VEGETATIVE FACTORS INFLUENCING THE GERMINATION AND SURVIVAL OF DOUGLAS-FIR SEEDS AND SEEDLINGS IN THE TILLAMOOK BURN

by

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VEGETATIVE FACTORS INFLUENCING THE GERMINATION AND SURVIVAL OF DOUGLAS-FIR SEEDS AND SEEDLINGS IN THE TILLAMOOK BURN

Introduction

Four major fires (in 1933, 1939, 1945, and 1951) swept over a large portion of the coast range of Northwestern Oregon and left devastated an area that had been covered by a Douglas-fir (*Pseudotsuga menziesii* (Mirb.) forest. This burned area is known as the Tillamook Burn. Much of this 350,000 acres has been burned two or more times. This succession of fires has left no source of natural seed for the bulk of the area. Therefore, if this land is to be reforested, it will have to be done by artificial means. Hand-planting of coniferous nursery stock and direct seeding, either by helicopter or by hand operated seeders, are currently the principal methods of reforestation in the Douglas-fir region.

Planting has the following advantages: 1) it requires no control of seed eaters to be successful; and 2) the most favorable micro-sites are stocked with relatively large seedlings. The disadvantages of planting are its expense and slowness.

In contrast, direct seeding is rapid and much less expensive. Success of a direct seeding project however, is dependent upon efficient and effective control of seed-eating mammals and favorable seed beds for seed germination and seedling survival. Past surveys (14, p. 1-2) have evaluated the apparent effects of vegetation upon seed germination and seedling survival. The seed-eating mammals control measures employed are known to be less than 100 per cent effective, and further, the level of effectiveness is known to have varied. An additional factor is that seed dispersal patterns of helicopters in the rough terrain which characterizes the Tillamook Burn are not uniform. The results of these surveys were based on data which could have been modified by these inequalities. The project described herein was designed to evaluate the effects of vegetative cover upon seed germination and seedling survival when both seed distribution and seed-eating mammal control were uniform.

General Project Plan

The vegetative cover on the portion of the Tillamook Burn sampled by this experiment varies from very light on some microsites to heavy on others. The rugged terrain provides slopes among which any given exposure and degree of slope may be found. The field phase of this experiment was designed to compare the effects of different cover intensities on the four major exposures, north, south, east, and west, upon the germination of seeds and the establishment of Douglas-fir seedlings.

The laboratory phase of the study, an investigation of the effects of vegetative debris upon Douglas-fir seed germination was designed to supplement field data.

It was felt that the data collected during this project would serve as a practical guide for reforestation work in the Tillamook Burn and in other areas with similar soil and cover types, and, in addition, increase our knowledge of the ecology of Douglas-fir seedlings.

Description of Experimental Material and Apparatus

Seed

The seeds used in this study were collected by the investigator near Marion Forks (elevation 3600 feet above mean sea level) in the North Santiam River drainage in the fall of 1953. The cones were dried at temperatures of from 85° F. to 110° F. The seeds were extracted by hand and cleaned on a Clipper fanning mill. The seeds were stored at 0° F. until the fall of 1954, when they were further cleaned with a South Dakota Blower (figures 1 and 2) until the cutting test[1] indicated that the seed lot was 98.25

[1]Four hundred seeds, selected at random, were bisected along the long axis and the condition of the embryo and endosperm were noted. The per cent of seed classified as "sound" may be considered as an estimation of the maximum possible germination per cent.

per cent sound. Six hundred seeds selected at random were utilised for a germination test[1]. The results of this test showed the seed lot to have a viability of 91 per cent. Such viability is somewhat above that (70 - 85 per cent) of the majority of the Douglas-fir seed employed in reforestation work and is responsible for the high field germination. This germinative vigor may also be reflected in the extremely high per cent of germinants which were established seedlings at the conclusion of this project. In 1956 the viability of this seed lot dropped to 89 per cent, but these seeds still produced 50 per cent more seedlings in the field than did a lot of 1955 seeds which germinated 83 per cent in the laboratory.

Seed-eating Mammal Exclosures

Any investigation of coniferous tree seed germination and survival conducted on the forest lands of the Pacific Northwest must provide some means of protecting the seeds from the depredations of the ubiquitous seed-eating mammals. The apparatus

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[1]Germination test. This test is the most closely controlled, reproducible trial of germinative vigor currently employed in coniferous seed testing work. A complete description of the procedures followed may be found in Lavender and Engstrom, "Viability of Douglas-fir Seed from Squirrel Cut Cones," p. 10 - 13.

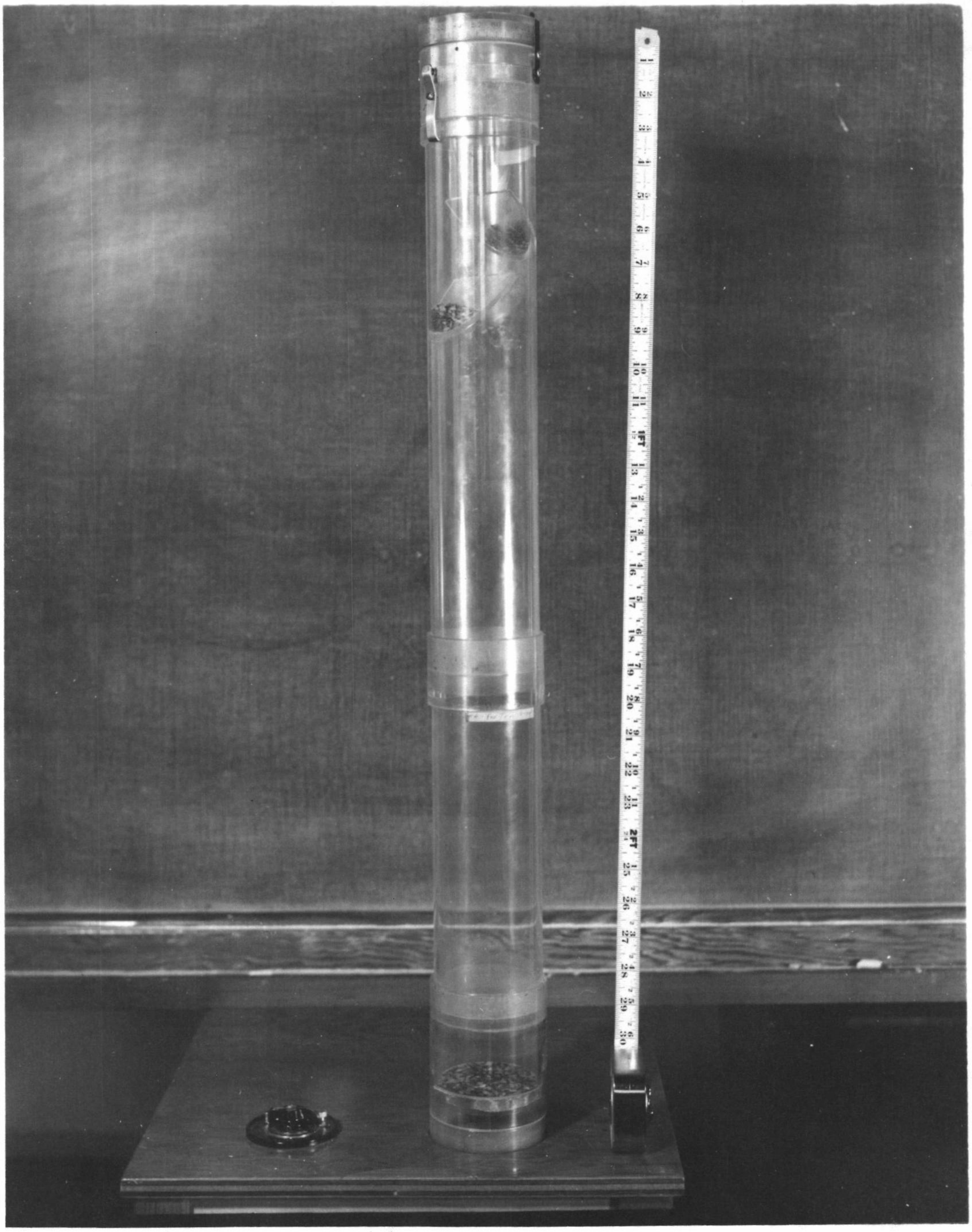

Figure 1. South Dakota Blower. Machine developed for cleaning agricultural seeds. Separates seeds on basis of density; the light, blank seeds are trapped in cups at upper end of the tube while the heavy, sound seeds remain in lower reservoir.

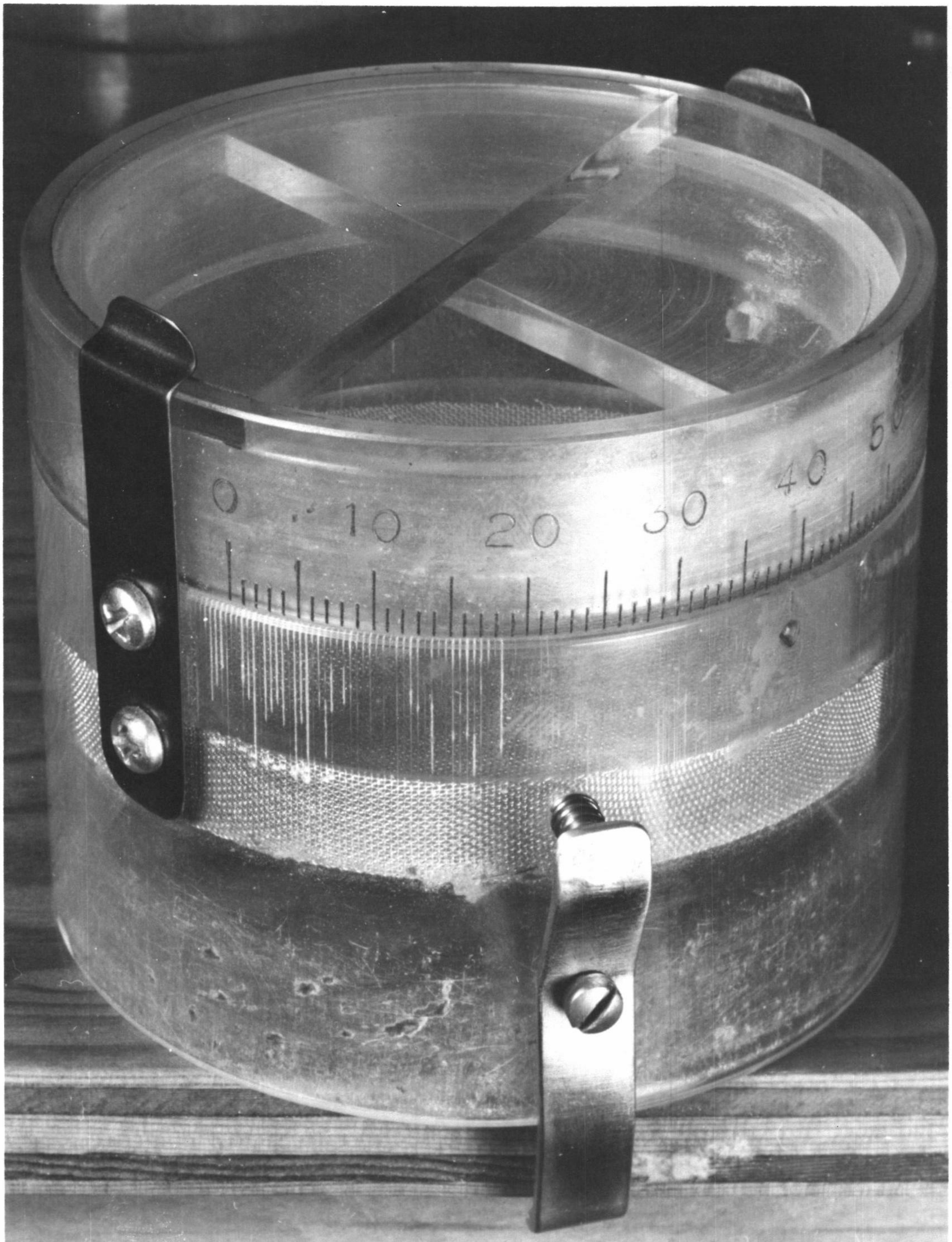

Figure. 2. Movable head controls air stream in tube. A uniform seed lot may be obtained by "blowing" small increments at identical time and wind settings. Seeds employed in this project were "blown" at a gate setting of 33 for 30 seconds.

employed in this study was very similar to that described by Krauch (18, p. 1-2) and consisted of the following:

1. Galvanized iron rings (figure 3) forced into the soil until the sides were approximately 1/4-inch above the soil surface.
2. A hood of 1/4-inch hardware cloth approximately eight inches high pegged down over the ring (figure 4).

This procedure has the following advantages in field seed research projects:

1. The iron ring is readily forced into all except the rockiest soils without the aid of special tools.
2. In previous years, the heavy rains prevalent in the winter washed many seeds through the mesh of boxes constructed entirely of hardware cloth. Although the area immediately adjacent to the iron ring is not the most favorable for seedling growth, such seeds as are washed against the ring are at least apparent to the investigator. Those seeds which were washed through the mesh of the boxes could be tallied only as "missing". Only a few of the cans were so badly washed as to render the data useless.

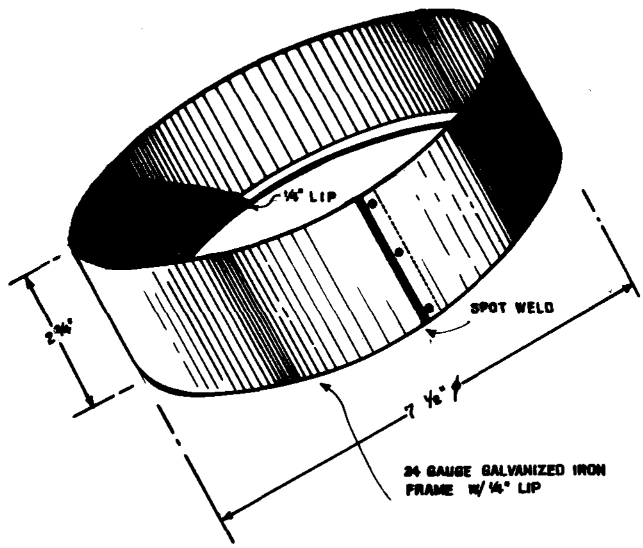

Figure 3. Diagram of iron ring used to protect seed spots.

Figure 4. Sample seed spots with protective hoods on West Plot 8, May 27, 1955. Coniferous reproduction is the result of a planting experiment.

Meteorological Instruments

A number of temperature and moisture measuring devices were installed in the experimental area. The variation in soil moisture and temperature due to non-uniform plant cover which occurred in an area as small as seven and one half inches in diameter made accurate measurement of the meteorological factors of the micro-site of each seedling impractical. For this reason the data provided by the instruments on each of the four slopes must be regarded as the mean for the given slope and cover type. The seedlings in any given seed spot may have experienced temperature and moisture stresses more or less severe than the data obtained from the instruments within the seed spot indicated.

Weksler 6-inch maximum mercury thermometers were employed to measure soil surface temperatures. Inasmuch as it was possible to visit the plots only once a week, these thermometers permitted the observer to record the highest temperature sustained by a given micro-site. Unfortunately, the expense of instruments designed to measure and record the duration of maximum soil temperatures prohibited their use on this study. During the winter and spring of 1956, Lowry, Research Meteorologist, Oregon Forest Lands Research Center, and the author compared the temperatures recorded by these thermometers with those obtained from thermocouples under varying conditions. The data indicate that the temperatures recorded by the thermometers were approximately 2° F. lower than those of the thermocouples.

Bacarach 7-day tempscribes were used to record air temperatures. These instruments were housed in shelters on the north side of logs or stumps (figure 5).

Fiber glas soil moisture units containing the electrode sandwich and 6-foot lead-in wires were installed at the surface of the soil and at the 3 and 10-inch levels in accordance with the manufacturer's instructions (4, p. 10-13). These units were "read" once a week with the Colman Soil Moisture Ohm meter.

Experimental Area

Location of Area. The study plots were located in a rectangular area, near the center of the Tillamook Burn, bounded by Range Lines 5 and 9 West and by Township Lines 1 South and 2 North, Willamette Baseline (45° 30' North Latitude, 123° 30' West Longtitude) (figures 6 and 7). The elevation of this area varies from 500 to 2800 feet above mean sea level. The topography of the northern Oregon coast range is that of a dissected plateau (5, p. 460). Therefore the physiography of the experimental area

Figure 5. "Tempscribe" installation on West Plot 8, May 27, 1955.

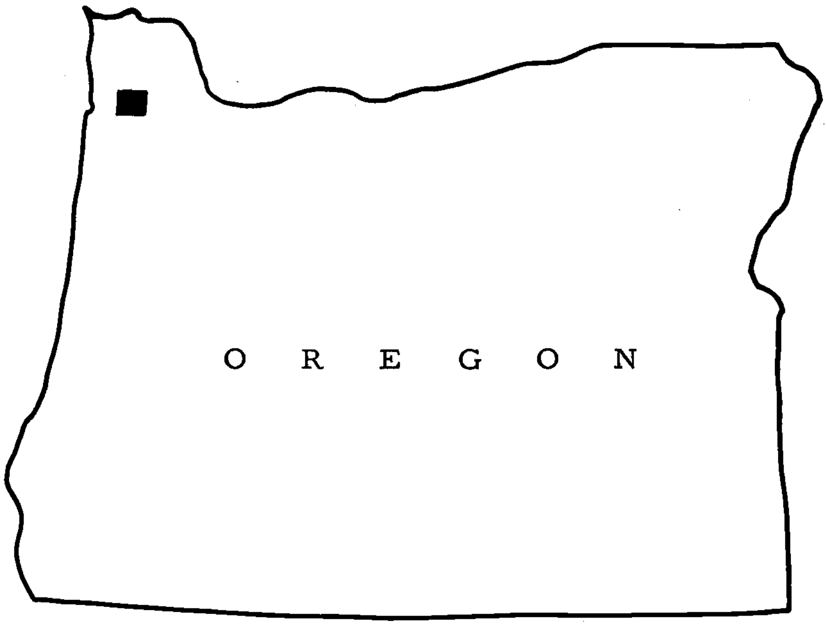

Figure 6. Black square marks location of experimental area.

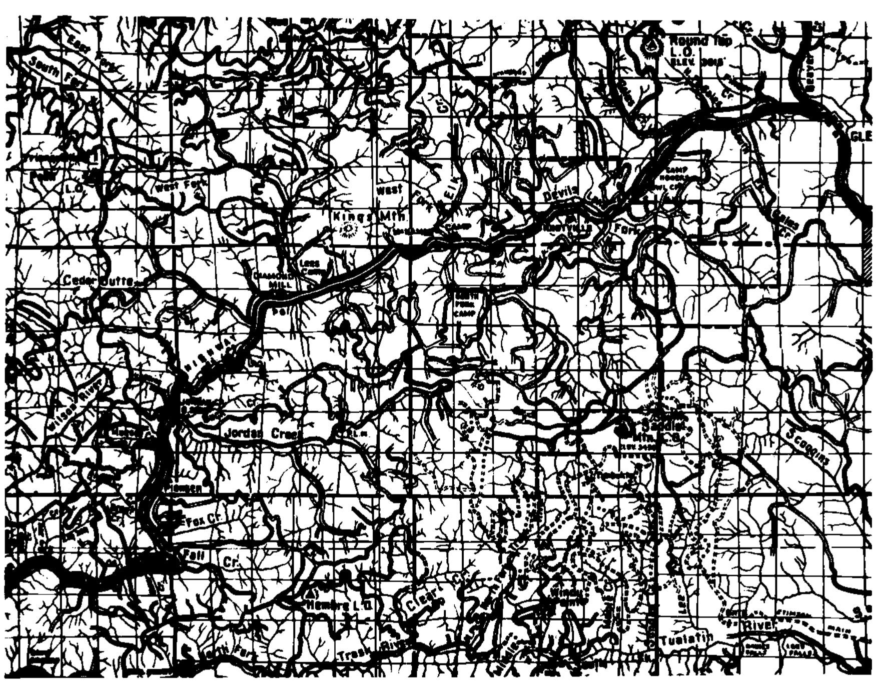

Figure 7. Detail of the portion of the Tillamook Burn where the study was carried out.

includes broad, flat ridges and sharp, narrow valleys.

Vegetation. The west side of the Tillamook Burn has the heavy brush and herbaceous cover typical of the fog belt zone of Oregon and Washington. The majority of the Burn (including the experimental area) however, has a much lighter vegetative cover similar to the vegetation found in the Oregon Cascades at comparable altitudes. The following plant species are found in the experimental area.

Herbaceous

(Annual and Perennial)

Scientific Name	Common Name
Achlys triphylla	Vanilla Leaf
Agrostis exarata Trin.	Western Bent-grass
Aira caryophyllea L.	Silvery Hair-grass
Anaphalis margaritacea var. occidentalis Greene	Pearly Everlasting
Anthriscus vulgaris (L.) Pers.	Bur-chevril
Campanula Scouleri Hook.	Scouler's Campanula
Cerastium L. sp.	
Chrysanthemum Leucanthemum L. var. pinnatifidum Lec. and Lam.	Ox-eyed Daisy
Cirsium lanceolatum (L.) Scop.	Common Thistle
Clintonia uniflora (Schult.) Kunth.	One-flowered Clintonia
Coptis laciniata Gray.	Western Gold-thread
Cornus canadensis L.	Dwarf Dogwood
Deschampsia Beauv. sp.	Hair-grass
Disporum Smithii (Hook.) Piper	Large-flowered Fairy Bells
Elymus L. sp.	Rye-grass
Epilobium angustifolium L.	Fire-weed

Scientific Name	Common Name
Epilobium L. sp.	Willow-herb
Fescue Myuros L.	Rat-tail Fescue
Galium L. sp.	Bedstraw
Gnaphalium L. sp.	Cudweed
Hieracium albiflorum Hook.	White-flowered Hawkweed
Holcus lanatus L.	Velvet-grass
Hypericum perforatum L.	Common St. John's-Wort
Hypochaeris radicata L.	Hairy Cat's-ears
Lotus corniculatus L.	Birds-foot Trefoil
Lotus micranthus Benth.	Small-flowered Lotus
Lotus stipularis Greene var. subglaber Ottl.	Thicket Lotus
Lupinus oreganus Hel.	Oregon Lupine
Lupinus rivularis Dougl.	Riverbank Lupine
Luzula campestris (L.) DC. var. multiflora (ehr.) Celak.	Common Wood-rush
Luzula parviflora (Ehrh.) Desv.	Small-flowered Wood-rush
Mitella ovalis Greene.	Oval-leaved Mitrewort
Oxalis oregana Nutt.	Oregon Oxalis
Plantago major L.	Common Plantain
Poa L. sp.	Bluegrass
Prunella vulgaris L.	Heal-all
Rumex Acetosella L.	Red or Sheep sorrel
Sanicula (Tourn) L. sp.	Snake-root
Scrophularia californica C. and S.	California Figwort
Smilacina racemosa (L.) Desf.	False Solomon's Seal
Stachys rigida Nutt.	Rigid Hedge Nettle
Streptopus amplexifolius (L.) DC	Large Twisted-stalk
Taraxacum officinale L.	Dandelion
Trientalis latifolia Hook.	Broad-leaved Star-flower
Vancouveria hexandra (Hook.) Morr. & Dene	Inside-out Flower
Verbascum Thapsus L.	Mullein
Viola sp.	
Xerophyllum tenax (Pursh.) Nutt.	Bear-grass

Ferns

Scientific Name	Common Name
Pteridium aquilinum (L.) Kuhn. var. pubescens Underw.	Western Brake-fern

Brush and Shrubs

Scientific Name	Common Name
Amelanchier florida Lindl.	Western Serviceberry
Arctostaphylos columbiana Piper	Hairy Manzanita
Berberis nervosa Pursh.	Long-leaved Oregon Grape
Gaultheria Shallon Pursh.	Salal
Rubus parviflorus Nutt.	Thimbleberry
Rubus spectabilis Pursh	Salmon Berry
Rubus vitifolius C. and S.	Western Dewberry Trailing Blackberry
Sambucus glauca Nutt.	Blue Elderberry
Symphoricarpos mollis	Creeping Snowberry
Vaccinium parvifolium Smith	Red Huckleberry

Experimental Design and Procedure

Experimental Design

__Field Phase__. It has been the practice of the Oregon State Board of Forestry to conduct pre-planting or pre-seeding surveys on areas selected for reforestation projects. Among other data recorded for each survey plot is a description of the plant cover. No attempt has been made to estimate accurately the per cent of plot area covered by living plants for two reasons: 1) the time and equipment necessary to accurately tally plant cover on 1/250-acre plots would have been prohibitive; and 2) data so obtained would have been consolidated in large classes to provide a meaningful number of samples in a class. Therefore the cover intensity in the Tillamook Burn has been estimated in three cover classes; light, 0-33 per cent of the ground surface is covered by living plant material (figure 8); medium, 33-66 per cent of the ground surface is covered by living plant material (figure 9); and heavy, 66-100 per cent of the ground surface is covered by living plant material (figure 10).

This study was designed to determine the effects of such cover classes upon the germination and survival of Douglas-fir seeds and seedlings. Accordingly, six areas of each cover type were located for each major exposure. In most areas two or three of the cover classes were located on a single hillside. For each replicate of each type of cover a set of three seed spots[1] was installed as the sample unit. Each of the three seed spots received one of the following pre-seeding treatments;

1. The term "seed spot" in this report includes an afore-described metal ring forced into the ground, 10 Douglas-fir seeds randomly scattered over the surface of the soil within the ring, and a hood pegged down over the ring.

Figure 8. Typical "light" cover. Photograph taken on North Plot 3, September 23, 1955.

Figure 9. Typical "medium" cover. Photograph taken on South Plot 3, September 23, 1955

Figure 10. Typical "heavy" cover. Photograph taken on East Plot 15, September 23, 1955.

1. Ground surface within the ring scraped bare. This was a check or control seed spot. These spots are hereinafter termed "mineral".
2. Neither living nor dead organic material within the ring was disturbed prior to seeding. (This procedure simulated seeding after leaf fall.) These seed spots are hereinafter termed "undisturbed".
3. Dead organic material was removed prior to seeding and replaced after seeding in a close approximation to the original arrangement. (This sub-treatment simulated seeding before leaf fall.) These seed spots are hereinafter termed "disturbed".

Thus the experimental design contained 4 exposures (NSEW); 3 covers (light, medium, and heavy); 3 pre-seeding treatments (mineral, undisturbed, disturbed) combined factorially with 6 replications.

Laboratory phase. During the course of previous years' studies on seeding with Douglas-fir the author had noted examples of germinated seeds which had been unable to force their radicles through partially decayed leaves. A. Koroleff, in published material (16, p. 178) and in correspondence with the author[1] indicates the severe problem hardwood leaves present to satisfactory stocking

1. A. Koroleff, Director of Woodlands Research, Pulp & Paper Research Institute of Canada. Private correspondence, April, 1954.

of forest lands in eastern North America.

The laboratory phase of this experiment was designed to determine if the physical impedance presented by layers of dead organic material was sufficient to prevent successful germination of Douglas-fir seed when other physical factors were favorable. Accordingly 14 2 1/2x12x19-inch greenhouse flats were filled with thoroughly mixed Hembre silt loam. This Tillamook Burn soil is in the Brown Latosol great soil group and is a deep, friable siltloam developed on weathered basalt.

The organic litter was arbitrarily divided into three types: hardwood (Quercus oregoni, Acer circinnatum, Alnus rubra, Acer macrophyllum, Rubus parviflorus, & Rubus spectabilis); fern (Pteridum aquilinum var. pubescens); and grasses (Festuca Myuros, Poa sp., Agrostis exorata Trin., Holcus lanatus, and Aira caryophyllea). Figures 11, 12, and 13 illustrate these three types.

Four seed flats were provided to test each cover type. A layer of dead organic material sufficient to just obscure the surface of the soil was placed in these twelve flats. In addition, a second layer was added to half the flats. Thus two flats were covered with a single layer of organic material of each of the three classes; and two, with a double layer. The soil surface of the last two of the fourteen flats was left bare to serve as a control.

Figure 11. Typical hardwood cover flat. Light layer of peat moss utilized to keep leaves moist. Photograph taken April 19, 1955.

Figure 12. Typical fern cover flat. Photograph taken April 12, 1955.

Figure 13. Typical grass cover flat. Photograph taken April 12, 1955.

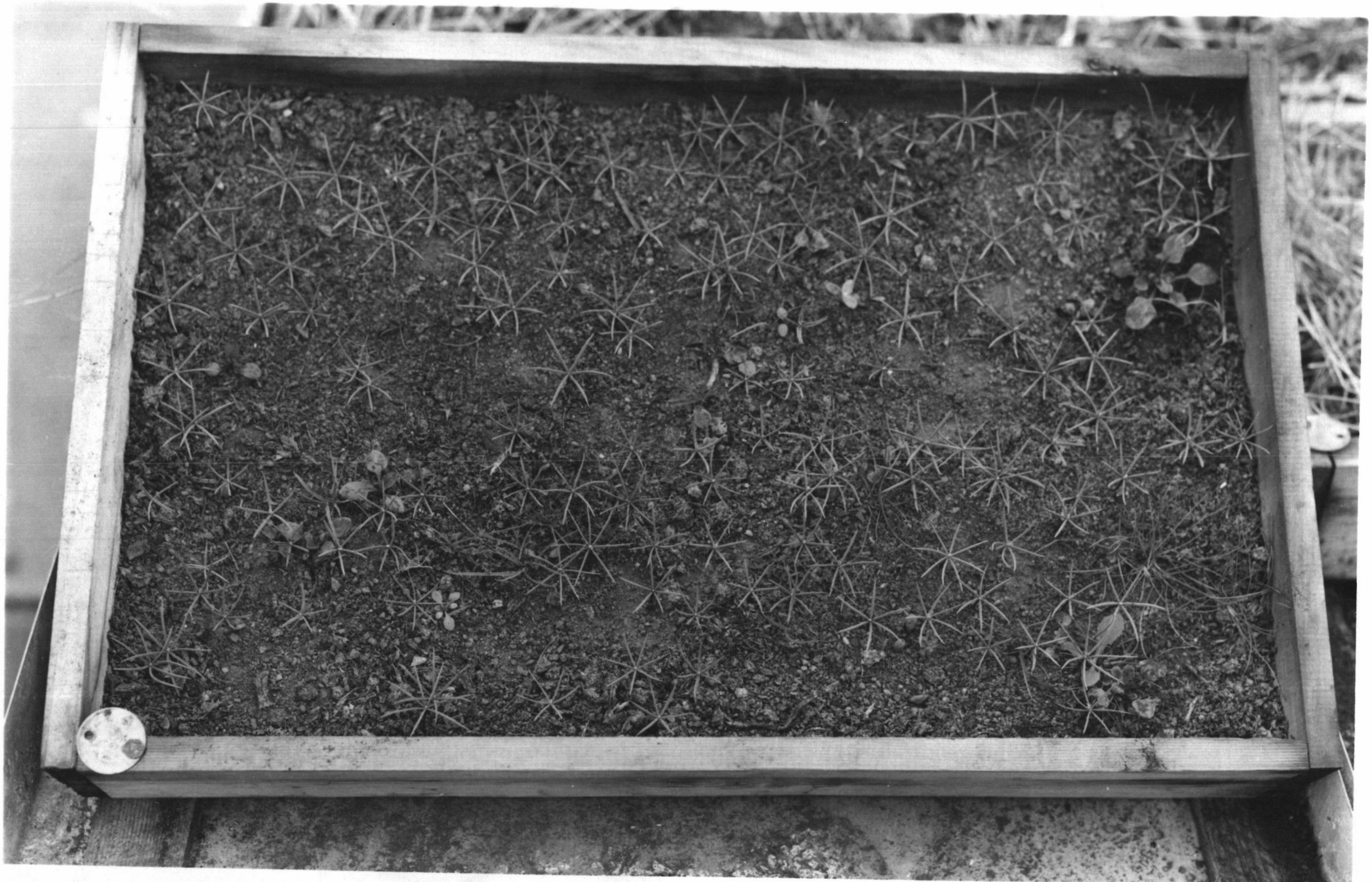

Figure 14. Control flat. Photograph taken April 12, 1955.

Three hundred seeds were spaced equally over the surface of each flat. Half the seeds were planted below the single layer and half, on the single layer in each flat with only one layer of organic cover. Where two layers of organic cover were placed in a flat, one-third of the seeds were planted on the soil; one-third, between the layers; and one-third, on both layers. Random selection was used to locate the various planting techniques within each flat. This procedure was followed to insure equal numbers of seeds in all possible positions relative to the cover at the initiation of the study.

The flats were placed in steel pans which permitted watering from below once a week. This procedure was followed to avoid disturbing the layers of cover during watering and to insure a uniform moisture in all the flats.

Experimental Procedure

Field Phase As stated previously, the field design specified six replications of every cover type and major exposure. Limitations of time and equipment made it impossible to visit all the areas required by this design every week to record meteorological data, therefore the field plots were divided into two classes: 1) non-instrument plots; and 2) instrument plots.

The majority of the plots had no soil moisture or temperature registering devices. These plots were visited on an average of every three weeks to a month. During each visit the condition of the living seedlings was noted together with any germination or mortality which might have occurred subsequent to the previous examination.

Temperature and soil moisture measuring equipment was installed at only one replicate for each major exposure. Four areas, each of which contained plots of light, medium, and heavy cover were selected. Three soil moisture units were installed at each seed spot, one at the soil surface, one at the three-inch level, and one at the ten-inch level. In addition, one unit was installed at the soil surface immediately adjacent to each of two seed spots to provide a means of measuring the effects of the iron rings on soil moisture. The units were installed in the fall of 1954 to allow ample time for establishment of proper contact between the units and the soil.

One maximum thermometer was placed on the soil surface in each seed spot. In addition, one thermometer was placed on the soil surface immediately adjacent to each of two seed spots to provide a means of measuring the effects of the hardware cloth hoods on the soil temperature. All thermometers were placed so that the plane of the soil surface bisected the thermometer bulb (figure 15).

These four areas were visited weekly from April 4th until the termination of the field phase of the experiment in October of 1955.

Figure 15. Illustrates typical placement of thermometers. Wires on right hand side of seed spot lead to soil moisture block buried at the soil surface.

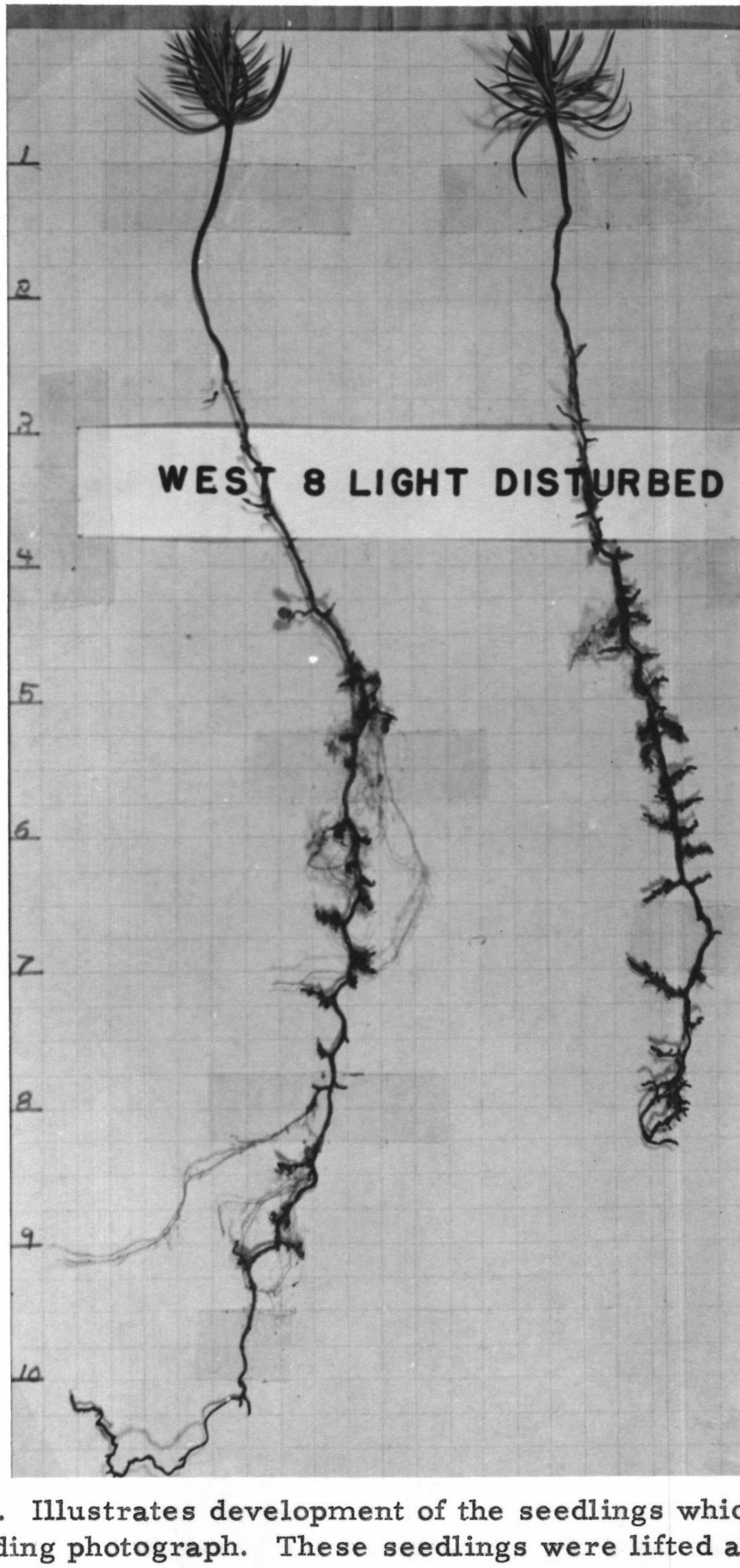

Figure 16. Illustrates development of the seedlings which appear in the preceding photograph. These seedlings were lifted and photographed in October 1955.

Data recorded on the weekly inspections included a description of the seedlings together with readings of the soil units and thermometers. In addition, the tempscribe installed on each exposure was serviced every week.

On June 1st, the hoods on all the seed spots which contained organic debris that had been removed prior to seeding and then replaced were removed. Inasmuch as all the seed spots for each cover class and exposure were placed in micro-sites as nearly identical as possible, this procedure provided 12 pairs of screened and unscreened seed spots to measure the effects of the hood on maximum soil temperatures and on seedling survival.

Laboratory Phase The flats were inspected and watered once a week from the date of seeding until this phase of the study was terminated on July 29, 1955. After planting the flats were treated with "fermate" to kill any of the following "damping off" fungi which may have been present: *Fusarium spp.*, *Rhizoctonia solani*, and *Pythium irregulare*.

Germination counts were made with the aid of a string frame divided into sixty small areas (figure 17). This frame enabled the investigator to tally seedlings by rows and columns and provided an accurate method of recording germination in each row of each flat. Unfortunately, the seeds were disturbed early in the course

Figure 17. String frame used to make germination counts.

of the study by air currents which agitated the organic cover placed on the seed flats. Therefore, it was not possible to tally germination by original position in respect to cover. The counts were made on the following dates: April 12, April 25, May 2, May 9, May 16, and June 23.

No attempt was made to control the growth of herbaceous cover plants. A comparison of figures 18 & 19 will show the extent living herbaceous cover developed during the course of the study.

Early in August all seedlings, living and dead, were removed from each flat and tallied. The results of this final examination together with the results of the greenhouse examinations are shown in figures 20 - 22.

Analysis of Data

Field Data

Tables 1 - 5 present a summary of the germination and survival data for each factor studied during the course of this project. It was felt that an arc-sine transformation of the data would permit a better analysis of the whole range of the data. However, when the analysis of variance computed from the arc-sine transformation was compared with that prepared from count data, little differences in corresponding "f" values were found to exist. Therefore only the

Figure 18. Flat with a single layer of fern cover. Photograph taken April 12, 1955.

Figure 19. Same flat as that shown in figure 18, photograph taken June 29, 1955. Major herbaceous species present include velvet grass, silver hair grass and sheep sorrel.

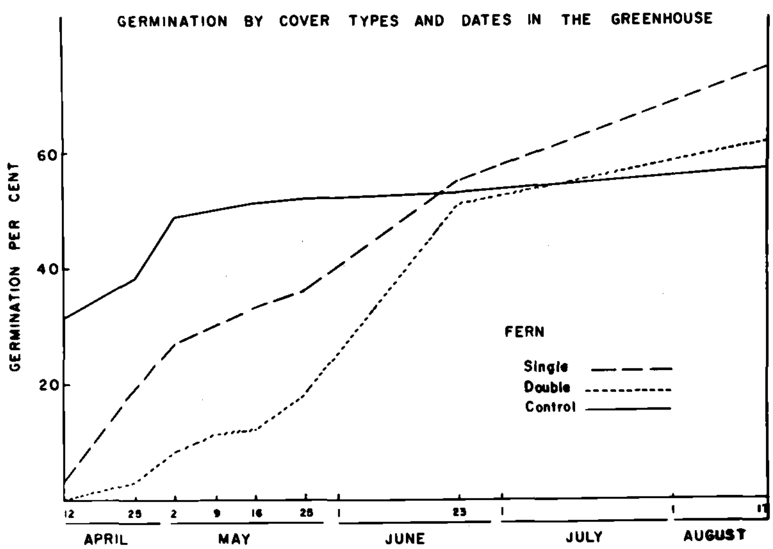

Figure 20. "Single" and "Double" refer to the layers of fern placed on the soil surface of the seed flats.

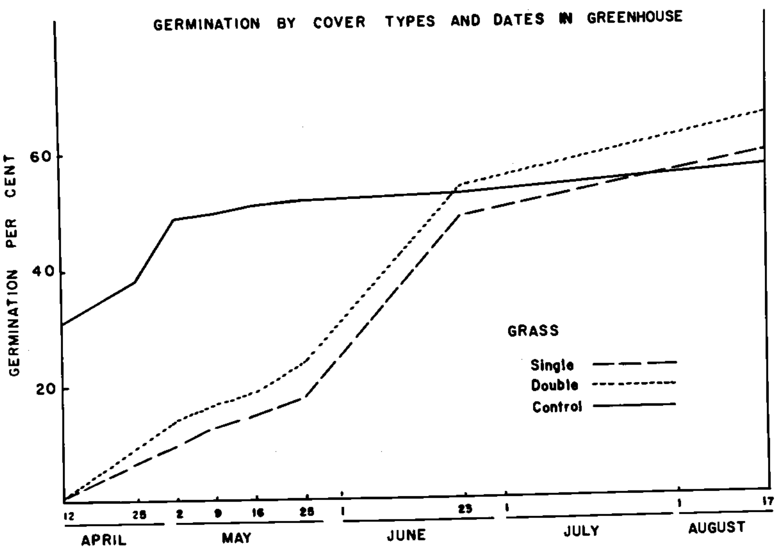

Figure 21.

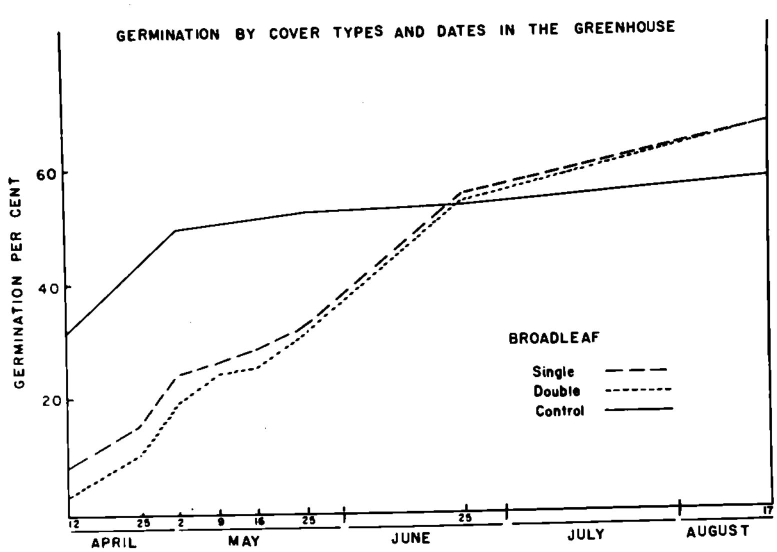

Figure 22.

analysis based on count data is presented in the appendix of this report.

Only the "exposure" treatment is significant. However, the interactions are all significant. Therefore no statement as to favorable cover or seeding condition may be made for all exposures.

Laboratory Data

Chi-square analyses of the data presented in figures 20 - 22 and table 6 indicate that the organic litter on the surface of the seed flats significantly reduced the germination of Douglas-fir seed until the latter part of June (or until about two months after initial germination on mineral seed beds). Had this occurred under field conditions, it is entirely possible that this two month delay in germination would result in much greater mortality as the seedlings would not have developed their root systems before the customary summer drought. Although differences exist between the effects of the different litter types and intensities, none are significant.

Discussion

This experiment was designed primarily to compare the germination and survival of Douglas-fir seeds and seedlings under varying conditions of vegetative competition in the Tillamook Burn. The following discussion of ecological observations made during the course of the study is presented, therefore, with the qualification that these observations were made to provide additional information on the ecology of Douglas-fir seedlings but were not the primary purpose of the study.

Effect of Screen Hoods upon the Survival of Seedlings and upon Soil Surface Temperatures

Experience in other regions indicates that the use of screened seed spots results in increased germination and survival of coniferous seedlings. Schopmeyer, C. S. & Helmers, A. E. (29 p 29-30) found that the use of screens appeared to reduce the mortality of seedling Engelmann spruce (Picea engelmanni [Parry] Engelm.), ponderosa pine (Pinus ponderosa Dougl.), and western white pine (Pinus monticola Dougl.) in the northern Rocky mountains. In the same region, Miller, C. I. (22 p 733-34) found it necessary to leave the screen caps over ponderosa pine and white pine seedlings for a year to prevent depredations by mice and other rodents. Fowells, H. A. & Schubert, G. H. (6 p 3) report that the germination and survival of ponderosa pine, sugar pine (Pinus lambertiana Dougl.), Jeffrey pine (Pinus jeffreyi Grey et Balf.) and white fir (Abies spp.) was greater under screen caps in California even when the rodent population was low. Krauch, H. (19 p 585-88) noted that

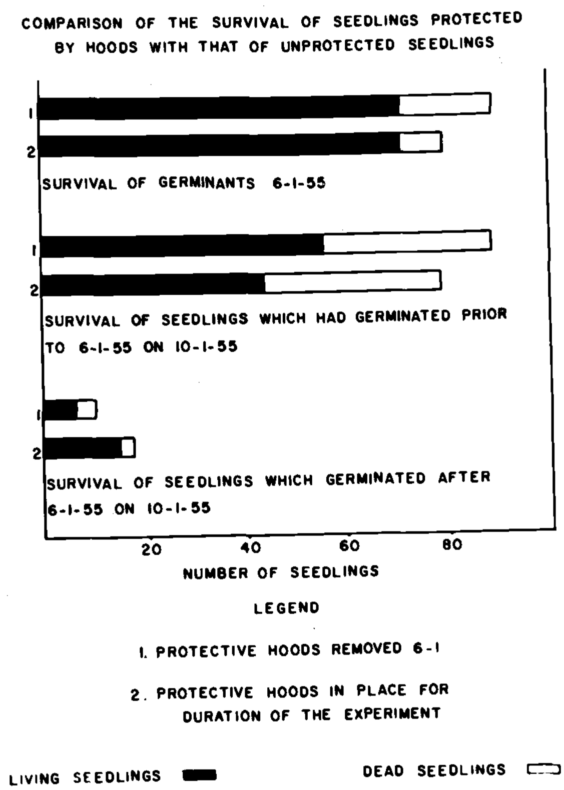

Figure 23.

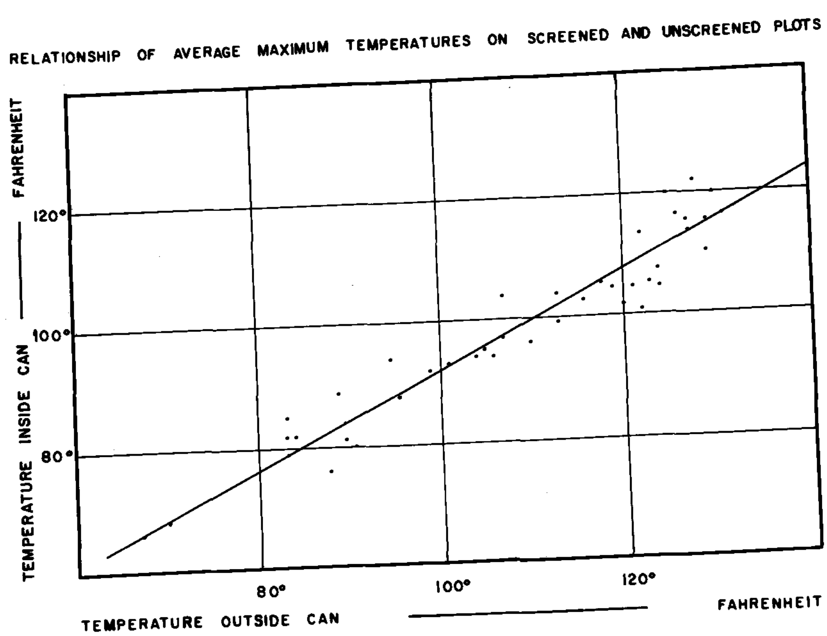

Figure 24.

newly germinated Douglas-fir seedlings in unscreened seed spots in Arizona were clipped by mice shortly after emerging. The same author (18 p 1, 2) indicates that the screen reduces soil temperature and mortality of the second year seedlings.

In spite of this unanimous evidence of the favorable effect of seed caps upon the survival of coniferous seedlings, Chi-square tests of the data presented in figure 23 indicate that differences in survival of seedlings in the screened and non-screened seed spots are non-significant except for the following. The survival of the seedlings which were alive on June 1 in the seed spots which were not screened subsequent to that date was significantly greater than that of similar seedlings in screened seed spots. Inasmuch as these seed spots were randomly selected, they should have been representative of the conditions obtaining over the entire experiment. No seedling was greater than four weeks old at the time the hoods were removed and an examination of the maximum temperature records for the unscreened thermometers prior to June 1 shows that only on the southerly exposure were temperatures recorded which might have been lethal to young seedlings. And even here, a maximum as great as 120° F was recorded only once. Therefore it is safe to assume that, regardless of the modification of the physical conditions which the hoods may have created, they could have increased the survival of the seedlings on all except the southerly exposures only by preventing animal damage.

Figure 24 presents the average weekly maximum temperatures which were noted on the paired screened and unscreened thermometers located in the plots with the soil surface scraped bare and in the 12 pairs of plots described above. This chart clearly shows that the screens do reduce the surface soil temperatures. This difference is probably due, at least in part, to the compaction of the herbaceous growth by the screen. Fowells & Arnold (7 p. 821-22) report that the average maximum temperatures inside a cone of 4-mesh 20 gauge hardware cloth 10 inches high and 10 inches in diameter average 12.2° F less than comparable maxima outside of the cone. This difference was found to be highly significant by the Student's T test. Laboratory trials by the author showed that the hood reduced soil temperature by 13° F when the true soil temperature reached 177° F.

Effect of Soil Surface Temperatures

The problem of the effect of extreme temperatures upon the tissues of plants has been the subject of numerous investigations during the past century. The results of only a few studies which were directly concerned with Douglas-fir seedlings will be reviewed here.

In California, Baker (1 p 970) found that, under controlled laboratory conditions, soil surface temperatures in excess of 151° F were fatal to all Douglas-fir seedlings. His equipment included containers of soil in which coniferous seedlings had germinated and a radiant heat source. Temperature measurements within the seedlings and in the layer of dry sand which was spread over the moist soil were made with thermocouples. He found that maximum temperatures within the sand exceeded those inside the seedlings by as much as 17° F. The age of the treated seedlings is not given, however the stems are described as being succulent. This condition obtains with Douglas-fir until the seedlings are from eight to ten weeks old.

In Colorado, Roeser (27 p 381-395) arranged Douglas-fir (Rocky Mt. variety) through holes in a board so that the roots were in water and then placed a 1/4th inch layer of heated sand on the board and around the stems of the seedlings. Five minute exposure to sand at temperatures of from 146° F to 154° F was fatal to all seedlings from four to eleven weeks old.

In Washington, Isaac (11 p 570) observed that under natural conditions soil temperatures of 125° F were injurious and those of 137° F were fatal to Douglas-fir seedlings five to ten days old. Resistance to heat injury increased as seedlings grew older. Soil surface temperatures of 147° F failed to damage eleven week-old seedlings.

Hunt & Chilcote (10 p. 11) report Douglas-fir seedlings were able to survive surface soil temperatures in excess of 160° F during the first growing season. And Clarkson (3 p. 10) states that the critical period for heat damage is during the first few weeks after germination.

The consensus of the investigators concerned with this problem is that the lethal temperature varies with the moisture content and the physical structure of the soil and with the size of the stem of the coniferous seedling and its age. Work with other species has shown that, in general, the duration of exposure also affects the maximum temperature a given plant can withstand, but this relationship has not been determined for Douglas-fir.

In the study reported here maximum thermometers were arranged in the manner illustrated in figure 15. The bulbs were placed so that they were bisected by the plane of the soil surface. The soils in the experimental plots were light colored silt and clay loams with very little humus.

Field examinations revealed no evidence that seedling mortality was due to heat damage. However, laboratory trials have shown that heat damage may be exceptionally difficult to detect (even in the laboratory where conditions for examination are ideal) especially on seedlings which have been lignified (i. e. more than eight to ten weeks old). Thirty ten week-old seedlings were subjected to 10 minute exposures to air temperatures between 140° F and 160° F. Ninety per cent of these seedlings died but only four of the seedlings showed any signs of heat damage on the stem prior to death. The remaining seedlings appeared healthy for some time after exposure but then gradually withered. After two months they had the appearance of drought stricken seedlings. Evidence of positive heat damage on all save the very youngest seedlings is even more difficult to detect under field conditions, especially if the examination of seedlings is necessarily from one to thirty days after the period of high temperature. Figure 25 shows the relationship between total seedling mortality by date and maximum soil temperatures recorded for each date. Very little correlation between dates of maximum temperature and those of mortality may be seen. This may be due partially to the aforementioned laboratory data which indicate that death may not occur until several weeks subsequent to heat injury. The seedling mortality in the individual seed spots which were equipped with maximum thermometers varied from 0 to 80 per cent. The average maximum temperatures for the duration of the study varied from 80° F in one of the seed spots on the northern exposure to 111° F in seed spots on the southerly and westerly exposures. When the

RELATIONSHIP OF MORTALITY WITH AVERAGE WEEKLY MAXIMUM TEMPERATURES ON EASTERLY EXPOSURE

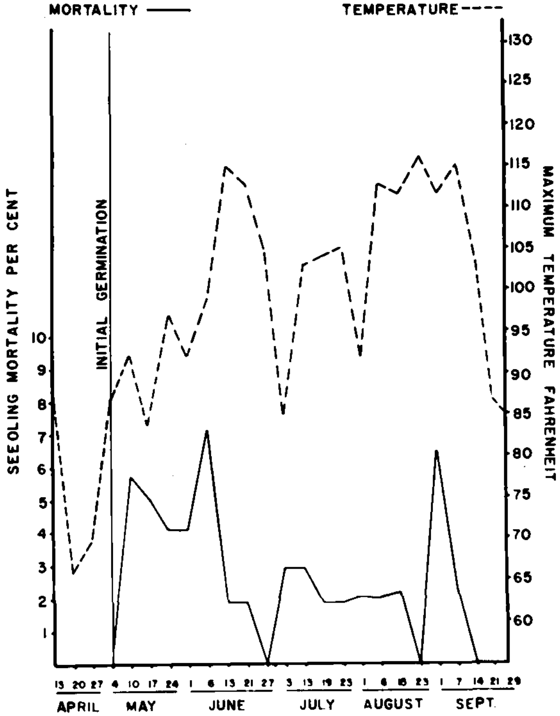

Figure 26.

RELATIONSHIP OF AVERAGE MORTALITY WITH AVERAGE WEEKLY MAXIMUM TEMPERATURES FOR ALL EXPOSURES

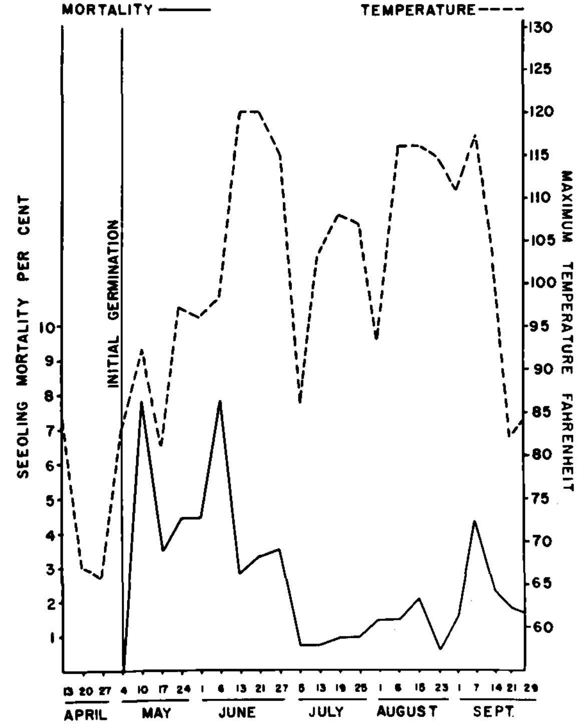

Figure 25.

mortality which occurred in the individual seed spots is plotted over the average maximum temperatures of these same seed spots, no correlation is noted. It would appear that, for the growing season of 1955, which was characterized by a cold, moist spring, and a cool, relatively dry summer, soil temperature was not a limiting factor for seedling survival in much of the Tillamook Burn.

Effect of Screen Hoods upon the Soil Moisture Content.

The data taken during this study indicate a slight tendency for the soil within the seed spots to be drier than the soil immediately outside the iron rings. Since these rings cannot affect the vertical movement of soil moisture, their slight drying effect must be a result of the impedance of the lateral movement of soil moisture. In any event, the slight drying effect of the seed spots was not sufficiently pronounced to affect the germination of the seeds. And since the effect extended to a depth of only two inches, it is believed that the change in soil moisture produced by the seed spots had no effect upon seedling survival.

Effect of Soil Moisture upon Seedling Survival.

Foresters in the Pacific Northwest have long known that soil moisture is an important factor in the survival of coniferous seedlings on cut-over and burned-over forest lands. Unfortunately, soil

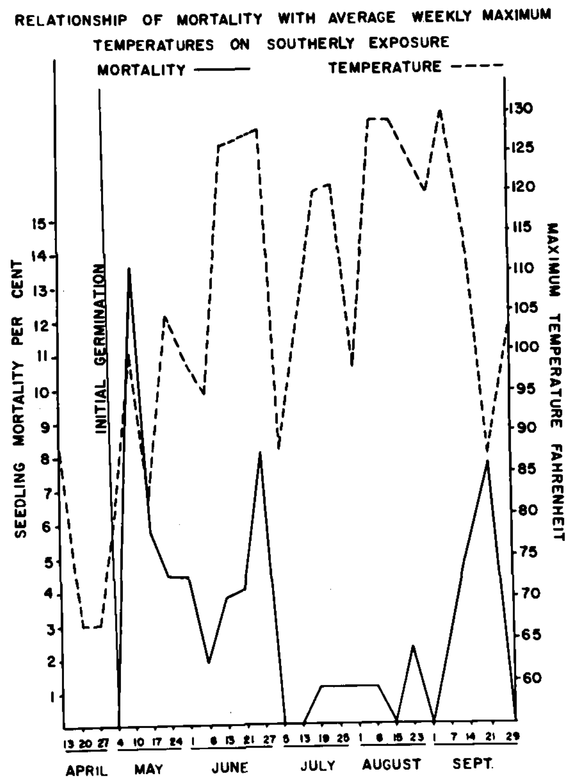

Figure 28.

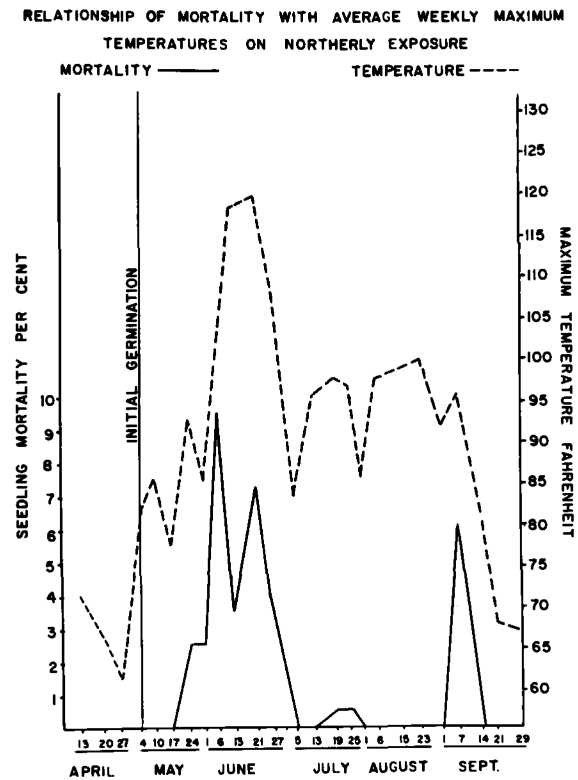

Figure 27.

moisture is difficult, if not impossible to measure accurately in the immediate micro-site of a seedling when the moisture level approaches the wilt point (i.e. 15 atmospheres or approximately 20 per cent soil moisture in the Hembre silt loam). The soil blocks were installed within the seed spot in the hope that the roots of the germinating seedlings would grow in close proximity to the blocks. Laboratory calibration demonstrated however, that soil moisture could vary from 9 per cent to 33 per cent within a distance of 6 inches.

Figures 30 to 35 summarize the soil moisture data recorded during the summer together with a summary of the seedling mortality believed to be caused by drought in the seed spots equipped with soil moisture blocks. These graphs show that soil moisture dropped below the wilt point for only a short period during the summer. Isaac (12 p 25) suggests that losses due to drought during periods when soil moisture determinations indicate a moisture level above wilt point may be due in part to variations of the soil moisture holding capacity of the soil. The data presented in this report would appear to confirm this hypothesis.

Although the graphs show some correlation between periods of low soil moisture and seedling mortality in August and early September, the failure of the instruments to provide data which can be

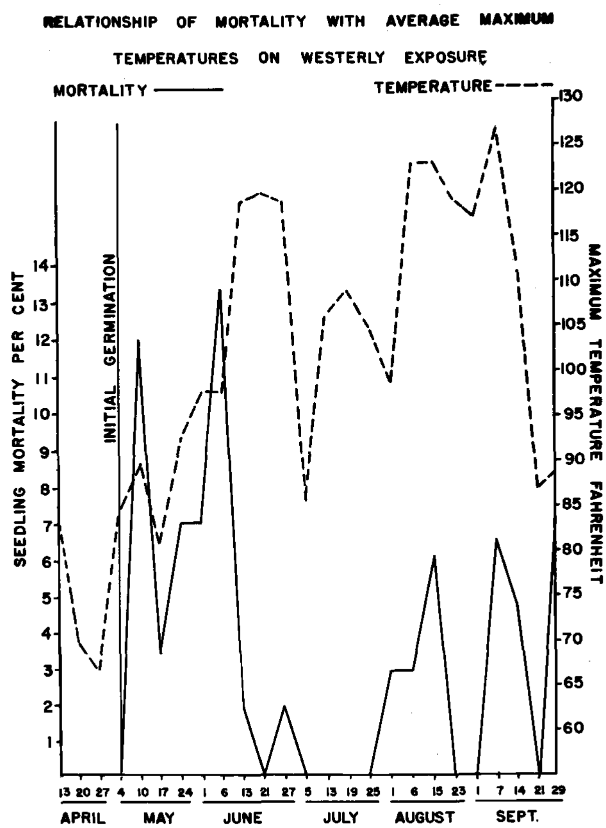
RELATIONSHIP OF MORTALITY WITH AVERAGE MAXIMUM
TEMPERATURES ON WESTERLY EXPOSURE
MORTALITY
TEMPERATURE
SEEDLING MORTALITY PER CENT
INITIAL GERMINATION
MAXIMUM TEMPERATURE FAHRENHEIT
13 20 27 4 10 17 24 1 6 13 21 27 5 13 19 25 1 6 15 23 1 7 14 21 29
APRIL
MAY
JUNE
JULY
AUGUST
SEPT.

Figure 29

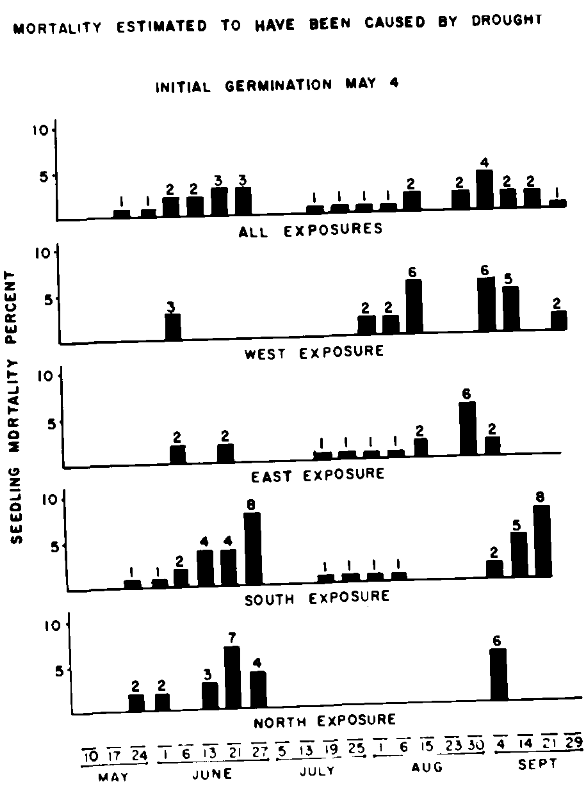

Figure 31.

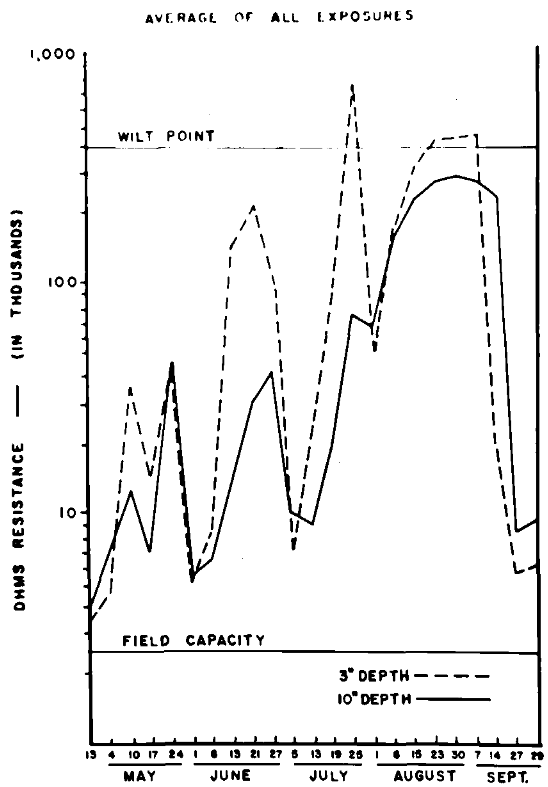

Figure 30.

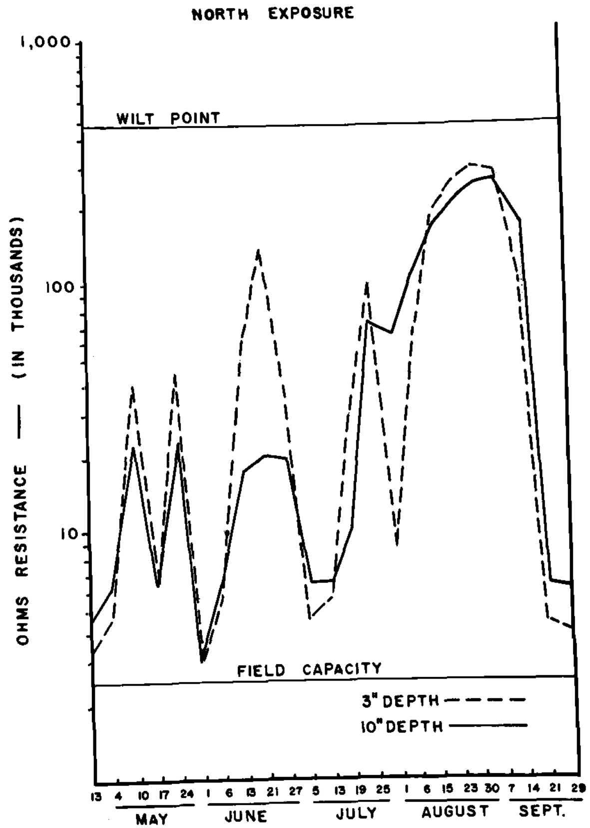

Figure 33.

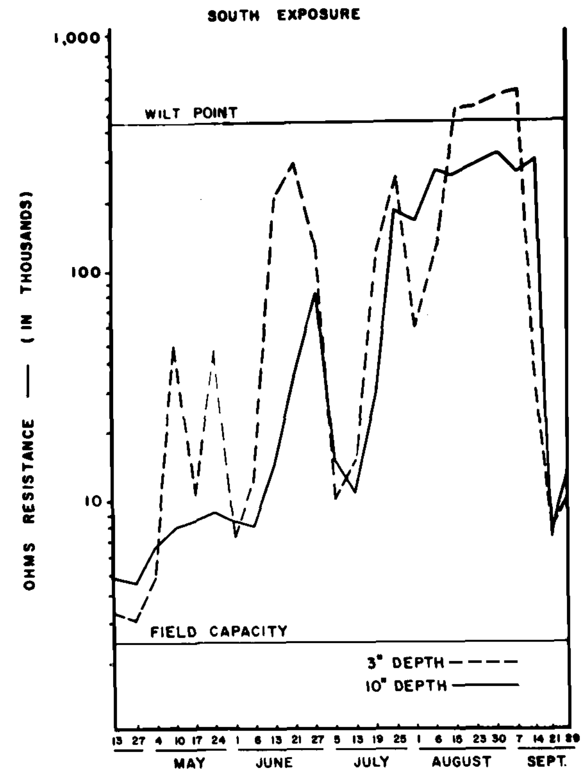

Figure 32.

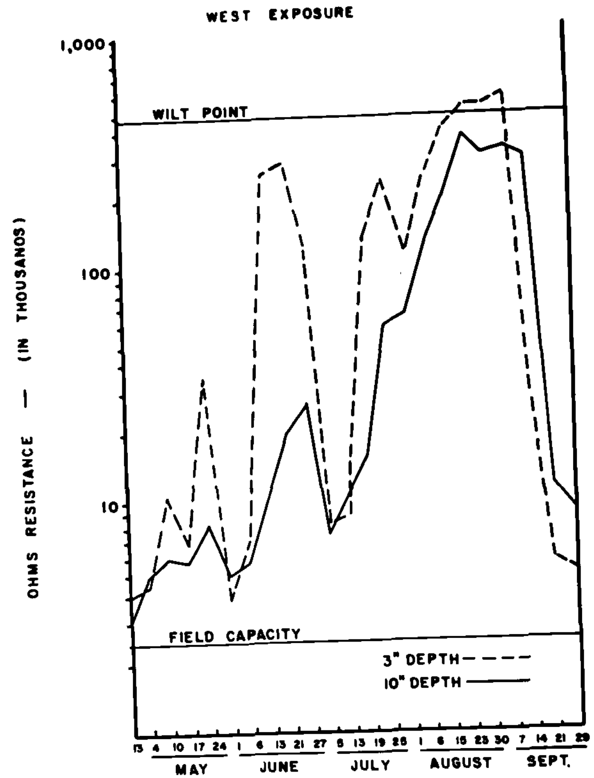

Figure 35.

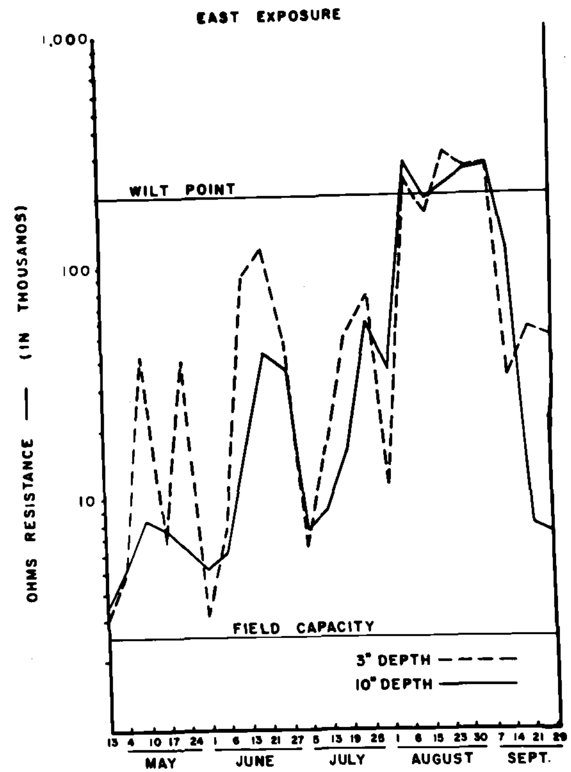

Figure 34.

interpreted to define the causal factors in seedling mortality strongly indicates that such data may be obtained only through basic physiological research. Such laboratory and greenhouse studies should provide the criteria to guide workers in the Pacific Northwest in developing truly hardy strains of seedlings suitable for reforesting the more severe sites.

Comparison of Weather During the Experimental Period with Previous Years' Weather in the Tillamook Burn

The data presented in figure 36 was recorded by the U. S. Weather Bureau Station in Forest Grove. However, there is a definite correlation between the daily maxima recorded there and those obtained from the Oregon State Board of Forestry station in the Tillamook Burn (figures 37 - 39). Since many more years of data were available from the Forest Grove station, it was decided to use these readings to establish the relationship of 1955 weather with that of other years. Because heat-caused seedling mortality is due primarily to the maximum temperatures in a given area, the weather in 1955 is compared with that of previous years on the basis of maximum daily temperatures. An examination of the data presented in figure 36 indicates that the year 1955 was one of the coolest years of the past decade. The average maximum

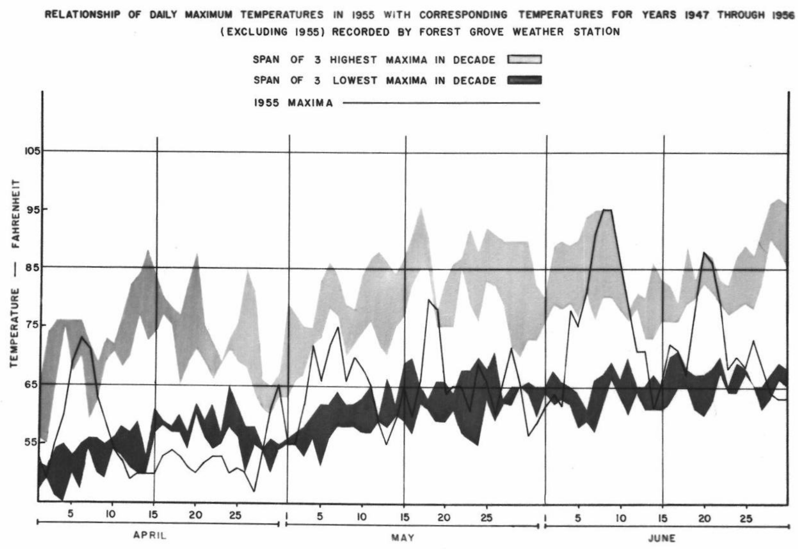

Figure 36a.

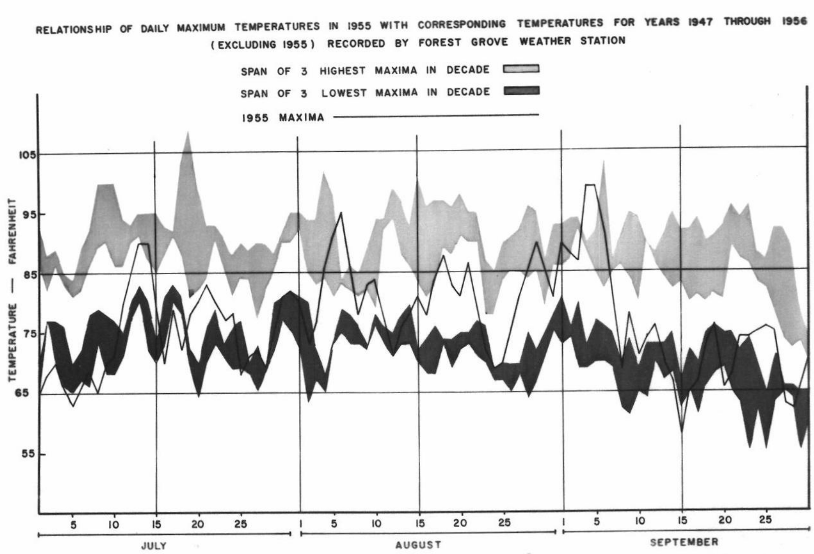

Figure 36b.

temperature of April was nearly six degrees lower in 1955 than it was for the same period in 1954. This difference is reflected in the germination dates of Douglas-fir seed. In 1954, considerable germination occurred in April; while in 1955, initial germination was not noted until the first week in May. Although the average maximum temperatures in 1955 were cooler than the mean for the decade 1947 - 1956, the records for only three other years list higher temperatures than those which occurred in September, 1955. The highest temperature of the decade occurred in July, 1956 (109° F). Observations were made of the effects of this extreme temperature upon Douglas-fir seedlings during a similar study and no signs of heat damage were detected.

Bates and Roeser (2, p. 13) state ". . . in nature it is probably the momentary maximum temperature which determines the degree of injury. It is also in agreement with results obtained in 1919, which showed that seedlings surviving one severe exposure were in no danger from a repetition of the same thing." If this be true, the high temperatures of June and September of 1955 must have produced as severe a heat stress as occurred during the decade.

The period of May through the middle of September in 1955 was the second driest period in the decade. From July 28 until

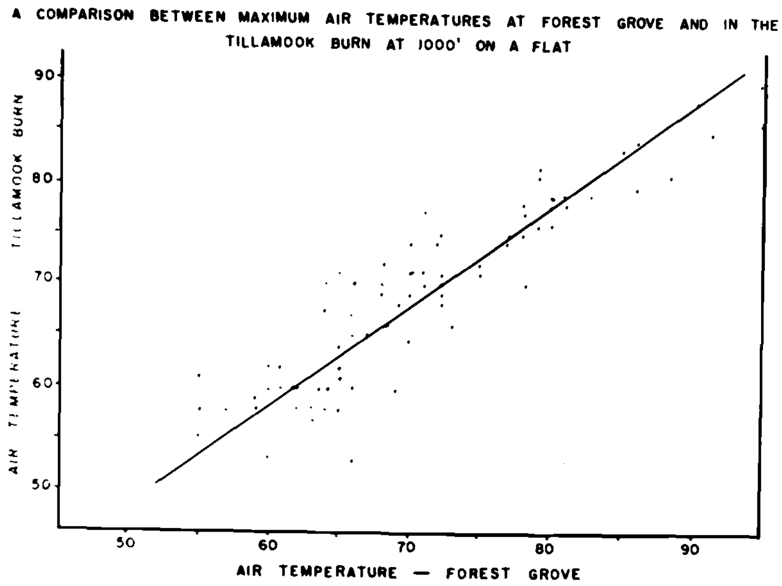

Figure 37.

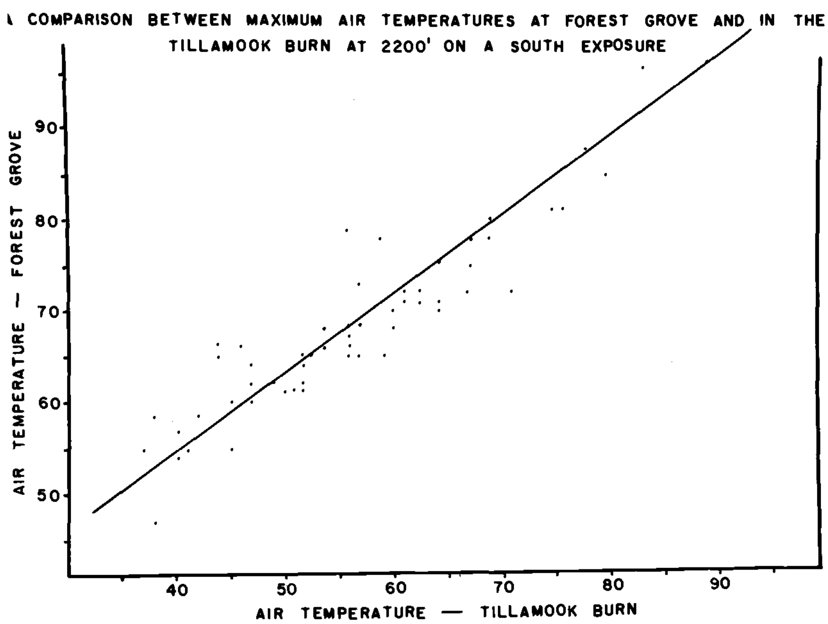

Figure 38.

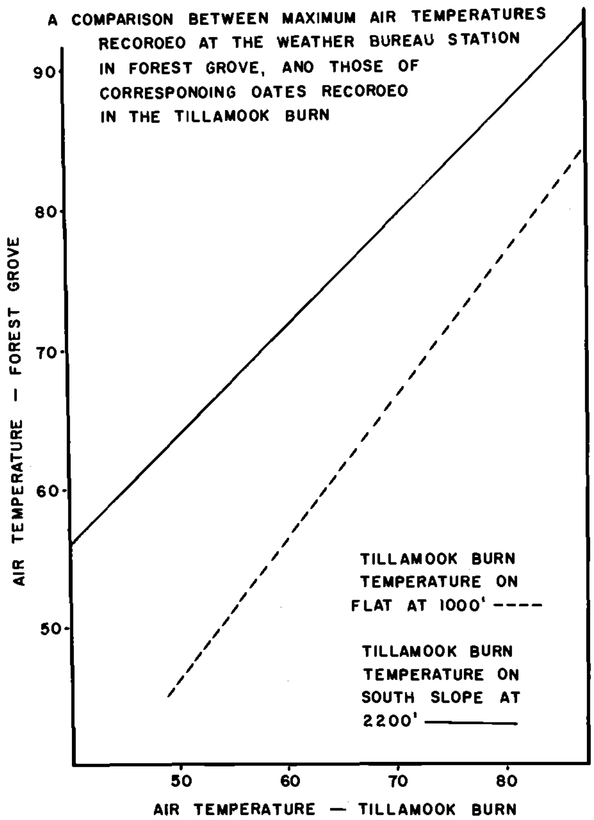

Figure 39.

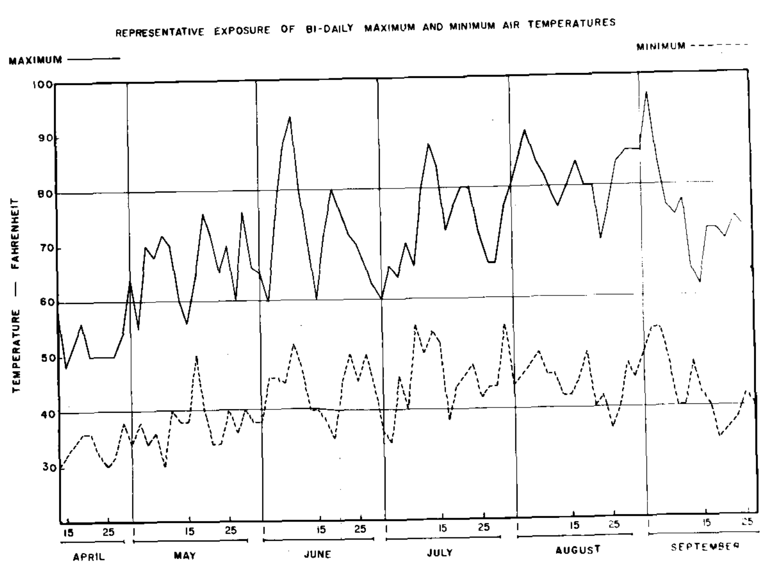

Figure 40.

September 13, a period of 47 days, there was no measurable precipitation in the burn. This was the longest period of drought in the decade.

Effect of Root Development on Seedling Survival

During the last week of September, 1955 all the experimental equipment was removed from the area (previous experience had shown that any equipment left in the Tillamook Burn area during the hunting season had been damaged or destroyed). Several of the seed spots were very carefully dug and the soil was washed off the seedling roots. Figures 41 - 44 illustrate the root development of the surviving and dead seedlings. Parker (24, p. 263) states "When, however, the entire soil mass dries down to levels near the ultimate wilting point, the root seems to become dormant or at least to cease growth." Since all the dead seedlings succumbed within a month of the date of the photograph, and since the entire soil mass was extremely dry until the latter part of that period, it would appear that the same differences in root development between dead and surviving seedlings existed when the dead seedlings died. The pictures show the clear superiority of the root systems of the surviving seedlings. The importance of vigorous root development to seedling survival is further emphasized when

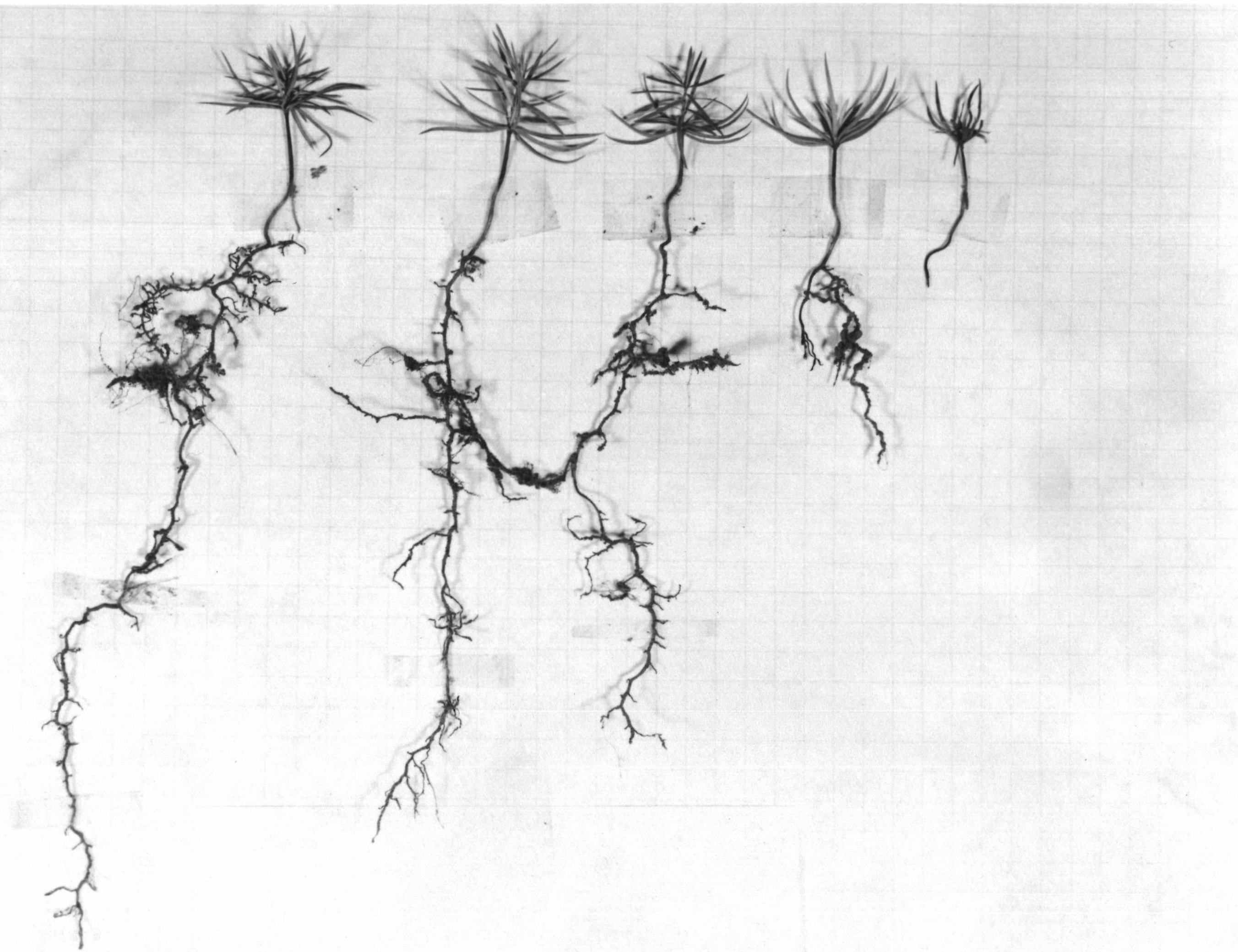

Figure 41. These seedlings were removed from a seed spot on a northerly exposure on September 26, 1955. The seedling on the right was dead, and the others, alive on this date.

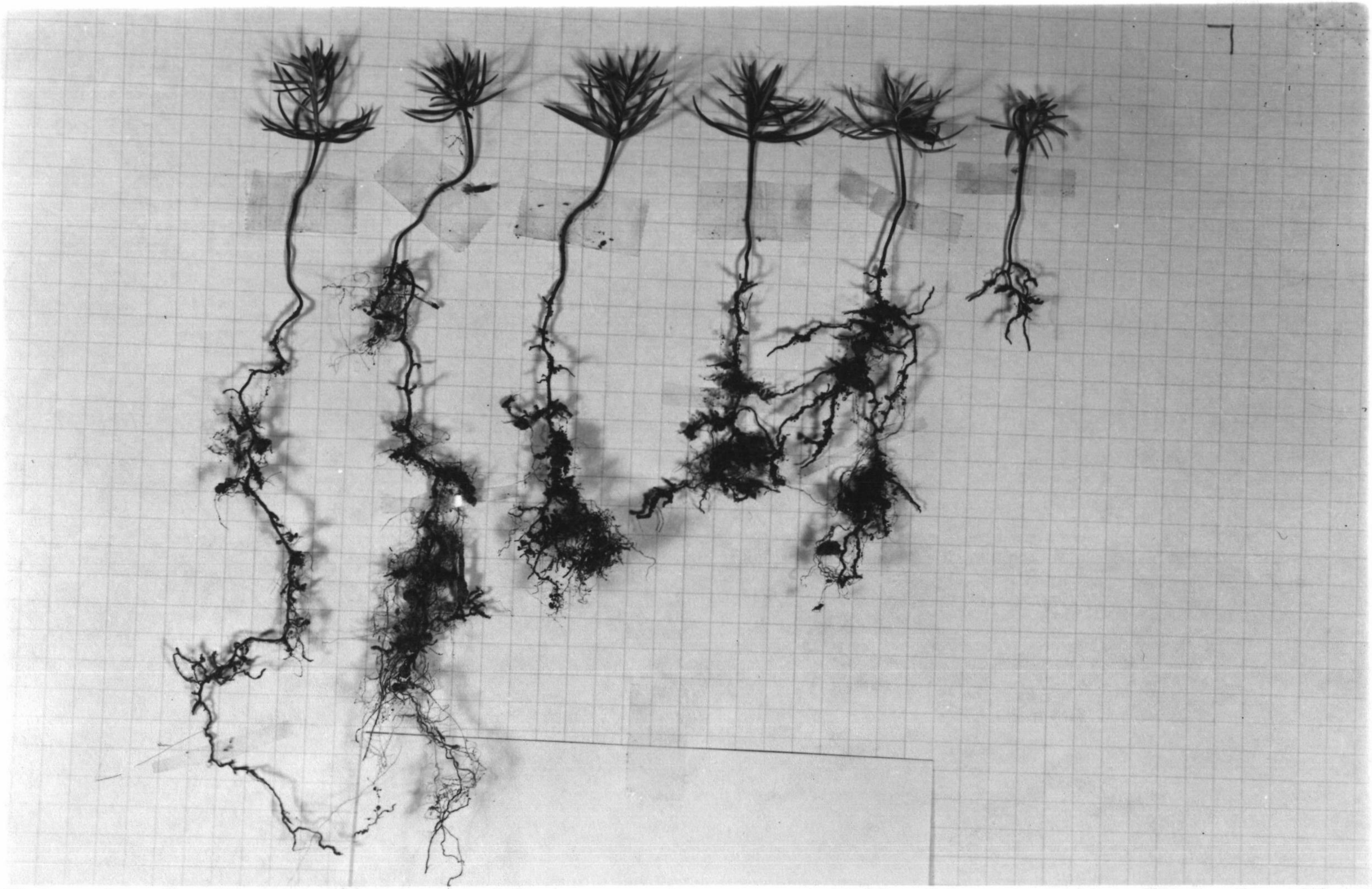

Figure 42. Seedlings were removed from a seed spot on a southerly exposure on September 26, 1955. The two seedlings on the right were dead, the others, alive when dug up. The cross section paper in the background of figures 41-45 has four squares to the inch.

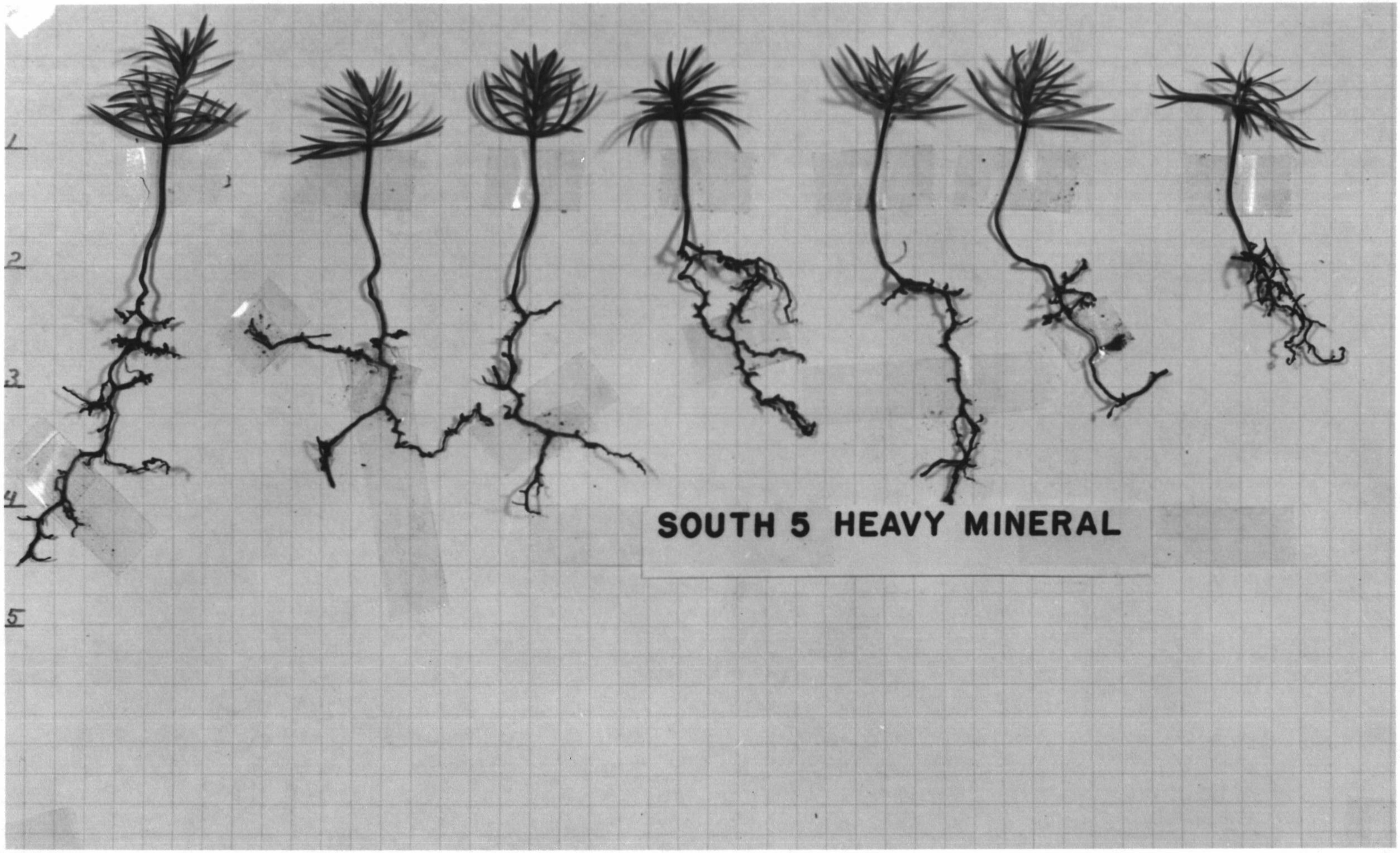

Figure 43. Seedlings were removed from a seed spot on a southerly exposure on October 6, 1955. Seedling on the right died during the second week in September, the remaining plants were alive when they were dug up.

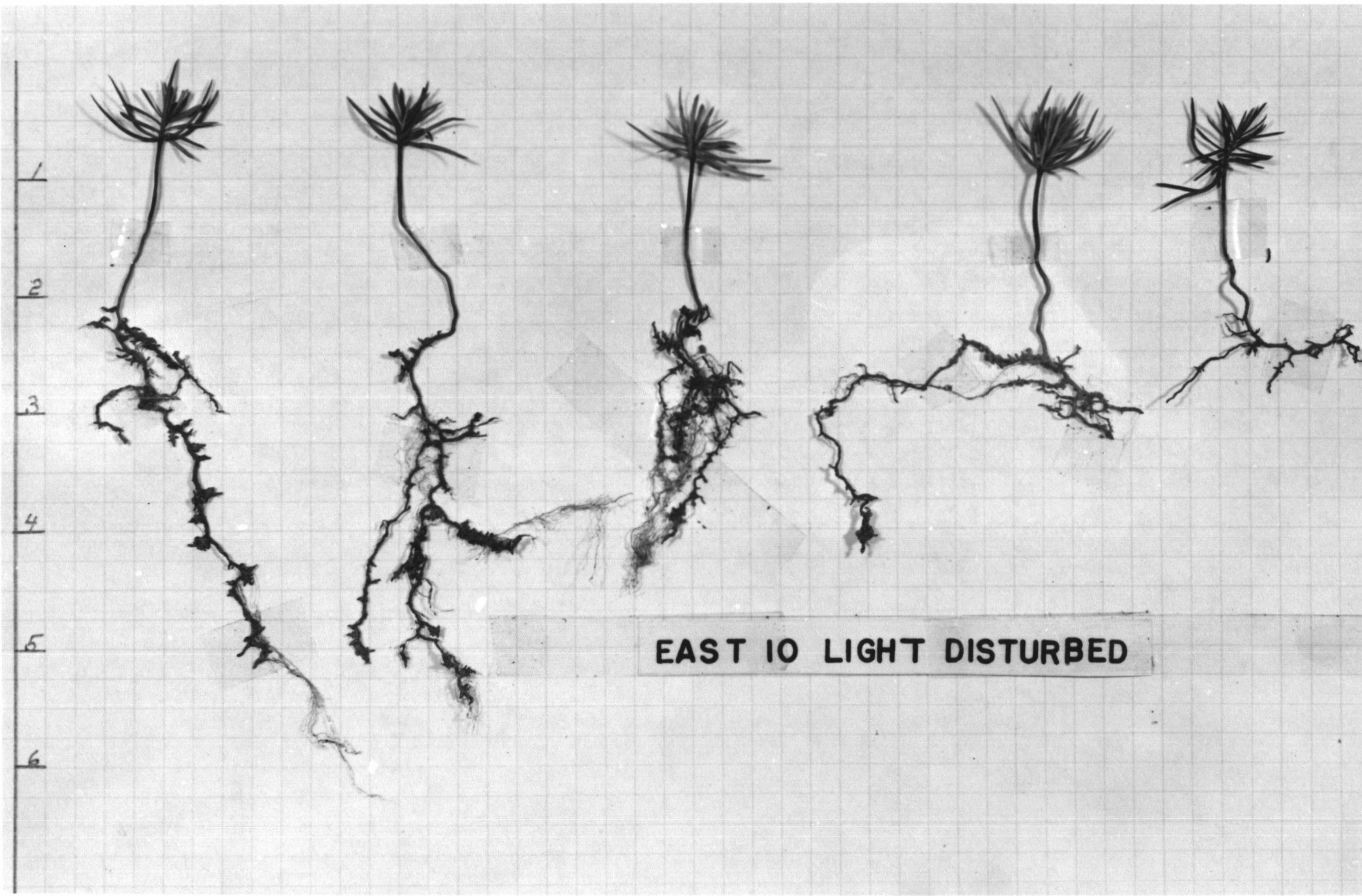

Figure 44. Seedlings removed from an easterly exposure on October 6, 1955. Seedling on right died after September 1, the remaining seedlings were alive when dug up.

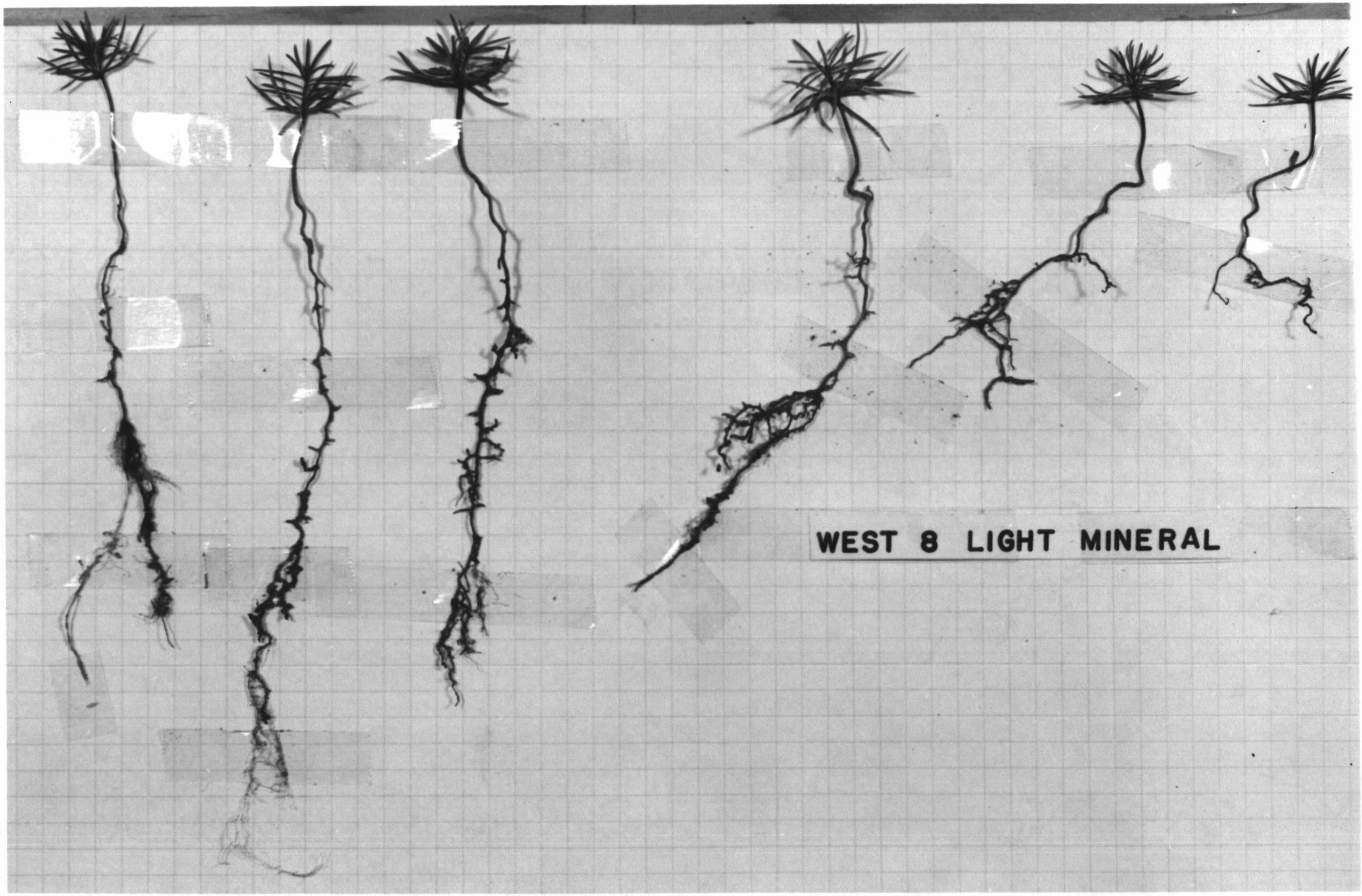

Figure 45. Seedlings removed from a westerly exposure on October 6. The two seedlings on the right died after September 1, the remainder were alive when excauvated.

it is realized that the dead seedlings were not weaklings, but were sufficiently vigorous to survive until the last part of the growing season. These data are in agreement with that of the numerous workers cited by Parker (24, p. 262 - 266).

Since the longest recorded rainless period in the Tillamook Burn occurred in August and September, it is felt that the surviving seedlings demonstrated sufficient drought resistance to survive the driest year in this area.

All the seedlings in each of the preceding five figures were removed from the same seed spot, and all the seedlings, living or dead that were found in a seed spot at the time of final examination appear in the photograph. Representative seed spots were dug up on each slope, the only criterion for a seed spot's selection being the presence of both living and dead seedlings. The dead seedlings all died subsequent to late August. Except for this one attribute, then, the seed spots photographed represent a random sample of the whole experimental population.

Effect of Germination Date on Seedling Survival

The field observations of the effect of this factor must be qualified by the following points:

1) Most of the plots were not checked frequently enough to permit recording an accurate sequence of all germination (the first examination of a seed spot usually fell in the middle of the germination period for that seed spot). It was noted that, on the plots checked weekly, full field germination was completed in less than one month subsequent to the initial germination in a given seed spot. Inasmuch as most plots were checked only once a month, the germination was frequently completed before the second check.

2) The seeds were randomly scattered over the surface of the soil within the seed spots. Therefore, it is possible that the germination date of a given seed might reflect the influence of the micro-site rather than the inherent vigor of the seed.

3) An earlier report (20, p. 14) stresses the importance of rapid, early germination of seed to successful seeding projects. The data presented here should not be construed as contradicting this belief, as this

experimental seed lot did demonstrate a vigorous germination. Had the germinative vigor of the seeds been less, it is very probable that many more of the seeds would have failed to germinate, and thus the number of surviving seedlings would have been correspondingly reduced.

The germination dates of the seedlings were compared on a seed spot basis in an attempt to equalize the effects of the microsite. That is, the seedlings of seed spot "A" were listed in order of germination dates and assigned appropriate ranks. Those of seed spot "B" were listed in order of their germination, etc. The survival datum for each seedling was recorded and two summations of these resulting data were prepared: (1) for all the seed spots in the experiment and (2) a second for all plots visited weekly.

The summation of data for the entire experiment shows the earliest seedlings to have a survival of 64 per cent; the later germinants, 67 per cent. A slightly larger difference is shown by the totals of the instrument plots. Here the early germinants had a 53 per cent survival, while the later seedlings had a 61 per cent survival. Neither of these differences is significant at the five per cent level.

Similar work conducted in the summer of 1956 showed a 61 per cent survival of the early germinants and 49 per cent for the later germinants. A Chi-square test shows this difference to be statistically significant.

Conclusions

The following conclusions are evident from the data and analyses presented in this report.

1) On the portion of the Tillamook Burn which supports the degree and type of herbaceous cover described earlier in this report (p. 12 - 14) the degree of herbaceous plant cover does not affect the germination of Douglas-fir seeds nor the survival of the seedlings.

2) The condition of the seed bed does not affect the germination of Douglas-fir seed nor survival of the Douglas-fir seedlings. In the greenhouse, a single layer of herbaceous cover was sufficient to retard seed germination for two months. Such retardation was not noted in the field. However, in general, there was little organic litter present in the field plots.

3) Northerly exposures are more faverable to germination and survival than are the southerly. The different seed

beds and cover types did not maintain a constant relative degree of favorableness from one exposure to another.

4) The majority of the mortality of seedlings in 1955 appears to be due to lack of moisture rather than excessive heat. Inasmuch as 1955 was a dry but relatively cool year, losses due to heat may be more important in most years than the data indicate.

5) Date of germination did not affect seedling survival.

6) The germination and survival of seedlings studied in this project were much higher than similar figures determined for seeding projects. This was probably due to three factors: 1) high quality, vigorous seed; 2) excellent seed-eating mammal control; and 3) relative ease in locating seedlings.

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Appendix

Analysis of Variance

Source of Variation	D. F.	Sum of Squares	Mean Square	"F"	Tab. "F"
Total	202				
Exposure	3	1,212.97	404.32	13.79	3.91**
Cover	2	101.77	50.88	1.73	3.05 ns.
Seeding Condition	2	164.13	82.06	2.80	3.05 n.s.
Exp x Cover	6	1,643.05	273.84	9.34	2.92**
Exp x Seeding Cond.	6	1,478.45	246.41	8.40	2.92**
Cover x Seeding Cond.	4	344.67	86.17	2.94	2.40*
Exp x Cover x Seeding Condition	12	2,321.95	193.50	6.60	2.29**
Error	167	4,898.06	29.33		

** Significant at 1% level.
* Significant at 5% level.
n. s. non-significant

Table 1

Number of Seedlings on All Exposures

	Degree of Cover			Seedbed Condition			
	Light	Medium	Heavy	Mineral	Disturbed	Undisturbed	Total
Germinants							
Total Alive	287	343	315	293	349	303	945
Total Dead	215	184	147	196	163	187	546
Total	502	527	462	489	512	490	1,491
Total Possible Germinants	650	700	680	660	680	690	2,030
Germination Per Cent	77	75	68	74	75	71	73
Mortality Per Cent	43	35	32	40	32	38	37
No. of living seedlings/100 seeds placed	44	49	46	44	51	44	47

Table 2

Number of Seedlings on North Exposure

	Degree of Cover			Seedbed Condition			
	Light	Medium	Heavy	Mineral	Disturbed	Undisturbed	Total
Germinants							
Total Alive	91	132	103	106	118	102	326
Total Dead	41	19	11	31	19	21	71
Total	132	151	114	137	137	123	397
Total Possible Germinants	170	180	180	170	180	180	530
Germination Per Cent	78	84	63	81	76	68	75
Mortality Per Cent	31	13	10	23	14	17	18
No. of living seedlings/100 seeds placed	54	73	57	63	65	56	62

Table 3

Number of Seedlings on West Exposure

	Degree of Cover			Seedbed Condition			
	Light	Medium	Heavy	Mineral	Disturbed	Undisturbed	Total
Germinants							
Total Alive	64	88	66	64	76	78	218
Total Dead	40	38	37	50	33	32	115
Total	104	126	103	114	109	110	333
Total Possible Germinants	130	160	150	150	140	150	440
Germination Per Cent	80	79	69	76	78	73	76
Mortality Per Cent	38	30	36	44	30	29	35
No. of living seedlings/100 seeds placed	49	55	44	43	54	52	50

Table 4

Number of Seedlings on East Exposure

	Degree of Cover			Seedbed Condition			
	Light	Medium	Heavy	Mineral	Disturbed	Undisturbed	Total
Germinants							
Total Alive	63	67	67	51	83	63	197
Total Dead	58	61	28	48	41	58	147
Total	121	128	95	99	124	121	344
Total Possible Germinants	170	180	140	150	170	170	490
Germination Per Cent	71	71	68	66	73	71	70
Mortality	48	47	29	48	33	48	43
No. of living seedlings/100 seeds placed	37	37	48	34	49	37	40

Table 5

Number of Seedlings on South Exposure

	Degree of Cover			Seedbed Condition			
	Light	Medium	Heavy	Mineral	Disturbed	Undisturbed	Total
Germinants							
Total Alive	69	56	79	72	72	60	204
Total Dead	76	66	71	67	70	76	213
Total	145	122	150	139	142	136	417
Total Possible Germinants	180	180	210	190	190	190	570
Germination Per Cent	81	68	71	73	75	72	73
Mortality Per Cent	52	54	47	48	49	56	51
No. of living seedlings/100 seeds placed	38	31	38	38	38	32	36

Table 6

Number of Germinants in Greenhouse Flats*

Type of Cover	Date 4/12	4/25	5/2	5/9	5/16	5/25	6/23	8/17
Mineral	187	228	292	302	308	314	321	344
Single fern	16	117	163	163	177	216	332	444
Double fern	0	19	49	65	75	108	308	370
Single grass	4	20	62	76	89	107	292	351
Double grass	5	35	83	101	113	133	**	399
Single broadleaf	48	92	147	158	171	191	332	403
Double broadleaf	17	58	114	142	148	186	326	403

* Table lists total number of germinants recorded for each date. Total possible for each cover type is 600.

** No count made on this date.