197	14	161	378
Per cent	3.0	98.5	7.0	80.5	47.25

Table 11. Number of frost injured seedlings by planting date and site.

Planting date	Planting Site ND	SD	NA	SA	Total
11/21/59	0	12	0	11	23
12/23/59	0	25	0	10	35
1/30/60	0	23	0	27	50
2/27/60	0	27	0	23	50
4/2/60	0	37	0	37	74
Total	0	124	0	108	232
Per cent	0	62.0	0	54.0	29.0

Table 12. Number of seedlings browsed by deer by planting date and site.

Planting date	Planting Site ND	SD	NA	SA	Total
11/21/59	1	12	0	0	13
12/23/59	0	5	1	28	34
1/30/60	0	3	0	10	13
2/27/60	0	1	6	0	7
4/2/60	0	0	0	0	0
Total	1	21	7	38	67
Per cent	0.5	10.5	3.5	19.0	8.4

Table 13. Chi-square test of significance of mortality and frost injury (*, significant at 5 per cent level).

Comparison Made	Chi-square Value
Mortality on SA Plot at Second Examination	
12/23/59 vs. 4/2/60	less than 1.0 with 1 d.f.
11/21/59 vs. 4/2/60	11.61* with 1 d.f.
Mortality on SA Plot at Third Examination	
11/21/59 vs. 2/27/60	8.21* with 1 d.f.
Frost Injury on SD Plot	
11/21/59 vs. 1/30/60	6.15* with 1 d.f.
1/30/60 vs. 4/2/60	13.09* with 1 d.f.
12/23/59 vs. 4/2/60	1.82 with 1 d.f.

DISCUSSION

Influence of Soil and Aspect on Survival

It has been recognized that south slopes are the most difficult to regenerate in the Willamette Valley foothills; this study is further confirmation of this difficulty. The differential in rate of survival between north and south slope plots is in all likelihood due to a combination of factors, but principally the intensity and duration of solar radiation. Differences in solar radiation would cause differences in evaporation, transpiration, air temperature, soil surface temperature, relative humidity and in any other measure which reflect the water economy of the seedlings. It was most likely the water economy of the seedlings which set the pace of survival or death in older seedlings.

There are several approaches which might be used to combat the problem of obtaining satisfactory regeneration of Douglas-fir on south slopes. One approach is to reduce the competition for the available moisture. This could be done by scarification, application of herbicides, or smothering of the competing vegetation. Another, less direct method of reducing the moisture stress on the seedlings, is to insure partial shading for the first few years. This could be accomplished by erecting artificial barriers to direct sunlight, or to employ a partial cut method of timber harvest. A system of partial cutting might also reduce the amount of frost injury and deer browsing. It would reduce frost injury by reducing the amount of out-going radiation and slowing down the rate of thawing in the event the seedlings are frozen. Partial cutting by prolonging the initiation of spring growth in comparison to the openings might reduce the amount of deer browsing. The presence of an overstory would also reduce the amount and variety of vegetation, thus reducing the attractiveness of the area to deer. Furthermore, with the presence of an overstory the deer would tend toward the warm sunny openings on spring days.

Other possible approaches to regeneration of south slopes are employment of a special pattern of planting on grass-occupied openings and planting prior to clearcutting on areas to be harvested. A special pattern of spatial placement of planting stock in grassy clearings bordered by shrubs or trees would be developed in the form of progressive centripetal, concentric planting; this is to take advantage of the favorable microclimate provided by the earlier plantings and the initial stand border. Planting at the base of trees to be harvested one to two years prior to removal of the overstory would allow the seedlings to recover from planting shock and become more firmly established in a more moderate microclimate than is normally present following clearcutting. The major difficulty in this approach would be the education of the loggers to avoid unnecessary damage to the seedlings while felling and yarding.

Of course the breeding of drought resistant stock or the recognition of existing strains which are comparatively drought resistant is an approach of considerable merit. However, this approach is longer-ranged in scope, whereas the other approaches mentioned could be tested in the field immediately with less detail in planning.

Soil moisture was probably the soil factor which exerted the greatest influence on survival of the seedlings. Variations in soil moisture very likely accounted for most of the variation in study results. Studies by Youngberg (65 and 66) sufficiently illustrate the importance of soil moisture; therefore, no attempt was made to record similar data.

As has already been alluded, oversimplification is easy. The influence of soil moisture, for example, is a complex of factors and is dependent on amount of precipitation, atmospheric moisture stress, intensity and timing of demands on soil moisture by plants as well as differences in soil features. This is further complicated if there are differences in abilities within a group of Douglas-fir seedlings and between a group of Douglas-fir seedlings and other plants to extract moisture and survive at low levels of soil moisture.

The study data provided only limited evidence that differences in soil had a differential effect on survival during the first year. On the south slope plots, for all planting dates, the plot having Aiken soil had 18 per cent greater survival than did the plot having Dixonville soil. On the north slope plots the situation was reversed, but to a lesser degree. The plot having Dixonville soil had a four per cent advantage in survival over the plot having Aiken soil.

On the south slope plots the plantings made during January and February had a considerably higher per cent of survival up to July, 1960. Had there been more late summer precipitation these two plantings may have demonstrated a distinct advantage over the other planting dates. The February planting on the SA plot was superior to all other plantings on both the south slope plots. Therefore there is some evidence that planting just prior to initiation of rapid spring root growth can improve the per cent of survival on south slopes. If late winter planting was combined with special site preparation and/or unique regeneration methods a reasonable level of survival might be achieved on south slopes.

On south slope areas that have been indiscriminately clearcut, the approach to regeneration will have to be from the point-of-view of reducing or removing the competing vegetation and reducing the intensity of solar radiation and outgoing radiation. It is a difficult problem and most likely uneconomical in terms of planting and treatment at the present time. The rate of planting is not sufficient to take care of those areas which are feasible to plant economically and biologically.

Deer Browsing

No pattern appears to be present by planting date in the data on deer browsing. Brown (3, p. 66) states that in his study, Douglas-fir was used in small quantities throughout the year, but shows two peaks. The one in February was caused by heavy use during winter periods of greater than normal severity, while the June peak corresponds to the start of new growth. In this study there was no apparent peak due to heavy winter use. There was, however, an apparent increase in use by deer with the flush of spring growth.

The browsing of a particular group of seedlings is very likely due to chance; the occurrence of seedlings directly in the path of a deer in his wanderings. This is not to say that deer are not creatures of habit or that they do not have preferences, but observation seems to lead to the conclusion that browsing coincides with the direction of the deer's travel rather than a seeking out of a particular group of seedlings or having a preference for any one planting date.

Three theories are offered as explanation of the differences in amount of browsing between the north and south slope plots: (1) The climate of the south slopes, higher day-time temperatures and higher incidence of sunshine, is preferred by the deer in early spring. (2) The earlier initiation of spring growth on south slopes provides a preferred forage and results in a higher concentration of deer on south slopes. (3) The juxtaposition of habitat requirements may be more favorable on south slopes because of a greater degree of mixing of vegetative types, e.g., a mosaic of grassy openings, shrubby glades, and patches of timber.

Brown (3, p. 10) has observed that a Douglas-fir though heavily browsed by deer, will make some height growth each year. He also stated that some trees which were heavily browsed will grow at a faster rate than normal for the first year or two after browsing. In this study, other than pulling some of the seedlings out of the ground it appears that deer were not a significant deleterious agent. If their numbers are in balance with the carrying capacity of their range little effect on regeneration can be anticipated from browsing. Since McDonald Forest and other areas of the Willamette Valley have relatively good access to goodly numbers of nimrods the deer population should be controllable.

Frost Injury

That there was frost injury to 58 per cent of the seedlings on the south slopes and none on the north slopes can be attributed to any or all of the following conditions: (1) Rapid thawing can be just as harmful as freezing (11, p. 203-204). The south slopes may have sustained more frost injury through rapid thawing than the north slopes which warm up more slowly in the mornings following frosts. (2) There is less natural protection on south slopes than on north slopes, thus more outgoing radiation on cloudless nights. Tall shrubs bordering the north slope plots should reduce the amount of outgoing radiation. On the south slope plots which were bordered by low-lying grass for some distance from plot borders would have little or no effect on outgoing radiation over the plot. Geiger (12, p. 55, 398) considers the reduction in outgoing radiation afforded by overstory vegetation as being of great importance in preventing frosts at levels near the soil surface. (3) The fact that the plots had dense sod which was not removed while the plots on the north slopes were largely devoid of plant debris on the soil surface would cause a greater reduction in night temperatures near the ground on the south slope plots. Geiger (12, p. 398) gives two reasons why temperatures are lower over grass and weeds than over bare soil: Heat loss through evaporation is considerably higher over grass than over bare soil and plant debris is a poorer conductor of heat than is bare soil. (4) There is also the possibility that drainage of cold air on the south slope plots was impeded to a greater degree than on the north slopes. On the south slopes timber was situated on the downhill side of the plots at a distance of approximately 200 feet; while on the north slope plots timber had been removed from the entire drainage in one area and from a point just above the plot to the bottom of the drainage in the other area.

Seedlings for all five planting dates on both the south slope plots did not receive comparable frost injury. A possible explanation for the differences is the occurrence of important differences in microclimate of the plot and perhaps within a given planting, since the seedlings of each planting date were grouped together. Of special interest is the lower incidence of frost damage on the first planting on the SD plot and the first and second plantings on the SA plot when compared with the later plantings. The last planting, the April planting, when compared with the other planting dates had a considerably higher incidence of frost injury. It is thought that the April planting suffered more frost injury because growth activity had commenced prior to transplanting and at an earlier date than on the seedlings already planted; therefore, because of the earlier initiation of growth activity they were more susceptible. The nursery environment was favorable for an earlier flush of growth than that of the field environment. The first planting may have had a lower incidence of frost injury because of the longer period of "field conditioning." In effect the first planting seedlings may have adjusted their physiological activity to the regimens of the field environment to a greater degree than subsequent plantings. No explanation can be offered for the differences in frost injury of the second planting between the two south slope plots.

If frosts occur frequently enough to be a threat to regeneration on the south slopes of McDonald Forest the following proposals might be tested: (1) Change the harvest method on south slopes from clearcutting to partial cutting. Overstory reduces outgoing radiation. (2) In openings where Douglas-fir had been absent for long periods plant a species such as Oregon white oak which in turn will be under-planted with Douglas-fir. The nurse crop would ameliorate the microclimate and maybe even produce a commercial product at some future date. (3) Breed a frost resistant strain of Douglas-fir or use recognized frost-hardy, existing strains. Pauley and Perry (38, p. 186) conclude that species of _Populus_ are adapted to habitats which vary in length of frost-free season through a genetic mechanism which controls their seasonal period of growth. Nienstaedt (36, p. 1) suggests from the results of his study on frost resistance in eastern hemlock, _Tsuga canadensis_ (L.) Carr., that relative frost resistance can be predicted with reasonable accuracy from small indoor tests of growth performance. (4) Remove plant debris and eliminate sod so that heat loss through evaporation is reduced and better conduction of heat from the soil is assured. (5) The planting of Douglas-fir strains having a comparatively late bud-burst could possibly increase the chances of avoiding damage by late frost.

SUMMARY AND CONCLUSIONS

Recognizing that this study covered the span of only one year and that past and future years could present completely different results in a planting date study, the following summary and conclusions are presented:

(1) Planting on north slopes from November to early April meet with equally high success. The percentage survival on the south slope plots was very low. The differences in per cent of survival between the planting dates on the south slopes were small, but of potential importance.

(2) Transplanting the seedlings to the field following the initiation of accelerated root growth in the spring, late March in this study, appears to be the least desirable of the planting dates studied.

(3) Frost injury to the transplanted seedlings was present only on the south slope plots. There was some indication that planting in the fall versus planting in the early spring or late winter may better "condition" the seedlings to withstand late frosts because of a longer "adjustment period" to the field environment.

(4) Browsing of Douglas-fir seedlings by deer was more prevalent on the south slope plots than on the north slope plots.

BIBLIOGRAPHY

1. Baker, Fredrick S. Principles of silviculture. New York, McGraw-Hill, 1950. 414 p.

2. Bever, Dale N. Evaluation of factors affecting natural regeneration on staggered settings in central western Oregon. Salem, Oregon. 1954. 49 p. (Oregon. State Board of Forestry. Research Bulletin 3)

3. Brown, Ellsworth R. The black-tailed deer of western Washington. Olympia, 1961. 124 p. (Washington. State Game Department. Biological Bulletin 13)

4. Gannon, W. A. and E. E. Free. Physiological features of roots, with special reference to the relation of roots to aeration of the soil. Washington, D. C., 1925. 168 p. (Carnegie Institution of Washington. Publication 368)

5. Carmean, Willard H. Site quality for Douglas-fir in southwestern Washington and its relationship to precipitation, elevation, and physical soil properties. Soil Science Society of America Proceedings 18:330-334. 1954.

6. Carmichael, Ralph L. Relation of seeding date to germination of Douglas-fir seed. Northwest Science 31:177-182. 1957.

7. Chapman, A. G. Classes of shortleaf pine nursery stock for planting in the Missouri Ozarks. Journal of Forestry 42:818-826. 1944.

8. Ching, Kim K. and Dale Bever. Provenance study of Douglas-fir in the Pacific Northwest Region. Silvae Genetica 9:1-17. 1960.

9. Coile, T. S. Distribution of forest tree roots in North Carolina Piedmont soils. Journal of Forestry 35:247-257. 1937.

10. Cooper, Robert W., Clifford S. Schopmeyer and William H. Davis McGregor. Sand pine regeneration on the Ocala National Forest. Washington, 1959. 37 p. (U. S. Dept. of Agriculture. Forest Service. Production Research Report 30)

11. Daubenmire, R. F. Plants and environment. 2d ed. New York, John Wiley & Sons, 1959. 422 p.

12. Geiger, Rudolf. The climate near the ground. Cambridge, Massachusetts, Harvard University Press, 1957. 494 p. (Translated by Milroy N. Stewart et al. from the second German edition of Das Klima Der Bodennahen Luftschicht)

13. Griffith, Braham G. Growth of Douglas-fir at the University of British Columbia Research Forest as related to climate and soil. Vancouver, British Columbia, 1960. 58 p. (Faculty of Forestry, University of British Columbia. Forestry Bulletin 2)

14. Haasis, R. W. Relations between soil type and root form of western yellow pine seedlings. Ecology 2:292-303. 1921.

15. Heiberg, S. C. and D. P. White. A site evaluation concept. Journal of Forestry 54:7-10. 1956.

16. Irgens-Moller, Helge. Ecotypic response to temperature and photoperiod in Douglas-fir. Forest Science 3:79-83. 1957.

17. Isaac, Leo A. Reproductive habits of Douglas-fir. Washington, D. C., Charles Lathrop Pack Forestry Foundation, 1943. 107 p.

18. Kramer, Paul J. and Theodore T. Kozlowski. Physiology of trees. New York, McGraw-Hill, 1960. 642 p.

19. Kostler, Josef. Silviculture. Edinburgh, Oliver and Boyd, 1956. 416 p. (Translated by Mark L. Anderson from the German edition of Waldbau)

20. Krygier, James T. Survival and growth of thirteen tree species in coastal Oregon. 1958. 20 p. (U. S. Dept. of Agriculture. Forest Service. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. Research Paper 26)

21. Laing, E. V. Studies on tree roots. London, England, 1932. 73 p. (Great Britain. Forestry Commission. Bulletin 13)

22. Lavender, Denis P. Effect of ground cover on seedling germination and survival. Corvallis, Oregon, 1958. 32 p. (Oregon. Forest Lands Research Center. Research Note 38)

23. Lavender, Denis P. Effect of seed size on Douglas-fir seedlings. Corvallis, Oregon, 1958. 8 p. (Oregon. Forest Lands Research Center. Research Note 32)

24. Lavender, Denis P. Seeding dates and Douglas-fir germination. Corvallis, Oregon, 1958. 15 p. (Oregon. Forest Lands Research Center. Research Note 34)

25. Lavender, Denis P., Morris N. Bergman and Lyle D. Calvin. Natural regeneration on staggered settings. Salem, Oregon, 1956. 36 p. (Oregon. State Board of Forestry. Research Bulletin 10)

26. Li, Jerome C. R. Introduction to statistical inference. Ann Arbor, Edwards Brothers Inc., 1957. 553 p.

27. Limstrom, G. A. Forestation of strip-mined land in the central states. Washington, D. C., 1960. 74 p. (U. S. Dept. of Agriculture. Agriculture Handbook 166)

28. Limstrom, G. A. and Raymond A. Finn. Seed source and nursery effects on yellow-poplar plantation. Journal of Forestry 54:828-831. 1956.

29. Lutz, H. J., J. B. Ely and S. Little Jr. The influence of soil profile horizons on root distributions of white pine (Pinus strobus). New Haven, Conn., 1937. 56 p. (Yale University. School of Forestry. Bulletin 44)

30. Lyon, T. L., H. O. Buckman and N. C. Brady. The nature and properties of soils. 5th ed. New York, MacMillan, 1952. 591 p.

31. Mason, Herbert L. and Jean Langenheim. Natural selection as an ecological concept. Ecology 42: 158-165. 1961.

32. Merritt, Clair. Studies in the root growth of red pine (Pinus resinosa Ait.) Ph.D. Thesis. Ann Arbor, University of Michigan, 1959. 135 p. (Abstracted in Dissertation Abstracts 20:1513-1514. 1959, and in Forestry Abstracts 21:no. 2858. 1960)

33. Munger, Thornton T. and William G. Morris. Growth of Douglas-fir trees of known seed source. Washington, D. C., 1936. 40 p. (U. S. Dept. of Agriculture. Forest Service. Technical Bulletin 537)

34. McGee, Charles E. Soil site index for Georgia slash pine. 1961. 9 p. (U. S. Dept. of Agriculture. Forest Service. Southeastern Forest Experiment Station, Ashville, North Carolina. Station Paper 119)

35. Nienstaedt, Hans. Height growth is indicative of the relative frost resistance of hemlock seed sources. 1958. 2 p. (U. S. Dept. of Agriculture. Forest Service. Lake States Forest Experiment Station, St. Paul, Minnesota. Technical Note 525)

36. Nienstaedt, Hans. The ecotype concept and forest tree genetics. Ann Arbor, Michigan, 1960. 11 p. (Paper presented before the Fourth Lake States Forest Tree Improvement Conference)

37. Orr-Ewing, A. L. A cytological study of the effects of self-pollination of Pseudotsuga menziesii (Mirb.) Franco. Silvae Genetica 6:179-185. 1957.

38. Pauley, S. S. and Thomas O. Perry. Ecotypic variation of photoperiodic response in Populus. Journal of the Arnold Arboretum 35:167-188. 1954.

39. Perry, Thomas O. and Chi-Wu Wang. The value of genetically superior seed. Journal of Forestry 56: 843-845. 1958.

40. Reed, J. F. Root and shoot growth of shortleaf and loblolly pines in relation to certain environmental conditions. Durham, North Carolina, 1939. 68 p. (Duke University. School of Forestry. Bulletin 4)

41. Richardson, S. D. Photosynthesis and root growth in tree seedlings. Overdruck Uit Net Landbouwkundig Tijdschrift 9:775-782. 1956.

42. Richardson, S. D. Studies of root growth in Acer saccharinum L. IV. The effect of differential shoot and root temperatures on root growth. Koninklijke Nederlandse Akademie Van Wetenschappen, Amsterdam, Proceedings, Series C, 59:428-438. 1956.

43. Righter, F. I. Pinus: The relationship of seed size and seedling size to inherent vigor. Journal of Forestry 43:131-137. 1945.

44. Sabhasri, Sanga and William K. Ferrell. Invasion of brush species into small stand openings in the Douglas-fir forests of the Willamette Foothills. Northwest Science 34:77-88. 1960.

45. Santamour, Frank S. Seasonal growth in white pine seedlings from different provenances. 1960. 4 p. (U. S. Dept. of Agriculture. Forest Service. Northeastern Forest Experiment Station, Upper Darby, Pa. Forest Research Note 185)

46. Shoulders, Eugene. Effect of seed size on germination, growth, and survival of slash pine. Journal of Forestry 59:363-365. 1961.

47. Silen, Roy R. Lethal surface temperatures and their interpretation for Douglas-fir. Ph.D. Thesis. Corvallis, Oregon State College, 1960. 170 numb. leaves.

48. Simon, Charles L. Effects of lifting date, cold storage, and grading on survival of some coniferous nursery stock. Journal of Forestry 59:449-450. 1961.

49. Snyder, E. B. (ed.) Glossary for forest tree improvement workers. New Orleans, 1959. 22 p. (Published for the Society of American Foresters by the U. S. Dept. of Agriculture. Forest Service. Southern Forest Experiment Station)

50. Squillace, A. E. and R. T. Bingham. Localized ecotypic variation in western white pine. Forest Science 4:20-34. 1958.

51. Stevens, C. L. Root growth of white pine (Pinus strobus L.). New Haven, Conn., 1931. 72 p. (Yale University. School of Forestry. Bulletin 32)

52. Stone, E. C., E. E. Gilden, D. W. Cooper, and R. J. Malain. Planting dates for Douglas-fir seedlings in California forest lands. California Agriculture 15:15-16. 1961.

53. Stone, E. C. and G. H. Schubert. Root regeneration of ponderosa seedlings lifted at different times of the year. Forest Science 5:322-331. 1959.

54. Stone, E. C. and G. H. Schubert. The physiological condition of ponderosa pine _Pinus ponderosa_ Law. planting stock as it affects survival after cold storage. Journal of Forestry 57:837-841.

55. Toumey, James W. and Clarence F. Korstian. Foundations of silviculture. 2d ed. New York, John Wiley & Sons, 1947. 467 p.

56. Turner, L. M. Root growth of seedlings of _Pinus echinata_ and _Pinus taeda_. Journal of Agriculture 53:145-149. 1936.

57. Urie, Dean Howard. Soil-site relationships in second growth Douglas-fir stands in the central Oregon coast range. Master's thesis. Corvallis, Oregon State College, 1959. 95 numb. leaves.

58. Vinokur, R. L. Influence of temperature of the root environment on root activity, transpiration and photosynthesis of leaves of lemon. Plant physiology U. S. S. R. 4:268-273. 1960. (Translated from Fiziologiya Rastenii)

59. Wakeley, Philip C. Five-year results of the Southwide pine seed source study. Raleigh, North Carolina, 1959. 7 p. (Paper presented before the Fifth Southern Conference on Forest Tree Improvement)

60. Walters, J. and J. Soos. The effect of month of planting upon survival and growth of Douglas-fir and Scots pine seedlings. Vancouver, B. C., 1961. 12 p. (Faculty of Forestry, University of British Columbia. Research Paper 38)

61. The Western Forestry and Conservation Association. Reports of the Pacific Northwest Seeding and Planting Committee on various recommended reforestation practices and techniques. Portland, Oregon, 1953. 69 p.

62. Wilcox, Hugh. Regeneration of injured root systems in noble fir. Botanical Gazette 116:221-234. 1955.

63. Wright, Jonathan W., R. T. Bingham and K. W. Dorman. Genetic variation within geographic ecotypes of forest trees and its role in tree improvement. Journal of Forestry 56:803-808. 1958.

64. Youngberg, C. T. Effect of soils on the establishment of tree crops. Soil Science Society of America Proceedings 19:86-90.

65. Youngberg, C. T. Some site factors affecting the success of reforestation and afforestation activities in the Willamette Valley foothills. Soil Science Society of America Proceedings 19:368-372. 1955.

66. Youngberg, C. T. The influence of soil moisture on the survival of planted Douglas-fir seedlings on clay soils. Journal of Forestry 57:842-844. 1959.

67. Youngberg, C. T. and C. T. Dyrness. Soils of McDonald Forest. Corvallis, Oregon State College, n.d. 11 p. (Mimeographed)