

THE GROWTH OF SEEDLINGS OF SOME
CONIFEROUS SPECIES IN A CONTROLLED ENVIRONMENT

by

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A THESIS

submitted to

OREGON STATE UNIVERSITY

in partial fulfillment of
the requirements for the
degree of

DOCTOR OF PHILOSOPHY

June 1962

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Date thesis is presented April 27, 1962

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ACKNOWLEDGMENT

The author would like to acknowledge his indebtedness for the following invaluable assistance rendered during the course of the study and the preparation of this thesis to: Dr. R. O. Belkengren for his advice on experimental procedures and critical review of the manuscript; Messrs Carmichael, Halber and Overhölser for their fine efforts in chemical analyses, micro-technique, and photography, respectively; Mrs. Dorothy Ehrichs for her superb secretarial services; and, finally, to my wife, Lolita, for her support and encouragement throughout the whole of the graduate program.

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THE GROWTH OF SEEDLINGS OF SOME CONIFEROUS SPECIES IN A CONTROLLED ENVIRONMENT

INTRODUCTION

The last century has seen tremendous increases in yields per acre of the major agricultural crops. A small part of these increases is the result of more efficient cultivation and harvest; the remainder, the result of development of superior hybrids or varieties and the use of soil amendments which enable these improved plants to achieve maximum possible development in their allotted growing space. In contrast, the relatively few studies undertaken to increase forest productivity have been concerned primarily with seedling establishment or with regulation of the growing stock of a "wild" stand.

However, there has been a marked increase in both genetic and nutrition research in the Pacific Northwest in the last decade. Unfortunately, Douglas fir (Pseudotsuga menziesii [Mirb.] Franco) is far from an ideal subject for either area of investigation. With the exception of rare, precocious individuals that bear viable seed in their first decade, the great majority of trees bear pistillate flowers only after twelve to fifteen years. Naturally, many years

are required to segregate desirable characteristics by controlled breeding in such a species. In like manner, nutritional investigations have been hampered by the relatively slow and markedly erratic growth of Douglas fir seedlings in greenhouse or field environments.

The cultivation of perennial woody plants in a greenhouse is more complex than that of many annuals, which may be grown successfully from seed to maturity under one environment. In contrast, different stages in the annual growth cycle of perennials frequently have widely differing optimum environments. Further, seedlings of a species such as Douglas fir make relatively little growth, even under the most favorable conditions, during their first growth cycle.

The growth cycle of Douglas fir (and of many other temperate woody species) is characterized by a relatively brief period of extension growth and a much longer period of dormancy. Therefore, while no data existed which defined the minimum time necessary for each phase of a Douglas fir seedling's growth cycle, it appeared that, if these seedlings could be successfully grown through two or more growth cycles in a year by cultivation in a facility which permitted

establishment of a closely controlled (optimum) environment for each phase of the annual growth cycle, the time required for genetic or physiological research might be correspondingly reduced. Accordingly, this study was designed to determine if cultivation of Douglas fir seedlings in controlled environments would: 1) produce more than one natural growth cycle per year and thus possibly reduce the juvenile period of this species; and 2) produce larger, more uniform plants that could be obtained in a similar period in a greenhouse and thus greatly facilitate the study of the nutritional requirements of this species.

LITERATURE REVIEW

While numerous isolated effects of photoperiod and thermoperiod on the growth of woody species have been reported in the past twenty years, little data have been published on the degree to which the natural annual growth cycle of a coniferous species may be altered by controlled daylengths, soil moistures, and temperatures. Workers at the California Institute of Technology have reported apparent success in achieving early flowering of a species of Pinus by cultivating it under a "growth" regime of sixteen hour photoperiods and eight hour nyctoperiods for several weeks followed by a "dormancy" regime of eight hour photoperiods and sixteen hour nyctoperiods¹. These regimes were alternated during the year to produce several periods of growth. Precocious, erratic flowering of Pinus spp. has been reported however under natural conditions, Rishten (130), and therefore the data reported to date should not be interpreted as evidence of absolute control of the growth cycle of a coniferous plant. Hellmers and Sundahl's report (67) contains the only published data on the thermoperiodic response of Douglas fir, although Redisky² has reported that he caused alternating periods of growth and dormancy in Douglas fir seedlings by concurrent alternation

1. Hellmers, H. Personal communication, 1958.
2. Redisky, J. Personal communication, 1960.

of sixteen hour and eight hour photoperiod regimes together with appropriate thermoperiods. The experiments were conducted for only six months however and there was no evidence to indicate that the resting periods were not a "temporary or summer dormancy".

Zelawski (186, 187) reports that the annual growth cycle of European larch (Larix europeaea D. C.) may be compressed into a period of less than two months by photoperiodic manipulation alone. He also cites the researches of Malczewki and of Leman (186 p. 19), who were able to produce, with similar methods, three growth cycles in maple and ash in fourteen months, and seven to nine flushes of growth of oak in a ten month period.

All these species are probably much more photoperiodically sensitive than Douglas fir. Zelawski selected European larch as his experimental material because this species commonly grows continuously from spring until September and shows a distinct dependence of growth upon photoperiod. Several workers, Olmsted (116 p 390), Pollock (125 p 113), Kramer (85 p 135), have shown that decreasing daylength has played an important role in leaf abscission in many deciduous trees. In contrast, the author has observed that Douglas fir seedlings, under natural conditions, may grow either

without setting a resting terminal bud until late summer or early fall, or grow in one or more flushes separated by the formation of a terminal bud and its subsequent bursting, or set a terminal bud early in the summer and make no more growth that season. Irgens-Moller (76 p 326) notes that Douglas fir seedlings may make two or more flushes of growth in rapid succession. This erratic growth response has made the interpretation of studies of the nutrient requirements of Douglas fir very difficult. While the mechanism governing the growth response of this species is not understood, it is probably the total environment rather than a single environment factor such as the photoperiod which stimulates the plant to break dormancy, grow vigorously, and finally, enter dormancy again.

The growth period of North American conifers has been examined by several workers since Illick (72) first published his observations on the shoot elongation of northeastern conifers. The consensus of several investigators, Baldwin (9), Cook (25), Johnson (79), Kienholz (80), Kozlowski and Ward (82), Daubenmire and Deters (28), Buckland (17), and Kramer (84), is that the duration of growth in many North American forest trees is substantially shorter than the frost-free period of their native areas. Most species studied produced more than ninety per cent of their total shoot elongation between

May first and the middle of July. Chalk (19) reports that the terminal growth of Douglas fir in England proceeds from the end of April into July. Other workers, Bawcom (12), Warrack and Joergensen (169), and MacDougal (98 p 89-91), present data which show that the greatest radial growth of Douglas fir occurs during May and June, but may continue from April until early fall. But Priestley (127 p 352), states that:

"maintenance of cambial activity throughout the summer shows no close connection with extension growth; radial growth usually continues much longer than extension growth."

In the Willamette Valley, Douglas fir trees normally complete their height growth between early May and the middle of July. Unseasonal precipitation or irrigation may cause a short second flush of growth in midsummer, but such growth is usually only a minor part of the total seasonal growth.

In his paper on the physiology of dormancy in woody species, Pollock (125 p 118) noted that very little data existed on either the time of the initiation of dormancy or the associated developmental stages in plants. He concluded that, in the case of Acer platanoides, all stages of development of the rest period extend for a long time. obviously, if the time of inception of rest can not be sharply defined, it is difficult to determine the environmental factors causing rest.

Chalk (19 p 14) states:

"It can scarcely be doubted that the beginning of growth, both of the wood and of the new shoot contained in the winter buds, is closely connected with temperature. But temperature appears to have very little connexion with cessation of growth."

MacDougal (98 p 89-91) cites evidence to show that the diameter growth of Douglas fir is greatest in May-June and that growth in late summer is limited by moisture. Similar data on the height growth of Douglas fir is presented by Hiley and Cunliffe (69). Wareing (168 p 213) describes Douglas fir as a

"Species in which growth ceases in July or August, when daylength conditions have not changed appreciably from those prevailing during the early stages of growth in April and May."

Additional work by the same author (166) showed that short photoperiods induced dormancy in other species of the same classification (with respect to time of cessation of growth). Similarly, Van der Veen (156) working with species of Populus, Robak (131), working with several coniferous species including Douglas fir, Downs and Borthwick (33) and Kramer (85), working with both angiospermous and coniferous species indigenous to the eastern United States have shown that photoperiods less than 14 hours induce early formation of

terminal buds. Vaartaja (154) found such photoperiodic inhibition of growth to be more pronounced with species from northern latitudes. Waxman (173) and Van der Veen (156) have shown that the effectiveness of photoperiodic treatments in inducing dormancy may be modified by the concurrent thermoperiods. Kramer (87 p 54) suggests that cessation of shoot growth may be caused by the hot nights of July, August and September.

Although a paucity of definitive data exists regarding environments which promote dormancy, there is a voluminous literature describing methods of hastening the resumption of growth. Chouard (24 p 64-80) thoroughly reviews the many papers describing chemical methods of lifting dormancy. Since investigation of chemical agents to break dormancy is beyond the scope of this study, no citations of original papers in this area will be made.

Delayed foliation in regions with mild climates has prompted considerable research into the duration and character of thermoperiods required to satisfy the "chilling" requirements of many woody species. Chandler (22 p 40) discusses this problem at great length and observes that the response to inadequate chilling varies with both species and variety. He notes that eight weeks with a mean temperature of about 40°F. will satisfy the chilling requirements of many

orchard trees, and that, while the process of emerging from the rest period is gradual, it is much more rapid after a chilling period with 40° temperatures than after one with 50°. Trees exposed to favorable growing temperatures before their chilling requirements are satisfied open buds more slowly than those receiving an adequate chilling period.

Similarly Chandler et al (21 p 5) report that, while the most effective chilling temperatures have not been determined by direct experimentation for many trees, temperatures between 33° and 40°F. are as good or better than below freezing temperatures and better than higher temperatures for most species tested. These authors note that the great variation in chilling requirements which may exist within a species is evidenced by the reaction of elm trees. Individuals growing within a few rods of each other in Sacramento showed a variation in developing a full leaf cover of from April 4th to May 15th after a warm winter.

However, Crocker (26 p 230) observes that effective chilling temperatures may be as high as 50°F. and as low as freezing. While Davidson (29), working with peach seedlings germinated from inadequately chilled seeds, reports a five week exposure to temperatures below 45°F. will permit the seedlings to complete their dormancy and will result in improved growth when they are returned to

favorable growing conditions. Went (178 p 151) observes that:

"Precise laboratory experiments on the chilling requirements of deciduous trees have not been carried out as yet. Numerous observations in nature have led to the following conclusions:

Only temperatures below 5-8°C seem to be effective in breaking dormancy. These low temperatures must last for a sufficient number of hours so that for each species and variety of plant a minimal number of hours below 5 °C can be assigned, which are required before the tree will leaf out. These hours have not necessarily to be consecutive, but the effect is cumulative. Varieties native to colder climates have a longer chilling requirement than those from climates with warmer winters. Therefore northern varieties grown in the south usually show delayed foliation (late and erratic breaking of buds in spring), whereas southern varieties may be killed farther north when their chilling requirements have been met before the danger of late frosts is past. Although the purely factual description of chilling requirements is very incomplete as yet, the physiology of the buds is better investigated."

Denny (31) and Lamb (89), working with gladiolus corms and raspberry canes respectively have found temperatures between 0°C and 10°C more effective in breaking dormancy than higher or lower temperatures. But Lamb does report that the retarding effect of sub-freezing temperatures appears to be due to an initial shock effect of such temperatures (since continued exposure to sub-freezing temperatures breaks rest rapidly.) Womack¹ reports a constant 5°C temperature to be superior in breaking the rest period of Douglas

1. Personal communication, January 8, 1961.

fir seedlings germinated from seeds collected from widely scattered areas within the natural range of this species than constant 0, 10, or 15°C temperatures or an alternating eight hours at 5 °C and sixteen hours at 0°C thermoperiod. However Olmsted (116) presents data which show that temperatures of -8° to -10°C were greatly beneficial in hastening the resumption of growth of sugar maple (Acer saccharum Marsh.). Finally, in their reviews of dormancy in woody plants, both Samish (134) and Doorenbos (32) agree that the optimum temperatures to satisfy the chilling requirements of woody plants have not been determined.

While it is beyond the scope of this study to investigate the biochemical reactions favored by low temperatures, it is interesting to note that several recent investigations, Phillips and Wareing (123), Pollock (125), and Allen (5), have reported increasing concentrations of indole acetic acid or compounds which chromatograph in a similar manner and corresponding decreases in concentrations of inhibitors in the buds of several woody species during the dormant period. Pollock (125 p 213) suggests that the growth inhibitors found in newly formed buds may be products of incomplete oxidation and that the cold temperatures are necessary to adjust the metabolic rate of the plant to the greatly limited quantity of oxygen which penetrates the

bud scales. But Wareing (167 p 82) observes that it is not likely that dormancy in buds is a result of interference with oxygen exchange as the terminal bud (of birch) is not tightly enclosed by the scales. Furthermore, before the bud forms there can not be interference with the oxygen exchange of the terminal meristem and hence this can not be a primary cause of dormancy.

Mineral Nutrition of Coniferous Species

About a century ago, after hundreds of years of cropping, the steadily falling productivity of forest lands began to disturb northern European foresters. Until this time it was generally believed that forest trees required little more than moisture and anchorage for their roots to thrive. However Rennie (128 p 72-3) presents data from many studies during the past hundred years which show that, while forest does not make as heavy a drain on the nutrient capital of the soil as agricultural crops, nevertheless trees do utilize substantial quantities of the major essential elements during their life cycle. Most European forests are indigenous to a cool climate which retards the decomposition of the nutrient-rich but acid coniferous litter. This condition, together with the fact that moisture does not normally limit forest growth in Europe, has engendered much

research to determine methods of accelerating litter decomposition. In recent years, the increased yields, obtained by planting beech (whose litter is high in calcium) in admixture with coniferous stands or by the addition of lime to the soil, have demonstrated the importance of rapid incorporation of forest litter into the soil Laurie (91), Mayer-Krapoll (100), and White and Leaf (181).

In the United States, however, the climate of the forested areas (except for the extreme northeast is sufficiently mild to promote rapid decomposition of the litter, while forest growth may be limited by available moisture. Therefore the bulk of the forest land productivity research in this country has investigated the relationship of soil structure to tree growth. Many of the workers in the southern and eastern forest areas reviewed by Urie (153) have related the moisture available to trees during the growing season to the productivity of the forest. White (179 p 6), in his review of forest soil research in the eastern United States is emphatic when he states:

"Except in situations of acute nutrient deficiency, a scheme which would estimate the amount and distribution of available water during the growing season would probably most accurately evaluate site."

In direct contrast, however, Voigt (161 p 31) presents data which demonstrate a correlation between moisture supply and

nutrient content of soils and observes:

"While no one can deny the sometimes paramount importance of soil moisture in tree growth, it should be appreciated that the level of available nutrient elements also exerts a very positive influence. In a natural soil system, the factors which regulate the supply of available water are often the same as those which regulate or are related to the supply of available nutrients."

Gagnon et al (45) found a direct correlation between the nutrient content of the A₀ horizon and the productivity of an area, but this work was done in the forests of northeastern Canada, which are characterized by slow litter incorporation, and, consequently, by a high accumulation of nutrients in the forest litter layer.

The results of research concerning the factors governing forest site quality¹ in the Pacific Northwest are similarly divided. Workers at the University of Washington, Gessel, Walker, and Haddock (48), Gessel and Walker (49), Gessel (52), and Gessel and Shareeff (51), have demonstrated nutrient deficiencies in conifers in the greenhouse and have conducted fertilizer trials in young Douglas fir stands on the glaciated soils in western Washington. Gessel and Walker (50 p 19) summarize their field observations

1. Toumey and Korstian (145 p 8) define site quality as "the productive capacity of an area of forest land, usually for a given species or a combination of species."

by stating:

"Although we occasionally have noted apparent deficiencies of phosphorus, magnesium, and possibly calcium in the field, only deficiencies of nitrogen are common."

In British Columbia, Griffith (57 p 55) relates productivity differences on the University of British Columbia experimental forest to differences in available moisture during the growing season. But he does acknowledge that the areas of higher site quality are in locations receiving seepage waters from slopes above them and that:

"As yet there are no data available on the chemical nature of the seepage water of the soils of the University Forest but it is reasonable to assume that water moving through the enriched soil horizons would dissolve from the soil considerable amounts of water-soluble materials. This would be a particularly valuable source of nutrients on the University Forest where the soils are generally shallow and where bedrock or an impervious soil layer is rarely more than a short distance below the surface. Thus drainage water would be retained within the soil zone that contains many of the tree roots and be available to them."

McMinn (104), working on Vancouver Island, found that areas of higher site quality had a greater supply of available moisture during the growing season than did less productive sites. But he noted that, in some locations, highly leached soils were less productive than more droughty areas. Data from greenhouse studies conducted by Krajina (83) and the results of the study of fertilization

of planting stock Walters, Soos and Haddock (163) demonstrate nitrogen deficiencies in some British Columbia forest soils.

Urie (153) reviews several studies of physical properties of soils and their relationship to site quality in the Pacific Northwest. Again, available soil moisture is cited as an important determinant of the productivity of a given area. Strand (139), Chalk (20), and Griffith (57) present evidence which demonstrates that, if moisture stress does not determine site quality directly, it is certainly the environmental factor which limits the duration of the growth period of Douglas fir over most of its range.

Austin (6) reports positive response to nitrogen fertilizer pellets placed in planting holes with seedlings in areas of sedimentary soils on the Oregon coast and in northwestern Oregon. But Tarrant (143 p 719) states:

"No statistically significant relation was found between site class and values obtained from laboratory determinations of soil reaction, silt plus clay content, total nitrogen, available phosphorus and potash, base exchange capacity, replaceable calcium and magnesium and organic matter. In general, the nutrient content of forest soils of the Douglas fir region appears to be too high to constitute a limiting factor in tree growth"

But this last worker also observes that this apparent lack of correlation between soil fertility and site quality may very well be due, at least in part, to the inadequacy of methods presently employed to measure the availability of nutrients to plants.

METHODS

The growth of Douglas fir seedlings under natural or greenhouse environments is most frequently both erratic and slow. In any given population of seedlings some individuals enter dormancy after a few weeks of active growth; some make more than one flush of growth before forming a resting terminal bud; and others may grow continuously for several months. Further, these plants appear to have a much smaller growth potential prior to their first winter than they do in subsequent growth periods (135 p 66).

An objective of this study was to produce a uniform dormant period by subjecting the seedlings to environments designed to induce dormancy while they were all actively growing, and to produce larger seedlings by growing them through more than one growth period in a year.

The second objective was to determine if each such growth period would be the equivalent physiologically of a normal calendar year. Unfortunately, the effectiveness of the artificial growth cycles in reducing the juvenile period of Douglas fir, as measured by initiation of seed production, may not be determined for several years.

When this study was initiated, the relative efficiency of a rapid transition from an environment favoring growth to one greatly inhibiting growth as opposed to a more gradual transition was not known. Therefore, it was decided to construct an artificially shortened "year" employing photoperiods and thermoperiods corresponding to those naturally obtaining during each growth cycle phase. The mean maxima and minima for each phase of the growth cycle were determined by consulting the U. S. Weather Bureau's records of fifty years of meteorological observations at Salem, Oregon (151). The daily photoperiods were obtained from The World Almanac and Book of Facts (111). Table 1 presents the initial scheme for compressing an annual growth cycle into three months.

The relationship of soil fertility and available moisture is discussed in the literature review section of this paper. To minimize the possible effect of available moisture upon the relative productivities of the three soils during the study, and to establish the most effect growth control environments, a carefully controlled irrigation schedule designed to 1) maintain equivalent amounts of available moisture in each of the three soil types; and 2) maintain soil moisture levels to approximate as closely as practicable those occurring naturally during a given growth period and thus utilize

Table 1

Initial Schedule for an Artificially Compressed Annual Growth Cycle

Temperature		Photoperiod (hours)	Duration (days)	Corresponding Natural Period	Purpose
Maximum	Minimum				
°F	°F				
61	40	12.25	7	late March	break dormancy
68	43	13.50	7	mid April	initiate growth
75	48	14.75	7	mid May	growth
80	51	15.50	28	mid June	growth
82	52	14.75	7	mid July	end growth
77	49	13.50	7	late August	set buds
67	46	12.00	7	late September	induce dormancy
57	40	10.50	7	late October	induce dormancy
48	36	9.50	5	mid November	break dormancy (chilling)
46	30	9.50	4	early January	break dormancy (chilling)
53	37	10.50	5	mid February	break dormancy (chilling)

the presence of a soil moisture deficit to induce dormancy, was employed during the course of this experiment.

Prior to planting the seedlings, samples of each soil were submitted to the Soil Physics Laboratory, Oregon State University, for determinations of the moisture percentages which would correspond to two, five and fifteen atmospheres soil moisture tension. The weights of empty containers and their filled weight at the time of planting were recorded. In addition, samples of the soil used to fill each container were weighed and oven-dried and the mean moisture content of the soil in each at the time of planting was computed. Immediately after planting, the containers were slowly watered with distilled water until free moisture dripped from the drainage hole. (This drain was approximately one half inch in diameter, covered with a thin layer of glass wool to prevent washing of soil particles, and was located in the bottom of the containers.) The containers were allowed to drain for forty eight hours and then were weighed. This weight was taken as the field capacity of the soil and the watering schedule was planned so that this weight was never exceeded. It is believed that this system of irrigation resulted in soil moisture more closely approximating that obtaining in undisturbed soil at field capacity than would have resulted if the containers had been watered until water dripped from them each time.

In addition, it would appear that the saturated condition described by Wadleigh and Richards (162 p 422) which results when containers are irrigated until moisture drains from them was avoided.

Each container was weighed to the nearest five grams every week or fortnight during the growing cycle and the current mean moisture status was computed from this weight and the above data. Sufficient distilled water was then added (when necessary) to bring the mean moisture content to the desired level. It is appreciated that the effectiveness of this watering technique is limited by phenomena governing the addition of moisture to soils below field capacity, but it is believed that any such discrepancies were equivalent in all these soils.

Table 2

Total moisture Added to the Soil Containers

Soil	Moisture Added (cc) Growth Cycle				Total
	1	2	3	4	
Burnt Woods	3,516	3,987	5,155	4,133	16,791
Black Rock	3,492	2,729	4,173	3,576	13,970
Black Rock Poor	3,437	2,523	3,139	2,600	11,699
Above are mean values per individual soil container					

Table 2 presents data on the quantities of moisture supplied to each container during the study. Attempts to run "blank pots" and thus separate evaporation loss from transpiration use by each group of seedlings produced inconsistent results. Therefore, it may be said only that the Burnt Woods seedlings apparently used more moisture than did those seedlings grown in Black Rock poor soil.

The following data were recorded for each seedling during each growth cycle (bud burst not present in first growth cycle):

1. date of terminal and lateral bud burst
2. length of new terminal growth (measured from the base of the previous cycle's terminal bud to tip of current growth)
3. color of elongating shoot
4. occurrence of multiple flushes of growth
5. date of initiation of a resting terminal bud
6. bud set

During the dormant period of the first, second, and fourth growth cycles, the seedlings were removed from the containers and a number randomly selected for harvest. Sufficient seedlings were withdrawn from the experimental populations during the first dormant period to reduce the number replanted in each container

to ten. Further harvest of seedlings after the second growth period left a residual population of six seedlings per container. Although the transplanted seedlings were placed in the same soil type, the actual soil in Black Rock Container I, for example, in the first cycle was not identical with that in this pot in succeeding cycles. Some addition of new soil and mixture with soil from other containers of the same soil type occurred during each transplanting operation.

The harvested seedlings were divided into shoot and roots and dried to a constant weight at 70° C. After drying, the shoots were divided into stems and needles. This procedure was followed to provide a better basis for comparison with data of other studies than that which would have resulted from analysis of the whole shoot. The oven-dry weights of all seedlings harvested from each soil container were determined and recorded by tissue type. All the samples were then ground in a micro-Wiley mill equipped with a 60 mesh screen. Because all the seedling harvested after the first two growth periods were randomly selected from the wind pollinated population, and because individual seedlings (especially those grown in Black Rock Poor soil) were too small to permit proper chemical analysis, the needles of all the seedlings harvested

from a given container were ground together as a single sample. The same procedure was followed for the seedling stems and roots. These tissues were stored in tightly closed glass vials in a desiccator until analyzed for nitrogen, phosphorus, potassium, calcium, and magnesium.

Nitrogen analysis was carried out using the micro-Kjeldahl method with a mercury catalyst as described in Wilson (184 p 495-509) and the AOAC Handbook (115 p 12-13). The phosphate and cations were determined from a common solution prepared by dissolving the tissue samples in nitric and sulphuric acids and digesting with hydrogen peroxide. The phosphate was determined by the Fiske-Subbarow method; calcium and potassium, with a Beckman DU Flamephotometer, and magnesium, by the Titan-yellow procedure.

Sufficient seedlings of both the wind pollinated and the hand pollinated seeds were germinated to provide a control population for each group. These control seedlings were grown in a greenhouse until May, 1959 or until they were about sixteen weeks old. They then were given a chill period to break their dormancy and placed out-of-doors, where they remained for the duration of the experiment. Similar data to that recorded in the growth rooms were taken for the control population. Since these containers

were subject to natural precipitation, no attempt was made to maintain a watering schedule. The containers were irrigated, however, during the late summer whenever the soil appeared dry. Such procedure was, of course, a deviation from the natural late summer environment, but was considered necessary to prevent seedling mortality.

In addition to the above populations, a few seedlings of grand fir (Abies grandis Lind.), noble fir (Abies nobilis Lind.), western hemlock (Tsuga heterophylla [Rafn.] Sarg.), and ponderosa pine (Pinus ponderosa Dougl.) were grown under the same conditions as the Douglas fir. Unfortunately, the space limitations of the Bowser oven limited the populations of these species to the number of seedlings which could be grown in a single ceramic soil container per species. Therefore, observations on the growth responses of these trees are based upon populations of from four to twelve seedlings. All these plants, save the pine, were grown in the Black Rock soil. The pine seedlings were planted in a soil taken from a coniferous nursery near Bend, Oregon. These pots were irrigated under the same schedule as that employed for the Douglas fir seedlings.

MATERIALS

Seeds

Although its wide distribution and ability to pioneer both the hot, dry and cool moist slopes attest to the great heterogeneity of Douglas fir (figure 1), it was believed that the extreme variability of response to environmental factors often reported in genetic and physiological studies of this species might have been reduced if selected seeds and not "wild seed lots" had been employed. Accordingly, it was planned to use only those seeds resulting from the controlled pollination of one tree with the pollen secured from one other Douglas fir tree. Unfortunately, controlled pollination trials conducted by Dr. K. K. Ching of the Oregon Forest Research Laboratory and the author did not produce sufficient sound seed from any pair of parent trees to permit establishing an entire population from such seeds. As an alternative, the experimental population was composed of forty eight seedlings which were the progeny of a pollen parent from southern Oregon and a tree near Corvallis, and three hundred and thirty six seedlings which were the progeny of a single wind-pollinated tree near Salem, Oregon. These latter seeds were selected on the basis of the results of

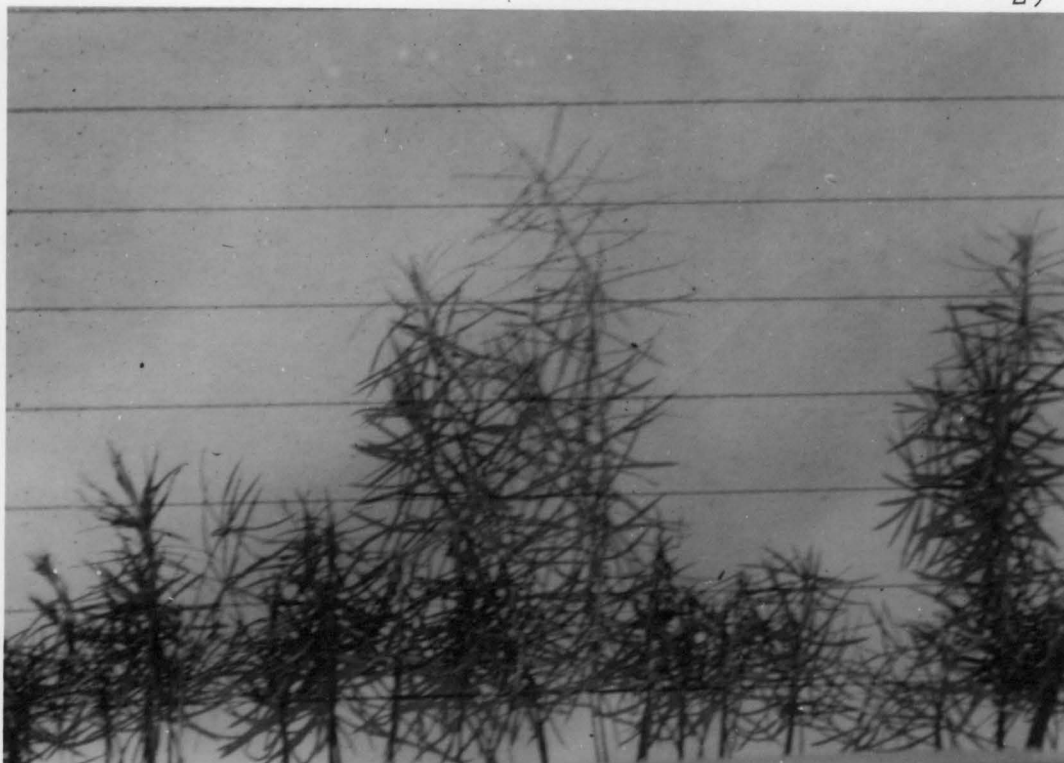


Figure 1. Variation in growth which frequently occurs in populations of Douglas fir seedlings. All the seedlings were between seventeen and nineteen weeks old and were grown in a greenhouse from seed collected from a single tree.
(After Lavender, 1958a)

an earlier study by the author (93) which showed the progeny of this tree to have less variation in size than those resulting from any one of thirty nine other single tree seed lots.

Investigations by Aldrich-Blake (2 p 55), (3 p 55-6), Laverder (92) and Spurr (138 p 478) have shown that, while the weight of a coniferous seed may have no lasting effect upon the size of the resulting seedling, positive correlations have been shown between the weight of the seed and that of the year-old seedling. Therefore all the seeds were weighed on an analytical balance and only those having weights between fourteen and seventeen milligrams were employed in this study (the weights of seeds in the original population varied from eight to eighteen milligrams). It was determined that the average seed moisture content was 7.6 per cent and that the seed coats represented twenty eight per cent of the total seed weight.

Studies by the Oregon State Seed Laboratory, the Boyce Thompson Institute, and others (118) have shown that Douglas fir seeds germinate more uniformly if they are subjected to a cold, moist storage period ("stratification") prior to being placed in an environment favorable to germination. Accordingly, the seeds were soaked in distilled water for forty eight hours and then mixed

with equal quantities of moist pumice and stored at 2°C. for six weeks.

The germination period included a daily cycle of eight hours at 30°C. with light and sixteen hours at 20°C. without light. The first seeds germinated in six days. At the end of ten days, there were sufficient germinated seeds to permit planting sixteen germinants in each of twenty four containers of soil. Records were kept of the seed weight of each germinant to insure that the different weight seeds were uniformly distributed in all the soil containers. In addition, the two progeny from the southern Oregon cross were assigned different positions in the containers to eliminate any possible bias resulting from interior vs. edge growth conditions.

Containers

Considerable unforeseen delay in production of the soil containers designed for this project necessitated the use of one-half-gallon milk cartons for the first phase of the study. These containers were about four inches square and eight inches deep and held approximately nineteen hundred grams of oven-dry soil.

The seedlings were transplanted into the ceramic pots after the active growth portion of the first cycle. These pots were about five inches in diameter and twelve inches deep, were glazed

on their inner surfaces and provided with a drainage hole in the base. Each held about two thousand grams of oven-dry soil.

Soils

Three soils from areas of differing productivity were selected for use in this study.

The first, hereinafter termed "Black Rock" was obtained from the Black Rock Experimental Forest west of Fall City in the Oregon Coast Range (Sec 13 T8S R7W WM). This soil has developed from sedimentary rocks under a rainfall of approximately seventy inches annually, and has been classified in the Melbourne series. The texture is medium and the depth is at least sixty six inches. The plot is located on a ten per cent south facing slope at an elevation of eleven hundred feet. This area supports a stand of second-growth Douglas fir timber about forty five years old with an average height of one hundred and five feet for the dominants and co-dominants (figure 2).

The second, hereinafter referred to as "Black Rock Poor" was collected from a site about three quarters of a mile northwest of the previous plot, in Section 11 at an elevation of about eleven hundred and fifty feet. The exposure, slope, and rainfall are very



Figure 2. Typical dominant Douglas fir trees growing on the Black Rock area. These trees are about forty five years old and approximately 105 feet tall. This area is classified as a Site II.

similar to the previous area, but the soil is markedly deficient in organic material (table 3). This soil is a well-drained, reddish-brown lateritic soil derived from shale with a depth of forty one inches to the C horizon. The average height of the co-dominant and dominant trees in the forty five year old Douglas fir stand growing on this site is only fifty five feet (figure 3).

The third soil, hereinafter referred to as "Burnt Woods", was developed on sedimentary rock under a rainfall of approximately seventy inches per year at an elevation of one thousand feet near Burnt Woods, Oregon (Sec 22 T11S R8W WM) in the coast range. In contrast to the previous two areas which support closed stands, this area has been more recently cut-over and now has a scattered stand of seedlings, saplings, and young poles (figures 4 and 5). In addition, there are a few open-grown trees approximately ninety years old and one hundred and sixty five feet in height. This soil is a dark loam with a depth of forty four inches to the C horizon. Detailed profile descriptions of these soils are included in the appendix of this report.

Foresters commonly describe the productivity of a given forest area in terms of "site quality" or "site class". These somewhat nebulous expressions are, perhaps, best defined by

Table 3
Nutrient Content of Forest Soils from the Three Study Areas

Soil	Site Class	Total Nitrogen (%)	Phosphorus (lbs/A me/100g)	Potassium (lbs/A me/100g)	Magnesium (me/100g)	Calcium (me/100g)	
Burnt Woods	High II	0.436	41	1856	2.38	5.1	7.7
Black Rock	Low II	0.252	37	686	0.88	2.1	8.3
Black Rock Poor	V	0.154	8	515	0.66	1.5	2.8



Figure 3. Typical dominant Douglas fir trees growing on the Black Rock Poor soil. These trees are about forty five years old and average around fifty five feet in height.



Figure 4. Burnt Woods tree No. 2. This tree is approximately the same size and age as Burnt Woods No. 1.



Figure 5. Burnt Woods tree No. 1. This is a twenty five year old second growth Douglas fir approximately fifty five feet tall. This area is classed as a high site II. 37

McArdle, Meyer, and Bruce (101 p 8) who state:

"Various combinations of the physical characteristics of forest areas, such as soil, drainage, rainfall, temperature, altitude, slope, and aspect, result in different degrees of favorableness for tree growth. The combined effect of these characteristics on the stand is embraced in the term "site" or "site quality". Between the best and poorest sites in the Douglas fir region is a range in productivity, as measured in cubic feet of wood produced, of over 250 per cent. It would be difficult, if not impossible, to determine the part that each physical factor has in making an area productive, although this study has given some indications of the combinations of factors that contribute toward productivity."

The criterion most frequently used to define the site of a given area is the mean height of the dominant and co-dominant trees in the stand. Since this measurement varies with stand age, as well as with site productivity, tables have been prepared which convert height measurements for any age stand to height data for the same trees at age one hundred years (site index) (101 p 12). The most productive soils are termed Site I and will produce dominant and co-dominant trees with a mean height of between one hundred and ninety and two hundred and ten feet at one hundred years. Similar trees will attain a mean height of less than one hundred feet on an area of Site V.

The three study areas have the following productivity or site index ratings based on the above scale: Burnt Woods, site index 180 (high site class II); Black Rock, site index 160 (low site class II); and Black Rock Poor, site index 85 (site class V).

Tables 3 and 4 summarize the organic matter and mineral content, and the water holding capacity of these soils as determined by the Oregon State University Soils Laboratory. Inasmuch as forest soils experts advised utilizing only the surface foot of each soil instead of the whole profile, the data below apply strictly to only this upper foot and not to the whole profile.

The methods employed to determine the chemical characteristics of the soils are described in Alban and Kellogg (1). The pressure membrane method was used to determine moisture holding capacity of each of the three soils.

Control Chambers

This study was conducted in several chambers in which the temperature, photoperiod, and moisture could be controlled to simulate the average environment in the different seasons in the Willamette Valley. The first of these chambers was a Bowser oven (figure 6) having interior dimensions of 30" x 36" x 45" high

Table 4.

Moisture Holding Capacity of Forest Soils from the Three Study
Areas

Soil	Atmosphere Tension		
	2	5	15
	(per cent oven-dry weight)		
Burnt Woods	39.2	35.0	30.8
Black Rock	34.8	31.0	25.4
Black Rock Poor	36.3	31.7	24.8



Figure 6. The original growth control chamber was this Bowser oven which had the temperature and humidity controller mounted on the left side together with the bank of control switches.

and providing space for thirty glazed pots each 5-3/4" in diameter and 12" deep. The oven was equipped with sixteen twenty watt daylight fluorescent tubes and an incandescent bulb which together produced approximately 1100 foot candles at a distance of one foot from the lights. It was possible to set the controls to regulate chamber temperature and humidity within a range of from below 32°F to 100°F and twenty per cent to one hundred per cent respectively. This equipment was employed during the first growing season of the seedlings and during the dormant period between the second and third growth periods. In general the oven responded well to the setting of the controls, but difficulty with the relay system caused a failure in the control system during the initial stages of the dormant period at the end of the first growing season.

A large, walk-in cold room maintained at a constant temperature of 34°F was employed to chill the seedlings after the first growth period. A two hundred watt bulb suspended immediately above the pots of seedlings provided an eight hour photoperiod during the two month chill period.

A ten-foot-square, walk-in room was constructed during the summer of 1959. Forty-two eight foot fluorescent warm white 2.2 ampere tubes were set in a bank on 2 3/4" centers 7 1/2' above

the floor. Immediately below the fluorescent tubes a thin polyethylene sheet served as a barrier between the air around the lights and the air in the room proper. The "attic" formed by the film was ventilated by a fan to remove some of the heat from the lamps. Four incandescent lamps were mounted immediately below the polyethylene film to provide a source of far red radiation. The total illumination produced by both fluorescent and incandescent lamps was approximately 1400 foot candles at the plant bench level as measured with a Weston Illumination Meter Model 756 Quartz Filter held horizontally. Measurements made with a net radiometer as described by Lowry (95) indicated that the radiant energy received on a horizontal plane at pot height was about 0.15 Langley. Measurements with a spherical pyroheliometer produced slightly low values, but this instrument is calibrated for the sun's spectrum and therefore may not be precise for other sources of radiation.

The fluorescent lights were wired so that one third, two thirds or all the lamps might be employed. In addition, the fluorescent and incandescent lamps were controlled by separate time clocks.

Since the lights produced sufficient heat in the plant growth area to achieve any desired temperature, temperature control

was effected by means of refrigeration. This unit was controlled by two thermostats, one with a "day setting"; and the second, with a "night setting". Both of these thermostats were controlled by a time clock. Brooks and Kimball (16 p 2) discuss temperature control in plant growth rooms and indicate that the practice of abruptly changing from a day maximum to a night minimum temperature produces a square shaped curve as opposed to a natural temperature curve which approximates a sine curve, and that maxima and minima of such curves are not equivalents. It was found that, if the change from the day thermostat to the night thermostat was timed to occur two to three hours after the start of the nyctoperiod, and the switch from night to day settings, a corresponding period after the start of the photoperiod, the resulting temperature plot approached the natural sine curve.

This light room was employed during the second, third, and fourth growing periods, and during the dormant period between the third and fourth growth periods. Requirements of other investigations necessitated maintaining the light room on a long day regime and therefore the original Bowser oven was employed as the chilling chamber between the second and third growth periods.

After the fourth growth period, requirements of other investigations again necessitated maintaining the light room in a long day cycle and so the seedlings were brought into a dormant state in a greenhouse immediately adjacent to the light chamber. This phase of the study was conducted during December, 1960 and January, 1961 when outside temperatures were normally below 45°F at night and 55°F during the day. Under these conditions it was possible to maintain the greenhouse temperature within \pm 2°F. of the desired setting. The greenhouse was equipped with steam heat regulated by thermostats and a modulated compressed air system. Time clocks permitted automatic control of previously selected day and night temperatures. A small bank of six foot fluorescent tubes, controlled by a time clock, was employed to supplement the winter daylight. The natural and artificial light was approximately five hundred foot candles at the seedling level, as measured with the previously described Weston meter held in a horizontal plane.

A second light room with similar dimensions to the first was constructed in 1960 (figure 7). The barrier between the room and the lights was made of a translucent, corrugated plastic



Figure 7. Walk-in control chamber employed during the latter portion of this study. Seedlings have completed four growth cycles.

installed on a slight slant to permit the moisture which condensed to drain to the edge of the room when the room was held at low temperatures. With all the lights on, this room could be maintained between 20° and 100°F. This second light room was employed during the chilling period after the fourth growth period.

RESULTS

The data recorded during this study were collected to establish the effectiveness of the environments employed in producing the desired seedling growth response, the uniformity of this response, and, finally, the relative productivity of the three soils studied. During each cycle the time of bud burst, observations of stem tip color, weekly measurements of stem elongation, number of growth flushes, and the approximate date of terminal bud set were recorded for each seedling and are the basis for assessing the degree and uniformity of growth control achieved. The mean shoot lengths, and oven-dry weights of seedlings harvested from each soil together with determinations of the respective mineral uptakes form the basis for comparison of the relative productivities of the three soils studied. In addition, the growth rates and mineral contents of the seedlings are compared with the growth and mineral content of second growth trees as a measure of the relationship of the growth possible within the artificial environments with that occurring under natural conditions. Finally, a series of micrographs illustrate the effectiveness of the series of environments in reducing the annual growth cycles of the coniferous species studied.

The germinants described in the section on "seeds" were planted in twenty four half gallon milk cartons (these cartons were employed as substitute soil containers until the end of the first growth period because the delivery of the ceramic pots was delayed), eight cartons for each soil type. The excess germinants were planted in a seed flat in Black Rock soil and placed in a greenhouse with a daily fluctuation in temperature of from about 60°F to 75°F and a natural photoperiod of about ten hours.

The soil containers were watered with distilled water until water drained from them and were then placed in the Bowser oven in a random arrangement. The controls were set to simulate late March, the normal time of seed germination in the Willamette Valley, according to Table 1. The seedlings were checked daily during the first week and any dead germinants were replaced with new seedlings. After this first week any dead seedlings were removed but not replaced. However, only five per cent of the seedlings died during the first cycle.

Table 5 is a summary of the environments employed in growing the seedlings through the four cycles discussed in this paper. The first cycle followed the schedule presented in Table 1 until the absence of the desired seedling growth response

Table 5

Operation of Controlled Environment Chambers During Four Growth Cycles

Days After Start of Study	Environment	Photo- period hrs.	Temper- ature		Soil Moisture Tension*	Seedling Response
			Max.	Min.		
			°F	°F		
<u>First Cycle</u>						
0	Bowser oven	12.25	61	40	field capacity	active growth
7	Bowser oven	13.50	68	42	field capacity	active growth
14	Bowser oven	14.75	75	48	field capacity	active growth
21	Bowser oven	15.50	80	51	field capacity	active growth
49	Bowser oven	14.75	82	51	field capacity	active growth
56	Bowser oven	13.50	77	49	2 atmos.	active growth
63	Bowser oven	12.00	67	46	2 atmos.	active growth
70	Bowser oven	10.50	57	40	2 atmos.	formation of lateral buds
79	Bowser oven	9.50	57	40	field capacity	formation of lateral buds

(continued)

Table 5 - continued

Days After Start of Study	Environment	Photo- period hrs.	Temper- ature Max. Min.		Soil Moisture Tension*	Seedling Response
			°F	°F		
106	Bowser oven	9.50	79	56	2atmos.	increasing dormancy
139	Bowser oven	9.50	85 (erratic)	45	2atmos.	increasing dormancy
171	Bowser oven	9.50	54	40	field capacity	dormancy
178	Bowser oven	9.50	38	34	field capacity	dormancy
185	Walk-in cold room	9.50	34	34	field capacity	dormancy
<u>Second Cycle</u>						
245	out of doors	11.25	80	45	field capacity	dormancy
261	light room 1	14.00	80	60	field capacity	break dormancy
275	light room 1	15.00	75	51	field capacity	active growth
290	light room 1	15.50	80	51	field capacity	active growth
309	light room 1	14.75	82	51	field capacity	some bud formation
316	light room 1	13.50	78	53	2atmos.	some bud formation

(continued)

Table 5. - continued

Days After Start of Study	Environment	Photo- period hrs	Temper- ature		Soil Moisture Tension*	Seedling Response
			Max.	Min.		
			°F	°F		
325	Bowser oven	12.00	76	54	2 atmos.	some bud formation
329	Bowser oven	10.50	72	54	2 atmos.	some bud formation
336	Bowser oven	10.00	72	55	2 atmos.	some bud formation
350	Bowser oven	9.50	72	55	2 atmos.	increasing dormancy
365	Bowser oven	9.50	66	48	2 atmos.	increasing dormancy
372	Bowser oven	9.50	62	45	2 atmos.	dormancy
383	Bowser oven	9.50	55	40	field capacity	dormancy
387	Bowser oven	9.50	50	37	field capacity	dormancy
390	Bowser oven	9.50	45	34	field capacity	dormancy
393	Bowser oven	9.50	40	32	field capacity	dormancy
<u>Third Cycle</u>						
407	Bowser oven	10.50	53	37	field capacity	dormancy
411	Bowser oven	12.00	61	38	field capacity	dormancy

(continued)

Table 5 - continued

Days After Start of Study	Environment	Photo- period hrs.	Temper- ature Max. Min.		Soil Moisture Tension*	Seedling Response
			°F	°F		
414	Bowser oven	13.50	66	41	field capacity	dormancy
419	Bowser oven	14.50	75	46	field capacity	dormancy
424	light room 1	15.50	78	46	field capacity	break dormancy
455	light room 1	15.50	72	46	field capacity	active growth
480	light room 1	15.50	84	46	field capacity	active growth
505	light room 1	12.00	78	53	2 atmos.	bud initiation
509	light room 1	9.00	70	53	2 atmos.	increasing dormancy
551	light room 1	9.00	60	46	2 atmos.	increasing dormancy
556	light room 1	9.00	57	43	2 atmos.	dormancy
563	light room 1	9.00	52	42	field capacity	dormancy
568	light room 1	9.00	48	40	field capacity	dormancy
570	light room 1	9.00	46	38	field capacity	dormancy

(continued)

Table 5 - continued

Days After Start of Study	Environment	Photo- period hrs	Temper- ature		Soil Moisture Tension*	Seedling Response
			Max.	Min.		
			°F	°F		
573	light room 1	9.00	44	35	field capacity	dormancy
577	light room 1	9.00	40	34	field capacity	dormancy
<u>Fourth Cycle</u>						
615	light room 1	12.00	52	36	field capacity	dormancy
617	light room 1	13.00	60	40	field capacity	dormancy
621	light room 1	15.50	78	46	field capacity	break dormancy, growth
687	greenhouse	12.00	68	53	2 atmos.	growth
694	greenhouse	11.00	68	53	2 atmos.	growth
697	greenhouse	9.00	73	61	2 atmos.	gradual de- velopment of dorman- cy
754	light room 2	9.00	60	50	field capacity	dormancy
760	light room 2	9.00	55	45	field capacity	dormancy
764	light room 2	9.00	40	36	field capacity	dormancy

*mean soil moisture content in each container immediately after watering. Since the containers were irrigated at intervals of one week or more, the minimum soil moisture content for each period was somewhat less than that listed.

necessitated the modifications described below. The initial plan was discarded for the final three cycles, each of which is composed essentially of three environments. These environments were designed to promote growth, to induce dormancy, and to satisfy the cold requirements of the seedlings.

The first indication that the initial plans for controlled growth of coniferous seedlings required modification appeared when the plants were eleven to twelve weeks old, when the chamber controls were set to induce dormancy. Lateral buds, but no terminal buds, formed on many of the seedlings. A comparison of the programmed thermoperiods in the Bowser oven with that obtaining the two previous months in the greenhouse during the period when the control seedlings went into dormancy revealed that the long nyctoperiods in the greenhouse were associated with relatively high minimum temperatures (55-65°F), while the schedule outlined in Table 1 called for much lower minimum temperatures during long nyctoperiods. Investigations by Vegis (157 p 97) and workers cited by Nitsch (113) have shown that many plants are no longer photoperiodically sensitive below temperatures of from 50°F to 68°F. Perhaps such was the case with the present population of Douglas fir seedlings.

Therefore the controls on the chamber were set to a 75°F maximum during the 9.5 hour photoperiod and a 55°F minimum during the nyctoperiod. These settings were maintained until the twenty fourth week of the study, when the majority of the seedlings had set terminal buds. Unfortunately, however, the operation of the chamber became quite erratic between the nineteenth and twenty fourth week so that temperatures as much as 10° above and below the programmed settings were recorded.

Although the practice of planting germinants resulted in a more uniform spacing of seedlings than could have been obtained by sowing seeds, the method invalidated any total height measurements as it was impossible to plant germinants whose ages differed by even as little as one day, at a uniform depth. Therefore, the length of the seedling crown, from the first whorl of needles (cotyledons) to the base of the terminal needles was chosen as one criterion of relative seedling vigor. At the end of nine weeks the average crown length for seedlings growing in Burnt Woods soil was 26 mm. (figure 10); for seedlings growing in Black Rock soil, 24 mm.; and for seedlings growing in Black Rock Poor soil, 12 mm. The seedlings in the greenhouse produced very little crown elongation above the cotyledons before they set terminal buds,



Figure 8. Seedlings three weeks after planting. Left to right, Black Rock, Black Rock Poor, Burnt Woods. Letters are one inch high. The same three groups of seedlings appear in all pictures of growing Douglas fir seedlings raised in growth rooms.



Figure 9. Seedlings six weeks after planting. Left to right, Black Rock, Black Rock Poor, Burnt Woods.



Figure 10. Seedlings after nine weeks in the Bowser oven. Left to right, Black Rock, Black Rock Poor, Burnt Woods. Letters are one inch high.



Figure 11. Seedlings at the beginning of the second growth period. The soil surface is about one inch below the top of each container. Left to right, Black Rock Poor, Black Rock, Burnt Woods.



Figure 12. Seedlings raised out-of-doors after one season's growth and the Burnt Woods seedlings at the start of the second growth period. Seedlings on the left were germinated from wind pollinated seeds; those in the center, from control pollinated seeds. Note the greater uniformity of the center population.

the average being about 8 mm.

The number of days after the initiation of the study when bud initials first were noted for each seedling are shown in the appendix in Table 28. Only the six seedlings which were grown throughout the experiment, in each container are noted in this table. Because detailed observations were made only every two weeks, the data minimize the variation between seedlings. However, there was definitely less variation between seedlings in the setting of terminal buds during this first cycle than occurred during subsequent growth periods. The differences between the mean times of bud set for the three seedling populations were found to be non-significant.

When the seedlings were twenty four weeks old they were transplanted to the ceramic pots. Ten seedlings, the two control pollinated seedlings and eight randomly selected wind pollinated seedlings, were potted. The remaining seedlings were divided into roots and shoots and dried in an oven at 70°C to a constant weight. The mean weights for seedlings grown in each soil are recorded in table 6. The mean weights of the four to six seedlings harvested per container (number of seedlings harvested per container of soil varied with the number of living plants in each container at the

time of transplanting) are shown in Table 29 in the appendix. The mean lengths of the seedling crowns are listed in Table 7.

It was noted at this time that the terminal buds were somewhat smaller (1-3 mm. in length) than those found on one-year-old Douglas fir seedlings grown in the Oregon Forest Nursery. Perhaps this growth response was caused by factors similar to those which produced the small terminal buds reported on Scots pine (Pinus sylvestris) seedlings by Wareing (166 p 263). This worker notes that such buds developed on seedlings which had very short growth periods as a result of cultivation under twenty two or more hours of light per twenty four hours.

The ceramic pots were watered to field capacity and placed in the control chamber and the controls were set according to the schedule for the "chilling" period listed in Table 1. After two weeks it was necessary to completely over-haul the Bowser oven. The pots were transferred to a walk-in cold room maintained at 34°F. A two hundred and fifty watt incandescent bulb suspended above the seedlings was the light source for a 9.5 hour photoperiod. The seedlings remained in the cold room for nine weeks until the thirty fifth week of the study, as repairs to the control chamber were greatly delayed.

Table 6
Mean Oven-dry Weights of Douglas Fir Seedlings Harvested After
One Growth Period*

Soil	Needles	Stem	Shoot	Roots	Total
	gm	gm	gm	gm	gm
Burnt Woods	0.0860	0.0265	0.1125	0.1100	0.2225
Black Rock	0.0637	0.0277	0.0914	0.1135	0.2049
Black Rock Poor	0.0461	0.0198	0.0659	0.0651	0.1310

*By testing the differences between the seedlings grown on the three soils with an individual degree of freedom, the mean oven-dry total weight of the Burnt Woods seedlings was found to be equal to that of the Black Rock seedlings and both were different from that of the Black Rock Poor seedlings at the 1% significance level.

Table 7
Mean Length of Douglas Fir Seedling Crowns After First Growth
Period*

Seedling Population	Crown Length (mm)		
	Soil		
	Burnt Woods	Black Rock	Black Rock Poor
Wind Pollinated	31	24	15
Southern Oregon- Willamette Valley Cross	26	20	14
All Seedlings	30	23	14

*Differences between soils and between pollen sources found significant at the 1% level. The data for individual seedlings are shown in Table 30 in the appendix.

The second growth period was begun with poor control over the environment. The repairs to the Bowser oven were not complete and the cooling unit for the light room had not been installed. However, it was believed that the average maxima and minima occurring outside in the month of October were appropriate to break the dormancy of the seedlings. That natural temperatures were, in fact, adequate to initiate growth was evidenced by the large number of seedlings whose buds began to swell during mid-October.

After the cooling unit was installed, the thermoperiod and photoperiod in the light room were regulated as shown in Table 5.

Late in the seedling dormant period, between the second and third growth cycles, four of the wind pollinated seedlings from each plot were harvested. The remaining seedlings were repotted in the same soil. Two of the harvested seedlings from each soil container were dried, weighed, and ground as in the previous cycle. The means of these data are presented in Table 8. It may be noted that the seedlings grown in the Burnt Woods soil produced much more growth during the second cycle than did the seedlings grown on the remaining soils (figure 13, 14).

The entire third cycle was conducted in the first light room. This cycle was marked by the most erratic bud bursting and

Table 8

Mean Oven-dry Weights of Douglas Fir Seedlings Harvested After
Two Growth Periods*

Soil	Needles	Stems	Shoots	Roots	Total
	gm	gm	gm	gm	gm
Burnt Woods	0.4081	0.1584	0.5665	0.4664	1.0329
Black Rock	0.1602	0.0472	0.2074	0.2868	0.4942
Black Rock Poor	0.0724	0.0234	0.0958	0.1518	0.2476

* Differences between the mean total weights of seedlings grown on the three soils are significant at the 1% level. Data for the mean weights of seedlings harvested from the individual soil containers are shown in Table 31 in the appendix.



Figure 13. Douglas fir seedlings in controlled environment during the second growth cycle. Burnt Woods soil on left; Black Rock soil on the right.

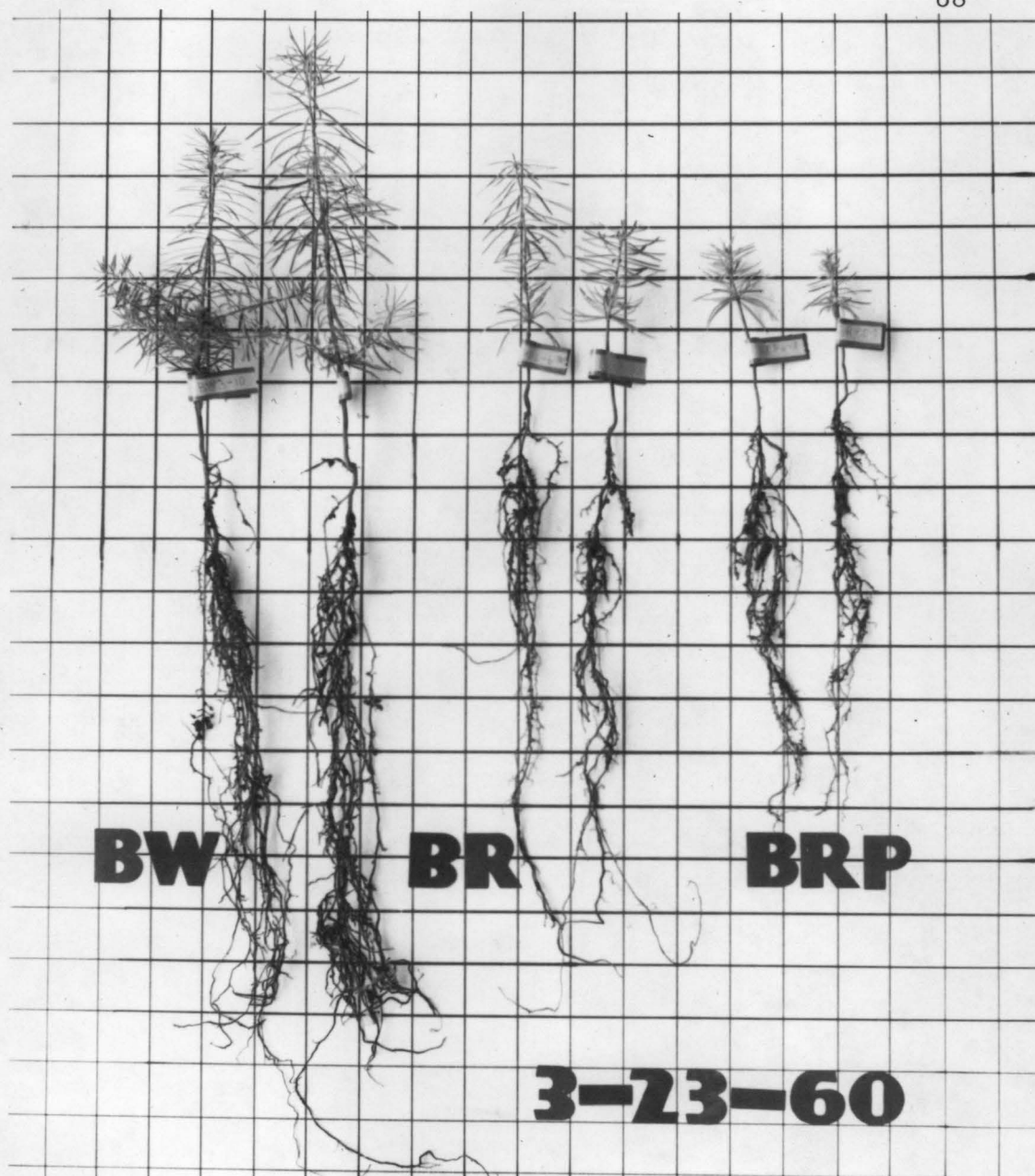


Figure 14. Douglas fir seedlings harvested from the three study soils between the second and third growth periods. Background grid is composed of one inch squares.

sporadic growth patterns of any of the four cycles. Many of the Burnt Woods seedlings, in particular, either failed to open their buds or suffered anomalous bud burst which resulted in poorly formed, slow growing new foliage (figure 15). This response was probably caused by insufficient chilling. Recent data¹ show that at least eight weeks of temperatures about 40°F are necessary to satisfy the chilling requirements of Douglas fir, and these plants had only three weeks of such temperatures. Chandler et al (21 p 9) note that vigorous shoots have a greater chilling requirement than other, less vigorous shoots on a given tree. If insufficient chilling was the cause of the reduced growth of the seedlings during the third cycle, the relatively greater reduction in growth of the previously more vigorous seedlings growing on the Burnt Woods soil would appear to confirm this observation. The mean terminal growth made by seedlings on the Burnt Woods, Black Rock and Black Rock Poor soils, 1.5, 4.6 and 1.2 centimeters respectively (data for individual seedlings shown in Table 32 in the appendix), do not reflect a continuation of the superior growth made by the Burnt Woods seedlings during the first two cycles. However this reduced growth was greater than that of the plants grown in the Black Rock

1. Womack, Don, personal communication (1/8/61).



Figure 15. Terminal growth made during the third growth cycle confined to the short leaders above the uppermost laterals. Seedlings in this container made more growth than the average Burnt Woods seedling in the third cycle.

Poor soil.

It is interesting to note, however, that the surplus seedlings which were grown in the greenhouse and which became dormant about nine weeks after germination did not require a long chilling period to break their dormancy. These seedlings were transplanted to several pots after a dormant period of about six weeks. The pots were then placed in the cold room for periods of from two to six weeks (it had been planned to use the data on the growth response after these chilling periods as a guide to chilling requirements of the cycling seedlings) and then returned to the natural summer environment. Seedlings in all the containers resumed growth within a month after leaving the cold room, and none of the seedlings produced the anomalous growth noted in the third growth period.

The seedlings were grown in both light rooms and a greenhouse during the fourth cycle (table 3). In contrast to the third cycle, all buds broke normally three to five weeks after resumption of the growth-promoting environment and, as the data in Table 33 in the appendix show, all the seedlings produced a flush of new growth. This table, however, presents only measurements of leader growth. Although the Burnt Woods seedlings again produced the greatest mean terminal growth, (table 9), perhaps a more

Table 9

Mean Terminal Growth of Douglas Fir Seedlings During the Fourth Growth Cycle*

Seedling Population	Length of Terminal Shoot (cm.)		
	Burnt Woods	Black Rock	Black Rock Poor
Wind Pollinated	5.2	5.0	3.9
Willamette Valley- Southern Oregon Cross	5.1	5.2	3.3
All Seedlings	5.2	5.1	3.7

* The differences between the mean lengths of the terminal shoots of the Burnt Woods and Black Rock seedlings and that of the Black Rock Poor seedlings is significant at the 1% level.

accurate measure of their superiority are data on lateral growth.

The Burnt Woods seedlings averaged fourteen laterals which produced at least a centimeter of new growth each as opposed to eight and two for Black Rock and Black Rock Poor seedlings, respectively. In all cycles of this study (as well as in other growth studies conducted by the author) the lateral buds normally broke before the terminal bud. In some cases the lateral buds were active two weeks prior to swelling of the terminal bud. In general, too, the lowest lateral buds were the first to break.

Figure 16, taken after the main growth period of the fourth cycle, and figure 17, taken after the seedlings were harvested



Figure 16. From left to right: Douglas fir seedlings (after growth period of the fourth cycle) grown in Black Rock Poor, Burnt Woods, and Black Rock soils. Seedlings at extreme right have grown in Black Rock soil out-of-doors for two natural growth periods. Ruler at the base of the pot is six inches long.

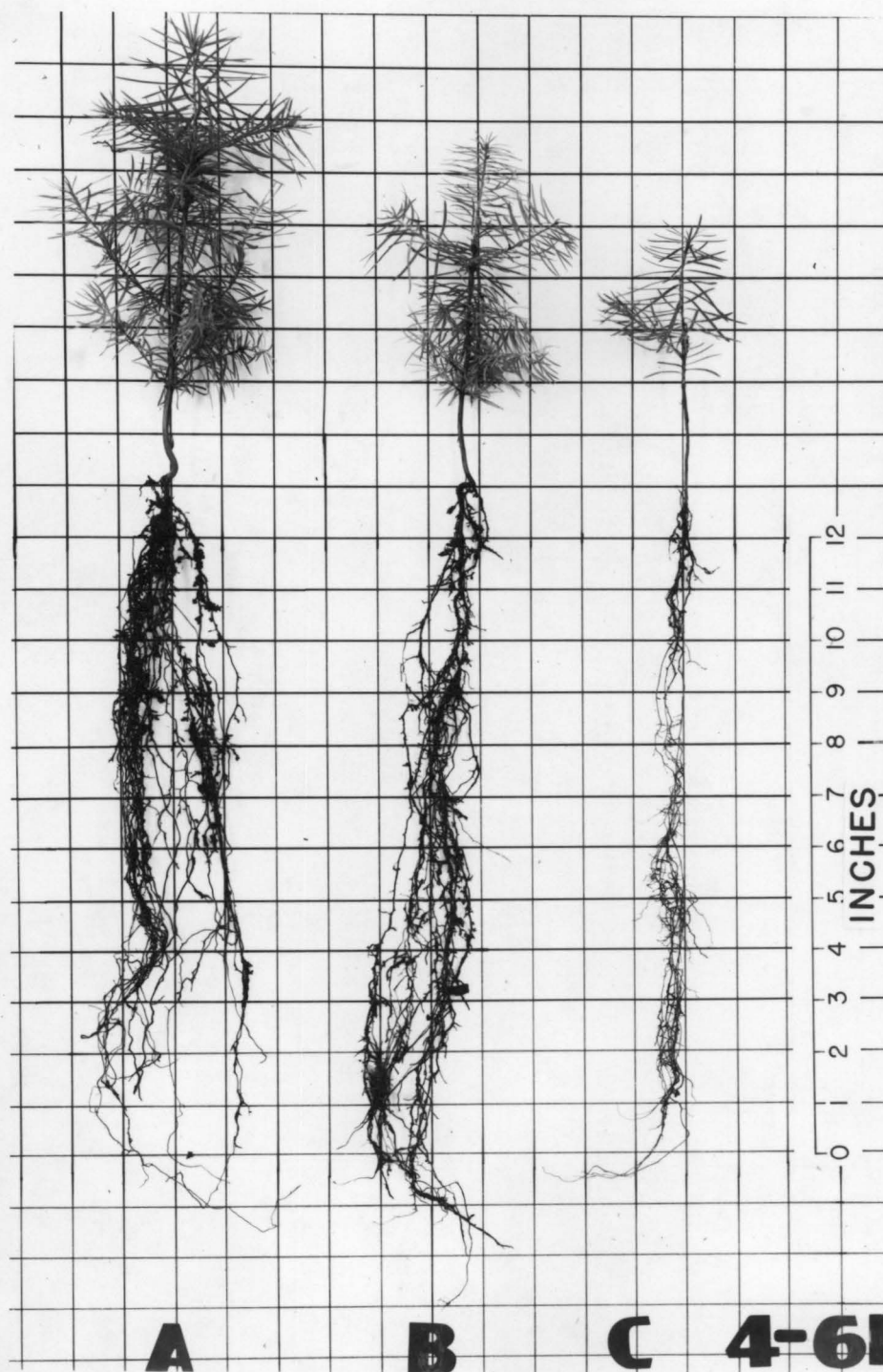


Figure 17. Douglas fir seedlings harvested after the fourth growth period. A is the seedling number 2-6 (slightly larger than the mean of seedlings grown in Burnt Woods soil); B, seedling number 5-5 (slightly smaller than the mean of seedlings grown in Black Rock soil); C, seedling number 7-3 (very slightly larger than the mean of seedlings grown in Black Rock Poor soil).

show the superiority of the Burnt Woods seedlings. A comparison of these last two figures with figure 18, which shows the diameter growth rate of trees on each of the study sites, reveals the relation between growth rates of seedlings in pots and those of mature trees.

After the two month chill period the seedlings were removed from the light room. Approximately half of the seedlings in each soil type were transplanted to three gallon containers, each holding between twenty five and thirty pounds of oven-dry soil. These seedlings continue to be grown under a "cycling" schedule. Although this report describes in detail only the results of the first four growth cycles, occasional reference in the discussion will be made to data recorded during the fifth and sixth cycles. The remaining seedlings were harvested, weighed, dried, ground, and analyzed according to methods previously described.

The total mean heights of each seedling population from the cotyledon scar to the tip of the fourth cycle bud are shown in table 10. It will be noted that the heights listed in this table are slightly less than the sums of measurements for each of the four cycles. This is primarily due to the fact that the length of the growth of the second cycle was measured from the base of the

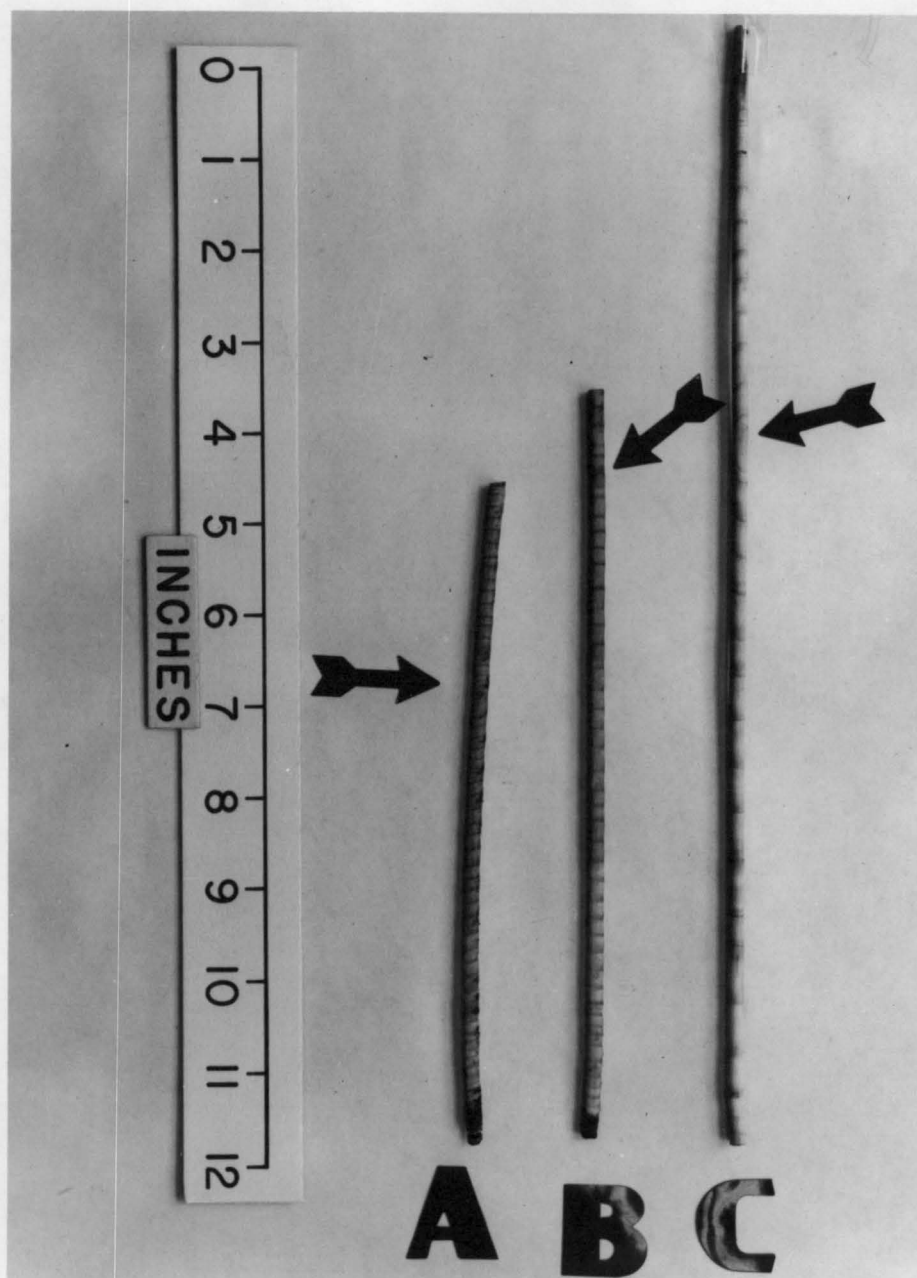


Figure 18. Increment cores from Douglas fir trees growing on each of the three study sites. A is from a tree in the Black Rock Poor area; B, a tree in the Black Rock area; and C, a tree in the Burnt Woods area. Arrows point to the pith. The difference in ring widths between the Burnt Woods core and the other two is probably greater than the difference in site productivity because the Burnt Woods core was taken from an open-grown tree half the age of the trees composing the closed stands on the other areas. (Ring width has been shown to diminish for a given site with increased age and stocking).

Table 10

**Mean Total Height of Douglas Fir Seedlings from Cotyledon Scar
to Terminal Bud Tip After the Fourth Growth Period***

Seedling Population	Total Height (cm)		
	Soil		
	Burnt Woods	Black Rock	Black Rock Poor
Wind Pollinated	16.6	14.0	6.8
Willamette Valley- Southern Oregon Cross	15.0	13.5	5.7
All Seedlings	16.0	13.7	6.4

*The differences between the mean total heights of the seedlings on the three soils are significant at the 1% level. Data for individual seedling heights are shown on table 34 in the appendix.

terminal bud of the second cycle. Growth of succeeding cycles was similarly measured and therefore each bud length was tallied twice.

The mean oven-dry weights of seedlings harvested during the fourth cycle are presented in Table 11. The seedling data are segregated by the fresh weights of the seedlings harvested from each soil (i. e., the four heaviest Burnt Woods seedlings were separated into roots, stems, 1st-3rd cycle foliage, and fourth cycle foliage. Each tissue class for these four seedlings was then dried, weighed, and ground as a group.) The data in Tables 14 and 15 represent the mean weights for four seedlings in each case; those in Table 16, five seedlings. The seedling foliage produced during the fourth cycle was separated from that produced during previous cycles to provide a better basis for comparison with foliage of the second growth trees.

Fresh weight determinations (Table 17) were made for both the wind pollinated and controlled cross seedlings grown in each soil. They show that the seed sources grew equally in each soil. They show, too, the superiority of the seedlings grown in Burnt Woods soil.

Table 11

Mean Oven-dry Weight of Douglas Fir Seedlings Harvested After the Fourth Growth Period

Soil	Roots	Stem*	Mean Weight (gms)		Total
			1st-3rd Cycle Foliage	4th Cycle Foliage	
Burnt Woods	1.6493	0.6120	0.4707	1.0019	3.7335
Black Rock	0.9621	0.4027	0.5702	0.3219	2.2568
Black Rock Poor	0.3225	0.0969	0.1641	0.1641	0.6458

*The difference between the mean weight of seedlings grown on the Burnt Woods soil and that of seedlings grown on the Black Rock soil is significant at the 5% level. The differences between the mean weights of the seedlings grown on both these soils and that of the seedlings grown on the Black Rock Poor soil are significant at the 1% level. Data for the individual seedling classes are shown in Tables 35-37 in the appendix.

Table 12

Fresh Weight of Douglas Fir Seedlings After Four Growth Periods

Soil	Seedling					
	Wind Pollinated Seeds			Southern Oregon Cross		
	No. of Seedlings	Total Weight gm.	Mean Seedling Weight gm.	No. of Seedlings	Total Weight gm.	Mean Seedling Weight gm.
Burnt Woods	32	478	14.9	16	261	16.3
Black Rock	32	347	10.8	14	142	10.1
Black Rock Poor	31	106	3.4	16	52	3.3

Bud Break and Set

As noted on page 48, data were taken on the time of bud burst and bud set as measure of the degree of control of the seedling's annual growth cycle achieved by the controlled environments. Obviously, the time of bud burst could be tallied with good precision. However, the time of bud set could be estimated only. When multiple flushes occurred, the time of bud set was estimated for the final resting bud.

No consistent sequence of bud break within each seedling population was noted during the study. When the observations on the time of bud burst were grouped for each of the tree soils and then arranged, within each group, in the sequence of bud burst, it was found that only one seedling (Black Rock 3-4) was among the first twenty five per cent of the seedlings (in its group) to break their buds during each of the four cycles. The remaining seedlings were very erratic, plants which initiated growth early during one cycle often were among the last the following growth period. Nor was there any apparent difference in speed or consistency of bud burst between the open pollinated seedlings and those grown from the southern Oregon-Willamette Valley cross seeds. Similarly, there was no consistent order of bud burst among the

populations on the different soils. At the start of the second growth period, seedlings grown in the Burnt Woods soil broke their buds an average of eight days sooner than those in the other two soils. At the start of the third growth period, Black Rock seedlings broke their buds sixteen days before the other seedlings. Finally, there was little difference between the mean dates of bud burst for seedlings on all three soils during the fourth growth cycle. The same relation obtained during the fifth cycle, but the Black Rock Poor seedlings broke their buds a week before the remainder during the sixth cycle. The data for bud set reflect a similar inconsistency among the seedling populations.

In the great majority of cases, the lateral buds broke dormancy first. Further, those near the base of the seedling frequently were the first laterals to open. This is in accord with Kramer and Kozlowski's (88 p 480) observation for woody plants in general, and with the author's experience during other greenhouse and controlled environment studies. Douglas fir seedlings and saplings also demonstrate the same order of bud breaking under natural conditions.

Because the third growth cycle was characterized by growth responses conditioned by insufficient chilling, the data

in table 13 are taken from only the second and fourth growth cycles. They illustrate the inconsistency of flushing over the whole seedling population, and, further, a possible increased tendency to double flush of the seedlings grown on the poorer soils. This is in accordance with other observations of the author and Ingestad who notes (75 p 519) that Pinus silvestris seedlings grown under deficient conditions entered dormancy more rapidly than others.

Color of Leader

Perhaps the only data which are consistent for all cycles are the observations made on the color of the upper terminal stem. The wind pollinated seedlings produced leader growth which varied in color from green for some seedlings to deep red for others. But the Willamette Valley-Southern Oregon cross seedlings produced only green terminals.

Table 13

Incidence of Multiple Growth Flushes in Douglas Fir Seedlings
Grown Under Controlled Environments

Soil	Number of Seedlings			Total number of multiple flushes
	Failed to flush twice	Flushed twice in one growth period	Flushed twice in both growth periods	
Burnt Woods	25	22	1	24
Black Rock	12	25	8	41
Black Rock Poor	15	21	11	43

Chemical Analyses

The data in tables 14-16, which were obtained by tissue analysis as described in the methods section, were determined by subtracting the quantities of the different elements found in a week-old Douglas fir germinant from those of the nutrients in the harvested seedlings. This procedure was followed because the seed contributed a large proportion of the total nutrients determined for the first cycle seedlings. For example, the Burnt Woods seedlings contained an average of three times as much nitrogen as the Black Rock Poor seedlings after one growth period. But when the nitrogen derived from the seed was subtracted, the ratio of the nitrogen uptake of seedlings grown on these two soils became nearly twenty to one.

The data in table 16 are, in effect, the ratios of the mean concentrations of the elements supplied to the seedlings by Burnt Woods and Black Rock soils to the corresponding values for seedlings raised in Black Rock Poor soil. The data for the 1st cycle seedlings demonstrate the superiority of the Burnt Woods soil as a nitrogen source and suggest that seedling growth on the Black Rock Poor soil is limited primarily by this element and secondarily, by phosphorus.

The data in tables 14-20 clearly demonstrate that the total uptake of nutrients is a more definitive measure of a seedling's nutrient status than is the concentration of these elements in any seedling tissue. The mean Burnt Woods seedling obtained eighteen times as much nitrogen from the soil during the first two growth periods as the mean Black Rock Poor seedling, but the ratio of the foliar nitrogen concentrations was only one and one half to one. Similarly, the data in table 20 show that nutrient concentrations, but not nutrient uptake, vary very little from the largest to the smallest seedlings grown on each soil.

The data in tables 17-19 emphasize the importance of recording nutrient concentrations by specific tissue types and not, as has been reported elsewhere (135) by "shoot" and "root".

Further evaluation of the significance of the data reported in these tables is restricted by the evident impoverishment of the available nitrogen supply of the Burnt Woods soil during the course of the investigation. A more detailed analysis of this phenomenon is presented in the discussion section.

Table 14
Mean Nutrient Uptake Per Douglas Fir Seedling Grown in the
Controlled Environments

Soil	Element					
	Nitrogen	Phosphorus	Calcium	Potassium	Magnesium	Sodium
	(gms. x 10 ⁻⁵)					
<u>1st Cycle</u>						
Burnt Woods	234	38	37	181	27	0.7
Black Rock	62	23	38	96	17	0.9
Black Rock						
Poor	12	5	20	55	13	— *
<u>2nd Cycle</u>						
Burnt Woods	981	171	175	922	183	15.0
Black Rock	372	107	134	343	44	9.0
Black Rock						
Poor	53	21	40	116	26	6.0
<u>4th Cycle</u>						
Burnt Woods	3156	755	1118	2843	426	46.0
Black Rock	1710	536	549	1642	234	60.0
Black Rock						
Poor	396	78	77	305	58	17.0

* Too small to measure with methods employed.

Table 15
Relationship of the Total Uptake of Nutrients by Seedlings Grown in Burnt Woods and
Black Rock Soils with that of Seedlings Grown in Black Rock Poor
Soil

Soil *	Oven-dry weight of seedling	Element					
		Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sodium
<u>1st Cycle</u>							
Burnt Woods	1.7	19.5	6.4	3.3	1.8	2.0	--
Black Rock	1.6	5.2	4.2	1.7	1.9	1.2	--
<u>2nd Cycle</u>							
Burnt Woods	4.2	18.5	8.3	7.9	4.3	7.1	2.4
Black Rock	2.0	7.0	5.2	2.9	3.3	1.7	1.4
<u>4th Cycle</u>							
Burnt Woods	5.8	8.0	9.6	9.3	14.4	7.3	2.7
Black Rock	3.5	4.3	6.8	5.4	7.1	4.0	3.5

* Black Rock Poor equals 1.0 in all cases

Table 16
Relationship of Total Nutrient Uptake per gram of Seedling Dry Weight by Seedlings
Grown in Burnt Woods and Black Rock Soils with that of Seedlings Grown in Black
Rock Poor Soil

Soil*	Elements					
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sodium
<u>1st Cycle</u>						
Burnt Woods	11.5	3.8	1.9	1.1	1.2	--
Black Rock	3.2	2.6	1.1	1.2	0.8	--
<u>2nd Cycle</u>						
Burnt Woods	4.4	2.0	1.9	1.0	1.7	0.6
Black Rock	3.5	2.6	1.4	1.6	0.8	0.7
<u>4th Cycle</u>						
Burnt Woods	1.4	1.7	1.6	2.5	1.3	0.5
Black Rock	1.2	1.9	1.5	2.0	1.1	1.0

* Black Rock Poor equals 1.0 in all cases

Table 17.

Mean Nutrient Content of Douglas Fir Seedling Roots

Soil	Elements					
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sodium
	%	%	%	%	%	%
<u>1st Cycle</u>						
Burnt Woods	1.40	.178	.737	.225	.068	.012
Black Rock	0.78	.154	.457	.248	.019	.011
Black Rock Poor	0.73	.100	.436	.213	.028	.050
<u>2nd Cycle</u>						
Burnt Woods	1.06	.172	.977	.244	.139	.034
Black Rock	0.81	.183	.712	.328	.017	.032
Black Rock Poor	0.55	.092	.424	.175	.045	.039
<u>4th Cycle</u>						
Burnt Woods	0.79	.172	.706	.474	.064	.027
Black Rock	0.79	.180	.662	.292	.069	.047
Black Rock Poor	0.65	.107	.472	.160	.074	.047

Table 18.

Mean Nutrient Content of Douglas Fir Seedling Stems

Soil	Elements					
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sodium
	%	%	%	%	%	%
<u>1st Cycle</u>						
Burnt Woods	1.05	.167	.542	.059	.197	— *
Black Rock	0.47	.120	.139	.023	.208	.006
Black Rock						
Poor	0.50	.100	.154	.031	.207	— *
<u>2nd Cycle</u>						
Burnt Woods	0.59	.089	.440	.053	.161	— *
Black Rock	0.67	.137	.457	.050	.169	— *
Black Rock						
Poor	0.36	.086	— *	.035	.191	.042
<u>4th Cycle</u>						
Burnt Woods	0.57	.119	.456	.105	.108	.002
Black Rock	0.54	.120	.406	.102	.079	.011
Black Rock						
Poor	0.60	.081	.134	.015	.079	.008

* Too small to measure with methods employed.

Table 19
Mean Nutrient Content of Douglas Fir Seedling Foliage

Soil	Element					
	Nitro-	Phos-	Potas-	Cal-	Magne-	Sodium
	gen	phorus	sium	cium	sium	
	%	%	%	%	%	%
1st Cycle						
Burnt Woods	1.76	.255	1.094	.142	.201	*
Black Rock	0.88	.209	.728	.153	.154	.002
Black Rock Poor	1.13	.172	.862	.142	.230	*
2nd Cycle						
Burnt Woods	1.26	.216	1.037	.151	.236	*
Black Rock	1.28	.367	1.151	.233	.211	*
Black Rock Poor	0.81	.217	.840	.203	.242	*
4th Cycle						
(1st-3rd Cycle)¹						
Burnt Woods	1.02	.394	.778	.289	.283	*
Black Rock	0.86	.434	.871	.320	.171	.011
Black Rock Poor	0.84	.239	.091	.155	.185	.003
(4th Cycle)						
Burnt Woods	1.12	.215	1.177	.136	.129	*
Black Rock	0.97	.226	1.049	.147	.135	.012
Black Rock Poor	1.06	.181	.798	.079	.104	.013
5th Cycle²						
Burnt Woods	1.42	.186	.940	.109	.230	*
Black Rock	1.53	.160	1.134	.180	.280	.001
Black Rock Poor	1.64	.256	1.143	.040	.101	.043

* Too small to measure with methods employed

¹ Foliage collected after fourth growth period. These needles were separated from those produced in the fourth growth period to provide a better basis for analysis.

² Needles alone were collected during the fifth cycle.

Table 20
Mean Nutrient Content of Each Size Class of Douglas Fir Seedlings
Harvested After the Fourth Growth Cycle

Soil	Element					
	Nitro-	Phos-	Potas-	Cal-	Magne-	Sodium
	gen	phorus	sium	cium	sium	
	%	%	%	%	%	%
<u>Roots</u>						
Burnt Woods						
1	0.77	.184	.754	.484	.032	.027
2	0.80	.179	.694	.482	.069	.033
3	0.75	.160	.721	.477	.093	.023
4	0.83	.172	.665	.491	.064	.025
5	0.81	.168	.696	.431	.063	.029
Black Rock						
1	0.74	.204	.725	.273	.063	.051
2	0.81	.197	.694	.313	.074	.044
3	0.77	.173	.721	.283	.100	.043
4	0.79	.165	.665	.313	.061	.050
5	0.82	.161	.696	.278	.046	.049
Black Rock Poor						
1	0.65	.107	.494	.175	.080	.045
2	0.69	.113	.491	.145	.069	.038
3	0.61	.102	.431	.159	.073	.059
<u>Stems</u>						
Burnt Woods						
1	0.53	.111	.437	.099	.102	---*
2	0.63	.123	.487	.105	.107	---*
3	0.57	.117	.443	.101	.104	.002
4	0.61	.132	.475	.114	.122	.003
5	0.51	.112	.438	.108	.107	.003
Black Rock						
1	0.53	.118	.398	.090	.077	.011
2	0.54	.115	.361	.128	.071	.010
3	0.56	.120	.421	.084	.090	.012
4	0.54	.115	.404	.110	.086	.013
5	0.55	.131	.446	.100	.073	.010
Black Rock Poor						
1	0.56	.079	.117	.015	.071	.010
2	0.66	.092	.136	.029	.080	.024
3	0.56	.078	.150	---*	.081	---*

Continued

Table 20 - Continued

Soil	Element					
	Nitro-	Phos-	Potas-	Cal-	Magne-	Sodium
	gen	phorus	sium	cium	sium	
	%	%	%	%	%	%
<u>1st-3rd Cycle, Foliage</u>						
Burnt Woods						
1	0.96	.429	.883	.288	.296	---*
2	1.01	.422	.788	.272	.290	---*
3	1.01	.356	.687	.278	.280	---*
4	1.06	.374	.723	.281	.256	---*
5	1.02	.391	.808	.325	.289	---*
Black Rock						
1	0.96	.440	.901	.296	.137	.014
2	0.82	.509	.910	.364	.195	.010
3	0.83	.394	.853	.315	.189	.010
4	0.80	.345	.898	.327	.167	.012
5	0.90	.480	.792	.297	.166	.011
Black Rock Poor						
1	0.80	.234	.103	.196	.145	---*
2	0.87	.247	.077	.107	.194	---*
3	0.85	.236	.094	.161	.217	.010
<u>4th Cycle, Foliage</u>						
Burnt Woods						
1	1.10	.238	1.243	.134	.110	---*
2	1.12	.217	1.116	.130	.120	---*
3	1.09	.205	1.110	.123	.139	---*
4	1.16	.211	1.103	.144	.135	---*
5	1.12	.213	1.314	.150	.141	---*
Black Rock						
1	0.94	.230	1.072	.136	.130	.013
2	1.08	.233	1.107	.160	.135	.012
3	0.95	.200	1.035	.138	.140	.010
4	0.96	.218	1.049	.162	.129	.011
5	0.95	.247	0.980	.139	.132	.012
Black Rock Poor						
1	1.02	.169	0.825	.067	.105	.007
2	1.16	.177	0.760	.075	.098	.004
3	1.00	.198	0.809	.094	.108	.027

* Too small to measure with methods employed.

Table 21

**Nutrient Content of the Current Year's Foliage from the Upper
Three Whorls of Second Growth Douglas
Fir Trees**

Tree	Element					
	Nitro- gen	Phos- phorus	Potas- sium	Cal- cium	Magne- sium	Sodium
	%	%	%	%	%	%
Burnt Woods						
1	1.48	.225	.992	.286	.143	.001
2	1.73	.145	.812	.249	.164	.001
mean	1.60	.185	.902	.267	.154	.001
Black Rock						
1	1.39	.175	.522	.322	.190	.007
2	1.44	.169	.499	.537	.326	.009
mean	1.41	.172	.511	.430	.258	.008
Black Rock Poor						
1	1.15	.176	1.116	.436	.136	.003
2	1.20	.344	1.003	.190	.136	.009
mean	1.18	.260	1.060	.263	.136	.006

Wood Anatomy

Figures 19 to 22 illustrate the effect of the described alteration of growth promoting environments with those designed to cause dormancy or satisfy cold requirements upon the growth of the Douglas fir seedlings. The "annual rings" produced by seedlings growing in all three soils appear very similar, although somewhat smaller than those produced under natural environments and, incidentally, longer growing season. Although all three seedlings grown in the control chambers flushed twice during the third cycle and the Burnt Woods and Black Rock seedlings flushed twice during the fourth cycle, these flushes were not reflected by false annual rings in the radial growth. This is in accordance with the findings of Larson (90 p 121).

Dr. W. von Wettstein-Westersheim, who has conducted experiments designed to shorten the juvenile period of Picea abies (L.) Karst., reports that it was possible to produce three growth periods in one year by photoperiodic control of growth processes.¹ However, it was necessary to chill the seedlings to break the dormancy after the last period of growth, therefore it is possible that these three growth periods were really only flushes during one

1. Dr. W. von Wettstein-Westersheim, Chief of Division of Forest Genetics, Austrian Federal Forest Experiment Station, Vienna, Austria. Conversation 9/60.

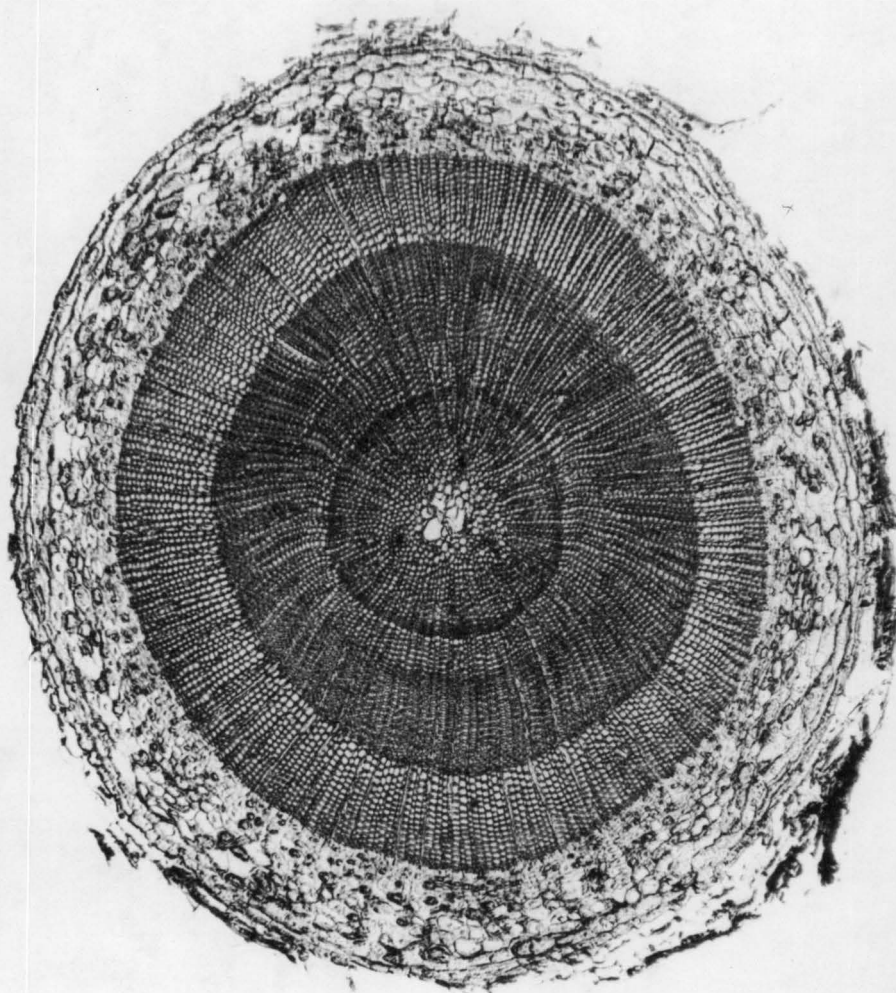


Figure 19. Cross section of the hypocotyl of Black Rock seedling number 5-5. This seedling was harvested after four growth periods under controlled environments. 60X actual size.

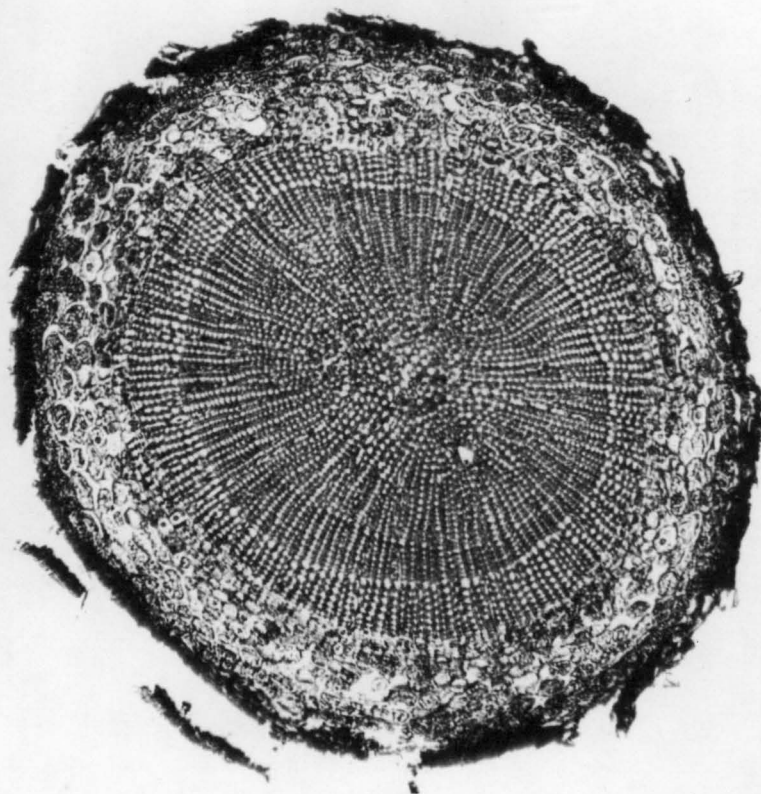


Figure 20. Cross section of the hypocotyl of Black Rock Poor seedling number 7-3. Seedling harvested after four growth periods. 70X actual size.

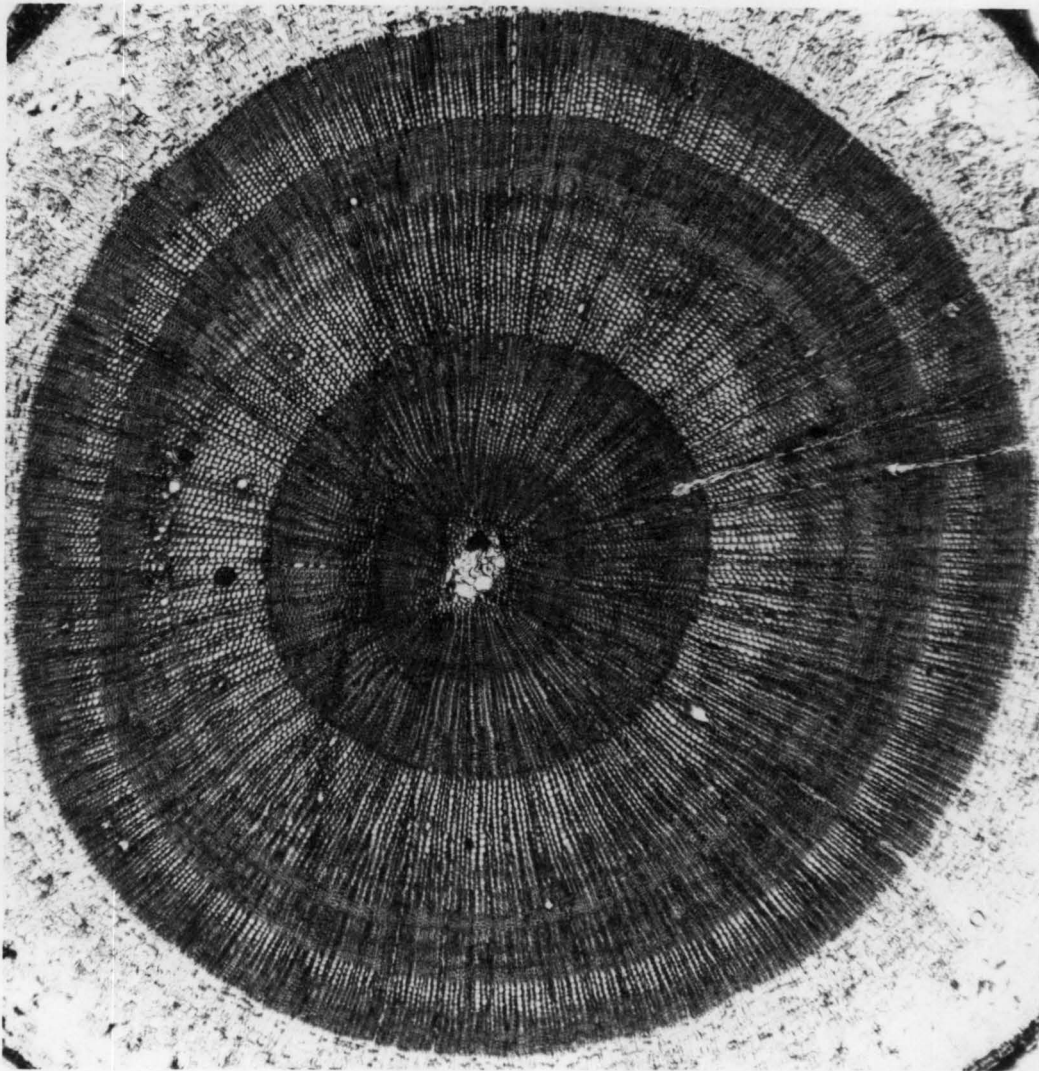


Figure 21. Cross section of the hypocotyl of one of the Douglas fir seedlings which was grown outside. This seedling was harvested at the end of the third growing season. Note false ring in the center that resulted from the early spring dormancy during the first growing season. Photograph 50X actual size.

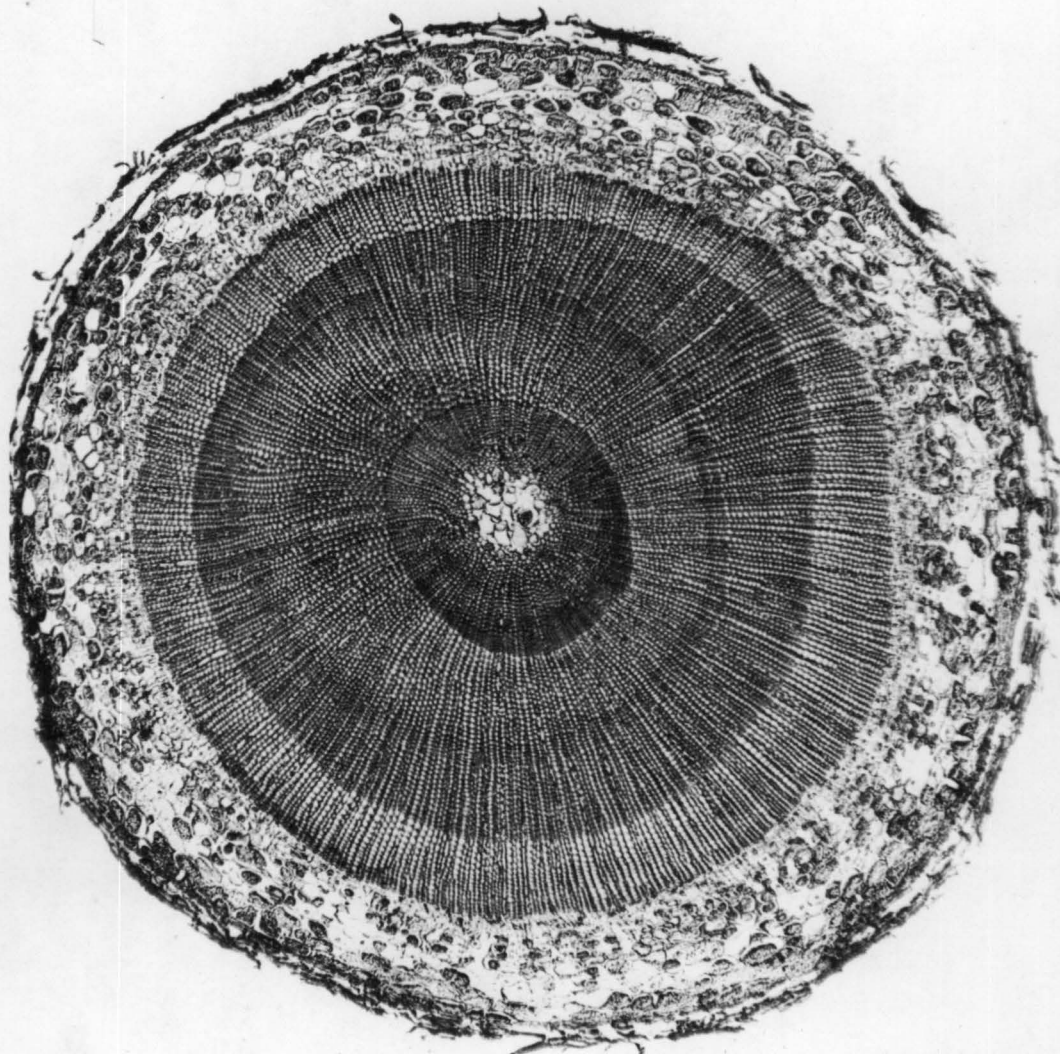


Figure 22. Cross section of the hypocotyl of Burnt Woods seedling number 2-6. Seedling was harvested after fourth growth period. 50X.

period of growth. Further, no alternating bands of "spring" and "summer" wood, which this worker believes must be formed if the growth period is to be considered more than a flush, were produced either in the spruce or in the European larch reported by Zelawski (186). Therefore, it would appear that both temperature and photoperiod control are probably necessary to shorten the annual growth cycles of coniferous seedlings.

Other Coniferous Species

As noted previously, there was sufficient space in the Bowser oven for only one container of each of the other coniferous species tested. It was believed that the very small number of seedlings could not reflect accurately the growth response of each of these species. Therefore no quantitative growth data were recorded. The only observations on the growth of these seedlings were the dates of bud burst and set. Further, since it was possible to maintain only a single controlled environment at any given time during much of this study, the deciding factor in determining the nature of the environment at any period was the growth response of the primary coniferous species of this study, Douglas fir. Therefore, even these bud burst and set data for the other species must

be qualified by the fact that the environments were not always optimum for the physiology of the hemlock, pine, noble and grand fir seedlings. All these species initiated growth and became dormant much more readily than did Douglas fir. In all probability, the true firs might have made at least one more cycle of growth if it had been possible to treat them separately.

The average fresh and oven-dry weight of the hemlock, pine and noble fir seedlings are shown in table 22. The grand fir seedlings are omitted because none of these seedlings were oven-dried. The figures in parenthesis beside each weight indicate the number of seedlings employed in determining a species mean. Some of the seedlings, whose fresh weight was determined, were repotted for future study, and therefore the oven-dry weights represent smaller populations than do the fresh weight determinations. But, in general, the repotted seedlings were about the same size as those oven-dried. It may be noted that the largest Douglas fir seedlings grown in the same soil as the noble fir and hemlock seedlings (Black Rock) have an oven-dry weight (3.41 gms.) about equal to that of the noble fir seedlings. The pine seedlings were grown in an eastern Oregon soil, and therefore a comparison of their weights with those of other coniferous seedlings tested would not be appropriate.

Table 22
Weights of Coniferous Seedlings Harvested After Four Growth Periods
Under Controlled Environments

Species	Fresh Weight gms.	Oven-dry Weight		
		Roots gms.	Shoots gms.	Totals gms.
Noble fir	19 (6)	1.65	1.89	3.54 (6)
Hemlock	6 (11)	0.34	0.69	1.04 (6)
Ponderosa Pine	20 (9)	1.14	1.53	2.68 (4)

The data in table 22 and figures 23-26 illustrate the relative top and root development of the seedlings of the different species. Considerable differences were noted in the root activity in the various seedlings after they had been exposed to temperatures below 40° F for about two months. The true fir seedlings had a few active root tips one to two centimeters in length; the pine, many root tips a few millimeters long; and the hemlock seedlings, many active root tips, some of which were one to two centimeters in length. In contrast, the Douglas fir seedlings had only a very few short active root tips. It is not known whether these active root tips were initiated while the seedlings were stored at low temperature or whether they were produced just prior to the cold storage

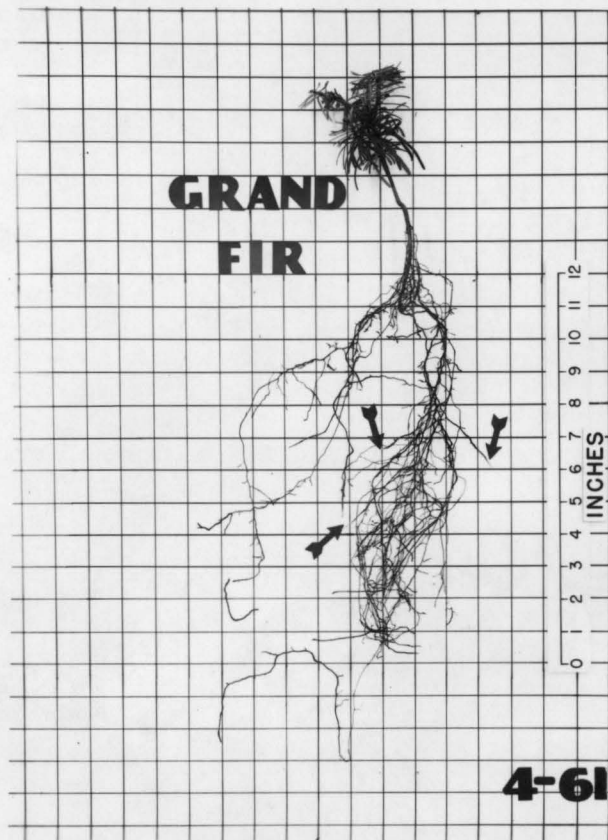


Figure 23. Grand fir seedling after four growth periods under controlled environments. Arrows point to active root tips.

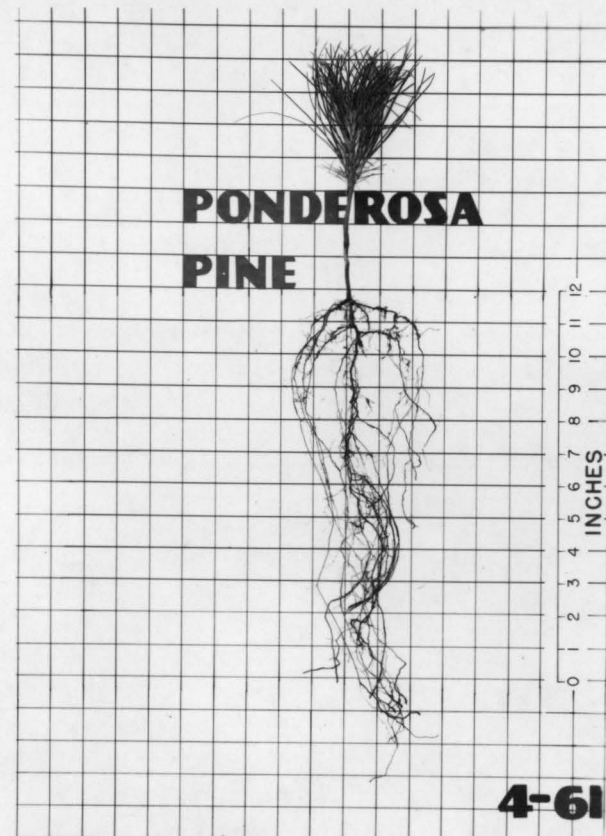


Figure 24. Ponderosa pine seedling after four growth periods under the controlled environments.

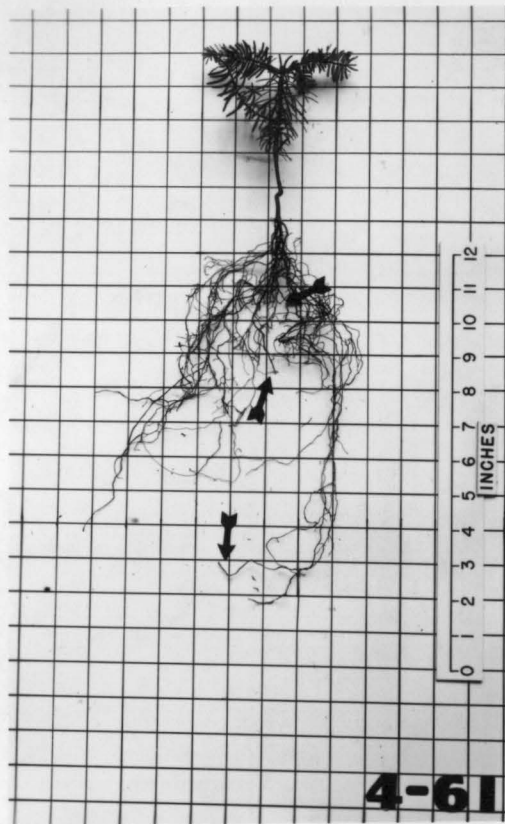


Figure 25. Noble fir seedling after four growth periods under controlled environments. Arrows indicate active root tips.

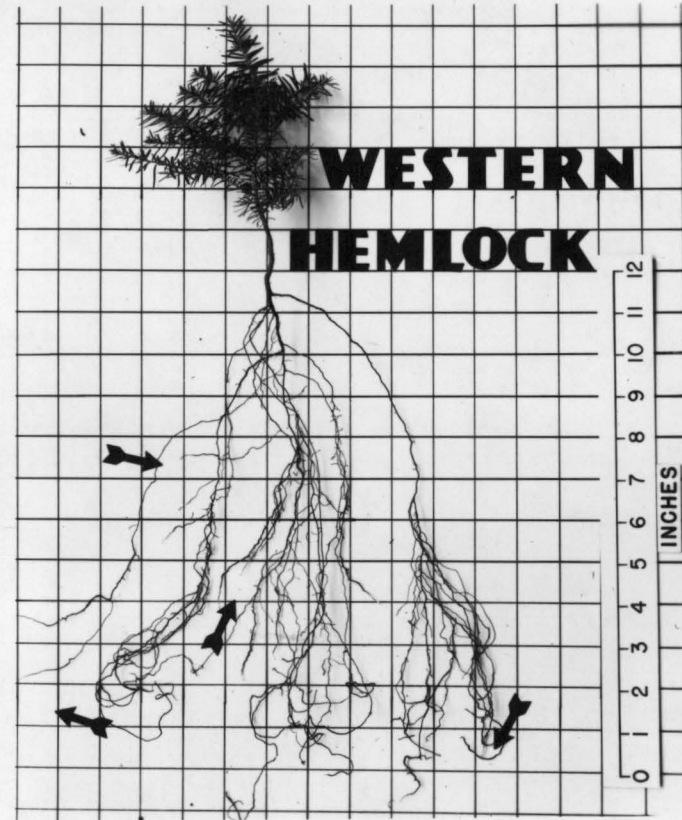


Figure 26. Hemlock seedling after four growth periods under controlled environments. This species was held in a dormancy-inducing environment two months longer than the remaining experimental population after the fourth growth period because it was extremely difficult to determine the presence of resting buds. The arrows indicate active root tips.

and remained in a non-suberized condition until harvest. A British report (120 p 15) notes reduced root growth of Douglas fir seedlings when the soil temperature is maintained at 36° F and the air temperature, 60° F. Very few active roots have been noted on nursery grown Douglas fir seedlings during the winter, when normal root zone temperatures vary between 35° F and 45° F¹.

Table 23 presents a summary of the nutrient contents of the various coniferous seedlings grown in Black Rock soil during this study. No grand fir seedlings were analyzed and the ponderosa pine seedlings were grown in eastern Oregon soil.

Wood Anatomy

Figures 27 to 30 illustrate the effects of the described alteration of growth promoting environments with those designed to induce dormancy or satisfy cold requirements upon the growth of grand fir, hemlock, noble fir, and pine seedlings. The four grand fir seedlings grown during this study had all been grown for a year in the greenhouse prior to initiation of this experiment. Two lots of noble fir seedlings, one of which was grown for a year in the greenhouse prior to initiation of this experiment were grown in the

1. Lavender, D.P. and Ernest Wright unpublished data (1959-62).

Table 23

Nutrient Content of Coniferous Seedlings Harvested After Four Growth Periods Under Controlled Environments on Black Rock Soil

Species	Element				
	Nitro-	Phos-	Potas-	Cal-	Mag-
	gen	phorous	sium	cium	nesium
	%	%	%	%	%
<u>Roots</u>					
Douglas fir	0.79	.180	.662	.292	.069
Noble fir	0.76	.122	.867	.332	.233
Hemlock	1.34	.136	.571	.385	.151
<u>Stems</u>					
Douglas fir	0.54	.120	.406	.102	.079
Noble fir	0.49	.107	.668	.272	.198
Hemlock	0.61	.076	.556	.219	.111
<u>1st-3rd Cycle Foliage</u>					
Douglas fir	0.86	.434	.871	.320	.171
Noble fir	0.95	.222	.820	.383	.328
Hemlock	1.48	.086	.797	.768	.234
<u>4th Cycle Foliage</u>					
Douglas fir	0.97	.226	1.049	.147	.135
Noble fir	0.74	.249	.643	.195	.246
Hemlock	1.24	.137	1.210	.311	.241

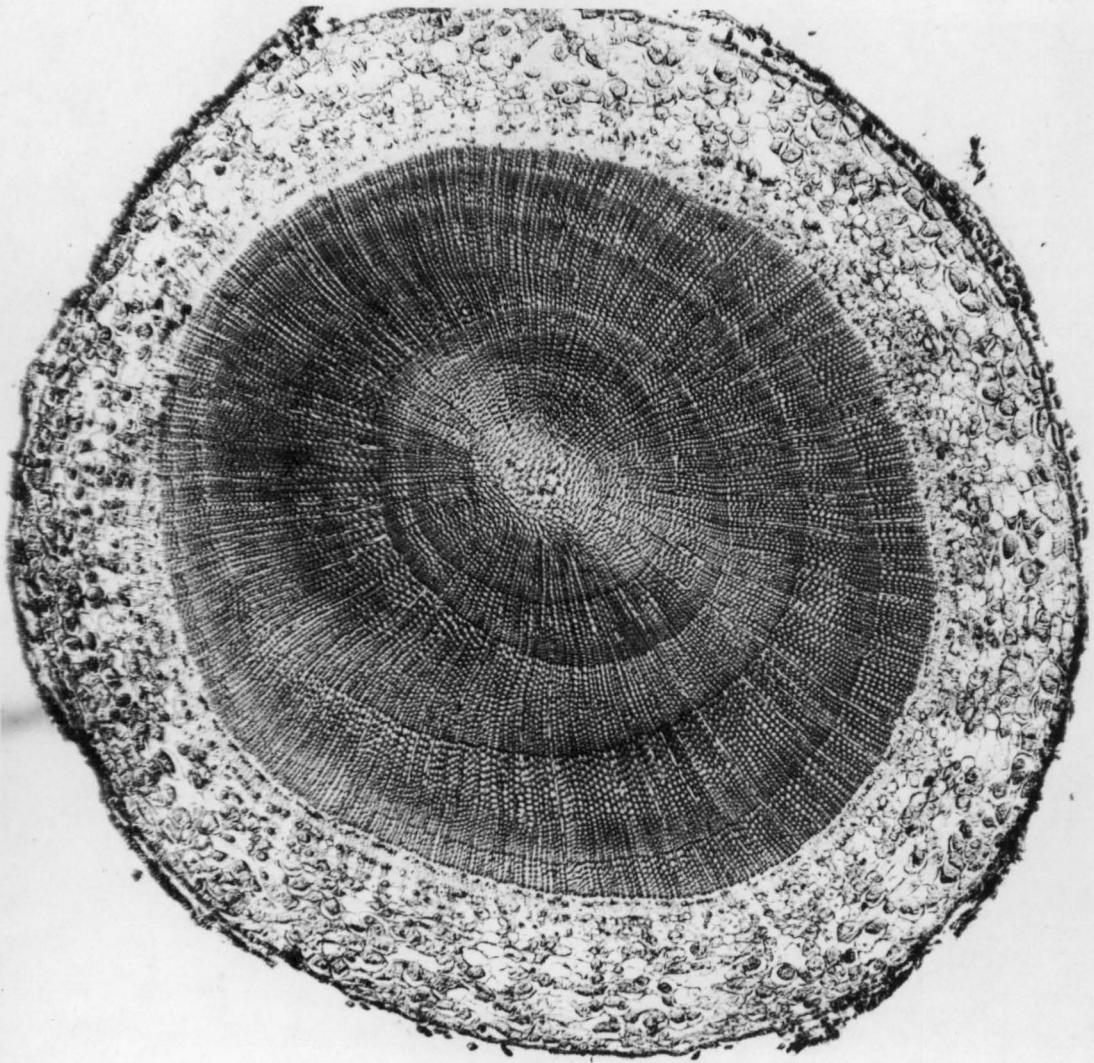


Figure 27. Cross section of the hypocotyl of a noble fir seedling. This plant was harvested after one natural growth period in a greenhouse and four growth cycles in the controlled environment chambers. 45 X natural size.

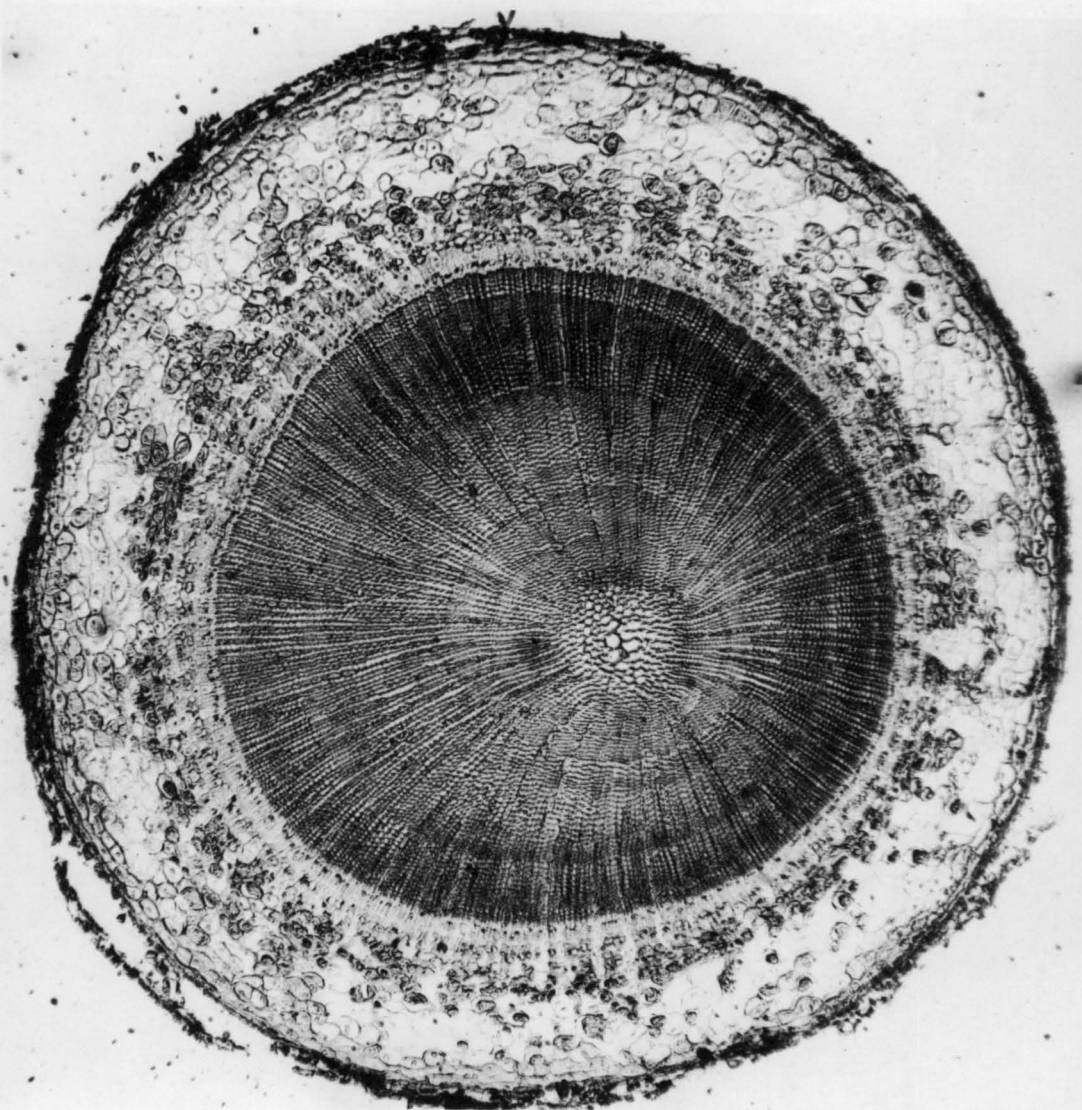


Figure 28. Cross section of the hypocotyl of a grand fir seedling. This plant was harvested after one natural growth period in a greenhouse and four growth cycles in the controlled environment chambers. 50X natural size.

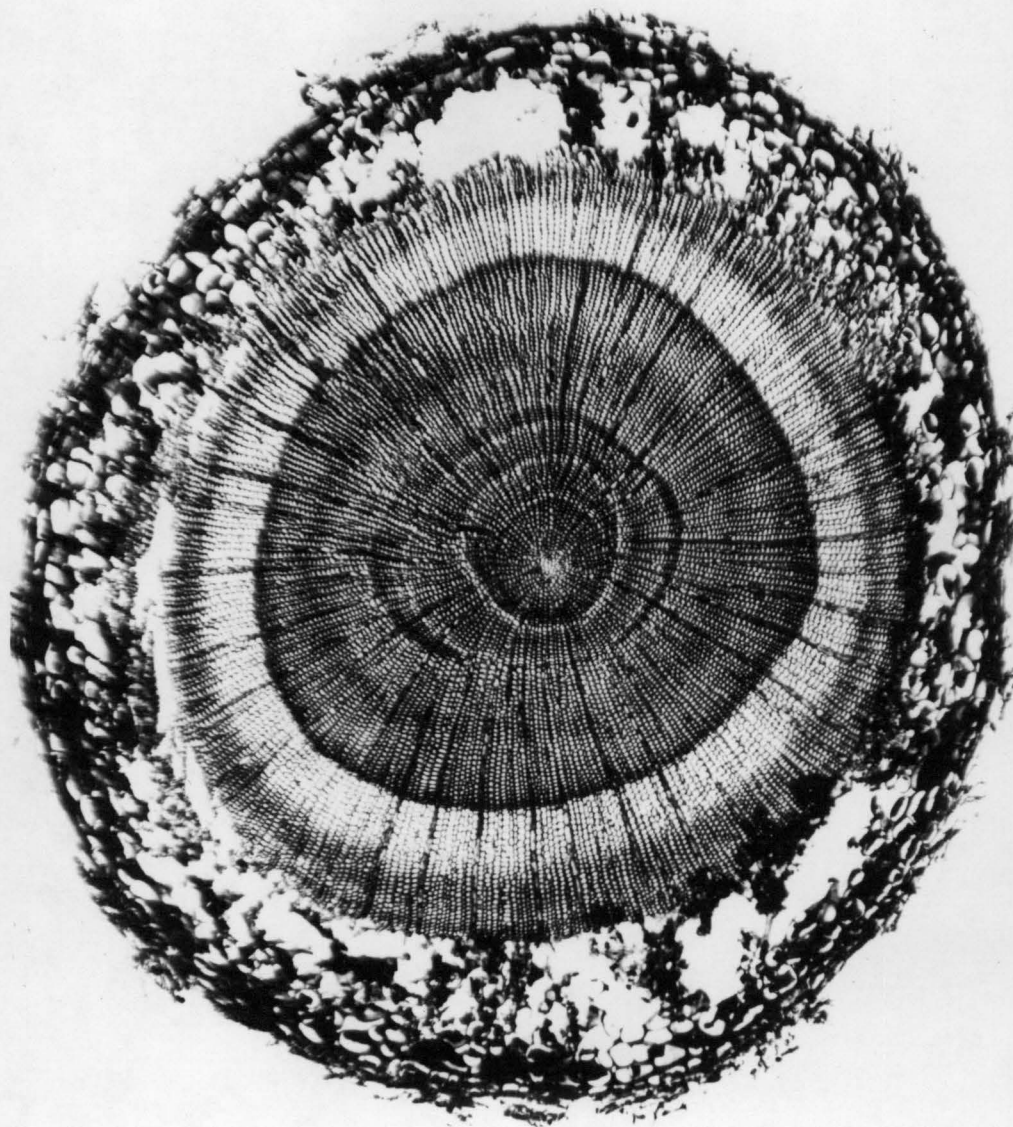


Figure 29. Cross section of the hypocotyl of a hemlock seedling which was harvested after four growth cycles. 50X.

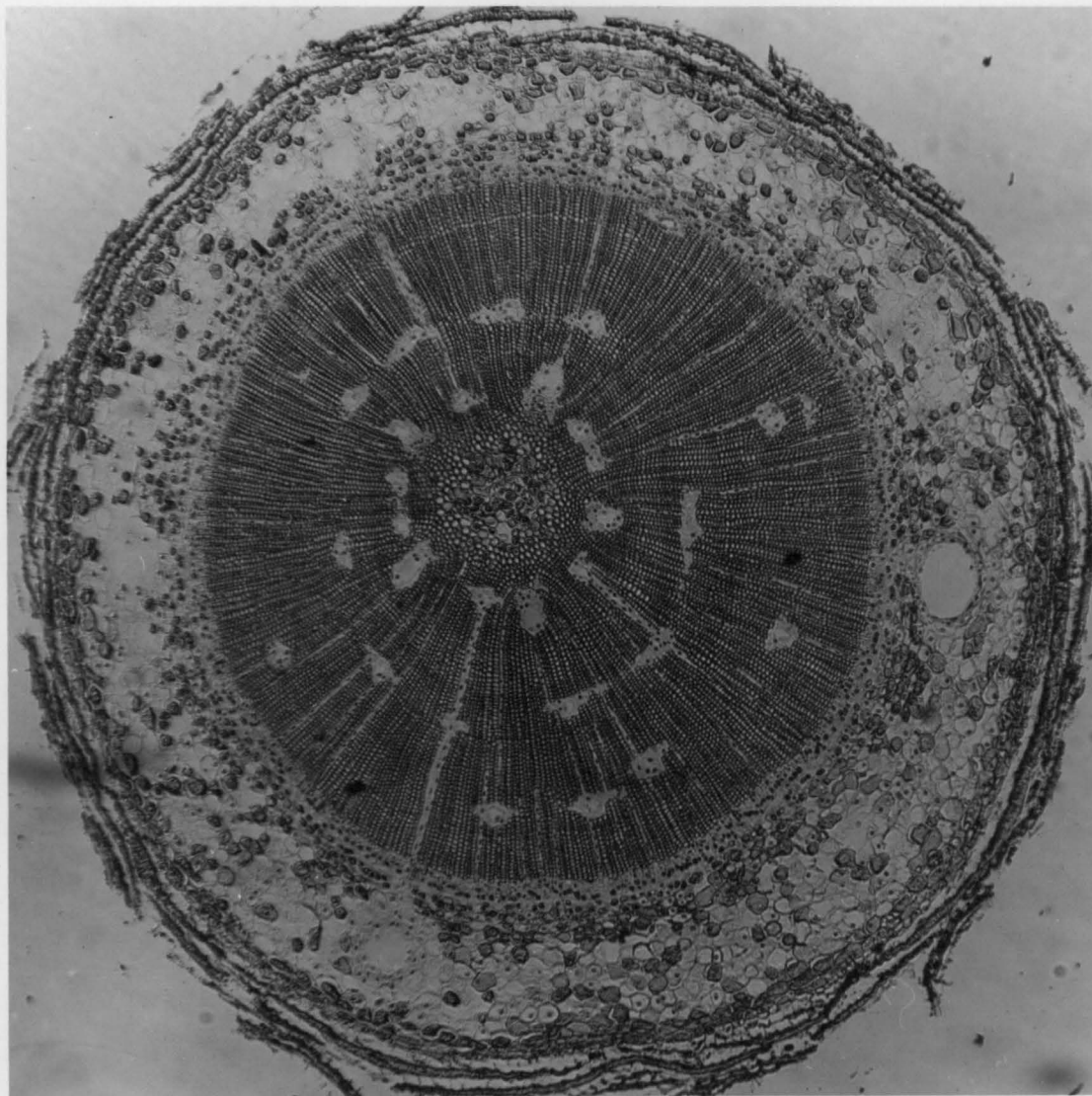


Figure 30. Cross section of the hypocotyl of a pine seedling which was harvested after four growth periods. The open areas appear to be resin canals and secretory cells. Note that the definition of the growth cycles is very faint. 40X natural size.

controlled environments. Figure 27 is a cross section of the hypocotyl of a noble fir seedling which was grown in both the greenhouse and growth room. Both figure 27 and 28 show the well defined "annual rings" of the Abies seedlings which reflect the sharp growth responses seedlings of this genus made with changes in environment.

In contrast, the absence of alternating spring and summer wood in the pine is at variance with the growth response of this species noted during the study. During all the growth cycles, pine seedlings appeared to break dormancy and to set terminal buds readily in response to environment changes.

DISCUSSION

Buds

The accurate determination of the onset of dormancy proved very difficult. The very slow development of buds, especially in the earliest stages, and the atypical appearance of the buds formed in the growth rooms during this study were the two major reasons for this difficulty. The following figures illustrate the differences found within a group of buds set by the "cycling" seedlings and buds set in the nursery on Douglas fir seedlings of similar size. In figure 31 the nursery seedling had a crown length of thirteen centimeters and a fresh weight of about thirteen grams, approximately equivalent to the average fourth cycle seedling grown in Black Rock soil. Nevertheless, it may be seen readily that the bud scales formed by the nursery grown plant are larger, more numerous, and more heavily lignified than those produced by the seedlings grown under the cycling schedule described in this report. Wareing (166 p 263) has noted a similar phenomenon on Pinus sylvestris seedlings grown in an environment which permitted only a short growth period. Douglas fir seedlings which were grown in the control chambers but under a growth promoting environment until



Figure 31. A is the terminal bud produced by a nursery grown Douglas fir seedling; B, by Burnt Woods #2-6; C, by Black Rock #5-5; and D, by Black Rock Poor #7-3. The shorter, darker needles of the nursery seedling may reflect an adaptation to the higher light intensities, or the greater moisture stress obtaining in the nursery soil at the end of the normal growth period.

they became dormant produced buds very closely resembling that of seedling "A" in figure 31. Zelawski (186 p 11) describes similar buds of Larix Europaea which were produced after inadequate photoperiodic stimulation. Therefore it would appear that the reduced size of the buds formed during this study is characteristic of terminal buds produced by coniferous seedlings during an abbreviated growth period.

Figures 32 and 33 show two seedlings with sharply differing buds after the fourth growth period. Figures 34 and 35 show the new growth made by these seedlings midway through the fifth cycle. Finally, figures 36 and 37 are micrographs of a well formed bud and a very small bud respectively. It will be noted that the bud initials in these figures are similar.

Figures 34 and 35 also show active lateral growth which developed from buds laid down on terminal shoots which were produced from buds illustrated in figures 32 and 33, and which were still elongating at the time of the photographs. This lateral growth, then, was formed from lateral buds which developed and then broke during the uninterrupted elongation of the terminal shoot. In this regard Doorenbos states:

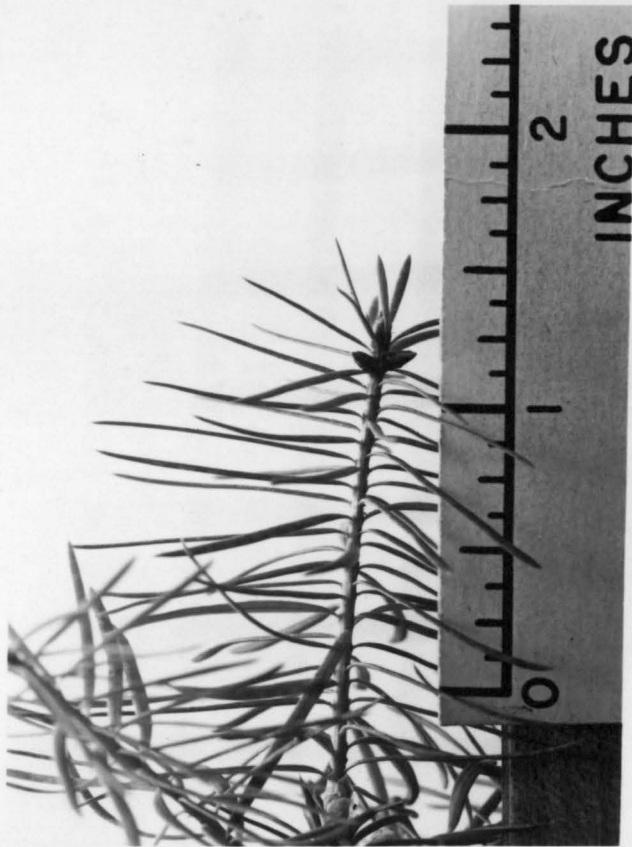


Figure 32. The relatively well-formed terminal bud on the above seedling (Black Rock #2-5) is typical of the largest terminal buds formed during this study. Photograph taken in May, 1961 just prior to the fifth growth period.

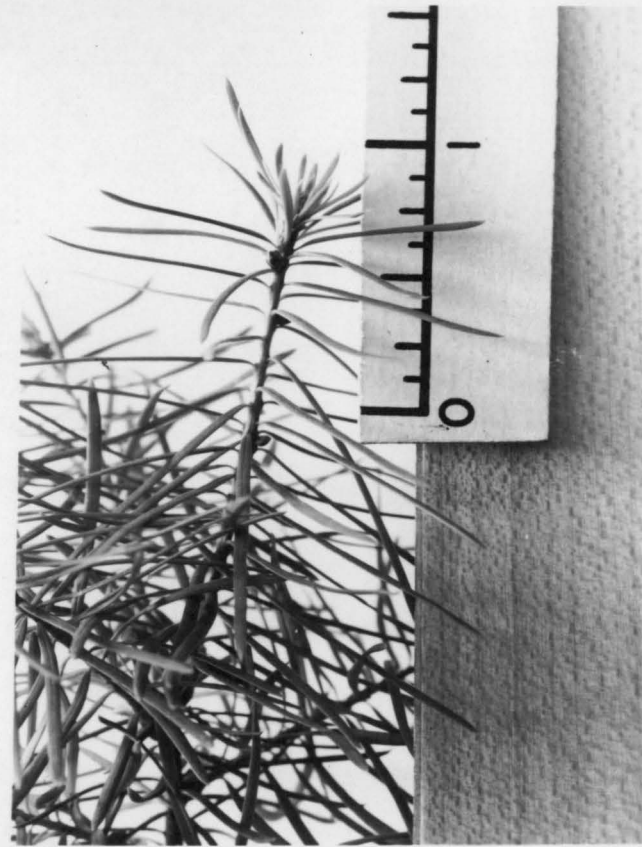


Figure 33. The very small terminal bud shown on this seedling (Burnt Woods #7-5) is typical of many such buds produced during the study. Photograph taken in May, 1961 just prior to the fifth growth period.



Figure 34. Terminal growth which developed from the bud pictured in figure 32. Photograph taken in July, 1961



Figure 35. The terminal shoot shown above developed from the bud pictured in figure 33. The remains of this bud may be seen opposite the 0.6" division on the rule. Note the active lateral growth developing on the still extending terminal shoot. Photograph taken in July, 1961.

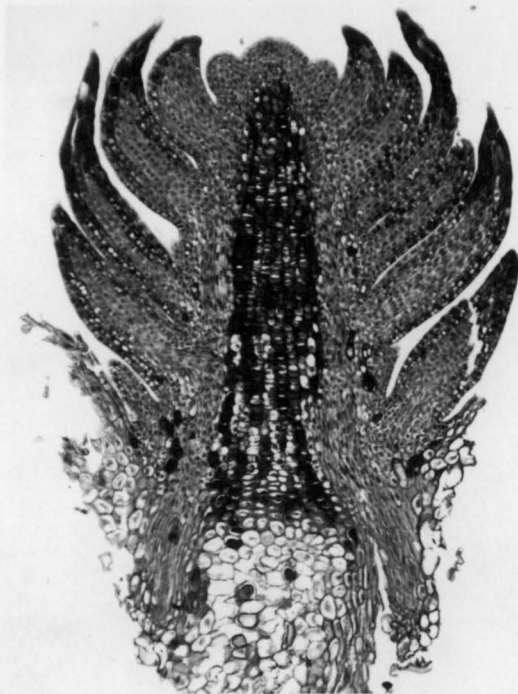


Figure 36. Cross section of the terminal bud of Black Rock seedling 1-2. This plant had a bud very similar to that shown in figure 32. 60X.



Figure 37. Cross section of the very small terminal bud of Black Rock seedling 4-5. This seedling had several small buds at the stem tip similar to those pictured in figure 33. 60X.

"Lateral buds do not develop in the season during which they are initiated, except in rare cases like some species of Ulmus where the oldest lateral growing points elongate immediately, often without forming bud scales, giving rise to what Spaeth (1912) has called sylleptic shoots. Normally the lateral buds are prevented from sprouting by a strong inhibitory influence exercised by the terminal growing point (Goebel 1880) and a similar influence, although much weaker, from the leaf in the axil of which the bud is situated (Dostal 1909). Since Thimann and Skoog discovered in 1934 that auxin descending from the terminal bud is of crucial importance in this inhibition, the phenomenon has been widely studied, and various explanations have been proposed."

But Vegis (157 p 97) observes:

"On the other hand, the shooting of newly formed axile buds is a common phenomenon in the woody species, especially in young plants, which shoot early in the spring when the temperature is relatively low. Moreover, these axile buds shoot without previous formation of bud scales and without temporary suspension of growth."

Several workers have correlated this phenomenon with the growth of plants under long photoperiods. The lateral buds of spruce (Picea glauca) grown under a twenty hour photoperiod in Florida develop promptly, while the incidence of prolepsis (the development of lateral growth from buds on the leader the same growing season) and lammas growth (two or more distinct periods of growth on lateral shoots, separated by the formation of a bud, in a single growing season) on Pinus banksiana is increased by long photoperiods (150 p 12, 16). Vaartaja (154 p 101) reports the development

of numerous laterals on both coniferous and broadleaf seedlings and that this growth habit was more frequent under photoperiods greater than fourteen hours. Similarly, Wareing (168 p 215) notes several examples of increased lammas shoot development on Pinus sylvestris under long photoperiods.

However, Gunkel, Thimann and Wetmore (58 p 315) present data which demonstrate that the development of the lateral shoots of Ginkgo biloba L. is dependent upon the general vigor of the plant. Similarly, Gregory and Veale (55 p 19) have shown that the apical dominance of the flax plant is greatly reduced when the plants are vigorous. While Aldrich-Blake (3 p 48) notes that the number of lateral shoots formed on Corsican pine seedlings grown under natural summer photoperiods in England increased with increasing supplies of nitrogen. Such would appear to be the case with Douglas fir, as the development of lateral shoots occurred only on the seedlings grown in the Black Rock and the Burnt Woods soils.

Mycorrhizae

Examination of the root systems of seedlings harvested after both the second and fourth growth periods showed that mycorrhizae were much more abundant both in per cent of infected root tips and in total number, on the seedlings grown in Burnt Woods

and Black Rock soils than on those grown in the Black Rock Poor soil. These data are in sharp contrast with the results observed on species of Pinus reported by HacsKaylo and Snow (61 p 12), Fowells and Krauss (41 p 101, 103) and Hatch (64 p 152). The last writer states:

"Soil culture experiments revealed that the abundance of mycorrhizae on the roots of pine seedlings is determined in normal forest soils by the availability of mineral salts. They were produced in abundance under conditions of low availability of any one or more than one of four elements - nitrogen, phosphorus, potassium, and calcium - or lack of balance in the availability of these elements."

Mitchell et al (110 p 70) present data from nursery experiments which confirm Hatch's results and speculate that even the most productive forest soils are not sufficiently fertile to preclude the formation of mycorrhizae. They further suggest that in many regions the range in forest soil fertility is not sufficient to test Stahl's theory that mycorrhizae are most prevalent in infertile soils.

Mineral Nutrients

The data in table 16 show that the ratio of the nitrogen uptake per unit weight of seedling tissue of the Burnt Woods seedlings to that of the Black Rock Poor seedlings dropped from 11.5 for

seedlings harvested after the first growth period to 1.4 for those harvested after the fourth. In addition, it will be noted that the foliar nitrogen content of Burnt Woods seedlings harvested after the first growth period was equivalent to the foliar nitrogen content of the second growth trees growing on Burnt Woods soil (tables 19, 21). But the youngest foliage of Burnt Woods seedlings harvested after the fourth growth period had a substantially lower nitrogen content than foliage either of previously harvested seedlings or of second growth trees.

One possible explanation for these data was that the Burnt Woods seedlings had absorbed most of the available nitrogen from the soil. Since each container held about two thousand grams of oven-dry soil, and since the Burnt Woods soil contained 0.436 per cent total nitrogen, it is apparent that each pot held about nine grams of nitrogen. The total nitrogen removed from the soil by the seedlings in each pot was about 0.24 grams or between two and three per cent of the total soil nitrogen. Several workers have noted that the rate of nitrification in soils is accelerated with increased mean temperature. Mikola (106 p 66), Lutz and Chandler (97 p 166), Schaedle (135 p 38), and Russell (133 p 483), while Aldrich-Blake (4 p 75-6) notes that the mixing of soil associated

with pot tests increases the decomposition of organic material. Therefore this impoverishment of the soil had not been expected. However, analyses of foliage collected after the fifth growth period (the seedlings were transplanted to much larger containers of fresh soil between the fourth and fifth growth periods) produced data shown in table 19. These data tend to support the above hypothesis for the Burnt Woods seedlings.

The high nitrogen content of the Black Rock Poor seedling foliage after the fifth growth period was also unexpected. Perhaps this is a reflection of current foliar growth limited by the food reserves produced in previous growth periods as noted by Baldwin (9 p 669) together with the substantially increased supplies of this element contained in the larger volume of soil.

Since the Burnt Woods seedling growth was restricted after the first growth period by the reduction of the available nitrogen, the data on the uptake of other nutrients by seedlings grown in this soil does not necessarily reflect the ability of the Burnt Woods soil to supply these elements. Therefore, only data produced by analyses of seedlings harvested between the first and second growth periods will be compared with similar data for other seedlings and for second growth trees. It may be noted, however that the distribution of the elements within the seedlings (i. e., decreasing

nitrogen and increasing calcium with needle age) is similar to that reported by Will (183 p 704) for Pinus radiata and by Wittich¹ for open-grown Douglas fir in Germany. Further, data indicating that, in coniferous seedlings, the elements discussed in this paper are concentrated in the seedling foliage has been reported frequently.

The nutrient data for the trees growing on the three study areas described on pages 32 to 40 were determined by analyses of foliage collected in November from the current year's growth of the upper three whorls. This procedure is in accordance with recommendations of Will (183 p 705), White (180 p 326), Tamm (142 p 34), Wehrmann (176) and Leyton and Armson (95 p 217) for other conifers. While no similar data has been published for Douglas fir, current studies indicate that the nitrogen content of the upper foliage reflects site quality more closely than that of the middle or lower crown.

The data in tables 19 and 21 clearly show that there is no relation between the concentrations of minerals in the seedling foliage and those in the foliage of second growth trees growing in the same soils. The differences may be due, at least in part, to the following factors:

1. Wittich, W. Personal communication, 10/60.

1. The foliage of the second growth trees is subject to the leaching action of rain. Tukey and Amling (147 p 880), Tukey et al (148 p 505) and Mes (105 p 168) have all shown that both rain and periods of soaking will remove substantial quantities of nutrients from plant foliage. But Tukey et al (148 p 499) note that plants with waxy leaves (Douglas fir has a waxy layer over the cuticle) lost smaller quantities than those with non-waxy leaves. Voigt (160 p 322), Tamm (141 p 187), and Madgwick and Ovington (99 p 14) all report substantial increases in the nutrient content of rainwater collected under forest stands over that obtained in open areas. Nitrogen and phosphorus were much less subject to leaching than were calcium, magnesium, potassium, and sodium. It should be noted, however, that none of the above reports indicated what, if any, provisions were taken to exclude the possible contribution of dust on the foliage to the values of leached nutrients.
2. The soil collected from each area represented only the upper foot and not the entire soil profile.

3. The number of trees sampled on each soil was probably inadequate to characterize the different soil fertilities accurately. Wehrmann (176) and Strebel (140 p 41) recommend samples from at least ten trees for determinations of nitrogen and phosphorus; thirty for potassium and magnesium; and one hundred for calcium. Unfortunately, such extensive sampling is currently beyond the author's resources.
4. The foliar content of the first cycle seedlings reflected in varying amounts the nutrient capital of the seeds. In table 24 the nutrient uptake of the seedlings (expressed as per cent of seedling dry tissue) is compared with the concentrations of the different elements in the second growth foliage. Here both the seedling and tree data reflect the higher nitrogen content of the Burnt Woods soil, but little correlation may be seen with the other elements studied.
5. Current investigation indicates a tendency of the phosphorus and potassium content of Douglas fir seedling foliage to rise with decreasing shade. Maximum values were found in foliage grown under full sunlight.

Table 24

**A Comparison of Seedling Nutrient Uptake with the Nutrient Content
of Second-growth Foliage**

Tissue Analyzed	Element				
	Nitro-	Phos-	Potas-	Cal-	Magne-
	gen	phorus	sium	cium	sium
	%	%	%	%	%
Burnt Wood Seedlings	1.05	.17	.81	.17	.12
Black Rock Seedlings	0.30	.11	.47	.18	.08
Black Rock Poor Seedlings	0.09	.04	.42	.15	.10
Burnt Woods Trees	1.60	.18	.90	.27	.15
Black Rock Trees	1.41	.17	.51	.43	.25
Black Rock Poor Trees	1.18	.26	1.06	.26	.14

Table 26 presents a comparison between the nutrient content of the foliage of second growth trees analyzed during the course of this study with data reported elsewhere. Little is known of the relationship of the levels of the different nutrients in the foliage to the vigor of Douglas fir trees, although Gessell and Walker (49 p 100) do note that chlorotic foliage is associated with a nitrogen content of below 0.8% and that green, vigorous foliage will have at least 1.1% nitrogen. The data in table 26 show the wide range of mineral content and of relative levels of the different minerals reported for Douglas fir.

Table 25

A Comparison Between the Nutrient Contents of the First Cycle Douglas Fir Seedlings and the Only Other Data Known to the Author on the Nutrient Content of One Year Old Douglas Fir Seedlings*

Source	Mineral Composition (Per Cent Oven-dry Weight)				
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
	<u>Shoot</u>				
Burnt Woods, 1st Cycle	1.58	.23	.96	.11	.20
Black Rock, 1st Cycle	0.78	.18	.57	.11	.19
Black Rock Poor, 1st Cycle	0.94	.16	.64	.11	.22
U.B.C. Forest, Haney, B.C. 1957	1.29	.14	.53	.21	.11
University of British Columbia 1957	2.77	.15	.79	.51	.11
Green Timbers Forest Nursery 1957	2.01	.10	.74	.41	.05
Green Timbers Forest Nursery 1958	1.40	.09	.70	.33	.13
	<u>Root</u>				
Burnt Woods, 1st Cycle	1.40	.18	.74	.23	.07
Black Rock, 1st Cycle	0.78	.15	.46	.25	.02
Black Rock Poor, 1st Cycle	0.73	.10	.34	.21	.03
U.B.C. Forest, Haney, B.C. 1957	0.93	.12	.21	.22	.10
University of British Columbia 1957	1.95	.15	.63	.50	.12
Green Timbers Forest Nursery 1957	1.85	.10	.29	.36	.13
Green Timbers Forest Nursery 1958	0.93	.10	.35	.19	.10

* The seedlings from Haney, B.C. were grown under natural field conditions, but the remainder were irrigated and fertilized.

Table 26

A Comparison of the Nutrient Content of Current Year Douglas Fir Foliage Analyzed During This Study
With Similar Data Reported From Other Forested Areas

Source	Mineral Composition (Per Cent Oven-Dry Weight)				
	Nitrogen	Phosphorous	Potassium	Calcium	Magnesium
Burnt Woods	1.48	.225	.992	.286	.143
	1.73	.145	.812	.249	.164
Black Rock	1.39	.175	.522	.322	.190
	1.44	.169	.499	.537	.326
Black Rock Poor	1.15	.176	1.116	.436	.136
	1.20	.344	1.003	.190	.136
Washington State					
Soil: very gravelly loam					
Foliage: chlorotic	0.91	.18	.89	.386	.85
Soil: shallow loam					
Foliage: chlorotic	1.17	.08	1.05	.278	.87
Soil: gravelly loam					
Foliage: green	0.95	.16	.64	.318	.16
Soil: loam					
Foliage: green	1.59	.08	1.21	.274	.17
Soil: deep loam					
Foliage: green	2.10	.24	.90	.348	.74
Germany	2.28	.25	1.11	.59	.18
England	1.27	.09	.38	.74	.17
	1.02	.19	.43	1.37	.14

Washington State data after Gessel et al, 1950

German data after Wittich (personal communication 1961)

English data after Ovington, 1956

No published data on the nutrient requirements or the foliar mineral content for the other species analyzed in this study are known to exist. However, Ovington (119 p 27-8) presents data on the nutrient content of Abies grandis and Tsuga heterophylla foliage which are very similar to those found for Douglas fir in this study.

In table 20 the analysis data are arranged by seedling size classes, the mean weights of which are listed in tables 35-37 in the appendix, in each soil type. The size classes contain four seedlings each in the Burnt Woods and Black Rock soils and five in the Black Rock Poor. No two seedlings in any size class were grown in the same soil container. It may be noted that there is no relation between mean seedling size and the level of nutrient content for any of the three soils. Similarly, there was no relation between seedling size within a soil and the nitrogen content of seedlings harvested after the first and second growth cycles. (There was sufficient tissue to permit nitrogen analyses of seedlings harvested from each container after the first two growth periods, but not for the remaining nutrients. The nitrogen content data for the first two cycles in tables 17-19 are, therefore, mean values.)

Several laboratory and field studies have been conducted in Europe to determine the relationship between the nutritional

status of seedlings and trees with the efficiency of their foliage. Ingestad has published graphs for Pinus silvestris L. (75 p 520), for Picea abies (L.) Karst. (74 p 579), and for Betula verrucosa (Ehrh.) (73 p 428), which demonstrate that the efficiency of the foliage of all three species was a constant and independent of the nutritional status of the seedlings. He also reports that his data confirm the field studies of Stafelt, who worked with Swedish conifers several decades ago.

Figure 38 presents the relationship of the oven-dry weight of the foliage of the seedlings harvested during the course of this study to the oven-dry weight of the stems and roots of the same seedlings. The points plotted represent the mean weights of seedlings harvested from each soil after the first two growth periods, and the mean weights of each seedling size class for plants harvested after the fourth growth period. None of the data shown on this graph were statistically analyzed, but the very consistent manner in which these data plot makes it clear that the efficiency of Douglas fir foliage is independent of the seedling's nutrition.

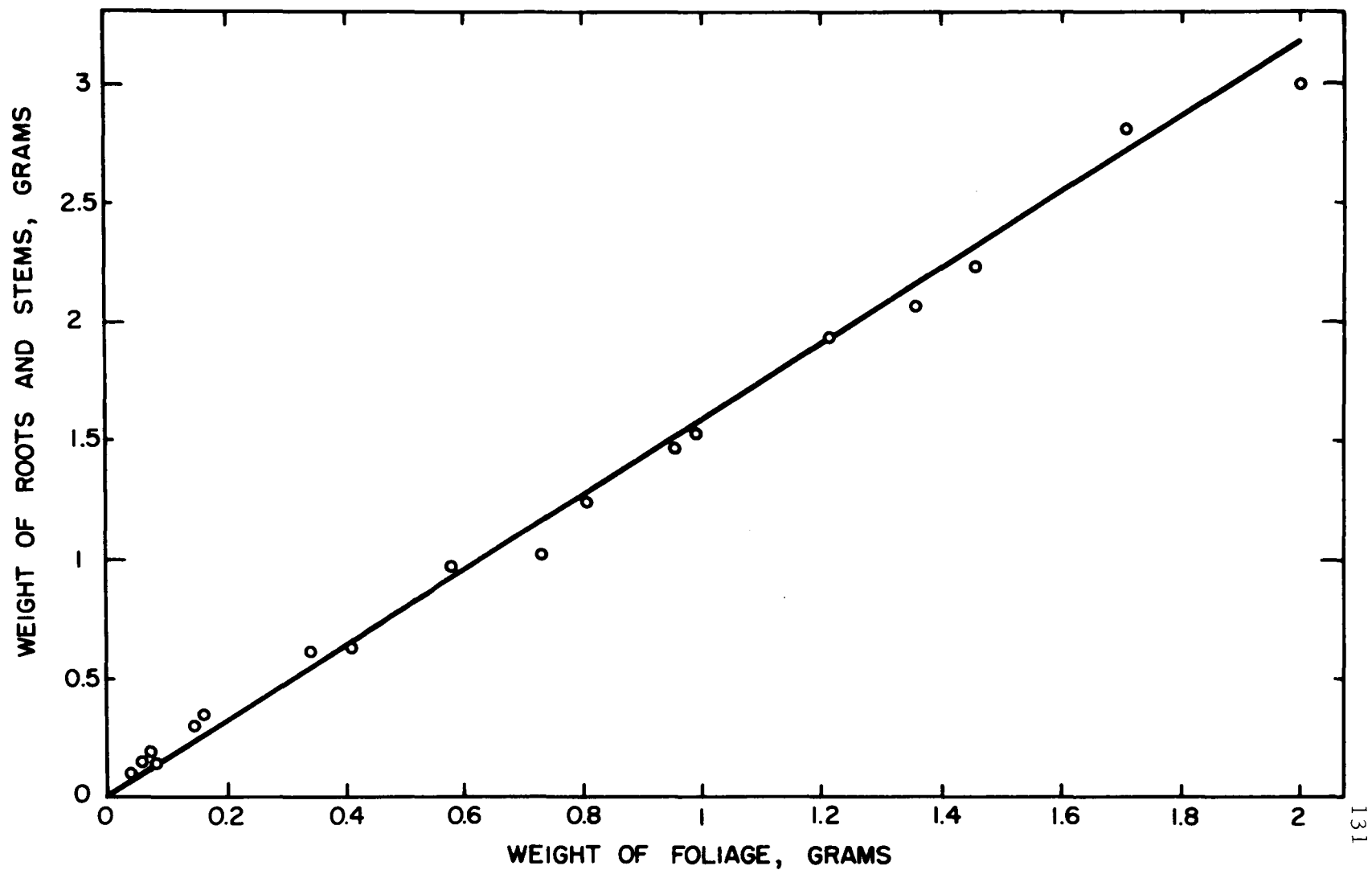


Fig. 38. The Relationship between Oven-dry Weight of Foliage and the Sum of Oven-dry Weights of Stem and Root within All Cycles and Soils.

Growth Response

One objective of this study was to determine if a more uniform growth response of Douglas fir seedlings could be obtained by growing them in controlled environments. Went (177 p 320) states:

"....the variability is at least halved, when plant material is grown in greenhouses with positive temperature control provided by simple air conditioning. A further reduction in variability, again of the order of 50 per cent, is possible with the use of artificial light. Additional improvements can be achieved by control of air pollution, rate of air movement over the plants, uniform nutrition by eliminating the soil, etc."

However, the data obtained during the present study do not confirm Dr. Went's observations. The variation within the population of seedlings grown in the Black Rock soil in the growth rooms with respect to duration and quantity of leader growth was very similar to that of the control population, which was grown upon the same Black Rock soil but outside for two years. The period of active leader growth of Douglas fir is initiated and terminated by a gradual sequence of morphological changes. The duration of leader growth, then, cannot be determined accurately and, therefore, may not be a good index of the regulatory effect of controlled environments. But total leader growth can be measured fairly

accurately and these data show no increase in uniformity of growth response within the control chambers over that produced under natural conditions. This failure of the controlled environments to produce a more uniform growth response from Douglas fir seedlings is illustrated further by the fact that terminal elongation of some seedlings continued for as long as four or five weeks after the plants were placed under an environment designed to induce dormancy, while other seedlings developed both terminal and lateral buds under a photoperiod that favored elongation (figure 39). These buds then frequently broke and the plants resumed active growth after they were transferred to an environment designed to induce dormancy. In general, however only a small fraction of the terminal elongation was produced under short photoperiods. The majority of the variation in leader length was a result of variation in growth rate or growth duration while the seedlings were in growth-promoting environments.

Hutchinson (18 p 44) notes that the genetic variation in any given population has the greatest opportunity for expression under the most favorable environments. Therefore, if the controlled environment chambers provided a more favorable regime for growth (during the growth-promoting period) than obtained naturally,



Figure 39. The bud shown on Burnt Woods seedling #6-6 above formed under a long photoperiod and then broke eight days after the seedlings were placed under short photoperiods.

the lack of increase in uniformity of the growth response of the seedlings would (according to this theory) be a logical result.

It was noted in the literature review that little was known of the environments which were most effective in influencing the growth of Douglas fir seedlings. Ideally the optimum environment for each stage of a seedling's annual growth cycle should have been determined prior to the initiation of this study. However, the equipment then available was so limited that such an approach would have required a long time. Therefore approximations of the natural environments obtaining during each stage of the annual growth cycle were employed. Unfortunately, however, these estimates were not always the most effective possible environments for inducing desired growth responses and this fact may have contributed to the lack of uniform growth.

As noted in the results section, the original project plan failed to provide a period of warm, long nights to induce seedling dormancy. Although this discrepancy was at least partially corrected during the first and subsequent cycles, an environment has not yet been found which was able to cause a rapid cessation of growth in all seedlings. More elaborate investigations of environmental causes of dormancy are needed to determine if a more

uniform growth response of Douglas fir in controlled environment chambers is possible.

Went notes (1977 p 219) that it has been possible to reduce the normal annual cycle of bulbs no more than fifty per cent. The results of the current study indicate that no more than a similar reduction is possible for the average population of Douglas fir seedlings produced from western Oregon seeds. The results further indicate that the controlled environments were able to influence only the length of the chilling period, which is apparently determined naturally by climate and not by seedling metabolism.

The Abies seedlings appeared more flexible in their growth response and future investigation may show that these species require less than six months to complete the annual growth cycle.

Light

As previously noted, this project was designed to determine whether the growth of seedlings on soils obtained from forest areas of differing productivity reflected these fertility differences and whether the annual growth cycle could be compressed by manipulation of closely controlled environments. While it is true that individual environmental factors are subject to much greater

manipulation within a greenhouse or growth chamber than is possible under natural conditions, it is also true that environmental factors not studied may be modified to such an extent that any data obtained are invalid under natural environments. Two such factors which are both difficult to measure and control are light and soil moisture.

In the study of plant growth in controlled environments, perhaps the environmental factor most greatly changed, and, at the same time, the one factor most difficult to measure and assess, is light. As noted in the description of the growth chamber, the illumination available at plant height was approximately 1400 foot candles or about 14 per cent of maximum sunlight in the latitude of Corvallis at mid-day during the summer months (185 p 445). The use of intensity as the sole measure of a plant's light environment has been criticized (47 p 668) on the basis that measuring instruments and plants are sensitive to different parts of the spectrum, and that intensity is an instantaneous measurement which may very well not reflect the total radiant energy received by the plant during the entire growing season (i.e., the fact that full sunlight has an intensity of about 10,000 foot candles has little value as a basis for comparing a natural environment with that obtaining in a control growth room unless the per cent of the

total hours of sunlight which have this and lower values is also known). Therefore, as mentioned previously, attempts to measure the total radiation available to the plants were made. The results indicated an energy level of about .15 langley or about 9 langleys per hour, or 140 langleys during the 15.5 hour photoperiod. The following table presents the mean number of langleys per day received on a horizontal plane in the vicinity of Corvallis during 1958. These data indicate that the light available in the light room was no more than 25 per cent of the light energy available on a mean day during the normal growth period. (May-July).

Table 27
Solar Radiation at Corvallis, Oregon

Month	Mean Number of Langleys per Day
January	87
February	109
March	313
April	383
May	577
June	514
July	684
August	606
September	402
October	266
November	118
December	77

From Volume 10 Climatological Data National Summary U.S. Dept. of Commerce, Weather Bureau, Asheville, North Carolina 1958.

Gast (47 p 671) notes that, at radiation intensities of approximately 20 per cent of full sunlight, only a low level of nitrogen (above the control) could be utilized by Scots pine before radiation became limiting to growth, and further, that radiation levels approximating fifty per cent of full natural radiation during the growth period are necessary if Scots pine is to utilize fully the available nitrogen in rapidly mobilizing raw humus. The same author and Mitchell (108 p 20) state, however, that seedlings grown under conditions of limiting radiation will produce a high shoot/root ratio. The data in tables 14-16 indicate that the seedlings harvested during this study had a well balanced shoot/root ratio.

Baker (8 p 434) has shown that Douglas fir seedlings raised in an average light intensity of about 1400 foot candles for a twelve hour period grew larger than those raised in full sunlight in the same greenhouse (2800 foot candles). He admits, however, that the unfavorable temperatures sustained by the unshaded seedlings may have contributed to their poorer growth. The implication in this last statement that all other factors of the environment must be held at an optimum and that this does not occur over prolonged time intervals even under carefully controlled conditions emphasizes that much of the data reported for light intensities which

are reported to give optimum growth can have only general application.

The following data indicate further the difficulty in assessing the effects of light quality and intensity upon the vegetative growth of plants. Went (177 p 283) has shown that 1000 to 1500 foot candles represents the saturating intensities for photosynthesis for many herbaceous plants, but that results vary with temperature, light quality, and duration of photoperiod. Wassink et al (172 p 256) have shown that optimum light levels at any period in a plant's growth may be conditioned by the light intensities to which the plant was previously exposed, and Richardson (129 p 456) indicates that leaf age must be considered when effects of light intensity on the photosynthetic rate of detached leaves are measured. Kramer (86 p 163), Bormann (14 p 201) and Decker (30 p 306) report considerably higher optimum light intensities (up to full sunlight) for coniferous species than those reported for many angiosperms, but mutual shading of foliage may have been a factor in these results. Krueger¹ minimized this last factor by measuring the apparent photosynthesis of two to five-week-old Douglas fir seedlings before their crowns had developed sufficiently to cause appreciable shading. His data show that 3000 foot candles of incandescent

1. Personal conversation 12/18/61.

light (a value only slightly higher than those reported for many angiosperms) is the saturation intensity for Douglas fir. Finally, a weakness in all data based on measurements of apparent photosynthesis for a very brief period is that there are no data which indicate that such high light intensities, if maintained for an entire growing season, would result in higher yields than are obtained under natural light regimes.

Schaedle (135 p 56) reports that the oven-dry weight of seedlings after one summer's growth in a fertilized nursery bed was 0.11 to 0.17 grams. Lavender (92 p 7) notes that the oven-dry weight of first year Douglas fir seedlings raised in the Corvallis forest nursery was between 0.2 and 0.3 grams. It is appreciated that adverse temperatures in these nurseries may have reduced seedling growth, but it would appear that a comparison of such data with the oven-dry weight of seedlings harvested after the first growth period (about 0.2 grams) indicates that the light intensities employed in this study did not limit the interpretation of the seedling response to the different soils.

Soil Moisture

As noted in the methods section, the irrigation schedule followed in this study was designed to provide equal moisture

stress (in so far as physics of moisture distribution in a disturbed soil permitted) in all soils at any one time; to prevent saturation and leaching of the soils; and to produce a soil moisture regime compatible with the environment desired (i. e., moist but not saturated soils favor seedling growth while dry soils are generally considered to favor the initiation of dormancy). The normal development of the roots and the lack of any evidence of poor soil aeration such as abnormally low potassium uptake (94 p 267-8) indicate that soil saturation, at least for prolonged periods, was avoided.

During the "dormancy inducing" periods of the various cycles the mean soil moisture was maintained between two and fifteen atmospheres tension in all the containers. Such procedure involved the addition of some water every week, which moisture wetted some of the soil to field capacity. Recent trials with Douglas fir seedlings indicate that these plants can withstand prolonged periods of soil moisture tensions greater than fifteen atmospheres. The use of large containers with correspondingly slower rates of moisture loss than occurred in pots employed during this study, together with more drastic drying of the soil between additions of moisture might prove more conducive to seedling dormancy than the regime employed.

SUMMARY

The study reported here was designed to determine if the natural annual growth cycle of coniferous seedlings could be shortened by manipulation of environmental factors, and whether the growth response of Douglas fir seedlings so cultivated would be more uniform than the species demonstrates under greenhouse environments. The results indicate that the annual growth cycle of Douglas fir seedlings may be shortened to six months. However, this represents a reduction of the winter resting period only. Limitations of facilities prevented an accurate determination of similar data for the other species tested, but it appears probable that the annual growth cycles of grand and noble fir and western hemlock might be shortened below six months.

The manipulation of the environment did not produce a significantly more uniform growth response in the Douglas fir seedlings, although the difference in size between seedlings grown on soils from high and low sites was shown to be highly significant. The data do suggest, however, that the suitability of this tree as a bio-assay agent may be greatly increased by growing it through a very short first growth period and a much longer second growth period.

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APPENDIX

Table 28

Age of Seedlings at Initiation of Terminal Buds

Container Number	Seedling Number					
	1	2	3	4	5	6
<u>Burnt Woods</u>						
1	151*	151	137	116	116*	137
2	137*	137	137	137*	137	137
3	116	137*	116	116	116*	116
4	137*	137	137	116	116*	137
5	116	116*	116	116	137*	137
6	137	137*	116	137	137	116*
7	137	116*	137	137	116	116*
8	116	137	116	137*	116	116*
mean						128
<u>Black Rock</u>						
1	116*	116	137	116*	137	116
2	137*	137	116*	137	137	151
3	137*	116	137	137	116*	151
4	116	137*	137	137*	137	137
5	116	137*	116	137	137	137*
6	116	137	137*	137	116	116*
7	116	116*	116	137	116	151
8	137	151	116	151*	151	137*
mean						131
<u>Black Rock Poor</u>						
1	116*	116	116*	116*	137	137
2	116*	137	137	116*	116	116
3	116	116*	116	137	116*	116
4	137*	116	116	137*	116	137
5	137	116	137*	116	137*	137
6	137	151	137	137*	116	137*
7	116	137*	116	116	116*	116
8	116	137	116	137*	137	137*
mean						125

* Willamette Valley-Southern Oregon Cross.

Table 29
Oven-dry Weights of Douglas Fir Seedlings Harvested After One
Growth Period

Container Number	Mean wt. of needles gm	Mean wt. of stems gm	Mean wt. of shoot gm	Mean wt. of roots gm	Total mean wt. gm
<u>Burnt Woods</u>					
1	0.0744	0.0222	0.0966	0.0656	0.1622
2	0.0936	0.0308	0.1244	0.0892	0.2136
3	0.0811	0.0266	0.1077	0.0994	0.2071
4	0.0788	0.0271	0.1059	0.1147	0.2206
5	0.1011	0.0288	0.1300	0.1226	0.2526
6	0.0889	0.0266	0.1155	0.1406	0.2561
7	0.0946	0.0276	0.1222	0.1563	0.2785
8	0.0684	0.0197	0.0881	0.0827	0.1708
mean	0.0860	0.0256	0.1125	0.1100	0.2225
<u>Black Rock</u>					
1	0.0798	0.0277	0.1075	0.1186	0.2261
2	0.0549	0.0189	0.0738	0.1145	0.1883
3	0.0755	0.0281	0.1036	0.1370	0.2406
4	0.0803	0.0261	0.1064	0.1176	0.2240
5	0.0654	0.0241	0.0895	0.1044	0.1939
6	0.0624	0.0177	0.0801	0.0974	0.1775
7	0.0732	0.0220	0.0952	0.1043	0.1995
8	0.0477	0.0151	0.0628	0.1116	0.1744
mean	0.0637	0.0277	0.0914	0.1135	0.2049
<u>Black Rock Poor</u>					
1	0.0432	0.0180	0.0612	0.0505	0.1117
2	0.0517	0.0235	0.0752	0.0707	0.1559
3	0.0415	0.0188	0.0603	0.0515	0.1118
4	0.0529	0.0194	0.0723	0.0928	0.1651
5	0.0449	0.0194	0.0643	0.0653	0.1296
6	0.0478	0.0185	0.0663	0.0771	0.1434
7	0.0512	0.0188	0.0700	0.0763	0.1463
8	0.0429	0.0220	0.0649	0.0615	0.1264
mean	0.0461	0.0198	0.0659	0.0651	0.1310

Table 30

Length of Douglas Fir Seedling Crowns After First Growth Period

Container Number	Crown Length (mm.)					
	1	2	3	4	5	6
<u>Burnt Woods</u>						
1	31*	29	41	48	36*	35
2	43*	40	28	29*	51	36
3	32	33*	24	35	35*	33
4	14*	41	35	20	31	19
5	21	15*	24	27	23*	25
6	26	29*	35	34	39	25*
7	44	21*	38	18	34	21*
8	31	13	19	15*	31	19*
mean						30
<u>Black Rock</u>						
1	35*	41	29	34*	41	41
2	17*	23	19*	24	19	13
3	15*	26	17	17	13*	17
4	39	19*	21	11*	38	26
5	24	19*	11	21	18	26*
6	17	25	18*	7	10	17*
7	21	14*	10	28	17	23
8	41	26	32	22*	26	20*
mean						23
<u>Black Rock Poor</u>						
1	11*	18	13	19*	11	18
2	20*	18	19	13*	21	18
3	19	4*	8	19	13*	14
4	18*	10	6	18*	13	20
5	15	18	16*	19	13*	17
6	11	10	9	14*	13	14*
7	14	10*	18	13	14*	15
8	12	13	14	15*	16	13*
mean						14

*Willamette Valley-Southern Oregon Cross.

Table 31
Mean Oven-dry Weights of Douglas Fir Seedlings Harvested After
Two Growth Periods

Container Number	Mean wt. of needles gm	Mean wt. of stems gm	Mean wt. of shoot gm	Mean wt. of roots gm	Total mean wt. gm
<u>Burnt Woods</u>					
1	0.3385	0.1350	0.4735	0.5512	1.0247
2	0.5164	0.2188	0.7352	0.5862	1.3214
3	0.4277	0.1732	0.6009	0.4064	1.0073
4	0.4297	0.1740	0.6037	0.4194	1.0230
5	0.4388	0.1609	0.5997	0.5392	1.1389
6	0.4089	0.1546	0.5635	0.4003	0.9638
7	0.3283	0.1299	0.4582	0.4222	0.8804
8	0.3766	0.1206	0.4972	0.4066	0.9038
mean	0.4081	0.1584	0.5665	0.4664	1.0329
<u>Black Rock</u>					
1	0.2311	0.0782	0.3093	0.4138	0.7231
2	0.1295	0.0402	0.1697	0.2012	0.3709
3	0.1113	0.0447	0.1560	0.2710	0.4270
4	0.2125	0.0485	0.2610	0.3501	0.6111
5	0.1355	0.0352	0.1707	0.2135	0.3842
6	0.1038	0.0353	0.1391	0.1718	0.3109
7	0.1684	0.0539	0.2223	0.3441	0.5664
8	0.1895	0.0416	0.2311	0.3291	0.5602
mean	0.1602	0.0472	0.2074	0.2868	0.4942
<u>Black Rock Poor</u>					
1	0.0712	0.0380	0.1092	0.1668	0.2760
2	0.0823	0.0261	0.1084	0.1688	0.2772
3	0.0890	0.0296	0.1186	0.1955	0.3141
4	0.1031	0.0168	0.1199	0.1585	0.2784
5	0.0681	0.0212	0.0893	0.1409	0.2303
6	0.0628	0.0174	0.0802	0.1202	0.2004
7	0.0554	0.0242	0.0796	0.1377	0.2173
8	0.0473	0.0145	0.0618	0.1258	0.1876
mean	0.0724	0.0234	0.0958	0.1518	0.2476

Table 32
Length of Terminal Growth of Douglas Fir Seedlings During the
Third Growth Cycle

Container Number	Length of Terminal Shoot (cm.) ¹					
	Seedling Number					
	1	2	3	4	5	6
<u>Burnt Woods</u>						
1	1.5**	3.5	2.5	3.5	3.5**	1.5
2	1.5**	1.0	1.5	2.5	0.0	2.5
3	1.0	2.5**	3.5	1.0	0.0**	1.5
4	3.5**	2.5	2.5	1.0	2.5**	3.5
5	0.0	0.0**	0.0	0.0	0.5**	0.0
6	0.0	0.5**	2.5	0.0	0.0	1.5**
7	0.0	0.0**	0.5	0.5	0.0	0.0**
8	2.5	0.0	3.5	1.5**	1.5	1.5**
mean						1.5
<u>Black Rock</u>						
1	0.0**	3.5	2.5	2.5**	0.0	0.0
2	4.5**	5.5	0.0**	5.5	10.0	9.5
3	4.5**	8.5	4.5	6.5	10.0	8.0
4	3.5	2.5**	3.5	2.5**	2.5	3.5
5	0.0*	5.5**	5.5	2.5	5.5	6.5**
6	5.5	8.5	5.5**	6.5	8.5	7.5**
7	2.5	6.5**	7.5	5.5	2.5	2.5
8	3.5	3.5	1.5	4.5**	3.5	1.5**
mean						4.6
<u>Black Rock Poor</u>						
1	0.5**	0.5	0.5**	0.5**	0.5	0.0
2	1.5**	2.5	0.5	0.5**	0.5	3.5
3	2.5	2.5**	1.5	1.5	1.5**	0.0*
4	0.5**	3.5	2.5	1.5**	0.5	3.5
5	0.0	0.5	0.5**	0.5	0.0**	0.0
6	0.5	0.5	0.0	0.5**	0.5	0.5**
7	0.5	2.5**	0.5	0.0	0.5**	0.5
8	1.5	2.5	2.5	2.5**	1.5	0.5**
mean						1.2

¹Length measured to nearest 0.5 centimeter.

* Dead

**Willamette Valley-Southern Oregon Cross.

Table 33
Length of Terminal Growth of Douglas Fir Seedlings During the
Fourth Growth Cycle

Container Number	Length of Terminal Shoot (cm.)					
	Seedling Number					
	1	2	3	4	5	6
<u>Burnt Woods</u>						
1	4.7**	4.1	5.7	4.4	6.9**	3.8
2	3.3**	4.0	5.8	6.7	7.0	5.2
3	4.8	4.7**	6.5	4.0	3.0**	5.1
4	6.7**	4.7	5.4	5.3	7.0**	6.1
5	5.0	3.1**	5.2	3.6	4.2**	4.7**
6	4.6	6.6**	6.9	4.6	5.2	5.1**
7	5.9	4.0**	6.7	4.5	5.2	5.2
8	5.8	3.8	7.3	4.5**	5.3	5.3**
mean						5.2
<u>Black Rock</u>						
1	2.9**	6.2	5.1	4.5**	4.7	4.6
2	5.2**	5.4	---*	4.8	4.9	5.4
3	3.5**	5.3	3.8	3.0	5.5**	4.9
4	5.9	6.4**	6.1	6.9**	5.4	7.5
5	---*	6.3**	6.3	4.7	5.0	7.5**
6	4.5	4.8	3.6**	3.0	3.8	4.9**
7	3.5	5.8**	5.0	5.2	4.5	4.5
8	5.5	5.2	4.9	5.6**	6.0	4.8**
mean						5.1
<u>Black Rock Poor</u>						
1	2.5**	2.7	2.6**	3.1**	4.2	1.5
2	3.6**	4.6	4.8	3.1**	4.3	6.0
3	4.3	5.0**	4.0	4.6	5.1**	---*
4	2.5**	3.5	3.5	2.5**	3.9	4.4
5	4.4	3.3	3.6**	4.5	2.9**	3.0
6	4.9	4.0	3.7	2.9**	4.8	3.7**
7	4.4	5.0**	4.8	3.5	2.2**	3.2
8	3.3	3.1	4.5	3.8**	2.5	1.3**
mean						3.7

* Dead

** Willamette Valley-Southern Oregon Cross.

Table 34
Total Height of Douglas Fir Seedlings from Cotyledon Scar to Terminal Bud Tip After the Fourth Growth Period

Container Number	Seedling Height (cm.)					
	Seedling Number					
	1	2	3	4	5	6
<u>Burnt Woods</u>						
1	12.4*	12.3	16.8	16.8	16.9*	13.2
2	13.1*	15.2	15.0	15.3*	18.4	16.0
3	16.2	15.4*	18.3	15.0	11.8*	18.8
4	22.2*	13.0	21.0	14.6	20.1*	18.6
5	15.4	11.4*	16.1	16.1	13.5*	16.0
6	14.3	18.8*	21.1	17.2	19.3	15.7*
7	19.1	13.3*	18.8	12.1	15.9	14.4*
8	20.0	11.1	18.8	12.9*	19.2	13.2*
mean						16.0
<u>Black Rock</u>						
1	9.0*	15.6	12.5	11.5*	11.8	15.4
2	14.5*	15.8	dead	14.8	17.2	18.0
3	8.5*	17.8	11.1	11.9	18.2*	15.4
4	11.4	15.0*	13.2	10.8*	11.5	15.8
5	dead	16.0*	19.3	9.8	11.8	19.3*
6	14.4	14.8	11.0*	12.3	14.0	15.5*
7	11.8	14.6*	12.8	12.8	11.2	12.1*
8	18.2	12.5	11.2	12.8*	15.4	11.1*
mean						13.7
<u>Black Rock Poor</u>						
1	5.5*	6.2	6.1	7.0*	7.8	4.9
2	6.6*	8.0	8.2	5.7*	7.8	11.4
3	8.9	8.0*	7.2	7.2	9.0*	dead
4	4.6*	8.9	6.2*	4.8*	6.9	9.5
5	7.0	6.0	6.0*	8.0	4.8*	5.2
6	6.3	6.2	4.7	4.7*	6.9	5.6*
7	6.5	7.2*	6.8	5.0	2.2*	5.3
8	5.1	5.8	6.7	6.1*	4.2	3.0*
mean						6.4

*Willamette Valley-Southern Oregon Cross.

Table 35
Oven-dry Weight of Burnt Woods Seedlings Harvested After the
Fourth Growth Period

Seedling group	Mean Weight (gms.)				Total Seedling
	Roots	Stem*	1st-3rd foliage	4th cycle foliage	
I	2.1883	0.8185	0.6850	1.3220	5.0138
II	1.9766	0.7135	0.5048	1.2083	4.4032
III	1.6193	0.5977	0.4774	0.9864	3.6808
IV	1.3766	0.5416	0.3664	0.8487	3.1333
V	1.0839	0.3886	0.3200	0.6440	2.4365
Mean	1.6493	0.6120	0.4707	1.0019	3.7335

* Includes stem, branches, buds, dead foliage

Table 36
Oven-dry Weight of Black Rock Seedlings Harvested After the
Fourth Growth Period

Seedling group	Mean Weight (gms.)				Total Seedling
	Roots	Stem*	1st-3rd foliage	4th cycle foliage	
I	1.4425	0.6157	0.8836	0.4725	3.4144
II	1.0500	0.4755	0.6231	0.3617	2.5103
III	0.8637	0.3707	0.5131	0.2921	2.0396
IV	0.7288	0.3003	0.4496	0.2809	1.7596
V	0.7255	0.2509	0.3813	0.2024	1.5601
Mean	0.9621	0.4027	0.5702	0.3219	2.2568

* Includes stem, branches, buds, dead foliage

Table 37
Oven-dry Weight of Black Rock Poor Seedlings Harvested After the
Fourth Growth Period

Seedling group	Mean Weight (gms.)				Total Seedling
	Roots	Stem*	1st-3rd foliage	4th cycle foliage	
I	0.4668	0.1310	0.0942	0.2428	0.9348
II	0.3222	0.0976	0.0550	0.1597	0.6345
III	0.2074	0.0689	0.0441	0.1050	0.4260
Mean	0.3225	0.0969	0.0623	0.1641	0.6458

* Includes stem, branches, buds, dead foliage

Black Rock Poor Soil Profile

- A₁ 0-6" Dark brown (7.5 YR 4/4, moist) silt loam; strong, very fine, granular structure; very friable, soft, slightly sticky, slightly plastic; abundant fine interstitial pores; abundant fine manganese concretions; abundant roots; pH 5.75; lower boundary clear and smooth.
- A₃ 6-11" Reddish-brown (5 YR 4/4, moist) silt loam; strong, fine subangular blocky structure; friable, slightly sticky, slightly plastic; abundant fine and medium interstitial pores; abundant roots; pH 5.35; lower boundary clear and smooth.
- B₂₁ 11-16" Yellowish-red (5 YR 4/6, moist) silty clay loam; plastic, slightly sticky and slightly hard; moderate subangular blocky structure; common fine tubular pores; common thin clay flows; common roots; pH 5.3; lower boundary gradual.
- B₂₂ 16-41" Yellowish-red (5 YR 5/6, moist) silty clay loam; plastic, slightly sticky; moderate subangular blocky structure; common fine tubular pores; pH 5.2; lower boundary gradual.
- B₃ 41+ Yellowish-red (5 YR 5/8, moist) sandy clay loam, containing pieces of weathered parent material; slightly plastic, slightly sticky; weak subangular blocky structure; pH 5.2.

The soil is a well-drained, red-brown latosol derived from shale. The soil series has not been determined.

Burnt Woods Soil Profile

- A₁ 0-5" Very dark greyish brown (10 YR 3/2, moist) loamy fine sand; granular structure, very friable, soft, slightly sticky, slightly plastic; abundance of fine roots and pieces of decaying wood; pH 5.5; lower boundary clear and smooth.
- A₃ 5-14" Dark brown (10 YR 3/3, moist) sandy clay loam; subangular blocky structure, friable, slightly plastic, slightly sticky; fine tubular pores; abundant fine roots; pH 5.1; boundary to lower horizon gradual; horizon contains bands of darker soil (10 YR 3/2, moist) and spots of yellow-orange soil (5 YR 5/8, moist) indicating one-time burning.
- B₂ 14-32" Dark yellowish-brown (10 YR 4/4, moist) silt loam; firm, plastic, slightly sticky; medium subangular blocky structure; fine tubular pores; clay flows on peds; abundant medium and fine roots; pH 5.4; boundary to lower horizon gradual.
- B₃ 32-44 Yellowish-brown (10 YR 5/6, moist) silty clay loam; firm, plastic, sticky; fine subangular blocky structure; abundant fine roots; pH 5.2; lower boundary gradual and smooth.
- C 44+ Brownish-yellow (10 YR 6/8, moist) fine sandy loam containing large fragments of slightly weathered sand stone; pH 5.1.