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Abstract approved
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Sod and brush cover has developed in many of the clearcut units on the Umpqua National Forest. The competition from this vegetation virtually precludes establishment of desirable tree species. Site preparation that utilizes crawler type tractors equipped with land clearing blades to remove competing vegetation prior to seeding or planting would result in considerable loss of topsoil and exposure of large areas of subsoils for seedbeds.

To investigate the effects of the exposed subsoils on the first year development of commercially important species from seed, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), ponderosa pine (*Pinus ponderosa* Laws.), and sugar pine (*Pinus lambertiana* Dougl.) were grown in seedbeds established on exposed B_2 horizons and on the surface horizons of the Dumont soil series. Both north and south aspects were investigated. Douglas-fir was also grown in the

greenhouse on A, B_2, and C_1 Dumont soil horizon material. In the greenhouse study, an attempt was made to duplicate the undisturbed density and structure in root boxes.

In the greenhouse, the largest seedlings were produced on the A horizon material. The rooting configuration of the smaller seedlings grown on the B_2 horizon material indicated that the physical characteristics of this material did not limit growth. In packing the C_1 horizon material in the root boxes, the resulting bulk density was greater than that of the C_1 horizon in the field. As a result, the root form was altered considerably and the seedlings produced on this horizon were the smallest.

In the field, at the end of the first growing season, more sugar pine and ponderosa pine seedlings were found on the B horizon seedbeds. No Douglas-fir survived on the south aspect A horizon seedbeds. Survival for Douglas-fir and sugar pine was greater on the north aspect. These results were attributed to the absence of forb competition on the B horizons, the more favorable moisture regime of the north aspect, and the high soil surface temperatures of the south aspect, and the high soil surface temperatures of the south aspect A horizon beds.

Bulk densities of the exposed B horizons ranged from 1.49 gms/cc, which definitely limited growth, to 1.33 gms/cc which did not limit growth. The more fertile A horizons produced larger

Douglas-fir and ponderosa pine on the north aspects. Sugar pine seedlings tended to be heavier on the B horizon seedbeds if the bulk density was not limiting, but this trend will probably be reversed the next growing season.

Exposure of subsoil horizons may aid in initial seedling establishment but the low fertility and high bulk densities that may be encountered cannot be expected to favor seedling growth over a long period of time.

FIRST YEAR DEVELOPMENT OF THREE CONIFERS ON SURFACE AND EXPOSED SUBSOIL HORIZONS

by

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FIRST YEAR DEVELOPMENT OF THREE CONIFERS ON SURFACE AND EXPOSED SUBSOIL HORIZONS

INTRODUCTION

On the South Umpqua district of the Umpqua National Forest, many of the clearcuts that have been made in the mixed conifer types since 1950 have not regenerated but have become covered with various grasses, shrubs, and forbs. The competition from this vegetation is so great that establishment of desirable tree species is virtually precluded. This problem seems to be particularly acute on south aspects.

Eliminating this undesirable cover for a sufficient length of time to allow establishment of desirable tree seedlings appears to be a possible solution. This could be accomplished by removing the sod and brush cover by using a brush blade or a similar device mounted on a bulldozer. This alternative presents certain perlexing problems. In many cases, use of such a method would result in a considerable loss of top soil and expose large areas of subsoil for seedbeds. Supposedly, this subsoil has many undesirable properties, when compared to the surface soil, that would make it undesirable for a seedbed. However, in many places within this geographic area there are desirable coniferous seedlings which appear to be growing vigorously on subsoils that have been exposed by logging and road building activities.

This thesis constitutes an investigation of the first year development from seed of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), ponderosa pine (*Pinus ponderosa* Laws.), and sugar pine (*Pinus lambertiana* Dougl.) on surface and exposed B_2 horizons of the Dumont soil series, in place, on both north and south aspects, and of Douglas-fir on A, B_2, and C_1 horizons in the greenhouse.

REVIEW OF LITERATURE

Shaner (24, p. 915) states that "by utilizing the mobile power of big crawler type tractors and equipping them with special land clearing blades, economical site preparation was and is, being accomplished over many thousands of acres in the Pacific Northwest." Shaner (24, p. 915-916) cites one example where sod and brush competition effectively curtailed reforestation on Oregon Pulp and Paper Company land. A D-7 caterpillar with an angle dozer was used to plow furrows 6 to 12 inches below the ground level running generally along the contour with a center to center spacing of 11 feet. Erosion was not excessive and the furrowing effectively retarded sod and most other competition for at least two years giving the planted seedlings an opportunity to become well established.

Land scarification creates a different environment for the germinating seed and the seedling. To aid later discussion it is necessary to review portions of the literature that are connected with survival and early development of tree seedlings.

Seedling Survival

Isaac and Dimock (15, p. 8-9) state that Douglas-fir will germinate on almost any seedbed that provides adequate moisture and proper temperature but that it germinates and develops best on a mineral soil surface. On good seedbeds a large proportion of viable seeds will normally germinate but about three-fourths of the seedlings usually die during the first year. Major causes of death are heat injury to the stem, drought, plant competition, frost, insects, disease (root rot and damping off), and rodents.

Fowells and Schubert (12, p. 7-9) report that the rates of germination of sugar pine seedlings are as high or higher than for species with which it is normally associated. During the first year, sugar pine seedlings are exceptionally vigorous compared to their natural associates and have a higher rate of first year survival. The seedlings are only slightly attacked by cutworms (Noctuidae) and "records of seedling mortality in Oregon show no losses from heat injury even where seedlings grew through beds of charcoal on south exposures." On the other hand, Stein (30, p. 11) observes that in seasons with exceptionally hot dry periods, losses of sugar pine seedlings can be expected from drought and heat. Fowells and Schubert (12, p. 8-9) state that drought may cause high mortality of sugar pine seedlings and that rodents destroy many seedlings during the first two months after germination. Stein (28, p. 1-2) states that sugar pine seedlings have germinated and survived best on bare mineral soil and that vegetation is detrimental because it provides competition for moisture and often supports cutworms, grasshoppers and other insects.

Curtis and Lynch (8, p. 10) in discussing the survival of ponderosa pine seedlings note that available evidence indicates that soil moisture is the most critical factor influencing survival. They conclude therefore, that soil texture, plant competition and condition of the seedbed exert a strong influence, separately or collectively, on the survival of very young seedlings. The cutworm (*Euxoa excellans infelix*) can cause appreciable damage and rodents and birds destroy many young seedlings. Stem temperatures of about 130 degrees Fahrenheit and greater are lethal to seedlings up to three months old. Stein (29, p. 18) found that damping off of ponderosa pine seedlings was occasionally serious in southwestern Oregon.

In comparing the survival of Douglas-fir, sugar pine and ponderosa pine, Stein (29, p. 18) observed that ponderosa pine and sugar pine survived better than Douglas-fir both when seeded and when planted. The primary roots of the two pines grow more rapidly and deeper and the pine seedlings are more drought resistant. Also, the stems of the pines are larger and thicker which enable them to withstand higher surface temperatures.

Early Growth

Isaac and Dimock (15, p. 9) state that new Douglas-fir seedlings need light shade but, when once established, thrive best in full sunlight. Plant cover greater than 25 percent may be progressively harmful as it increases above this level. Shoot growth and diameter growth in the seedling stage usually continues for three to four months after the buds burst.

Fowells and Schubert (12, p. 8-9) report that brush hinders the establishment and development of sugar pine seedlings. When not hindered, sugar pine seedlings have a rapid first year root development. The primary root develops as a taproot with a few short lateral branches. In a study on the Stanislaus Experimental Forest, the average rooting depth at the end of one growing season on bare sandy soils was 17 inches as compared to seven to nine inches for seedlings which germinate on duff cover. The first year's shoot growth reaches four to five inches on high quality sites with little competition.

Curtis and Lynch (8, p. 11-13) state that the nourishment in the large seed of ponderosa pine and the innate ability to send down a fast growing taproot enable ponderosa pine to survive on and dominate the more exposed sites or other sites where competition is not high. The seedling can also withstand prolonged drought with soil moisture contents very close to or even below the permanent wilting point. Roots of one-year-old natural seedlings have been known to reach lengths of 22.4 inches. Normal growth is hindered when there is less than 40 percent sunlight and competing vegetation is clearly a detriment to early survival and development of young seedlings.

To further facilitate later discussion it is essential to review the factors that could affect survival and growth on exposed subsoils and undisturbed surface soils. These factors are (1) soil surface temperatures, (2) soil physical conditions and root growth, (3) moisture availability, and (4) nutrient requirements of the seedlings.

Soil Surface Temperatures

Geiger (13, p. 7-8) states that in the daytime, the highest temperatures occur at the soil-air interface while rapid decreases in temperature occur both upward and downward away from the soil surface.

Baver (5, p. 367) reports that soil temperatures depend upon the factors responsible for (a) differences in the intensity of absorption of heat such as color, (b) variations in the specific heat of the soil such as composition and water content, and (c) differences in heat conductivity such as compaction and water content. Although dark colored soils may be warmer than light colored soils, the effect of color is often overbalanced by other properties of the soil that affect the heat capacity and the heat conductivity.

The heat capacity of a given material is equal to its specific heat capacity times its mass (23, p. 274). The specific heat capacity of a material may be defined as the quantity of heat that must be supplied to a unit mass of material to increase its temperature one degree. The equation $\Delta T = Q/mc$ shows how the specific heat capacity affects the temperature rise of a substance. ΔT (degrees) is the rise in temperature resulting from the quantity of heat Q (calories) supplied to mass m (grams) with a specific heat capacity of c (calories/gram, degree). Specific heat capacities can also be determined on a unit volume basis. The above definition, equation and explanation still apply if the desired unit of volume is substituted for the mass. The units of specific heat capacity then change from calories per gram per centigrade degree to calories per cubic centimeter per centigrade degree.

The specific heat capacity of water is compared with some soil components in the following table.

Table 1. Specific heat capacities of some different soils and soil components.

Material	Specific Heat Capacity	Source
Water	1.0 cal/gram, degree	Baver (5, p. 370)
Granite	0.52 cal/cm^3, degree	Geiger (13, p. 28)
Sand	.185 - .193 cal/gram, degree	Baver (5, p. 370)
Wet sandy soil	0.3 cal/cm^3, degree	Geiger (13, p. 28)
Dry sandy soil	0.2 cal/cm^3, degree	Geiger (13, p. 28)
Peaty soil	0.1 cal/cm^3, degree	Geiger (13, p. 28)
Humus	.165 - .477 cal/cm^3, degree	Baver (5, p. 370)

Because of the high specific heat capacity of water, increases in water content will cause an increase in the specific heat capacity of the soil mass (7, p. 257). In addition to the tabled values Silen

(25, p. 9) reports that the specific heat capacity of dry organic material is lower than the specific heat capacity of sand.

Conduction accounts almost exclusively for heat transmission within the earth (13, p. 27). Baver (5, p. 373-376) states that heat flow in a porous material such as the soil is much more complicated than flow through solid bodies but the same fundamental features of heat flow operate in both types of materials. The equation

$$Q/At = K(T_1 - T_2)/d$$

is presented for heat flow through a substance. Q/At is the heat flow per unit time (calories/square centimeter, second), $(T_1 - T_2)/d$ represents the temperature gradient with T_2 being the temperature a distance d through the material from a temperature of T_1 (degrees/centimeter), and K is the heat conductivity of the material (calories/degree, centimeter, second).

The heat conductivity of the soil constituents, with the possible exception of organic matter, varies little from one soil to another. The degree of packing and the porosity of the soil seem to be the major factors affecting soil conductivity. Increasing the water content of the soil increases the heat conductivity by replacing the air and giving better contact between soil particles. Table 2 shows a portion of the data presented by Baver (5, p. 374) indicating the importance of compaction and water content.

Table 2. Relative heat conductivity.

Material	Air-Dry Compact	Air-Dry Loose	Moist Loose
Quartz powder	106.7	100	201.7
Kaolin clay	96.4	90.7	155.6
Humus	98.1	90.7	94.3

It is evident that an increase in moisture content increases the specific heat of a substance as well as its conductivity (25, p. 9). The highest surface temperatures are reached on seedbeds in which a low proportion of total energy passes downward into the soil (25, p. 10). Smith (26, p. 33) assumes that the high specific heat and conductivity of moist bare mineral soil account for the relatively low temperatures observed in an investigation of natural seedbeds for eastern white pine. He believed that the mortality of newly germinated eastern white pine seedlings on dry mineral soil was caused by the lower specific heat and conductivity in these soils. Silen (25, p. 9) states that the surface temperatures remain below lethal levels in all soils if the surface is moist. Different soils become dry on the surface at different time intervals under the same exposure to sunshine due to variation in their components and physical properties. Silen (25, p. 135) found that variation in subsurface moisture is a very important factor influencing surface temperatures. He also found that temperature on a soil in a surface dry condition was lowered considerably by the presence of moisture a fraction of an inch below the surface. Consequently, a seedbed material that is capable of holding much water near the surface may be protected from high surface temperatures for considerable periods during drying weather (25, p. 140).

Soil Physical Conditions and Root Growth

Richards and Wadleigh (21, p. 107) state that the mechanical impedance of soil to root penetration can markedly affect root distribution and that under unfavorable conditions soil moisture studies can be greatly complicated. They report that sunflower roots are unable to penetrate clays that have been artifically compacted to densities of 1.46 to 1.65 grams per cubic centimeter. However, Lutz (18, p. 53) contends that pore size and not apparent density is the limiting factor. Because of the slow rate of unsaturated moisture flow in soils, thorough permeation of the soil mass by fine roots is necessary for complete utilization of soil moisture.

Anderson and Cheyney (3, p. 32-34) grew seedlings of Norway pine, white spruce, and southern balsam, in the greenhouse for four months on soils of different texture under conditions of varying soil moisture. They found that regardless of moisture content, the length of the taproots increased as the content of fine particles decreased.

The length of the side roots did not show this trend and in some cases showed a slight trend in the opposite direction. They believed that this suggested the following possible difference in the two classes of roots: the length of the taproot is largely controlled by heredity, and its growth would be hindered by the density of the soil while side roots are influenced more by the available water supply. They noted less development of lateral roots under high soil moisture conditions.

Lutz, Elyand, and Little (19, p. 2-10) reviewed some foreign papers on the relation of forest tree root development to soil horizons. They report that Groth investigated the behavior of Douglas-fir roots and found that in fine-textured soils, root development was less extensive but the roots were more branched than in soils of medium and coarse texture. Hilf also found that pine roots became more branched with increasing content of the finer fractions in the soil. Laitakari observed that moisture induces unusually rich branching in roots of Scotch pine (Pinus sylvestris L.), however excess moisture causes long branchless roots to develop.

Hassis (14) studied root development of ponderosa pine seedlings and found that for comparable top development, root development is greater in clayey soils than in loamy, rocky soils (14, p. 303). He states that shorter roots and greater top-root ratios are formed on more loamy soils. He attributes this to a greater supply of available moisture in the loamy soil.

Wahlenberg (33, p. 138) states that hard soil causes root branching, whereas open soil appears to stimulate growth of tap-roots.

Moisture Availability

In a review of the pertinent factors governing the availability of soil moisture to plants, Jamison (16, p. 459) lists the following factors:

(1) Plant factors which are the condition of the plant, its rooting habits, and drought resistance.

(2) Climatic factors including air temperature and air humidity.

(3) Soil factors including moisture tension relations, soil solution-osmotic pressure effects, kinds of ions present in the soil, soil moisture conductivity, soil depth, soil stratification and soil temperature.

Plant factors. Stein (28, p. 18) stated that the primary roots of ponderosa and sugar pine seedlings grow more rapidly than those of Douglas-fir and consequently pines are less subject to high moisture stress in the surface horizons than Douglas-fir. Fowells and Kirk (10, p. 130) conducted experiments with ponderosa pine seedlings which showed that ponderosa pine seedlings have the ability to survive and remove moisture from the soil after the soil moisture content has reached the death point for sunflowers. Stone (30, p. 130) reached the same conclusion and found that dew, if it occurs, enables the ponderosa pine seedling to survive even longer at low levels of soil moisture.

Jamison (16, p. 459) stated that any factor that will effect the vigor or condition of the plant may be expected to influence its ability to extract soil moisture.

Climatic factors. Geiger (13, p. 214) states that topography has a great effect on climate in that different quantities of heat are received by different directions and angles of slope.

The lesser amounts of direct solar radiation striking north slopes, as compared to south slopes, would result in a lower rate of evapo-transpiration on north slopes and consequently more moisture would be available for growth.

Soil factors. Lutz (18, p. 58) and Alexander and Middleton (2, p. 14) state that clay soils have high water holding capacities but that this moisture is not all in the range useful to plants because much of the moisture is held at high tensions. Jamison (16, p. 463) reports that water movement is very slow at moisture contents below field capacity and that a moisture potential gradient exists throughout the soil mass in which the roots of transpiring plants are growing. He further states that the tension gradient away from absorbing roots in very fine or coarse textured soils would be greater than in soils of intermediate texture and structure. Baver (5, p. 252) states that "the texture and structure of the soil affect capillary conductivity as they influence the number, size and continuity of the pores." Pores in some soils may be too large to permit establishment of a continual moisture film while in other soils the pores may be so small that there is considerable resistance to flow.

Fertility Requirements

Wilde (33, p. 945) states that a deficiency of any of the essential nutrients or an unbalanced ratio of nutrients has a far reaching influence on the processes of metabolism. Size and color of leaves, inadequate root systems, and unbalanced top-root ratios are among the many features reflecting an unbalanced nutrient supply. Wilde (33, p. 949) advocates the analysis of soils under a productive forest stand as a guide for determining optimum fertility levels for seedbeds. Youngberg and Austin (35, p. 4) report that "fertility standards obtained by the analysis of productive forest soils have been thoroughly tested and proven by practical reforestation in the Lake states."

Youngberg and Austin (35, p. 4-5) present results of the analysis of surface layers of soils to a depth of seven inches under productive forest stands of Douglas-fir in the coast and Cascade ranges of Oregon and Washington and in the Puget Sound Region of Washington. The reported values are pH, 4.8 to 5.8; total nitrogen, 0.28

percent; available P_2O_5, 82.3 pounds per acre; available K_2O, 198.3 pounds per acre; exchangeable Ca, 4.65 milliequivalents per 100 grams; and exchangeable Mg, 1.79 milliequivalents per 100 grams. The nitrogen:phosphoric acid:potash ratio was found to be the same as found for other coniferous species.

Vlamis, Biswell and Schultz (31, p. 27) found from a pot test study that phosphorus deficiency symptoms did not occur in ponderosa pine seedlings whereas on the same soils they did show up on barley and lettuce plants. They point out that Rennie has suggested that the phosphorus demand by pines is only five percent of that of agricultural crops, 40 percent of that of hardwoods and one-half that of other conifers.

Fowells and Krauss (11, p. 12) found that loblolly pine and Virginia pine seedlings grew well at a phosphorus level of one ppm. They point out that this does not agree with the results of Mitchell which indicated that deficiencies occurred for white pine at levels less than 50 ppm.

Youngberg (34, p. 2) found from a sand culture nutrient solution study that ponderosa pine seedlings grown in a sand medium continuously supplied with a complete solution containing 112 ppm N, 62 ppm P, 64 ppm S, 78 ppm K, 120 ppm Ca, 48 ppm Mg, plus all the micronutrients gave an average seedling weight of 0.943 grams. "Decreasing the various element treatments stepwise to

0 ppm resulted in the following reductions in yield: N to 0 ppm, .139 grams; P to 0 ppm, .200 grams; S to 0 ppm, .788 grams; K to 0 ppm, .455 grams; Ca to 0 ppm, .738 grams; and Mg to 0 ppm, .669 grams."

Austin and Strand (4, p. 26) in conducting tests on the effects of various urea pellets placed in the planting holes of Douglas-fir seedlings found that no response was obtained to any of the fertilizers when no site preparation measures were carried out to reduce the competition from bracken fern (Pteridium aquilinum pubescens). When the bracken fern was removed by clipping several times during the growing season, a pellet made of commercial resin, Dupont's Uramite, in combination with super phosphate resulted in a 42 percent increase in height growth and a 24 percent increase in diameter growth by the end of the second growing season after planting.

DESCRIPTION OF THE AREA

Location

The study area is located in the southeast quarter of section four (4) and the northeast quarter of section nine (9), Township twenty-nine (29) South, Range one (1) East in the South Umpqua Ranger District of the Umpqua National Forest in southeast Douglas County. The seedbeds are located approximately one mile north by northwest of South Umpqua falls at an elevation of approximately 2,800 feet. .

Climate

According to Richlen (22, p. 6) the frost-free season lasts from 100 to 120 days. The average July temperature is 64 degrees Fahrenheit. The average annual precipitation is 40 to 60 inches and less than an inch of rainfall per month occurs from July through September. August is usually the driest month. During 1961 when the field work was done the rainfall on the study area was 47.79 inches. Within this period, June rainfall was 0.52 inches, July rainfall was 0.18 inches, August rainfall was 0.39 inches, and September rainfall was 0.77 inches. The rainfall data were furnished by Mr. William H. Hallin, Roseburg Research Center leader, who collected the information in connection with another study.

Vegetation

Richlen (22, p. 1) states that the area lies in a complex ecological transition zone between Douglas-fir forests to the north and the mixed pine types to the south. Most of the region surrounding the study area is naturally timbered with Douglas-fir, sugar pine, and ponderosa pine constituting the bulk of the commercial timber. Insence cedar (Libocedrus decurrens Tarr.), western hemlock (Tsuga heterophylla Sarg.), and grand fir (Abies grandis Lindl.), also occurred on the units that were logged before the study was installed.

Before cutting, the understory vegetation was composed of salal (Gaultheria shallon Pursh.), bear grass (Xerophyllum tenax Pursh.), sedges (Carex sp. (Ruppins) L.), Oregon grape (Berberis nervosa Pursh.), and bear berry (Arctostaphylos uva-ursi (L.) Spreng.).

After logging the vegetative cover on the north aspect in the vicinity of the study plots was in decreasing order of abundance; false dandelion (Hypochoris sp. L.), salal, Oregon grape, fescue (Festuca sp. L.), bull thistle (Cirsium lanceolatum L.), common thistle (C. vulgare L.), sedges, mustard (Brassica sp. L.) and snowbrush (Ceanothus velutinus Dougl.). The vegetative cover of the south aspect portion was in decreasing order of abundance, bull thistle, mustard, bent grass (*Agrostis* sp. L.), sedge, and fescue.

Soils

The Dumont series consists of well-drained, medium-textured, Reddish-Brown Lateritic soils developed in medium-textured residium from basic reddish breccia which originated in the Oligocene and Miocene epochs of the Tertiary period (22, p. 23). A detailed description of the series appears in the appendix. Dumont soils occupy large areas of the Umpqua National Forest and they are similar to many of the lateritic soils that occur in western and southern Oregon.

Past History

According to information furnished by ranger district personnel, the north aspect portion of the study area was within a unit that was logged in 1957, relogged in 1958, and burned in 1959. The south aspect portion of the study area was in a unit that was cut in 1957 and 1958 and burned in 1958. Seventy-five and five tenths percent of the volume removed from both units was Douglas fir, 10.3 percent of the volume was sugar pine and ponderosa pine, and 14.2 percent was grand fir and hemlock.

Most of the area was cable logged although some tractor logging was done on the more gentle slopes. Old skid trails and accumulations of debris suggest that the area in the immediate vicinity of the plots was cat logged.

In attempts to regenerate the north aspect unit, 191 pounds of sugar pine seed were seed spotted in November of 1959 using a four by eight foot spacing. This seeding resulted in the establishment of only 170 trees per acre which was considered inadequate. Consequently the area was again reseeded in the fall of 1960. The south aspect unit was planted with 2-0 sugar pine seedlings in 1959. Only 14 percent of these survived so the unit was next seed spotted with sugar pine seed using a four by eight foot spacing in October 1960. Thirty percent of these germinated the following spring. The percent survival of these germinants is unknown.

METHODS OF STUDY

Greenhouse Phase

An experiment was carried out in the greenhouse for two reasons: to compare the nutrient supplying ability of the A, B_2, and the C_1 horizons under conditions of adequate moisture; and to evaluate the physical barriers that might be offered to root penetration. Douglas-fir was chosen as a test plant because the larger sugar pine and ponderosa pine seedlings would have required greater volumes of soil.

Soils used in the greenhouse came from the pit that is described in the appendix. This pit is located on the north aspect portion of the study area. Soil from the three horizons was placed in cedar boxes with dimensions of 12 x 12 x 18 inches. A completely randomized block design was set up with the three horizons as treatments replicated three times.

In order to approximate the naturally occurring bulk densities as closely as possible, known volumes of the A and C_1 horizons were taken and immediately weighed on a balance set up in the field. A weight:volume ratio was then calculated for these materials. The inside of each of the boxes to be filled was previously marked off in increments four inches high and the volumes of these increments were calculated. As materials were taken from the pit they were weighed on a spring scale and using the weight:volume ratio previously calculated, the weight of the soil necessary to attain this ratio for the marked-off volume was carefully placed in the box until each successive increment was filled. The fine granular to fine subangular blocky structure of the A horizons permitted a fair duplication of undisturbed conditions.

The moderate to strong subangular blocky structure of the B_2 horizon prevented the use of this method. To obtain a structure and bulk density comparable to that in the field the B_2 horizon material was removed in blocks approximately 4 x 4 x 4 inches in size. These blocks were placed in the boxes and pressed together just enough to unite the individual blocks.

The chemical and physical data for horizons of the pit from which the materials were taken are presented in Tables 3 and 4.

The chemical and physical analyses were performed at Washington State University soil testing laboratory in connection with a study conducted by Mr. W. I. Stein, research forester, formerly stationed at the Roseburg Research Center. pH was determined by the standard method using a 1:1 soil water paste. The ammonium acetate method was used for cation exchange capacity. Calcium and potassium were determined by the flame photometer. Total nitrogen was determined by the Kjeldahl method. Phosphorus was determined

Table 3. Chemical data for the soils used in the greenhouse experiment.

Soil Horizon	Depth	Soil Reaction	Available P	Exchangeable Ca	Exchangeable K	Cation Exchange Capacity	Total N
	Inches	pH	ppm	----m. e./100 grams soil---			Percent
A_1	0- 4	5.6	4.6	12.5	.80	30.4	.09
A_3	4- 8	5.1	5.7	10.4	.64	29.5	.06
B_{22}	18-25	4.8	1.0	6.5	.61	26.1	.02
C_1	50-64	4.8	2.2	.6	.25	32.6	.01

Table 4. Physical data for the soils used in the greenhouse experiment.

Soil Horizon	Bulk* Density	Particle Size Distribution Sand	Silt	Clay	Moisture at 15 Atmospheres Tension
	Gms/cc	--------Percent---------			
A_1	.81	43.3	35.7	21.0	17.72
A_3	.88	40.0	34.8	25.2	18.72
B_{22}	1.21	25.0	27.1	47.9	25.18
C_1	1.04	31.4	41.8	26.8	22.50

* Density of the horizon in place.

by extraction with sodium bicarbonate. Bulk density was determined from core samples. The pipette method was used for the mechanical analysis. A pressure membrane apparatus was used to determine percent moisture at 15 atmospheres.

The boxes were brought into the greenhouse in February 1961, and randomly assigned a position on a greenhouse bench. Thirty-two Douglas-fir seeds were sown in each box. The seed used was from a lot collected in 1956 on the upper South Umpqua drainage between the elevations of 2500 and 3000 feet. Germination was almost complete by March 2 and the seedlings were thinned to 20 per box giving a spacing of approximately 2 x 2 inches.

On June 9, 1961, the seedlings were removed intact from the boxes and measurements were made of top height, rooting depth, number of lateral roots, length of the three longest lateral roots, and the oven dry weights of the roots and tops.

Field Phase

A completely randomized two by two factorial experiment was set up in the field as follows: Due north and due south aspect positions on each side of an east-west oriented saddle were chosen for seedbed locations. The slope on both aspects was 20 percent.

Four seedbeds were established on each aspect, two on the A_1 horizon and two on the B_2 horizon. Each seedbed was enclosed by a 4 x 8 foot wooden frame made from 1/2 x 6 inch dimension lumber. Each bed was fitted with a lid made of 1/4 inch mesh screen tacked to a 4 x 8 foot rectangular frame of 1/2 x 2 inch dimension material. The sides of the seedbed frames were embedded two inches into the soil. The A_1 horizon seedbeds were prepared by removing the vegetation and the surface litter. The B_2 horizon locations were exposed by excavating an area large enough to accommodate the 4 x 8 foot seedbed frame and a drainage trench around the bed two feet away from the bed frame. The sides of the resulting pit were sloped back away from the trench so that the bed surface would receive as much light as the beds on the surface horizon. On the downhill side of the pit a drainage trench was dug leading down slope (Figure 1).

Locations for the beds were determined by the physical conditions of the area. It was desired to have the plots as close together as possible, but large logs, stumps, skid trails and heavily burned spots were avoided. Spots where sedge, salal, or grass cover were established also had to be avoided to prevent competition. For the A horizon plots, logs were rolled away to expose surfaces that were not burned and that were without grass, salal or sedge cover. The beds on the south aspect portion were about 0.3 of a mile distant from those on the north aspect. Because of a strip of uncut timber running down the center and on top of the saddle it was not possible to obtain a due south aspect location any closer on a Dumont soil.

After the beds were established, they were divided into thirds. Within each third, two row locations each for Douglas-fir, ponderosa pine and sugar pine were randomly selected. The rows were spaced four inches apart and the ponderosa and sugar pine seeds were sown four inches apart within the row. The depths of sowing were as follows: sugar pine, 1/2 to 1 inch, ponderosa pine, 1/4 to 1/2 inch, and Douglas-fir seeds were just barley covered. The Douglas-fir seed that was used came from the same lot as the seed used in the greenhouse. The seeds for the other two species were collected in 1956 on the upper South Umpqua drainage; sugar pine seed was collected between elevations of 2500 and 3000 feet, and ponderosa pine

Figure 1. General view of a seedbed on an exposed B_2 horizon.

seed was collected between 1700 to 3200 feet.

The beds are designated as follows: N1A, N2A, N1B, N2B, S1A, S2A, S1B and S1A. The letters N or S designate the north or south aspect, the numbers 1 or 2 indicate the replication, and the letter A indicates that the bed is on the surface horizon while the letter B indicates that the bed is on the exposed B_2 horizon.

The seeds were sown in late December 1961 and part of the seedlings were lifted in December 1962. The beds were divided into thirds because the personnel at the Roseburg Research Center were interested in following the development of the seedlings for a longer period of time than one year. It was hoped that seedlings could be lifted from one-third of the bed only, leaving the rest of the bed intact for future observation.

Since it would be impractical from the standpoint of preserving the beds for future study to lift the middle third of any of the beds, a coin was tossed to determine which one of the end thirds should be lifted. When possible, 12 intact seedlings of each species were removed from each bed. As the seedlings of each species were removed they were taped and numbered and, if more than 12 seedlings survived, 12 were randomly chosen for measurement. If 12 seedlings did not survive in the third of the bed being sampled, the remainder necessary to fill the quota was selected and lifted on the basis of closeness to the excavated area.

Seedling rooting depth was measured for each seedling as it was removed from the bed. In addition the following measurements were made on selected seedlings: top height, number of lateral roots, length of the three longest lateral roots, and the oven dry weights of the roots and tops.

Chemical and physical data of the field plots. Table 5 presents the chemical data obtained from composite samples collected by sampling with a tube to a depth of six inches in at least six scattered locations within each bed. The samples were analyzed by the Oregon State University soil testing laboratory using the methods of Alban and Kellogg (1). Potassium, calcium, magnesium, and sodium were determined by the flame photometer method. The standard method using a 1:1 soil water paste was used to determine pH. The cation exchange capacity was determined by the ammonium acetate method. Organic matter was determined by the Walkley-Black method and total nitrogen was determined by the Kjeldahl method. The sodium bicarbonate method was used for phosphorus.

The particle size distribution and the bulk density for the upper six inches of each prepared bed are given in Table 6. The pipette method was used for mechanical analysis. Samples for the analysis were taken to a depth of six inches in at least four scattered locations within each bed. Bulk densities of the bed surfaces were determined by taking core samples from the A horizon plot, and by

Table 5. Chemical data for soils on the field plots.

Bed	Soil Reaction	Available P	Exchangeable Bases Ca	Exchangeable Bases Mg	Exchangeable Bases K	Exchangeable Bases Na	Cation Exchange Capacity	Organic Matter	Total N
	pH	ppm	----------m. e./100 grams soil---------					-----Percent-----	
N1A	6.6	19.8	25.3	2.1	1.39	.21	40.7	8.65	.180
N2A	6.0	20.0	10.5	2.1	.76	.21	21.0	3.30	.088
N1B	5.2	3.0	12.7	2.7	.69	.21	25.1	.82	.039
N2B	5.2	4.2	5.4	2.1	.39	.15	20.8	.54	.029
S1A	6.6	22.0	15.4	2.1	.87	.20	24.0	5.27	.125
S2A	6.2	27.0	14.5	2.6	.95	.25	28.1	6.80	.146
S1B	5.5	9.0	8.1	3.1	1.08	.25	19.0	1.08	.064
S2B	5.1	3.6	7.4	4.0	.71	.22	24.0	.82	.052

Table 6. Physical data for the field plots.

Bed	Bulk Density	Particle Size Distribution Sand	Silt	Clay
	Gms/cc	------------Percent------------		
N1A	.90	35.3	38.2	26.5
N2A	.90	47.0	29.9	13.1
N1B	1.41	25.4	36.7	37.9
N2B	1.40	29.1	36.7	34.1
S1A	.96	40.5	39.1	20.3
S2A	.90	37.1	40.4	22.5
S1B	1.49	16.4	30.4	53.2
S2B	1.33	15.8	21.5	62.8

the use of cores and the clod method for the B horizon plots. Data from the clods and the cores were in close agreement for each of the B horizon beds.

Differences in clay content between aspects are striking. According to Richlen[1] the amount of clay is often higher in soils on south aspects in this region. He attributes this to the higher temperatures on these aspects which give rise to a greater degree of chemical weathering. The percent clay, percent organic matter and the cation exchange capacity suggest that different types of clay minerals are predominant in the soils on the two aspects.

[1] Preliminary draft, Soil Survey Report for South Umpqua Soil Survey Area.

Moisture tension curves for each bed were constructed from pressure membrane data obtained on core samples and from loose samples taken for this purpose. Each point plotted on the curves shown in Figures 2, 3, 4 and 5 represents an average of determinations made on at least two samples taken within the bed.

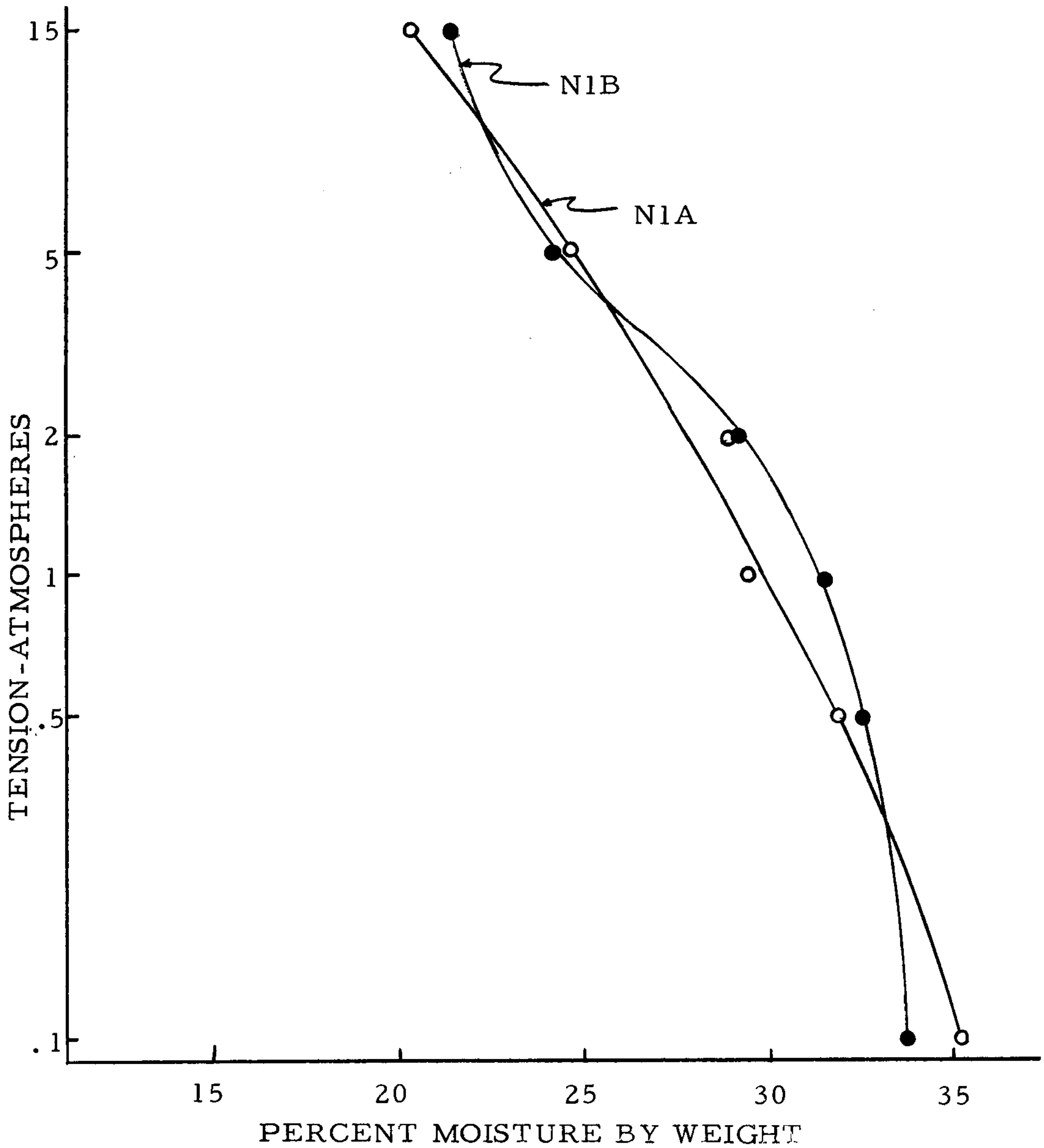

Figure 2. Moisture tension curves for beds N1A and N1B.

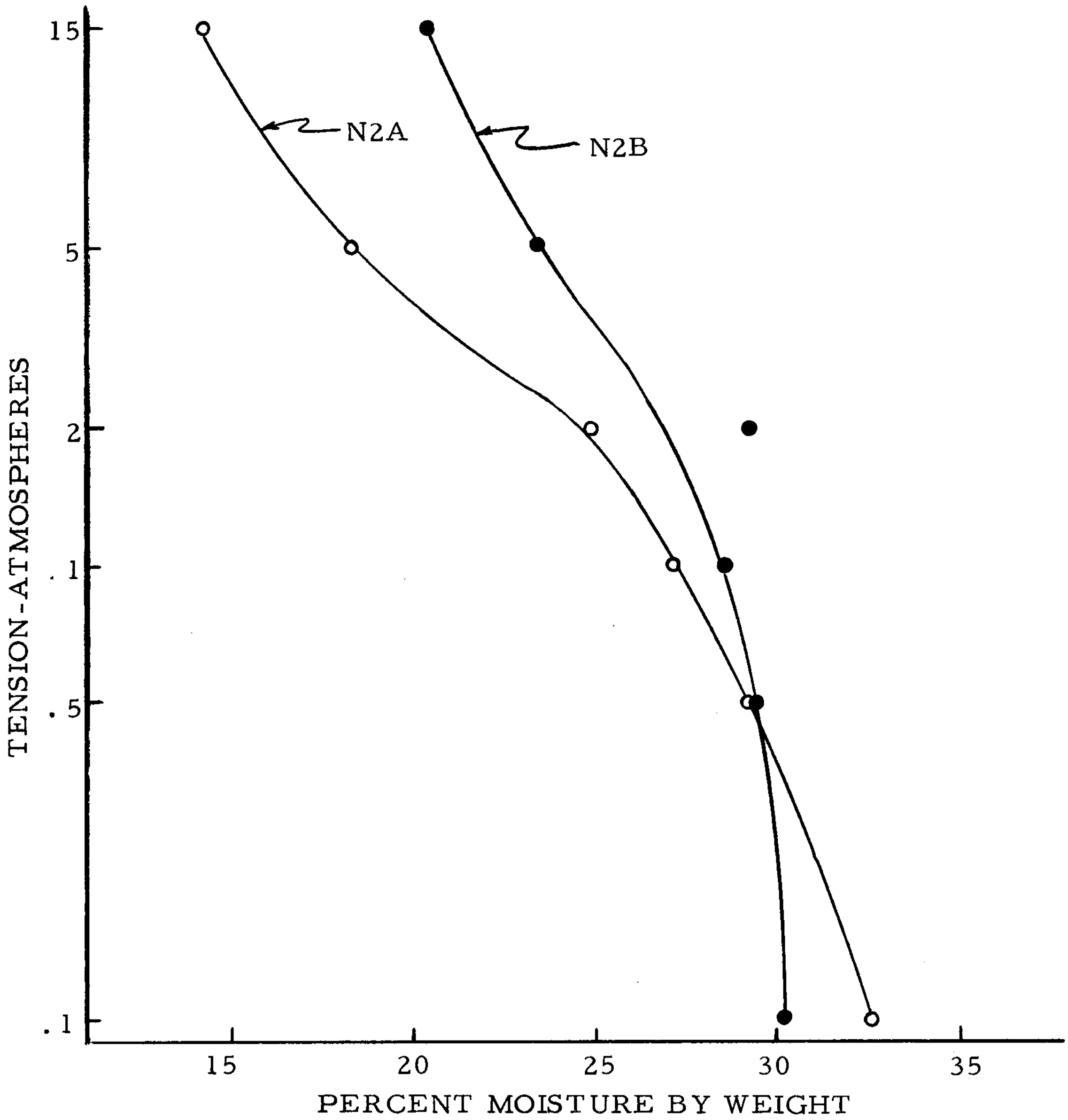

Figure 3. Moisture tension curves for beds N2A and N2B.

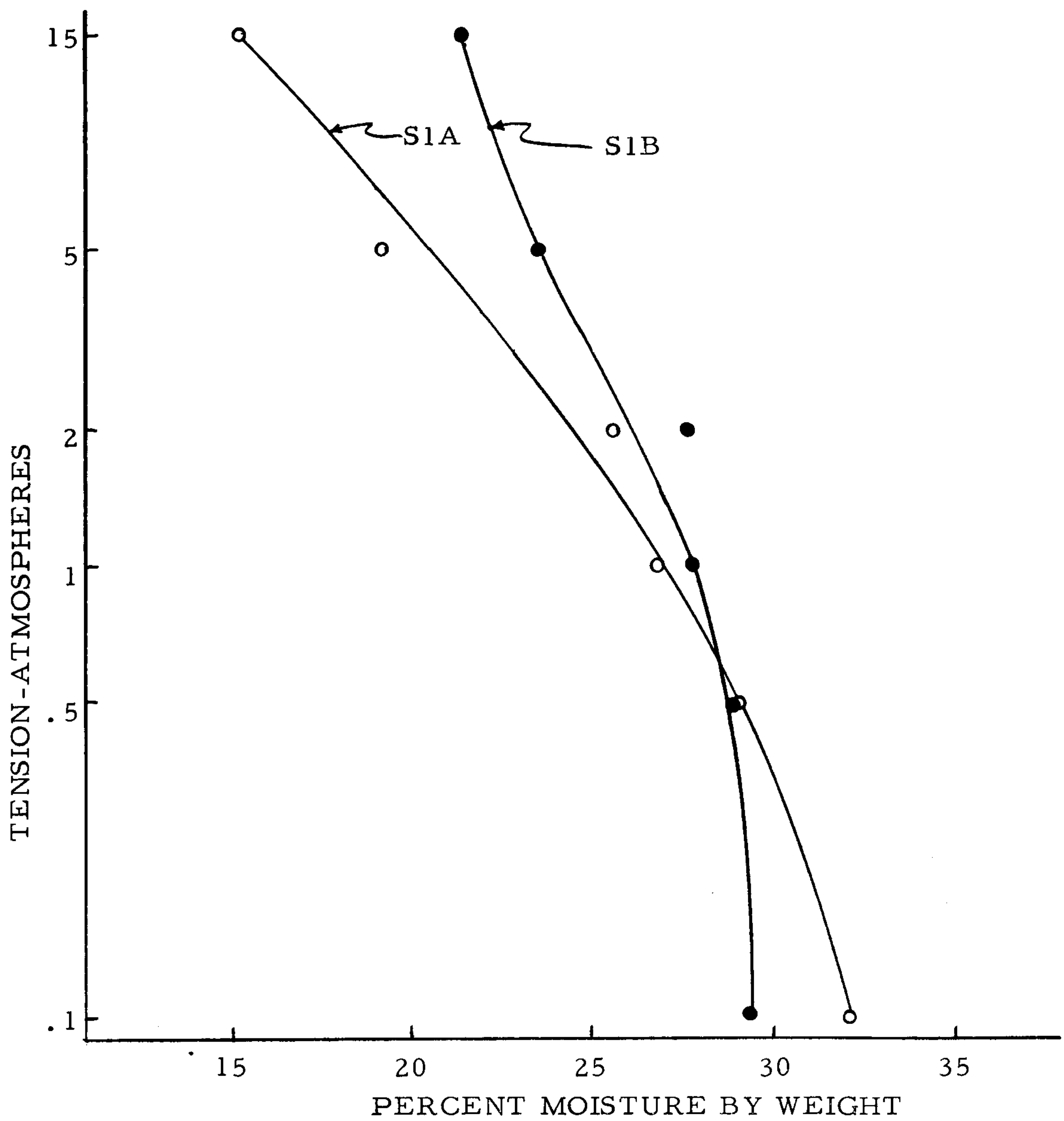

Figure 4. Moisture tension curves for beds S1A and S1B.

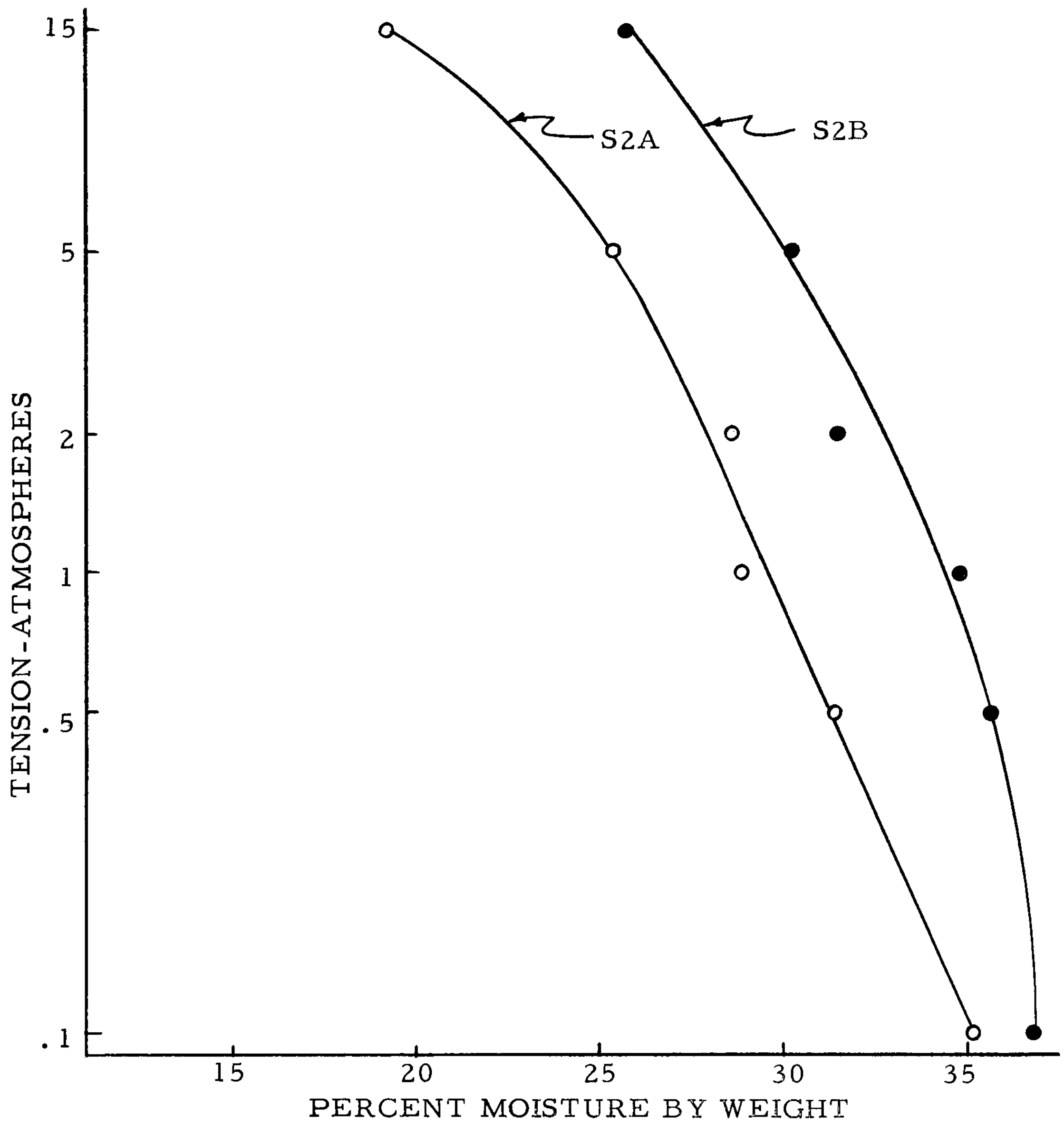

Figure 5. Moisture tension curves for beds S2A and S2B.

RESULTS AND DISCUSSION

Greenhouse Phase

As Figures 6 and 7 show, the root boxes filled with A horizon material produced the largest seedlings while the smallest seedlings were produced in the root boxes containing C_1 horizon material. Analysis of variance shows significant differences at the 0.5 percent level for top height, rooting depth and total weight. The seedlings grown on the C_1 horizon developed the least number of lateral roots. Significant differences were not found for the total length of the three longest laterals although trends were evident. The data for the greenhouse study are summarized in Table 7.

Only the seedlings growing on A horizon material maintained constant growth throughout the experiment. They developed lateral shoots and their roots were the only ones that penetrated to the bottom of the root boxes. Plants growing on the C_1 horizon material began to develop terminal buds as early as April 12. After a terminal bud developed it would break in two to three days; the seedling would then grow for two or three days to one week, and then set bud again. This cycle was repeated two to three times before bud set was permanent. By May 5, trees in the B_2 horizon root boxes also began to set buds and then follow the bud bursting and growth pattern

Table 7. Summary of growth data for seedlings grown in the greenhouse experiment.

Horizon Material	Top Height	Rooting Depth	Dry Weight	Number of Lateral Roots	Total Length of the Three Longest Laterals
	------inches------		grams		-----inches-----
A	5.4	18.0	.33	44	14.2
B_2	2.5	14.6	.20	43	13.6
C_1	1.9	7.2	.11	32	13.5

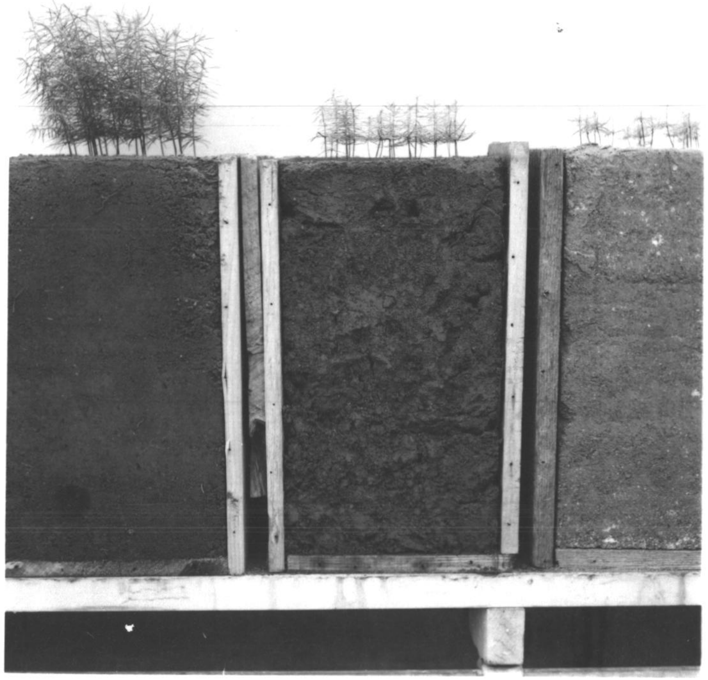

Figure 6. Douglas-fir seedlings in the root boxes before lifting. The A horizon material is shown on the left. The C_1 horizon material is shown on the right.

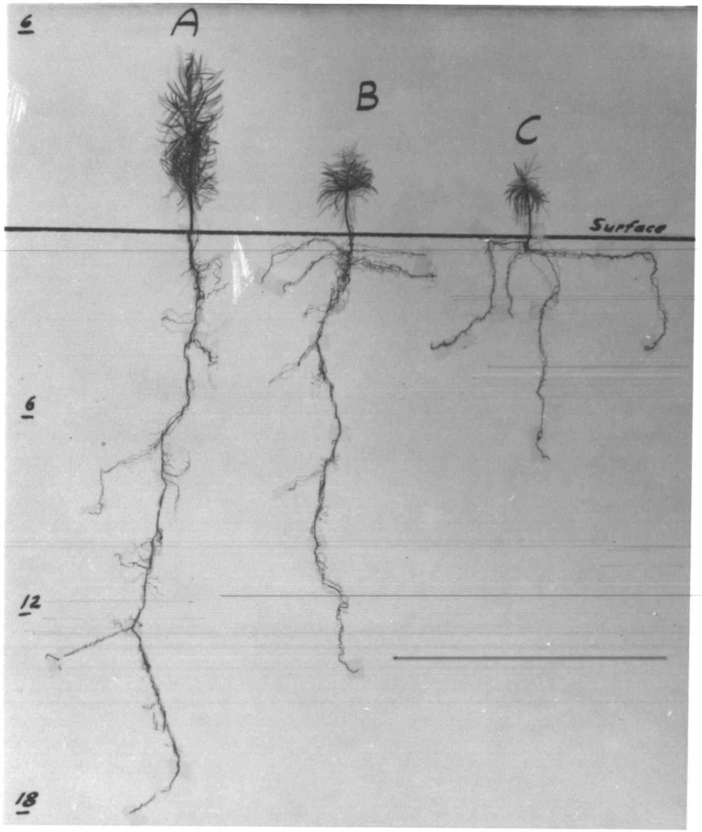

Figure 7. Douglas-fir seedlings taken from root boxes containing the A, B_2, and C_1 horizon material.

described for those in the C_1 horizon. By May 22, most of the B_2 and C_1 horizon seedlings had developed permanent terminal buds. The seedlings growing on the A horizon material never formed terminal buds and continued to grow up to the date of lifting, June 9.

Figure 7 shows that the root configuration of the seedlings grown in the C_1 horizon was different than the root configuration of seedlings grown in the A and B horizon materials. The roots were small and their position suggests that the C_1 horizon material was packed into the boxes too tightly and at a density greater than that found in the field. The rooting configuration of the seedlings produced in the B_2 horizon material was quite different from that of the seedlings grown in the C_1 horizon and resembled the seedlings grown in the A horizon material.

Since moisture was not a limiting factor in the greenhouse, the larger seedling size produced in the A horizon material seems attributable to the higher fertility of this material. Table 1 shows that the A horizon material has a higher level of nitrogen, phosphorus, potassium, and calcium.

The bud setting of the Douglas-fir seedlings on the B horizon material apparently was a result of the lower fertility level. The early bud setting of the seedlings grown on the C_1 horizon material is probably a result of artifical packing which prevented normal root development as well as the low nutrient level.

The experiment shows that when moisture is not limiting and there is no other plant competition, the A horizon has, because of its higher fertility status, the potential to produce the largest Douglas-fir seedlings. The physical characteristics of the B_2 horizon material used in this experiment are not the factors limiting growth in the greenhouse where moisture is adequate.

Field Phase

Seedling survival. During the spring of 1961, when the seedlings germinated, germination was from three to four weeks later than usual[1]. Consequently, the seedlings did not start emerging until about June 1[2].

In order to subject the survival data to analysis of variance, the number of seedlings surviving were converted to percentages on the basis of seeds sown and then were angularly transformed as described by Li (17, p. 453) to obtain normal distributions. The transformed values were then used in the analysis.

Table 8 gives the number of seedlings present on June 24 and the resulting analysis of variance. This table shows that significantly greater numbers of sugar pine and Douglas-fir seedlings were found on the north aspect and on the B horizon beds.

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[1] Personal communication, Lou Billips, South Umpqua Ranger District

[2] Personal communication, William H. Hallin, Roseburg Research Center Leader.

Table 8. The number of seedlings present on June 24 and the analysis of the transformed percentage values.

	BEDS								MS VALUES Degrees of Freedom			
									1	1	1	4
Species#	N1A	N2A	N1B	N2B	S1A	S2A	S1B	S2B	Horizon	Aspect	Interaction	Error
PP	45	63	50	69	29	32	54	62	488.281	308.761	133.6612	113.656
SP	37	46	52	65	13	23	46	42	686.351*	576.301*	20.161	38.744
DF	31	82	85	106	7	8	37	45	630.125*	1132.88*	13.162	77.121

PP refers to ponderosa pine, SP refers to sugar pine, and DF refers to Douglas-fir.
* Indicates significance at the five percent or lower probability level.

Since it was not possible to obtain germination counts, it is impossible to tell if the differences in the number of seedlings present on June 24 are more attributable to variations in germination or to differences in early mortality. On June 24, about 40 percent of the surface of each of the A horizon beds was shaded by forbs, chiefly bull thistle. The majority of the seedlings on the south aspect beds appeared to be growing beneath this shade. The soil beneath the shade seemed to be moist about 1/16 of an inch below the surface while the unprotected surfaces of the south aspect A horizon beds were air dry to a depth of 1-1/2 to 3 inches. The B horizon surfaces were air dry to only 1/2 inch. On the north aspect, bed N1A was air dry to a depth of 1 inch while beds N1B and N2B were air dry to a depth of 1/2 inch. The surface of bed N2A was moist and this bed had the largest number of seedlings of the A horizon beds. When a seed germinates, its radical must encounter moist soil to survive (20, p. 542). It is possible that the feeding roots of the forbs on the unshaded portions of three of the A horizon beds dried the soil sufficiently so that many of the seeds could not germinate or survive. Douglas-fir, the species most shallowly sown, would have the poorest chance of survival. Sugar pine, the deepest sown species, would seem to have the best chance of initial survival while ponderosa pine on the basis of sowing depth would be intermediate. Larger numbers of sugar pine and Douglas-fir seedlings were found on north aspect beds and on B horizon beds but this was not true for ponderosa pine. This indicates that other factors besides depth of sowing must be important.

In an effort to obtain a comparative view of the losses that occurred on each bed after June 24, the percent loss that occurred between this date and December 18 was calculated using the number of seedlings present on June 24 as a base. These percentages were angularly transformed and analyzed. The results of the analysis are given in Table 9. The data show that significantly greater losses of Douglas-fir and sugar pine seedlings occurred on beds on the south aspect. Although horizon is not significant, a trend toward better survival on the B horizons is evident.

Due to the infrequent visits to the area and the lack of moisture and temperature data, it is not possible to ascertain with any certainty the causes of mortality. Some deductions are possible, however. Losses to rodents were negligible because the beds were screened and there was no evidence of rodent burrowing under any of the beds. No evidence was encountered that indicates damping off contributed to mortality. Dead seedlings found on each of the beds were erect whereas seedlings dying from damping-off are usually found to be drooping over or lying on the surface (6, p. 79). It is possible however that pre-emergence damping-off destroyed some seedlings or that some seedlings died and disappeared before the first

Table 9. Percent losses between June 24 and December 18 with the analysis of the transformed percentage values.

									MS VALUES Degrees of Freedom			
	BEDS								1	1	1	4
Species#	N1A	N2A	N1B	N2B	S1A	S2A	S1B	S2B	Horizon	Aspect	Interaction	Error
PP	31.0	25.4	2.0	15.7	76.0	28.0	24.0	19.4	610.751	344.531	2.531	135.712
SP	8.1	10.9	7.8	7.7	92.5	66.7	39.2	4.8	1265.045	2132.045*	1096.445	265.450
DF	61.5	7.3	4.7	0.9	100.0	100.0	89.2	60.0	1476.961	5891.551*	8.611	216.450

PP refers to ponderosa pine, SP refers to sugar pine, and DF refers to Douglas-fir.
* Indicates significance at the five percent or lower probability level.

inspection of the plots.

It is doubtful that frost was a factor affecting mortality. The climate is characterized by a frost free season of 120 days (22, p. 6) and when frost does occur it usually is after the seedlings are preconditioned against injury.

Insects caused some mortality on at least one A horizon bed. Two ponderosa pine seedlings and one sugar pine seedling in bed N1A were found to be clipped just below the soil surface. In the same bed a Douglas-fir root was found to be clipped at a depth of five inches. This damage was apparently done in December when rain beetle larva (Pleocoma spp.) are known to be active. Rain beetle larva were found in the area the previous year when the beds were being prepared; however, none were found when the seedlings were being lifted.

Although the moisture tension curves show that more moisture should be available for plant growth on the A horizon beds, the presence of forbs on these beds probably resulted in less water being available for the growth of the individual seedlings than on the B horizon beds.

There are several reasons why the non-shaded surfaces of the A horizon beds on a given aspect should become warmer than the B horizon bed surfaces. Table 10 presents some of the factors that affect surface temperatures.

Table 10. Factors affecting soil surface temperatures.

Bed	Bulk Density (gms/cc)	Percent Porosity	Percent Moisture 15 atm.	Percent Organic Matter
N1A	.90	67.0	20.40	8.65
N2A	.90	67.0	14.20	3.30
N1B	1.41	46.8	21.50	.82
N2B	1.40	47.2	20.44	.54
S1A	.96	63.8	15.10	5.62
S2A	.91	67.0	18.30	6.80
S1B	1.49	43.9	21.32	1.08
S2B	1.33	49.7	25.62	.86

It is seen that the A horizon soils have a lower bulk density and a higher percent porosity than the B horizon soils. When dry or moist, heat would not be as readily conducted downward from the surface of the A horizon soils because the conductivity of water and air are less than that of soil particles. The B horizon material also has the ability to hold more moisture close to the surface while the A horizon beds have a higher percentage of organic matter. This moisture has a higher specific heat and a higher conductivity than both soil air and dry organic matter which has a much lower specific heat than the other soil components. Consequently, as energy strikes the dry surface of the B horizon beds the heat would be more readily conducted downward away from the surface resulting in smaller increases in temperature at the soil surface.

Douglas-fir, more susceptible to heat injury and drought than either ponderosa or sugar pine, did not survive through the summer on the A horizon south aspect plots. These particular plots were weeded on June 24 exposing the entire bed surface to direct insolation and the highest surface temperatures probably occurred on these beds. There was probably less available moisture for tree seedlings because of competition from plants that re-invaded the plots after the initial June 24 weeding. High soil temperatures on the exposed surfaces on the A horizons on the south aspect, moisture depletion of the A horizons by forbs, and the higher losses of moisture on the south aspect due to larger amounts of direct insolation are probably the reasons for finding the fewest numbers of Douglas-fir on the A horizons and on the south aspects on June 24. These same factors are probably the reasons for the complete loss of Douglas-fir on the A horizon south aspect beds and the larger percent loss on the south aspect beds through the summer.

Sugar pine, because of its large stem diameter is the least susceptible to stem heat injury of the three species studied. Since the beds were covered with 1/4 inch wire mesh it is possible that the soil surface never attained the lethal tissue temperature for this species. Drought would seem to be the major cause of the sugar pine mortality and the lower available moisture of the south aspect and the A horizon beds would account for the lower numbers of seedlings found on the south aspect and the A horizon beds on June 24. After establishment, the less favorable moisture conditions of the south aspect would account for the higher seedling losses that occurred through the summer.

Ponderosa pine, because of its long tap root compared to Douglas-fir and its small top or transpiring surface compared to sugar pine, is probably the least susceptible to drought of the three species studied. It is known that ponderosa pine seedlings have the ability to survive under conditions where the soil moisture tension exceeds 15 atmospheres (10, p. 603). Fowells and Arnold (9, p. 821-822) found that maximum temperatures at 1/4 inch below the soil surface under cones made of four mesh 20 gauge hardware cloth averaged 12.2 degrees Fahrenheit less than corresponding temperatures outside the screens on a south exposure. If the screens over the beds prevented the soil surfaces from reaching lethal tissue temperatures for ponderosa pine and sugar pine, the fact that no significant differences were found in the number of seedlings present on June 24 or the percent losses between June 24 and December 18 indicates that ponderosa pine can withstand the low levels of soil moisture better than sugar pine or Douglas-fir can.

Table 11 gives the number of seedlings present on each of the beds on December 18 and the analysis of the transformed percentage values. The data show that significantly larger numbers of ponderosa

Table 11. The number of seedlings present on December 18 and the analysis of the transformed percentage values.

	BEDS								MS VALUES Degrees of Freedom			
									1	1	1	4
Species#	N1A	N2A	N1B	N2B	S1A	S2A	S1B	S2B	Horizon	Aspect	Interaction	Error
PP	31	47	49	55	7	23	41	50	693.781*	355.111	120.901	63.879
SP	34	41	48	60	1	11	28	40	754.661*	992.351*	166.531	50.224
DF	10	76	81	107	0	0	4	18	716.31	2404.71*	27.75	150.592

PP refers to ponderosa pine, SP refers to sugar pine, and DF refers to Douglas-fir.
* Indicates significance at the five percent or lower probability level.

pine and sugar pine seedlings were found to be growing on the B horizon beds in December. Horizon tends to be significant for Douglas-fir. Significantly larger numbers of sugar pine and Douglas-fir seedlings were found on the north aspects and aspect tended to be significant for ponderosa pine.

Seedling development. The growth of sugar pine and ponderosa pine seedlings on the two B horizon beds on the south aspect is compared in Table 12.

Table 12. Seedling development on beds S1B and S2B.

	Beds		
	S1B	S2B	F Value
Sugar Pine:			
rooting depth, inches	8.1	15.8	24.9171*
total weight, grams	.47	.55	4.5532*
top weight, grams	.24	.25	12.9764*
root weight, grams	.23	.30	5.6973*
Ponderosa Pine:			
rooting depth, inches	7.2	19.1	277.3807*
total weight, grams	.20	.26	4.9843*
top weight, grams	.10	.12	2.9595
root weight, grams	.10	.14	256.0348*

* Indicates significance at the five percent or lower probability level.

Consideration of the data in Tables 5 and 6 and the moisture tension curves in Figures 2, 3, 4, and 5 lead to the conclusion that the high bulk density of the soil in bed S1B and the corresponding low porosity are the most probable reasons for the differences in development.

In order to determine if there were similar differences between replicates on the other horizon and aspect combinations, analysis of variance was made for the total seedling weight data. No significant differences were found.

Because of the poor development of the seedlings on bed S1B, ponderosa pine and sugar pine seedlings from bed S2B were used for the south aspect B horizon treatment in the analysis of the horizon by aspect factorial design. The elimination of seedlings from bed S1B and the poor survival of seedlings on beds S1A and S2A limited the size of the samples that could be used for each treatment in the factorial design to 12 seedlings for ponderosa pine and 11 seedlings for sugar pine. To choose these numbers of seedlings from the remaining treatments, random selection was employed.

Analysis of variance of unequal sample sizes (17, p. 176-177) was used for the Douglas-fir data because of the poor survival of this species on bed N1A and because complete mortality on beds S1A and S2A eliminated the south aspect A horizon treatment.

Seedling development data for ponderosa pine are given in Table 13. The heaviest seedlings were produced on the A horizon on the north aspect. Differences between other treatments were not

Table 13. Average values for development data of ponderosa pine and the results of the analysis of variance.

	Treatments 1/				F Values			Treatment
	NA	NB	SA	SB	Horizon	Aspect	Interaction	LSD 2/
Total weight, grams	.41	.29	.26	.25	6.6428*	12.9706*	5.6289*	.08
Top weight, grams	.20	.15	.13	.12	8.3188*	20.8038*	3.5273	.04
Root weight, grams	.21	.14	.13	.13	4.4135*	5.5269*	6.7654*	.05
Top height, inches	2.5	1.9	1.9	1.9	6.9226*	10.1179*	7.3421*	.3
Root depth, inches	20.3	15.1	13.2	20.8	.8179	.9132	36.2537*	
Number of lateral roots	86	67	67	86	.00002	.0002	12.6256*	
Total length of the three longest lateral roots	3.9	7.5	3.7	6.9	20.3472*	.3219	.0758	2.3

* Indicates significance at the five percent or lower probability level.

1/ Indicates treatments, NA indicates north aspect A horizon, NB indicates north aspect B horizon, SA indicates south aspect A horizon, and SB indicates Bed S2B.

2/ Stands for least significant difference.

significant. This may indicate that the more favorable moisture status on the north aspect allowed seedlings to benefit from the higher fertility level of the A horizons, while on the south aspect moisture was the limiting factor. The significance of the interaction of aspect and horizon suggests an additive effect of the more favorable moisture regime on the north aspect and the higher fertility levels of the A horizons. The results for top and root weights are similar except that the interaction term only tends to be significant for top weights. Top height follows the same pattern as total weight, the tallest seedlings being produced on the north aspect A horizon treatments, while the other treatments are the same.

The rooting depth data is interesting in that seedlings rooted deeper in the A horizons on the north aspect, while the deepest roots were produced on bed S2B on the south aspect. This, plus the fact that significant differences do not occur between the A horizon north aspect treatment and bed S2B, suggests the possibility that the higher bulk densities of the B horizons on the north aspect may be limiting root growth somewhat.

The heaviest sugar pine seedlings were also produced on the north aspect plots (Table 14). In contrast to the development of ponderosa pine seedlings, the sugar pine seedlings produced on the B horizons tend to be heavier than the seedlings produced on the A horizons. The top weights follow the same pattern as total weights. Top

Table 14. Average values for development data of sugar pine and the results of the analysis of variance.

	Treatments 1/				F Values			Treatment
	NA	NB	SA	SB	Horizon	Aspect	Interaction	LSD 2/
Total weight, grams	.59	.64	.50	.55	1.6634	4.3975*	.9535	.14
Top weight, grams	.30	.31	.25	.25	.5293	5.3893*	.3543	.06
Root weight, grams	.29	.33	.24	.30	3.3937	2.2435	.0246	
Top height, inches	2.6	2.4	2.2	2.3	.0014	6.1896*	2.3788	.3
Root depth, inches	19.3	15.9	14.8	19.4	.4465	.3232	19.3462*	
Number of lateral roots	66	64	57	57	.3071	.3878	.2703	
Total length of the three longest lateral roots	5.6	14.1	4.6	9.2	21.3942*	3.5900	2.3963	4.6

* Indicates significance at the five percent or lower probability level.

1/ Indicates treatments, NA indicates north aspect A horizon, NB indicates north aspect B horizon, SA indicates south aspect A horizon, and SB indicates Bed S2B.

2/ Stands for least significant difference.

heights were greatest on the north aspect and the tallest seedlings were produced on the A horizon. The seedlings grown on B horizons produced the heaviest roots in direct contrast to ponderosa pine. The total length on the three longest lateral roots of seedlings grown on the B horizon were much longer than those from seedlings produced on the A horizons. The difference in lateral root lengths for seedlings from A and B horizons is much greater for sugar pine than for ponderosa pine. No significant differences occur in the number of lateral roots. Interaction is the only significant term for rooting depth because on the north aspect the A horizon produced the deepest rooted seedlings while on the south aspect, bed S2B produced the deepest roots. Again this may indicate that the bulk densities of the B horizons on the north aspect are limiting root growth.

The differences in development of sugar pine and ponderosa pine seedlings may be due to one or a combination of the following factors:

1. Due to its larger seed size sugar pine may be less dependent upon soil nutrients during the early stages of development than ponderosa pine.

2. As a result of a larger initial seedling size, sugar pine develops a root system capable of permeating a larger volume of soil in the absence of competition than ponderosa pine does. This would enable sugar pine seedlings to extract more nutrients and moisture

from the B horizon beds.

3. Forb competition may in some way be more harmful to the early development of sugar pine seedlings than to ponderosa pine seedlings.

Since the lateral movement of soil moisture ceases or is extremely slow at soil moisture contents below field capacity, a plant must continually extend its root system as it exhausts the supply of soil moisture. Data for root weights and for length of the lateral roots indicate that, in the initial stages of development, sugar pine is more capable of extending its root system in the heavier textured B horizons having high bulk densities than is ponderosa pine.

The heaviest Douglas-fir seedlings were produced on the north aspect A horizon (Table 15). No differences in top weights or top heights were found, but the heaviest roots were found on the seedlings growing on the north aspect A horizon. Seedlings grown on the north aspect B horizon developed heavier root systems with more lateral roots than the seedlings grown on the south aspect B horizon and the roots of these seedlings also penetrated to a greater depth. However, the greatest rooting depth was attained by seedlings grown on the north aspect A horizon.

The production of the largest Douglas-fir seedlings on the A horizons of the north aspect may be attributable to the higher fertility

Table 15. Average values for developmental data of Douglas-fir and the results of analysis of variance.

	Treatments 1/			F Values	
	NA	NB	SB	NA vs. NB	NB vs. SB
Total weight, grams	.16	.11	.10	17.4678*	2.3645
Top weight, grams	.06	.05	.05	3.3347	2.4600
Root weight, grams	.10	.06	.05	27.2959*	4.3078*
Top height, inches	1.6	1.4	1.4	3.9322	.614
Root depth, inches	14.8	10.1	8.4	24.7936*	4.3145*
Number of lateral roots	62	56	49	1.1494	2.479
Total length of the three longest lateral roots	4.1	3.8	4.6	.3315	2.0400

* Indicates significance at the five percent or lower probability level.

1/ Indicates treatments, NA indicates north aspect A horizon, NB indicates north aspect B horizon, and SB indicates Bed S2B.

and the lower bulk densities of these seedbeds. The much larger root weights of the seedlings grown on the A horizons and the non-significant difference in top weights suggest that the bulk densities of the exposed B horizons on the north aspect limited growth.

CONCLUSIONS

At the end of the first growing season, larger numbers of sugar pine and ponderosa pine seedlings were found on the exposed B horizons. No Douglas-fir survived on the south aspect A horizons and survival of Douglas-fir and sugar pine was lower on the south aspect than on the north. These results were attributed to the absence of forb competition on the B horizons, the more favorable moisture regime of the north aspect, and the high soil surface temperatures of the south aspect A horizon plots.

Bulk densities of the exposed B horizons varied and the growth data for these beds gives some indication of the influence of bulk density on growth. A bulk density of 1.49 gms/cc on bed S1B limited growth, while bulk densities of 1.40 and 1.41 gms/cc on beds N1B and N2B appeared to be somewhat limiting to root growth. Ponderosa and sugar pine seedlings produced on bed S2B, which had a bulk density of 1.33 gms/cc, were as large as those produced on the south aspect A horizon beds even though the A horizon beds contained over twice as much total nitrogen and over five times as much phosphorus by weight. It appears, therefore, that bulk densities below 1.40 gms/cc are not limiting to ponderosa pine and sugar pine seedling growth.

On the north aspect, the A horizons produced the largest ponderosa pine and Douglas-fir seedlings. This is in agreement with greenhouse results where, under conditions of adequate moisture, material taken from the A horizon produced larger seedlings than material taken from B_2 and C_1 horizons. In the field, sugar pine seedlings tended to be heavier on the B horizons on both aspects because of the more extensive root development on these beds. When considering these results, the late germination and the resulting short growing season should be kept in mind. Had the growing season been of normal length, it is probable that the sugar pine seedlings on the A horizon would have been larger due to the higher level of soil fertility in this horizon. Since sugar pine has the largest seed of the three species studied, it probably would be less sensitive to low fertility levels than the other two species.

The factors limiting growth in the field phase of the experiment appeared to be forb competition on the A horizons, low soil moisture, particularly on the south aspect, and the high bulk densities and the low soil fertility of the B_2 horizons. In the greenhouse low soil fertility of the B_2 horizon material limited growth of Douglas-fir. While exposure of B horizons may aid in initial seedling establishment, the low fertility and high bulk densities that may be encountered cannot be expected to favor seedling growth over a long period of time.

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APPENDIX

APPENDIX

DUMONT SOIL SERIES

Soil Horizons	Profile Thickness	Morphological Features
Aoo	2-1"	Undecomposed pine and fir needles, chinkapin leaves.
Ao	1-0"	Black to very dark gray decaying Aoo, grey mycelia layer between Ao and A.
A1	0-4"	Dark reddish brown (5YR3/3 moist); light clay loam; weak to moderate fine and very fine granular structure; loose when dry, friable when moist slightly sticky slightly plastic when wet; many fine and large roots; many fine and very fine fe-mn concretions; clear slightly wavy boundary.
A3	4-8"	Dark reddish brown (5YR3. 5/4 moist); silty clay loam; weak fine and medium sub angular blocky breaking to very fine sub angular blocky structure; slightly hard when dry; slightly firm when moist, nonsticky and slightly plastic when wet; many fine and few coarse roots; many fine and very fine soft fe-mn concretions; gradual wavy boundary.
B1	8-11"	Reddish brown (5YR4/4) moist); silty clay loam; moderate fine sub angular blocky structure, slightly hard dry, slightly firm moist, slightly plastic and slightly sticky when wet; numerous fine and medium roots, few coarse roots; common fine and very fine fe-mn concretions; gradual boundary.
B21	11-18"	Reddish brown (5YR 4/4) moist); silty clay; nut-like structure (10 to 25 mm in size) breaking to moderate fine and very fine sub

		angular blocky structures; thin discontinuous and patchy clay films; hard when dry; firm when moist plastic and sticky when wet; common fine, medium and a few coarse roots; few fine fe-mn concretions; gradual boundary.
B22	18-25"	Yellowish red (5YR4/6 moist) silty clay; nut-like structure (10 to 25 mm in size) breaking to moderate to strong sub angular blocky structure; thick discontinuous patchy clay films; very hard when dry, very firm when moist, sticky and plastic when wet; few fine, medium and coarse roots, gradual boundary.
B23	25-30"	Yellowish red (5YR4/8 moist) silty clay; nut-like structure (10 to 25 mm in size) breaking to moderate fine and very fine sub angular blocky structure; discontinuous thin patchy clay films; very hard when dry, firm when moist, slightly sticky and plastic when wet; few fine medium and coarse roots; gradual boundary.
B31	30-36"	Yellowish red (5YR5/8) moist) silty clay loam; weak to moderate fine sub angular blocky structure; thin discontinuous patchy clay films; slightly hard when dry, slightly firm when moist, slightly plastic to plastic when wet; few fine medium and coarse roots; gradual boundary.
B32	36-43"	Yellowish red (5YR5/8 moist); silty clay loam; weak fine and very fine sub angular blocky structure; thin discontinuous patchy clay films; slightly hard when dry, friable when moist, slightly plastic when wet; very few fine, medium and coarse roots; gradual boundary.
B33	43-50"	Yellowish red (5YR5/8 moist) silt loam; very weak fine sub angular blocky to massive structure; thin discontinuous red clay films (2. 5YR4/5); soft when dry, friable when

		moist; nonplastic and slightly sticky when wet; gradual boundary.
C1	50-64"	Strong brown (7.5YR5/8 Moist) heavy silt loam; dominately massive with a few nut-like structures; clay films along root channels are red (2.5 YR4/5); soft when dry, friable when moist, nonplastic and slightly sticky when wet; clear, wavy boundary.
Dr	64-72"	Dark reddish breccia with exotic colors of reds, purples, greens, pinks, yellows, etc.

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