THE INFLUENCE OF SEEDBED MICROENVIRONMENTS UPON THE ESTABLISHMENT OF DOUGLAS FIR (*Pseudotsuga menziesii* (Mirb.) Franco) SEEDLINGS

by

RICHARD HERMANN

A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

DOCTOR OF PHILOSOPHY

June 1960

APPROVED: [redacted]

Associate Professor of Botany

In Charge of Major

[redacted]

Chairman Department of Botany

[redacted]

Chairman of School Graduate Committee

[redacted]

Dean of Graduate School

Date thesis is presented May 2, 1960

Typed by Pat Allison

ACKNOWLEDGEMENT

The assistance and advice received throughout this study from Dr. William Chilcote is sincerely appreciated. His enthusiasm and interest has been of considerable value. I wish to express my sincere thanks for the help received in field work as well as in the numerous discussions with him.

Special acknowledgement is due to Dr. F. H. Smith for valuable advice on the presentation of the data; to Drs. R. O. Belkengren, E. G. Knox, and W. K. Ferrell for helpful comments and suggestions.

Grateful acknowledgement is due to the Bureau of Land Management and the Oregon Forest Research Center for financial assistance. Without this aid the completion of this study would have been impossible.

Special acknowledgement is also due to Mr. Bent Gerdes of Manning Seed Company, Seattle, for the donation of bonded seed for this study; to Mr. Arthur Theisen for help with the drawings.

TABLE OF CONTENTS

LIST OF FIGURES

Figure		Page

Figure | Page

FIGURES - APPENDIX

Figure | Page

LIST OF TABLES

Table | Page

TABLES - APPENDIX

Table Page

THE INFLUENCE OF SEEDBED MICROENVIRONMENTS UPON THE ESTABLISHMENT OF DOUGLAS FIR (*Pseudotsuga menziesii* (Mirb.) Franco) SEEDLINGS

INTRODUCTION

The earliest phases of regeneration are the most critical ones in the establishment of a new forest. Seeds and young seedlings are confined to a limited space on the ground where the climate is extremely variable. The physical and biotic agents which can be fatal during this stage of a tree's life-cycle are recognized, but the extent to which these factors are influenced or modified by micro-environmental features is only imperfectly understood. The importance of the micro-habitat for the relationships between plant and environment was pointed out as early as 1911 by Kraus (59) and was later emphasized again by Geiger (36), but few detailed studies were made concerning the implications in forest regeneration.

The restocking of cut-over lands in the Douglas fir region of the Pacific Northwest is not as pressing a problem as in many other forest types. Yet the areas where reproduction has failed have added up in time and comprise today a sizeable acreage (122). A considerable portion of these unstocked lands occur on south slopes where removal of the old stands created severe site conditions and natural reproduction failed to develop.

The artificial reforestation of such sites meets with great difficulties and has often been unsuccessful in the past. Heat injury, drought, and rodents are regarded as the principal causes of failure. The rodent problem has been partially solved through the development of effective rodenticides which have greatly helped in reducing the loss of seeds on the seedbeds. However, effective measures to counteract high seedling mortality from heat injury and drought are still lacking. The use of nurse crops as a means of increasing seedling survival has been tested but the results were not generally satisfactory.

Students of regeneration realize that the mosaic of burned and unburned soil, duff, and other surfaces on a cut-over area represent various micro-environments. These surfaces usually blend into each other so that investigators are unable to clearly distinguish between the effects of each kind of seedbed material. The presence of a cover of herbaceous vegetation, or of a nurse crop, during the first successional stage on such areas superimposes an additional environmental factor. The interpretation of the influence of either the natural or the introduced herbaceous cover on seedling establishment poses enough problems of its own, but becomes even more difficult without a thorough knowledge of the characteristics of seedbed materials _per se_.

The present study was designed to distinguish the microenvironmental characteristics of seedbeds commonly found on clear-cut and burned-over south slopes, and to ascertain the nature and extent of their influence on the establishment of Douglas fir seedlings.

LITERATURE REVIEW

Many studies have emphasized the importance of seedbed conditions for the establishment of seedlings. They indicated also that germination and initial survival of seedlings may, or may not be similar on identical seedbed materials depending on the effectiveness of other environmental factors.

Reference to the effect of aspect as a factor influencing seedbeds were made more than 50 years ago by Wollny (132, Kerner von Marilaun (53), and Buehler (17). Wollny indicated that degree of slope is of considerable importance. As the inclination increases, a south slope becomes warmer and a north slope becomes cooler. The effect of slope is of less importance on east and west exposures. He noted also that soil moisture was greatest on north slopes, followed in order of decreasing moisture content by west, east, and south slopes. Geiger (36) discussed the consequences of inclination and aspect for the microclimate in great detail and pointed out that they are most pronounced under a clear sky in middle latitudes.

Henne (42) reported instances from the Swiss Alps where the higher temperatures on south slopes helped in the establishment of young trees but throughout many parts of the western United States high temperatures on south exposures were mostly detrimental to the establishment of coniferous reproduction. Bates (12), from an ecological study in the Rocky Mountains, came to the conclusion that high temperatures and rapid dessication of the surface soil on south slopes kept Douglas fir from invading such sites unless it could take advantage of some existing shade. The unfavorable high temperature and low soil moisture conditions for the regeneration of Douglas fir on south aspects have been pointed out many times (43, 48, 73, 86, 103). Silen (103), for example, found that by July 1, 69 per cent of the area on a south exposure reached temperatures of 140°F.

Attempts to protect young seedlings on such sites by means of a nurse crop were mostly unsuccessful (20, 29, 45, 77, 78, 91). The nurse crop lowered surface temperatures but offset this advantage by competing for moisture.

Inclination and exposure are but two factors which will influence the characteristics of a seedbed. As Isaac (49), and many others, pointed out, cutting of the old stand will change profoundly the light, temperature, and moisture conditions on the ground. In addition, logging activities may alter the physical properties of the soil to some extent (88, 109, 110). Of the surfaces found after cutting, bare mineral soil was frequently mentioned as the best medium for the establishment of Douglas fir seedlings (34, 49, 58). That this finding applies also to other species was illustrated by Smith's (107) comment "The silvical axiom that light-seeded species, including eastern white pine, regenerate most vigorously on moist, bare mineral soil has stood the test of time."

Duff, litter and other organic debris were generally found to be poor substrates for germination and survival of seedlings (11, 30, 34, 39, 63, 70, 107). The investigators attributed this to the unfavorable moisture and temperature regime of such seedbeds. Haig (39) described an instance where in May seedlings on duff were killed by frost while seedlings on near-by mineral soil escaped frost injury. Temperature records confirmed that on mineral soil temperatures had remained above freezing. Vaartaja (126) demonstrated the occurrence of extreme diurnal variations of temperature on humus and fine litter. Maguire (76), in a study of the relationships between radiation intensity and surface temperature, found sawdust to have thermal properties similar to those of duff and litter. He suggested that the extremes of temperature on such media during the months of April and May, when radiation intensities are high, may be the primary cause for the failure of seedlings to establish themselves on these seedbeds.

The disposal of slash by fire is a common practice and many investigations have been devoted to the kind of seedbed conditions which are created by burning. Studies in the Scandinavian countries, reviewed by Aaltonen (1), showed that regeneration of Scotch pine (<u>Pinus sylvestris</u>) and birch was usually favored by burning. It was not clarified whether this was the result of changes in the micro-flora and fauna, the H-ion concentration, or the nutrient status of the soil. Favorable effects of ashes on germination and growth of coniferous seedlings were reported repeatedly (30, 63, 97). Fabricius (27), on the other hand, found that ashes were detrimental to germination and seedling development and did not consider burning an aid to the establishment of any tree species. Tryon (121) reported that germination of white pine seeds was reduced if the soil contained charcoal. The reduced germination was ascribed to an increase in the concentration of the soil solution through salts released by the charcoal, which resulted in decreased absorption of water by the seeds. Isaac and Hopkins (47) conducted extensive tests on the effect of slash burning and came to the following conclusions. A higher concentration of Ca, K, and

P will be in the surface soil immediately after the slash fire but at the same time unfavorable soil conditions are created by the destruction of organic matter. Seedling development will be influenced unfavorably through the reduced moisture-holding capacity of the soil and through the loss of nitrogen. Furthermore, the blackened areas of the burn will be a hazard to seedling survival on account of the high temperatures which they attain under strong insolation. Fuller et al. (32) reported that burning of the duff resulted in a greater dispersion and greater compaction of the uppermost soil layers than was found in unburned soil. Dyrness and Youngberg (26) investigated the effects of slash burning in the Coast Range of western Oregon. Their results indicated that the effects of slash burning may not be as detrimental as was previously claimed. Tarrant (115, 116) was especially concerned with the changes in the pH of a soil after burning. His work showed that soils will become nearly neutral or even slightly alkaline after burning, depending on the severity of the fire. Alkalinity _per se_ does not appear to have adverse effects on the germination of Douglas fir seeds (118), but may have an detrimental effect on seedlings by favoring damping-off organisms (94, 117). Bever (15), after an extensive stocking survey of cut-over lands in Oregon, reported much better stocking on burned than on unburned sites. Lavender et al. (64) made a similar study and came to the opposite conclusion. These investigators emphasized, however, that these apparently contradictory results may not be at variance. They explained that a seed bed created by fire is not optimum for seedling establishment but is far more suitable for seedling growth than are heavy slash concentrations. Garman (34) summed up the present status of information when he stated "Our knowledge of the full effects of burning is fragmentary. It is known, however, that burning influences seed-bed conditions in numerous ways, both favourably and unfavourably."

Many investigators have shown the difficulties of ascribing seedling responses to a single environmental factor. Ferrell (28), in a comprehensive review of studies, concerned with the effect of light and moisture on seedling survival, noted that workers sharply differed in their opinions regarding the relative importance of these two factors for seedling establishment. Most regeneration studies in the Douglas fir region do not cover the influence of light in detail. Tiedemann (119), for example, simply stated that survival of seedlings in the open was far better than under the shade of trees. The higher survival on clearings was attributed to the absence of competition. Isaac (49) was the only worker to conduct experiments on the light requirements of Douglas fir seedlings. He concluded that 20 per cent of full light is the minimum for successful seedling establishment even under favorable moisture conditions. Failure of Douglas fir seedlings to survive in full sunlight was ascribed to drought and high soil surface temperatures rather than high light intensity as such by several investigators (34, 48, 49, 86).

In many regeneration studies drought was reported as a major cause of seedling mortality and was attributed to the exhaustion of available soil moisture. Daubenmire (22) and Vaartaja (127) attempted to determine to what extent excessive transpiration, even though soil moisture conditions are favorable, is a factor in mortality by drought. They subjected coniferous seedlings to a degree of atmospheric drought much more severe than ever found under natural conditions, but obtained very little mortality. The factors to which drought resistance of seedlings is linked remained largely unknown. It was found that drought resistance of seedlings may depend primarily on root development and growth rate (39, 68, 70) which, according to Karschon (52), are favored by long photoperiods. Shirley (101) noted dormancy as a means by which seedlings may withstand drought.

Some of the first observations of high temperature injury were made by Muench (82, 83, 84). Since this time many studies in various and diverse forest habitats (6, 8, 39, 43, 48, 56, 69, 70, 71, 90, 99, 107) pointed to heat injury as an important cause of seedling mortality. The symptoms of heat injury, appearance of a discolored spot on the stem which gradually develops into a constriction, were found to be essentially the same in all species investigated.

Observations in the field stimulated great interest in the heat tolerance of seedlings and numerous laboratory experiments (7, 13, 22, 40, 72, 86, 87, 93, 101, 104, 120, 127) were conducted to determine the critical temperature levels. Most investigators found that injury was likely to occur at temperatures above 120°F and that temperatures in excess of 140°F would lead to death in a short time. Yet the results of some workers were considerably below or above this range. Various reasons were advocated to account for differing results. Bates and Roeser (13) proposed that seedlings are protected by evaporative cooling up to a certain temperature level which varies for different species according to their rate of transpiration. Baker (7) did not accept this hypothesis. He proposed instead that critical internal temperatures are reached by different species under different external heat conditions depending on the anatomical characteristics of a species and on the age of the seedlings. Daubenmire (22) was not able to correlate heat resistance with stem anatomy and attributed much of the discrepancy in results to methods of measuring temperatures.

Experiments with flowering plants indicate that short-term fluctuations in the resistance to high temperatures occur. Laude (61) detected a diurnal cycle of heat resistance in several field crops. The daily maximum resistance to heat was attained at about mid-day and continued during the afternoon while the minimum resistance prevailed early in the morning. For example, sorghum was injured less by exposure to 150°F for five hours beginning at 1 P.M. than by exposure to 140°F for the same length of time beginning at 8 A.M. Schwemmle and Lange (100) could demonstrate cycles of heat resistance in *Kalanchoe blossfeldiana*, only here the situation was reversed. The maximum of heat resistance occurred during the middle of the dark period and the minimum during the middle of the light period.

The influence of temperature on root growth of seedlings has remained almost unknown. Adams (2), working with eastern white pine, demonstrated the important influence of soil temperature on initial root growth and its consequent effects in maintaining contact of the seedlings with moist soil. Barney (10) conducted laboratory studies on the relation between temperature and root growth of loblolly pine. Temperatures below 41°F and above 96°F caused complete cessation of root elongation. The range between 78°F and 84°F appeared to be most favorable to vigorous root growth.

In certain regions, especially in Europe, low rather than high temperatures will limit seedling establishment (54). In the Pacific Northwest frost is not a prohibitive factor in the regeneration of Douglas fir according to Isaac (49).

Injuries to seeds from extreme temperatures are seldom discussed in the literature. Morris (81) found in oven tests that dry (7% moisture content) Douglas fir seeds withstood temperatures up to 150°F without material loss of viability. Moderately moist seeds (30% moisture content) lost their viability completely when heated to 140°F. He considered it possible that the relatively low temperatures which injured wet seeds may be responsible for the frequently observed reduction of germination under field conditions. Vaartaja (127) measured internal and external temperatures of seeds of Scotch pine which were exposed to strong insolation. The difference between outside and inside temperatures was found to be insignificant. The temperatures reached by the seeds depended on their color but even more on the nature of the substrate. The extreme temperature variations commonly taking place on exposed forest sites were considered by him as an important factor affecting dormant tree seeds. Allen (3) reported that temperatures between 70°F and 95°F have little effect on germination rates of Douglas fir seeds which have over-wintered in the ground. In a later publication (4) he pointed out that a fixed optimum for the germination of Douglas fir seeds does not exist because the temperature requirements for this process change progressively as the seeds receive longer periods of stratification. He conceded that under natural conditions control of dormancy and of germination is probably related to temperature. But he added (4, p. 185) "whether it is the average temperature, or the maximum, or the minimum or some other measure of heat level that is important, is not yet known." Baldwin (9) giving the most comprehensive summary of work done on forest tree seeds up to 1942, stated that temperature is one of the most important factors governing germination of all seeds. However, he cautioned against the interpretation of seed responses in terms of temperature alone because each environment presents a new and special complex of factors, the interaction of which produces a characteristic effect. Siegel (102) demonstrated that responses of seeds to high temperatures are coupled in some way with responses to light. High-temperature conditioning of the seeds of several wild and cultivated flowering plants resulted in either photo-stimulation or photoinhibition of germination. He stated that evidence in his experiments was insufficient to permit a conclusion as to which of these two types of response to high-temperature conditioning is more characteristic of seeds in general.

Certain biotic agencies have often proved to be of equal or even greater importance than physical factors of the environment for germination and survival of seedlings. The severe effects of the activities of rodents and birds on seedling establishment was shown in many studies. Smith and Aldous (106), in an extensive review of this subject, made it clear that these agents are perhaps the most important of all biotic factors with regard to forest regeneration. Hunt and Calvin (44) stated that in the Douglas fir region the white-footed deer mouse (*Peromyscus maniculatus*) consumes more Douglas fir seeds than any other animal. Jameson (50), in a thorough study of the feeding habits of this rodent, acknowledged the potential destructiveness of it but pointed out that deer mice are at the same time a powerful beneficial force as consumers of cutworms. Cutworms (Euxoa spp.) have been reported repeatedly to cause serious damage to seedlings (31, 39, 49).

Certain fungi, generally grouped as damping-off fungi, have often been recognized as causes of seedling mortality, but infections have mostly been discussed in connection with nursery practices (16). Little is known about the conditions which favor their occurrence in the field although losses by damping-off organisms have been reported in several regeneration studies (11, 39, 49).

DESCRIPTION OF STUDY AREA

The study was conducted in the Mary's Peak Watershed which is situated in the Coast Range approximately 15 miles southwest of Corvallis, Oregon. The major part of the east slope of Mary's Peak is occuped by stands of Douglas fir. Vine maple (<u>Acer circinatum</u> Pursh.), salal (<u>Gaultheria Shallon</u> Pursh.), and chinquapin (<u>Castanopsis chrysophylla</u> (Dougl.) A. DC.) are the more common associates in the understory. For a detailed listing of plants of the understory and of the herbaceous vegetation the reader is referred to Merkle (80).

A 10 to 12 per cent south-facing slope, at an elevation of approximately 1700 feet, in T. 28 S., Section 22, was chosen as the experimental area (Figures 1, 2, and 3). The slope had been covered by a stand of mature Douglas fir until it was clear-cut and burned in 1955.

The soil on this slope is a well-drained Brown Latosol, and was tentatively classified as belonging to the Hembre Series. The parent material is residuum from basaltic rocks. Examination of a soil profile on the slope showed the following structural and textural characteristics:

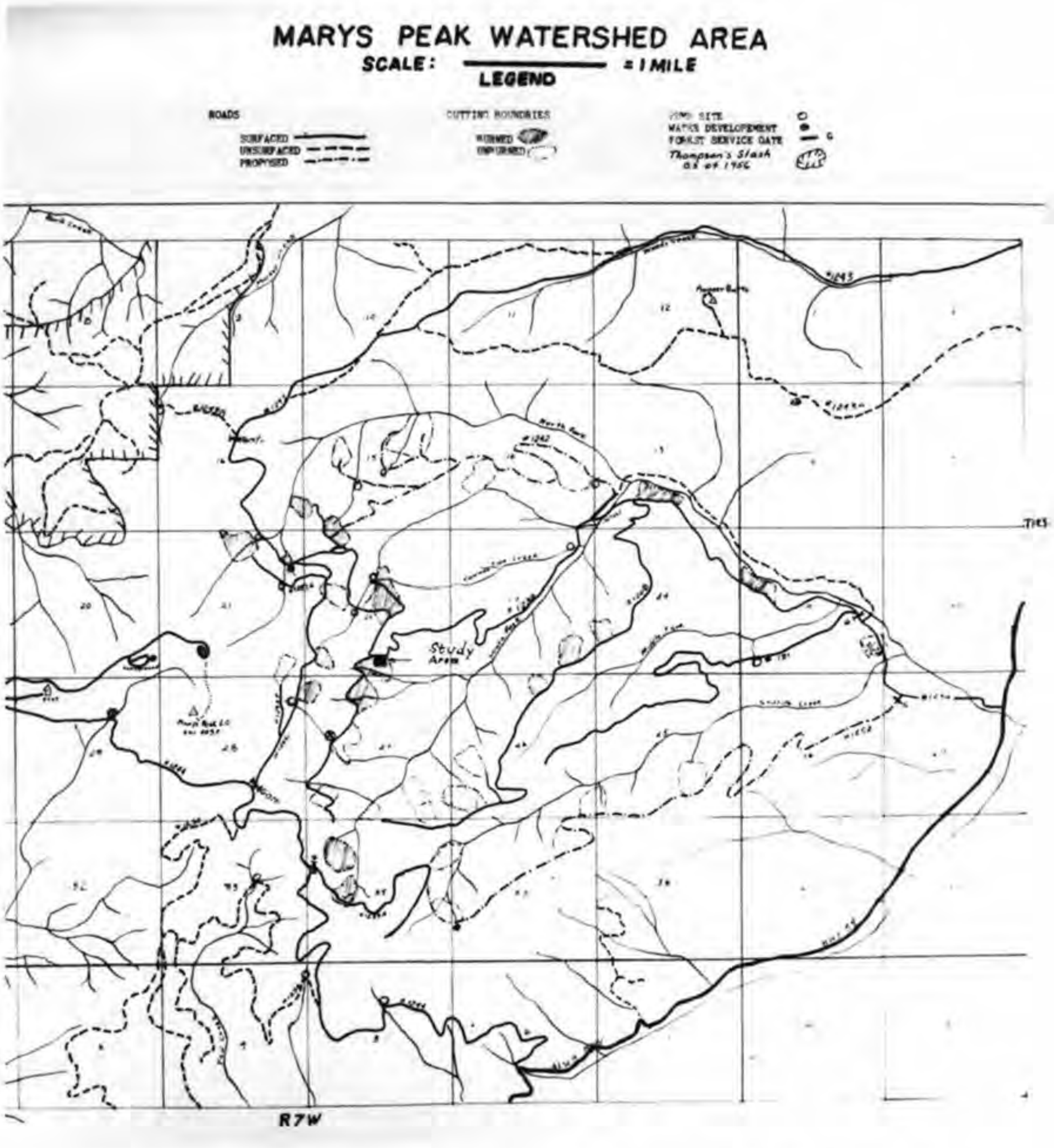


Figure 1. Forest Service map of the Mary's Peak Watershed showing the location of the study area. The map was issued in 1957.

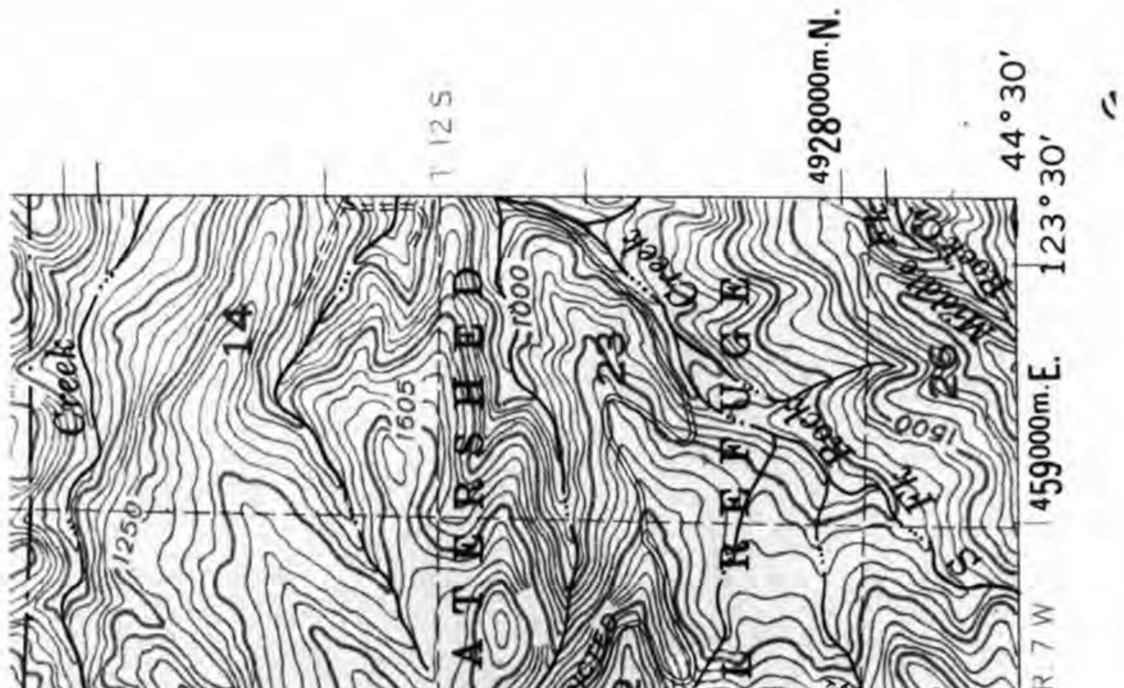


Figure 2. Topographic map of the Mary's Peak Watershed showing the location of the study area. The map was issued in 1956.

Figure 3. View at the study area from the southwest.

A_1 0-15 cm. Dark reddish brown (5YR 3/3, moist)[1/] silt loam; strong, very fine, granular structure; very friable, soft, slightly sticky, slightly plastic; abundant fine interstitial pores; abundant fine spherical concretions; 20 per cent gravel; abundant roots; pH 5.8; lower boundary clear and smooth.

A_3 15-25 cm. Dark reddish brown (5YR 3/4, moist) silt loam; strong, fine, and very fine subangular blocky structure; friable, slightly sticky, slightly plastic; abundant fine and medium interstitial pores with few fine clay flows in pores; 10 per cent gravel; abundant roots; pH 5.4; lower boundary clear and smooth.

B_2 25-90 cm. Dark yellowish red (5YR 3/6, moist) silty clay loam; plastic, slightly sticky and slightly hard; moderate, fine subangular blocky structure; common fine tubular pores; common thin clay flows, both on peds and pores; common fine MnO_2 coatings; common roots; basalt cobbles in lower part of

---

1/ Munsell color notations. Use described in Soil Manual USDA Handbook 18.

horizon; pH 5.2; lower boundary gradual and smooth.

B_3 90-110 cm. Yellowish red (5YR 4/6, moist) silty clay loam; slightly sticky, slightly plastic; moderate, fine subangular blocky structure; common fine tubular pores; few small MnO_2 coatings; 30 to 60 per cent basalt fragments; pH below 5.0.

Data[2] on some of the chemical properties of the A-horizon of this profile are given below.

Organic matter %	Total N %	Available P ppm	Exchangeable K m.e./100 gm.	Exchangeable Ca m.e./100 gm.	Exchangeable Mg m.e./100 gm.	Cation exchange capacity m.e./100 gm.
7.69	0.17	4.05	0.80	7.30	2.60	34.57

2/ The chemical analysis was made by the Oregon State College Soil Testing Laboratory. The data presented are the mean values of two samples.

METHODS AND MATERIALS

Preparation and arrangement of plots

Approximately one quarter of an acre on the previously described area was cleared completely from logging debris and vegetation during fall and winter of 1956. Following the clearing, 90 plots, each one square meter in size, were laid out. The distance between plots was one meter.

Six kinds of seedbeds, mineral soil, charcoal chips three to six millimeters in diameter, hard-burned soil, light-burned soil, litter, and Douglas fir sawdust, were selected for the study. To obtain as good a replication as possible, these seedbeds were prepared by spreading the seedbed materials on top of the existing mineral soil as a layer two and one half centimeters thick (Figure 4). Each of the seedbed materials, except sawdust, was collected from the same source, a nearby recently clear-cut and burned-over area, to keep variations within the seedbed materials at a minimum. The following criteria were used for the collection of seedbed materials:

1) Hard-burned soil - soil transformed by fire to bright red cinders

2) Light-burned soil - soil which had attained a greyish-black color through burning and was mixed with ashes, but whose particles were not baked together

3) Charcoal - thoroughly charred chips from logs and branches

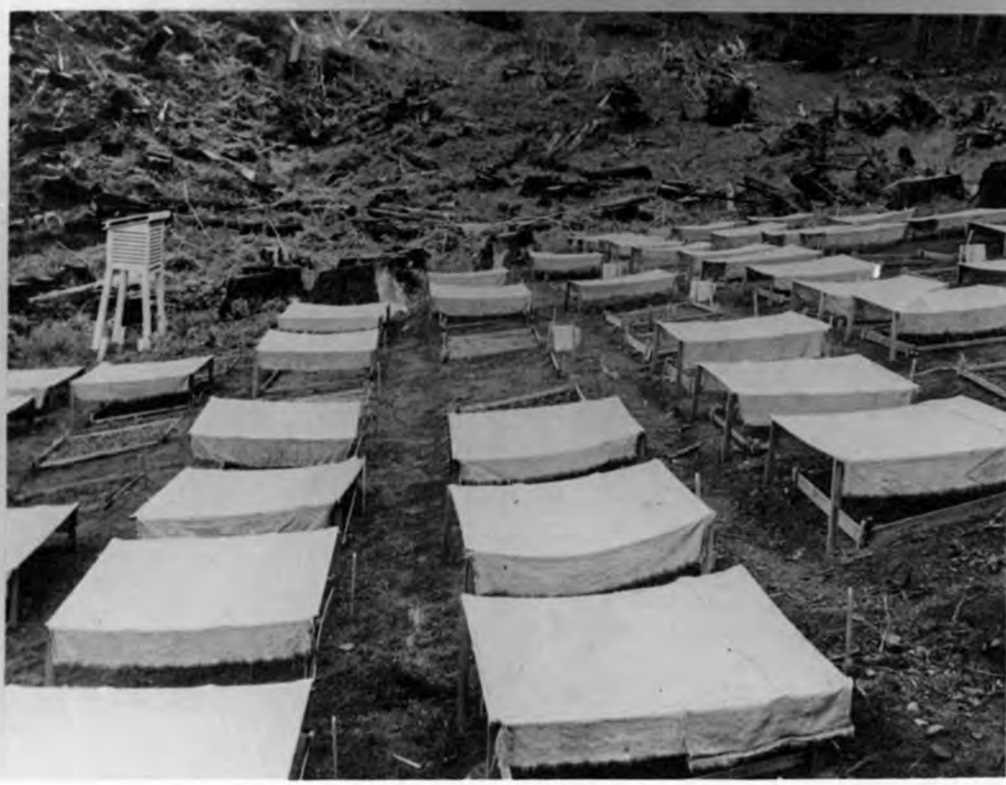
4) Litter - a mixture of unburned small twigs, needles, leaves and dried-up mosses

These materials occupied often very small areas and usually formed a layer not more than one to three inches thick. They were cautiously removed with a trowel to avoid mixing with the underlying mineral soil or adjacent other materials. The sawdust stemmed from recently cut logs. It had a coarse texture and its predominantly light yellowish color suggested that it was derived largely from sapwood. Lath, about four centimeters high, was placed along the four sides of each plot to prevent the seedbed materials from being washed off the plots.

Thirty plots were exposed to full sunlight, another thirty plots to three quarters of full sunlight, and the last thirty plots to one fourth of full sunlight. Decrease in light intensity on the plots was achieved by means of shade frames, 120 by 120 centimeters wide, which were placed 30 centimeters above the plots (Figure 5). To obtain a reduction in light intensity to three quarters that of full sunlight, two layers of cheesecloth were stapled on a lath-frame, and to get a reduction to one fourth that of full sunlight one layer of burlap was used. All light intensities were determined with a Weston Photronic Foot-candle Meter, Model 614. All frames

Figure 4. View of the study area just after the seedbed materials had been spread onto the plots. The squares, noticeable in the centers of some plots in this picture, are spots left free to bury soil moisture blocks. After the soil moisture blocks had been installed, these spots were also covered.

Figure 5. The shade frames shown in this picture were used to reduce light intensity on the plots to 1/4 and to 3/4 that of full sunlight. The color contrast is not sharp enough to distinguish between burlap and cheesecloth covers in this picture.



extended twelve centimeters beyond the south side of each shaded plot and had flaps on the east and west sides to prevent insolation from the sides.

The 90 plots were divided into five blocks of 18 plots each for the purpose of statistical analysis. Each block contained three plots with each of the six seedbed materials. Of the three plots with the same seedbed material within each block, one was exposed to full sunlight, one to 75 per cent of full sunlight, and one to 25 per cent of full sunlight. Thus the following arrangement was replicated five times:

Percentage of full sunlight	Mineral Soil	Charcoal Chips	Hard-burned Soil	Light-burned Soil	Litter	Sawdust
100	1	1	1	1	1	1
75	1	1	1	1	1	1
25	1	1	1	1	1	1
	3	3	3	3	3	3

Assignment of seedbed materials and shade frames to the plots was made by means of random number tables.

All plots were continuously weeded throughout the duration of the study to keep the plots absolutely free from vegetation other than Douglas fir seedlings.

Source of seeds

The seeds used in this study were bonded seeds obtained from the Manning Seed Company. According to the information on the bonding certificate, the seeds were collected from a 20-year old Douglas fir stand in Washington County, Oregon. The exact location of this stand was given as a southeast slope at an elevation of about 900 feet in T. 3 N., R. 5 W., Section 4.

Seeding procedure

On March 30, 1957, 400 seeds that had been stratified for two weeks at $35^{\circ}F$ were sown on each plot. Because of excessive seed and seedling losses during 1957, each plot was reseeded with 500 unstratified seeds on January 3, 1958. The seeds were broadcast on all plots and no attempts were made to press the seeds into the soil or to cover them with the seedbed materials.

Recording of germination and mortality

Emergence of seedlings was recorded every two weeks from the beginning of germination until July. Emerged seedlings were marked by means of colored toothpicks placed on the north side of each seedling.

A count of killed seedlings was made twice each month from April until November. Killed seedlings were extracted from the soil and examined for the cause of death. The principal causes of death and the criteria for the determination of each were:

1) Heat - presence of lesions and/or constrictions on the stem.
2) Frost - glassy appearance of the stem and loss of turgor of needles.
3) Damping off - presence of a bluish-greenish tinge on the stem and loss of turgor of needles. Dead seedlings having such an appearance were collected and taken into the laboratory for identification of the fungi which had infected the seedlings.
4) Drought - drying and discoloration of seedlings without any external signs of injury.
5) Biotic agents - clipping of the cotyledons or, in older seedlings, removal of the top by cutting or chewing.

Cases where the cause of death could not be determined were recorded as "unknown".

Recording of growth characteristics of seedlings

The heights of all living, undamaged seedlings on all plots were measured twice a year, in the middle of

July and in the middle of September. The height of each seedling was recorded as the distance in centimeters from the soil surface to the top of the leader.

After the setting of terminal buds had begun, the number of seedlings that had set buds was recorded every week.

At the end of the growing season, five seedlings from each of the 18 plots in Block III were removed from the soil to examine their root systems.

Determination of air and soil temperature

A standard weather shelter was erected at the southwest corner of the study area. A Taylor two-pen recording thermometer was installed in the shelter for measuring air temperature at 150 centimeters above the ground and for measuring soil temperature at 10 centimeters below the surface of bare mineral soil.

Four Tempscribe temperature recorders were placed along a diagonal from the northwest to the southeast corner of the study area to record air temperature at 2.5 centimeters above the ground. Four Auto-Lite Model 1000 recorders with extension bulbs were installed to measure soil temperature 5 centimeters below the surface of the following kinds of seedbeds: charcoal, litter, hard-burned soil, and mineral soil. Both the Tempscribe and Auto-Lite recorders were placed in white-painted cardboard containers which had slits to allow sufficient air circulation.

Mercury-in-glass type maximum thermometers were placed on the surface of all plots and read once a week. Thermocouples made of copper and constantan wire were installed at the surface and at depths of 2.5, 7.5, 12.5, and 17.5 centimeters on six unshaded plots. Each of these plots was covered by one of the six seedbed materials used in this study. Temperature measurements extending over a whole day were made several times during the growing season with a portable Brown Potentiometer, Model 126 W2P.

<u>Determination of precipitation and soil moisture</u>

Precipitation was measured with a standard U. S. Weather Bureau rain gage which was installed at the southwest corner of the study area. Soil moisture was determined by means of Bouyoucos-type plaster of paris blocks buried 5 and 15 centimeters deep on all plots. Resistance measurements were taken every two weeks with a Coleman Soil Moisture Meter, Model 300, and the resistance readings converted into soil moisture percentages and soil moisture tensions. The moisture percentage at tensions of 1/10, 1/2, 1, and 15 atmospheres was determined by the Oregon State College Soil Testing Laboratory on pressure membrane equipment.

Protective measures for the experimental area

To provide some degree of protection from rodents a 50-foot wide strip around the study area was baited with poisoned grain and two dozen mousetraps were installed in this strip. The Douglas fir seeds that were broadcasted onto the plots were coated with a rodenticide, endrine, previous to seeding.

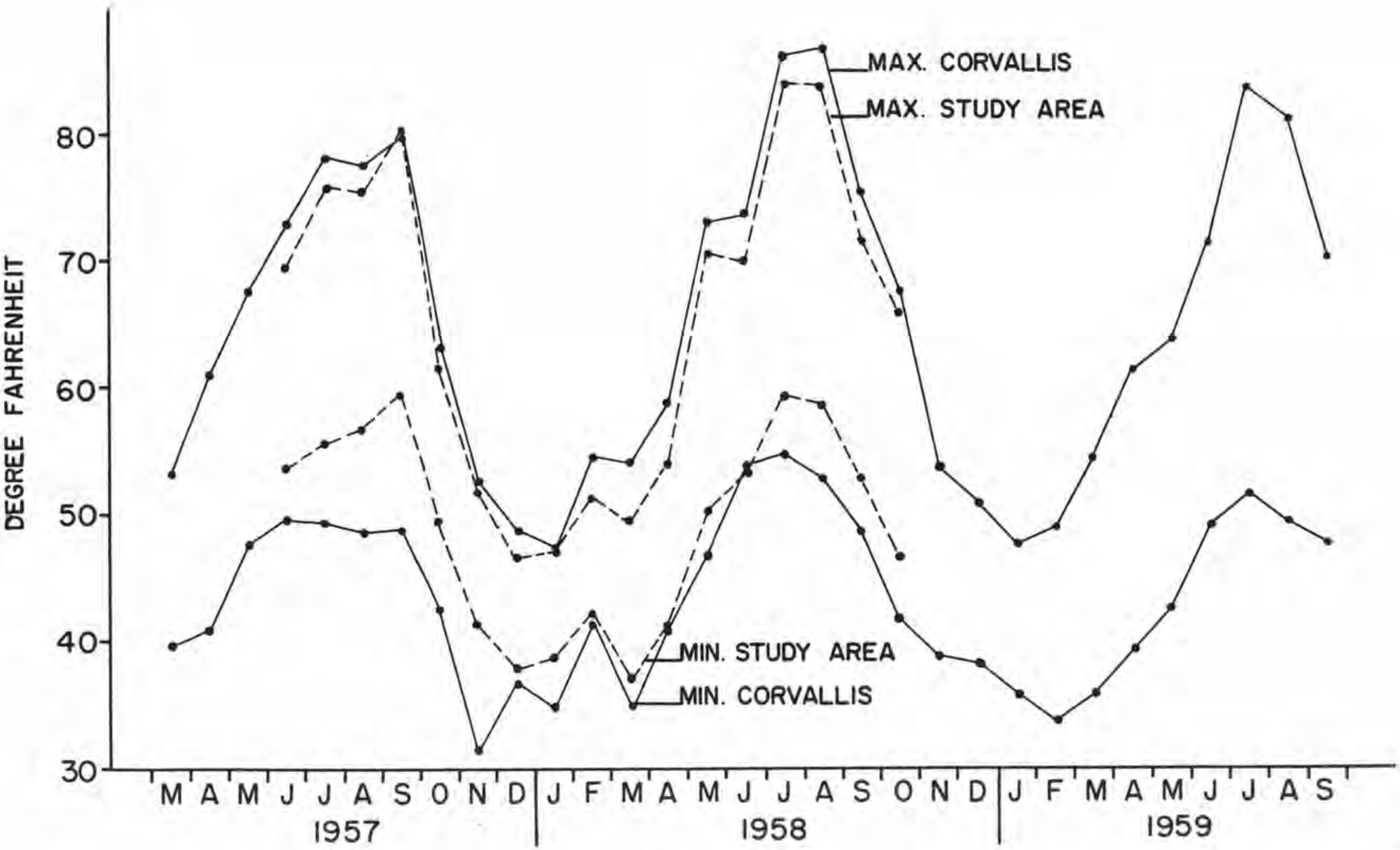
CLIMATIC CONDITIONS

Air temperatures

Air temperatures 150 centimeters above the ground were recorded continuously in the study area from June 1, 1957 to October 31, 1958. The daily maxima and minima for this period are compiled in Table 1 in the Appendix. The seasonal course of temperature in the study area and at Corvallis is illustrated by the average monthly maxima and minima in Figure 6. A comparison of the values from the study area and from Corvallis shows that temperatures at the study area have a much narrower amplitude than those at Corvallis, the maxima being lower and the minima higher at the study area. However, the trend of temperatures is the same for both locations and, keeping the differences in mind, the data from Corvallis can be used to draw a general picture of the course of temperatures at the study area during the time for which records are not available.

The course of temperatures during the growing season was quite different in each of the three years during which the study was conducted. The summer of 1957 was relatively cool until September which was unusually warm. According to the U. S. Weather Bureau (123) such a warm September in western Oregon occurred only eight times in the past 67 years. Very high temperatures were attained

Figure 6. Average monthly maximum and minimum temperatures 150 centimeters above the ground in the study area and at Corvallis.


MAX. CORVALLIS
MAX. STUDY AREA
MIN. STUDY AREA
MIN. CORVALLIS
DEGREE FAHRENHEIT
30
40
50
60
70
80
M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S
1957
1958
1959

during a large part of the 1958 growing season. Temperatures in the months of May to August rose higher than during the corresponding period in either the 1957 or 1959 growing season. The warm weather continued through September and into the first half of October. The spring of 1959 was much cooler than that of the two preceding years. Temperatures in July and August were higher than during the same months in 1957 but remained below the record high of 1958.

Temperatures higher than 80°F were reached on 18 days in June, July, and August 1957 (Table 1). The same months in 1958 had almost three times as many days with temperatures above 80°F. The highest temperature, 102°F, was recorded on July 27, 1958.

The winter 1957/58 was one of the mildest in Oregon since the beginning of an organized collection of weather records. Freezing temperatures were recorded once during this winter at the study area, namely on January 7, 1958. The only other time when frost occurred was on March 5 and 6, 1958. The winter 1958/59 was colder than the preceding one but records of the numbers of days with freezing temperatures in the study area during this period were not obtained.

Air temperatures at 2.5 centimeters above the ground were recorded concurrently with the temperatures at a

Table 1. Numbers of days with temperatures above 80°F in the years 1957 to 1959.

	Study Area	Corvallis
	1957	
May	No records	4
June	1	5
July	10	14
August	7	9
September	17	16
	1958	
May	6	6
June	6	7
July	23	26
August	24	28
September	6	7
	1959	
May	No records	2
June	"	4
July	"	20
August	"	17
September	"	3

height of 150 centimeters. The results of these measurements (Table 2, Appendix) show clearly the influence of the ground on air temperatures in its immediate vicinity. From May to August 1958 temperatures recorded at 2.5 centimeters height exceeded 100°F on 20 days but temperatures at 150 centimeters remained below 100°F except for one day (Table 1, Appendix). Frost prevailed at 2.5 centimeters above the ground on March 11, 12, and 14, 1958 while temperatures at 150 centimeters did not drop below freezing during these days. The average monthly maxima and minima of temperatures at the two levels of measurement (Figure 7) illustrate clearly the more extreme temperatures in the lower layer of air. Throughout the whole year the temperatures at 2.5 centimeters have a greater amplitude than at 150 centimeters above the ground although the differences are most pronounced during the summer.

The daily maxima were reached almost simultaneously at both heights so that the difference in time could not be determined accurately from the temperature charts. The same was true for the daily minima. The daily maxima were usually attained between 1 P.M. and 3 P.M. while the minima occurred mostly between 4 A.M. and 7 A.M. Examination of the temperature charts showed, however, that the downward course of temperatures towards the minimum was sometimes interrupted during the night by a sudden temperature rise. Usually, this increase of temperature began around midnight, reached its peak at about 2 A.M. to be followed by a new decline. A few instances were noted when the decrease of temperature was interrupted several hours before midnight. The temperature course at 150 centimeters above the ground on three days when this phenomenon was very distinct is given in Figure 8. On

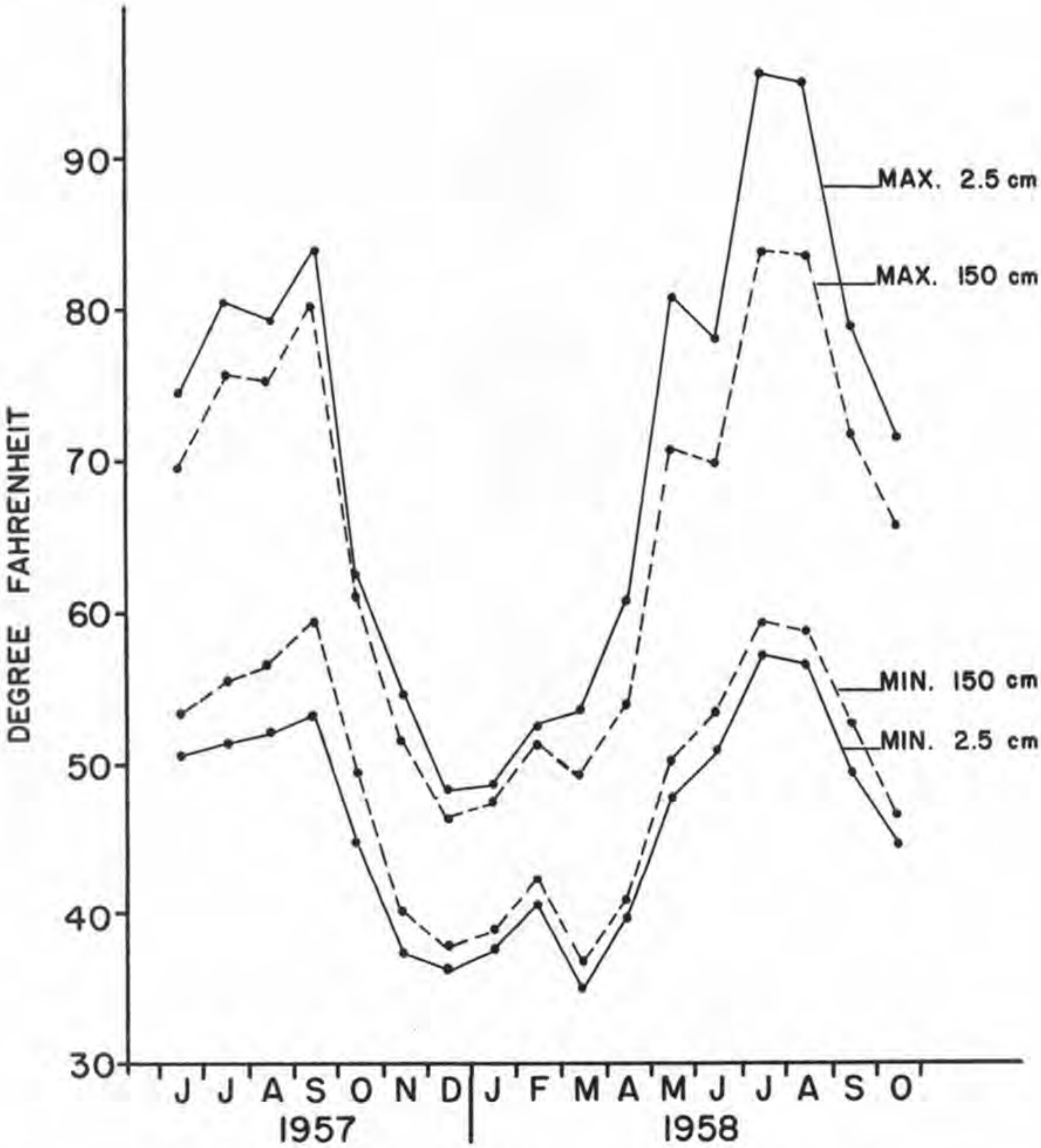
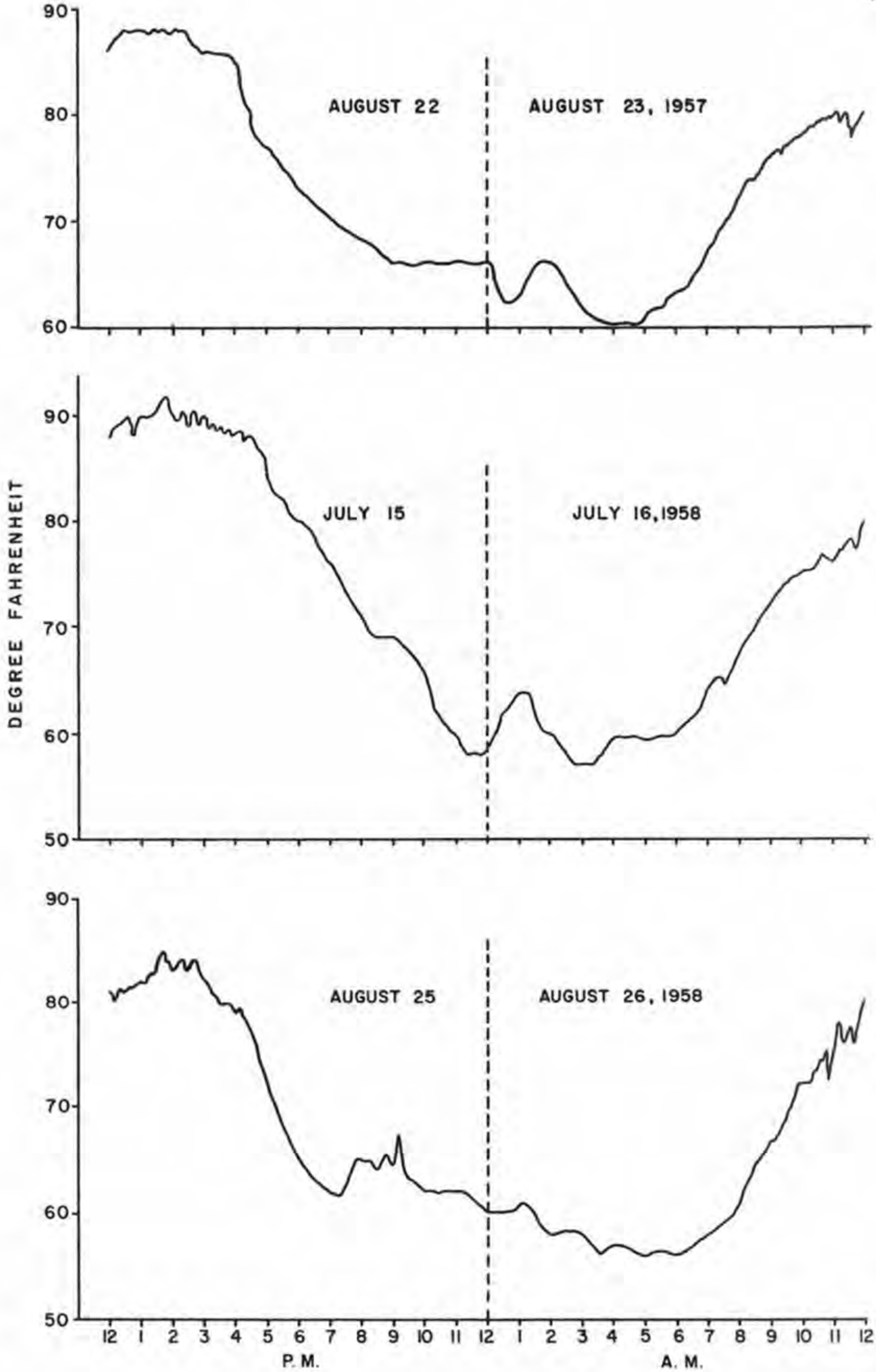


Figure 7. Average monthly maximum and minimum temperatures 150 centimeters and 2.5 centimeters above the ground in the study area.

Figure 8. Examples of nocturnal temperature rises in the study area. The temperatures were recorded 150 centimeters above the ground.


AUGUST 22
AUGUST 23, 1957
JULY 15
JULY 16, 1958
AUGUST 25
AUGUST 26, 1958
DEGREE FAHRENHEIT
90
80
70
60
50
12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
P. M.
A. M.

August 22, 1957 the temperature stayed around 86°F until 4 P.M. when it dropped sharply until it reached 66°F at 9 P.M. For about three hours it remained at this level and then after midnight it began to drop again. After falling to 62°F, the temperature started to rise again at 12:40 A.M. and at 2 A.M. stood at 66°F. The temperature fell again and reached its minimum of 60°F at 4 A.M. The course of temperature during the night of July 15/16, 1958 is similar to that in the first example, except that in the latter case the temperature dropped steadily until midnight. The following temperature rise was also somewhat steeper than that on August 23, 1957. The temperature curve for the night of August 25/26, 1958 depicts an instance where the decrease of temperature was interrupted several hours before midnight. Nocturnal rises of temperature were observed in all months during which temperature records were obtained (Table 2).

Temperatures on the surface of seedbeds

The weekly maximum temperatures on the surface of each seedbed material were recorded with mercury thermometers from the third week of April 1957 until the last week of September 1958 (Table 3, Appendix). As was to be expected, appreciable differences in maximum surface

Table 2. Numbers of nights with nocturnal temperature rise in the months June 1957 to October 1958.

	1957	1958
January	No record	8
February	"	4
March	"	4
April	"	6
May	"	11
June	3	3
July	12	8
August	11	11
September	7	4
October	9	6
November	11	No record
December	6	"

temperatures were found between the fully exposed, lightly shaded, and heavily shaded seedbeds.

Heavily shaded seedbeds were those on which the light intensity was reduced by burlap covers to 25 per cent of the intensity of full sunlight. During the 1957 growing season, temperatures of surfaces thus shaded did not at any time exceed 110°F and the temperature differences between the six seedbed materials were very small; they varied mostly between 1°F and 4°F. Temperatures between 110°F and 120°F were recorded in eleven weeks during the 1958 growing season. The highest temperature, 122°F, was recorded on charcoal in the week of July 20 to 26. The temperature differences between the seedbed materials were slightly larger than in 1957 but values were not consistently higher or lower on any of the materials.

Seedbeds on which the light intensity was reduced by cheesecloth covers to 75 per cent of full sunlight are referred to as lightly shaded. Although the light shade provided by cheesecloth prevented excessive heating of the seedbeds, their surfaces frequently reached temperatures of 125°F and higher, temperatures which are considered as critical to seedling survival. Due to the fact that April, the first half of May, and September 1957 were warmer than the corresponding periods in the following year, seedbeds reached temperatures in excess of 125°F during more weeks in 1957 than in 1958 (Table 3). In both years critical temperatures were recorded most frequently on charcoal and litter. Differences between the maximum surface temperatures of the six seedbed materials were seldom larger than 6°F (Table 3, Appendix).

Turning now to the fully exposed seedbeds, it is hardly surprising that the highest maximum temperatures were measured on their surfaces. Temperatures between 130°F and 150°F were recorded on unshaded seedbeds in 23 out of the 24 weeks between April 14 and September 28, 1957. May 5 to 11 was the only week when temperatures on all seedbeds remained below 130°F. In 1958, it was

Table 3. Numbers of weeks during 1957 and 1958 when maximum temperatures exceeded 125°F on seedbeds shaded by cheesecloth.

Degrees Fahrenheit:	125-129	130-134	135-139	140-144	Total weeks
			1957		
Charcoal	5	14	3	-	22
Hard Burn	6	5	-	-	11
Light Burn	6	9	2	-	17
Mineral Soil	8	9	-	-	17
Litter	9	10	3	-	22
Sawdust	4	5	-	-	9
			1958		
Charcoal	2	7	3	1	13
Hard Burn	7	2	-	-	9
Light Burn	4	5	1	1	11
Mineral Soil	7	3	1	-	11
Litter	6	5	1	1	13
Sawdust	9	1	1	-	11

not until the end of April, two weeks later than in the preceding year, that temperatures in excess of 130°F were recorded. In the last week of May and the first week of June, temperatures on all surfaces remained below 120°F. During the second and fourth week of June temperatures exceeded 130°F except on sawdust and hard-burned soil. In the week of June 15 to 21, and in ten consecutive weeks from June 29 to September 6, temperatures between 140°F and 160°F were recorded on all seedbeds. In 1957, temperatures in excess of 130°F were reached over a longer period of time than in 1958 (Table 4), but the data indicate also that the temperatures recorded in 1958 were often considerably higher than those measured in the preceding year.

The highest temperatures were measured on charcoal and litter while temperatures recorded on mineral soil and light-burned soil were usually 1 to 5 degrees lower than those of the first mentioned materials. The temperatures on hard-burned soil and sawdust were the lowest ones measured. Arrangement of the seedbed materials in order of decreasing temperatures is somewhat arbitrary because the temperature differences between the seedbed materials were not always consistent. The only exception was sawdust which always had considerably lower temperatures than the other materials.

The records of weekly maximum temperatures on the seedbeds indicate those weeks during which critical temperatures were attained, but they cannot provide information on how fast and for how long seedbeds are warmed up to a certain temperature level. In order to obtain a picture of the daily course of temperature on the seedbed

Table 4. Numbers of weeks during 1957 and 1958 when maximum temperatures exceeded 130°F on unshaded seedbeds.

Degrees Fahrenheit:	130-134	135-139	140-144	145-149	150-154	155-159	160-164	Total weeks
				1957				
Charcoal	1	3	10	9	-	-	-	23
Hard Burn	8	12	2	-	-	-	-	22
Light Burn	1	3	14	4	-	-	-	22
Mineral Soil	2	6	12	2	-	-	-	22
Litter	2	-	7	11	3	-	-	23
Sawdust	11	7	1	-	-	-	-	19
				1958				
Charcoal	4	1	2	-	7	4	1	19
Hard Burn	-	2	4	5	1	1	-	13
Light Burn	2	2	1	2	8	-	1	16
Mineral Soil	3	1	1	4	6	-	1	16
Litter	1	1	3	-	5	6	1	17
Sawdust	1	2	8	3	-	-	-	14

materials, thermocouple measurements were made on several days in July and August 1958. Reading of a mercury maximum thermometer was taken simultaneously with each thermocouple measurement. Figures 9 and 10 contain the data which were obtained on August 13, 1958. The day was bright and cloudless but had intermittent periods of strong westerly winds. The sun reached the experimental area at 7:45 A.M. and left it by 5:05 P.M. The measurements were begun at 7:45 and continued until 5:20 P.M. Temperatures on the surface of each seedbed material were recorded in intervals of approximately 15 minutes. The seedbeds showed no sign of dew when the measurements were commenced. The temperatures rose about 30°F on the seedbeds during the first hour after the sun had reached the area. By 9 A.M. all seedbeds had attained temperatures of 100°F. Temperatures continued to climb steadily until noon. By this time charcoal had reached 140°F, sawdust 130°F, and the other materials 135°F to 136°F. From noon to 3 P.M. temperatures rose and fell within a range of six to eight degrees. During this period the temperature of mineral soil rose to 143°F, thereby surpassing the temperature of charcoal. Beginning at about 3 P.M. temperatures started to decline, first gradually and then more abruptly, and were below 100°F on all seedbeds by 5 P.M. Each seedbed material, except mineral soil, reached the maximum

Figure 9. Surface temperatures recorded with thermocouples and maximum thermometers on mineral soil, charcoal, and sawdust. Measurements were made at 15-minute intervals on August 13, 1958. The temperature 150 centimeters above the ground was recorded by a Taylor temperature recorder in the weather shelter.

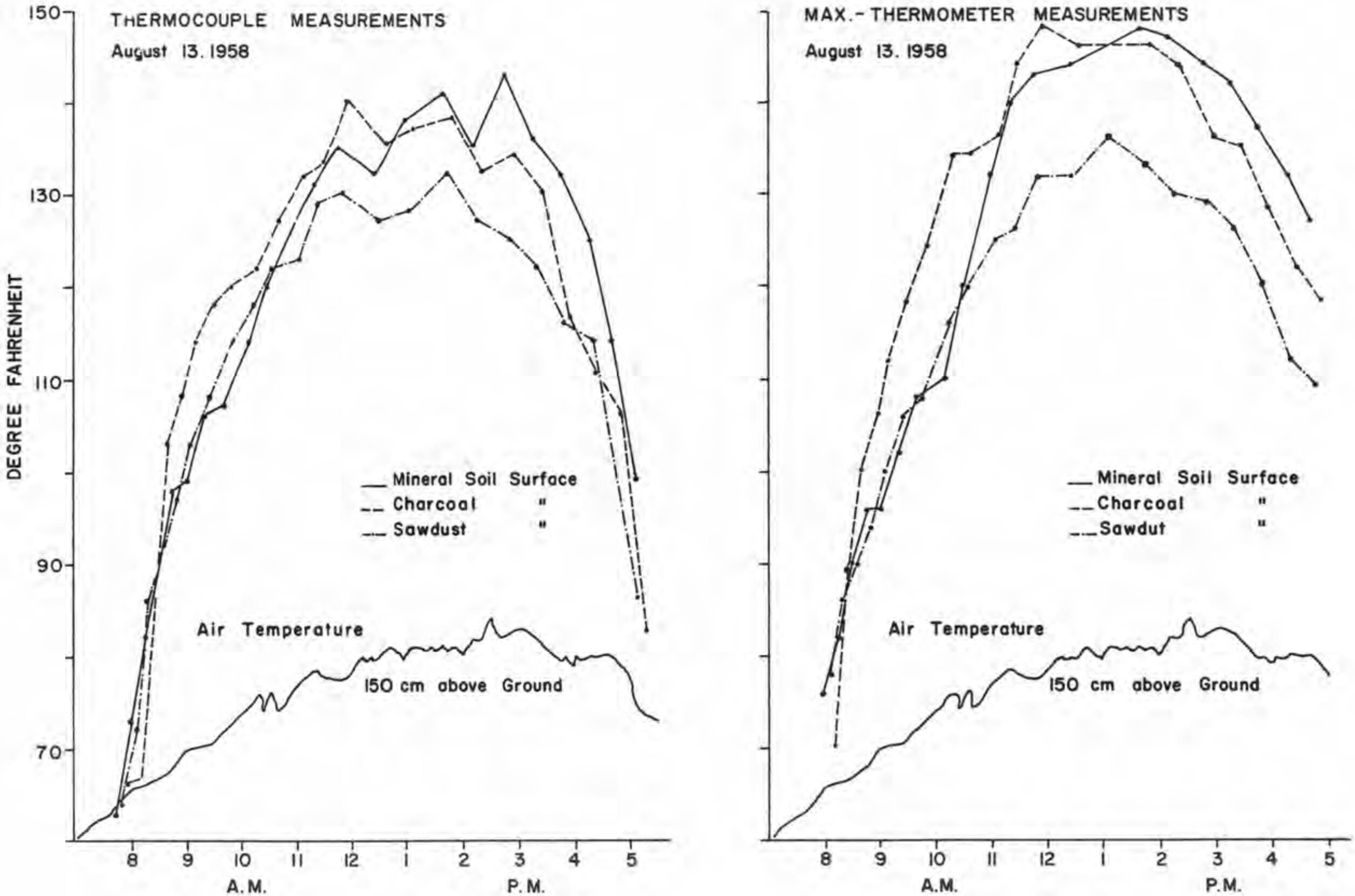
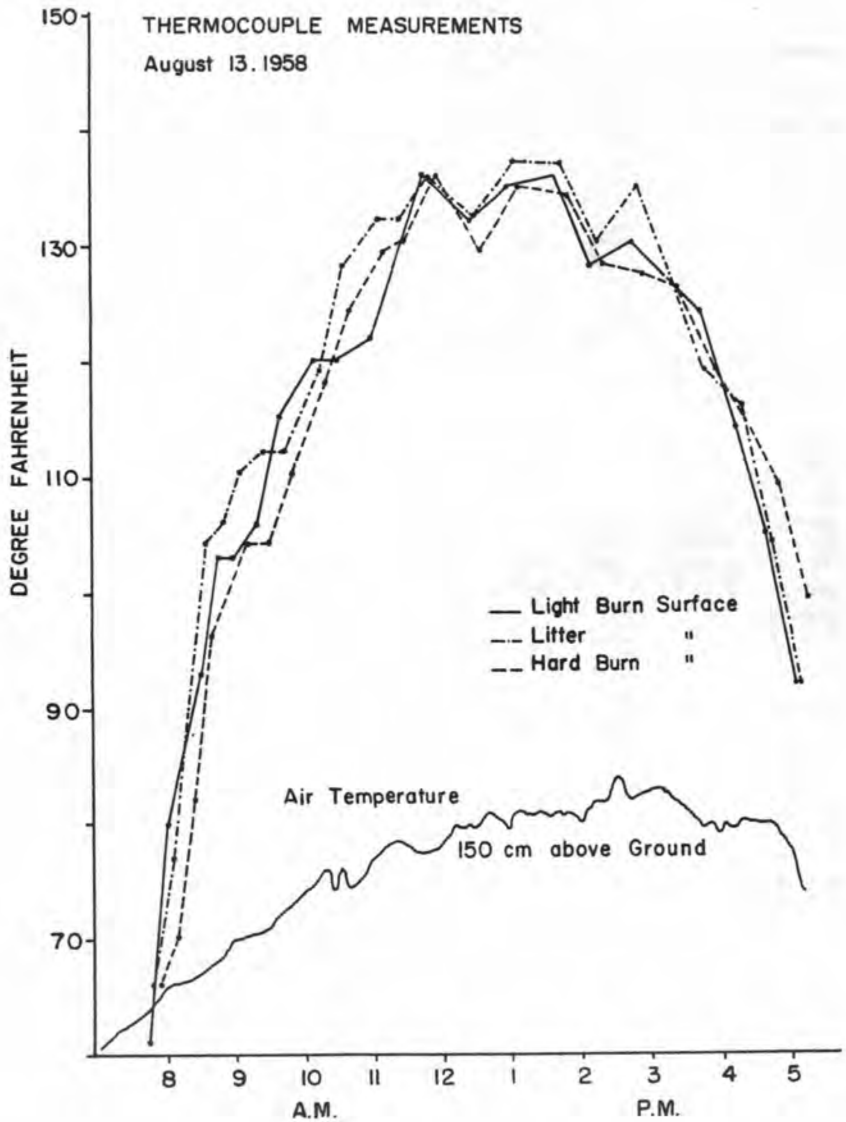
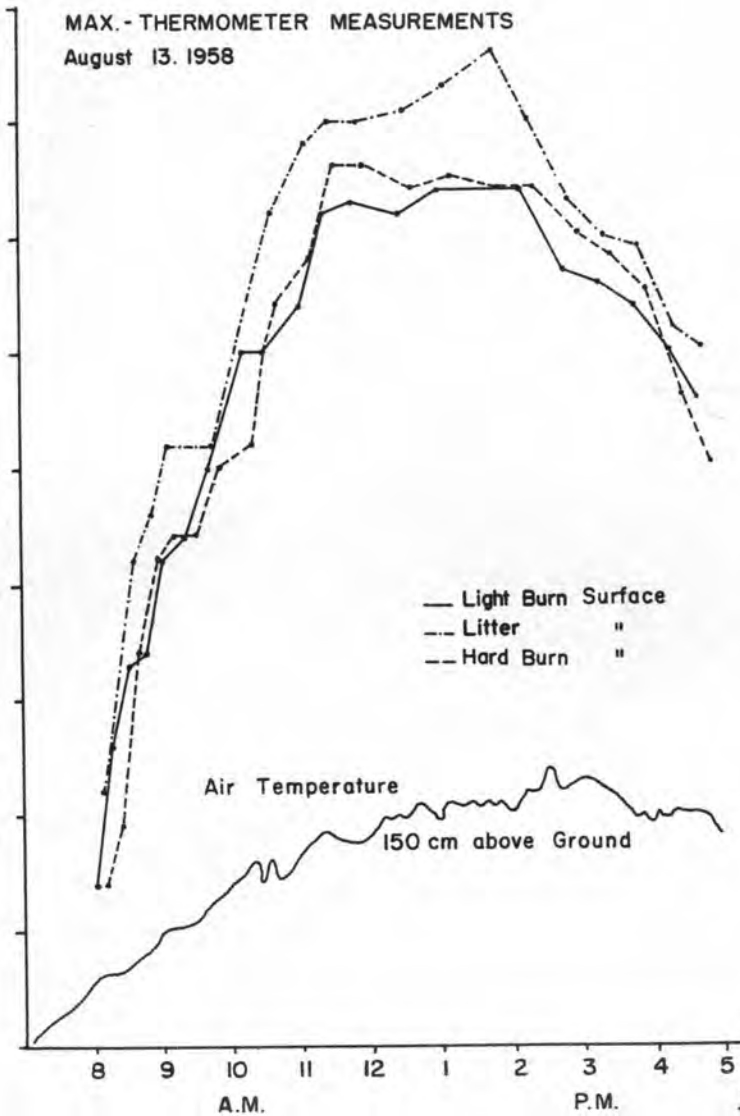

THERMOCOUPLE MEASUREMENTS
August 13. 1958
DEGREE FAHRENHEIT
150
130
110
90
70
Mineral Soil Surface
Charcoal "
Sawdust "
Air Temperature
150 cm above Ground
8 9 10 11 12 1 2 3 4 5
A.M.
P.M.
MAX.- THERMOMETER MEASUREMENTS
August 13. 1958
Mineral Soil Surface
Charcoal "
Sawdut "
Air Temperature
150 cm above Ground
8 9 10 11 12 1 2 3 4 5
A.M.
P.M.

Figure 10. Surface temperatures recorded with thermocouples and maximum thermometers on light-burned soil, hard-burned soil, and litter. Measurements were made at 15-minute intervals on August 13, 1958. The temperature 150 centimeters above the ground was recorded by a Taylor temperature recorder in the weather shelter.


THERMOCOUPLE MEASUREMENTS
August 13. 1958
DEGREE FAHRENHEIT
150
130
110
90
70
Light Burn Surface
Litter "
Hard Burn "
Air Temperature
150 cm above Ground
8 9 10 11 12 1 2 3 4 5
A.M.
P.M.


MAX.-THERMOMETER MEASUREMENTS
August 13. 1958
Light Burn Surface
Litter "
Hard Burn "
Air Temperature
150 cm above Ground
8 9 10 11 12 1 2 3 4 5
A.M.
P.M.

temperature before the air attained its maximum temperature of 84°F at 2:30 P.M. Although the temperatures of charcoal and litter rose faster until 10 A.M. than those of the other materials, temperature differences between all materials were surprisingly small by noon. Sawdust was the only seedbed which remained considerably cooler than the other seedbeds.

Temperatures recorded during measurements on July 28 (Tables 4-9, Appendix), August 6 (Figure 11; Tables 4-9, Appendix), and August 20 (Tables 4-9, Appendix) were approximately eight to ten degrees higher on each seedbed than on August 13. By examining the data from all measurements the great variability of temperature differences between the six seedbed materials becomes apparent. This makes it difficult to place the seedbed materials into a definite order with regard to their heatability. Nevertheless, the seedbeds may be divided into three broad groups on the basis of the recorded data. The first group is comprised of charcoal, litter, and mineral soil. These three materials reached the highest temperatures, and temperatures critical for seedling survival were maintained for a considerably longer time than on the other seedbeds. The temperatures of light-burned and hard-burned soil approached closely sometimes, as on August 13, those of the first group, but the duration of critical

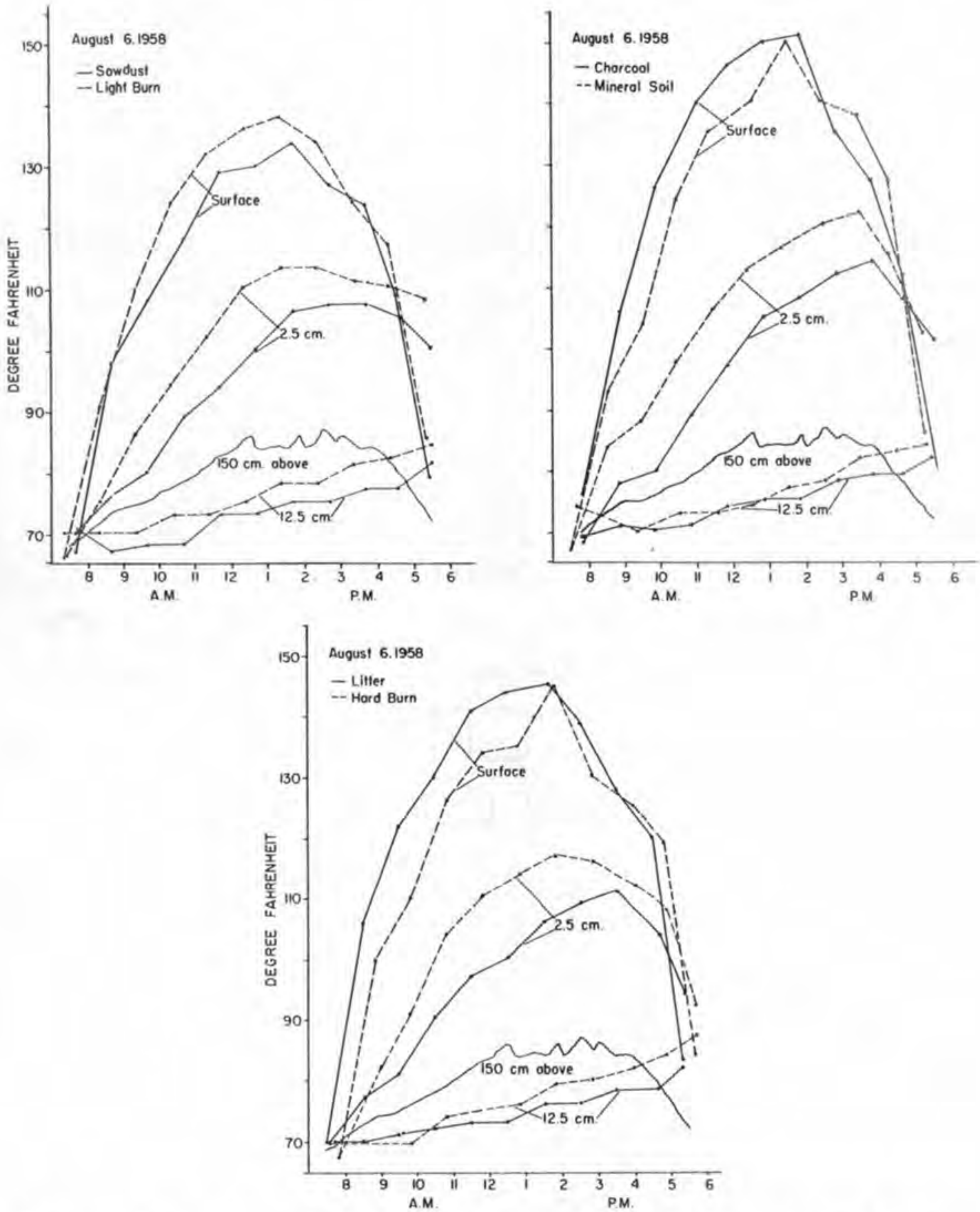


Figure 11. Course of temperatures on the surface of six seedbed materials, at 2.5 and 12.5 centimeters depths under each material, and at 150 centimeters above the ground.

temperatures was always shorter. Sawdust was consistently the coolest material and the duration of critical temperatures was always shortest.

The simultaneous measurements of temperatures with thermocouples and mercury maximum thermometers yielded interesting results (Table 5). The temperatures obtained with the mercury thermometer were usually several degrees higher than those measured with the thermocouples. A few times the thermometers gave lower readings than the thermocouples. However, temperatures obtained with the thermometer in the late afternoon were always higher than those obtained with the thermocouples. This difference was most pronounced during the time when the sun left the plots. The differences between thermocouple and thermometer readings on August 13 are illustrated by Figures 9 and 10. On this day the thermometer gave frequently lower readings than the thermocouple, especially in the forenoon. In the afternoon, however, the thermometer gave mostly higher readings than the thermocouple. The temperature curves for each seedbed drawn from thermometer data are more even and further apart than those constructed from thermocouple data.

Time	Mineral Soil			Light-burned Soil			Hard-burned Soil			Charcoal			Litter			Sawdust		
	Thermocouple	Mercury Thermometer	Difference	Thermocouple	Mercury Thermometer	Difference	Thermocouple	Mercury Thermometer	Difference	Thermocouple	Mercury Thermometer	Difference	Thermocouple	Mercury Thermometer	Difference	Thermocouple	Mercury Thermometer	Difference
							July 28, 1958											
9:50 - 10:45 AM	129	135	+ 6	108	116	+ 8	110	126	+16	130	138	- 8	117	422	+ 5	110	118	+ 8
11:00 - 11:35	145	148	+ 3	135	138	+ 3	130	140	+10	150	150	0	133	150	+17	123	133	+10
11:50 - 12:25	148	154	+ 6	136	142	+ 6	141	146	+ 5	153	152	- 1	151	158	+ 7	137	141	+ 4
12:50 - 1:30 PM	154	156	+ 2	142	142	0	145	149	+ 4	158	157	- 1	150	158	+ 8	139	142	+ 3
2:00 - 2:40	145	156	+ 8	144	143	- 1	148	149	+ 1	154	157	- 3	146	158	+12	147	142	- 5
3:00 - 3:45	138	150	+12	148	146	- 2	133	149	+16	130	157	-27	152	158	+ 6	132	142	+10
							August 6, 1958											
8:20 - 8:55 AM	93	90	- 3	91	92	+ 1	100	94	- 6	106	112	- 6	106	104	- 2	98	96	- 2
9:20 - 9:55	104	106	+ 2	110	114	+ 4	110	110	0	126	124	- 2	122	122	0	108	111	+ 3
10:20 - 10:55	124	126	+ 2	124	119	- 5	126	126	0	140	142	- 2	130	136	+ 6	118	128	+10
11:20 - 11:55	135	138	+ 3	132	130	- 2	134	135	+ 1	146	152	- 6	141	148	+ 7	129	140	+11
12:20 - 12:55 PM	140	144	+ 4	136	136	0	135	142	+ 7	150	152	- 2	144	152	+ 8	130	144	+14
1:20 - 1:55	150	150	0	138	142	+ 4	145	142	- 3	151	152	- 1	145	154	+ 9	134	146	+12
2:20 - 2:55	140	150	+10	134	142	+ 8	130	144	+14	135	152	-17	139	154	+15	127	146	+19
							August 20, 1958											
8:10 - 8:34 AM	77	77	0	67	66	- 1	76	77	+ 1	84	84	0	85	74	-11	83	80	- 3
8:53 - 9:24	97	102	+ 5	96	95	- 1	109	100	- 9	106	113	+ 7	108	101	- 7	101	99	- 2
9:50 - 10:17	116	121	+ 5	120	117	- 3	120	116	- 4	123	129	+ 6	116	124	+ 8	117	114	- 3
10:41 - 11:12	130	137	+ 7	127	124	- 3	124	126	+ 2	135	142	+ 7	130	136	+ 6	124	126	+ 2
11:44 - 12:15	145	145	0	130	130	0	140	136	- 4	146	152	+ 6	134	146	+12	136	134	- 2
12:36 - 1:13 PM	148	150	+ 2	139	136	- 3	136	138	+ 2	140	156	+16	144	150	+ 6	134	135	+ 1
1:39 - 2:13	136	152	+16	139	136	+ 3	139	144	+ 5	148	152	+ 4	143	150	+ 7	126	138	+12
3:38 - 4:05	137	146	+ 9	125	136	+11	121	140	+19	116	138	+22	132	142	+10	117	133	+16
4:20 - 4:40	122	138	+16	116	130	+14	114	130	+16	114	121	+ 7	115	132	+17	104	120	+16
5:08 - 5:25	101	128	+27	104	118	+14	88	122	+34	86	112	+26	87	120	+33	83	112	+25

Table 5. Comparison of temperatures recorded by thermocouples and by mercury thermometers on the surface of six seedbed materials. All temperatures are given in degrees Fahrenheit. The column "Differences" indicates degrees Fahrenheit by which the readings of thermometers were higher or lower than those of the thermocouples.

Soil temperatures

The temperatures at a depth of 5 centimeters and 10 centimeters in mineral soil, and temperatures in the soil 5 centimeters below the surface of hard-burned soil, charcoal, and litter were recorded continuously from July 1, 1957 until September 31, 1958. Average monthly maximum and minimum temperatures show that charcoal and litter are very effective insulators (Table 6).

Hard-burned soil on the other hand appears to be a good heat conductor, but less so than mineral soil. The temperatures at 10 centimeters depth in mineral soil (Table 10, Appendix) are about of the same magnitude as those at 5 centimeters under a cover of litter or charcoal. The moderating effect of litter and charcoal on temperatures in the soil beneath them became especially evident in the warmest months of the 1957 and 1958 growing season. The temperature maxima at 5 centimeters depth under a surface of mineral soil (Table 11, Appendix) exceeded 100°F almost every day and frequently reached 110°F during July and August 1958. The daily maxima at the same depth under hard-burned soil (Table 12, Appendix), under charcoal (Table 13, Appendix), and under litter (Table 14, Appendix) were on the average 10, 16, and 18 degrees lower, respectively, during these two

Table 6. Average monthly maxima and minima of soil temperatures under four different seedbed materials, and of air temperatures 150 centimeters above the ground. Temperatures are given in degrees Fahrenheit.

		MS 5 cm below	MS 10 cm below	HB 5 cm below	Li 5 cm below	Char 5 cm below	150 cm above
1957							
Jun	Av.Max.						69.4
	Av.Min.						53.5
Jul	Av.Max.	85.7	73.5	79.1	74.6	75.1	75.9
	Av.Min.	58.1	64.3	56.1	60.5	59.1	55.5
Aug	Av.Max.	89.0	75.1	80.8	77.6	77.7	75.2
	Av.Min.	59.6	64.2	57.9	62.8	61.1	56.6
Sep	Av.Max.	92.3	76.4	82.8	79.3	80.3	80.3
	Av.Min.	61.2	66.1	58.5	64.0	61.9	59.6
Oct	Av.Max.	67.0	59.1	61.4	59.2	60.6	61.4
	Av.Min.	48.5	55.5	46.8	51.7	50.6	49.3
Nov	Av.Max.	59.5	51.7	55.2	51.6	52.9	51.7
	Av.Min.	41.5	46.2	40.6	44.5	50.6	40.1
Dec	Av.Max.	49.3	46.0	46.9	45.4	46.3	46.4
	Av.Min.	39.7	42.5	38.9	41.3	41.8	37.9
1958							
Jan	Av.Max.	49.7	45.5	47.5	44.9	45.7	47.1
	Av.Min.	39.9	42.3	39.9	41.4	42.0	38.6
Feb	Av.Max.	54.0	49.5	52.2	49.1	49.4	51.3
	Av.Min.	43.4	45.2	43.9	45.9	45.7	42.3
Mar	Av.Max.	55.3	48.4	53.2	49.2	49.6	49.0
	Av.Min.	39.1	42.5	39.3	42.2	42.1	36.5
Apr	Av.Max.	64.8	54.3	61.1	56.3	56.8	53.9
	Av.Min.	43.2	47.0	44.1	46.5	45.9	40.9
May	Av.Max.	86.8	69.2	80.6	73.7	74.3	70.4
	Av.Min.	55.3	61.2	55.5	59.8	58.5	50.1

Table 6. (Cont'd)

		MS 5 cm below	MS 10 cm below	HB 5 cm below	Li 5 cm below	Char 5 cm below	150 cm above
1958							
Jun	Av.Max.	83.8	68.1	78.2	74.6	74.3	69.9
	Av.Min.	58.9	62.9	58.1	63.0	61.0	53.3
Jul	Av.Max.	106.0	87.3	96.3	87.9	90.0	83.9
	Av.Min.	67.5	72.5	66.2	72.2	68.9	59.3
Aug	Av.Max.	105.1	88.4	94.9	87.5	91.2	83.7
	Av.Min.	66.9	74.3	64.9	72.9	68.2	58.8
Sep	Av.Max.	82.9	74.0	76.4	73.2	73.9	71.4
	Av.Min.	57.1	63.1	55.2	62.8	58.6	52.9

months. The daily amplitude of temperatures at 5 centimeters depth under litter and charcoal was also considerably narrower than at this depth under hard-burned soil and mineral soil, the maxima being lower and the minima being higher under hard-burned soil and mineral soil. Thermocouple measurements of the temperatures at 2.5, 7.5, 12.5, and 17.5 centimeters depths under the surfaces of each of the six seedbed materials were made in July and August 1958. The purpose of these measurements was to learn to what depth soil temperatures are influenced by the nature of the surface. Temperatures differed markedly to a depth of 7.5 centimeters under each of the seedbed materials (Tables 4-9, Appendix). The differences were still clearly noticeable at 12.5 centimeters in the ground but ceased to be distinct at a depth of 17.5 centimeters. The course of temperatures on August 6, 1958 at 2.5 and 12.5 centimeters depth provides a good example of the contrast between temperatures under the well-insulating materials, litter, charcoal, and sawdust, and the well-conducting materials, hard-burned, light-burned, and mineral soil (Figure 11). The course of temperatures on August 6 illustrates not only the extent of the temperature differences but shows also that the temperature maximum at 2.5 centimeters depth is reached sooner under the well-conducting than under the poorly-conducting surfaces (Figure 11). The maximum temperature at 2.5 centimeters depth was reached between 1/2 and 2 hours later than on the surface on the days during which measurements were made. The lag was approximately two to three hours at a depth of 7.5 centimeters and more than four hours at 12.5 and 17.5 centimeters. The course of temperatures in mineral soil on August 20, 1958 demonstrates the time lag between the daily maximum temperatures at the five levels of measurement (Figure 12).

Precipitation

Precipitation in the study area was recorded from April 1957 until October 1958 (Table 7). The annual precipitation in the study area is about twice as large

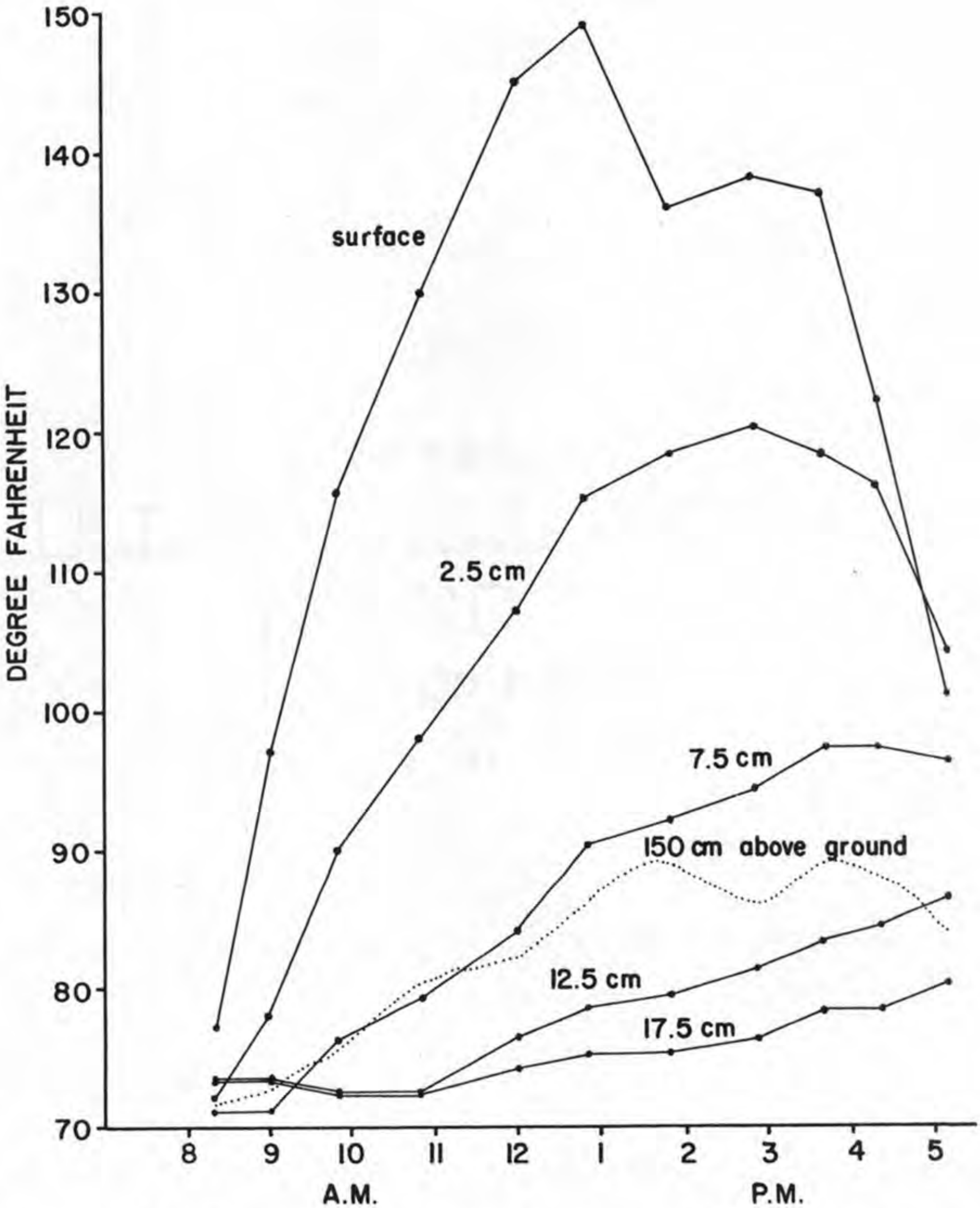


Figure 12. The course of temperatures on the surface of mineral soil, at four depths beneath it and at 150 centimeters above the surface during August 20, 1958.

Table 7. Precipitation at the study area and at Corvallis during 1957 and 1958.

	Precipitation in inches 1957		Departure from long-term mean	Precipitation in inches 1958		Deviation from long-term mean
	Study area	Corvallis		Study area	Corvallis	
January	No record	2.78	-3.27	14.36	8.75	2.10
February	"	4.89	0.31	26.30	7.81	3.23
March	"	7.01	3.13	6.94	2.55	-1.33
April	6.27	2.11	0.10	14.25	3.66	1.65
May	5.16	3.21	1.54	1.67	1.12	-0.55
June	4.87	1.07	-0.15	2.30	2.91	1.69
July	7.85	.17	-0.18	.10	.02	-0.33
August	5.65	.22	-0.19	.72	.02	-0.39
September	8.90	1.50	0.24	2.50	1.30	0.04
October	6.56	3.14	-0.46	5.50	2.54	-1.06
November	8.05	2.81	-2.58	No record	8.49	3.10
December	20.35	10.38	3.53	"	4.15	-2.70
Totals	73.66	39.29	2.02	74.54	43.32	5.45

as that in Corvallis (Table 7). The rainfall during the growing season is also considerably higher in the study area than in Corvallis.

The study area experienced completely different conditions of precipitation during the 1957 and 1958 growing seasons. The total amount of rainfall during spring and summer of 1957 was much higher and distributed differently than during the same period in 1958. 1957 had its first longer rainfree period from July 17 until August 2. It was ended by six days with a total of 5.56 inches of rain. The next dry spell lasted for seven weeks, from August 10 to September 26. This dry period was brought to an end by heavy rains in the last four days of September totaling almost nine inches of precipitation.

In 1958 an extremely wet April was followed by a relatively dry May. The first two weeks of May were without precipitation. Intermittent periods of light rain during the second half of May and during June were followed by dry weather in July and August. The nine weeks from July 1 to August 29 experienced rain only once, namely 0.1 inches on July 10. This long dry spell was ended by 0.73 inches of rain during the last two days of August and nearly two inches of precipitation in the second week of September.

Soil moisture

The course of soil moisture at 5- and 15-centimeter depths during the 1957 and the 1958 growing seasons reflects clearly the rainfall conditions in the two years. Irrespective of the surface cover and the degree of shading, soil moisture remained in the low-tension range, i.e., at tensions less than 1 atmosphere, throughout the major part of the 1957 growing season. September was the only month when moisture was held at tensions higher than 1 atmosphere (Figures 13-15). In 1958 soil moisture was in the high-tension range by the middle of July and approached or exceeded tensions of 15 atmospheres by mid-August (Figures 13-15).

In 1958 as in 1957, moisture depletion was greater at a depth of 5 than at 15 centimeters. However, an influence of either shade or seedbed material on the soil moisture status was not apparent in either growing season. During the middle of August 1958, soil moisture at 5 centimeters depth had reached or exceeded a tension of 15 atmospheres under all unshaded seedbeds but the soil at this depth under the shaded seedbeds was also closely approaching that level of moisture. An exception was found in 1958 under heavily shaded charcoal where soil moisture did not much exceed a tension of 1 atmosphere during the dry spell in July and August. Another

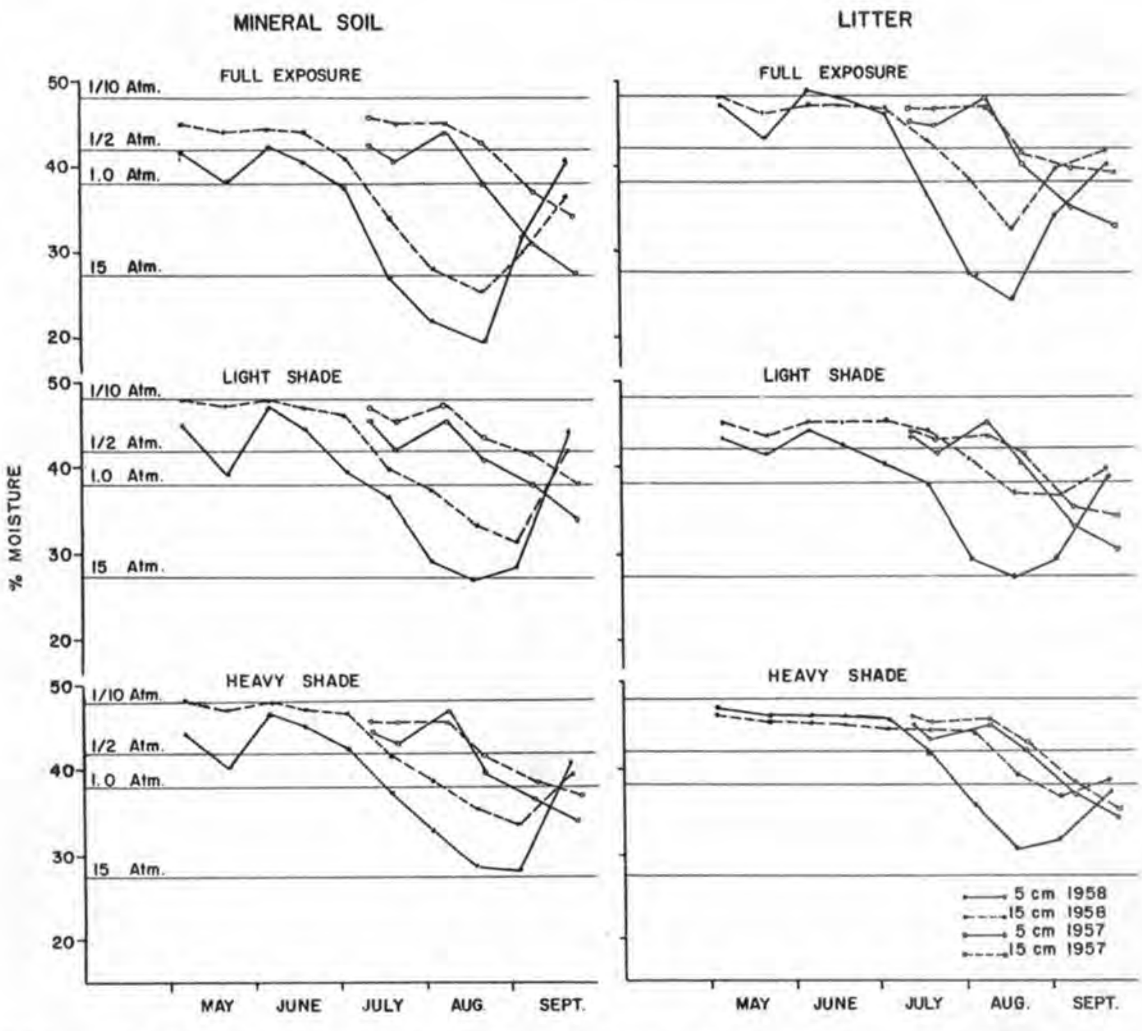


Figure 13. Status of soil moisture under exposed, lightly shaded, and heavily shaded surfaces of mineral soil and litter during the 1957 and 1958 growing seasons. The data for May and June 1957 are omitted because soil moisture remained at tensions below 1/2 atmosphere under all seedbeds.

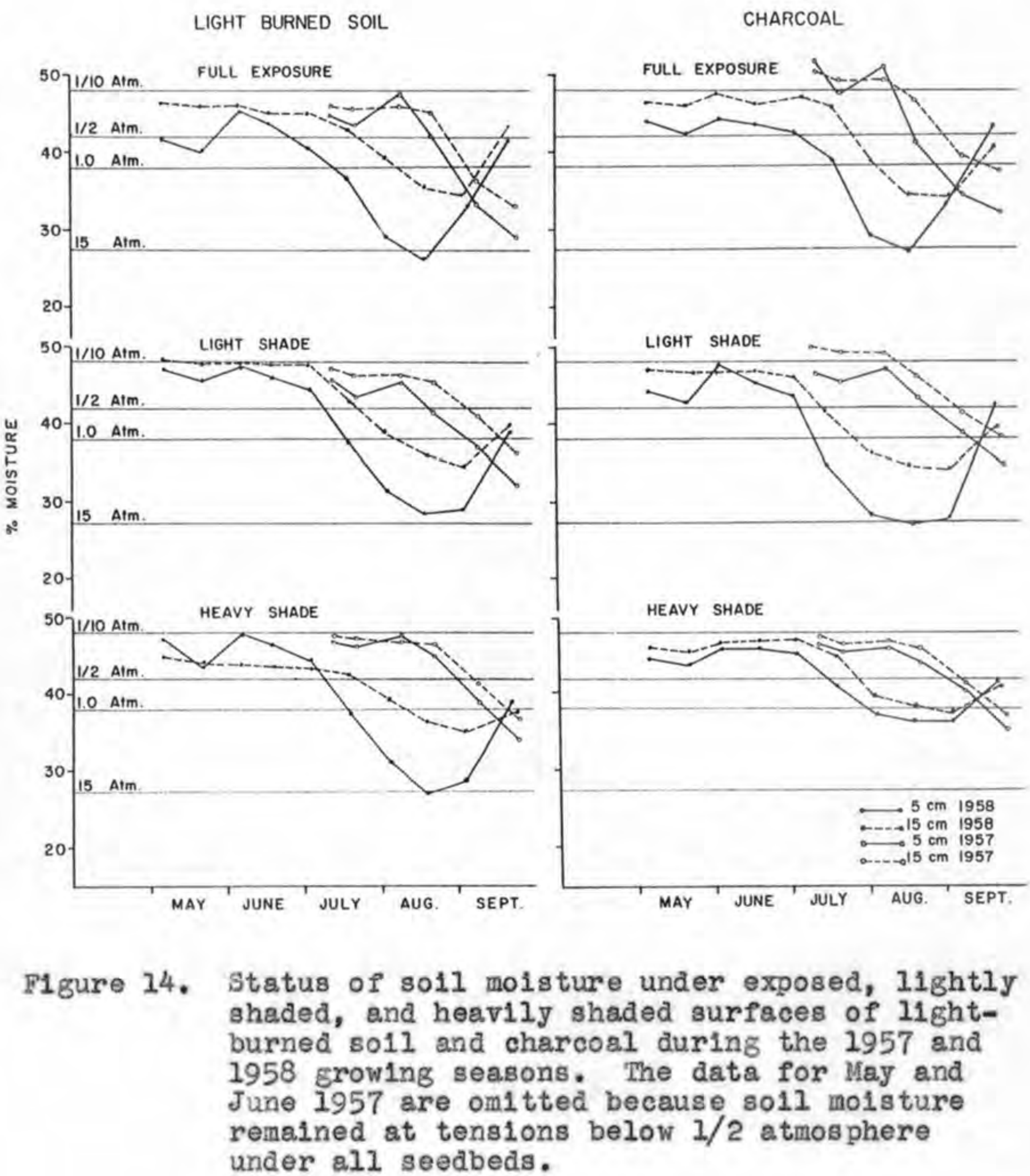


Figure 14. Status of soil moisture under exposed, lightly shaded, and heavily shaded surfaces of light-burned soil and charcoal during the 1957 and 1958 growing seasons. The data for May and June 1957 are omitted because soil moisture remained at tensions below 1/2 atmosphere under all seedbeds.

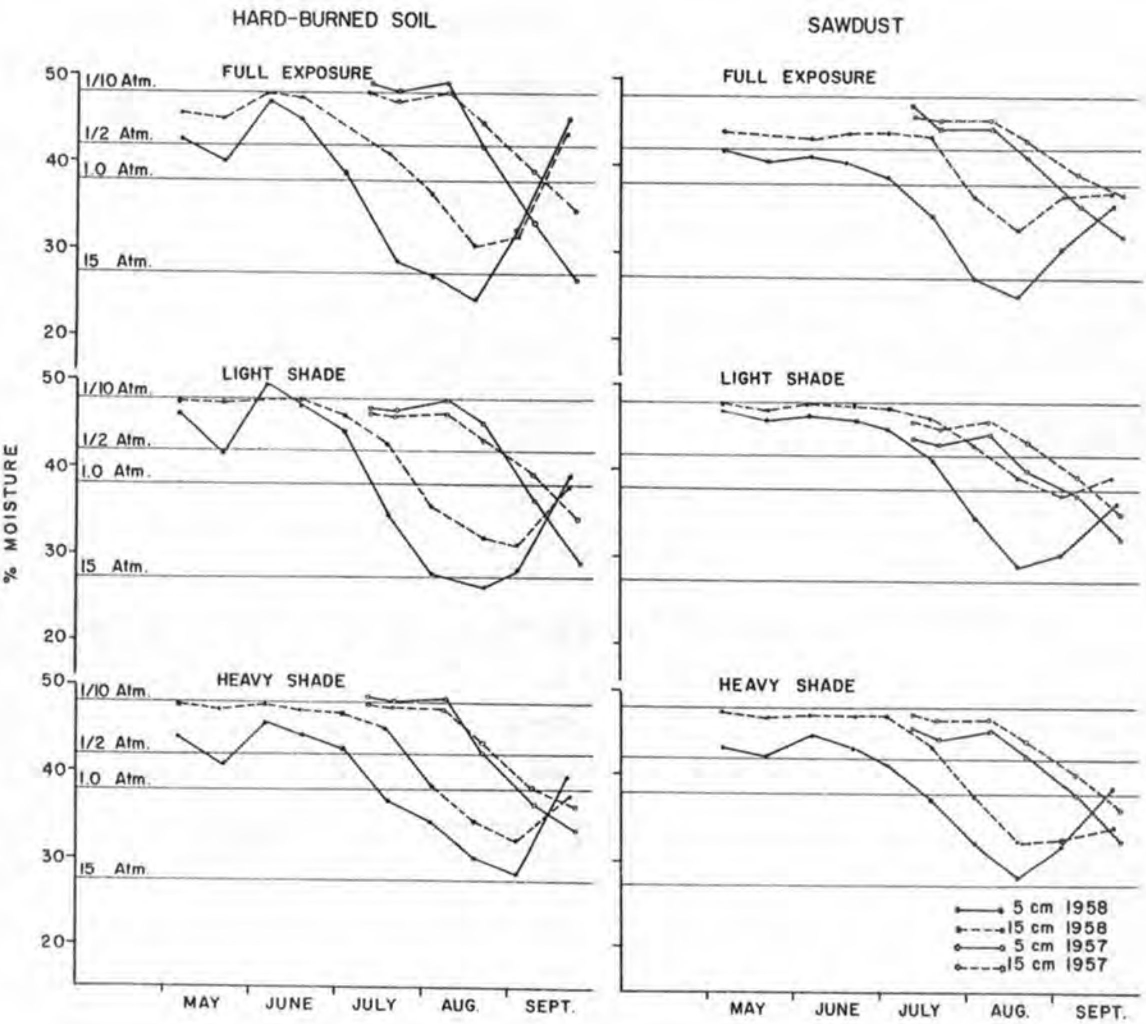


Figure 15. Status of soil moisture under exposed, lightly shaded, and heavily shaded surfaces of hard-burned soil and sawdust during the 1957 and 1958 growing seasons. The data for May and June 1957 are omitted because soil moisture remained at tensions below 1/2 atmosphere under all seedbeds.

exception, although in the reverse direction, was unshaded mineral soil. The soil 5 centimeters below the surface reached the 15-atmosphere tension by mid-July, about one month earlier than under the other seedbed materials.

Discussion of climatic conditions

There can be little doubt that exceptionally hot weather prevailed through a large part of the 1958 growing season, creating conditions even more adverse than the usual ones for seedling survival on south slopes. From June to September 1958, weather stations in western Oregon recorded temperatures which were much above the long-term average for this period. In the main portion of the Willamette Valley this was not only one of the warmest summers on record but also one of the longest dry spells with a total of less than 0.10 inches of rain recorded in the 62-day period from July 1 to August 31. Judging from this and from the 1957 climatic data for the study area, the summer of 1958 appears to have been warmer and drier than during other years in this particular area.

An interesting result of the temperature measurements was the detection of a nocturnal temperature rise during certain nights. The cause of the rise is not clear. It may be considered to indicate the presence of a thermal belt. However, a closer examination of the temperature course during nights when this phenomenon occurred casts doubt on the validity of this assumption. Geiger (36) has discussed the origin of the thermal belt in detail and has shown that the temperature maximum migrates gradually upwards on the slope according to the rate of accumulation of cold air at the foot of the slope. However, the absolute temperature in the thermal belt does not increase, on the contrary it usually decreases, but it remains considerably above the temperatures of the lower and uppermost segments of the slope. The rather abrupt temperature increase on the slope in the study area does not conform to the course of events as described by Geiger.

Investigations on the nature of the land breeze (25, 131), and weather studies made in Western Oregon to find ways of improving fire-danger ratings (74), have demonstrated the existence of meteorological conditions which may offer an explanation for the sudden temperature rise at night. A layer of relatively cool air is formed at lower elevations when a sea breeze occurs in the afternoon. During the night drainage winds from the Cascades gliding on the surface of the cold air layer, and coupled with a tendency for a land breeze circulation, bring subsiding air from an eastward direction which could account for the observed temperature rise.

While the temperature rise during the night is relatively small, never exceeding $7^{o}F$ in the experimental area, it may have an important bearing on seedling development. Such a nocturnal rise in temperature is associated with a sharp drop in relative humidity which would imply the prevention of dew formation. Dew is ordinarily of little consequence as a moisture supply for plants in temperate zones, but it may be of importance when soil moisture is at a critically low level. Dew water added to the soil will provide, at least temporarily, some additional moisture. During the cold season a nocturnal temperature rise is likely to diminish the danger of frost. The infrequent occurrence of frost in the experimental area may be, at least in part, a consequence of this phenomenon. It is also conceivable that such nocturnal temperature fluctuations may result in some kind of thermoperiodic response by seedlings.

The magnitude of differences between temperatures at the ground and at 150 centimeters above the ground indicates the severity of the site selected as the study area. The temperature differential, however, was appreciably decreased if the ground was shaded.

The shade covers made of burlap absorbed much of the solar radiation and were the surfaces of maximum heat transfer rather than the shaded seedbeds. As a consequence the temperatures on the heavily shaded seedbeds remained below critical levels and quite uniform for each material. The cheesecloth covers permitted a larger portion of the solar energy to reach the seedbed surfaces so that critical temperatures were attained on days with high radiation intensities. The amount of radiant energy absorbed or reflected by the cheesecloth covers was apparently enough to prevent marked temperature differences between the seedbed materials.

The temperature differences between the unshaded seedbed materials were surprisingly small considering the strong insolation on a bare south slope. Perhaps this was due in part to the rather complete drying of all seedbeds which tends to decrease markedly the specific heat and the conductivity of mineral materials. The strong winds which were frequently observed in the experimental area offer a further explanation. The increased speed of horizontal air movement favors convective cooling and thus may narrow greatly the temperature differences between the various seedbeds.

Silen (104) exposed in the laboratory a number of seedbed materials to a source of radiant energy which supplied 2.0 cal/cm^2/min. Materials used in the present study reached the following temperatures after 30 minutes: charcoal, 165°F; litter, 158°F; mineral soil, 153°F; sawdust, 149°F; hard-burned soil, 147°F. He was able to differentiate clearly between the heating properties of these materials, probably because he could maintain an even level of radiation and could largely eliminate convective cooling. Although field conditions are quite different from this laboratory situation, the order in which the seedbeds at the experimental area ranked according to temperatures reached is in rough agreement with Silen's sequence of materials.

Calculations of the amount of solar radiation received by the surface of a 10° south slope at 47°N latitude during the noon hours of clear summer days give values between 1.3 and 1.4 cal/cm^2/min. However, such computed values are approximations which provide merely an estimate of the intensities to be expected. The actual amounts of direct solar radiation will in general differ from the calculated values because the ratio of diffuse radiation to direct solar radiation, assumed to be a constant in the computation, may vary considerably even for a day with a cloudless sky.

Another indication of the complexity of the factors determining the heat transfer on the surface of the seedbeds are the temperature fluctuations that were recorded on their surfaces during noon hours. These fluctuations are probably the result of a chain reaction. The extreme heating of the ground makes the air layer immediately above it highly unstable. This instability leads eventually to an upset of the stratification of the air above the ground in which hot air eddies upwards and cooler air sinks down. The formation of dust whirls, a phenomenon resulting from this upset of air stratification, was repeatedly observed in the study area.

The accurate recording of the temperature on the surface of seedbeds is in itself a problem that should be mentioned in a discussion of the results of such measurements. The use of thermocouples is not a guarantee that the recorded temperatures are identical with the actual temperatures which prevailed on the surface at the moment the measurements were made. An important and frequently overlooked source of error, resulting from the conduction of heat along the thermocouple wires to the cooler air layer above the soil surface, was discussed in detail by Vaartaja (124). Geiger (36) called attention to another error which is caused by direct radiation of the thermocouple. The radiation error increases with size of thermocouple wires. Because the diameter of the thermocouple wire used in this study was about 2.5 millimeters, at attempt was made to reduce the radiation error by shielding the thermocouples with a thin strip of white tape. Effort to eliminate the conductivity error consisted of keeping about 30 centimeters of the wires behind the measuring junction flat on the ground. These precautions should have decreased appreciably the magnitude of the measuring errors but the recorded values are still considered approximations, though close ones, of the true surface temperatures.

Mercury thermometers have been, and still are widely employed for the measurement of surface temperatures although their usefulness for this particular purpose has been disclaimed repeatedly (7, 22). Geiger (36) stated perhaps most clearly why the temperature of the earth's surface cannot be measured accurately with a mercury thermometer. When it is place flat on the ground, the temperatures obtained are those of the lowest air layer which is cooler than the soil surface. On the other hand when the thermometer is embedded in the surface and covered by a very thin layer of soil, then it measures only the temperature of the uppermost soil layer which is also cooler than the soil surface. Toumey (120), Johnson (51), and Lavender (65) compared mercury thermometers and thermocouples and obtained identical readings for surface temperatures with both instruments. While it is unlikely that these findings provide sufficient evidence against the validity of Geiger's statement, the question remains whether mercury thermometers record surface temperatures which may be considered as reasonable approximations of the actual surface temperatures. This question is acute in evaluating the record of weekly maximum temperatures on the seedbeds of the study area. The comparison of maximum thermometer and thermocouple readings which were made in an attempt to answer the question gave puzzling results. The thermometer readings were mostly higher than the thermocouple readings although in theory the opposite should have been the case. It is possible that infra-red waves trapped inside the thermometers may have resulted in a miniature greenhouse effect. However, this effect should be most pronounced during the hours of most intense radiation while the greatest temperature differences between thermocouples and thermometers prevailed in the late afternoon. On the days when thermometers and thermocouple readings were taken for comparison, the maximum temperatures recorded by thermometers were on the average 5^{o}F higher for the organic materials and 2^{o}F higher for the mineral materials than the maximum temperatures recorded with the thermocouples. That would indicate that thermometers tend to exaggerate the temperature differences between organic and mineral materials. The differences between the maximum temperatures obtained with thermocouples and thermometers are regarded as small enough to justify the use of the data on weekly temperature maxima as an index of the weeks in which critical temperatures were reached.

The record of data on sub-surface temperatures demonstrates that the diurnal change in the amount and direction of heat flow in the soil is appreciably affected by the nature of the overlying seedbed material. The downward conduction of heat during the day and the upward flow of the heat during the night is greater and more rapid under the mineral than under the organic materials. The magnitude of the daily temperature amplitude at 5-centimeter depth under the two types of materials illustrates this very clearly. Depth to which a diurnal temperature change in the soil occurs have been reported to vary from 30 centimeters (21) to 50 centimeters (36, 60). The influence of different surface covers, however, ceases to be effective at much shorter distances. It was between 15 and 20 centimeters below the surface in the study area. Temperatures which may become critical to the roots of seedlings were reached only in the first 5 centimeters below the surface of the seedbed materials.

The difference between subsurface temperatures under the mineral and under the organic surfaces might lead to the anticipation of a similar difference with regard to soil moisture. This, however, was not the case. Soil moisture was depleted at nearly the same rate and to a similar extent under all seedbeds except unshaded mineral soil and heavily shaded charcoal. The apparent lack of a relationship between depletion of moisture under the various seedbed materials and the numbers of seedlings on these seedbeds suggests that the major part of soil water was lost by evaporation rather than by transpiration. This in turn would indicate that the organic surfaces were not much more efficient in retarding evaporative losses of soil moisture than were the mineral surface materials.

The degree of depletion which can be considered critical is still disputed. The range between field capacity and permanent wilting percentage is generally referred to as the range in which water is available to plants. Baver (14) stated that little information exists concerning the tension at which water is held at field capacity though tensions from 1/3 to 1/2 atmospheres are customarily used to designate this point. The 15-atmosphere percentage is considered to correspond to the permanent-wilting percentage. Veihmeyer and Hendrickson (128) regard moisture in the range between field capacity and permanent-wilting percentage as equally available to plants while Richards and Wadleigh (92) consider water held at tensions beyond the one-atmosphere level as difficultly available. A critical level cannot be said to develop at a fixed point in the soil moisture tension range if the viewpoint of Richards and Wadleigh is accepted. However, it seems reasonable to regard moisture percentages in the upper half of the higher tension range, i.e., from 10-15 atmospheres, already as critical for normal plant growth. The range of moisture availability at low tensions, that is below one atmosphere, is relatively narrow for the soil in the study area (Figures 13-15). In spite of this narrow range the soil moisture content in the upper soil layer became critically low for only about five weeks. This indicates much more favorable soil moisture conditions than had been expected.

THE 1957 TRIAL

Germination

Germination was extremely low in 1957. Only 935 seeds germinated, i.e., 2.6 per cent of the 36,000 sown. The abundance of hulled seeds on all plots indicated that most of the seeds had been eaten by rodents in spite of poisoning precautions. Germination was uniformly low under all conditions of seedbed and exposure to light (Table 8), although the percentage of seeds which germinated on charcoal was slightly higher than that on the other seedbed materials. A statistical analysis of the germination data for this year was not made.

Mortality and survival

Only 20.2 per cent of the seedlings survived the 1957 growing season. 58.9 per cent were killed by animals, 14.8 per cent succumbed to heat injuries, and 6.1 per cent were lost by damping off. Mortality on account of animals was considerably higher on the shaded seedbeds than on those exposed to full light (Table 9). It was not possible to determine what kind of animals had killed the seedlings but it is assumed that rodents and perhaps birds caused these losses. Damping off was limited to seedlings on the shaded seedbeds (Table 9). Lethal heat

Table 8. Germination of Douglas fir seeds in 1957. Each combination of seedbed material and light intensity represents five replications.

Type of seedbed	Percentage of full sunlight									Totals		
	100			75			25					
	No. of seeds sown	Seeds germinated		No. of seeds sown	Seeds germinated		No. of seeds sown	Seeds germinated		No. of seeds sown	Seeds germinated	
		No.	%		No.	%		No.	%		No.	%
Charcoal	2,000	54	2.7	2,000	132	6.6	2,000	119	6.0	6,000	305	5.1
Hard-burned soil	2,000	18	0.9	2,000	70	3.5	2,000	53	2.7	6,000	141	2.4
Light-burned soil	2,000	24	1.2	2,000	43	2.2	2,000	53	2.7	6,000	120	2.0
Mineral soil	2,000	35	1.8	2,000	60	3.0	2,000	46	2.3	6,000	141	2.4
Litter	2,000	37	1.9	2,000	60	3.0	2,000	40	2.0	6,000	137	2.3
Sawdust	2,000	24	1.2	2,000	37	1.9	2,000	30	1.5	6,000	91	1.5
Totals	12,000	192	1.6	12,000	402	3.4	12,000	341	2.8	36,000	935	2.6

Table 9. Mortality and survival of Douglas fir seedlings in the 1957 growing season. Each combination of seedbed material and degree of exposure to light represents five replications.

Type of Seedbed	Number Seedlings Emerged	Causes of Mortality: Animals No's	Animals %	Heat Injuries No's	Heat Injuries %	Damping Off No's	Damping Off %	Total Losses No's	Total Losses %	Survival: Nov. 1, '57 No's	Nov. 1, '57 %	Mar. 1, '58 No's	Mar. 1, '58 %
					Exposure to full light: 100 per cent								
Charcoal	54	22	40.7	24	44.4	-	0.0	46	85.1	8	14.9	1	
Hard-burned Soil	18	1	5.5	13	72.2	-	0.0	14	77.7	4	22.3	1	
Light-burned Soil	24	4	16.6	10	41.7	-	0.0	14	58.3	10	41.7	3	
Mineral Soil	35	4	11.4	18	51.5	-	0.0	22	62.9	13	37.1	5	
Litter	37	19	51.4	10	27.0	-	0.0	29	78.4	8	21.6	-	
Sawdust	24	3	12.5	9	37.5	-	0.0	12	50.0	12	50.0	3	
Totals	192	53	27.6	84	43.7	-	0.0	137	71.3	55	28.7	13	
					Exposure to full light: 75 per cent								
Charcoal	132	82	62.1	26	19.7	2	1.5	110	83.3	22	16.7	1	
Hard-burned Soil	70	47	67.1	9	12.9	-	0.0	56	80.0	14	20.0	3	
Light-burned Soil	43	33	76.7	4	9.3	-	0.0	37	86.0	6	14.0	4	
Mineral Soil	60	44	73.3	1	1.7	1	1.7	46	76.7	14	23.3	3	
Litter	60	33	55.0	9	15.0	2	3.3	44	73.3	16	26.7	3	
Sawdust	37	15	40.5	5	13.5	2	5.4	22	59.4	15	40.6	5	
Totals	402	254	63.2	54	13.5	7	1.7	315	78.4	87	21.6	19	
					Exposure to full light: 25 per cent								
Charcoal	119	85	71.4	-	0.0	22	18.5	107	89.9	12	10.1	-	
Hard-burned Soil	53	32	60.4	-	0.0	8	15.1	40	75.5	13	24.5	1	
Light-burned Soil	53	45	84.9	-	0.0	5	9.4	50	94.3	3	5.7	-	
Mineral Soil	46	32	69.6	-	0.0	3	6.5	35	76.1	11	23.9	5	
Litter	40	32	80.0	-	0.0	6	15.0	38	95.0	2	5.0	-	
Sawdust	30	18	60.0	-	0.0	6	20.0	24	80.0	6	2.0	2	
Totals	341	244	71.6	-	0.0	50	14.4	294	86.0	47	14.0	8	
Grand Total	935	551	58.9	138	14.8	57	6.1	746	79.8	189	20.2	40	4.3

injuries to seedlings were more frequent on the seedbeds exposed to full light than on those exposed to 75 per cent of light. Heat mortality of seedlings did not occur at an exposure to 25 per cent of full light (Table 9). Of the 138 seedlings killed by heat injuries, 80 per cent were less than two weeks old and 18 per cent were from two to four weeks old.

During the winter 1957/58 deer killed 149 seedlings by browsing. On March 1, 1958, 40 seedlings were left (Table 9), i.e., 4.3 per cent of those emerged in 1957. The surviving seedlings were without exception badly browsed. Although the browsing continued, these seedlings survived both the 1958 and the 1959 growing season. A statistical analysis of the survival data was not attempted because of the low numbers of seedlings which had emerged in 1957.

Discussion of the 1957 trial

The 1957 trial serves as an impressive demonstration of the devastating effect which seed-eating animals may have on the establishment of a new tree crop. The major part of seed losses was undoubtedly due to white-footed deer mice. During April 1957 alone, nearly 70 mice were killed by either trapping or poisoning. Experiments by Jameson (50) and by Garman and Orr-Ewing (33) have shown that a single deer mouse can eat 200 to 300 Douglas fir seeds a day. In view of the voracious appetite of this rodent and the large numbers present, the extent of the damage becomes easily understandable. The amount of destroyed seeds further indicates that a rodent repellent, such as endrine, does not provide adequate protection when a strong population pressure exists. The heavy concentration of seeds on a relatively small area, and the disturbance caused by clearing and preparing this area for seeding, may have attracted unusually large numbers of mice. As Garman and Orr-Ewing (33) have pointed out, many who have studied the problem concluded that mice are attracted to ground which has been freshly disturbed. However, in tests carried out in British Columbia, a relationship between the intensity of rodent attack and preparation of the ground was noticeably only during the very first days after disturbance of the ground.

The extremely low germination under all seedbed conditions is without question a consequence of the severe losses of seeds. It is noteworthy that almost twice as many seeds germinated on charcoal than on any of the other seedbed materials. That may simply mean that on charcoal more seeds escaped consumption by rodents though it may also suggest the favorable effect of charcoal on germination which appeared quite distinct in the 1958 trial.

Seedling mortality was nearly 80 per cent in the 1957 growing season. The high proportion of seedlings killed by animals, accounting for three-fourths of the total loss, also reflects the impact of rodents in this year. The numbers of seedlings were too small and the toll taken by animals was too heavy to allow sound conclusions regarding the relationship between seedbed materials and seedling mortality.

THE 1958 TRIAL

Germination

In 1958, germination began during the second week of March and continued until the middle of July. During this period 16,494 of the 45,000 seeds sown germinated. The numbers of germinated seeds differed appreciably on the various seedbed materials (Table 10). Better germination occurred on the open than on the shaded seedbeds. An analysis of variance (Table 11) confirmed that the extent of germination was significantly influenced by both the kind of seedbed material and the degree of exposure to light, though independently from each other. The differences between replications were insignificant.

Charcoal and hard-burned soil were better media for germination than were the other four seedbed materials (Table 10). Further statistical analysis was required to decide whether the numbers of germinated seeds on the various seedbeds were significantly different from each other. This was done by means of a multiple range F test (Table 12). Charcoal proved to be the best medium for germination. Hard-burned soil was not as good as charcoal but was superior to the other kinds of seedbed material. The differences in germination on light-burned soil, mineral soil, litter, and sawdust cannot be regarded

Table 10. Germination of Douglas-fir seeds in 1958. Each combination of seedbed material and light intensity represents 5 replications.

Type of Seedbed	Percentage of Full Sunlight: 100			75			25			Totals		
	No. of Seeds Sown	Seeds Germinated No.	Seeds Germinated %	No. of Seeds Sown	Seeds Germinated No.	Seeds Germinated %	No. of Seeds Sown	Seeds Germinated No.	Seeds Germinated %	No. of Seeds Sown	Seeds Germinated No.	Seeds Germinated %
Charcoal	2,500	2,326	93.0	2,500	1,719	68.8	2,500	1,965	78.6	7,500	6,010	80.2
Hard-burned Soil	2,500	1,230	49.2	2,500	1,213	48.5	2,500	1,199	48.0	7,500	3,642	48.5
Light-burned Soil	2,500	733	29.3	2,500	724	29.0	2,500	499	20.0	7,500	1,956	26.1
Mineral Soil	2,500	741	29.6	2,500	636	25.4	2,500	621	24.8	7,500	1,998	26.7
Litter	2,500	582	23.3	2,500	495	19.8	2,500	551	22.0	7,500	1,628	21.7
Sawdust	2,500	662	26.5	2,500	267	10.7	2,500	331	13.2	7,500	1,260	16.8
Totals	15,000	6,274	41.7	15,000	5,054	33.7	15,000	5,166	34.4	45,000	16,494	36.7

Table 11. Analysis of variance of number of Douglas fir seeds which germinated on six different kinds of seedbed exposed to three different degrees of light intensity.

Source of variation	SS	DF	MS	F	Significance at 5 per cent level
Replication	33,914.933	4	8,478.733	1.97	Not significant
Seedbed (S)	1,073,212.133	5	214,642.426	49.76	Significant
Intensity of light (L)	30,317.866	2	15,158.933	3.51	Significant
S x L	34,561.60	10	3,456.160	0.80	Not significant
Error	293,303.067	68	4,313.280		
Total	1,465,309.600	89			

Table 12. Multiple Range F-test of mean numbers of Douglas fir seeds which germinated on six different kinds of seedbeds.

Seedbed:	Sawdust	Litter	Light-burned soil	Mineral soil	Hard-burned soil	Charcoal
No. of seeds germinated:	84.00	108.53	130.40	133.20	242.80	400.67

Note: Any 2 means not underscored by the line are significantly different at the 5 per cent level of significance.

Any 2 means underscored by the line are not significantly different.

as a reflection of differences in the nature of these media but must be attributed to chance.

The method of individual degrees of freedom was used to determine the significance of differences between the three levels of light with regard to germination (Table 13). Germination was significantly higher on the seedbeds exposed to full light, regardless of the kind of seedbed material. Decrease in light intensity resulted in lower germination irrespective of the degree of light reduction, i.e., the differences in extent of germination were not significant between the plots on which the light intensity was reduced by either 25 or 75 per cent.

Table 13. Comparison of influence of degree of light intensity upon germination of Douglas-fir seeds by the method of individual degrees of freedom.

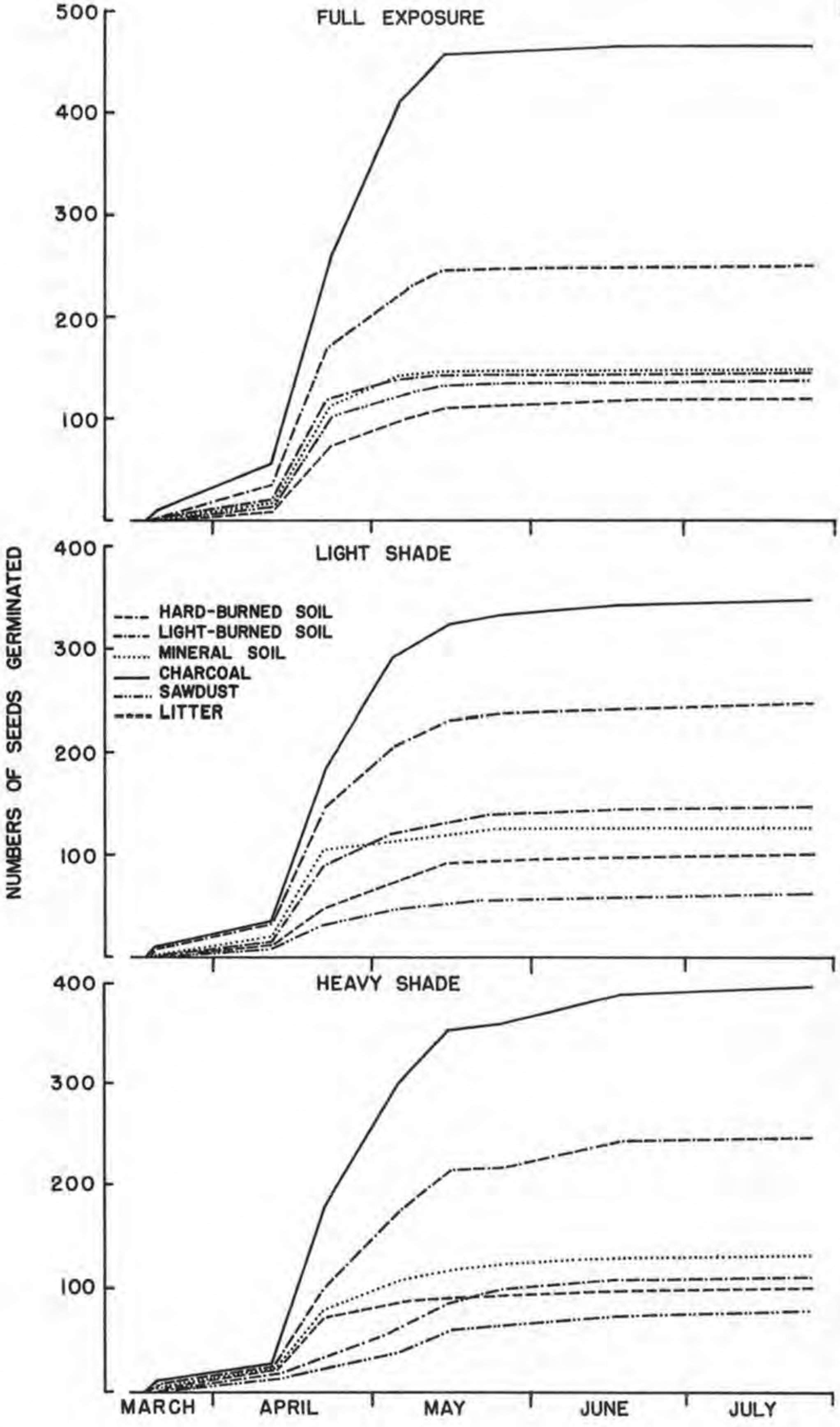
Percentage of light	Total No. of seeds germinated	F	Significance at 5 per cent level
100	6,274	6.98	Significant
75	5,054	0.05	Not significant
25	5,166		

The date at which germination started and the length of the germination period were not appreciably influenced by the kind of seedbed material or the degree of shading. Germination on charcoal began about two days earlier than on the other materials but germination remained low on all seedbeds until April 8. At this date a sharp rise in germination occurred under all seedbed conditions which continued until May 13 (Figure 16). After this date the rate of germination leveled off although the rate of leveling off was not the same under all seedbed conditions. The decrease in rate of germination was slower on charcoal and hard-burned soil exposed to 25 per cent of full light, and on charcoal, hard-burned soil, and light-burned soil exposed to 75 per cent of full light, than on the other kinds of seedbed.

Discussion of germination

The overall rate of germination in 1958 was 36.7 per cent as compared to 2.6 per cent in 1957. This large difference was due primarily to the decreased activity of rodents in 1958. Signs of damage to seeds were not detected until the middle of April and even thereafter relatively few hulled seeds were found. It is possible, though very unlikely, that the time of seeding was a factor which contributed to the differences in germination between the 1957 and 1958 trials. It has been repeatedly reported (19, 33, 35, 66) that seeding of Douglas fir in fall or winter has resulted in better germination than seeding in spring. However, extreme

Figure 16. Accumulative germination of Douglas fir seeds during spring 1958 on six kinds of seedbeds under three degrees of exposure to light. Each curve represents the average of five replications.


FULL EXPOSURE
LIGHT SHADE
HEAVY SHADE
NUMBERS OF SEEDS GERMINATED
500
400
300
200
100
HARD-BURNED SOIL
LIGHT-BURNED SOIL
MINERAL SOIL
CHARCOAL
SAWDUST
LITTER
MARCH
APRIL
MAY
JUNE
JULY

losses of seeds by rodents apparently were not involved in any of these studies.

Owen (86), Gartz (35), and Garman (34) noted that spring seeding often led to delayed germination, i.e., a certain portion of the seeds did not germinate until the following spring. Delayed germination of seeds sown in 1957 may have taken place in 1958, although it is highly improbable that it was significant enough to confound the analysis of the 1958 germination data. The extent of seed destruction in 1957 speaks against such a possibility. Another indication was given in 1959 that both delayed germination and germination from natural seedfall may be regarded as insignificant. In the spring of that year less than 50 newly germinated seedlings were counted on all 90 plots. In view of these considerations, and the fact that losses of seeds by rodents were negligible in 1958, little doubt can be left that the observed patterns of germination in this year are closely connected with some specific characteristics of the seedbeds.

The characteristic which had probably the most important influence was the differential water retention by each seedbed material. In the first three weeks of April, rain fell almost daily and kept the surfaces of seedbeds continually wet. During this period germination was high on all seedbeds. After the end of April, precipitation became less frequent and the surfaces of litter and sawdust began to dry out rapidly. The intermittent rainfalls were not sufficient to moisten their surfaces effectively. The surfaces of the mineral soil and light-burned soil also dried out though it took slightly longer. The surfaces of hard-burned soil and of charcoal, on the other hand, dried slowly and some moisture remained on charcoal until June.

The depletion of moisture in the surface of the seedbed materials could not be determined quantitatively but an indicator was found which showed the status of moisture very clearly. _Funeria hygrometrica_, a moss commonly found on burned-over lands, appeared on charcoal and light-burned soil. As the latter material began to dry, the moss started to shrivel and by June it was completely desiccated while _Funeria_ growing on charcoal was still green and succulent.

Germination on charcoal and hard-burned soil continued to be high until mid-May while the effect of rapid desiccation on the other seedbed materials is indicated by the sharp decrease in germination the last week of April (Figure 16). Differences of this nature have often been held responsible for the varying success of germination on different seedbeds. For instance, Smith (107), who studied the influence of seedbed conditions on the regeneration of eastern white pine (Pinus strobus), came to the conclusion that those seedbeds which provided ample moisture were the ones most conducive to high germination.

Under field conditions, desiccation is almost invariably associated with high temperatures. They prevent germination though little is known about the mechanism of this process. Siegel (102) has shown that short exposures of the seeds of certain flowering plants to high temperatures result in photoinhibition of germination. Whether this applies to coniferous seeds is as yet uncertain. Although desiccation and heat inhibit germination, dry Douglas fir seeds remain viable at temperatures below 200°F (43). If the seeds contain moisture, they lose their viability when heated to 130° to 140°F (81). Absorption of water during rains in late spring or summer and subsequent rapid heating may have accounted for the loss of viability in many of the seeds that did not germinate in the spring of 1958. This would offer an explanation for the almost complete lack of second-year germination.

Temperatures of 70° to 80°F have been given as the most favorable range for the germination of tree seeds in general (9) and of Douglas fir seeds in particular (62). However, such values cannot be used to correlate the temperature on the seedbeds at the time of germination to the numbers of germinates. Germination is governed also by the degree of alternation between day and night temperatures and the extent of stratification. The complexity of the temperature factor is recognized but it is not known which particular temperature sequences will lead to optimum germination. Therefore, it would be futile to attempt a correlation of surface temperatures with the extent of germination on each seedbed material. The simultaneous beginning of germination on all plots further indicates that temperature differences between the seedbed materials were apparently of little importance.

The major effect of temperatures probably consisted of the faster drying of some of the surfaces which in turn caused a significant reduction of germination on account of unfavorable moisture conditions. Even during the early part of the germination period when moisture was abundant, considerable differences existed between the amount of germination on charcoal and hard-burned soil on one hand and the rest of the seedbed materials on the other hand (Figure 16). This observation suggests that perhaps some other factor contributed to the differential germination on the various seedbeds.

A small experiment conducted in 1959 pointed again to this possibility. Twenty-four flats were filled with soil from the experimental area and four flats were covered with each of the seedbed materials used in the field study. On April 2, each flat was sown with 100 seeds which had been stratified at 35°F for two weeks. By August 29, the percentage of germination on each seedbed was as follows: charcoal, 90.7; hard-burned soil, 72.2; mineral soil, 70.5; light-burned soil, 68.0; litter, 36.0; sawdust, 24.0. The values are the averages of four replications. Even though water was supplied every day, partial drying or sometimes complete drying of the surfaces of litter and sawdust between two waterings could not be avoided. The other seedbed materials remained continuously moist. The flats were not exposed to direct insolation at any time and heating of the surfaces did not occur.

Several conclusions can be drawn from these results. Sawdust and litter are poor media for germination even under conditions far more favorable than in the field. Light-burned and mineral soil are satisfactory media if their surfaces remain moist. The low germination on litter and sawdust was probably caused by the alternate drying and wetting of their surfaces. The excellence of charcoal as a germination medium, on the other hand, cannot be satisfactorily explained by more favorable moisture conditions than on other seedbeds.

When moisture, temperature, different pretreatments, and different seed sources are ruled out as factors which could be responsible for the differential extent of germination, then it seems logical to consider the possible effects of the chemical nature of the substrate on which the seeds germinated. The H-ion concentration of the medium has often been regarded as a factor influencing germination. Baldwin (9) holds the opinion that different germination responses attributed to different pH levels seem to arise more from the chemical substances rendered soluble, and upon the strength of their buffer action, than from the reaction of the medium alone. This view is supported by the work of Thrupp (118) who came to the conclusion that available nutrients in the soil exert a strong influence on germination. He claimed that a high content of Ca or Mg will increase the speed and total percentage of germination. K and P may have a similar but less marked effect. Burning renders substantial amounts of each of these nutrients mobile. Consequently, they will be more readily available in burned soil and charcoal than in unburned soil, sawdust, and litter. To use availability of these nutrients as an explanation for the observed patterns of germination is not fully satisfactory either. That germination was just as high on unburned mineral soil than on the burned soils could be attributed to the relatively high amount of available Ca in the unburned soil as shown by the analysis given on page 22. However, there is no reason to assume that the burned had a lower nutrient content than charcoal. Why then was germination on the latter material always so high? While this question cannot be answered at the present, the beneficial effect of charcoal in regard to germination has been noted before. Baldwin (9) mentions that abundant regeneration is frequently found on abandoned charcoal pits. Went (130) attributed the stimulating effect of charcoal on germination to inactivation or absorption of inhibitors.

The shade treatments of the seedbeds on the experimental area likewise presented some puzzling problems. Change in degree of light intensity on the surface did not erase the effects of the seedbed materials on germination. Charcoal and hard-burned soil were superior to the other materials under all three light conditions. However, shade must have retarded germination in some manner because germination was highest in full light on each of the seedbed materials. Usually higher germination has been reported in shade which is attributed to favorable moisture conditions on seedbeds protected from direct insolation (9). Of special interest in connection with the present study is an investigation by Garman (34) at

Lois Lake, B.C. in which he studied the effects of four different light intensities on the germination of some western conifers. Germination of Douglas fir seeds was higher on shaded than on open seedbeds and more seeds germinated under 25 than under either 50 or 75 per cent shade. Garman did not attempt to explain the differences in germination under the four light intensities. However, his statement that germination on the quadrats without shade was probably assisted by watering seems to imply that the more rapid desiccation of the unshaded soil was held responsible for the lower germination. In the experimental area, moisture was not a limiting factor during the main period of germination, and the germination curves (Figure 16) do not indicate that the moisture status was much more favorable under shade as seedbeds began to dry out.

Temperature differences between the shaded and open seedbeds are unlikely to have been the cause for reasons discussed previously. There remains the possibility that light as such had some effect. Allen (3), in a review of this subject, pointed to the many contradictory results reported with regard to the effect of light on the germination of coniferous seeds. He showed in his own work that new seeds of coastal Douglas fir showed a definite response to light. However, his treatments consisted only of exposure to complete darkness or light and give no indication of the effect of various light intensities. The shade covers certainly did alter the spectral composition of light although it is questionable whether this had any effect on germination. Information about the responses of seeds to spectral composition of light is extremely scarce (9). The only fact clearly established is the injurious effect of wave lengths shorter than 290 μ.

Causes of seedling mortality

The fate of 16,494 seedlings was followed from their emergence in spring 1958 until November 1, 1959. During this time, biotic and physical agents took a toll of 11,122 seedlings, or 67.4 per cent. In addition, 180 seedlings were removed for examination of root development.

The heaviest losses were suffered in the 1958 growing season during which 10,182 seedlings were killed (Table 14; Table 15, Appendix). Animal depredations and heat injuries accounted for the largest share while fungi were responsible for but a modest portion of the total losses. Frost and, surprisingly enough, drought were wholly insignificant as factors of mortality.

Mortality dropped sharply during the period November 1, 1958 to April 1, 1959 although the loss of 899

Causes of Mortality

Type of Seedbed	Number Seedlings Emerged	Animals		Heat Injuries		Damping Off		Frost		Drought		Unknown Cause		Total of Seedlings killed by Nov. 1, 1958	
		No's	%	No's	%	No's	%	No's	%	No's	%	No's	%	No's	%
						Exposure to Light: 100 per cent									
Charcoal	2,326	243	10.4	1,304	56.1	1	0.1	22	0.9	-	0.0	-	0.0	1,570	67.5
Hard-burned Soil	1,230	197	16.0	614	49.9	-	0.0	-	0.0	-	0.0	2	0.2	813	66.1
Light-burned Soil	733	153	20.8	438	59.8	-	0.0	-	0.0	-	0.0	1	0.1	592	80.8 -
Mineral Soil	741	51	6.8	428	47.8	-	0.0	-	0.0	-	0.0	-	0.0	479	64.6
Litter	582	78	13.4	282	48.5	-	0.0	-	0.0	-	0.0	-	0.0	360	61.9
Sawdust	662	123	18.5	264	39.9	1	0.2	2	0.3	-	0.0	-	0.0	390	58.9
Totals	6,274	845	13.5	3,330	53.0	2	0.1	24	0.4	-	0.0	3	0.1	4,204	67.1
						Exposure to Light: 75 per cent									
Charcoal	1,719	626	36.4	185	10.8	35	2.0	7	0.4	-	0.0	12	0.7	865	50.3
Hard-burned Soil	1,213	364	30.0	269	22.2	17	1.4	-	0.0	-	0.0	11	0.9	661	54.5
Light-burned Soil	724	281	38.9	69	9.5	43	5.9	-	0.0	-	0.0	3	0.4	396	54.7
Mineral Soil	636	111	17.5	116	18.2	6	0.9	-	0.0	-	0.0	2	0.3	235	36.9
Litter	495	144	29.2	67	13.6	15	3.0	-	0.0	-	0.0	2	0.3	228	46.1
Sawdust	267	41	15.4	57	21.3	8	3.0	2	0.7	-	0.0	-	0.0	108	40.4
Totals	5,054	1,567	31.0	763	15.1	124	2.5	9	0.2	-	0.0	30	0.5	2,493	49.3
						Exposure to Light: 25 per cent									
Charcoal	1,965	1,170	59.5	-	0.0	117	6.0	9	0.5	-	0.0	23	1.2	1,319	67.1
Hard-burned Soil	1,199	766	63.9	-	0.0	119	9.9	-	0.0	17	1.4	13	1.1	915	76.3
Light-burned Soil	499	183	36.6	-	0.0	127	25.5	-	0.0	-	0.0	3	0.6	313	62.7
Mineral Soil	621	366	58.9	-	0.0	43	7.0	-	0.0	-	0.0	2	0.3	411	66.2
Litter	551	276	50.1	-	0.0	44	8.0	-	0.0	-	0.0	5	0.9	325	59.0
Sawdust	331	184	55.6	-	0.0	12	3.6	5	1.5	-	0.0	1	0.3	202	61.0
Totals	5,166	2,945	57.1	-	0.0	462	8.9	14	0.3	17	0.3	47	0.9	3,485	67.5
Grand Totals	16,494	5,357	32.5	4,093	24.8	588	3.6	47	0.3	17	0.1	80	0.5	10,182	61.8

Table 14. Mortality of Douglas fir in the 1958 growing season under various combinations of seedbed material and light intensity. Each combination of seedbed material and light intensity represents five replications.

seedlings in these months is still an appreciable one (Table 15; Table 16, Appendix). Most of the seedlings were eaten by deer while some died from causes associated with heat injuries which were received during the preceding summer. During the 1959 growing season mortality was extremely low with only 41 seedlings killed by what appeared to be drought.

All percentage figures express losses as per cent of emerged seedlings. It is specifically indicated when this procedure was not followed.

Animal depredations. Animal depredations were responsible for the loss of 5,357 seedlings, i.e., 32.5 per cent, in the 1958 growing season, and of another 858 seedlings, or 5.2 per cent, in the winter 1958/59. Animals were the most important cause of mortality, accounting for slightly more than one-third of all seedlings lost.

The losses in the winter of 1958/59 can be attributed with certainty to deer but during the 1958 growing season it was not clear in many instances what kind of animal had caused death. Presumably, mice, and to a lesser extent birds, killed most of the seedlings but this assumption is based entirely on circumstantial evidence. The activity of rodents other than mice and of insects

Table 15. Mortality of Douglas fir seedlings during the winter of 1958/59 and during the 1959 growing season. Losses are summarized according to seedbed material and exposure to light during the 1958 growing season. Each combination of seedbed material and previous exposure to light represents five replication.

Type of Seedbed	Number Seedlings Emerged	Causes of Mortality: Winter 1958-59: Animals No's	%	Heat Injuries No's	%	Removal for Root Study No's	%	Total Losses No's	%	1959 Growing Season Drought No's	%
		Exposure to light during the 1958 growing season: 100 per cent									
Charcoal	2,326	144	6.2	5	0.2	10	0.4	159	6.8	-	0.0
Hard-burned Soil	1,230	24	2.0	4	0.3	10	0.8	38	3.1	1	0.1
Light-burned Soil	733	11	1.5	1	0.1	10	1.4	22	3.0	1	0.1
Mineral Soil	741	35	4.8	4	0.5	10	1.3	49	6.6	-	0.0
Litter	582	11	1.9	1	0.2	10	1.7	22	3.8	-	0.0
Sawdust	662	41	6.2	2	0.3	10	1.5	53	8.0	-	0.0
Totals	6,274	266	4.2	17	0.2	60	0.9	343	5.3	2	0.1
		Exposure to light during the 1958 growing season: 75 per cent									
Charcoal	1,719	16	0.9	15	0.9	10	0.6	41	2.4	5	0.3
Hard-burned Soil	1,213	27	2.3	-	0.0	10	0.8	37	3.1	7	0.5
Light-burned Soil	724	71	9.8	-	0.0	10	1.4	81	11.2	5	0.7
Mineral Soil	636	43	6.8	4	0.6	10	1.6	57	9.0	-	0.0
Litter	495	29	5.8	3	0.6	10	2.0	42	8.4	-	0.0
Sawdust	267	28	10.5	2	0.7	10	3.7	40	14.9	-	0.0
Totals	5,054	214	4.3	24	0.5	60	1.2	298	6.0	17	0.3
		Exposure to light during the 1958 growing season: 25 per cent									
Charcoal	1,965	170	8.7	-	0.0	10	0.5	180	9.2	12	0.6
Hard-burned Soil	1,199	58	4.9	-	0.0	10	0.8	68	5.7	6	0.5
Light-burned Soil	499	23	4.6	-	0.0	10	2.0	33	6.6	2	0.4
Mineral Soil	621	84	13.5	-	0.0	10	1.6	94	15.1	-	0.0
Litter	551	21	3.8	-	0.0	10	1.8	31	5.6	1	0.2
Sawdust	331	22	6.7	-	0.0	10	3.0	32	9.7	1	0.3
Totals	5,166	378	7.3	-	0.0	60	1.2	438	8.5	22	0.4
Grand Total	16,494	858	5.2	41	0.2	180	1.1	1,079	6.5	41	0.2

cannot be ruled out completely.

Seedling mortality did not show any consistent differences among seedbed materials but the degree of exposure to light was definitely related to the magnitude of losses (Figure 17). Mortality was lowest on plots exposed to full light and highest on those which were heavily shaded. Another factor which seemed to influence losses to some extent was the location of the plots. Mortality was higher on the plots along the borders and also higher in the eastern than in the western part of the study area.

Of special interest were the distinctive fluctuations of losses during the 1958 growing season (Figure 18). In mid-April mortality reached a peak which was followed by a second, though smaller peak in the last week of May and the first two weeks of June. During the next 12 weeks losses remained very low but rose again sharply at the end of the growing season. This periodic rise and decline of mortality was noticeable on all seedbeds regardless of the degree of exposure to light.

The appearance of killed seedlings was different in spring than in fall 1958. Figure 19 illustrates the types of damage found in the earlier part of the growing season. Frequently the seedlings were clipped and no trace of the top was left although sometimes the top, apparently

Figure 17. Percentages of losses of Douglas fir seedlings due to animals during the 1958 growing season for 18 different combinations of seedbed material and exposure to light. Each bar represents the seedling losses of the five replications of the designated combination of seedbed material and exposure to light. The losses are expressed as a percentage of the total number of emerged seedlings.

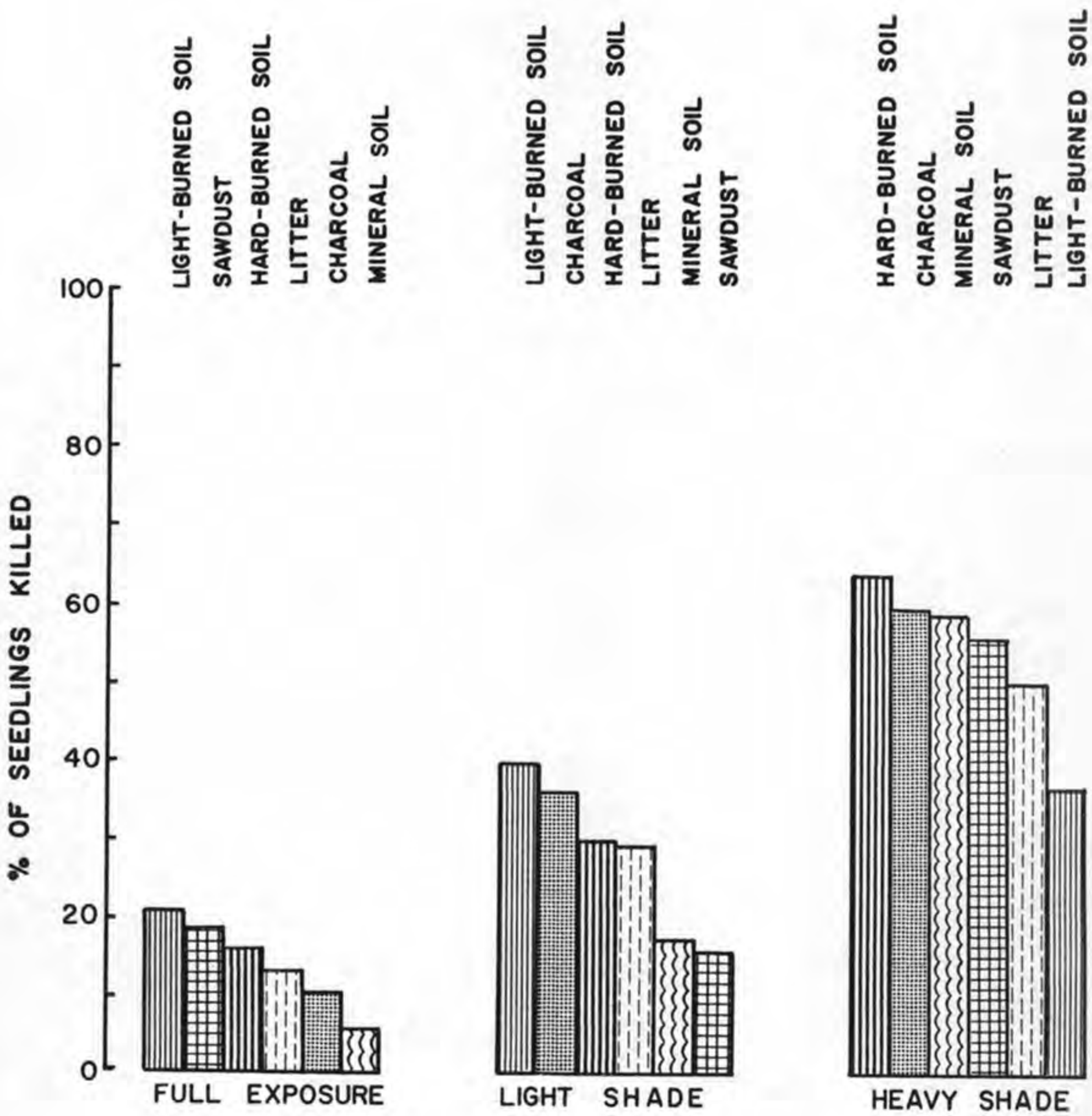

% OF SEEDLINGS KILLED
0
20
40
60
80
100
FULL EXPOSURE
LIGHT-BURNED SOIL
SAWDUST
HARD-BURNED SOIL
LITTER
CHARCOAL
MINERAL SOIL
LIGHT SHADE
LIGHT-BURNED SOIL
CHARCOAL
HARD-BURNED SOIL
LITTER
MINERAL SOIL
SAWDUST
HEAVY SHADE
HARD-BURNED SOIL
CHARCOAL
MINERAL SOIL
SAWDUST
LITTER
LIGHT-BURNED SOIL

Figure 18. Fluctuation of seedling losses caused by animals during the 1958 growing season. Each bar indicates the magnitude of losses during one-half of the month indicated. The losses are expressed as a percentage of the total numbers of seedlings killed by animals from April 1 to October 31, 1958.

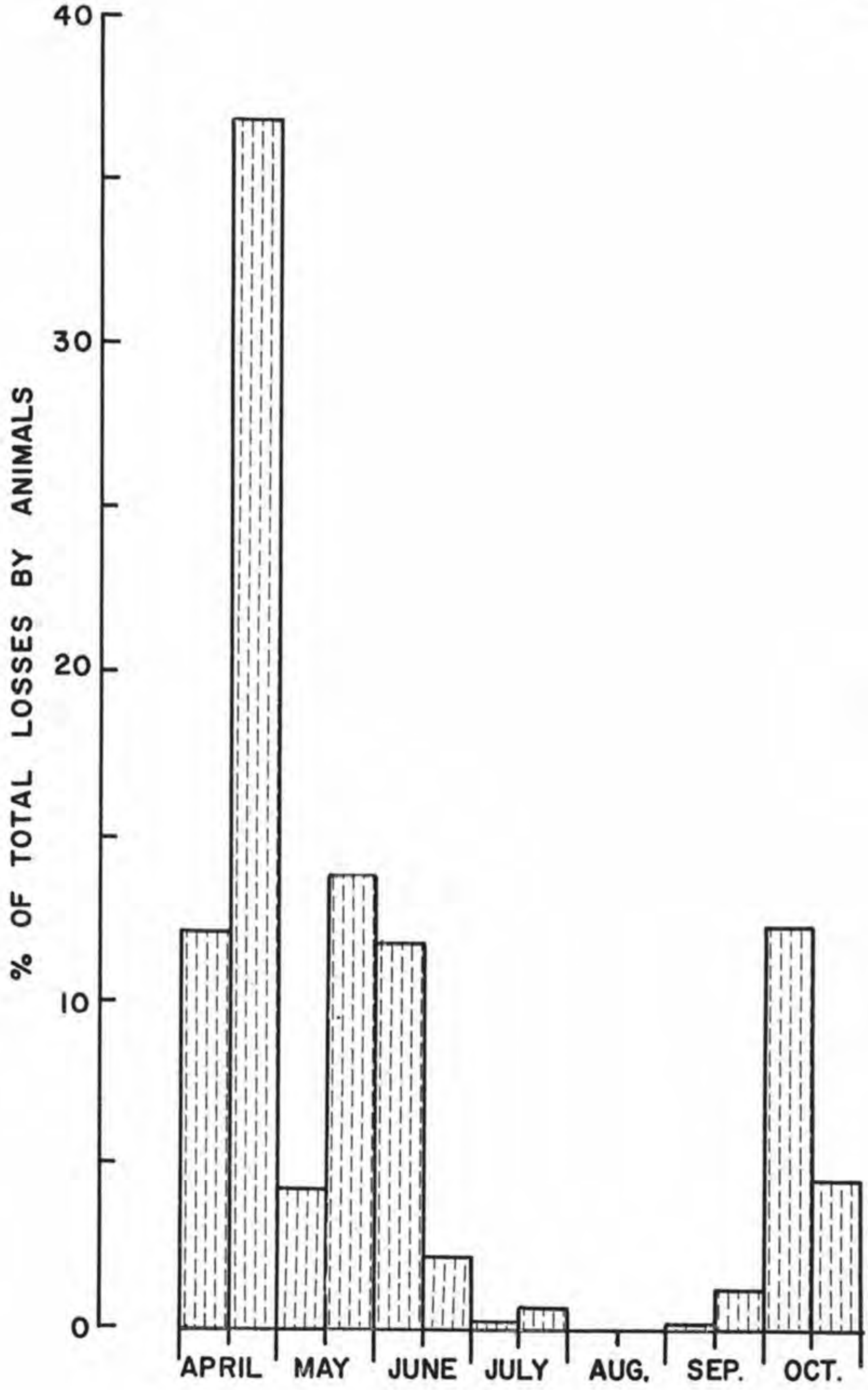

40
30
20
10
0
% OF TOTAL LOSSES BY ANIMALS
APRIL
MAY
JUNE
JULY
AUG.
SEP.
OCT.

Figure 19. Two- to four-week old seedlings killed by animals. Note the various degrees to which cotyledons were eaten. In the upper left corner are two hulled seeds, typical of mouse damage.

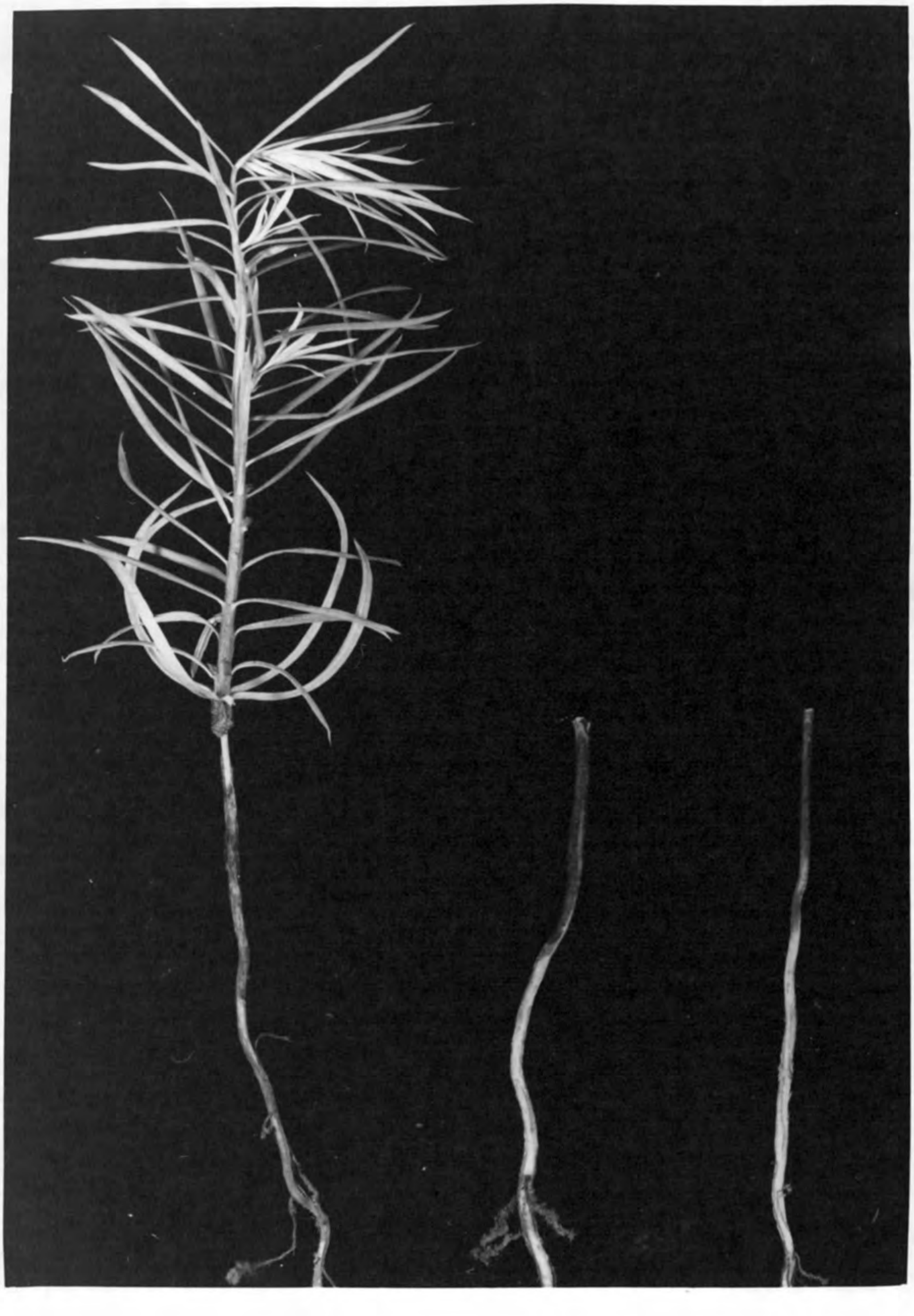
untouched, was found beside the seedling. Typical of damage during this time was the manner in which the cotyledons had been eaten. It looked as if the depredators had started from the very top and stopped at some distance from the base of the cotyledons. Relatively rare were instances in which some of the needles were eaten but one or more needles left uninjured. In the latter half of the growing season seedlings were cut close to the ground or halfway up the stem (Figure 20), but there was never a trace of the crown, indicating that it either had been eaten completely or had been carried away. The cuts were clean and did not show any tooth marks or other signs. Another, though less frequent, type of damage which led to the death of seedlings was the girdling of the stem directly underneath the lowest needles (Figure 20).

Damping-off fungi. Damping-off fungi accounted for the loss of 588 seedlings, or 3.6 per cent of the germinates. Diseased seedlings were recognized by a characteristic bluish-greenish tinge in the color of the stem and a curling of the needles. Isolations[3/] which were made from killed seedlings, showed that they had been attacked

---

3/ The isolations were made by Dr. R. L. Powelson, Department of Botany and Plant Pathology, Oregon State College.

Figure 20. Six-month old seedlings killed by animals. The seedling on the left was girdled underneath the lowest needles and the two seedlings on the right lost their tops.



by *Fusarium* spp. and *Rhizoctonia* spp.

Damping-off was confined to the earlier part of the growing season and seedlings killed by the disease were rarely older than six weeks. Reduction of light appeared to induce conditions that made seedlings more readily susceptible to damping-off, for mortality was highest on the heavily shaded seedbeds and lowest on those fully exposed to light. Seedbed materials on the other hand, had surprisingly little effect on mortality. Only light-burned soil seemed to provide more favorable conditions for damping-off fungi. Losses on this material under light and under heavy shade were consistently greater than on the other seedbeds.

Injury by heat. Heat, which accounted for the second largest share of total seedling losses, was the only physical factor of significance associated with mortality. In the 1958 growing season 4,093 seedlings, i.e., 24.8 per cent, were killed by heat. Another 41 seedlings, or 0.2 per cent, died between November 1, 1958 and April 1, 1959 of heat injuries which had occurred during the preceding summer.

Mortality was strongly influenced by the degree of exposure to light. On the open seedbeds, 53.0 per cent of the germinates succumbed to heat, while only 15.1

per cent were killed under light shade and none at all under heavy shade.

Obviously, the heaviest losses of seedlings may be expected on surfaces which are not protected against direct solar radiation. Furthermore, there can be little doubt that the nature of surfaces will be particularly important under such conditions. It was therefore attempted to test the effects of the unshaded seedbed materials on heat mortality by means of a X^2-test (Table 16).

The calculated X^2-value of 18.54 with 5 degress of freedom is significant at the 5 per cent level and indicates that a significant difference exists between the magnitude of heat mortality on the six seedbed materials. Further, X^2-tests (Table 17) show that the differences in seedling mortality are not significant between charcoal and mineral soil, hard-burned soil and litter, light-burned soil and litter, while significant differences exist between the mortality on all other materials that were compared with each other.

Resemblance to a Duncan series is suggested if the seedbeds are arranged in order of their seedling losses and the significance of differences in heat mortality is denoted (Table 18). Since the X^2-tests permit valid conclusions only for the significance of differences between

Table 16. X^2-test of the significance of difference between the numbers of Douglas fir seedlings killed by heat injuries on six different kinds of seedbed material.

	Charcoal	Light-burned soil	Hard-burned soil	Mineral soil	Litter	Sawdust	Totals
Seedlings killed by heat injuries	1,340	614	438	428	282	264	3,330
Seedlings not killed by heat injuries	1,022	616	295	313	300	398	2,944
Sample size	2,326	1,230	733	741	582	662	6,274

$$X = \frac{\frac{(1,022)^2}{2,326} + \frac{(616)^2}{1,230} + \frac{(295)^2}{733} + \frac{(313)^2}{741} + \frac{(300)^2}{582} + \frac{(398)^2}{662} - \frac{(2,944)^2}{6,274}}{\frac{3,330 \times 2,944}{(6,274)^2}}$$

$$= \frac{20.966}{1.131} = 18.54 \text{ with 5 degrees of freedom}$$

Table 17. Results of X^2-tests of the significance of differences between heat mortality on six seedbed materials.

Seedbed material	Heat mortality %	vs. Seedbed material	Heat mortality %	X^2-value with 1 DF	Significance at 5 per cent level
Charcoal	56.1	Hard-burned soil	49.9	12.24	significant
Charcoal	56.1	Light-burned soil	59.8	31.43	significant
Charcoal	56.1	Mineral soil	57.8	0.66	not significant
Charcoal	56.1	Litter	48.5	10.86	significant
Charcoal	56.1	Sawdust	39.9	54.20	significant
Hard-burned soil	49.9	Light-burned soil	59.8	17.84	significant
Hard-burned soil	49.9	Mineral soil	57.8	11.41	significant
Hard-burned soil	49.9	Litter	48.5	0.34	not significant
Hard-burned soil	49.9	Sawdust	39.9	17.42	significant
Light-burned soil	59.8	Mineral soil	57.8	0.60	not significant
Light-burned soil	59.8	Litter	48.5	16.70	significant
Light-burned soil	59.8	Sawdust	39.9	54.96	significant
Mineral soil	57.8	Litter	48.5	60.67	significant
Mineral soil	57.8	Sawdust	39.9	44.72	significant
Litter	48.5	Sawdust	39.9	9.26	significant

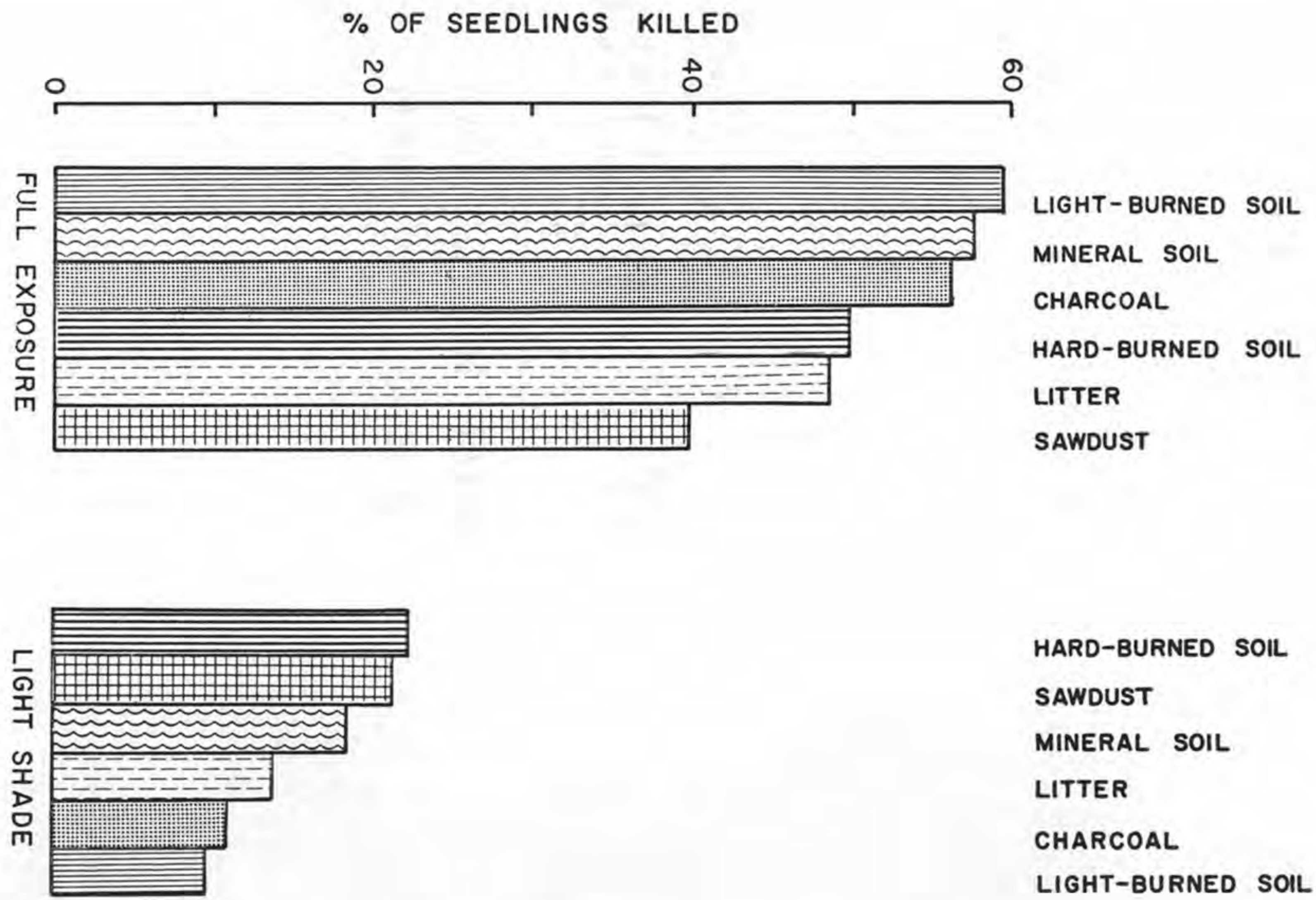
single pairs, statistical proof is not given for the significance of the order presented in Table 18.

Table 18. Seedbeds arranged in order of seedling losses by heat. The difference in mortality is not significant between seedbeds connected by a bar. The difference is significant between seedbeds not connected by a bar.

Seedbed Material	Heat Mortality %
Light-burned soil	59.8
Mineral soil	57.8
Charcoal	56.1
Hard-burned soil	49.9
Litter	48.5
Sawdust	39.9

Although the magnitude of seedling losses was influenced by the nature of the seedbed, the effect appears to have been dependent on the degree of exposure to light. On light-burned soil exposed to full light, for example, the proportion of losses by heat was higher than on any of the other materials, while on light-burned soil under light shade the percentage of heat mortality was lower than on any of the other seedbeds. A similar reversal of the magnitude of losses under the two conditions of light was noted on each seedbed material (Figure 21).

Figure 21. Percentage of losses of Douglas fir seedlings due to heat injuries during the 1958 growing season. Each bar represents the seedling losses of the five replications of the designated combination of seedbed material and exposure to light. The losses are expressed as a percentage of the total numbers of emerged seedlings for each combination of seedbed material and exposure to light.


% OF SEEDLINGS KILLED
0
20
40
60
FULL EXPOSURE
LIGHT-BURNED SOIL
MINERAL SOIL
CHARCOAL
HARD-BURNED SOIL
LITTER
SAWDUST
LIGHT SHADE
HARD-BURNED SOIL
SAWDUST
MINERAL SOIL
LITTER
CHARCOAL
LIGHT-BURNED SOIL

In regard to mortality, the effect of seedling age was perhaps even more important than the effect of seedbed materials. There can hardly be any doubt that germinates were most susceptible to heat injury shortly after emergence. Of the 3,300 seedlings which were killed in the 1958 growing season on fully exposed seedbeds, 46.3 per cent were less than two weeks old. The age effect was even more pronounced under light shade for there 1- to 14-day old seedlings constituted 62.8 per cent of the total losses by heat. Seedlings older than six weeks accounted for less than one-fourth of all heat casualties (Table 19).

On the open seedbeds, the date of emergence also showed a correlation with mortality. The later germination occurred, the greater was the proportion of germinates killed by heat (Table 20). However, such an effect was not evident on the seedbeds under light shade, presumably because temperatures did not increase as sharply with the advance of the season than they did on the surfaces of the open seedbeds.

The distribution of heat mortality (Figure 22) through the 1958 growing season is of interest for it shows clearly that the extremely hot weather in July and August was not reflected by any large increase of heat mortality. On the contrary, losses declined sharply after

Table 19. Douglas fir seedlings killed by heat injuries during the 1958 growing season tabulated according to the age at which they died.

	Age of seedlings in weeks									Total No. of seedlings lost by heat injuries
	0 - 2	2 - 4	4 - 6	6 - 8	8 -10	10-12	12-14	14-16	16+	
	Degree of exposure to light: 100 per cent									
No. of seedlings killed	1,540	666	354	159	99	84	188	132	108	3,330
Per cent of total heat/losses	46.3	20.0	10.6	4.8	3.0	2.5	5.6	4.0	3.2	100.0
	Degree of exposure to light: 75 per cent									
No. of seedlings killed	479	113	60	21	13	5	15	10	47	763
Per cent of total heat/losses	62.8	14.8	7.9	2.8	1.7	0.6	1.9	1.3	6.2	100.0

Table 20. Douglas fir seedlings killed by heat injuries during the 1958 growing season tabulated according to the period of their emergence.

Period during which seedlings emerged	Degree of exposure to light					
	100 per cent			75 per cent		
	No. of seedlings emerged	No. of seedlings killed	Per cent	No. of seedlings emerged	No. of seedlings killed	Per cent
Mar 18 to Mar 31	68	20	29.4	34	4	11.8
Mar 31 to Apr 14	727	213	29.3	422	37	8.8
Apr 14 to Apr 28	3,365	1,784	53.0	2,570	440	17.1
Apr 28 to May 12	1,540	945	61.4	1,236	164	13.0
May 12 to May 26	454	276	60.8	519	75	14.5
May 26 to Jun 9	29	17	58.6	72	7	9.7
Jun 9 to Jun 23	91	75	83.3	172	33	19.2
Jun 23 to Jul 7	-	-	-	23	2	8.7
Jul 7 to Jul 21	-	-	-	6	1	16.7

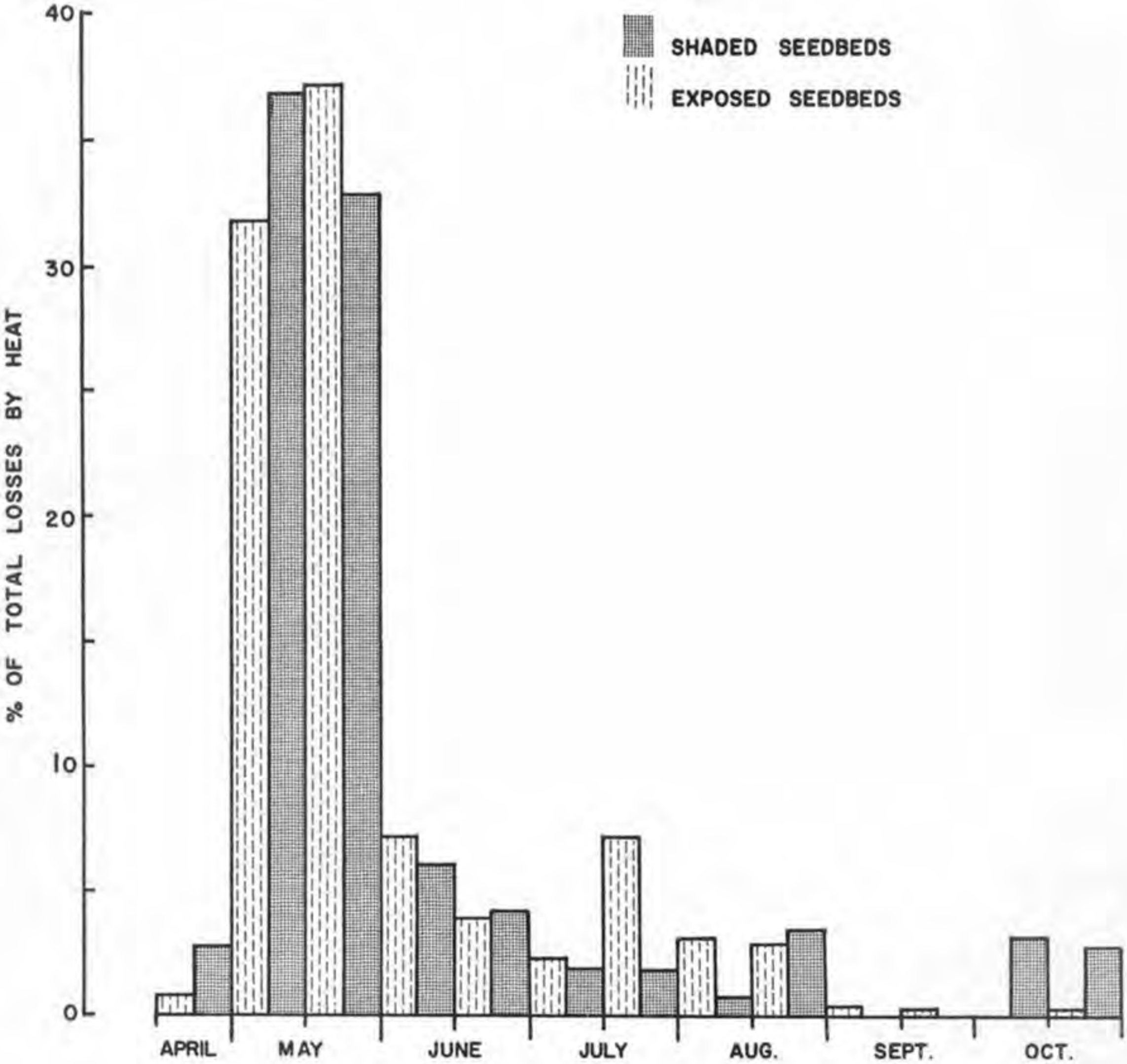


Figure 22. Distribution of heat mortality of Douglas fir seedlings through the 1958 growing season. Each bar indicates the magnitude of losses during one-half of the month indicated. The losses are expressed as a percentage of the total numbers of seedlings killed by heat from April 1 to October 31, 1958.

a high in May and remained low for the remainder of the season, except for a minor rise during the second half of July.

Heat injury was easily identifiable in the majority of cases. A lesion developed on the south side of the stem, usually two to five millimeters above the surface of the ground though in some instances the lesion appeared up to heights of 10 millimeters. Sometimes, when the seedcaps were still in the ground, lesions formed on the back of the curved hypocotyls. Generally, a lesion spread quite rapidly and formed a large constriction (Figure 23) that led to the toppling of the seedling. When seedlings were older than six weeks, the lesion appeared to spread slowly and the seedling remained erect after it had died. The size of lesions on seedlings killed at an age of three and one-half months is illustrated by Figure 24. Very characteristic was the appearance of seedlings which had received heat injuries but continued to live for several weeks or even months. Either the whole upper half of the stem was swollen (Figure 25) or a rather short section of the stem had a ball-like swelling (Figure 26). The needles on most of these seedlings remained green until the stems were broken by wind or rain closely underneath the swelling. Such a fracture is displayed by the left seedling in Figure 25.

Figure 23. Two weeks old Douglas fir seedlings killed by heat injuries. Note the large constrictions.

Figure 24. Douglas fir seedlings killed by heat injuries at the age of three and one-half months.

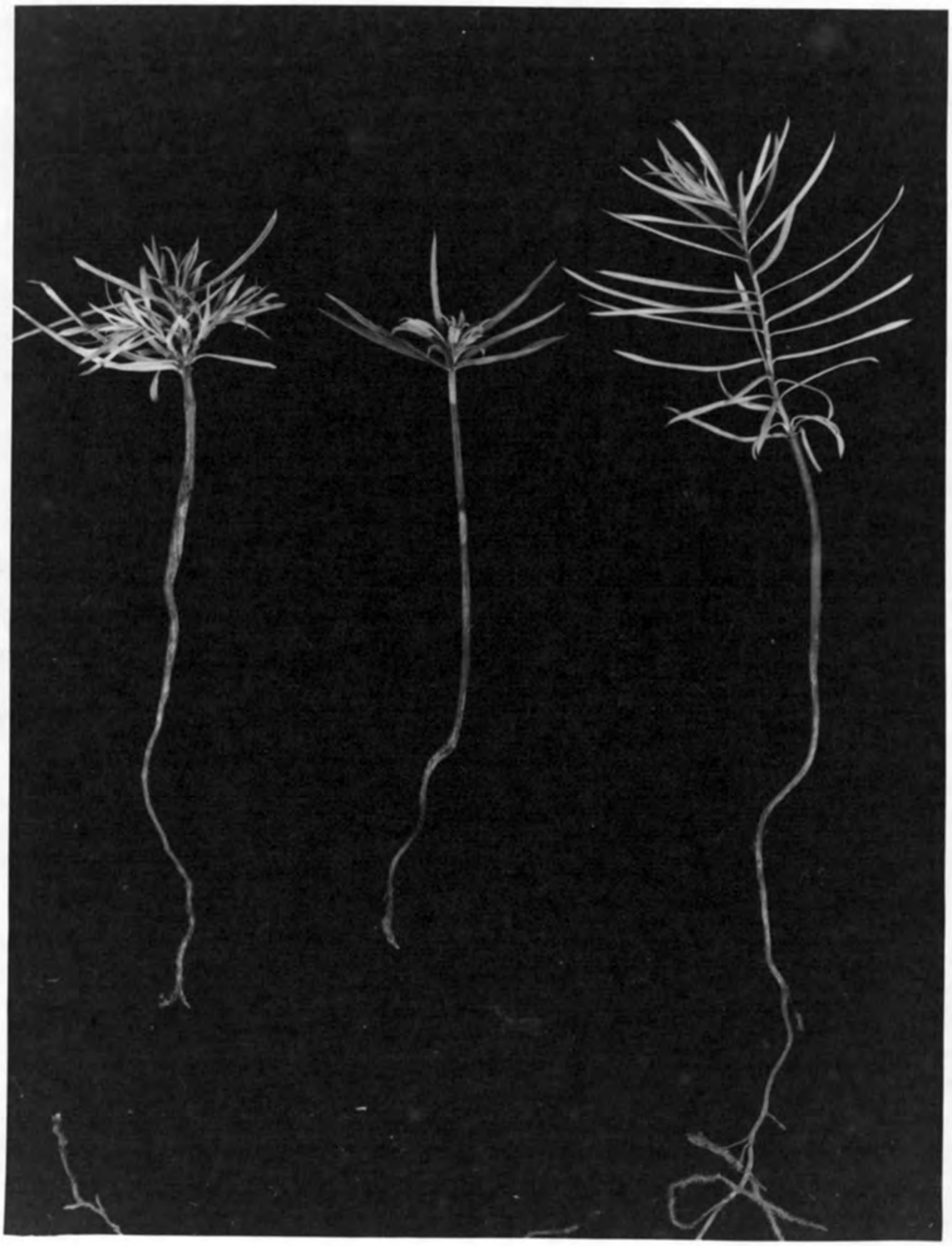


Figure 25. 11-month old Douglas fir seedlings that died in March 1959 as a consequence of heat injuries received during the preceding growing season.

Figure 26. One-year old Douglas fir seedling killed by several-month old heat injuries in March 1959. Note the ball-like swelling underneath the lowest needles.

Drought. Drought was the least important of all causes of mortality in the 1958 growing season. It accounted for the death of 17 seedlings, i.e., 0.1 per cent. These seedlings which had grown in hard-burned soil under heavy shade, died during September and ranged in age from two to four months. The entire seedling losses of the 1959 growing season, amounting to 41 seedlings, were also attributed to drought.

Frost. Frost was a minor cause of mortality killing only 47 seedlings, that is 0.3 per cent. Seedling losses were confined to charcoal and sawdust. This is probably due to the fact that the only frost to occur, came immediately after germination, and that the very first seedlings which had emerged were those on these two seedbed materials.

Discussion of causes of mortality

About 55 per cent of the total seedling losses during the 1958 growing season were attributed to biotic agents and 45 per cent to physical agents. Physical factors accounted for most of the mortality on the open seedbeds while biotic agents were the chief cause of losses on the shaded seedbeds. Full exposure and heavy shade proved to be equally adverse to seedling survival because the one favored physical and the other biotic agents of mortality. Light shade, on the other hand, apparently struck some kind of balance between the undesirable effects of full exposure and heavy shade, resulting in fewer seedling losses.

Animal depredations were responsible for the largest proportion of seedlings killed by biotic agents. The peaks of seedling losses in different seasons of the year indicate certain periods during which seedlings are most attractive to a particular animal. Deer, for instance, seem to prefer older seedlings and did not cause any appreciable mortality until December 1958. It may be mentioned that deer damage is easily identified for deer tear off, rather than cut, seedlings they eat.

Of all animal life the white-footed deer mouse (<u>Peromyscus maniculatus</u>) constitutes perhaps the most serious threat to the regeneration of Douglas fir. The role of deer mice as depredators of seeds has been generally recognized but their potential as eaters of seedlings is much less appreciated although Isaac (49) called attention to it. Recent laboratory studies by Lawrence (67) have shown that <u>Peromyscus</u> readily accepts seedlings in the cotyledon stage as food. They noted further that as soon as true needles developed, stem slipping ceased and mice confined their feeding to remaining cotyledons.

This habit gives an explanation for the appearance of many of the killed or damaged seedlings (Figure 19) found in the study area during spring. There can be little doubt that the major part of the early-season losses from animals was caused by deer mice.

The animal or animals responsible for the appreciable losses from mid-September to the end of October could not be identified. As has previously been described, seedlings were killed in two different manners. Either the stem was cut through halfway up from the ground or the seedling was girdled right underneath the lowest needles (Figure 20). The clean cut in those cases where the top had been severed did point to rodents as the cause, but there was no further evidence of their presence. On the other hand, the kind of tracks and droppings which were observed on the plots, suggested the activity of birds although for this the cuts seemed to be too smooth. The girdling was the most puzzling feature. Neither birds nor rodents are known to strip bark from first-year seedlings in this fashion. It might have been done by insects though references to this peculiar kind of damage were not found in the literature.

Damping-off fungi accounted only for a modest share of seedling losses. They were most severe under heavy shade while mortality from this disease was almost non-existent on the open seedbeds. The cooler seedbeds in heavy shade seemed to have favored the development of the fungi. Support for this notion can be found in the literature (89) but there appear to be situations where shade is of little or no importance with regard to the presence of fungi. Haig's (39) experiments failed to show consistent differences in damping-off losses between full-sun, part-shade, and full-shade stations.

Laboratory and nursery investigation (94, 117, 118) have indicated that neutral or alkaline media favor damping-off. Accordingly, higher losses should have occurred on the burned soils and charcoal than on the three other seedbed materials, but only light-burned soil showed consistently higher seedling mortality from damping-off. Under field conditions, however, other factors besides pH seem to be involved in favoring these fungi. Haig (39) and Barr (11) reported significantly higher losses in acid substrates such as duff composed predominantly of fir and pine or spruce needles.

From the standpoint of evaluating the effects of physical factors of seedling mortality, it was fortunate that the losses caused by animal life and fungi were concentrated on the shaded seedbeds. Large numbers of seedlings and small losses by biotic agents on the open seedbeds provide ideal conditions to study on an exposed south slope the consequences of an extremely hot and dry summer such as in 1958.

Throughout the entire growing season, unshaded seedbeds were exposed to direct insolation for eight to nine hours a day, except for short periods of cloudy or rainy weather in May and June. Seedbed temperatures which are considered critical for seedling survival prevailed from three to six hours on clear days. However, heat mortality did not increase concomitantly with the seasonal increase in temperatures. Most of the seedlings which died of heat injury were killed in May. As temperatures continued to climb during the next months, seedling losses declined sharply. The abatement of heat mortality in spite of rising temperatures forces the conclusion that seedlings must have become heat resistant to some degree in a rather early stage of their growth. Judging from the data in Table 19 this resistance was acquired at an age of approximately six weeks. Further evidence for this view is given by the fact that in the latter part of the growing season fewer seedlings had been killed outright by excessive heat than would appear from Figure 22. Many of the seedlings which died in the months following June, succumbed to heat injuries received earlier in the season. In some instances death on account of prior heat damage did not occur until winter or next spring.

Several workers (7, 86, 107, 125) have reported the development of heat resistance in approximately two-month old seedlings. They attributed this phenomenon to the desiccation and collapse of the formerly succulent cortex. The resulting air spaces within the cortex were believed to greatly impede the conduction of heat to the living tissues inside the stem. However, this view has not always been shared. Daubenmire (22) observed differences in tolerance of high soil surface temperatures between seedlings which could not be accounted for on the basis of relative thickness of insulating tissues in the vicinity of the soil surface. Silen (104) obtained results which indicated that seedlings were equally vulnerable to high temperatures at any age during the first growing season. These conflicting findings have an interesting implication. If drying of the cortex does not provide protection against high temperatures, then the varying behavior of seedlings in regard to the development of heat resistance must have a physiological basis related either to inherent qualities of the seedling or to preconditioning effects associated with the seedbed environment.

The variation in heat losses of seedlings between seedbed materials points to the nature of the surface as another important factor in heat mortality. However, the interpretation of the influence of seedbed materials on seedling losses poses a serious problem. Temperature measurements show that charcoal, litter, and mineral soil were heated more intensely and for longer periods of time than the other surfaces. In the case of sawdust, a good correlation exists between seedbed temperature and seedling mortality. It was the coolest material and it had the lowest percentage of seedlings killed by heat. But such a relationship is not apparent on litter; it was among the hottest seedbeds but losses were the lowest ones next to sawdust. Light-burned soil on the other hand, which was cooler than litter, had the highest percentage of heat mortality.

That the degree and duration of temperature required to kill a seedling may vary with different seedbed materials has long been recognized. Baker (7) proposed a widely accepted hypothesis to explain these differences. An internal temperature of 131°F will almost instantly kill the living cells of a seedling but there are different time lags according to the kind of seedbed before the lethal internal temperature is reached. Silen (104) found certain faults with this explanation and attempted to resolve the problem in terms of an energy budget. His calculations showed that the amount of energy available at the surface is not the same for all seedbed materials at a given temperature. He concluded that higher temperatures are required to kill a seedling on a well-conducting material having a high specific heat than on a poorly-conducting material having a low specific heat.

In the present study, greater mortality on litter than on mineral soil would have been in accord with this hypothesis but the opposite was the case. Vaartaja (127) was faced with the same situation and explained it in this manner. Due to the relatively steep temperature gradient between litter and the underlying soil, a seedling growing in litter conducts heat downward very efficiently. In the absence of a cover of litter, the temperature gradient between the surface and the underlying soil layers is not very pronounced. Therefore, downward conduction of heat by the seedling may not be as effective in mineral soil and death may result at a lower temperature than on litter.

Under laboratory conditions conduction and reradiation have to account for the dissipation of most of the energy at the seedbed surface because energy losses by convection are usually reduced to a minimum. In the field, however, energy losses by convection play a significant role. Therefore, the use of heat transfer calculations based on laboratory data has definite limitations in the interpretation of heat mortality in the field. This is perhaps best illustrated by the seedlings which grew on charcoal in the study area. This material is generally considered the worst possible seedbed because it absorbs more heat than any other surface. Temperatures above 150°F prevailed on charcoal at least one hour during many days in July and August 1958. Judging from the data presented by Silen (104), temperatures of 135°F should be lethal if they last for one hour. Theoretically all seedlings should have been killed but actually 32 per cent survived. The first question which comes to mind is, whether seedlings received protection of any kind. The bases of some seedling stems could conceivably have been shaded by coarse charcoal particles or other seedlings. During the noon hours when the seedbeds were hottest, however, protective shades were not cast because of the southern exposure. Neither was evaporative cooling a factor, for the seedbeds were dry. When dew fell during the night, all moisture had generally evaporated from the surface not later than one hour after sunrise. Cooling of the seedling's stem by the transpiration stream has been discounted (7, 101, 104) as a possible means of protection. There remain only two alternatives to account for the survivors, some as yet unknown biological mechanism of resistance, or convective cooling. The latter appears to be the most likely explanation in view of the frequent winds observed in the study area.

The heat casualties on the seedbeds shaded by cheesecloth demonstrated that light shade does not give complete protection from the effects of strong insolation. Like on the fully exposed seedbeds, the effect of age on mortality was clearly noticeable, losses being highest shortly after germination (Table 19). The pattern of heat mortality in regard to different surfaces was almost the reverse of that in the open. The reasons for this reversal are not apparent but it is possible that the effect of seedbed materials on heat mortality of seedlings was obscured under light shade by the relatively high losses due to biotic agents.

Lethal heat injuries were not observed during the second growing season. Heat damage of seedlings in their second year appears to be a rare occurrence and very few cases of it are reported in the literature (55).

The almost complete lack of mortality due to drought was a surprise, for in the second half of the growing season soil moisture began to become limiting and seedlings were under severe transpirational stress. The question of differentiating heat from drought injury may be raised. However, errors of this type would appear limited since only those seedlings which showed a lesion or constriction were counted as heat casualties. On the other hand, it has been observed (65, 104) that seedlings may die of heat without any external signs of injury. They dry out and turn red just as do seedlings killed by drought. In fact, it is more than likely that part of the large drought losses claimed in many field studies were actually losses from heat. Death may result from a combination of heat injury and moisture stress but there is no way of ascertaining whether this was the case.

It can be regarded as certain that moisture generally did not become a limiting factor in the study area. Two principal reasons may account for this circumstance. Enough moisture was stored in the soil by the abundant precipitation in spring so that seedlings could draw on this supply far into the summer. The absence of competing vegetation contributed probably most of all to the relatively slow depletion of soil moisture. When the amount of available soil water became critically low in August, the lack of competing vegetation was perhaps the deciding factor which enabled seedlings to persist through this dry period.

Roots had penetrated 10 to 15 centimeters deep into the soil by mid-August. Moisture in the uppermost soil layers was held by this time at or near 15 atmospheres tension while it was in general appreciably below this tension at 15 centimeters depth. Even though a larger amount of moisture was still present at the greater depth it was not easily available, and seedlings were doubtless under serious moisture stress. However, condensation of atmospheric moisture during the early morning hours may have helped to ease the moisture stress to some extent. Whether dew water can be absorbed directly through the leaves or whether it benefits plants by providing additional soil moisture is a matter of controversy. Stone (113), in a thorough review, cited numerous papers in which direct uptake of dew by a wide variety of plants had been reported. In greenhouse investigations, Stone and his collaborators (111) found that under conditions of soil drought artificial dew at night prolonged the life of Ponderosa pine seedlings as much as one month and a half. In a later study (114), such an effect of dew was reported for other western conifers also. From experiments designed to elucidate the mechanism involved, Stone (112) concluded "that the prolonged survival of pine seedlings in soil at the wilting point, when the tops receive dew at night, is due to a resaturation of the needle tissue and concomitant reduction in the amount of moisture removed from the root system." On the other hand, Arvidson (5), in his review of this subject, concluded that many investigators were unable to demonstrate direct water uptake by surface organs of higher plants.

Drought losses of seedlings in their second year of growth were just as low as in their first year. Seedlings which died in summer 1959 had without exception lost their leaders through browsing during the preceding winter. They may have expended most of their energy in building up a new crown rather than to enlarge their root system and were therefore more susceptible to moisture stress.

Another physical factor of mortality, namely frost, was of little importance in the study area. The temperature records indicate that conditions conducive to frost existed only in early spring. Losses by frost might have been higher if germination had begun a few days sooner.

Death by freezing is occasionally mentioned in regeneration studies but the symptoms are rarely described. Isaac (49) claimed that the symptoms of death by freezing and of death by heat are nearly identical, thus making it difficult to diagnose the cause of mortality. This situation was not encountered in the study area because seedlings killed by frost had a glassy appearance which was not noticed on those killed by heat.

Survival

6,312 seedlings, i.e. 38.2 per cent, lived through the 1958 growing season. On individual plots survival varied from zero to 75 per cent (Table 15, Appendix).

As has been pointed out in the preceding chapter, both full exposure and heavy shade favored mortality, and consequently fewer seedlings survived under these two conditions of light than under moderate shade (Table 22). The percentage of survivors varied on each seedbed material with the degree of exposure to light. For instance, mineral soil ranked third among seedbed materials exposed to full light, first among those under light shade, and fourth among those under heavy shade. However, a listing of seedbed materials in order of decreasing per cent survival of seedlings (Table 23) shows that under each light condition survival was usually highest on litter and sawdust.

One year later, on November 1, 1959, there were still 5,192 survivors, 31.5 per cent of the seedlings which had emerged in spring 1958. It is worth noting that the decrease in numbers of surviving seedlings was primarily due to mortality in the winter 1958/59 rather than to losses during the 1959 growing season. As has been mentioned earlier all plots remained fully exposed after November 1, 1958, but the effect of degree of exposure to light on survival in the 1958 growing season was still noticeable in fall 1959, for the highest percentage of survivors was found on seedbeds which had been shaded lightly in the preceding year (Table 23).

Table 22. Numbers of live Douglas fir seedlings present on November 1, 1958 and November 1, 1959 on six different seedbeds exposed to three different degrees of light intensity during the 1958 growing season. The number of seedlings present is expressed as both a percentage of the number of seedlings emerged, and as a percentage of the number of seeds sown. Each combination of seedbed material and light intensity represents five replications.

Type of seedbed	Seeds sown	Seedlings emerged		Seedlings present at the end of the 1st Growing Season (Nov. 1, 1958)			2nd Growing Season (Nov. 1, 1959)		
		No's	%	No's	Per cent of seedlings emerged	Per cent based on seeds sown	No's	Per cent of seedlings emerged	Per cent based on seeds sown
Exposure to light during the 1958 growing season: 100 per cent									
Charcoal	2,500	2,326	93.0	756	32.5	30.2	597	25.7	23.9
Hard-burned Soil	2,500	1,230	49.2	417	33.9	16.7	378	30.7	15.1
Light-burned Soil	2,500	733	29.3	141	19.2	5.6	118	16.1	4.7
Mineral Soil	2,500	741	29.6	262	35.4	10.5	213	28.8	8.5
Litter	2,500	582	23.3	222	38.1	8.9	200	34.4	8.0
Sawdust	2,500	662	26.5	272	41.1	10.9	219	33.1	8.8
Totals	15,000	6,274	41.7	2,070	32.9	13.8	1,725	27.5	11.5
Exposure to light during the 1958 growing season: 75 per cent									
Charcoal	2,500	1,719	68.8	854	49.7	34.2	808	47.0	32.3
Hard-burned Soil	2,500	1,213	48.5	552	45.5	22.1	508	41.9	20.3
Light-burned Soil	2,500	724	29.0	328	45.3	13.1	242	33.4	9.7
Mineral Soil	2,500	636	25.4	401	63.1	16.0	344	54.1	13.8
Litter	2,500	495	19.8	267	53.9	10.7	225	45.5	9.0
Sawdust	2,500	267	10.7	159	59.6	6.4	119	44.6	4.8
Totals	15,000	5,054	33.7	2,561	50.7	17.1	2,246	44.4	15.0
Exposure to light during the 1958 growing season: 25 per cent									
Charcoal	2,500	1,965	78.6	646	32.9	25.8	454	23.1	18.2
Hard-burned Soil	2,500	1,199	48.0	284	23.7	11.4	210	17.5	8.4
Light-burned Soil	2,500	499	20.0	186	37.3	7.4	151	30.3	6.0
Mineral Soil	2,500	621	24.8	210	33.8	8.4	116	18.7	4.6
Litter	2,500	551	22.0	226	41.0	9.0	194	35.2	7.8
Sawdust	2,500	331	13.2	129	39.0	5.2	96	29.0	3.8
Totals	15,000	5,166	34.4	1,681	32.5	11.2	1,221	23.6	8.1
Grand Total	45,000	16,494	36.7	6,312	38.2	14.0	5,192	31.5	11.5

Table 23. Seedbed materials listed in order of decreasing per cent survival of seedlings.

Exposure to light during the 1958 growing season					
100 per cent		75 per cent		25 per cent	
Type of seedbed	Survival per cent	Type of seedbed	Survival per cent	Type of Seedbed	Survival per cent
November 1, 1958					
Sawdust	41.1	Mineral soil	63.1	Litter	41.0
Litter	38.1	Sawdust	59.6	Sawdust	39.0
Mineral soil	35.4	Litter	53.9	Light-burned soil	37.3
Hard-burned soil	33.9	Charcoal	49.7	Mineral soil	33.8
Charcoal	32.5	Hard-burned soil	45.5	Charcoal	32.9
Light-burned soil	19.2	Light-burned soil	45.3	Hard-burned soil	23.7
November 1, 1959					
Litter	34.4	Mineral soil	54.1	Litter	35.2
Sawdust	33.1	Charcoal	47.0	Light-burned soil	30.3
Hard-burned soil	30.7	Litter	45.5	Sawdust	29.0
Mineral soil	28.8	Sawdust	44.6	Charcoal	23.1
Charcoal	25.7	Hard-burned soil	41.9	Mineral soil	18.7
Light-burned soil	16.1	Light-burned soil	33.4	Hard-burned soil	17.5

On the other hand, if listed in order of decreasing per cent survival, the seedbed materials did not rank in the same order at the close of the second growing season as they did at the end of the first.

Charcoal and hard-burned soil, however, appear as the most favorable media for seedling establishment when the numbers of live seedlings at the end of the 1958 growing season are expressed as a percentage of the seeds sown instead of as a percentage of the germinates (Table 22). Taking the amounts of seeds sown as a point of reference also permitted statistical treatment of the survival data. An analysis of variance (Table 24) indicated that the seedbed materials were the only significant source of variation. The significance of differences between the numbers of seedlings on the six seedbeds by November 1, 1958 was tested with a multiple range F-test. (Table 25). Stocking on charcoal was found to be significantly higher than on mineral soil, light-burned soil, litter, and sawdust, but the position of hard-burned soil could not be clearly determined by this test. The numbers of seedlings on hard-burned soil were neither significantly lower than those on charcoal, nor significantly higher than the ones on the rest of the seedbed materials.

The seedling losses during the next 12 months reduced overall stocking but did not efface the differences

Table 24. Analysis of variance of numbers of Douglas fir seedlings present November 1, 1958 on six different kinds of seedbeds exposed to three different degrees of light intensity.

Source of Variation	SS	DF	MS	F	Significance at 5 per cent level
Replication	28,684.2888	4	7,171.0725	2.20	Not significant
Seedbed (S)	135,686.6666	5	27,137.3340	8.34	Significant
Intensity of light (L)	12,964.4666	2	6,482.2350	1.99	Not significant
S x L	8,782.8668	10	878.2867	0.27	Not significant
Error	221,346.1112	68	3,255.0898		
Total	407,464.4000	89			

Table 25. Multiple range F-test of mean numbers of seedlings present November 1, 1958 on six different kinds of seedbeds.

Seedbed:	Sawdust	Light-burned soil	Litter	Mineral soil	Hard-burned soil	Charcoal
Mean number of seedlings per plot:	37.3	43.7	47.7	58.2	83.5	150.4

Note: Any 2 means not underscored by the same line are significantly different at the 5 per cent level of significance.

Any 2 means underscored by the same line are not significantly different.

between seedbed materials in regard to stocking. At the close of the 1959 growing season there were still more seedlings on either charcoal or hard-burned soil than on any of the other seedbed materials (Table 22).

<u>Discussion of survival</u>

There can be little doubt that lightly shaded seedbeds, regardless of the materials they were composed of, provided the most favorable conditions for seedling survival (Table 22). The reasons for the beneficial effect of light shade are probably twofold. It prevented excessive heating of the seedbeds but not enough light was intercepted to give animals the feeling of protection which they apparently felt under heavy shade.

The influence of seedbed materials on survival was largely confined to surfaces exposed to direct sunlight, for seedling losses on shaded seedbeds were mainly caused by animal depredations which appeared to be unrelated to seedbed materials. It is not surprising that on the exposed surfaces survival was best on sawdust since it was the coolest of all seedbed materials. But why survival on litter, a very hot seedbed, was almost as high as on sawdust is difficult to explain. In general, the differences between the exposed seedbed materials in regard to survival were relatively small which seems to suggest that none of them is entirely unsuitable on account of its thermal properties.

However, survival constitutes only one aspect of seedling establishment. The numbers of seedlings present on the various seedbeds at the end of the 1958 and of the 1959 growing seasons make it clear that survival by itself cannot be regarded as an entirely satisfactory criterion for the influence of seedbed conditions upon the establishment of seedlings. The greatest numbers of seedlings were not found on the seedbed materials with the highest seedling survival, sawdust and litter, but on charcoal and hard-burned soil which had been the best media for germination. This suggests that the initial advantage of high germination may often be of greater importance to seedling establishment than relatively high survival.

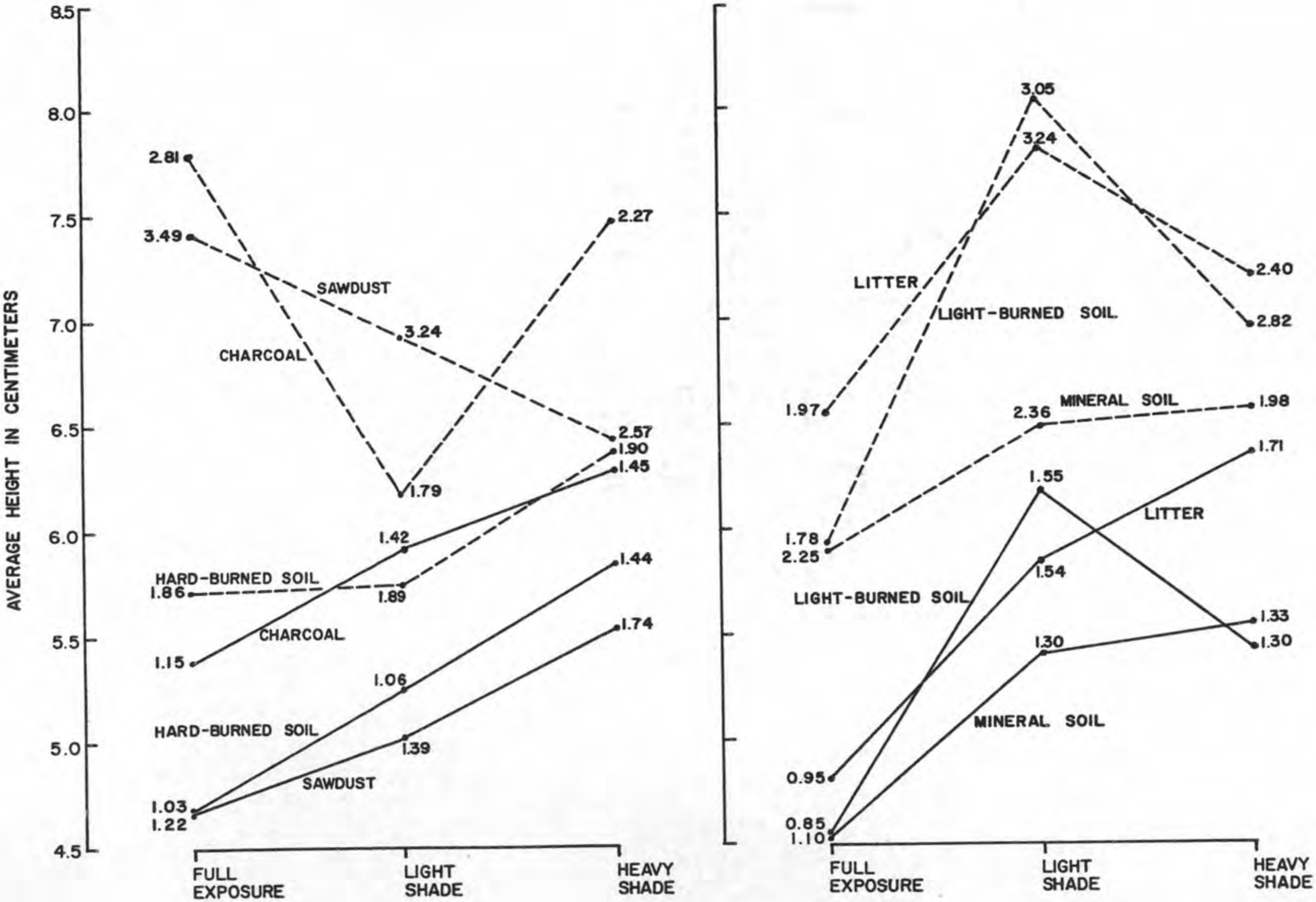
Development of seedlings

Most of the seedlings which survived the hot and dry summer of 1958 had grown considerably and looked vigorous. As it became obvious early in the season that seedlings were growing well, an attempt was made to determine whether their development was influenced by different seedbed conditions. The height of all living, uninjured seedlings in the study area was measured in July and in September. When cessation of height growth was noted, the setting of terminal buds was recorded at two-week intervals. Root development was not studied until late fall to avoid disturbance of the seedbeds while seedlings were still growing.

Height growth. In July 1958, at the time of the first measurements, seedlings were approximately two-month old and their heights ranged from 2 to 10 centimeters. For each seedbed material the average height of seedlings increased with a decrease in light intensity (Figure 27) except for light-burned soil where average height of seedlings was greater under light shade than under heavy shade. In general, the variations in the heights of individual seedlings were greater under shade than in the open which is indicated by the higher standard deviations of average heights under lower light intensities. Height growth of seedlings was not consistently better on any one of the seedbed materials under all three conditions of light.

When measurements were taken again in mid-September, about 30 per cent of the seedlings could not be included because they had lost their leaders as a result of browsing. Since seedlings so injured had usually been the tallest ones on each plot, their exclusion resulted in lower values than would otherwise have been obtained from

Figure 27. Average height of first-year seedlings on six kinds of seedbed materials under three different exposures to light. The variation of seedling heights for each combination of seedbed material and exposure to light is indicated by the standard deviation given for each average height.


AVERAGE HEIGHT IN CENTIMETERS
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
2.81
3.49
SAWDUST
3.24
CHARCOAL
2.27
2.57
1.90
1.45
1.79
1.42
HARD-BURNED SOIL
1.86
1.89
1.44
CHARCOAL
1.15
1.74
1.06
HARD-BURNED SOIL
1.39
SAWDUST
1.03
1.22
FULL EXPOSURE
LIGHT SHADE
HEAVY SHADE
3.05
3.24
LITTER
LIGHT-BURNED SOIL
2.40
2.82
1.97
2.36
MINERAL SOIL
1.98
1.71
1.55
LITTER
1.78
2.25
1.54
LIGHT-BURNED SOIL
1.33
1.30
1.30
MINERAL SOIL
0.95
0.85
1.10
FULL EXPOSURE
LIGHT SHADE
HEAVY SHADE

the second series of measurements. But even these values show (Figure 27) considerable height increment during the two month period since July. The size of seedlings ranged from 3 to 21 centimeters indicating that some had grown as much as 11 centimeters during a period of eight weeks. However, the relationship between seedling height and degree of exposure to light was different from the one apparent in July (Figure 27). Only seedlings on hard-burned soil and mineral soil still had the greatest average height in heavy shade. Seedlings on litter and light-burned soil were tallest in light shade while those on charcoal and sawdust were highest in the open.

Nearly all seedlings in the study area were badly browsed during the winter and became short and bushy as a consequence of the injuries suffered. During the 1959 growing season most seedlings recovered remarkably and many developed leaders that were 20 to 30 centimeters high.

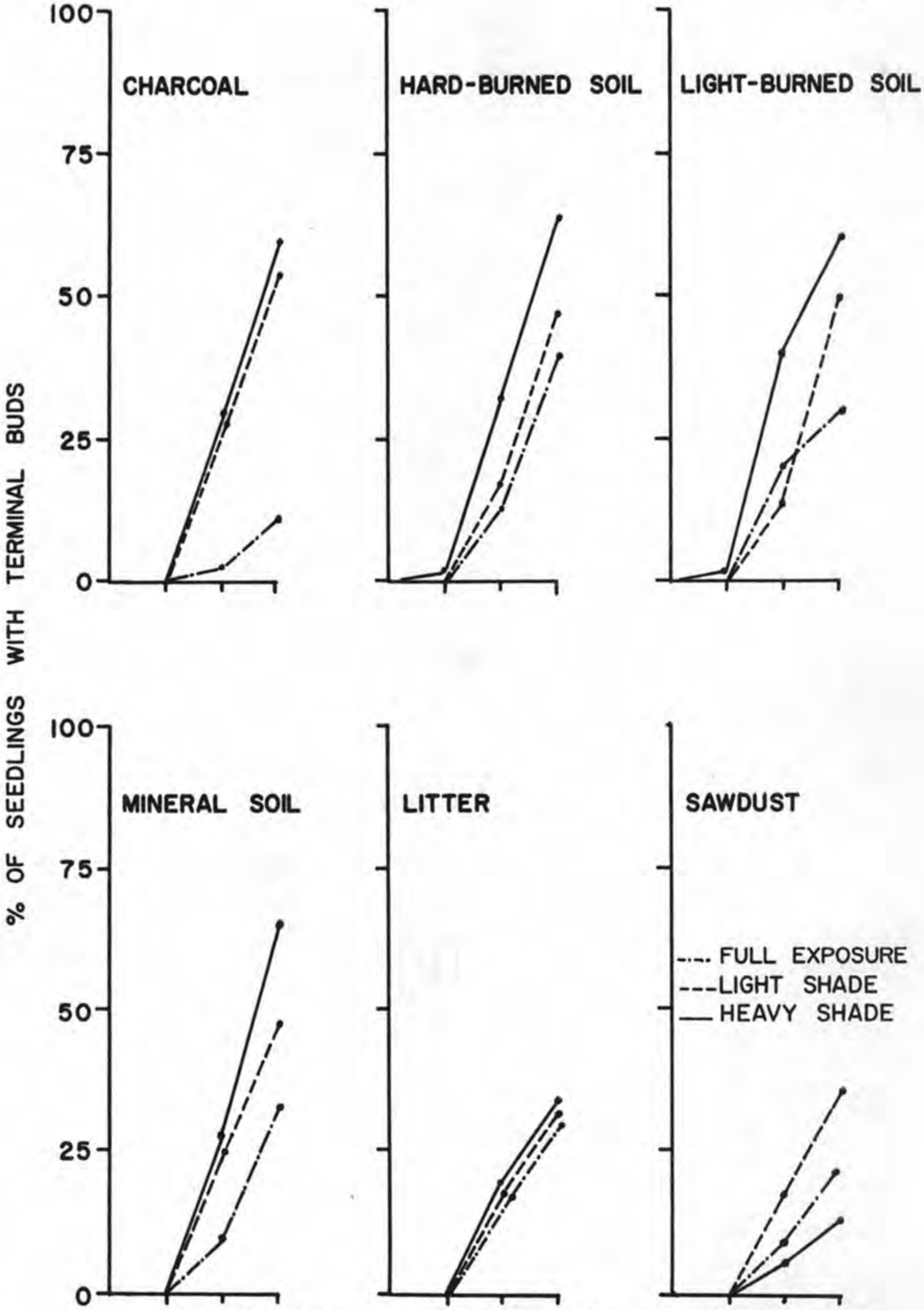
Seedling development during 1958 and 1959 is shown by Figures 1-20 in the Appendix. The photographs depict plots which were not shaded during the 1958 growing season.

Setting of terminal buds. Accurate counts of seedlings which had set terminal buds were kept only until September 22, 1958. Severe browsing damage made it impossible to continue observations after this date. Because of the sharply increasing seedling mortality in October, all percentage figures were based on the numbers of seedlings present at the end of September.

A few seedlings on hard-burned and on light-burned soil under heavy shade became dormant during mid-August. After August 25, the numbers of dormant seedlings increased steadily and by September 22, the time of the last count, approximately half of all seedlings in the study area had set terminal buds. As long as the onset of dormancy could be followed, it occurred more frequently under shaded than on exposed seedbeds except on sawdust (Figure 28). On litter the percentage of seedlings going into dormancy prior to September 22 was only slightly higher under shade than in the open. Development of terminal buds appeared to be considerably retarded on seedlings growing in both sawdust and litter.

Root development. In November 1958, 180 seedlings, ten from each combination of seedbed material and degree of exposure to light, were dug out for root examination. Length and spread of the roots and the numbers of laterals were recorded, but lengths of the tops were not measured because most of the seedlings had lost their leaders through browsing.

Figure 28. Percentages of seedlings which set terminal buds prior to September 22, 1958. Percentages are based on the numbers of seedlings present for each combination of seedbed material and degree of exposure to light.


% OF SEEDLINGS WITH TERMINAL BUDS
CHARCOAL
HARD-BURNED SOIL
LIGHT-BURNED SOIL
MINERAL SOIL
LITTER
SAWDUST
100
75
50
25
0
FULL EXPOSURE
LIGHT SHADE
HEAVY SHADE
AUG. 25
SEPT. 8
SEPT. 22

The average length of roots was greatest under light shade although it differed very little from that in the open and under heavy shade (Table 26). Average width of the root system and average numbers of laterals on the other hand, decreased with decreasing light intensity. A relationship was noticeable between seedbed material and length of roots. Seedlings which grew in litter and sawdust had usually the longest roots under each of the three degrees of exposure to light. Root length of seedlings on charcoal in light shade was relatively short, but in the open and in heavy shade it was equal to that of seedlings in litter and sawdust. The shortest roots had been developed by seedlings growing in hard-burned soil. Unlike the length of roots, their spread and the numbers of laterals did not show any consistent differences with seedbed materials.

Discussion of seedling development

Height growth of seedlings during both the first and second year was somewhat better than has usually been reported for this region. Of especial interest was the vigorous growth of seedlings on fully exposed seedbeds during the unusually hot summer of 1958. Isaac (49) found that first-season seedlings become only 2.5 to 5.0

Table 26. Results of root measurements on first-year Douglas fir seedlings in November 1958. The values for seedlings from each combination of seedbed material and degree of exposure to light represent the average of ten measurements.

Type of Seedbed	Degree of exposure to light in per cent: 100			75			25		
	Ave. root length in mm	Ave. root spread in mm	Ave. No. of laterals	Ave. root length in mm	Ave. root spread in mm	Ave. No. of laterals	Ave. root length in mm	Ave. root spread in mm	Ave. No. of laterals
Charcoal	172	55	34	159	35	30	178	23	38
Hard-burned soil	120	31	30	140	27	20	103	24	21
Light-burned soil	158	33	32	171	31	34	123	26	17
Mineral soil	154	67	31	127	28	20	150	34	27
Litter	168	32	24	188	28	33	208	21	21
Sawdust	174	34	28	190	30	20	177	22	21
Average	158	42	30	163	30	26	157	25	24

centimeters tall and seldom exceed an average height of 10.0 centimeters during their second year of growth. High temperatures and insufficient moisture are generally held responsible for poor growth on such extreme sites but the levels at which these factors begin to impair the growth of Douglas fir seedlings have not been established.

Reduction or even cessation of growth at high temperatures has been attributed to the differential effects of temperature on photosynthesis and respiration. At lower temperatures, the ratio of photosynthesis to respiration is larger than 10 while at higher temperatures respiration is increased relatively more and thus lower P/R ratios are found. For most plants, temperatures between 77°F and 86°F appear to result in an optimal P/R ratio (24, 130). In the study area, temperatures in the vicinity of the crowns of seedlings were above this range of optimum temperatures on many days for as long as three to five hours. At 2.5 centimeters height, temperatures in excess of 90°F were recorded during more than 70 days in the 1958 growing season.

However, not only day temperatures but also the relation between day and night temperatures must be considered in evaluating the effects of temperature on growth. Decreased growth has been observed with many plants if day and night temperatures were constant or if nocturnal temperatures were only slightly below day temperatures. Went (130) attributed decreased growth under relatively high night temperatures to slower translocation of sugars to the growing regions while other workers (24, 76) considered the increased use of food in respiration at higher temperatures a more probable explanation. Kramer (57), who used daily amplitudes of 0°F, 12°F, and 22°F in his experiments with Loblolly pine, noted the best growth when the temperature difference was largest. Hellmers and Sundahl (41) found that first-year Douglas fir seedlings showed optimum growth with a diurnal variation of 18°F while a diurnal variation of 28°F inhibited growth. These findings suggest that large differentials between day and night temperatures up to a certain range are beneficial to growth. However, it must be kept in mind that in all these investigations two fixed temperatures were alternated while under field conditions a gradual change occurs through a whole range of temperatures. The question remains whether a gradual change has the same effect as an abrupt change.

Differences of 30° to 40°F between day and night temperatures, such as were recorded in the study area during a large part of the growing season, probably influenced seedling growth appreciably. Perhaps the low night temperatures were effective by compensating for the high day temperatures which were most likely above optimum.

Turning to the effects of soil moisture conditions on the growth of seedlings, some brief comments on the physical properties of the soil in the study area and early root development of seedlings seem appropriate. The soil has a friable consistence throughout the upper horizons (see soil description p. 21) which is characteristic of latosolic soils (Youngberg 133). The clays are of the kaolinitic or non-expanding 1 - 1 lattice type and the soil is therefore not subject to cracking when dry. As was mentioned previously, the range of moisture availability at low tensions, i.e. below one atmosphere, is relatively narrow in this soil (Figures 13-15). The favorable structure of the soil permits easy penetration by roots, and when killed seedlings were removed it was observed that they had developed roots 6 to 10 centimeters long in the first two months after germination. The roots of the seedlings generally grew straight downward for about two months before lateral rootlets were formed and even afterwards development of lateral roots was not very pronounced during the first growing season (Table 26).

Depletion of soil moisture in the second half of the 1958 growing season was not serious enough to result in appreciable seedling mortality but nevertheless it might have affected the development of seedlings. Much evidence has accumulated in recent years that the growth of plants is substantially reduced at soil moisture tensions between 1 and 15 atmospheres (105, 108). In the study area, soil moisture tensions exceeded 1 atmosphere to at least 15 centimeters depth from mid-July to the end of August (Figures 13-15). As far as can be judged from seedlings which were removed, roots had extended little beyond the upper 20 centimeters of the soil. This seems to exclude the possibility that moisture in deeper soil layers was tapped. The restriction of roots to the surface horizon in which moisture was held at relatively high tensions during the latter part of the growing season would indicate the possibility of reduced seedling growth. However, one reservation has to be made at this point. While soil moisture is characterized more satisfactorily by its tension than by other means, it is still an incomplete expression of the properties of soil moisture which may affect growth. Although tension shows the negative pressure against which the plant must work, it neglects osmotic effects and gives no indication of either the amount of water which may be obtained in a given tension range or of the resistance to water movement from soil to plant.

Whatever effect moisture may have had on growth, the differences in height between seedlings on the six seedbed materials cannot be explained on the basis of the soil moisture data. They show a rather uniform depletion of soil water under all seedbeds as the growing season advanced (Figures 13-15).

Differential availability of nutrients under the six seedbed materials may be considered as a possible cause for the observed variations in height growth. The nutrient levels required for the growth of Douglas fir are not yet established (37) except for indications that seedlings will suffer from nitrogen deficiencies if the content of total nitrogen in a soil is less than 0.10 to 0.12 per cent. Analysis of two soil samples (page 22) shows a slightly higher percentage of nitrogen, 0.17 per cent, for the surface horizon in the study area. Whether the amounts of Ca, Mg, K, and P determined in this analysis indicate a low or a high nutrient level in regard to Douglas fir growth is not certain. Gessel and Walker (38) have emphasized that the whole concept of availability of elements in soils has to be substantiated, or perhaps modified for coniferous species before results of soil tests can be used to evaluate the nutrient status of forest soil in regard to tree growth. It was shown by these two workers that certain nutrients, such as P, are more readily available to coniferous seedlings than to some agricultural crops. Mycorhizal relations of conifers are probably of considerable importance as far as availability of some elements is concerned. Schaedle (96) found that Douglas fir seedlings in their first year of growth removed only small amounts of nutrients from the soil but still responded to fertilizer treatments, especially with nitrogen. Some of the seedbed materials in the study area may have had more available nutrients than others, but this did not become apparent in the growth responses of seedlings.

In this connection it is of particular interest that on the unshaded seedbeds height growth was best on charcoal, litter and sawdust although the latter two were probably unfavorable from the standpoint of nutrition. The application of undecomposed sawdust has repeatedly been found to depress the growth of coniferous and deciduous tree seedlings (23, 96). Undoubtedly, a major disadvantage of sawdust is its high C/N ratio which results in the fixation of nitrogen by cellulose-decomposing organisms. In some instances tannins and other organo-solubles present in certain types of sawdust may have amplified the adverse effects. Litter containing relatively large amounts of twigs would likewise have an unfavorable C/N ratio. But charcoal, litter, and sawdust are good insulators and kept the underlying soil cooler during the summer than did the mineral seedbed materials. In view of the high soil temperatures in the study area this cooling effect may have been of considerable importance for seedling growth. Cessation of root growth at temperatures above 95°F was observed in first-year loblolly pine seedlings by Barney (1) and in three-year old apple and pear plants by Nightingale (85). This worker found also that at temperatures between 85° and 95°F newly formed roots were deficient in carbohydrates while older roots contained unusually high concentrations of starch which was attributed to the inhibiting effects of these high temperatures on the enzymatic hydrolysis of starch. Dearth of carbohydrates limits growth largely because it checks synthesis of new cell-wall materials and may indirectly limit the synthesis of protoplasm for carbohydrates are required in amino-acid synthesis.

These findings demonstrate the severe consequences of high soil temperatures although it should be pointed out that the soil was evenly heated in the experiments of Barney and of Nightingale while a pronounced temperature gradient prevailed from the surface to the deeper soil layers in the study area. Such a temperature stratification in the soil may have less adverse effects on growth than a uniformly high soil temperature.

The influence of the shade treatments on seedling growth was not consistent throughout the growing season and is difficult to interpret. In the first half of the summer, seedlings were tallest under shade, a response also noted by Smith (107) in first-year seedlings of eastern white pine. Full exposure to light sometimes has a stunting effect on growth because light rich in blue and violet tends to inhibit elongation (79). But no explanation can be advanced why seedlings on different kinds of seedbeds showed differential responses to light during the latter part of the growing season.

The more frequent occurrence of an early beginning of dormancy in seedlings under shade seems to suggest that the shade covers created conditions conducive to early cessation of extension growth. The shade covers may have further reduced the effective daylength when the days became shorter in fall, but several reservations must be presented concerning this interpretation. While daylength has often been demonstrated to be of importance in inducing dormancy (129) the effects of temperature, moisture and mineral nutrients have likewise to be considered (95). Apart from the influence of these external environmental factors, the duration of extension growth is apparently also affected by certain aging processes of an endogenous nature (18) as well as by hereditary characteristics (46). A field study with inadequate control over the environment, however, does not permit a proper assessment of the relative importance of these various factors.

GENERAL DISCUSSION

The practice of clear-cutting in the Douglas fir region constitutes a compromise between the necessity for an economically feasible method of logging and an attempt to meet the high light requirements for Douglas fir reproduction. If seed supply is not a problem, clear-cutting will be frequently followed on most sites by satisfactory restocking. The complete removal of the old stand on a south slope, however, appears to be an undesirable practice since it results in an environment which is adverse to the establishment of a new crop of trees. A shelterwood-type of cutting on such severe sites probably would create less serious regeneration problems and might be more economical than clear-cutting in the long run.

The 1958 trial in the Corvallis Watershed has demonstrated the feasibility of direct seeding on a south slope but this does not imply that a formula has been found which will guarantee success on every such site. However, the results of the present study show that the chances for success of direct seeding are greatly improved in the absence of competing vegetation.

Perhaps the most effective measure in this regard would be to seed immediately after logging operations are terminated. Clear-cuts remain free of vegetation for about a year and seedlings do not face competition for moisture during this period. By the time the successional flora appears, most seedlings will have root systems developed well enough to be in a position to compete more efficiently for moisture. Information is scarce on the amounts of water removed by the vegetation on cut-over lands but what little data are available show the loss to be substantial. For instance, Haig (39), in comparing the relative amounts of soil water lost by transpiration and by evaporation on a north slope, noted that soil moisture loss at the 3- to 6-inch soil level from transpiring vegetation was more rapid than the moisture loss from the surface layer of the soil by evaporation. The experiments with nurse crops for Douglas fir seedlings have likewise shown how rapidly soil moisture is depleted by herbaceous vegetation. The shade provided by the natural vegetation developing after clear-cutting, or by a planted nurse crop, lowers soil surface temperatures to some degree but this advantage may be counteracted by competition for moisture. The observations made during the present investigations suggest furthermore that shade which is given by herbaceous plants may not substantially reduce evaporative losses of soil moisture nor will it afford complete protection of seedlings from heat injury.

It should be pointed out that the absence of competing vegetation is not necessarily a safeguard against drought. In areas where precipitation is comparatively low, as in the foothills of the Coast Range of western Oregon, or on sites which have very shallow soils, drought is most likely to remain a major hazard to seedling establishment. Direct seeding should not be attempted at all under such conditions.

Even if the danger of drought conditions is reduced there is still the problem of high soil surface temperatures. The extent of seedling survival on the fully exposed surfaces in the study area gives reason to believe that a stand of seedlings will not be completely decimated if heat is the only significant factor of mortality. None of the seedbed materials was found to be unsuitable for the establishment of seedlings because of its thermal properties. In this connection, charcoal should be mentioned in particular. Because of the high temperatures it reaches, this material is unanimously regarded as absolutely unsuitable as a seedbed. This view appears to be an oversimplification. On a sun-parched south slope, other seedbed materials may attain the same or sometimes even higher temperatures than charcoal. Furthermore, it has to be realized that seedling survival cannot be interpreted solely in terms of seedbed temperatures. Temperature measurements do not give an adequate estimate of the amounts of heat energy which are received and which are lost by a seedbed, but, as Silen (104) has shown, the magnitude of this heat transfer has to be known if a seedbed is to be evaluated properly with regard to its influence on seedling survival.

From the standpoint of seedling establishment, the effect of seedbed materials on germination was found to be far more significant in the present study than their influence on survival. After two growing seasons, the greatest numbers of seedlings were left on the seedbeds on which germination had been highest rather than on the seedbeds on which seedling mortality had been lowest. This indicates that the initial advantage of high germination was not offset by greater mortality. Essentially similar observations must have been made by Garman (34) for he wrote "Slow restocking appears to be more a reflection of germination and pre-germination conditions than of later loss of seedlings."

Seedbeds preserving moisture are undoubtedly favorable media for germination on sites which are subject to rapid desiccation. It was found in this study that materials which contain numerous coarse particles were the most efficient ones in retaining moisture because evaporation occurred very slowly from underneath these particles. The circumstance that germination was consistently highest on charcoal, even when moisture was not a limiting factor, suggests the presence of some chemical agent stimulating germination, but whether chemical characteristics of seedbed materials are of any importance in influencing germination cannot be decided on the basis of this finding. The few investigations (3, 98, 118) which have been concerned with the influence of chemical characteristics of the substrate on germination have yielded conflicting results and further work will be necessary to clarify this problem.

Apart from the effects of seedbed materials, the time of seeding appreciably influences germination. It has been shown repeatedly (19, 35, 66) that application of seeds in fall or winter results in much better germination than seeding in spring. Early seeding is particularly important on south slopes to take advantage of the moisture still present on the seedbeds at the beginning of spring. Early germination in turn will increase the chances for seedling survival since the older the seedlings are when the soil starts to attain high temperatures, the fewer seedlings are likely to be killed by heat injuries.

Animal depredations, especially by rodents, are still a major threat to the success of direct seeding. The almost complete destruction of seeds in the 1957 trial is an excellent indication that treatment of seeds with a repellent will not provide adequate protection if the rodent population is unusually high. Even if the seeds are spared, the seedlings which emerge become prone to animal attacks. The heavy losses of first-year seedlings in the study area emphasize this point very clearly.

Animal depredations were apparently not related to the kind of seedbed material. Whether the especially serious losses under the shade covers can be taken as an indication that depredations would also be higher under the shade of logging debris or plants is uncertain.

BIBLIOGRAPHY

1. Aaltonen, V. T. Boden und Wald. Berlin, Paul Parey, 1948. 457 p.

2. Adams, W. R. Studies in tolerance of New England forest trees. XI. The influence of soil temperature on the germination and development of white pine seedlings. Burlington, 1934. 18 p. (Vermont. Agricultural Experiment Station. Bulletin no. 379)

3. Allen, G. S. Light and temperature as factors in the germination of seed of Douglas-fir. Forestry Chronicle 17:99-109. 1941.

4. Allen, G. S. and W. Bientjes. Studies on coniferous tree seed at the University of British Columbia. Forestry Chronicle 30:183-196. 1954.

5. Arvidsson, I. Austrocknungs- und Duerreresistenzverhaeltnisse einiger repraesentativer oelaendischer Pflanzenvereine nebst Bemerkungen ueber Wasserabsorption durch oberirdische Organe. Oikos, Supplementum 1. 1951. 181 p.

6. Aulitzky, H. Die Bedeutung meteorologischer und kleinklimatischer Unterlagen fuer Aufforstungen im Hochgebirge. Wetter und Leben 7:241-252. 1955.

7. Baker, F. S. Effect of excessively high temperatures on coniferous reproduction. Journal of Forestry 27:949-975. 1929.

8. Baldwin, H. I. The density of spruce and fir related to the direction of exposure. Ecology 14:152-156. 1933.

9. Baldwin, H. I. Forest tree seed of the north temperate regions. Waltham, Massachusetts, Chronica Botanica, 1942. 240 p.

10. Barney, C. W. Effects of soil temperature and light intensity on root growth of loblolly pine seedlings. Plant Physiology 26:146-163. 1951.

11. Barr, P. M. The effect of soil moisture on the establishment of spruce reproduction in British Columbia. New Haven, 1930. 77 p. (Yale University. School of Forestry. Bulletin no. 26)

12. Bates, C. G. The transect of a mountain valley. Ecology 4:54. 1913.

13. Bates, C. G. and J. Roeser. Relative resistance of tree seedlings to excessive heat. Washington, 1924. 16 p. (U. S. Dept. of Agriculture. Departmental Bulletin 1263)

14. Baver, L. D. Soil physics. 3d ed. New York, John Wiley, 1956. 489 p.

15. Bever, D. N. Evaluation of factors affecting natural reproduction of forest trees in central western Oregon. Salem, 1954. 49 p. (Oregon. State Board of Forestry. Research Bulletin no. 3)

16. Boyce, J. S. Forest pathology. New York, McGraw - Hill, 1938. 600 p.

17. Buehler, A. Untersuchungen ueber die Temperatur des Bodens. II. Einfluss der Exposition und der Neigung gegen den Horizont auf die Temperatur des Bodens. Mittheilungen der Schweizerischen Centralanstalt fuer das Forstliche Versuchswesen 4:257-314. 1895.

18. Buening, E. Die Entwicklungs- und Bewegungsphysiologie der Pflanze. 3d ed. Berlin, Springer Verlag, 1953. 539 p.

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

20. Clarkson, Q. D. The use of mustard as a nurse crop in direct seeding of Douglas fir. II. Progress report to the Bureau of Land Management. Corvallis, 1955. 11 p. (Mimeographed)

21. Coutts, J. R. H. Soil temperatures in an afforested area in Aberdeenshire. Quarterly Journal of the Royal Meteorological Society 81:72-79. 1955.

22. Daubenmire, R. F. Soil temperature versus drought as a factor determining lower altitudinal limits of trees in the Rocky Mountains. Botanical Gazette 105:1-13. 1943.

23. Davey, C. B. Sawdust composts: Their preparation and effect on plant growth. Soil Science Society of America Proceedings 17:59-60. 1953.

24. Decker, P. Effect of temperature on photosynthesis and respiration in red and loblolly pines. Plant Physiology 19:679-688. 1944.

25. Defant, F. Local winds. In: Compendium of Meteorology. Ed. by T. F. Malone. Boston, Massachusetts, American Meteorological Society, 1951. p. 655-672.

26. Dyrness, C. T. and C. T. Youngberg. The effect of logging and slashburning on soil structure. Soil Science Society of America Proceedings 21:444-447. 1957.

27. Fabricius, L. Die Einwirkung von Waldbrandasche auf Samenkeimung und erste Pflanzenentwicklung. Forstwissenschaftliche Centralblatt 51:269-276. 1929.

28. Ferrell, W. K. Effect of environmental conditions on survival and growth of forest tree seedlings under field conditions in the Piedmont region of North Carolina. Ecology 34:667-688. 1953.

29. Finnis, J. M. Direct seeding of Douglas fir with special reference to survival. Master's thesis. Corvallis, Oregon State College, 1957. 108 numb. leaves.

30. Fisher, G. M. Comparative germination of tree species on various kinds of surface-soil material in the western white pine type. Ecology 16:606-611. 1935.

31. Fowells, H. A. Cutworm damage to seedlings in California pine stands. Journal of Forestry 38:590-591. 1940.

32. Fuller, W. H., S. Shannon and P. S. Burgess. Effect of burning on certain forest soils of northern Arizona. Forest Science 1:44-50. 1955.

33. Garman, E. H. and A. L. Orr-Ewing. Direct-seeding experiments in the southern coastal region of British Columbia, 1923 - 1949. Victoria, B.C., 1949. 45 p. (Dept. of Lands and Forests, British Columbia Forest Service. Technical Publication T 31)

34. Garman, E. H. Regeneration problems and their silvicultural significance in the coastal forests of British Columbia. Victoria, B.C., 1955. 67 p. (Dept. of Lands and Forests, British Columbia Forest Service. Technical Publication T 41)

35. Gartz, J. F. Stratified Douglas fir seed sown in April, May and June. Salem, 1955. 19 p. (Oregon. State Board of Forestry. Research Note no. 19)

36. Geiger, R. The climate near the ground. 2d ed. Boston, Harvard University Press, 1957. 494 p.

37. Gessel, S. P. and R. B. Walker. Diagnosing nutrient needs of forest trees. In: Forest fertilization, a handbook presented by the American Potash Institute, n.d.p.20-27.

38. Gessel, S. P., R. B. Walker and P. G. Haddock. Preliminary report on mineral deficiencies in Douglas fir and western red cedar. Soil Science Society of America Proceedings 15:364-369. 1951.

39. Haig, I. T. Factors controlling initial establishment of western white pine and associated species. New Haven, 1936. 149 p. (Yale University. School of Forestry. Bulletin no. 41)

40. Hartley, C. Stem lesions caused by excessive heat. Journal of Agricultural Research 14:595-604. 1918.

41. Hellmers, H. and W. P. Sundahl. Response of <u>Sequoia sempervirens</u> (D. Don.) Endl. and <u>Pseudotsuga menziesii</u> (Mirb.) Franco seedlings to temperature. Nature 184:1247-1248. 1959.

42. Henne, A. Untersuchungen ueber das Wachstum junger Fichten, Weisstannen und Laerchen auf verschiedenen Bodenarten, Expositionen und Neigungsgraden. Mittheilungen der Schweizerischen Centralanstalt fuer das Forstliche Versuchswesen 2:1-14. 1892.

43. Hofmann, J. V. The natural regeneration of Douglas fir in the Pacific Northwest. Washington, 1924. 62 p. (U. S. Dept. of Agriculture. Bulletin no. 1200)

44. Hunt, L. O. and L. D. Calvin. Evaluation of factors affecting Douglas-fir regeneration by direct seeding. Corvallis, 1955. 21 p. (Mimeographed)

45. Hunt, L. O. and W. W. Chilcote. The use of Indian mustard (Brassica juncea) in forest land rehabilitation. Corvallis, 1956. 15 p. (Mimeographed)

46. Irgens-Moller, H. Genotypic variation in the time of cessation of height growth in Douglas fir. Forest Science 4:325-330. 1958.

47. Isaac, L. A. and H. G. Hopkins. The forest soil of the Douglas fir region and changes wrought upon it by logging and slash burning. Ecology 18:264-279. 1937.

48. Isaac, L. A. Factors affecting establishment of Douglas fir seedlings. Washington, 1938. 45 p. (U. S. Dept. of Agriculture. Circular Bulletin no. 486)

49. Isaac, L. A. Reproductive habits of Douglas-fir. Washington, 1943. 107 p. (Published for the U. S. Forest Service by the Charles Lathrop Pack Foundation. Washington, D. C.)

50. Jameson, E. W. Food of deer mice, Peromyscus maniculatus and P. boylei, in the northern Sierra Nevada, California. Journal of Mammalogy 33:50-60. 1952.

51. Johnson, N. K. and E. L. Davies. Some measurements of temperature near the surface in various kinds of soils. Quarterly Journal of the Royal Meteorological Society 53:45-59. 1927.

52. Karschon, R. Untersuchungen ueber die physiologische Variabilitaet von Foehrenkeimlingen autochthoner Populationen. Mitteilungen der Schweizerischen Anstalt fuer das forstliche Versuchswesen 26:205-244. 1949.

53. Kerner von Marilaun, F. Die Aenderungen der Bodentemperatur mit der Exposition. Sitzungsberichte der Mathematischen-Naturwissenschaftlichen Klasse der kaiserlichen Akademie der Wissenschaften 100(IIa): 704-722. Wien, 1891.

54. Koestler, J. Waldbau. 2d ed. Berlin, Paul Parey, 1955. 418 p.

55. Korstian, C. F. and N. J. Feterolf. Control of stem girdle of spruce transplants caused by excessive heat. Phytopathology 11:485-490. 1921.

56. Korstian, C. F. Factors controlling germination and early survival in oaks. New Haven, 1927. 115 p. (Yale University. School of Forestry. Bulletin no. 19)

57. Kramer, P. J. Some effects of various combinations of day and night temperatures and photoperiod on the height growth of loblolly pine seedlings. Forest Science 3:45-55. 1957.

58. Krauch, H. Some factors influencing Douglas fir reproduction in the Southwest. Journal of Forestry 34:601-608. 1936.

59. Kraus, G. Boden und Klima auf kleinstem Raum. Jena, Gustav Fischer, 1911. 184 p.

60. Kristensen, K. J. Temperature and heat balance. Oikos 10:103-120. 1959.

61. Laude, H. H. Diurnal cycle of heat resistance in plants. Science 89:556-557. 1939.

62. Larsen, J. A. Some characteristics of seeds of coniferous trees from the Pacific Northwest. National Nurseryman 30:246-249. 1922.

63. Larsen, J. A. Some factors affecting reproduction after logging in northern Idaho. Journal of Agricultural Research 28:1149-1157. 1924.

64. Lavender, D. P., M. H. Bergman and L. D. Calvin. Natural regeneration on staggered settings. Salem, 1956. 36 p. (Oregon. State Board of Forestry. Research Bulletin no. 10)

65. Lavender, D. P. Effect of ground cover on seedling germination and survival. Corvallis, 1958. 32 p. (Oregon. Forest Lands Research Center. Research Note no. 38)

66. Lavender, D. P. Seeding dates and Douglas fir germination. Corvallis, 1958. 15 p. (Oregon. Forest Lands Research Center. Research Note no. 34)

67. Lawrence, W. H. Wildlife-damage control problems on Pacific Northwest tree farms. In: Transactions of the 23rd North American Wildlife Conference. Washington, 1958. p. 146-151. (Published by the Wildlife Management Institute. Washington, D.C. 1958)

68. LeBarron, R. K. Influence of controllable environmental conditions on regeneration of jack pine and black spruce. Journal of Agricultural Research 68:97-119. 1944.

69. Li, T. T. The effect of intense sunlight on tree seedlings. Lingnan Scientific Journal 6:315-321. 1928.

70. Linteau, A. Factors affecting germination and early survival of yellow birch (*Betula lutea* Michx.) in Quebec. Forestry Chronicle 24:27-86. 1948.

71. Lischka, W. Hitzschlag bei Saemlingen. Wiener Allgemeine Forst- und Jagdzeitung 49:117. 1931.

72. Lorenz, R. W. High temperature tolerance of forest trees. St. Paul, 1939. 25 p. (Minnesota. Agricultural Experiment Station. Technical Bulletin 141)

73. Lowry, G. L. and C. T. Youngberg. The effect of certain site and soil factors on the establishment of Douglas fir on the Tillamook burn. Soil Science Society of America Proceedings 19:378-380. 1955.

74. Lowry, W. P. and A. B. Berg. Fire weather studies on Bald Mountain. Corvallis, 1959. 59 p. (Oregon. Forest Lands Research Center. Research Note no. 39)

75. Lundegardh, H. Klima und Boden. 4th ed. Jena, Gustav Fischer, 1954. 598 p.

76. Maguire, W. P. Radiation, surface temperature, and seedling survival. Forest Science 1:277-285. 1955.

77. McKell, C. M. Use of a nurse crop in Douglas fir seedling establishment. III. Progress report to the Bureau of Land Management. Corvallis, 1956. 30 p. (Mimeographed)

78. McKell, C. M. and J. M. Finnis. Control of soil moisture depletion through use of 2,4-D on a mustard nurse crop during Douglas fir seedling establishment. Forest Science 3:329-335. 1957.

79. Meijer, G. The spectral dependence of flowering and elongation. Acta Botanica Neerlandica 8:189-246. 1959.

80. Merkle, J. An analysis of the plant communities of Mary's Peak, western Oregon. Ph.D. thesis. Corvallis, Oregon State College, 1948. 95 numb. leaves.

81. Morris, W. G. Viability of conifer seed as affected by seed-moisture content and kiln temperature. Journal of Agricultural Research 52:855-864. 1936.

82. Muench, E. Hitzeschaeden an Waldpflanzen. Naturwissenschaftliche Zeitschrift fuer Forst- und Landwirtschaft 11:557-562. 1913.

83. Muench, E. Nochmals Hitzeschaeden and Waldpflanzen. Naturwissenschaftliche Zeitschrift fuer Forst- und Landwirtschaft 12:169-188. 1914.

84. Muench, E. Beobachtungen ueber Erhitzung der Bodenoberflaeche im Janre 1914. Naturwissenschaftliche Zeitschrift fuer Forst und Landwirtschaft 13:244-260. 1915.

85. Nightingale, G. T. Effects of temperature on growth anatomy, and metabolism of apple and peach roots. Botanical Gazette 96:581-639. 1935.

86. Owen, H. E. Certain factors affecting establishment of the Douglas fir (Pseudotsuga taxifolia (Lamb.) Britt.) seedlings. Master's thesis. Corvallis, Oregon State College, 1953. 71 numb. leaves.

87. Paelinck, P. M. G. Effect of excessively high temperatures on ponderosa pine seedlings. Master's thesis. Berkeley, University of California, 1955. 64 numb. leaves. (Microfilm)

88. Pearse, P. H. A study of the effects of soil compaction on the early development of seedlings of Douglas fir and western hemlock. Vancouver, 1958. 7 p. (University of British Columbia, Forest Club. Research Note no. 16)

89. Pearson, G. A. Natural reproduction of western yellow pine in the Southwest. Washington, 192 . 144 p. (U. S. Dept. of Agriculture. Bulletin 1105)

90. Phillips, J. F. V. Mortality in the flowers, fruit and young generation of trees in the Knysna forests of South Africa. Ecology 8:435-444. 1927.

91. Pierovich, J. M. The use of mustard (_Brassica juncea_) as a nurse crop in direct seeding of Douglas fir. I. Progress report to the Bureau of Land Management. Corvallis, 1954. 33 p. (Mimeographed)

92. Richards, L. A. and C. H. Wadleigh. Soil water and plant growth. In: B. T. Shaw's (ed.) Agronomy, Vol. 2, New York, Academic Press, 1952. p. 73-251.

93. Roeser, J. Transpiration capacity of coniferous seedlings and the problem of heat injury. Journal of Forestry 30:381-395. 1932.

94. Salisbury, P. J. A review of damping-off of Douglas fir seedlings in British Columbia. Forestry Chronicle 30:407-410. 1954.

95. Samish, R. M. Dormancy in woody plants. Annual Review of Plant Physiology 5:183-204. 1954.

96. Schaedle, M. A study of the growth of Douglas fir (_Pseudotsuga menziesii_). Vancouver, 1959. 141 numb. leaves. (Unpublished manuscript. University of British Columbia)

97. Schmidt, W. Waldbrandboden und Keimling. Der Deutsche Forstwirt 11:189-190;193-194. 1929.

98. Schuette, K. H. and P. Martin. The influence of certain micro-nutrient deficiencies on the germination rates of radish and millet. Plant and Soil 10:299-302. 1959.

99. Schuster, L. Hitzetod junger Pflanzen. Naturwissenschaftliche Zeitschrift fuer Forst- und Landwirtschaft 12:377-379. 1914.

100. Schwemmle, B. and O. L. Lange. Endogen-tagesperiodische Schwankungen der Hitzeresistenz bei Kalanchoe blossfeldiana. Planta 53:134-144. 1959.

101. Shirley, H. L. Lethal high temperatures for conifers and the cooling effect of transpiration. Journal of Agricultural Research 53:239-258. 1936.

102. Siegel, S. M. Effects of exposures of seeds to various physical agents. I. Effects of brief exposures to heat and cold on germination and light sensitivity. Botanical Gazette 112:57-70. 1950.

103. Silen, R. R. Use of temperature pellets in regeneration research. Journal of Forestry 54:311-312. 1956.

104. Silen, R. R. Lethal surface temperatures and their interpretation for Douglas fir. Ph.D. thesis. Corvallis, Oregon State College, 1960. 170 numb. leaves.

105. Slatyer, R. O. The significance of the permanent wilting percentage in studies of plant and soil water relations. Botanical Review 23:585-636. 1957.

106. Smith, C. F. and S. E. Aldous. The influence of mammals and birds in retarding artificial and natural reseeding of coniferous forests in the United States. Journal of Forestry 45:361-369. 1947.

107. Smith, D. M. The influence of seedbed conditions on the regeneration of eastern white pine. New Haven, 1951. 61 p. (Connecticut. Agricultural Experiment Station. Bulletin 545)

108. Stanhill, G. The effect of differences in soil moisture on plant growth: A review and analysis of soil moisture regime experiments. Soil Science 84:205-214. 1957.

109. Steinbrenner, E. C. The effect of repeated tractor trips on the physical properties of two forest soils in southwestern Washington. Tacoma, 1953. 5 p. (Weyerhaeuser Timber Company, Tacoma, Washington. Research Note)

110. Steinbrenner, E. C. and S. P. Gessel. Effect of tractor logging on soils and regeneration in the Douglas-fir region of southwestern Washington. Society of American Foresters Proceedings 1955:77-80.

111. Stone, E. C. and H. A. Fowells. The survival value of dew as determined under laboratory conditions with Pinus ponderosa. Forest Science 1:183-188. 1955.

112. Stone, E. C., A. Y. Shachori and R. G. Stanley. Water absorption by needles of ponderosa pine seedlings and its internal redistribution. Plant Physiology 31:120-126. 1956.

113. Stone, E. C. Dew as an ecological factor. I. A review of the literature. Ecology 38:407-413. 1957.

114. Stone, E. C. Dew as an ecological factor. II. The effect of artificial dew on the survival of Pinus ponderosa and associated species. Ecology 38:414-422. 1957.

115. Tarrant, R. F. Effect of heat on soil color and pH of two forest soils. Portland, 1953. 5 p. (U. S. Dept. of Agriculture. Forest Service. Pacific Northwest Forest and Range Experiment Station. Research Note no. 90)

116. Tarrant, R. F. Effect of slash burning on soil pH. Portland, 1954. 5 p. (U. S. Dept. of Agriculture. Forest Service. Pacific Northwest Forest and Range Experiment Station. Research Note no. 102)

117. Tarrant, R. F. Soil reaction and germination of Douglas fir seed. Portland, 1954. 4 p. (U. S. Dept. of Agriculture. Forest Service. Pacific Northwest Forest and Range Experiment Station. Research Note no. 105)

118. Thrupp, A. C. Effect of seed-ash characteristics and treatment of seed and soils upon coniferous seed germination. Ph.D. thesis. Seattle, University of Washington, 1939. 327 numb. leaves.

119. Tiedemann, H. The establishment of Douglas fir reproduction in relation to certain natural environmental factors. Master's thesis. Corvallis, Oregon State College, 1934. 45 numb. leaves.

120. Toumey, J. W. and E. J. Neethling. Insolation, a factor in the natural regeneration of certain conifers. New Haven, 1924. 63 p. (Yale University. School of Forestry. Bulletin no. 11)

121. Tryon, E. H. Effect of charcoal on certain physical, chemical, and biological properties of forest soils. Ecological Monographs 18:81-115. 1948.

122. U. S. Department of Agriculture. Forest Service. Timber resources for America's future. Washington, 1958. 713 p. (Forest Resource Report no. 14)

123. U. S. Department of Commerce. Weather Bureau. Climatological data. Oregon. Volumes 63-65. 1957-1959.

124. Vaartaja, O. High surface soil temperatures. On methods of investigation, and thermocouple observations on a wooded heath in the south of Finland. Oikos 1:6-27. 1949.

125. Vaartaja, O. On factors affecting the initial development of pine. Oikos 2:89-108. 1950.

126. Vaartaja, O. Temperature and evaporation at and near the ground level in certain forest sites. Canadian Journal of Botany 32:760-783. 1954.

127. Vaartaja, O. Factors causing mortality of tree seeds and succulent seedlings. Acta Forestalia Fennica 62:1-30. 1955.

128. Veihmeyer, F. J. and A. H. Hendrickson. Soil moisture in relation to plant growth. Annual Review of Plant Physiology 1:285-304. 1950.

129. Wareing, P. F. Photoperiodism in woody plants. Annual Review of Plant Physiology 7:191-214. 1956.

130. Went, F. W. The effect of temperature on plant growth. Annual Review of Plant Physiology 4:347-362. 1953.

131. Wexler, R. Land and sea breezes. In: Local winds. Tooele, Utah, Army Service Forces, Signal Corps, Dugway Proving Ground, n.d. (SPSGS-EDS project 743A)

132. Wollny, E. Untersuchungen ueber die Feuchtigkeits- und Temperaturverhaeltnisse des Bodens bei verschiedener Neigung des Terrains gegen die Himmelsrichtung und gegen den Horizont. Forschungen auf dem Gebiete der Agricultur-Physik 10:1-54. 1888.

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

APPENDIX

Table 1.

DAILY MAXIMUM AND MINIMUM TEMPERATURES 150 CENTIMETERS ABOVE THE GROUND

Year and		Day of Month																														
Month		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Ave.
1957																																	
June	Max.	73	78	75	76	80	63	65	64	66	70	61	60	59	53	63	70	69	68	68	64	63	79	78	76	81	76	78	72	68	67		69.4
	Min.	51	49	52	54	56	53	51	55	58	55	55	50	51	47	50	52	57	55	56	51	49	54	54	53	56	60	60	54	53	53		53.5
July	Max.	70	75	80	86	82	69	74	82	80	81	68	81	72	62	68	67	66	80	85	83	79	78	78	80	74	72	76	82	80	72	72	75.9
	Min.	51	53	56	60	54	53	54	54	58	58	56	54	58	57	53	52	53	55	65	58	57	54	58	57	56	53	52	56	56	54	54	55.5
Aug.	Max.	77	81	67	66	65	65	68	67	72	68	73	79	74	77	76	78	78	78	80	83	86	89	80	75	71	77	74	75	75	75	82	75.2
	Min.	54	56	57	57	57	57	58	55	54	55	54	56	56	57	60	59	59	56	57	58	60	65	57	53	53	54	56	56	57	55	57	56.6
Sept.	Max.	83	80	86	88	86	81	78	81	89	94	85	77	96	95	64	65	64	76	77	82	85	95	94	78	76	61	67	67	82	77		80.3
	Min.	63	60	59	64	62	62	56	54	58	63	55	54	68	70	58	57	57	51	60	60	66	65	65	55	58	57	54	56	64	56		59.6
Oct.	Max.	71	58	53	49	53	50	57	56	66	67	67	60	60	59	62	62	64	66	68	70	68	56	58	62	64	64	63	62	70	61	58	61.4
	Min.	56	45	43	45	45	45	45	48	55	56	53	54	50	48	44	47	48	46	48	50	52	52	53	56	54	52	49	46	50	48	46	49.3
Nov.	Max.	56	61	60	60	58	59	53	54	52	47	46	49	49	45	43	48	43	48	48	48	49	52	61	57	52	49	47	50	56	52		51.7
	Min.	43	42	41	42	40	46	43	43	42	45	44	46	41	36	35	35	36	41	38	36	35	36	46	41	43	37	37	37	36	40		40.1
Dec.	Max.	48	52	45	46	47	52	52	55	56	52	47	45	45	47	47	48	44	43	48	46	42	39	41	47	51	38	47	45	38	40	44	46.4
	Min.	42	42	31	34	37	43	48	40	39	44	40	38	38	39	41	40	37	33	40	42	33	33	37	40	39	33	35	36	33	32	37	37.9
1958																																	
Jan.	Max.	45	46	48	47	45	42	40	48	50	49	48	49	43	52	54	57	51	45	42	42	44	46	49	43	48	52	51	48	46	43	48	47.1
	Min.	36	36	37	37	33	34	32	36	40	41	41	37	37	42	51	46	43	37	33	34	34	35	42	42	42	40	44	43	35	36	42	38.6
Feb.	Max.	52	58	51	60	47	52	50	46	48	52	48	53	44	48	50	49	56	60	56	55	60	51	57	55	42	40	47	48				51.3
	Min.	42	47	44	45	43	43	44	44	43	42	42	41	38	39	44	40	48	48	45	41	46	48	48	41	36	34	34	33				42.3
Mar.	Max.	54	50	54	54	42	43	39	38	46	51	51	46	43	52	50	51	46	51	56	59	52	48	52	44	46	54	62	50	47	45	44	49.0
	Min.	34	37	34	39	32	29	33	33	32	33	33	33	35	35	36	36	38	37	40	46	43	41	42	40	38	36	40	40	36	36	35	36.5
Apr.	Max.	48	40	43	45	55	49	54	47	49	59	67	76	51	56	50	52	50	48	52	55	48	45	48	48	50	52	61	70	72	77		53.9
	Min.	38	36	34	35	37	41	40	41	46	46	43	53	39	38	44	41	40	38	48	47	38	36	35	37	37	37	41	44	47	50		40.9
May	Max.	69	70	61	71	60	57	71	71	76	72	52	56	67	80	86	86	84	76	71	81	85	73	74	61	79	72	68	65	67	61	59	70.4
	Min.	47	43	44	45	46	43	47	47	48	46	38	37	40	51	60	64	63	54	52	55	62	54	52	56	56	53	51	52	50	48	49	50.1
June	Max.	69	63	58	70	78	56	65	65	63	60	60	62	61	75	79	89	90	86	76	81	92	91	59	61	74	66	62	63	60	64		69.9
	Min.	48	52	50	50	55	53	51	52	51	52	51	48	50	53	57	61	70	55	54	55	66	58	54	54	53	52	48	48	48	49		53.3
July	Max.	73	76	83	90	93	89	78	75	80	85	84	81	75	88	92	83	79	76	79	81	84	80	82	88	88	91	102	93	84	83	87	83.9
	Min.	52	60	60	65	70	62	53	54	54	61	62	55	50	54	58	55	54	52	54	58	61	58	59	68	68	67	74	65	58	58	59	59.3
Aug.	Max.	87	84	71	80	88	88	80	79	85	89	79	86	84	86	89	86	81	82	88	91	93	88	93	96	85	83	74	68	70	78	84	83.7
	Min.	59	54	54	52	59	60	59	58	57	63	55	59	58	62	65	62	58	59	57	64	72	62	63	70	60	56	51	48	54	56	58	58.8
Sept.	Max.	72	70	71	81	86	95	98	72	74	66	69	58	64	60	71	64	67	72	64	70	59	59	59	56	69	76	84	79	78	80		71.4
	Min.	51	49	49	55	60	63	66	60	56	55	52	51	54	55	54	51	51	51	49	47	47	44	44	45	52	50	58	58	56	53		52.9
Oct.	Max.	76	86	88	84	78	75	68	64	66	63	68	67	71	70	68	63	67	55	60	55	57	59	53	51	63	60	61	60	63	59	55	65.6
	Min.	59	59	68	45	45	50	52	55	45	50	49	46	50	52	48	45	43	48	50	46	38	39	40	39	38	41	38	40	42	39	42	46.5

Table 2.

DAILY MAXIMUM AND MINIMUM TEMPERATURES 2.5 CENTIMETERS ABOVE THE GROUND

Year and Month		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Ave.
1957																																	
June	Max.	76	80	79	80	84	68	69	69	72	75	62	64	60	55	66	80	79	75	75	71	68	84	84	83	86	81	84	75	71	70		74.2
	Min.	49	47	50	49	51	52	48	50	55	50	54	48	49	46	47	49	53	53	51	47	45	47	54	51	51	57	60	52	47	49		50.4
July	Max.	75	81	86	94	86	70	80	87	85	87	72	87	75	63	70	70	67	84	89	86	84	84	84	85	81	77	83	91	88	77	75	80.7
	Min.	47	48	49	53	49	49	48	47	55	55	53	49	56	56	52	47	47	49	55	56	53	53	53	51	53	52	48	54	55	52	51	51.5
Aug.	Max.	82	85	67	68	66	65	70	70	74	70	76	84	78	82	82	83	83	84	86	88	91	93	85	81	75	83	79	79	81	81	86	79.3
	Min.	49	50	55	53	53	54	56	53	49	52	49	50	52	52	55	55	57	54	55	52	54	57	53	48	49	48	50	49	50	50	49	52.0
Sept.	Max.	88	85	90	93	91	86	83	85	92	97	90	82	99	100	65	67	65	82	82	87	90	100	99	84	80	62	68	68	82	78		84.0
	Min.	55	54	52	55	57	60	51	50	51	55	53	50	59	54	53	57	56	51	45	49	52	58	53	52	51	55	54	49	56	55		53.4
Oct.	Max.	75	59	54	50	54	50	59	57	67	68	68	61	60	60	65	62	65	68	69	70	70	57	60	63	64	65	65	65	72	62	58	62.6
	Min.	52	43	41	42	42	42	43	47	50	50	48	51	45	43	39	43	43	40	41	43	44	50	51	52	49	44	44	40	44	44	41	44.9
Nov.	Max.	58	63	62	65	63	64	57	60	55	50	47	50	50	50	46	50	44	50	51	52	50	56	63	61	54	54	52	54	57	52		54.7
	Min.	36	36	35	36	36	39	37	40	40	45	44	45	40	35	35	35	35	40	36	33	32	33	40	38	42	35	34	35	35	35		37.2
Dec.	Max.	48	56	50	46	50	52	52	60	59	56	50	51	46	47	48	48	44	44	47	47	44	41	43	47	51	39	47	45	40	46	46	48.1
	Min.	42	38	30	34	37	40	46	37	35	36	38	32	32	39	40	40	36	34	39	40	31	32	34	40	38	32	34	35	31	30	35	36.0
1958																																	
Jan.	Max.	46	47	50	49	50	42	41	48	50	49	48	49	43	52	54	57	53	50	43	42	47	50	49	44	50	56	53	49	46	45	51	48.5
	Min.	35	35	36	35	35	32	29	36	40	40	40	36	36	40	49	46	39	35	32	33	34	34	40	42	40	37	38	42	35	35	39	37.3
Feb.	Max.	53	61	54	62	48	53	53	47	50	55	50	54	46	50	52	51	60	62	47	57	62	52	59	56	44	41	50	49				52.8
	Min.	40	45	41	41	41	42	42	43	40	42	40	39	37	37	42	39	45	46	40	39	45	46	47	40	34	33	31	30				40.3
Mar.	Max.	55	52	60	63	45	47	39	38	54	55	57	50	48	60	56	57	51	56	62	62	54	50	58	47	52	62	69	56	49	48	48	53.5
	Min.	31	35	32	30	30	28	33	33	31	33	30	30	35	31	34	34	37	35	38	44	40	41	40	40	36	35	36	39	35	34	34	34.6
Apr.	Max.	55	45	51	52	64	56	60	55	58	67	74	83	57	62	56	55	55	53	62	60	54	50	58	52	55	59	72	80	82	85		60.9
	Min.	36	34	33	34	35	40	40	39	44	42	49	48	37	36	42	40	39	37	47	45	36	34	34	36	35	36	40	43	44	50		39.5
May	Max.	82	80	70	80	67	65	84	82	87	84	60	67	80	93	100	100	95	91	81	92	98	85	84	67	83	80	79	72	78	67	65	80.9
	Min.	42	40	42	45	46	41	47	45	46	45	36	35	39	48	55	59	57	54	49	55	61	53	50	55	55	50	49	50	45	44	46	47.9
June	Max.	78	69	61	77	84	60	70	71	67	65	65	64	66	80	91	100	104	101	92	90	104	105	80	64	85	72	66	70	66	69		77.9
	Min.	46	50	49	46	54	50	51	50	50	50	45	46	48	51	55	57	65	54	50	55	62	55	51	50	50	50	44	44	48	49		50.8
July	Max.	80	85	92	101	104	100	90	87	91	95	96	93	89	100	103	95	90	87	92	94	98	93	94	98	98	102	114	104	97	96	99	95.4
	Min.	51	55	55	60	65	55	53	54	53	58	62	55	50	53	57	54	53	52	53	56	60	58	55	62	61	63	70	65	56	56	58	57.0
Aug.	Max.	100	96	80	92	100	98	88	90	98	101	92	99	95	97	101	98	93	95	98	101	104	100	103	107	98	94	84	79	80	87	95	94.9
	Min.	58	53	54	50	56	60	59	55	53	60	55	55	53	57	60	62	57	59	55	60	67	58	60	66	58	53	50	45	53	55	57	56.5
Sept.	Max.	83	80	79	90	94	107	110	79	84	72	78	61	70	60	78	66	71	79	71	77	64	65	68	60	76	82	90	88	89	91		78.7
	Min.	50	48	47	50	55	57	65	58	55	55	50	49	54	53	51	49	49	49	45	43	42	42	40	40	50	46	52	53	51	50		49.9
Oct.	Max.	87	89	90	87	80	77	72	67	72	69	71	70	76	78	73	68	75	58	67	59	60	64	57	60	71	69	70	70	77	65	59	71.2
	Min.	55	55	64	44	43	48	51	53	44	48	46	45	48	50	47	44	41	46	49	45	37	38	39	37	37	39	36	39	40	37	41	44.7

Table 3. Weekly maximum temperatures on the surfaces of seedbeds during 1957 and 1958. The temperatures are given in degrees Fahrenheit.

1957 Week of	Exposed to 100% Light						Exposed to 75% Light						Exposed to 25% Light					
	Charcoal	Hard-burned Soil	Light-burned Soil	Mineral Soil	Litter	Sawdust	Charcoal	Hard-burned Soil	Light-burned Soil	Mineral Soil	Litter	Sawdust	Charcoal	Hard-burned Soil	Light-burned Soil	Mineral Soil	Litter	Sawdust
Apr 14 - Apr 20	140	132	134	134	134	133	132	124	129	124	122	116	94	92	94	90	94	94
Apr 21 - Apr 27	131	124	127	125	132	119	124	114	116	115	128	112	84	81	84	84	88	84
Apr 28 - May 4	142	137	140	140	143	129	131	111	116	125	129	116	91	85	90	89	92	90
May 5 - May 11	100	96	97	103	115	104	89	81	85	86	88	86	80	77	76	77	77	78
May 12 - May 18	135	132	138	136	142	128	127	119	120	128	126	113	90	94	90	91	97	91
May 19 - May 25	138	133	140	138	143	130	126	119	120	118	125	116	96	96	93	97	101	95
May 26 - Jun 1	143	134	144	140	146	133	126	115	118	120	126	116	96	95	94	95	102	95
Jun 2 - Jun 8	142	135	141	138	144	131	131	124	128	126	126	120	98	97	97	96	102	97
Jun 9 - Jun 15	145	136	142	138	144	134	132	124	130	126	126	124	99	97	102	97	103	100
Jun 16 - Jun 22	142	133	139	138	143	133	130	122	128	122	129	126	98	96	101	96	101	99
Jun 23 - Jun 29	140	132	140	134	145	130	134	122	128	123	131	121	99	95	97	96	100	97
Jun 30 - Jul 6	149	139	145	144	151	137	138	133	136	133	138	132	106	103	107	103	107	105
Jul 7 - Jul 13	146	138	143	140	148	133	134	132	134	133	134	129	102	101	103	101	105	100
Jul 14 - Jul 20	140	133	140	135	145	129	127	124	126	126	130	120	99	99	99	97	101	98
Jul 21 - Jul 27	143	137	143	141	148	136	128	125	127	128	128	124	97	97	98	96	100	96
Jul 28 - Aug 3	149	140	145	146	150	139	138	133	137	134	139	132	97	98	99	98	100	97
Aug 4 - Aug 10	139	134	136	140	142	132	131	128	128	126	134	124	94	95	95	94	97	95
Aug 11 - Aug 17	142	136	142	141	145	137	130	129	132	131	131	130	102	97	98	97	104	100
Aug 18 - Aug 24	146	137	142	144	148	139	133	131	134	132	133	131	103	101	102	101	107	102
Aug 25 - Aug 31	145	135	143	141	148	134	133	120	132	128	132	123	93	93	93	93	97	94
Sep 1 - Sep 7	141	136	140	140	146	133	137	128	130	131	134	124	99	100	101	101	102	100
Sep 8 - Sep 14	147	138	142	143	150	138	138	128	134	131	136	128	104	104	103	104	106	104
Sep 15 - Sep 21	147	140	146	146	148	140	134	129	134	131	134	130	106	106	105	107	108	106
Sep 22 - Sep 28	147	138	145	144	146	136	134	130	134	132	133	129	105	105	106	104	108	104
Sep 29 - Oct 5	118	116	116	117	125	116	-	-	-	-	-	-	-	-	-	-	-	-
Oct 6 - Oct 12	93	90	90	92	93	92	-	-	-	-	-	-	-	-	-	-	-	-
Oct 13 - Oct 19	94	92	92	93	95	90	-	-	-	-	-	-	-	-	-	-	-	-
Oct 20 - Oct 26	100	96	97	99	98	98	-	-	-	-	-	-	-	-	-	-	-	-
Oct 27 - Nov 2	95	89	94	96	97	90	-	-	-	-	-	-	-	-	-	-	-	-
Nov 3 - Nov 9	93	89	92	90	93	92	-	-	-	-	-	-	-	-	-	-	-	-
Nov 10 - Nov 16	90	84	88	89	85	85	-	-	-	-	-	-	-	-	-	-	-	-
Nov 17 - Nov 23	81	82	81	84	85	83	-	-	-	-	-	-	-	-	-	-	-	-
Nov 24 - Nov 30	81	80	80	80	84	84	-	-	-	-	-	-	-	-	-	-	-	-
Dec 1 - Dec 7	74	71	72	71	76	76	-	-	-	-	-	-	-	-	-	-	-	-
Dec 8 - Dec 14	73	74	74	76	76	76	-	-	-	-	-	-	-	-	-	-	-	-
Dec 15 - Dec 21	53	50	51	50	56	56	-	-	-	-	-	-	-	-	-	-	-	-
Dec 22 - Dec 28	52	54	52	53	54	54	-	-	-	-	-	-	-	-	-	-	-	-
Dec 29 - Jan 4, '58	65	66	64	68	70	65	-	-	-	-	-	-	-	-	-	-	-	-

Weekly Maximum Temperatures 1958 Week of	Exposed to 100% Light						Exposed to 75% Light						Exposed to 25% Light					
	Charcoal	Hard-burned Soil	Light-burned Soil	Mineral Soil	Litter	Sawdust	Charcoal	Hard-burned Soil	Light-burned Soil	Mineral Soil	Litter	Sawdust	Charcoal	Hard-burned Soil	Light-burned Soil	Mineral Soil	Litter	Sawdust
Jan 5 - Jan 11	54	54	54	56	58	58	-	-	-	-	-	-	-	-	-	-	-	-
Jan 12 - Jan 18	68	74	68	70	72	70	-	-	-	-	-	-	-	-	-	-	-	-
Jan 19 - Jan 25	72	72	72	74	78	74	-	-	-	-	-	-	-	-	-	-	-	-
Jan 26 - Feb 1	74	80	76	80	86	83	-	-	-	-	-	-	-	-	-	-	-	-
Feb 2 - Feb 8	78	80	77	80	82	80	-	-	-	-	-	-	-	-	-	-	-	-
Feb 9 - Feb 15	64	66	62	66	66	66	-	-	-	-	-	-	-	-	-	-	-	-
Feb 16 - Feb 22	74	75	74	76	78	76	-	-	-	-	-	-	-	-	-	-	-	-
Feb 23 - Mar 1	88	86	88	86	86	86	-	-	-	-	-	-	-	-	-	-	-	-
Mar 2 - Mar 8	80	82	82	84	88	83	-	-	-	-	-	-	-	-	-	-	-	-
Mar 9 - Mar 15	94	94	96	96	98	94	81	80	81	82	82	80	76	76	77	76	78	76
Mar 16 - Mar 22	87	84	83	84	86	87	79	78	77	78	79	79	76	76	76	76	76	77
Mar 23 - Mar 29	98	100	102	99	103	96	87	88	88	87	89	87	79	79	80	79	80	79
Mar 30 - Apr 5	90	90	90	88	92	90	80	80	81	80	81	80	77	77	77	76	78	77
Apr 6 - Apr 12	120	120	122	120	125	118	104	103	106	103	107	104	81	81	82	82	83	82
Apr 13 - Apr 19	93	90	89	90	92	93	89	83	85	85	88	88	77	76	76	76	77	77
Apr 20 - Apr 26	94	90	89	90	92	93	88	82	84	85	89	88	78	76	76	76	77	77
Apr 27 - May 3	134	126	132	130	135	128	107	105	108	107	108	106	90	86	86	85	92	87
May 4 - May 10	140	128	138	134	140	130	116	106	114	112	120	111	95	91	92	91	96	93
May 11 - May 17	151	139	144	140	152	139	126	124	124	120	126	122	105	104	108	103	108	107
May 18 - May 24	141	135	138	139	144	136	127	120	123	121	128	122	109	107	108	108	109	108
May 25 - May 31	112	103	114	112	118	110	96	93	95	92	99	94	80	80	80	80	84	81
Jun 1 - Jun 7	114	104	112	106	118	112	99	93	98	92	103	98	86	83	86	81	87	86
Jun 8 - Jun 14	134	129	134	132	140	127	110	105	108	110	112	108	92	91	94	92	96	95
Jun 15 - Jun 21	153	147	152	150	155	142	131	128	132	128	136	125	112	110	113	112	115	112
Jun 22 - Jun 28	132	123	125	124	134	129	108	105	106	108	111	110	94	89	90	89	92	91
Jun 29 - Jul 5	157	144	154	149	154	145	135	124	135	131	134	128	112	111	111	110	117	115
Jul 6 - Jul 12	155	143	153	150	157	140	136	125	134	127	129	127	110	113	110	108	112	111
Jul 13 - Jul 19	154	147	152	152	154	144	135	130	134	131	134	130	113	110	112	112	117	115
Jul 20 - Jul 26	162	155	160	160	164	149	144	134	143	139	142	138	122	120	120	119	116	113
Jul 27 - Aug 2	151	143	147	150	152	141	132	126	126	127	128	127	110	109	114	108	115	109
Aug 3 - Aug 9	155	146	147	152	156	142	130	127	128	126	128	126	110	107	113	107	114	109
Aug 10 - Aug 16	153	142	150	148	155	140	131	127	129	125	127	127	110	107	108	108	114	109
Aug 17 - Aug 23	154	145	151	147	155	142	133	127	130	126	130	125	112	110	114	111	115	110
Aug 24 - Aug 30	156	150	152	151	156	145	133	128	130	130	131	126	112	111	114	112	117	112
Aug 31 - Sep 6	152	145	150	149	152	144	131	124	125	125	130	128	113	108	113	114	118	114
Sep 7 - Sep 13	130	119	124	121	122	120	112	101	106	102	108	105	95	91	94	90	93	91
Sep 14 - Sep 20	107	96	100	105	109	106	90	86	85	88	94	92	83	81	82	82	87	85
Sep 21 - Sep 27	135	125	126	129	129	129	111	102	108	106	111	109	101	99	100	99	103	102

Table 4. Hourly course of temperature on the surface of charcoal and at four depths beneath it. The measurements were made with thermocouples. Air temperatures were obtained from a Taylor temperature recorder in the weather shelter.

Time	Degrees Fahrenheit at: Surface of Charcoal	2.5	7.5	12.5	17.5	150 cm above ground
		Depth below surface of charcoal (cm)				
		July 28, 1958				
10:30 AM	130	105	85	76	75	86
11:30	150	115	88	79	77	89
12:17 PM	153	117	90	80	77	90
1:20	158	120	92	81	77	92
2:30	154	123	93	81	77	90
3:40	130	119	94	81	77	87
4:30	118	112	94	82	78	81
5:50	83	108	93	84	79	74
		August 6, 1958				
7:50 AM	76	68	67	69	71	70
8:55	106	78	69	71	71	75
9:55	126	80	70	70	70	78
10:55	140	89	72	71	71	81
11:55	146	97	74	74	71	83
12:55 PM	150	105	80	75	72	84
1:55	151	108	82	75	72	86
2:55	135	112	83	78	73	85
3:55	127	114	84	79	73	84
4:40	112	108	86	79	74	78
5:35	80	101	88	82	75	72
		August 20, 1958				
8:34 AM	84	73	74	69	70	72
9:24	106	76	76	70	70	75
10:17	123	80	77	71	71	78
11:12	135	83	79	72	72	82
12:15 PM	146	91	80	74	72	81
1:13	140	101	81	76	72	86
2:13	148	106	82	79	74	87
3:09	136	110	84	80	75	89
4:05	116	107	85	81	76	90
4:40	114	105	85	83	77	87
5:25	86	102	84	83	78	84

Table 5. Hourly course of temperature on the surface of hard-burned soil and at four depths beneath it. The measurements were made with thermocouples. Air temperatures were obtained from a Taylor temperature recorder in the weather shelter.

	Degrees Fahrenheit at					
Time	Surface of Hard-burned soil	2.5	7.5	12.5	17.5	150 cm above ground
		Depth below surface of hard-burned soil (cm)				
		July 28, 1958				
10:18 AM	110	101	76	74	74	85
11:20	130	114	84	80	78	87
12:10 PM	141	123	86	80	78	90
1:15	145	124	89	81	78	92
2:25	148	124	89	82	78	90
3:30	133	123	94	86	81	87
4:25	124	119	95	88	83	83
5:45	83	93	94	90	85	74
		August 6, 1958				
7:45 AM	68	67	70	70	70	70
8:45	100	82	70	70	70	74
9:45	110	91	70	70	70	76
10:45	126	104	78	74	74	79
11:45	134	110	82	75	75	83
12:45 PM	135	114	83	76	75	84
1:45	145	117	86	79	75	86
2:45	130	116	88	80	75	85
3:45	125	112	89	82	76	84
4:35	119	108	90	84	78	80
5:30	84	92	91	87	81	72
		August 20, 1958				
8:27 AM	76	74	69	72	72	71
9:17	109	86	70	71	72	74
10:12	120	99	74	72	72	76
11:04	124	109	78	72	72	79
12:10 PM	140	110	82	75	74	80
1:05	136	114	85	76	74	86
2:05	139	116	88	80	76	88
3:02	136	115	89	80	76	91
3:59	121	115	91	83	77	89
4:37	114	113	94	83	80	88
5:22	88	95	91	84	80	84

Table 6. Hourly course of temperature on the surface of light-burned soil and at four depths beneath it. The measurements were made with thermocouples. Air temperatures were obtained from a Taylor temperature recorder in the weather shelter.

Time	Surface of Light-burned soil	2.5	7.5	12.5	17.5	150 cm above ground
	Degrees Fahrenheit at	Depth below surface of light-burned soil (cm)				
		July 28, 1958				
9:50 AM	108	97	82	78	78	82
11:00	135	108	87	80	78	87
11:50	136	108	87	80	78	91
12:50 PM	142	108	87	82	80	90
2:00	144	118	94	85	81	90
3:00	148	116	95	86	81	89
4:05	127	115	98	87	84	83
5:25	89	97	96	88	85	76
		August 6, 1958				
7:25 AM	66	66	69	70	70	68
8:20	91	75	70	70	70	73
9:20	110	86	70	70	70	75
10:20	124	94	77	73	71	76
11:20	132	102	80	73	72	82
12:20 PM	136	110	86	75	73	84
1:20	138	113	90	78	74	84
2:20	134	113	90	78	74	86
3:20	124	111	93	81	76	85
4:20	117	110	93	82	79	82
5:17	85	98	92	84	81	72
		August 20, 1958				
8:10 AM	67	70	71	73	72	71
8:53	96	78	72	73	72	72
9:50	120	88	73	73	72	74
10:41	121	94	77	73	73	79
11:44	130	104	84	75	74	80
12:36 PM	139	112	90	80	77	83
1:39	139	113	92	80	77	85
2:39	134	114	91	81	77	88
3:38	125	112	92	82	77	86
4:20	116	108	92	82	79	89
5:08	104	100	95	86	81	84

Table 7. Hourly course of temperature on the surface of mineral soil and at four depths beneath it. The measurements were made with thermocouples. Air temperatures were obtained from a Taylor temperature recorder in the weather shelter.

		Degrees Fahrenheit at				
	Surface of mineral soil	2.5	7.5	12.5	17.5	150 cm above ground
Time		Depth below surface of mineral soil (cm)				
		July 28, 1958				
10:45 AM	129	108	80	77	76	86
11:35	145	120	87	81	78	88
12:25 PM	148	124	90	82	78	90
1:30	154	125	94	83	79	91
2:40	145	128	95	83	79	89
3:45	138	124	96	86	79	87
4:40	128	124	100	90	82	79
5:30	83	100	97	90	83	75
		August 6, 1958				
7:30 AM	68	67	68	74	74	69
8:30	93	84	68	72	73	73
9:25	104	88	71	70	70	78
10:25	124	98	76	73	73	81
11:25	135	106	79	73	73	83
12:25 PM	140	113	89	74	73	84
1:25	150	116	90	77	73	86
2:25	140	120	93	78	74	85
3:25	138	122	94	82	76	84
4:25	127	115	96	83	77	80
5:15	86	102	96	84	78	72
		August 20, 1958				
8:15 AM	77	72	71	73	73	71
9:00	97	78	71	73	73	73
9:55	116	90	76	72	72	76
10:46	130	98	79	72	72	80
11:49	145	107	84	76	74	82
12:43 PM	148	115	90	78	75	86
1:45	136	118	92	79	75	89
2:45	138	120	94	81	76	86
3:44	137	118	97	83	78	89
4:25	122	116	97	84	78	88
5:12	101	104	96	86	80	84

Table 8. Hourly course of temperature on the surface of litter and at four depths beneath it. The measurements were made with thermocouples. Air temperatures were obtained from a Taylor temperature recorder in the weather shelter.

Time	Surface of litter	2.5	7.5	12.5	17.5	150 cm above ground
		Degrees Fahrenheit at Depth below surface of litter (cm)				
		July 28, 1958				
10:00 AM	117	94	78	75	75	83
11:10	133	105	83	75	75	88
12:00 PM	151	114	86	80	79	91
1:00	150	117	88	80	79	91
2:10	146	126	89	81	77	89
3:10	152	116	93	82	77	89
4:10	133	117	92	84	78	83
5:35	84	91	89	84	78	75
		August 6, 1958				
7:35 AM	70	70	70	70	71	69
8:35	106	77	69	70	71	73
9:35	122	81	71	71	71	75
10:35	130	90	75	72	72	78
11:35	141	97	76	73	73	82
12:35 PM	144	100	83	73	73	86
1:35	145	106	86	76	74	84
2:35	139	109	86	76	74	87
3:35	128	111	88	78	74	84
4:35	120	104	89	78	74	80
5:20	83	94	89	82	75	72
		August 20, 1958				
8:20	85	72	70	72	72	71
9:06	108	74	70	71	72	73
10:02	116	78	74	72	72	76
10:52	130	82	77	74	74	80
11:56	134	89	82	74	74	81
12:50 PM	144	98	82	74	74	85
1:54	143	104	82	76	74	87
2:49	143	110	85	76	74	88
3:49	132	108	88	79	75	87
4:27	115	105	88	79	76	89
5:15	87	101	89	82	78	84

Table 9. Hourly course of temperature on the surface of sawdust and at four depths beneath it. The measurements were made with thermocouples. Air temperatures were obtained from a Taylor temperature recorder in the weather shelter.

	Degrees Fahrenheit at					
Time	Surface of litter	2.5	7.5	12.5	17.5	150 cm above ground
		Depth below surface of litter (cm)				
		July 28, 1958				
10:10 AM	110	100	79	73	72	84
11:15	123	110	84	74	74	87
12:05 PM	137	121	88	76	74	90
1:05	139	121	88	78	74	91
2:15	147	123	88	79	75	90
3:20	132	121	90	79	76	88
4:20	112	113	92	79	76	82
5:40	81	108	91	83	78	74
		August 6, 1958				
7:40 AM	67	70	70	70	72	69
8:40	98	76	69	67	67	74
9:40	108	80	74	68	68	77
10:40	118	89	78	68	68	81
11:40	129	94	85	73	73	83
12:40 PM	130	102	86	73	73	86
1:40	134	106	89	75	72	86
2:40	127	107	86	75	70	84
3:40	124	107	88	77	73	84
4:30	109	105	86	77	73	80
5:25	79	100	84	81	76	72
		August 20, 1958				
8:22 AM	83	73	69	69	70	71
9:12	101	74	72	70	70	73
10:06	117	79	76	71	70	76
10:58	124	84	77	72	71	80
12:04 PM	136	90	79	73	72	82
12:55	134	98	80	74	72	86
2:00	126	102	84	74	72	89
2:55	126	105	86	77	74	86
3:54	117	104	87	77	74	89
4:32	104	100	86	79	75	88
5:18	83	99	85	82	77	84

Table 10.

DAILY MAXIMUM AND MINIMUM TEMPERATURES 10 CENTIMETERS BELOW GROUND WITH MINERAL SOIL

Year and Month		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Ave.
1957																																	
July	Max.	73	76	76	79	80	67	69	69	70	74	60	61	61	59	69	69	66	76	81	80	80	81	79	81	79	77	77	80	79	76	74	73.5
	Min.	60	68	68	68	69	62	63	63	65	67	54	55	55	52	62	60	60	58	64	68	67	67	69	68	68	69	69	70	68	69	67	64.3
Aug.	Max.	77	79	70	70	67	66	67	69	70	68	68	74	71	74	74	74	77	79	79	82	83	84	80	80	78	80	77	77	77	76	80	75.1
	Min.	65	66	70	65	64	63	62	62	61	62	61	61	64	63	64	65	67	67	67	67	68	69	69	68	67	65	66	66	66	65	64	64.2
Sept.	Max.	80	77	81	83	82	79	80	80	81	83	83	79	83	83	70	68	67	75	75	76	77	80	80	78	75	64	64	65	73	72		76.4
	Min.	68	68	68	68	70	70	68	67	67	69	70	70	69	70	66	65	62	62	63	65	66	68	68	67	66	61	58	60	60	64		66.1
Oct.	Max.	70	64	59	54	56	53	57	55	59	58	60	56	59	58	61	58	60	61	62	62	61	56	54	57	61	62	60	61	62	59	57	59.1
	Min.	63	62	52	50	51	51	50	51	54	54	54	55	56	53	51	52	51	51	52	52	53	54	54	54	55	55	53	57	62	57	51	55.5
Nov.	Max.	57	57	57	56	57	57	55	57	54	51	50	51	52	50	48	52	45	48	48	49	49	49	53	52	52	51	49	50	49	47		51.7
	Min.	49	48	47	48	49	49	49	41	50	49	49	50	50	47	45	45	45	45	43	43	42	42	45	45	50	46	44	45	43	44		46.2
Dec.	Max.	47	51	49	45	48	50	50	52	51	49	48	49	45	48	47	46	44	41	46	45	44	39	40	43	49	46	43	45	41	42	43	46.0
	Min.	45	46	44	43	43	46	48	44	43	46	44	43	44	46	46	43	40	38	43	43	40	38	38	40	44	40	39	43	40	38	39	42.5
1958																																	
Jan.	Max.	41	43	46	46	45	43	41	43	44	44	45	45	43	46	49	49	50	50	45	43	45	45	48	46	48	50	48	48	46	41	45	45.5
	Min.	40	41	40	40	40	40	39	40	42	44	43	43	41	42	47	46	46	44	42	41	40	40	43	45	44	42	45	47	44	38	42	42.3
Feb.	Max.	47	52	48	52	48	48	48	47	47	52	49	50	48	46	50	49	53	52	54	53	51	51	52	52	45	44	47	51				49.5
	Min.	41	44	45	46	46	46	46	45	44	45	46	47	44	42	46	46	48	51	49	46	48	49	49	44	42	40	41	40				45.2
Mar.	Max.	53	49	53	52	49	48	44	40	39	38	48	45	45	51	49	49	48	51	51	50	50	49	52	49	48	54	55	53	48	46	45	48.4
	Min.	42	43	42	44	44	41	39	39	38	36	37	40	42	40	42	42	44	43	44	47	47	46	46	46	43	43	45	48	44	41	40	42.5
Apr.	Max.	49	47	47	49	55	51	54	50	50	58	62	66	57	56	53	52	53	51	53	55	53	51	52	47	50	52	58	63	66	68		54.3
	Min.	44	39	41	42	43	47	47	47	48	48	45	52	55	48	51	49	48	47	49	51	44	42	44	44	43	45	46	49	52	55		47.0
May	Max.	68	69	64	67	62	59	68	71	72	66	66	61	67	71	75	77	75	75	74	75	78	75	73	69	70	70	69	66	66	64	63	69.2
	Min.	56	56	59	56	58	55	59	59	62	62	62	54	53	58	62	65	67	67	66	65	67	69	66	63	61	64	63	62	61	60	60	61.2
June	Max.	65	64	61	64	66	64	64	63	62	62	61	61	60	67	70	74	78	78	76	77	80	82	77	68	72	69	66	65	63	63		68.1
	Min.	58	60	60	58	62	61	59	60	60	59	59	57	58	58	62	64	68	70	70	69	72	74	69	66	64	66	63	61	61	60		62.9
July	Max.	66	71	72	77	80	89	88	86	87	89	91	89	87	89	91	90	88	86	88	89	90	90	89	91	91	93	96	95	93	92	93	87.3
	Min.	61	63	65	68	71	74	71	72	72	72	74	73	71	70	73	74	74	73	72	72	73	74	73	74	75	76	78	80	77	76	76	72.5
Aug.	Max.	93	93	85	88	90	90	83	88	89	90	89	89	89	90	90	91	89	90	89	88	91	91	92	90	91	89	81	80	79	86	88	88.4
	Min.	76	77	75	70	72	74	76	74	73	75	75	74	74	75	76	76	76	76	74	75	77	76	76	78	77	75	75	69	70	68	68	74.3
Sept.	Max.	81	80	77	83	85	88	88	77	77	73	74	66	68	66	74	66	68	73	73	74	67	66	66	59	68	73	77	78	78	78		74.0
	Min.	69	65	65	65	68	70	73	75	70	68	64	64	62	62	60	62	58	58	62	58	63	57	55	56	58	57	60	63	64	63		63.1

Table 11.

DAILY MAXIMUM AND MINIMUM TEMPERATURES 5 CENTIMETERS BELOW GROUND WITH MINERAL SOIL

Year and Month		Day of Month 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Ave.
1957																																	
July	Max.	80	90	89	94	96	70	72	73	80	87	64	68	66	62	78	82	73	95	99	96	97	99	95	99	94	91	92	102	99	89	87	85.7
	Min.	56	63	57	60	62	53	57	57	51	61	50	52	50	46	53	54	53	53	60	62	61	62	66	60	62	64	59	61	65	69	61	58.1
Aug.	Max.	94	98	74	80	74	71	74	81	87	76	81	98	82	89	89	89	93	95	96	97	101	104	96	95	90	99	88	90	90	89	98	89.0
	Min.	57	57	66	60	63	62	59	58	55	56	54	57	59	57	59	60	64	63	64	60	61	64	63	60	59	60	62	58	57	57	57	59.6
Sept.	Max.	98	94	100	102	100	94	98	98	101	105	102	94	104	106	71	72	70	94	93	96	98	104	104	99	92	67	65	71	90	86		92.3
	Min.	62	64	63	63	64	66	61	59	60	62	63	61	63	65	65	65	63	58	54	57	59	62	65	64	62	58	54	50	66	59		61.2
Oct.	Max.	83	66	62	54	61	54	66	58	66	64	68	55	65	67	74	63	73	78	78	81	78	56	54	60	68	70	72	75	80	64	64	67.0
	Min.	58	50	46	48	42	47	47	50	52	52	50	52	56	50	42	44	44	44	45	46	48	52	52	53	51	50	48	46	48	48	44	48.5
Nov.	Max.	68	70	72	72	73	72	62	69	60	50	50	52	53	51	50	54	44	54	55	62	54	61	67	65	55	62	58	63	59	47		59.5
	Min.	40	38	39	39	41	42	42	46	43	48	50	49	49	46	44	42	40	44	39	39	36	36	39	37	46	38	39	40	38	36		41.5
Dec.	Max.	47	62	58	45	55	49	55	68	68	62	50	55	44	50	49	47	43	39	47	45	38	37	41	44	50	40	44	45	41	53	56	49.3
	Min.	43	44	38	38	40	44	48	42	40	38	40	37	37	42	44	44	40	36	42	42	36	35	36	40	44	37	36	37	37	36	38	39.7
1958																																	
Jan.	Max.	43	47	56	55	56	57	44	45	47	46	44	43	44	46	51	54	62	60	46	42	53	52	48	45	53	65	48	48	48	42	50	49.7
	Min.	38	39	37	34	36	38	34	38	40	43	41	38	37	42	46	46	46	40	36	37	35	36	43	44	42	38	46	44	43	37	42	39.9
Feb.	Max.	55	66	52	74	49	50	49	46	48	64	48	49	52	48	48	51	53	51	61	64	56	52	56	54	46	44	60	65				54.0
	Min.	37	42	41	44	44	45	44	43	43	44	44	48	41	42	44	42	48	49	46	40	45	48	48	52	41	37	37	37				43.4
Mar.	Max.	68	59	70	62	47	52	41	36	36	51	63	52	48	68	59	62	56	59	59	57	55	54	62	47	53	66	70	60	47	47	48	55.3
	Min.	36	37	38	38	41	36	38	36	36	36	36	36	38	36	36	37	42	38	37	45	47	43	44	43	38	39	41	46	44	37	38	39.1
Apr.	Max.	60	45	56	60	70	58	66	53	54	76	82	89	61	69	56	56	59	55	56	60	56	61	64	54	59	59	77	88	91	94		64.8
	Min.	42	38	36	41	37	40	44	42	45	48	42	47	50	41	49	47	48	41	48	51	50	40	38	36	36	38	38	43	47	54		43.2
May	Max.	91	90	72	87	70	66	88	89	93	94	72	73	90	96	100	102	93	96	95	102	104	91	90	66	88	95	89	81	84	72	71	86.8
	Min.	50	49	52	48	53	48	50	56	52	56	57	44	43	50	58	62	62	64	60	59	63	65	60	58	53	60	60	60	55	52	55	55.3
June	Max.	85	76	64	84	83	62	72	75	69	71	68	72	67	94	98	106	110	110	101	101	106	110	74	72	99	82	83	75	72	74		83.8
	Min.	49	60	56	53	60	60	53	57	55	55	55	53	53	52	58	62	68	68	68	66	69	71	65	62	57	62	58	51	54	56		58.9
July	Max.	85	98	101	105	107	107	104	100	102	105	108	106	104	105	110	108	105	102	105	106	109	108	107	108	109	112	114	114	110	110	113	106.0
	Min.	57	59	60	65	69	71	67	69	68	67	69	66	63	65	69	69	69	66	67	66	69	69	66	70	70	71	75	77	70	68	68	67.5
Aug.	Max.	110	110	96	104	108	107	95	105	108	110	108	109	107	107	109	110	108	112	109	107	110	110	108	110	109	107	86	92	91	96	101	105.1
	Min.	68	70	67	62	65	68	69	69	64	69	68	67	66	67	67	69	68	70	66	69	71	67	69	71	70	66	67	58	65	62	60	66.9
Sept.	Max.	90	90	84	97	99	103	104	78	85	77	82	65	73	66	87	69	76	87	81	84	69	73	76	58	80	87	92	92	91	91		82.9
	Min.	61	54	57	59	62	63	67	69	64	64	57	56	56	56	57	60	54	53	57	47	57	51	49	49	56	52	56	57	57	56		57.1

Table 12.

DAILY MAXIMUM AND MINIMUM TEMPERATURES 5 CENTIMETERS BELOW GROUND COVERED WITH HARD-BURNED SOIL

Year and Month		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Ave.
1957																																	
July	Max.	76	80	80	88	89	65	69	69	72	81	60	63	62	59	69	79	71	88	90	88	87	90	88	90	86	84	85	93	90	80	81	79.1
	Min.	56	61	56	57	61	51	55	55	50	58	49	48	48	45	50	54	53	53	58	59	58	59	64	59	60	62	57	60	62	62	58	56.1
Aug.	Max.	89	90	72	74	69	68	72	78	80	70	72	85	74	79	80	83	81	84	86	89	92	93	85	84	81	87	79	80	81	80	87	80.8
	Min.	56	58	66	58	60	58	58	56	56	51	50	60	56	54	57	62	62	58	60	60	62	63	61	57	58	57	58	56	56	56	55	57.9
Sept.	Max.	88	85	90	91	90	84	86	87	90	93	91	82	92	94	67	68	65	82	82	85	87	93	93	87	81	62	62	67	82	79		82.8
	Min.	60	62	60	60	62	63	59	58	58	60	61	59	60	62	62	62	60	56	52	54	56	59	62	60	58	56	52	50	55	57		58.5
Oct.	Max.	76	62	58	51	56	50	60	55	61	60	63	52	60	61	67	59	66	68	68	71	69	50	51	66	63	65	65	66	70	59	57	61.4
	Min.	56	55	45	46	43	45	44	47	49	48	47	49	53	47	41	43	43	42	42	44	45	49	49	50	52	48	50	42	45	51	41	46.8
Nov.	Max.	60	62	65	64	62	62	56	62	56	50	46	51	52	51	49	51	42	50	52	56	50	58	61	62	54	65	51	55	55	47		55.2
	Min.	38	37	37	38	38	38	38	44	43	48	46	49	50	46	44	43	40	41	38	38	36	37	40	40	45	38	36	37	37	39		40.6
Dec.	Max.	47	58	52	42	49	48	53	62	61	55	48	53	44	50	48	46	40	37	46	46	45	38	38	44	48	40	42	42	40	46	47	46.9
	Min.	44	44	37	36	38	42	48	42	39	36	40	38	38	43	44	42	37	35	35	43	37	37	35	40	44	37	34	35	36	35	34	38.9
1958																																	
Jan.	Max.	41	44	51	48	50	51	42	45	48	45	44	42	40	47	50	52	56	55	46	43	50	50	48	45	50	59	47	49	47	41	47	47.5
	Min.	37	36	36	34	35	36	36	40	43	42	41	37	36	44	48	46	45	40	38	38	38	38	42	44	42	38	45	45	38	38	41	39.9
Feb.	Max.	52	61	51	62	48	49	49	46	47	59	47	49	50	47	48	49	52	50	59	61	65	51	53	51	45	44	57	60				52.2
	Min.	37	43	43	45	44	45	45	45	45	44	44	47	42	42	45	41	47	49	46	43	46	48	47	50	40	38	39	39				43.9
Mar.	Max.	61	54	62	59	47	50	40	37	36	36	57	51	49	63	55	57	53	57	57	55	52	52	59	47	55	69	73	62	47	49	49	53.2
	Min.	37	37	37	38	42	38	38	37	36	36	35	38	41	37	37	36	41	39	40	45	46	42	45	44	40	37	38	44	42	37	39	39.3
Apr.	Max.	58	46	53	56	65	53	60	53	54	71	75	81	58	63	54	55	57	53	55	58	54	56	61	53	57	59	72	79	82	83		61.1
	Min.	42	41	39	40	37	41	44	44	48	48	45	48	50	40	48	47	49	42	47	51	49	48	38	39	38	40	40	43	47	51		44.1
May	Max.	82	83	69	80	67	65	82	82	83	86	67	69	83	89	91	93	86	89	87	93	95	86	84	65	81	87	83	77	79	69	68	80.6
	Min.	50	49	54	50	53	49	53	57	53	55	56	45	45	52	59	61	61	62	60	58	63	66	60	59	53	58	59	59	55	52	54	55.5
June	Max.	79	71	63	78	79	60	69	70	66	67	65	69	65	84	90	97	99	99	94	93	97	100	71	70	91	77	76	69	67	70		78.2
	Min.	50	56	55	53	59	59	54	56	54	54	55	53	53	52	57	60	67	68	68	64	67	69	64	62	57	61	57	50	53	55		58.1
July	Max.	78	89	95	98	99	96	95	92	94	96	97	95	91	96	101	100	95	91	92	95	98	96	97	99	99	101	105	104	102	100	100	96.3
	Min.	54	57	61	66	69	69	64	67	66	67	68	65	63	63	68	69	69	65	63	63	66	66	65	69	69	69	72	73	69	68	69	66.2
Aug.	Max.	100	97	87	93	98	97	87	94	98	99	97	97	96	97	99	99	97	97	97	96	100	99	98	100	99	96	81	83	84	87	92	94.9
	Min.	67	67	64	61	64	67	67	67	62	66	65	64	64	65	66	67	66	67	63	65	69	66	67	69	68	64	65	58	62	60	59	64.9
Sept.	Max.	83	82	78	87	90	94	95	73	78	72	77	63	69	63	80	65	71	79	75	77	65	67	69	57	75	79	83	82	82	83		76.4
	Min.	59	53	55	57	59	61	65	67	61	61	55	55	55	55	54	57	51	52	56	48	56	49	46	48	55	51	53	54	54	54		55.2

Table 13.

DAILY MAXIMUM AND MINIMUM TEMPERATURES 5 CENTIMETERS BELOW GROUND COVERED WITH CHARCOAL

Year and Month		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Ave.
1957																																	
July	Max.	72	78	79	85	84	63	67	66	69	78	59	61	64	60	72	72	66	80	84	84	82	84	81	82	80	78	79	86	83	75	75	75.1
	Min.	59	66	60	63	64	52	57	57	55	60	51	49	51	48	51	56	55	56	62	64	62	62	65	62	63	65	61	63	65	65	62	59.1
Aug.	Max.	80	83	69	70	67	66	69	74	76	68	71	82	73	79	80	78	79	82	84	85	86	85	82	82	78	83	77	80	79	78	84	77.7
	Min.	60	62	60	61	61	61	62	62	59	59	56	62	61	60	61	62	64	63	66	63	63	63	63	61	61	61	61	60	59	59	59	61.1
Sept.	Max.	85	82	87	89	87	82	83	83	85	90	89	80	87	89	68	69	67	80	79	81	83	87	88	85	80	66	62	65	76	75		80.3
	Min.	63	65	63	63	65	66	62	61	62	66	68	63	63	64	65	65	63	60	58	57	59	62	65	66	63	60	56	53	57	54		61.9
Oct.	Max.	72	62	58	50	54	52	60	55	61	60	63	53	60	60	67	59	65	65	64	65	64	55	53	57	61	63	64	64	67	59	67	60.6
	Min.	58	53	49	48	46	48	48	50	52	57	52	52	54	57	47	48	48	48	47	48	49	53	53	53	55	53	51	52	50	55	47	50.6
Nov.	Max.	59	59	59	59	61	61	55	58	53	49	49	50	49	50	48	49	42	50	50	53	49	54	56	56	53	54	51	54	53	45		52.9
	Min.	45	43	44	43	45	45	45	47	45	47	49	48	49	48	45	44	41	43	42	41	40	40	40	40	48	42	42	43	41	40		43.8
Dec.	Max.	46	53	51	43	50	48	51	59	58	53	48	50	42	46	47	46	44	42	46	45	44	39	39	41	48	44	42	43	40	45	44	46.3
	Min.	43	45	41	41	42	44	47	45	46	41	45	40	40	42	44	44	43	40	42	45	39	38	39	38	42	41	40	40	40	39	39	41.8
1958																																	
Jan.	Max.	40	43	48	49	48	44	40	42	44	44	43	44	42	46	50	50	52	50	43	42	45	46	47	46	49	55	46	48	46	40	46	45.7
	Min.	40	40	40	39	39	40	39	40	42	44	43	42	41	41	48	48	47	42	41	40	37	38	43	46	45	41	45	45	45	40	41	42.0
Feb.	Max.	49	56	49	57	46	47	47	45	46	55	47	47	47	45	45	47	50	50	53	55	52	50	51	50	46	44	51	55				49.4
	Min.	40	44	45	46	46	46	46	45	45	46	47	47	45	45	44	44	47	50	47	45	49	50	50	50	44	43	43	42				45.7
Mar.	Max.	56	52	58	54	46	46	41	40	39	39	51	46	46	57	50	53	50	52	53	53	50	49	54	46	48	57	62	55	46	45	45	49.6
	Min.	42	41	43	50	41	40	40	40	39	38	37	40	41	40	40	39	44	42	41	46	48	44	45	45	42	40	42	47	45	41	41	42.1
Apr.	Max.	52	43	49	53	61	51	57	49	50	63	68	73	57	59	53	53	54	50	51	55	53	54	56	50	53	53	65	71	73	75		56.8
	Min.	42	40	41	43	42	45	46	45	47	49	46	50	52	47	50	48	49	45	48	50	47	45	43	42	41	41	42	47	50	54		45.9
May	Max.	73	74	64	73	64	53	73	74	75	77	66	64	79	80	83	85	80	82	80	85	86	79	78	62	76	81	78	74	75	67	64	74.3
	Min.	53	51	55	51	57	61	55	58	53	57	57	50	52	54	60	62	63	64	63	63	67	67	63	61	57	62	63	62	59	57	56	58.5
June	Max.	75	70	63	74	75	62	66	69	67	60	63	66	63	77	83	90	90	90	86	86	89	93	74	68	84	74	72	68	66	67		74.3
	Min.	53	60	59	56	62	52	56	58	59	59	58	56	56	56	60	64	68	68	70	68	69	71	67	65	62	65	61	56	58	59		61.0
July	Max.	76	83	85	89	90	90	90	87	88	88	90	88	87	90	93	94	90	87	87	89	91	90	90	91	92	94	98	97	96	95	95	90.0
	Min.	60	62	64	66	68	70	68	70	70	70	70	67	66	67	70	72	72	69	67	66	69	70	68	70	71	72	74	76	72	72	71	68.9
Aug.	Max.	96	94	85	90	94	94	83	89	93	94	93	95	93	92	93	94	92	95	94	93	94	94	94	96	96	94	80	81	81	83	88	91.2
	Min.	70	70	68	66	68	70	70	68	65	69	69	69	70	69	68	69	69	71	68	69	71	68	69	71	72	70	69	62	64	61	62	68.2
Sept.	Max.	80	80	75	84	86	89	88	73	77	71	75	62	67	63	77	65	69	77	74	75	65	67	66	57	72	75	77	78	77	77		73.9
	Min.	63	60	59	60	63	64	66	67	65	65	60	58	56	56	58	59	55	56	59	53	59	54	51	52	56	54	57	58	59	56		58.6

Table 14.

DAILY MAXIMUM AND MINIMUM TEMPERATURES 5 CENTIMETERS BELOW GROUND COVERED WITH LITTER

Year and Month		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Ave.
1957																																	
July	Max.	71	78	78	84	84	62	66	66	69	77	59	60	63	60	70	72	66	79	82	80	81	83	80	84	81	78	78	84	83	78	77	74.6
	Min.	62	68	62	65	66	53	57	57	55	60	51	50	51	48	51	59	59	58	63	65	63	64	67	65	67	67	62	63	66	68	65	60.5
Aug.	Max.	81	83	67	70	69	67	70	75	77	70	73	80	73	78	78	77	79	81	82	85	87	88	81	80	78	83	77	78	79	77	84	77.6
	Min.	62	62	66	61	62	62	63	63	60	61	58	61	62	61	63	63	65	64	65	64	66	68	67	63	63	62	64	62	62	62	61	62.8
Sept.	Max.	84	81	85	87	86	82	83	83	85	88	88	81	87	89	69	68	66	80	77	78	79	84	85	82	77	68	62	65	75	74		79.3
	Min.	65	66	64	65	67	69	65	63	64	66	67	67	66	67	67	66	65	61	61	61	62	64	67	67	65	62	60	56	60	55		64.0
Oct.	Max.	70	64	56	52	55	51	57	54	59	59	61	54	59	60	64	57	62	62	62	63	63	57	54	55	60	62	62	63	64	58	56	59.2
	Min.	62	55	50	49	48	49	49	52	53	54	53	54	54	52	48	50	49	48	49	50	51	54	54	53	54	52	51	49	51	56	49	51.7
Nov.	Max.	57	57	57	57	58	57	53	57	52	51	49	51	51	52	48	54	43	48	47	51	47	52	54	53	51	52	49	53	49	44		51.6
	Min.	46	44	44	45	46	46	47	49	47	49	49	50	49	46	43	41	43	44	41	41	40	41	43	42	49	43	42	44	41	41		44.5
Dec.	Max.	46	54	50	43	45	45	49	55	55	51	47	49	43	48	47	47	44	37	44	44	44	39	39	42	49	46	41	41	39	43	42	45.4
	Min.	44	47	43	42	41	43	47	45	43	42	45	43	42	42	47	46	37	36	37	43	39	39	37	37	43	40	39	39	38	37	37	41.3
1958																																	
Jan.	Max.	40	43	46	44	44	40	39	42	43	43	41	41	40	45	49	50	53	50	43	41	45	45	47	47	48	53	47	48	47	43	44	44.9
	Min.	40	40	40	37	36	38	37	38	41	42	41	40	39	40	47	48	47	43	40	40	39	40	44	46	45	41	47	46	43	40	40	41.4
Feb.	Max.	45	54	48	55	49	47	47	46	46	54	47	47	47	47	47	47	49	51	55	56	51	49	51	51	49	44	51	45				49.1
	Min.	39	43	45	47	47	47	47	46	45	46	45	47	45	46	46	45	47	49	50	46	47	49	49	51	45	43	43	40				45.9
Mar.	Max.	55	48	57	54	49	45	43	40	39	39	51	45	45	54	50	50	48	53	53	53	51	47	52	47	49	60	61	55	48	43	44	49.2
	Min.	39	41	41	42	43	40	41	39	39	37	36	39	41	39	41	40	44	42	45	49	49	45	45	45	43	43	46	49	43	41	41	42.2
Apr.	Max.	50	46	50	52	59	50	56	49	51	64	69	71	59	57	53	53	55	51	51	53	50	51	55	49	52	53	65	70	71	73		56.3
	Min.	44	40	42	44	43	45	46	46	48	51	48	52	51	46	51	50	50	47	49	50	41	40	42	41	42	43	45	49	53	55		46.5
May	Max.	72	72	64	71	64	59	71	72	73	76	64	64	73	78	81	83	76	78	79	82	86	80	79	68	76	83	79	74	75	67	65	73.7
	Min.	55	54	57	55	59	55	55	58	55	58	59	51	57	57	62	64	64	65	64	63	67	71	66	61	58	63	64	63	61	59	59	59.8
June	Max.	75	70	63	74	73	65	66	69	66	67	64	67	63	67	81	87	91	91	86	85	90	93	76	70	85	75	74	69	67	70		74.6
	Min.	56	61	60	58	64	60	58	60	59	60	60	58	59	57	61	65	70	71	72	69	71	73	69	67	63	67	63	57	60	61		63.0
July	Max.	77	84	85	87	89	90	90	87	88	87	89	87	85	88	91	90	85	82	83	85	89	88	87	89	88	90	94	94	93	91	92	87.9
	Min.	63	65	66	67	69	72	71	72	71	73	73	72	71	71	75	76	75	71	70	70	73	73	73	75	74	74	76	79	76	76	76	72.2
Aug.	Max.	91	89	82	85	89	91	83	87	88	90	89	89	88	89	89	90	89	90	89	87	90	90	91	91	92	89	79	78	79	83	85	87.5
	Min.	75	75	73	69	71	74	76	74	71	74	73	72	72	73	73	74	75	75	77	73	75	73	73	76	76	73	73	67	69	67	68	72.9
Sept.	Max.	79	77	74	80	82	85	85	75	76	73	73	64	67	64	78	67	70	75	72	71	75	67	66	58	71	73	75	75	75	75		73.2
	Min.	69	64	64	64	66	67	71	72	70	69	64	61	61	61	62	63	60	60	63	56	61	58	59	57	58	58	60	61	63	63		62.8

Table 15. Mortality and survival of Douglas fir seedlings on each individual plot during the 1958 growing season.

	Exposure to light in per cent														
	100					75					25				
Charcoal															
	Plot					Plot					Plot				
	21	13	51	82	87	22	48	34	84	56	26	32	54	61	77
Cause of Mortality	No's of seedlings lost					No's of seedlings lost					No's of seedlings lost				
Animals	57	44	35	49	58	130	46	118	39	293	134	234	342	150	310
Heat Injuries	216	350	242	265	231	38	58	23	57	9	-	-	-	-	-
Damping Off	1	-	-	-	-	3	16	1	15	-	30	22	15	33	17
Frost	8	14	-	-	-	7	-	-	-	-	8	1	-	-	-
Drought	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unknown Causes	-	-	-	-	-	1	2	3	6	-	14	-	2	3	4
Totals	282	408	277	314	289	179	122	145	117	302	186	257	359	186	331
Seedlings surviving on Nov. 1, 1958 No's	90	90	194	177	198	131	361	77	280	5	253	50	43	230	70
Seedlings surviving on Nov. 1, 1958 %	25.6	18.1	41.2	36.0	40.7	42.3	74.7	34.7	70.5	1.6	57.6	16.3	10.7	55.3	17.5
Hard-burned Soil															
	Plot					Plot					Plot				
	19	41	40	65	90	20	8	33	83	57	3	7	9	66	74
Cause of Mortality	No's of seedlings lost					No's of seedlings lost					No's of seedlings lost				
Animals	7	6	15	8	161	29	103	51	159	22	138	183	113	133	199
Heat Injuries	107	125	101	198	83	24	76	25	75	69	-	-	-	-	-
Damping Off	-	-	-	-	-	2	-	3	8	4	7	12	2	71	27
Frost	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Drought	-	-	-	-	-	-	-	-	-	-	-	-	-	9	8
Unknown Causes	1	1	-	-	-	1	2	2	4	2	-	1	3	8	1
Totals	115	132	116	206	244	56	181	81	246	97	145	196	118	221	235
Seedlings surviving on Nov. 1, 1958 No's	84	75	66	148	44	138	36	88	150	140	26	26	10	131	91
Seedlings surviving on Nov. 1, 1958 %	42.2	36.2	36.3	41 8	15.3	71.1	16.6	52.1	37.9	59.1	15.2	11.7	7.8	37.2	27.9
Light-burned Soil															
	Plot					Plot					Plot				
	4	14	35	68	55	18	15	12	60	81	23	42	38	69	71
Cause of Mortality	No's of seedlings lost					No's of Seedlings lost					No's of seedlings lost				
Animals	14	35	80	10	14	51	37	88	84	21	45	18	57	17	35
Heat Injuries	157	80	27	127	47	28	16	-	13	12	-	-	-	-	-
Damping Off	-	-	-	-	-	3	-	5	2	33	9	26	25	36	31
Frost	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Drought	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unknown Causes	1	-	-	-	-	1	1	-	1	-	1	1	-	1	-
Totals	172	115	107	137	61	83	54	93	100	66	66	45	82	54	66
Seedlings surviving on Nov. 1, 1958 No's	37	29	3	43	29	126	62	-	28	112	10	47	11	43	75
Seedlings surviving on Nov. 1, 1958 %	17.7	20.1	2.7	23.9	32.2	60.3	53.4	0.0	21.9	62.9	13.2	51.1	11.8	44.3	53.2
Mineral Soil															
	Plot					Plot					Plot				
	17	29	50	70	78	25	47	53	59	89	45	6	11	86	76
Cause of Mortality	No's of seedlings lost					No's of seedlings lost					No's of seedlings lost				
Animals	27	3	12	4	5	7	26	22	12	44	109	54	81	78	44
Heat Injuries	111	48	105	87	77	18	61	19	8	10	-	-	-	-	-
Damping Off	-	-	-	-	-	4	-	-	1	1	18	15	1	5	4
Frost	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Drought	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unknown Cause	-	-	-	-	-	-	2	-	-	-	2	-	-	-	-
Totals	138	51	117	91	82	29	89	41	21	55	129	69	82	83	48
Seedlings surviving on Nov. 1, 1958 No's	62	38	71	21	70	116	175	36	25	49	173	14	0	16	7
Seedlings surviving on Nov. 1, 1958 %	31.0	42.7	37.8	18.8	46.1	80.0	66.3	46.8	54.3	47.1	57.3	6.9	0.0	16.2	12.7

	Exposure to light in per cent														
	100					75					25				
Litter															
	Plot					Plot					Plot				
	46	44	10	67	73	28	5	39	81	75	24	16	52	64	79
Cause of Mortality	No's of seedlings lost					No's of seedlings lost					No's of seedlings lost				
Animals	25	26	15	4	8	5	15	34	14	76	91	26	37	30	92
Heat Injuries	104	42	9	64	63	16	7	15	17	12	-	-	-	-	-
Damping Off	-	-	-	-	-	2	1	1	9	2	7	9	8	15	5
Frost	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Drought	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unknown Cause	-	-	-	-	-	1	-	-	1	-	-	-	-	2	3
Totals	129	68	24	68	71	24	23	50	41	90	98	35	45	47	100
Seedlings surviving on Nov. 1, 1958 No's	86	24	4	60	48	34	47	32	132	22	18	57	25	34	92
%	40.0	26.1	14.3	46.9	40.3	58.6	67.1	39.0	76.3	19.6	15.5	62.0	35.7	42.0	47.9
Sawdust															
	Plot					Plot					Plot				
	2	43	49	62	72	27	30	36	63	68	1	31	37	85	88
Cause of Mortality	No's of seedlings lost					No's of seedlings lost					No's of seedlings lost				
Animals	3	14	102	1	3	3	4	15	18	1	46	31	31	35	41
Heat Injuries	7	62	61	77	57	20	16	1	9	11	-	-	-	-	-
Damping Off	-	-	1	-	-	-	2	-	2	4	-	2	2	6	2
Frost	2	-	2	-	-	1	1	-	-	-	5	-	-	-	-
Drought	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unknown Cause	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Totals	12	76	164	78	60	24	23	16	29	16	51	33	33	42	43
Seedlings surviving on Nov. 1, 1958 No's	8	52	103	73	36	58	38	2	47	14	0	13	10	92	14
%	40.0	40.6	38.6	48.3	37.5	70.7	62.3	11.1	61.8	46.7	0.0	28.3	23.3	68.7	24.6

Table 16. Mortality and survival of Douglas fir seedlings on each individual plot during the winter of 1958/59 and the 1959 growing season.

		Exposure to light during the 1958 growing season (per cent)														
		100					75					25				
		Charcoal														
Mortality		Plot					Plot					Plot				
		21	13	51	82	87	22	48	34	84	56	26	32	54	61	77
During	Cause	No's of seedlings lost					No's of seedlings lost					No's of seedlings lost				
	Animals	19	2	108	-	15	5	8	3	-	-	47	8	31	61	22
Winter 1958/59	Heat injuries	-	-	2	-	3	5	3	1	6	-	-	-	-	1	-
	Removal for root study	-	-	-	10	-	-	-	10	-	-	10	-	-	-	-
1959 Growing Season	Drought	-	-	-	-	-	1	-	-	4	-	5	-	1	6	-
Total losses Nov. 1, 1958 to Nov. 1, 1959		19	2	110	10	18	11	11	14	10	-	62	8	32	68	22
Seedlings suviving on Nov. 1, 1959	No's	78	88	84	167	180	120	350	63	270	5	191	42	11	162	48
	%	20.6	17.7	17.8	34.0	37.0	38.7	72.5	28.4	68.0	1.6	43.5	13.7	2.7	38.9	12.0

		Hard-burned Soil														
Mortality		Plot					Plot					Plot				
		19	41	40	65	90	20	8	33	83	57	3	7	9	66	74
During	Cause	No's of seedlings lost					No's of seedlings lost					No's of seedlings lost				
	Animals	7	5	4	3	5	6	3	3	5	10	4	7	-	20	27
Winter 1958/59	Heat injuries	-	1	1	2	-	-	-	-	-	-	-	-	-	-	-
	Removal for root study	10	-	-	-	-	10	-	-	-	-	10	-	-	-	-
1959 Growing Season	Drought	-	1	-	-	-	1	2	-	4	-	2	1	-	1	2
Total losses Nov. 1, 1958 to Nov. 1, 1959		17	7	5	5	5	17	5	3	9	10	16	8	-	21	29
Seedlings surviving on Nov. 1, 1959	No's	67	68	61	143	39	121	31	85	141	130	10	18	10	110	62
	%	33.7	32.9	33.5	40.4	13.5	62.4	14.3	50.3	35.6	54.9	5.8	8.1	7.8	31.3	19.0

		Light-burned Soil														
Mortality		Plot					Plot					Plot				
		4	14	35	68	55	18	15	12	60	80	23	42	38	69	71
During	Cause	No's of seedlings lost					No's of seedlings lost					No's of seedlings lost				
	Animals	-	1	1	5	5	57	7	-	2	5	1	4	2	12	4
Winter 1958/59	Heat injuries	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Removal for root study	10	-	-	-	-	-	-	-	-	10	-	10	-	-	-
1959 Growing Season	Drought	1	-	-	-	-	2	-	-	1	2	-	-	-	2	-
Total losses Nov. 1, 1958 to Nov. 1, 1959		11	1	1	5	5	59	7	-	3	17	1	14	2	14	4
Seedlings surviving on Nov. 1, 1959	No's	26	28	2	38	24	67	55	0	25	95	9	33	9	29	71
	%	12.4	19.4	1.8	21.1	26.7	32.1	47.4	0.0	19.5	53.4	11.8	35.9	9.7	29.9	50.4

Exposure to light during the 1958 growing season (per cent): 100 : 75 : 25

Mineral Soil

Mortality During	Cause	100: Plot 17	29	50	70	78	75: Plot 25	47	53	59	89	25: Plot 45	6	11	86	76
		No's of seedlings lost					No's of seedlings lost					No's of seedlings lost				
	Animals	9	5	4	4	13	-	36	3	4	-	77	1	-	4	2
Winter 1958/59	Heat injuries	2	-	2	-	-	3	1	-	-	-	-	-	-	-	-
	Removal for root study	-	-	-	-	10	10	-	-	-	-	10	-	-	-	-
1959 Growing Season	Drought	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total losses Nov. 1, 1958 to Nov. 1, 1959		11	5	6	4	23	13	37	3	4	-	87	13	-	4	2
Seedlings surviving on	No's	51	33	65	17	47	103	138	33	21	49	86	13	0	12	5
Nov. 1, 1959	%	25.5	37.1	34.6	15.2	30.9	71.0	52.3	42.9	45.7	47.1	28.5	15.7	0.0	12.1	9.1

Litter

Mortality During	Cause	100: Plot 46	44	10	67	73	75: Plot 28	5	39	81	75	25: Plot 24	16	52	64	79
		No's of seedlings lost					No's of seedlings lost					No's of seedlings lost				
	Animals	5	-	-	1	5	8	4	4	13	-	-	6	4	1	10
Winter 1958/59	Heat injuries	-	1	-	-	-	-	-	1	-	2	-	-	-	-	-
	Removal for root study	10	-	-	-	-	-	-	10	-	-	-	10	-	-	-
1959 Growing Season	Drought	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Total losses Nov. 1, 1958 to Nov. 1, 1959		15	1	-	1	5	8	4	15	13	2	-	16	5	1	10
Seedlings surviving on	No's	71	23	4	59	43	26	43	17	119	20	18	41	20	33	82
Nov. 1, 1959	%	33.0	25.0	14.3	46.1	36.1	13.8	61.4	20.7	68.8	17.8	15.5	44.6	28.6	40.7	42.7

Sawdust

Mortality During	Cause	100: Plot 2	43	49	62	72	75: Plot 27	30	36	63	58	25: Plot 1	31	37	85	88
		No's of seedlings lost					No's of seedlings lost					No's of seedlings lost				
	Animals	-	6	11	24	-	19	-	1	6	2	-	-	2	16	4
Winter 1958/59	Heat injuries	-	-	2	-	-	-	1	-	1	-	-	-	-	-	-
	Removal for root study	-	-	10	-	-	-	-	-	10	-	-	-	-	10	-
1959 Growing Season	Drought	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Total losses Nov. 1, 1958 to Nov. 1, 1959		-	6	23	24	-	19	1	1	17	2	-	-	2	27	4
Seedlings surviving on	No's	8	46	80	49	36	39	37	1	30	12	0	13	8	65	10
Nov. 1, 1959	%	40.0	35.9	30.0	32.5	37.5	47.6	60.7	5.6	39.5	40.0	0.0	28.3	18.6	48.5	17.5

Figure 1. Plot 87, charcoal; July 20, 1958. The average height of seedlings on this seedbed material was 5 to 6 centimeters.

Figure 2. Plot 87, charcoal; September 15, 1958. The average height of undamaged seedlings on this seedbed material was 7 to 8 centimeters. Upright thermometer in rear center is 10 centimeters high.

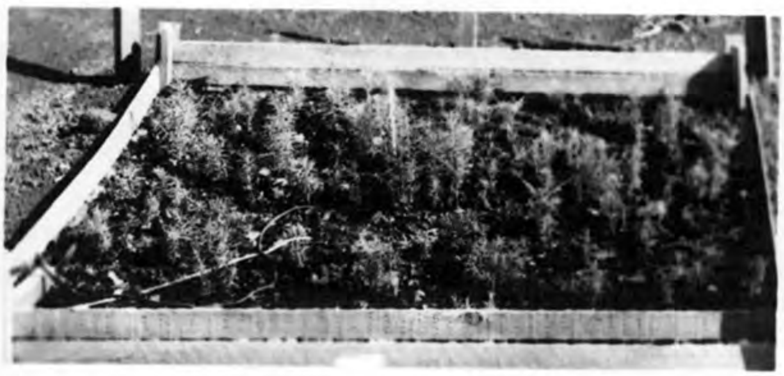


Figure 3. Plot 87, charcoal; May 20, 1959. Note the bushy appearance of the seedlings which was caused by extensive browsing during the preceding winter.

Figure 4. Plot 87, charcoal; September 1959. The seedlings have completely recovered from their injuries and made excellent height-growth during the growing season. The ruler at the rear of the plot is 30 centimeters high.

Figure 5. Plot 41, hard-burned soil; July 20, 1958. The average height of seedlings on this seedbed material was 4 to 5 centimeters.

Figure 6. Plot 41, hard-burned soil; September 15, 1958. The average height of undamaged seedlings on this seedbed material was 5 to 6 centimeters.

Figure 7. Plot 41, hard-burned soil; May 20, 1959. The seedlings were bushy as a result of browsing during the winter 1958/59.

Figure 8. Plot 41, hard-burned soil; September 15, 1959. The seedlings have completely recovered from the browsing. The ruler is 30 centimeters high.

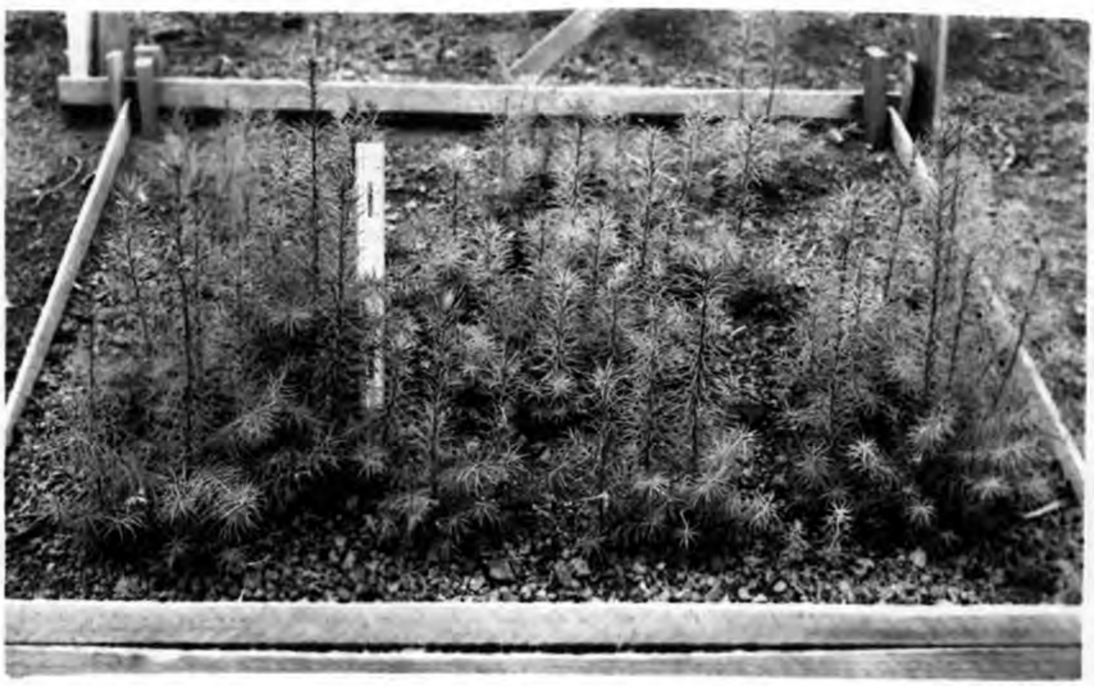


Figure 9. Plot 68, light-burned soil; July 20, 1958. The average height of seedlings on this seedbed material was 4 to 5 centimeters.

Figure 10. Plot 68, light-burned soil; September 15, 1958. The average height of undamaged seedlings on this seedbed material was 5 to 6 centimeters.

Figure 11. Plot 68, light-burned soil; May 20, 1959. The seedlings show severe browsing damage.

Figure 12. Plot 68, light-burned soil; September 15, 1959. Seedlings in the lower left corner have not fully recovered from the browsing damage while seedlings in the rear made excellent height growth during the 1959 growing season. The ruler is 30 centimeters high.

Figure 13. Plot 50, mineral soil; September 15, 1958. The average height of undamaged seedlings was 5 to 6 centimeters. Upright thermometer in rear center is 10 centimeters high.

Figure 14. Plot 50, mineral soil; September 15, 1959. The ruler is 30 centimeters high.

Figure 15. Plot 46, litter; September 15, 1958. The average height of undamaged seedlings on this seedbed material was 6 to 7 centimeters.

Figure 16. Plot 46, litter; September 15, 1959. The two seedlings in the lower left corner are a good example of the recovery from the browsing damage during the winter 1958/59. The rosettes of branches at the base of the seedlings show the point to which seedlings had been pruned by browsing. The height of the ruler is 30 centimeters.

Figure 17. Plot 43, sawdust; July 20, 1958. The average height of seedlings on this seedbed material was 4 to 5 centimeters.

Figure 18. Plot 43, sawdust; September 15, 1959. The average height of undamaged seedlings on this seedbed material was 7 to 8 centimeters. Upright thermometer is 10 centimeters high. Wires in right half of the plot are thermocouple wires used for soil temperature measurements. Wires in the left half lead to Bouyoucos soil moisture blocks.

Figure 19. Plot 43, sawdust; May 20, 1959. Seedlings were bushy as the result of browsing during the preceding winter.

Figure 20. Plot 43, sawdust; September 15, 1959. Seedlings showed excellent recovery from the browsing damage. Ruler is 30 centimeters high.