THE RELATIONSHIP OF THE SURVIVAL OF DOUGLAS-FIR, PSEUDOTSUGA MENZIESII (MIRB.) FRANCO, SEEDLINGS TO CERTAIN SOIL AND OTHER SITE CHARACTERISTICS ON THE TILLAMOOK BURN

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INTRODUCTION

For many years private, state and federal foresters have felt the need for more information on soil and other site characteristics which may be affecting tree seedling survival on burned and cut-over lands. Each year as the acreage of these denuded forest lands increased this need became more evident. Much of this land has become tax delinquent and has passed into the ownership of the counties and the state. One of the most publicized tracts of denuded land in State ownership is the vast Tillamook Burn. This study was initiated to provide preliminary information on the properties of the soils on the Burn and their effects on seedling survival.

To facilitate the reforestation of this area a special project was set up by the Oregon State Board of Forestry. This project was initiated in 1949 and is known as the Tillamook Burn Rehabilitation Project. Reforestation of the Burn thus far has been by hand planting and aerial seeding. This study deals only with the hand planting phase of the project.

Survival of planted trees has varied over the years and has thus prompted the foresters-in-charge to investigate the causes of this variability. Since the Board of Forestry is not set up at the present time to handle such a specialized field of study as forest soils, it was necessary to call upon the Oregon State College Experiment Station at Corvallis, Oregon, to cooperate in the work.

Reforestation activities involve long-time investments. Any negligence in the selection of planting or seeding sites may result in considerable financial loss. With this thought in mind it is hoped that specifications may be drawn up from the information obtained which will aid foresters to make a better evaluation of site factors. Pre-planting and pre-seeding surveys may then be made and a sounder basis for assigning seeding and planting priority established.

REVIEW OF THE LITERATURE

Investigations of soils and other factors related to the rehabilitation of burned and cut-over forest lands in the Pacific Northwest have not been extensive but have been adequate enough to point out the general problems of this region. In addition, the results of some studies in other regions are applicable to this region. One of the earlier investigations was made by Powers (29, pp.1-10) in 1932 into the general fertility status of a Latosolic forest soil. Factors investigated were reaction, cation exchange capacity and organic matter and total nitrogen contents. Fowells and Stephenson (11, p.181) studied the effects of fire on forest soils and concluded that burning may change the fertility status. Nitrification was stimulated and an increase of soluble mineral nutrients resulted. Organic matter was destroyed in varying amounts and the net effect was to impoverish the soil. Powers and Bollen (30, p.327) concluded that the base nutrient supplying power of forest soils is centered in the humus layers. Nitrate production is also greatest in this layer. Therefore, where organic matter is low, soil fertility may also be expected to be low. Isaac and Hopkins (19, pp.269-278) and Isaac (21, p.49) went a step further to postulate that a heavy slash fire may destroy as much as 435 pounds of nitrogen per acre as well as cause other detrimental effects. Cooper (6, pp.710-711) found a definite correlation between the loss of topsoil by erosion and a decrease in site index. Tarrant (36, p.4) found that most of the organic matter was centered in the upper horizons and found a direct correlation between organic matter and total nitrogen. In a later study Tarrant (37, p.719) concluded that the nutrient content of forest soils was generally high enough not to be a limiting factor to tree growth. Recent investigations by Gessel, et al. (14, pp.368-369) indicate that nitrogen is a limiting factor in the growth of Douglas-fir on severely burned soils. Youngberg and Austin (47, p.5) sampled forest soils under stands of Douglas-fir of all ages and arrived at recommended fertility standards for forest nurseries.

Soil fertility is not the only factor which may affect seedling survival. The role of soil moisture has been investigated by numerous authors (9, p.686), 20, pp.24-28, 42), 21, pp.34-38), 24, pp.344-349), 28, pp.54-56, 63) and 40, p.39). Without exception these authors concluded that where soil moisture conditions were critical seedling mortality was also high. The effects of severe summer droughts in western Oregon were investigated by Tiedemann (40, pp.20-22, 39-40) in 1934. He concluded that soil moisture was the most important factor affecting seedling survival. He also found that drought may be important in open lands as well as in dense forests.

Tiedemann also stated that seedling mortality was greatest the first year.

Other factors investigated include surface soil temperatures. Studies by Isaac (20, pp.8-21, 42), 21, pp.28-31, 39-40, 103) showed definite correlation between high surface soil temperature (above 123°F.) and seedling mortality. Owen (28, pp.21-27, 61) found essentially the same thing except that 131°F. was set as the minimum critical temperature. Both of these studies were conducted on first year Douglas-fir seedlings. Owen found that seedlings have a greater resistance to heat as they grow older.

Soil physical properties have been considered in many survival studies. Fire was observed to effect a change in many ways. Isaac (21, p.48, 50) and 19, p.278) noted dehydration of secondary minerals, colloid breakdown, unfavorable structure and reduction of moisture holding capacity. These observations were not directly associated with seedling survival. Soil structure is adversely affected by loss of organic matter as pointed out by Lunt (25, pp.35-36), Quastel (31, pp.419-420) and Isaac (21, p.48 and 50). Tarrant (38, pp.104-105) embodied three physical properties in his preplanting soil survey. These included surface soil texture, surface soil consistence and sub-soil consistence. Root penetration is greatly affected by these properties as is adequate aeration and drainage. Hill, et al. (18, p.841) mentioned that soil texture has some effect on Douglas-fir site quality.

Fire may adversely affect soil reaction. Tarrant (39, p.4) found the greatest pH change at temperatures below 900°F. He recommended fast moving slash fires to keep changes to a minimum. Wildfires may cause marked changes in pH. Tarrant sets a value of about 5.5 as optimum for Douglas-fir. Youngberg and Austin (47, p.5) set a range of 4.8 - 5.8 as optimum.

Topography has an effect on seedling survival. Cooper (6, pp.710-711) recognized the influence to topography on growth. Tarrant (38, pp.104-105) included percent slope and site aspect as criteria in his preplanting soil survey. It is generally agreed that slope and aspect are important with regard to differences in moisture relationships, especially in the rate of soil drying.

Physiology of the planted tree is often neglected in survival studies. The ability of the seedling to produce new roots after planting is of utmost importance. Fowells and Kirk (12, pp.602-603) in green house experiments with ponderosa pine found that mutilation of the roots and subsequent failure of new root regeneration consistently produced greater mortality. This poor physiological condition often results from poor planting or improper handling prior to planting. Lane and McComb (24, p.349) found poor root development of seedlings associated with heavy grass cover on the planting site. This was attributed to the rapid depletion of soil moisture by grasses resulting in a general soil moisture deficit. Stone (35, p.7, 15) worked with coniferous trees in California and also concluded that failure of roots to elongate would cause subsequent death due to drought. Youngberg and Austin (47, pp.5-6) noted better survival of 1-0 planted Douglas-fir when nursery fertilization resulted in a balanced ratio of the major nutrient elements in the nursery soil.

DESCRIPTION OF THE AREA

The Tillamook Burn is located in northwest Oregon in Tillamook, Clatsop, Washington and Yamhill counties. The largest portion is in Tillamook County on the west slope of the Coast Range from near sea level to the summit. Elevations range from about 400 feet near the coast to about 3500 feet on the uppermost part of the summit. Starting with the original fire in 1933 subsequent fires have occured every six years resulting in a total acreage of 355 thousand acres (22, p.85) or somewhat less than one half of the area of the State of Rhode Island. Certain portions have been burned more than once. Within the burned area are stands of green timber but these are scattered and amount to only 5 thousand acres.

Northwest Oregon is characterized by a humid, temperate climate with a summer rainfall deficit. Precipitation is high on the west slopes of the Coast Range and varies from 60 to 120 inches annually. Cool moist westerly winds blowing in from the Pacific Ocean provide the major source of precipitation with the greatest rainfall occurring at the middle elevations. Annual precipitation is less than 60 inches east of the summit. A typical lower elevation rainfall pattern is presented in Table I. At the present time adequate data are not available for the higher

TABLE I

CLIMATOLOGICAL DATA FOR LOWER ELEVATIONS
OF NORTHWEST OREGON
JEWELL, OREG.[1]

	Temperature (°F.)			Precipitation (inches)			
Month	Mean	Absolute Maximum	Absolute Minimum	Mean	Total for the driest year	Total for the wettest year	Average Snowfall
January	37.6	57	-4	10.44	3.82	15.53	5.7
February	40.7	65	8	8.96	11.02	11.87	1.7
March	45.0	82	24	7.69	4.89	10.72	2.2
April	48.3	90	26	4.60	3.57	5.71	.7
May	53.3	95	29	3.22	5.83	2.90	0
June	58.2	99	33	1.66	1.68	2.82	0
July	62.4	102	36	.47	0	.28	0
August	62.7	99	38	1.18	0	1.25	0
September	58.9	97	25	3.38	1.32	4.35	0
October	52.5	87	38	6.02	4.14	7.98	0
November	44.0	70	21	9.48	6.35	19.62	T
December	38.4	65	2	12.22	6.62	9.02	3.3
Year	50.2	102	-4	69.32	49.24	92.05	13.6

[1]Soil survey of the Astoria Area (43, p.8)

rainfall zones. Not evident from Table I is the possibility of early spring drought conditions. Semi-drought conditions often occur in the Coast Range during April or May but durations are seldom in excess of 3 to 4 weeks. During June, July and August there is a pronounced moisture deficit. It is during this summer drought period that seedling survival may be affected adversely.

Temperatures for the Tillamook Burn are influenced by its proximity to the Pacific Ocean. This marine influence is responsible for the lack of major fluctuations in temperature and temperatures may be termed as cool. Mean, maximum and minimum temperatures by months appear in Table I.

Prior to the burning, the native vegetation was dense, consisting of Douglas-fir, western red cedar, and western hemlock at the medium and higher elevations. At the lower elevations near the coast, Sitka spruce is also included in the association. Due to successive burns pioneer vegetation has become established on much of the area. Red alder, vine maple, and such plants as bracken fern, Oregon grape, salal, blackberry and salmonberry make up the cover at the present time. In 1953 less than 12 percent (22, p.84) of the burned area had adequate coniferous stocking from natural sources.

The Tillamook Burn is underlain almost entirely by the Tillamook Volcanic Series (45). This series is of Eocene age and consists of basaltic lavas and tuffs which form the backbone of the Coast Range in the southern part of the Burn. These strata are exposed along most of the major streams. In the northern part of the area more basaltic intrusions are present. These intrusions are often sills and dikes and frequently appear topographically as resistant ridges. Sandstones and shales are also present but are not continuous for any length due to the basalt intrusions. This complex association has resulted in differential geologic erosion and has left the area almost wholly in slopes (Fig.1). The Burn is rather well dissected by streams with upland terraces notably absent. Stream channels are narrow with flood plains being only a few yards wide. Hills rise steeply from the stream beds to produce local relief of 500 to 1500 feet.

Soils in the Tillamook Burn vary widely from place to place. Variation within the area is controlled primarily by slope. The steeper slopes generally have stony coarse textured soils. On gently rolling hills, soils higher in clay and silt predominate. Soil depths vary from less than 2 feet along the rocky ridges to well over 5 feet on the moderately sloping hillsides. Due to the mountainous topography internal and surface soil drainage is excellent. Weathering of the country rock has been fairly rapid,

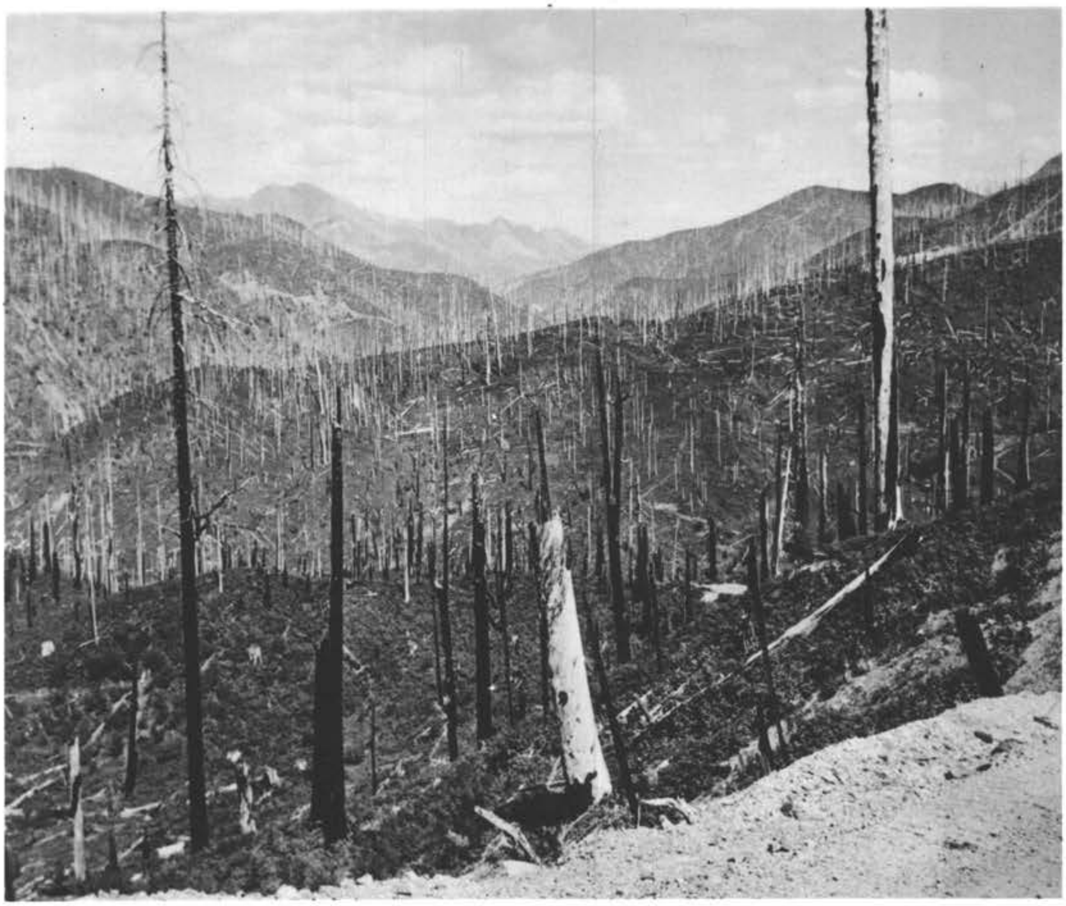

Fig. 1 Rough Mountainous Terrain typical of the Tillamook Burn Note the abundance of snags. (Photograph by Oregon State Board of Forestry)

keeping pace with normal geologic erosion to maintain good soil depth. Rock weathering has been aided by the high biologic pressure exerted on the area by a favorable climate.

THE EXPERIMENTAL PROCEDURE

These studies cover a two year period beginning June 1953 and ending in April 1955. The experimental methods will be discussed in two sections. The first will deal with the field studies conducted during the summer months on the planting sites. The second will cover the laboratory procedures.

FIELD STUDIES

Ten one-fifth acre plots were selected each year from the current planting areas. The plots were distributed over the many conditions of slope, aspect, soil and vegetative cover in order to make them representative of the area as a whole. Experience gained during the first summers work indicated a necessity for altering the procedure somewhat for the second season. Where differences of this type occur both will be discussed.

Profile examinations were made by opening pits to a depth of 60 inches or to bedrock if encountered sooner. In 1953 only one pit was dug on each plot. In 1954 two pits were opened on each plot. These two pits were necessary to conform to a change of method for moisture determinations. The moisture determination methods will be discussed later. Factors investigated with respect to the profile pits include:

1. Depth and thickness of horizons
2. Horizon boundary
3. Soil color by horizons
4. Soil texture
5. Soil structure
6. Soil consistence
7. Soil parent material
8. Stoniness
9. Root distribution
10. Effective soil depth

Soil samples for laboratory analysis were taken from the face of the profile pit. In 1953 the sampling was done on each plot at the 0-3, 3-6, 6-12, 12-24 and 24-36-inch levels. The samples from the 0-3 and 3-6-inch levels were later combined when moisture-tension relationships were studied in order to conform with the field moisture determinations. In 1954 sampling was done on both profile pits for each plot at the 0-4, 4-8, 8-16 and 24-36-inch depths. This change in sampling procedure was made in order that the sampling would be done at the same depths for which soil moisture determinations were made.

Certain other environmental factors were included in the plot analysis. These include:

1. Native vegetation and its vigor
2. Slope of the plot
3. Aspect of the plot
4. Drainage conditions (external and internal)

In addition to the above investigations moisture determinations were made weekly throughout the summer season. In 1953 soil was sampled at random on the plots with a sampling tube. Soil was taken from the 0-6 and 6-12-inch levels. The soil was placed in seamless steel cans and sealed with masking tape to prevent evaporation.

In 1954 moisture determinations were made by using fiberglas soil moisture units (44, pp.34-42) and 41, pp.1-48). Two locations were selected on each plot and a stack of 3 units each was installed at each location. Installation was made in March when the soil was near field capacity. Units were oriented vertically and pressed into the side of a shallow pit with a notched stick. Units were placed in mineral soil at 2, 6 and 12 inch depths. Soil was replaced and tamped thoroughly. Wires were led out of the soil and stapled to cedar stakes (Fig.2). Lead wires had been previously soldered into a special socket adapted to fit a battery-operated alternating-current microammeter (Colman meter) and readings were made in the usual manner (Fig.3).

At the time of installation of the field units soil cores were taken for laboratory calibration. Small cans with both ends removed were used. The object was to obtain undisturbed soil cores. Due to the rocky nature of the soil and to other factors this calibration method was abandoned in favor of other calibration methods.

In conjunction with the moisture determinations, rainfall records were kept for the planting area. The

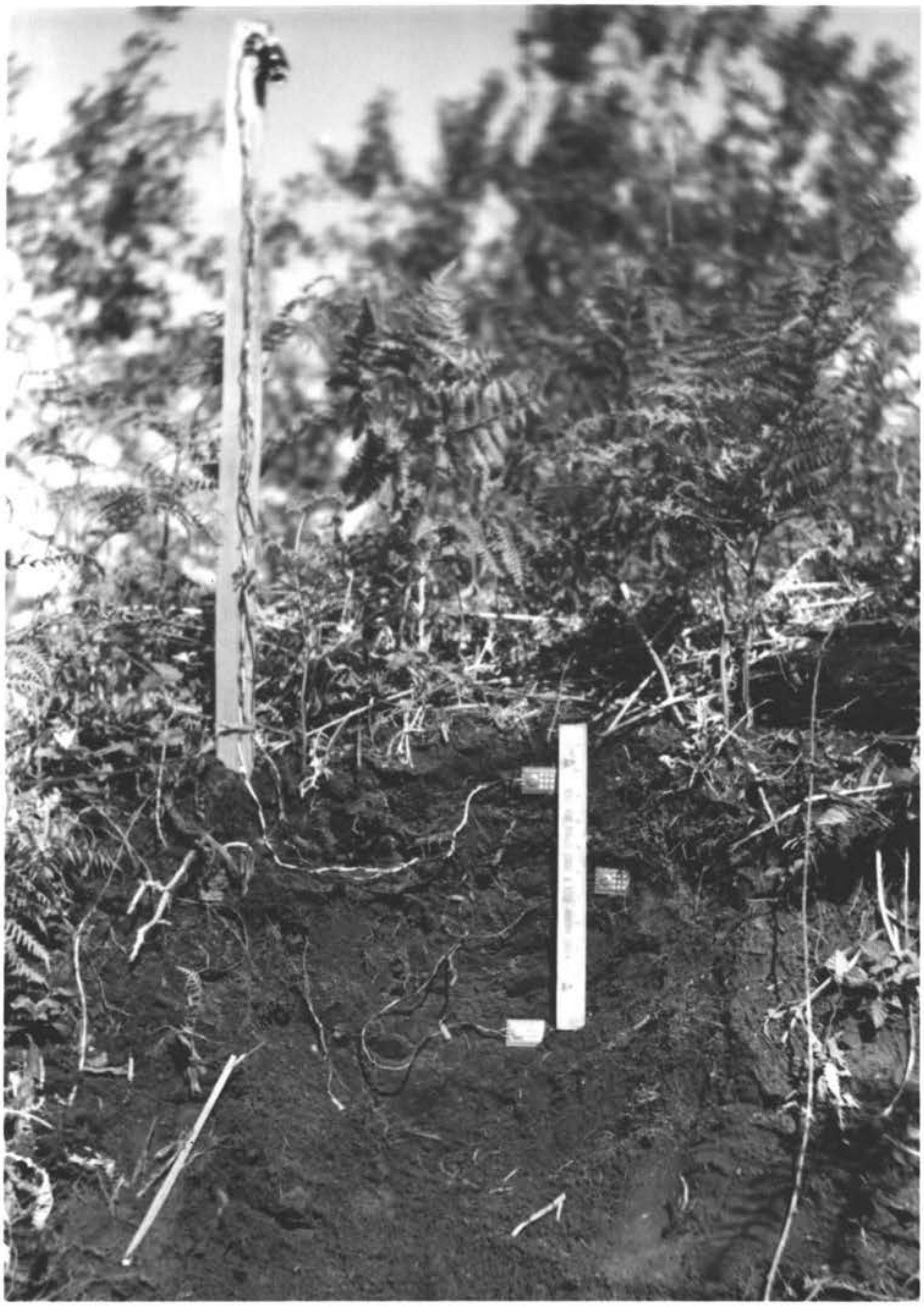

Fig. 2 Cut-Away View of a Moisture Unit Installation. Note depth and orientation of individual units.

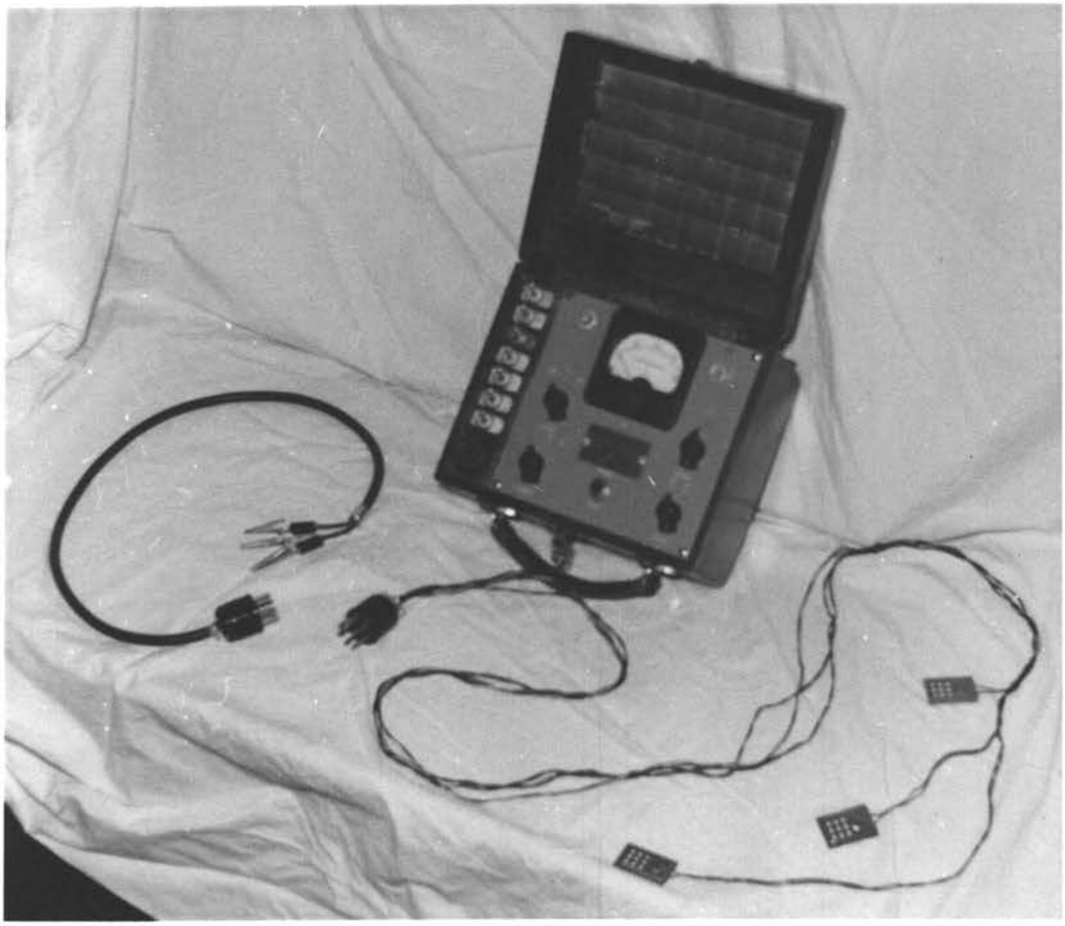

Fig. 3 Coleman Meter and Stack of Soil Moisture Units as Adapted to the Three Depth Determination Method. Socket and Switchboard installed by the author.

data were obtained from local fire look-out stations maintained by the Oregon State Board of Forestry.

Seedling survival records were kept by the Rehabilitation Department of the Oregon State Board of Forestry. Shortly after planting all trees within the plots were tallied and staked. At the same time an estimate was made of planting technique. Poorly planted trees were noted and all trees were checked periodically thereafter. At the end of the growing season and after the fall rains had begun, a final tally was made of all trees. Survival was calculated on the basis of total trees planted. The number of trees planted on each plot varied from 90 to 225 two year old (2-0) seedlings. The better sites or those having few snags and windfalls received the larger number of trees.

LABORATORY PROCEDURES

Soil samples used for analysis were air dried and ground to pass a 2 millimeter sieve. Before sampling for any determination the soil was placed on a clean paper and thoroughly mixed. Small samples were then selected at random throughout the pile and composited for each analysis. Determinations were made in duplicate in all cases and results expressed are the averages of duplicates. Where duplicates varied more than could be expected by experimental errors, a third sample was analyzed. The two agreeing values were then averaged. Determinations unless otherwise stated were performed according to the procedures as outlined by the Forest Soils Committee of the Douglas-fir Region (10).

Mechanical analysis was made by the Bouyoucos hydrometer method (10, pp.15-17). Additional hydrogen peroxide was required on the surface soil samples which were generally high in organic matter. Results were expressed in terms of the major textural classes (10, Fig.4).

Permanent wilting point was estimated by subjecting saturated soil to 15 atmospheres of pressure on a pressure membrane apparatus for 48 hours, or until equilibrium was reached. This determination is discussed in detail by Richards (32, pp.95-112). Moisture equivalent was determined as an approximation of field capacity using the standard Briggs-McLane method (10, pp.13-14). Moisture held at 15 atmospheres and the moisture equivalent were expressed as a percent of the oven dry weight of the soil. Range of available moisture was considered to be the difference between the 15 atmospheres and moisture equivalent percentages.

Soil reaction (pH) was determined by the glass electrode method using a 1.1 soil-water ratio (10, pp.23-24). Certain soils high in organic matter did not wet sufficiently at the 1:1 dilution. It was then necessary to add more distilled water until a thick paste was obtained.

Total organic matter was determined by the rapid dichromate oxidation method (modified - Walkley and Black) (10, p.21) and total nitrogen by the Kjeldhal method (10, pp.22-23). Results were expressed as a percent of the oven dry soil.

Soil samples collected for moisture determination throughout the summer months of 1953 were weighed, oven dried and reweighed. Moisture was expressed as a percent of the oven dry weight of soil. These values were plotted against time and points connected by straight lines. The 15 atmosphere percentages were plotted on the seasonal soil moisture graphs and the number of days that soil moisture was below 15 atmospheres was determined.

In 1954 moisture determinations were made with fiberglas units. Soil cores collected at the time of installation of field units were calibrated according to the method of Hendrix and Colman (18, pp.423-426). They were put through one drying cycle before calibration was begun. After calibration it was found that some of the moisture units failed to respond in the usual manner when immersed in water. Some of these units were buried in soil and subjected to 15 atmospheres of pressure in the pressure membrane. These units showed greater variations in resistance than would be expected by normal experimental errors. Other studies (41, pp.31-38) and 44, pp.34-41) showed errors in the can calibration method. Errors such as the failure of the cores to dry evenly during calibration or the continued drying of the core in the moist chamber could cause serious errors in the determination. For these reasons the can calibration method was abandoned.

The object of the soil calibration was to ultimately determine the number of days in which field soil moisture was less than the permanent wilting point. Since the permanent wilting point was estimated to be about 15 atmospheres of pressure, it was decided to use the pressure membrane apparatus as described earlier, together with a pan calibration method. The pan calibration was designed to eliminate the variability between moisture units and the pressure membrane to determine the difference, if any, in the resistance readings at 15 atmospheres.

A silt loam soil was placed in a shallow (2 inch) cake pan and saturated with distilled water. Both used and unused moisture units were rubbed thoroughly with saturated soil and embedded on edge in the soil. Lead wires were hung over the edge of the pan and the soil surface was smoothed with a spatula. The soil was allowed to dry to approximately 15 atmospheres of tension as previously determined for the soil on the pressure membrane. The surface was sealed with paraffin wax and the pan placed in a constant temperature room. After seven days the moisture units failed to show any significant change in resistance. It was then assumed that the soil no longer possessed a large moisture gradient and that the moisture units were measuring equilibrium conditions. The unit resistances were recorded, the wax removed and the moisture samples taken from various parts of the soil. Moisture samples were designed to show any differences between top and bottom and also between units of varying resistances. The procedure was repeated with a sandy loam soil, using some of the same moisture units.

After the pan calibration was completed units were selected which showed the least variation around their group mean (less than one standard deviation). These units were imbedded in a variety of saturated soils and subjected to 15 atmospheres of pressure for eight days. The soil was assumed to be at equilibrium by this time. The units at this time were assumed to be in equilibrium with the soil. The pressure membrane apparatus was opened, resistances recorded, and soil moisture determined to ensure a valid determination. The determination was considered valid if the soil moisture percent agreed with previous 15 atmosphere determinations.

The resistances obtained from the pressure membrane method for the various soils were used to estimate permanent wilting point and plotted on semi-logrithmic graph paper along with the summer field moisture resistances. The number of days in which the field readings were greater than 15 atmospheres was then estimated.

RESULTS AND DISCUSSION

FIELD STUDIES

Total soil depth and the thickness of the soil horizons was quite variable on the areas studied (Tables II, III and IV). "A" horizons varied in thickness between 3 and 30 inches averaging 11.5 inches (Tables III and IV). This difference may be attributed mainly to difference in the rate of weathering. Soil developed in the higher rainfall areas (middle elevations) had thicker soil horizons than those developed in areas of lower rainfall, other factors being equal. Colluvial soils with many rocks also tended to have deeper horizons than neighboring areas of residual soils. Rapid percolation of rain-water through these stony soils has sometimes been a factor contributing to their thicker "A" horizons.

"B" horizons varied between 9 and 44 inches in thickness averaging about 22 inches for all plots. Rate of soil development is responsible for the thickness of this horizon. Where thick "B" horizons were encountered, deep well weathered soils were noted. Very often these well weathered soils failed to exhibit parent rock even at 96 inches.

"C" horizons varied from a few inches to several feet in thickness. Like the "B" horizons thick "C" horizons

TABLE II

PROFILE DESCRIPTIONS OF REPRESENTATIVE SOILS FOR TWO SLOPE CLASSES

Plot 0-4 A

Elevation 900 ft. Slope 25% Exposure S.

Horizon	Depth (in.)	Color	Texture	Structure	Consistence
A_{00}	1 - 0	5 YR 2/1			
A_{11}	0 - 4	5 YR 2/1	sil	2 f gr	m vfr ws
A_{12}	4 - 12	7.5 YR 3/2	l	2 m cr	m fr ws
B	21 - 60	10 YR 4/3	cl	2 m abk	m fi wp
C	60 +	10 YR 4/3	cl		m vfi w vp

Plot 0-7B

Elevation 800 ft. Slope 70% Exposure N. 70 W.

Horizon	Depth (in.)	Color	Texture	Structure	Consistence
A_{00}	½ - 0	5 YR 2/2			
A_{11}	0 - 4	5 YR 2/2	sl	3 vfcr	m l w so
A_{12}	4 - 12	7.5 YR 2/3	l	3 vfcr	m vfr w ss
B	12 - 30	7.5 YR 4/4	l	2 vf gr	m vfr w ss
C	30 - 60+	7.5 YR 4/4	l		m f wss

Note: Nomenclature and abbreviations from Soil Survey Manual (42, pp.123-234).

were associated with deep well weathered soils.

Soil depth on the plots studied was considered to be sufficient from the stand-point of seedling survival (Tables III and IV). Horizon boundaries were abrupt to clear between the "A" and "B" and clear to gradual between "B" and "C". Diffuse boundaries were present only on very stony sites.

Soil color varied with horizons. "A" horizons typically were black to very dark gray-brown. These dark colors were due to high organic matter contents. Colors for "A" horizons varied between 2.5 YR 2/0 and 10 YR 3/2 when moist. Colors became slightly lighter upon drying. "B" horizons were dark reddish brown to brown (5 YR 3/4 to 10 YR 4/3). "C" horizons were lighter with more yellowish coloration.

Soil texture was estimated in the field by rubbing the moist soil between the fingers. Soils having high (greater than 10%) organic matter contents exhibited a silty feel and were generally classified as loam or silt loams. Mechanical analysis generally indicated a loam or sandy loam texture. Soils were grouped into broad textural classes varying in texture from sandy loams to light clay loams (Tables III and IV). Extremely fine textured soils that would tend to preclude good root development were not encountered. The sandy soils were usually high enough in organic matter to insure favorable moisture conditions and plant nutrition (Tables VII and VIII).

Soil structure was evaluated and found to be strongest in the surface few inches (Table II). "A" horizons typically had crumb or granular structure becoming coarser with depth. In the "B" horizon, structure was usually granular to sub-angular blocky becoming more blocky with depth until reaching the "C" horizon. Here soil structure was weakly expressed. If high in clay the "C" horizon tended to be massive. Loams were generally coarse blocky or single grain if sandy. Soil structure appeared to be favorable for root ramification.

Soil consistence was also noted and found to vary by horizons (Table II). Moist soil in the "A" horizons was generally loose to very friable becoming non-sticky to slightly sticky when wet. High organic matter contents are probably responsible for these excellent surface soil conditions. "B" horizons were very friable to firm in the moist condition becoming slightly sticky to plastic when wet. The plasticity is due to higher mineral clay content. "C" horizons increased in firmness and plasticity with depth. On none of the planting plots was soil consistence considered a limiting factor to plant growth or root elongation.

Descriptions of two representative soil profiles appear in Table II. These profiles were selected as being typical of moderate and steep slopes respectively.

Soil parent materials were residuum from the decomposition of basalt or tuffaceous sandstones and shales. Recent alluvium is present along the larger stream courses but only a very small percentage of the planted area is located on this type of material. No significant difference in seedling survival could be attributed to parent material (Tables III and IV).

Stoniness appears to influence soil moisture relations through its effect on the total volume of fine (less than 2 mm.) material in a given depth. Planting precision is also generally poorer on stony soils. It was found that in both 1953 and 1954, soils having more than 50 percent of rock fragments were associated with poor survival (B-2, B-8, O-2, P-5 and O-7), however, seedling survival was also poor on less stony soils (P-1, O-6 and O-9).

Root distribution was excellent to good on all plots. Herbaceous roots extended 12 to 18 inches into mineral soil. Woody plant roots were present at all depths and were observed penetrating into cracks of the bedrock when bedrock was less than 60 inches below the soil surface.

Relative density and vigor of native vegetation varied from very sparse to very dense on the areas studied (Tables III and IV). It was thought that some correlation might be found between vegetation and soil water relationships. From the 1954 soil moisture determinations it was possible to measure soil water depletion at three depths. Under very dense vegetation soils were depleted of their moisture at the lower depths (6 and 12 inch levels) more rapidly than near the surface (2 inch level)(Fig.8). This is probably due to a greater demand for water at the 6 inch depth. Under very sparse vegetation and especially on southern exposures this trend was reversed, the soils near the surface drying more rapidly than soils at lower depths (Fig.7). No direct effect on seedling survival could be attributed to vegetation. Vegetation was not dense enough on any of the plots to cause excessive shading of seedlings.

Percent slope was recorded and a rather close association was observed between slopes greater than 50 percent and poor seedling survival (Tables III and IV). Seven out of eight plots with over 50% slope had poor survival (less than 60% surviving) regardless of other factors. On the other hand of the remaining twelve plots, nine showed good survival (60 to 80%) and three exhibited excellent survival (80 to 100%). It appears that slope is an important factor influencing seedling survival. It may well be that since steep slopes are also commonly associated with very stony soils (B-2, B-8, O-2, P-5 and O-7) that the two factors are operating in combination.

Plot aspect was investigated and recorded to the nearest 5 degrees. Direction was taken from true north. In 1953 there appeared to be an association between southerly exposures and poor survival (Table III, plots B-2 and B-8). It should be pointed out that these two plots were also on steep slopes and had stony soils. In 1954 plot selection was aimed at separating these three factors. Various combinations of aspect, slope and stoniness were included in the plot selection (Table IV).

Survival on south slopes was on the average somewhat lower than on north slopes but the range in survival was too broad to establish any more than a trend. From observations of natural Douglas-fir reproduction on the Tillamook Burn it would appear that north slopes were more favorable to survival than south slopes (Fig.4). Survival of natural tree seedlings should not be much different than 2 year old planted trees. The major difference is the surface soil temperatures during their first growing season.

Drainage conditions, both internal and external were excellent on all soils investigated. In spite of the use of heavy logging equipment, serious soil compaction has occured only in the vicinity of landings and on roads. By and large soil physical conditions are optimum for

TABLE III

Summary of Field Study and Seedling Survival
Data from Plantation Establishment Plots
Tillamook Burn, 1953

Plot No.	"A" Horizon Depth (in.)	Surface Soil Texture	Parent Rock	Stoniness* (%)	Soil Depth (in.)	Vegetative cover	Slope (%)	Aspect	Survival (%)
B-1	12	sil	Shale	<20	>60	Very Dense	15	N.60 W	78.0
B-2	6	sl	Shale	80	48	Medium	70	S.20 E	57.0
B-3	8	sil	Basalt	20	48	Sparse	20	N.60 E	88.0
B-4	3	cl	Basalt	20	>60	Medium	40	S.20 W	75.4
B-5	7	cl	Basalt	40	>60	Dense	20	S.70 W	78.5
B-6	10	l	Basalt	40	>60	Very Sparse	30	N	93.7
B-7	16	cl	Shale	20	>60	Dense	50	S.10 E	62.2
B-8	13	sl	Shale	80	48	Sparse	60	S.20 E	24.8
B-9	9	l	Basalt	20	>60	Dense	25	E	63.9
B-10	4	cl	Shale	40	24	Very Sparse	20	N.70 W	70.4

*Soil volume occupied by stones greater than 2 mm.

TABLE IV

Summary of Field Study and Seedling Survival
Data from Plantation Establishment Plots
Tillamook Burn, 1954

Plot No.	"A" Horizon Depth (in.)	Surface Soil Texture	Parent Rock	Stoniness* (%)	Soil Depth (in.)	Vegetative cover	Slope (%)	Aspect	Survival (%)
P-1	7	l	Shale	20	>60	Medium	50	S.40 E	5.1
O-2	8	sil	Basalt	60	>60	Medium	65	S.35 E	22.2
O-3	11	sl	Basalt	40	36	Dense	40	S.45 W	67.4
O-4	12	l	Basalt	20	>60	Very Dense	30	S.20 W	64.1
P-5	8	l	Basalt	60	>60	Sparse	80	S.65 W	1.0
O-6	22	sl	Basalt	40	>60	Dense	60	N. 5 W	31.6
O-7	9	sl	Basalt	60	48	Medium	70	N.65 W	14.2
P-8	30	l	Basalt	40	>60	Very Dense	40	N. 5 E	95.3
O-9	23	sl	Basalt	40	48	Medium	70	N.30 W	39.0
O-10	12	l	Shale	20	>60	Sparse	65	S.75 E	63.0

*Soil volume occupied by stones greater than 2 mm.

Fig. 4 Looking East into an Area Naturally Restocked with Douglas-Fir. North exposure (right) is fully stocked. Stocking on south exposure (left) is inadequate.

infiltration and percolation.

Soil moisture data for 1953 indicated that the soils on only two plots (B-2 and B-8) went below the 15 atmosphere percentage point for an appreciable length of time (over 30 days) (Table V). Rainfall during the summer of 1953 was above average, however, only a trace was recorded during early August (Fig.5 and 6). In 1954 the soil on only one plot (P-5) was excessively dry and then only on one side of that plot (Table VI). The soils on plots P-1 and 0-10 dropped below the 15 atmosphere percentage point for periods of 8 and 11 days respectively (Table VI). These soils were not considered to be dry long enough to produce any significant difference in survival. Rainfall during the summer of 1954 was also above average, but unlike 1953, small rains occured nearly every week (Fig.7 and 8). These frequent rains helped to offset some of the normal soil moisture loss.

The poor survival on plots B-2 and B-8 may justifiably be attributed in part to excessively dry soil. It should be pointed out that no plot is so uniform as to preclude a wide range of micro-sites. The soil on some of these small areas is more moist than the average, thus the survival is higher than would normally be expected for a perfectly uniform area of dry soil. In 1954 the survival on plots P-1, 0-2, 0-6, 0-7 and 0-9 was very poor, but moisture conditions were not critical (Table VI). The survival on plot P-5 was poor but it is doubtful that survival would have been only one percent if moisture were the only critical factor. Therefore, it appears that the 1954 survival pattern is being complicated by some factor not apparent in the 1953 planting.

It was learned from the field planting supervisor that portions of the nursery stock used in 1954 were in poor physiological condition. There was a high proportion of seedlings with loose bark on the roots. The seriousness of this condition was not fully realized and some of the damaged stock was used in the planting program.

A preliminary greenhouse study has revealed the serious nature of the condition. Seedlings were selected which exhibited no root damage, moderate root damage and excessive root damage. The seedlings were planted in pots and grown under favorable moisture conditions. Survival for the undamaged seedlings was 100.0 percent, for the moderately damaged seedlings 66.7 percent, and for the severely damaged seedlings only 5.9 percent. It becomes clear that much of the variability in results from the 1954 planting may be attributed to unhealthy planting stock.

Examination of the damaged stock revealed the presence of both Pythium and Fusarium on the roots.

TABLE V. Soil Moisture Status and Seedling Survival for Plantation Establishment Plots. Tillamook Burn, 1953

Plot Number	Sample Depth	No. Days Below 15-Atm. %.	Survival (%)
B-1	0-6	0	78.0
	6-12	0	
B-2	0-6	40	57.0
	6-12	28	
B-3	0-6	0	88.0
	6-12	0	
B-4	0-6	2	75.4
	6-12	0	
B-5	0-6	0	78.5
	6-12	0	
B-6	0-6	3	93.7
	6-12	0	
B-7	0-6	0	62.2
	6-12	0	
B-8	0-6	33	24.8
	6-12	0	
B-9	0-6	0	63.9
	6-12	0	
B-10	0-6	0	70.4
	6-12	0	

TABLE VI. Soil Moisture Status and Seedling Survival for Plantation Establishment Plots. Tillamook Burn, 1954

Plot No.	Sample Depth	No. Days Below 15-Atm. % Station "A"	Station "B"	Survival (%)
P-1	0-4	1	8	5.1
	4-8	0	0	
	8-16	0	0	
0-2	0-4	0	0	22.2
	4-8	0	0	
	8-16	0	0	
0-3	0-4	0	0	67.4
	4-8	0	0	
	8-16	0	0	
0-4	0-4	0	0	64.1
	4-8	0	0	
	8-16	0	0	
P-5	0-4	31	4	1.0
	4-8	0	0	
	8-16	0	0	
0-6	0-4	0	0	31.6
	4-8	0	0	
	8-16	0	0	
0-7	0-4	0	0	14.2
	4-8	0	0	
	8-16	0	0	
P-8	0-4	0	0	95.3
	4-8	0	0	
	8-16	0	0	
0-9	0-4	0	0	39.0
	4-8	0	0	
	8-16	0	0	
0-10	0-4	11	0	63.0
	4-8	0	0	
	8-16	0	0	

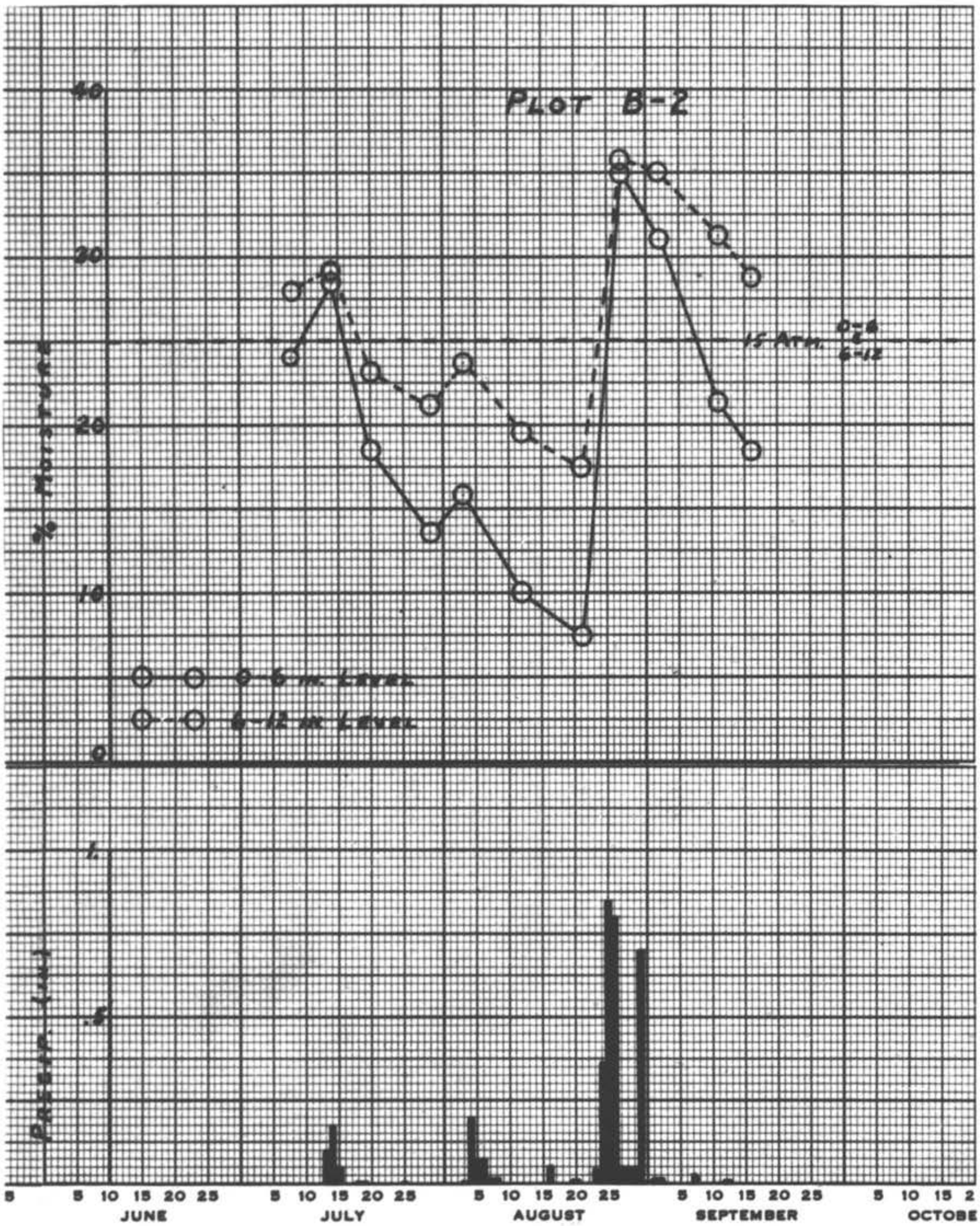

Fig. 5 Summer Precipitation and Soil Moisture Status for a Representative Plantation Establishment Plot. Tillamook Burn, 1953

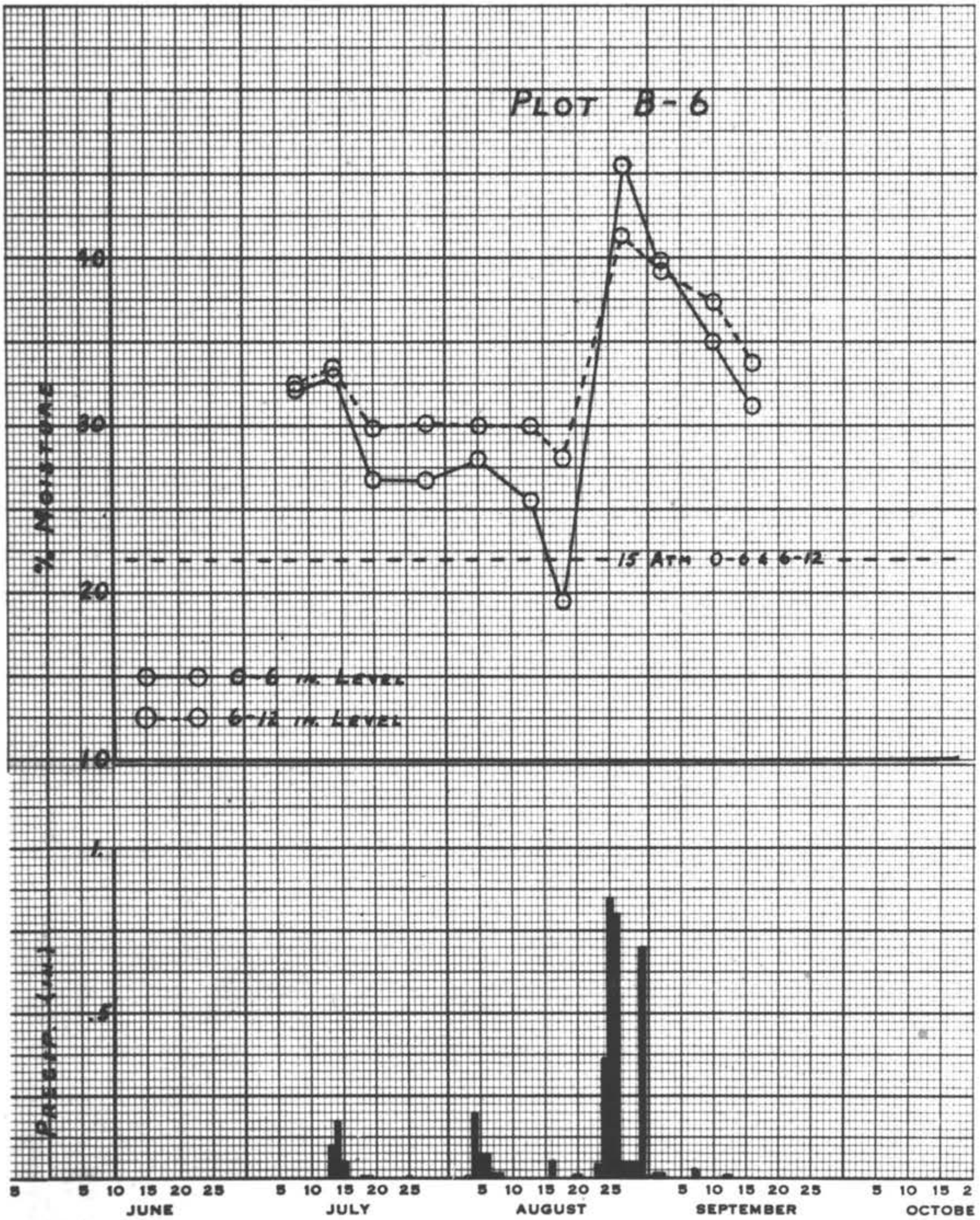

Fig. 6 Summer Precipitation and Soil Moisture Status for a Representative Plantation Establishment Plot. Tillamook Burn, 1953

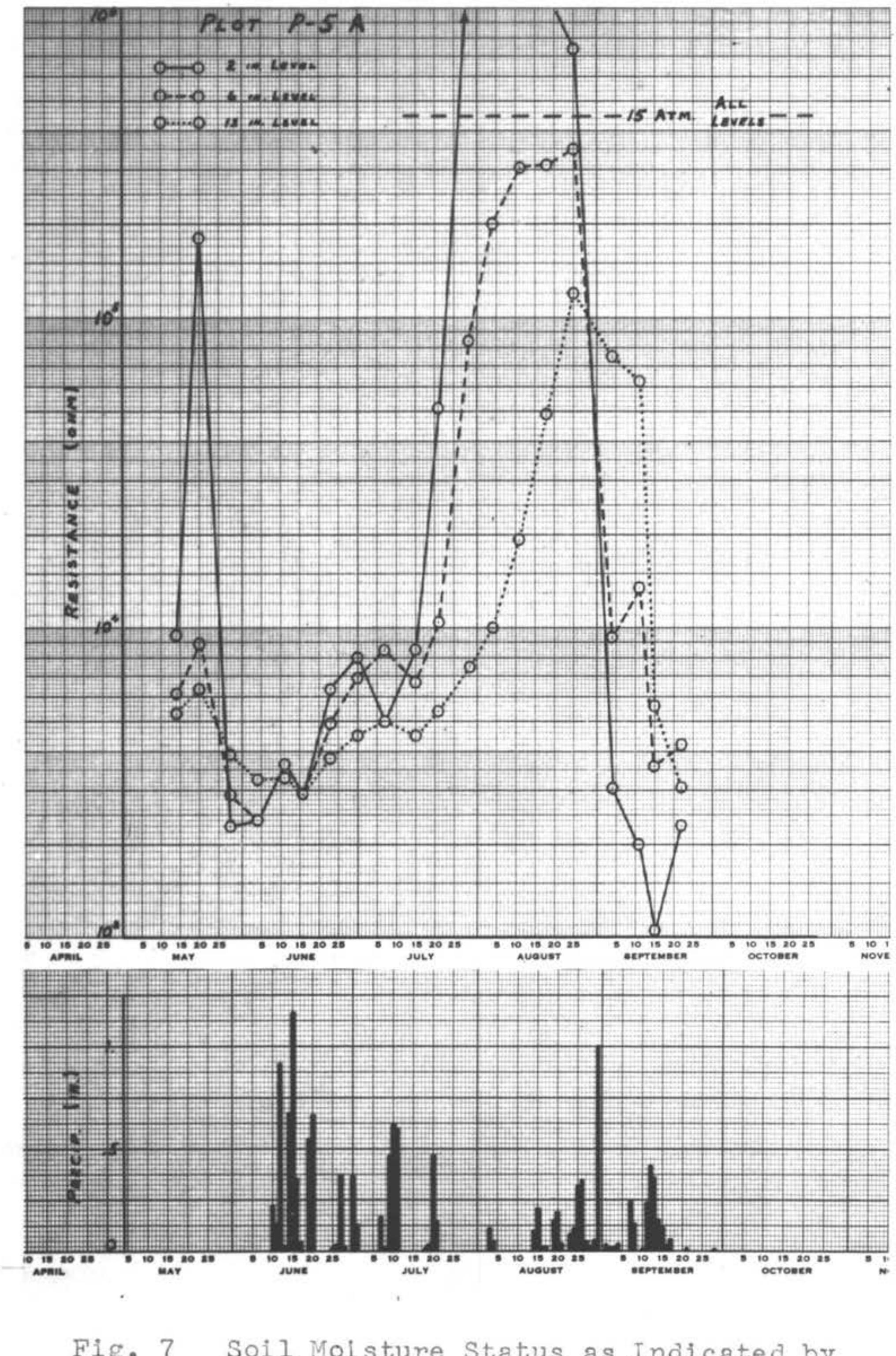

Fig. 7 Soil Moisture Status as Indicated by Electrical Resistance Block Readings in Relation to Summer Precipitation. Tillamook Burn, 1954

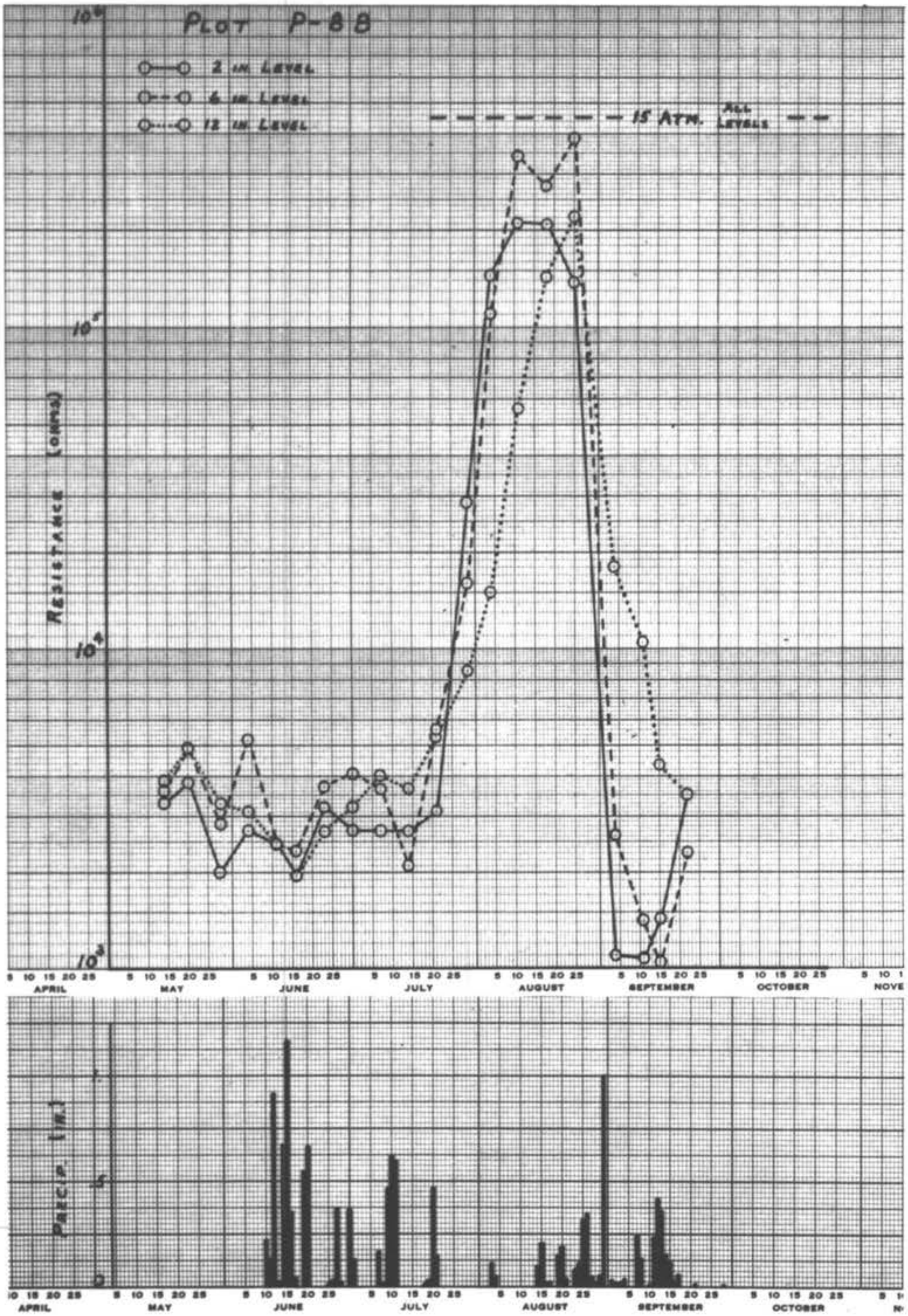

Fig. 8 Soil Moisture Status as Indicated by Electrical Resistance Block Readings in Relation to Summer Precipitation. Tillamook Burn, 1954

Unfortunately, there is no way of knowing which plots were planted with seedlings having damaged roots.

LABORATORY ANALYSIS

Mechanical analysis indicated a range of textures from sandy loam to clay loam in the surface soil (Tables III and IV). From the 1953 data it appeared as though there was a relationship between poor survival and sandy loam soil, however, this relationship was not as evident from the 1954 data. The sub-surface soil generally had a slightly higher silt and clay content than the surface soil, but it was not high enough to adversely influence seedling survival.

Moisture held at 15 atmospheres varied between 19 and 38 percent in the surface soil with an average of 24.5 percent. These high values are undoubtedly due to the high organic matter contents of the surface soils. This average is more than twice as great as the wilting coefficients for Wind River soils as reported by Isaac (21, p.35). Moisture equivalents were also high, varying between 33 and 51 percent with an average of 40.1 percent. This represents an average range of available moisture of 15.6 percent. The actual amount of water held at 15 atmospheres or moisture equivalent are in themselves not considered important in relation to seedling survival.

The difference between the two or range of available moisture for any given soil is thought to be more significant with regard to seedling survival, however no correlation was evident between seedling survival and range of available moisture (Tables VII and VIII).

Soil reaction for the various plots varied from pH 4.7 to 6.0. There is no reason to believe that fire has had any significant lasting effect on soil reaction.

Organic matter levels were generally high on all plots ranging from 4 to 24 percent (Tables VII and VIII). The soils on certain plots were disturbed by logging operations (B-6, B-10 and O-10). Under these conditions surface soil had been mixed with sub-soil and the organic matter contents were lower than expected. This was not considered detrimental to seedling survival since organic matter content at the lower depths of these disturbed soils was generally higher than on adjacent undisturbed soils. Total nitrogen levels were also generally high. Since total nitrogen was well correlated with organic matter contents on the 1953 plots this determination was omitted from the 1954 plots. Total nitrogen and organic matter levels were high enough to afford adequate nitrogen nutrition of seedlings.

TABLE VII. Summary of Laboratory Determinations and Seedling Survival on Plantation Establishment Plots. Tillamook Burn, 1953

Plot No.	Sample Depth (in.)	pH	Available Moisture (%)	Organic Matter (%)	Total Nitrogen (%)	Survival (%)
B-1	0-6	5.1	18.6 siL	11.0	.293	78.0
	6-12	5.0	17.2	10.5	.254	
B-2	0-6	5.6	16.4 sL	9.9	.220	57.0
	6-12	5.6	15.8	7.2	.172	
B-3	0-6	5.0	19.3 siL	8.8	.224	88.0
	6-12	5.2	18.1	5.9	.162	
B-4	0-6	5.5	11.3 cL	5.1	.132	75.4
	6-12	5.2	10.7	3.9	.099	
B-5	0-6	4.9	14.4 cL	5.9	.145	78.5
	6-12	4.9	13.4	2.4	.082	
B-6	0-6	4.9	13.5 L	4.7	.139	93.7
	6-12	4.9	12.9 L	3.6	.102	
B-7	0-6	4.9	17.2 cL	8.4	.255	62.2
	6-12	5.1	15.7 cL	5.4	.176	
B-8	0-6	4.8	12.9 sL	12.3	.282	24.8
	6-12	5.0	12.1 sL	7.1	.176	
B-9	0-6	5.0	16.8 L	10.5	.273	63.9
	6-12	5.4	14.3 L	4.8	.149	
B-10	0-6	4.7	20.6 cL	11.2	.227	70.4
	6-12	4.7	17.8	16.1	.228	

TABLE VIII. Summary of Laboratory Determinations and Seedling Survival on Plantation Establishment Plots. Tillamook Burn, 1954

Plot No.	Sample Depth (in.)	pH	Available Moisture (%)	Organic Matter (%)	Survival (%)
P-1	0-4	5.3	15.0 L	8.4	5.1
	4-8	5.3	13.7 L	4.7	
	8-16	5.3	13.1	2.7	
0-2	0-4	5.2	22.6 siL	12.1	22.2
	4-8	4.9	20.3 siL	8.6	
	8-16	5.0	18.2	4.4	
0-3	0-4	5.5	15.6 sL	14.2	67.4
	4-8	5.1	11.6 sL	10.2	
	8-16	5.3	12.1 sL	7.0	
0-4	0-4	5.1	22.9 L	13.3	64.1
	4-8	5.2	18.7 L	7.0	
	8-16	5.2	18.0 L	3.5	
P-5	0-4	6.0	20.5 L	13.3	1.0
	4-8	6.0	20.6 L	11.9	
	8-16	6.0	18.7	8.7	
0-6	0-4	5.2	12.0 sL	23.8	31.6
	4-8	5.4	12.3 sL	12.8	
	8-16	5.6	12.3 sL	10.6	
0-7	0-4	5.5	12.1 sL	13.4	14.2
	4-8	5.5	13.6 sL	8.4	
	8-16	5.5	14.4	4.7	
P-8	0-4	5.1	12.5 L	9.1	95.3
	4-8	5.1	12.9 L	7.2	
	8-16	5.2	13.3 L	3.7	
0-9	0-4	5.3	8.6 sL	11.0	39.0
	4-8	5.3	9.4 sL	8.9	
	8-16	5.4	9.7 sL	5.3	
0-10	0-4	5.1	12.3 L	4.6	63.0
	4-8	5.2	12.0 L	3.5	
	8-16	5.3	13.3 L	3.6	

SUMMARY AND CONCLUSIONS

Seedling survival was not affected by soil depth, horizon thickness, soil color or parent material. Soil consistence and structure were considered to be highly satisfactory for seedling establishment and plant growth. Except in the case of coarse textured soils, soil texture did not appear to have any effect on survival. No relationship was found between the density of vegetative cover and seedling survival. Soil air-water relationships were excellent on all sites.

Coarse textured soils, stony soils, steep slopes and southern exposures were all associated with poor survival. These factors, alone or in combination, produce rapid soil moisture depletion. Where soil moisture was depleted below the 15 atmosphere percentage point for periods approaching 30 days poor survival resulted. Sites exhibiting all four of these characteristics may be expected to have poor seedling survival even during moist years.

The physiological condition of the planted stock had a direct bearing on seedling survival regardless of other factors. Seedlings having diseased or damaged roots are unable to survive even under optimum growing conditions.

The range of available moisture, except as modified by extreme stoniness, was excellent on all sites. The range of available moisture of the sandy soils was comparable to that of the finer textured soils. Soil reaction was favorable on all sites. Organic matter and total nitrogen levels were generally high and in no case were they low enough to have a detrimental effect upon the establishment and growth of tree seedlings.

The results of this study indicate that soil conditions on the Tillamook Burn are generally favorable for the establishment of planted seedlings. Coarse texture and stoniness appear to be the only soil characteristics adversely influencing survival. Other site factors, the physiological condition of the nursery stock and the quality of planting are also important factors affecting seedling survival. Soil characteristics may be evaluated from soil survey information or from an examination of soil conditions during a pre-planting survey, at which time the other site factors may also be appraised. With this information, area priorities may be established and hazardous areas avoided, thus assuring the maximum possible success of the reforestation program.

It should be pointed out that this study was of a preliminary nature and had definite physical limitations. It is entirely possible that further detailed investigations will reveal other site or soil factors that are important with regard to seedling survival on the Tillamook

Burn.

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