AN ABSTRACT OF THE THESIS OF

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Title TEMPERATURE MICROENVIRONMENTS ASSOCIATED WITH EARLY STAGES IN PLANT SUCCESSION ON DOUGLAS-FIR CLEAR-CUTS IN THE OREGON COAST RANGE

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The influence of four successional dominant species on modifying both air and soil temperatures was investigated during the summers of 1961 and 1962. The study was carried out on the Marys Peak watershed, where a consistent pattern of succession has been found to occur on burned Douglas-fir clear-cuts. The early stages of succession are characteristically dominated by Senecio sylvaticus in the second year after cutting, Cirsium vulgare in the third, and Holcus lanatus and Lotus stipularis for several years following.

Maximum air temperatures one and one-half inches above the ground and soil temperatures three inches below the soil surface were measured in each of the four dominating species. All temperatures occurring in the vegetation were compared to associated areas of comparable exposure denuded of all plant life. Each bare-ground area was surrounded by five to eight temperature stations in the

vegetation. At each temperature station both maximum air temperatures and soil temperatures were taken. The bare-ground areas contained in addition to maximum thermometers, two thermographs for recording soil and air temperatures. All temperature measuring equipment was shaded from direct sunlight, and replicated three times on each clear-cut.

A relationship was found between the physical form of the species studied and its effect on maximum air temperatures. *Lotus* is characterized by a dense canopy of leaves one or two feet above the ground. This canopy reduces light sharply at the soil surface, causing maximum air temperatures to read about seven degrees below those occurring on similar bare-ground areas.

Holcus has a life form and a characteristic microclimate which differs from *Lotus*. Due to a combination of having no canopy of leaves, but possessing a dense mat of grass leaves at the soil surface, this species raises rather than lowers maximum air temperature when compared to bare-ground areas. Maximum air temperatures under *Holcus* were found to average five degrees above those occurring on bare ground.

Senecio and *Cirsium*, both members of the composite family, have similar life forms and similar temperature environments, which fall in between the extremes found in *Lotus* and *Holcus*. Both species depress maximum air temperatures about five degrees.

Cirsium by producing large amounts of white seed pappus, showed that a species may significantly change its temperature pattern over the course of a season.

Soil temperatures are always cooler under vegetation than under bare ground. The amount of temperature difference seems to be correlated with the amount of plant material to act as a heat insulating layer.

The early stages of plant succession (*Senecio* and *Cirsium*) create a temperature environment over the clear-cut which is highly changeable. As annuals and biennials shift populations rapidly during the first few years, many areas of the clear-cut are subjected to a changing temperature environment. The later stages of succession made up of mostly perennials (*Holcus* and *Lotus*) are relatively stable.

Any species attempting to become established after clear-cutting will be subjected to different temperature environments, depending on how soon it germinates after the clear-cut is made. The present study suggests that tree seedlings such as Douglas-fir would have the best chance of survival when planted within three years after clear-cutting.

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WITH EARLY STAGES IN PLANT SUCCESSION
ON DOUGLAS-FIR CLEAR-CUTS
IN THE OREGON COAST RANGE

by

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TEMPERATURE MICROENVIRONMENTS ASSOCIATED WITH EARLY STAGES IN PLANT SUCCESSION ON DOUGLAS-FIR CLEAR-CUTS IN THE OREGON COAST RANGE

I. INTRODUCTION

To understand the causes of plant succession requires a knowledge of the environmental complex, including climatic, edaphic, and biological aspects. A complete understanding of the complex is probably beyond man's grasp. However, a knowledge of some of the most important factors may be possible, and most certainly is necessary if man is to hope to manipulate vegetation systems successfully.

One major force which influences succession is temperature, and the present study has been limited to this factor. It is realized, however, that the knowledge of a single factor can not adequately explain the cause of succession. On the other hand, gaining a knowledge of a single factor such as temperature in relation to succession does provide a first step to understanding.

The investigation described in this report was carried out on Marys Peak, about eight miles southwest of Corvallis, Oregon. This area is of particular advantage because a reliable, consistent pattern of plant succession has been found to occur on Douglas-fir clear-cuts occurring in this area (6).

This successional sequence is characterized by a domination of Senecio sylvatius in the second year after cutting, Cirsium vulgar in the third, and Holcus lanatus and Lotus stipularis for several years following. Throughout the investigation the temperature associated with each of these successional stages was sampled.

In order to sample the temperature patterns occurring in the vegetation, maximum air temperatures were taken one and one-half inches above the soil surface, and soil temperatures were taken three inches below the surface. The maximum thermometers were shaded by wooded stands. Bare-ground areas denuded of all vegetation were established and equipped with temperature recording instruments in order to make temperature comparisons between the three stages of succession possible. All sampling was done on south-east slopes, between 1,000 and 1,500 feet.

The purpose of this study is to describe the temperature influences or modifications brought about by each of the four plants which dominate in the successional stages described above. Also an attempt is made to find a relationship between the physical form of a plant and its effect of temperature.

II. LITERATURE REVIEW

Although much has been written about the effects of temperature on plants, far less has been written about the influence of plants on temperature. One of the first reviews dealing with the influence of the forest upon climate is the text book entitled Forest Influences by Kittredge (13). One chapter of the book deals with the influence of the forest upon temperature and includes most of the literature written in English up to the time of publication.

The first extensive review of microclimatology was written by Geiger (9). When this book was translated from German into English, it stimulated much interest in the subject both in the United States and in England. Geiger's work not only contains information of the physical aspects of microclimate, but also has several chapters dealing with the influence of both forest and herbaceous vegetation on microclimate. Many references are given from continental Europe which are not included in Kittredge's book.

More recently Molga (15, vol. 2) has published a book in Poland on agricultural meteorology, which has since been translated into English. Molga has written several chapters treating the effects of vegetation on temperature. Many references are made to both German and Russian literature.

In general, most of the work dealing with the effects of the forest on temperature have shown that the forest moderates the temperature. (1; 8; 9, p. 326-335; 13, p. 52-61; 14; 22; 24). There is general agreement that the maximum temperature in a forest tends to be lower than those occurring in the open, and that minimum temperatures tend to be higher. This appears to be the case for both soil and air temperatures under the tree canopy.

Larsen (14) reported air temperatures in a Ponderosa pine forest to be about ten degrees cooler during the warm part of the day, and about ten degrees warmer than in the open at night. These measurements were taken in northern Idaho in 1922, during the months of July and August using maximum-minimum thermometers and thermographs. These instruments were placed in weather shelters four and one-half feet above the ground. Selleck and Schoppert (22) compared a pine forest to an adjacent prairie, at the University of Wisconsin Arboretum. In this case temperatures were measured at 20 cm. above the soil surface. Although the day-time air temperature was about ten degrees warmer in the prairie than in the forest, the night temperature in the prairie was only about four degrees cooler than the forest. Similar results have been obtained by Sparkes and Buell (24) working in New Jersey where temperatures in an oak-hickory forest were compared to those occurring in an adjacent field, and by Aikman and Smelsen (1) in central Iowa where temperature in a hardwood forest and in an open prairie were measured.

More recently Fritts (8) in 1961 analyzed the maximum summer temperatures inside and outside a hardwood forest in Illinois. He noted that differences in temperatures within and outside a forest are not only caused by the direct effects of radiation but also by evaporation and wind effects. He concluded that conditions which favor high rates of evaporation and transpiration will increase the difference between readings in the forest and in the open. High wind velocity, however, may decrease this difference in temperature.

Much less has been published about the microclimate of herbaceous vegetation than of the forest. A large share of this published material has been concerned with either potatoes or members of the grass family. The objectives of the studies with potatoes have been largely related to a better understanding of diseases where aphids are involved. One of the earliest studies in this regard was by Broadbent (2, p. 439-454) in England. He measured shade temperatures and humidity both in a potato crop 15 cm above the soil surface and in a weather shelter four feet above the ground. On dry sunny days he found that maximum temperature in the potato crop was from 0-13°F. higher than in the shelter, and averaged six degrees higher over a period of eleven weeks. Minimum temperatures taken within the potato crop averaged two degrees lower than in the weather shelter. Wind, wet soil, and cloudy weather all had the effect of reducing the temperature difference between the weather shelter and the potato crop.

Hirst, Long, and Penman (12) also working in England studied the potato crop by taking continuous wet and dry bulb temperatures over a period of two summers. Their findings are similar to those of Broadbent, but contain more information about humidity and dew point.

Grainger (10) studied the microclimate of potatoes in relation to eelworm disease. His study emphasized soil temperature and showed a correlation between high soil temperatures and an increase in potato eelworm.

According to Geiger (9, p. 285), some of the first information on the microclimate in grass was produced by Angstrom in Sweden in 1922. His studies were concerned with meadow grass, with particular emphasis on incident radiation at different levels. He reported that while sunshine penetrated the upper regions of the grass, there is a gradual decrease as one progressed downward into the grass leaves, with no direct insolation at the lower levels.

Other investigators following Angstrom have studied the microclimate of grass from the standpoint of temperature and other environmental factors (3; 4; 5; 7, p. 553-584; 9, p. 285-293; 15, vol. 2, p. 152-164; 18, p. 16-50; 21, 337-358; 25). In general, they have found that, contrary to effects of the forest on temperature, grass usually increases the temperature extremes. Maximum temperatures in grass usually read higher than for comparable areas on bare ground, and minimum temperatures usually read lower than on bare ground.

Cornford's (7, p. 553-584) studies in England in 1938 show that minimum temperatures in grass at night read consistently lower than for bare ground. He measured night temperatures at a height of three feet for bare ground, meadow grass, wheat, strawberries, raspberries, apple orchards, and woods. The temperatures over grass were two to six degrees cooler than those over bare ground. The minimum temperatures in woods and bare soil were the highest with the minimum temperatures for the other kinds of vegetation falling in between. Temperature profiles during the incoming radiation period are given by Champness (5) for timothy grass, and by Geiger (9, p. 289-291) for winter rye. They both observed that slightly above the ground surface in grass the temperatures were several degrees above those on adjacent bare-ground areas at a comparable height. Salisbury (21, p. 337-358) has reported higher temperatures in grass during the day, especially in grass that has been burned.

A detailed study of the microenvironment of grass in relationship to the activities of grass-living insects is reported by Waterhouse (25). His work included temperature profiles in grass under a variety of conditions, including windy days, grass flattened by rain, and grass that is dried and dead. He noted that on warm days it is normal to find air stratification in grass consisting of a warm middle layer of air sandwiched between two cooler layers of air. He explained this condition by noting that air in a crop is primarily heated conductively by warmed grass stalks and leaves. The hottest layer of air will therefore be found where "the crop is beginning to increase in density and strength and the incident radiation has not fallen off greatly."

Penman and Long (18, p. 16-50) concluded that the effects of grass on microclimate are directly dependent on the density of planting of the grass. The denser plantings have a greater effect in modifying temperature. Geiger (9, p. 287-291) has noted that density is also important in other types of vegetation in affecting temperature stratification. In his study of snapdragons he emphasized the importance of "joining hands" if the plants were to have a marked effect upon the temperature microclimate.

Probably the best summary of the problem concerning the influence of vegetation upon microclimate is given by Brunt (3; 4). In these articles, Brunt emphasizes the importance of the physical form of the plant in relation to temperature distribution. He observed that plants which contain a thick canopy of leaves, usually exhibit decreased temperature extremes near the ground surface, while plants such as grass without dense canopy of leaves may have the opposite effect. According to his reasoning, the increased range of temperature in grass was related to an increased amount of light penetration and to the matting of dead grass leaves and roots on the ground surface. Brunt (3; 4) noted the importance of other factors affecting temperature in grass such as type of soil, water content of soil, and wind.

A number of studies have been made concerning light and radiation within vegetation (16, p. 159-170; 17, p. 496-507; 19, p. 111-126; 20, p. 375-401). Most of these investigations also deal directly or indirectly with heat transfer and are in this way related to studies on temperature. The information in this area has recently been reviewed by Raschke (19, p. 111-126).

III. METHODS

In the summer of 1961, three clear-cuts on which to begin the study were selected on the Marys Peak watershed. Each selected clear-cut contained one of three successional stages and was covered by either one or two dominating plants. All clear-cuts used have been given numbers by the United States Forest Service, according to the order in which the cuts were made. These designated numbers will be referred to in this study. The youngest clear-cut (#44) was cut in 1959 and was dominated by Senecio sylvaticus, at the beginning of the investigation. The second clear-cut (#31) was cut in 1958 and was dominated by Cirsium vulgar. The third clear-cut (#12) was cut in 1955 and dominated by both Holcus lanatus and Lotus stipularis which occur together in a mosaic pattern.

Bare-ground areas were established on the three selected clear-cuts. This was done by completely denuding the vegetation from a circular area ten feet in diameter (Figure 1). The purpose of the bare-ground areas was to provide a control whereby all measurements in the vegetation could be compared to similar measurements in the absence of vegetation. The bare-ground areas also made it possible to compare microclimates between the three clear-cuts, with the vegetation factor held to a minimum.

Around each bare-ground area, five stations were established

Figure 1. Bare-ground area showing maximum thermometer stand and two protective canisters for air and soil thermographs.

in the vegetation. These stations were placed where the species to be sampled occurred in pure or almost pure stands (Figures 2, 3, 4, 5). There was one exception to this sampling arrangement. On clear-cut #12 containing both Lotus and Holcus, only three stations were located in the Holcus for each bare-ground area. This reduction in stations was necessary because of the limited amount of Holcus available during this year. As will be noted, the following year (1962) Holcus was sampled more completely on clear-cut #31 (which in 1961 was dominated by Cirsium).

Three replications were provided, so that each clear-cut contained three bare-ground areas, each surrounded by five stations in the vegetation (Figure 6). An exception to this is the case of the Holcus-Lotus clear-cut, which contained eight stations around each bare-ground area (five in Lotus and only three in Holcus).

A maximum thermometer was placed at each station in the vegetation and on each bare-ground area. The maximum thermometers were housed in wooden stands which were closed on three sides and open on the north side (Figure 7). The temperature-sensitive bulbs of these thermometers were placed one and one-half inches above the soil surface. This distance of one and one-half inches above the soil surface was selected to facilitate the sampling problem. It was thought inadvisable to sample temperatures on the soil surface, because the variation there is too high. On the other hand,

Figure 2. Maximum air temperature station under Senecio cover.

Figure 3. Maximum air temperature station under Cirsium cover.

Figure 4. Maximum air temperature station under Holcus cover.

Figure 5. Maximum air temperature station under Lotus cover.

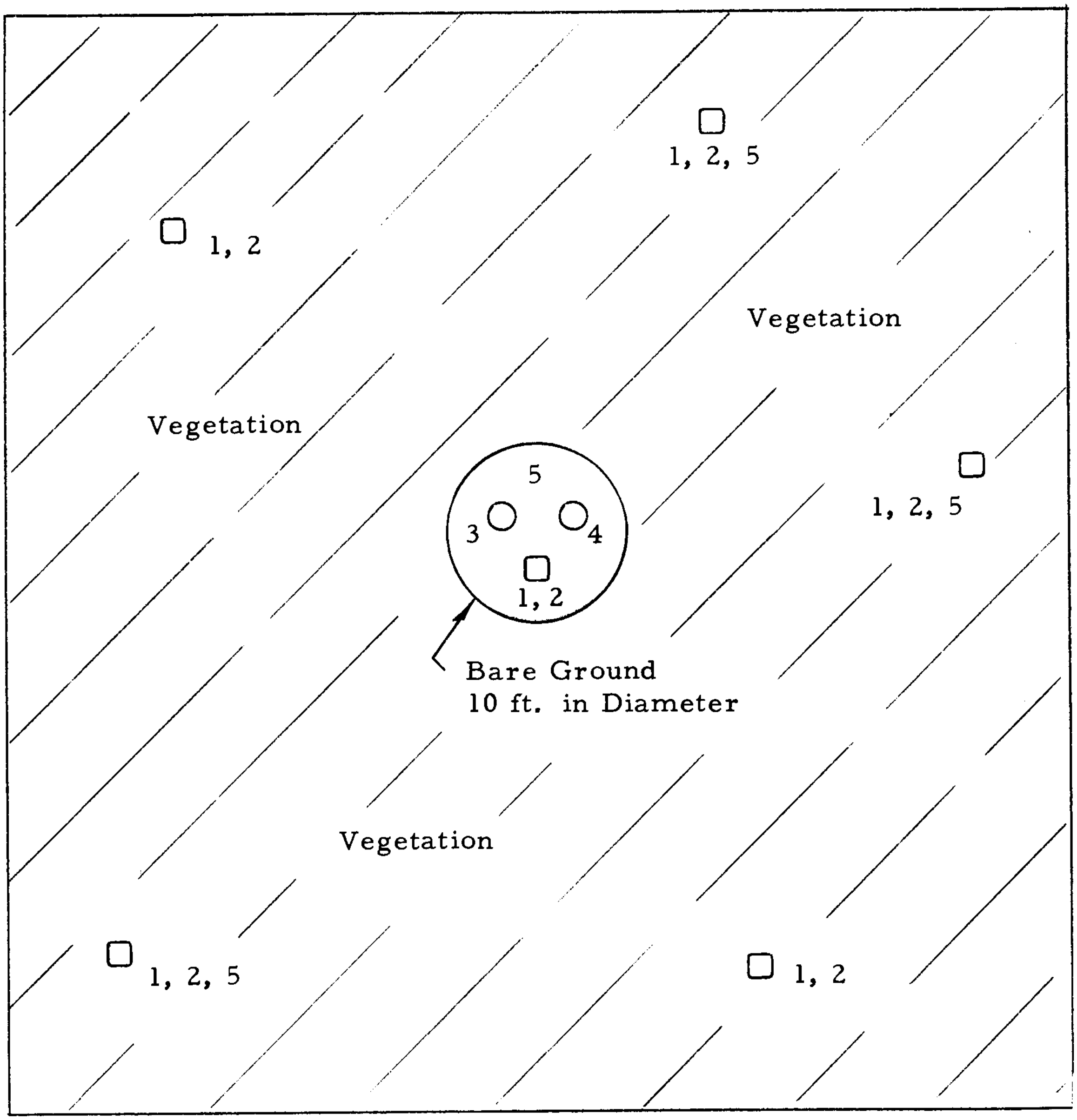

Figure 6. Diagrammatic sketch of sampling design used to sample the influence of certain herbaceous dominants upon the temperature environment. The above arrangement was replicated three times for each plant species.

1. Maximum air temperature station
2. Maximum soil temperature station
3. Air temperature thermograph
4. Soil temperature thermograph
5. Minimum temperature station

temperatures measured too high above the ground would lack significant temperature variation. The chosen distance of one and one-half inches above the soil surface represents a compromise between too much variation in temperature and too little variation.

Soil temperature data at a depth of three inches were taken both in the vegetation and on the bare ground at each station where a maximum thermometer was located. A distance of three inches was chosen as a compromise between too much variation which occurs at the soil surface and too little variation which would occur at deeper depths.

During the summer of 1961 all soil temperatures were taken by means of current reading thermometers. These were temporarily placed in the soil (with the aid of a metal probe) for a few minutes before the reading was taken.

In addition to a maximum thermometer, two thermographs were placed on each bare-ground area (Figure 8). These thermographs were used for the purpose of recording both air and soil temperatures. As in the case of the maximum thermometers, air temperatures were sampled one and one-half inches above the soil surface, and soil temperatures were sampled at a depth of three inches. Both thermographs were housed in aluminum-painted, ventilated canisters, designed to shield the instruments from the direct solar radiation.

Readings of all field instruments were made on Mondays and Fridays. However, the thermograms were changed only on Mondays since these instruments record for a week period.

In the summer of 1962 the work from the previous summer was continued. However, since the first summer's work had shown that Lotus and Holcus gave the most pronounced results, all work was concentrated on these two species.

Clear-cut #12 containing Lotus and Holcus from the previous summer had not changed appreciably, so that it was possible to use this clear-cut again to continue the study of these two species.

On clear-cut #31 the Cirsium which had dominated the previous year had been largely replaced by Holcus. This provided an opportunity to obtain additional temperature data for Holcus, which had been somewhat limited the previous year on clear-cut #12.

The sampling during 1962 was done in the same way as the summer before. Each clear-cut contained three bare-ground areas surrounded by eight stations in the vegetation on clear-cut #12 and five stations in the vegetation on clear-cut #31. However, during the work of the second summer, some new instruments were brought into use. These included enough additional maximum thermometers so that soil temperatures could be taken with maximum thermometers instead of current reading thermometers.

In order to use the maximum thermometers to record soil

Figure 7. Maximum thermometer hung inside wooden stand on bare-ground area.

Figure 8. Thermograph for recording air temperature on bare ground shown alongside protective canister.

temperature it was found necessary to carry a small thermos bottle full of ice and water into the field. This is because it is not possible to shake a maximum thermometer below soil temperature in hot weather. By immersing the maximum thermometer into the ice water for only ten seconds it was found possible to shake the thermometer down to about 40 degrees.

Finally, sixteen minimum thermometers were added to the study. Eight of these were used to sample Holcus temperatures and eight were used to sample Lotus temperatures. A minimum thermometer was placed on each of four bare-ground areas, two bare-ground areas being associated with Holcus and two being associated with Lotus. Around each of the four bare-ground areas, three minimum thermometers were placed in corresponding types of vegetation. All minimum thermometers were placed with the bulb one and one-half inches above the ground. As in the previous year all instruments were read on Mondays and Fridays.

IV. RESULTS

Several types of data were obtained from the two summers of work. The maximum thermometers used in the vegetation and on bare-ground areas indicated how much the vegetation either raised or lowered the temperature as compared to an area without vegetation. A similar type of data was collected for soil temperatures. The effects of vegetation on temperature are not always constant through the course of the summer, and the data allow these changes to be traced. Finally, the thermograph data showed when and for how long maximum temperatures occurred for both soil and air.

Average soil and air temperatures taken at biweekly intervals on bare ground and each associated cover type are given in Figures 15, 16, 17, 18, 19, 20, 21, 22, 23 for 1961 and 1962. The bars in these graphs represent either the average of three temperature readings taken on bare-ground areas, or the average of fifteen temperature readings taken in the associated cover type.

Because readings taken on bare-ground areas are used as a standard against which all other readings for a given sampling period are compared, it is desirable to know how much variation occurred between the three bare-ground areas of each clear-cut sampled (Figures 15, 16, 17, 18, 19, 20, 21, 22, 23). On clear-cut #44 (Senecio dominated) during the summer of 1961 the average range in maximum air temperature variation between the three bare-ground areas was 2.8°F. During the same summer this range in variation averaged 4.4°F. degrees on clear-cut #31 (Cirsium dominated) and 3.4°F. on clear-cut #12 (Holcus and Lotus dominated). The range of soil temperatures taken on bare-ground areas the same summer averaged 3.8°F. on clear-cut #44, 2.9°F. on clear-cut #31, and 3.9°F. on clear-cut #12.

A considerably higher amount of variation in values for a given sampling date may be noted when all the nine bare-ground areas from clear-cuts #12, #31, and #44 are viewed together. When this was done it was found that the range in maximum air temperatures occurring between the three clear-cuts averaged 5.6°F. during the summer of 1961. The range of soil temperatures between clear-cuts averaged 6.3°F. for the same summer. Air and soil thermograph data from a bare-ground area on each of the three clear-cuts for one week during the peak of the growing season are given in Figures 9, 10. The close similarity in diurnal temperature pattern may be noted. Similar seasonal temperature pattern of bare-ground areas from the three clear-cuts may also be noted in Figure 11.

In order to indicate the amount of variation in maximum air temperatures which occurred between the three replications of the Senecio clear-cut, temperature data were averaged together for each bare-ground area (replication). The range of these averages

TABLE I. MEAN MAXIMUM AIR TEMPERATURES AND SOIL TEMPERATURES ASSOCIATED WITH PURE STANDS OF SENECIO, CIRSIUM, HOLCUS, AND LOTUS.

	Mean Maximum Air Temperature						Mean Soil Temperature					
	Maximum Temperature		Difference From Bare Ground		Temp. on Warmest Day		Soil Temp.	Max. Soil Temp.	Difference From Bare Ground		Temp. on Warmest Day	
	'61	'62	'61	'62	'61	'62	'61	'62	'61	'62	'61	'62
SENECIO	103.5		-5		115		73		- 5		80	
CIRSIUM	101.5		-1.5		114		65		- 9		71	
HOLCUS	111	104	+5	+5	121	118	71.5	74	- 5	-10	79	82
LOTUS	98	98.5	-7.5	-4	105	112	66	66.4	-11	-18	71	74

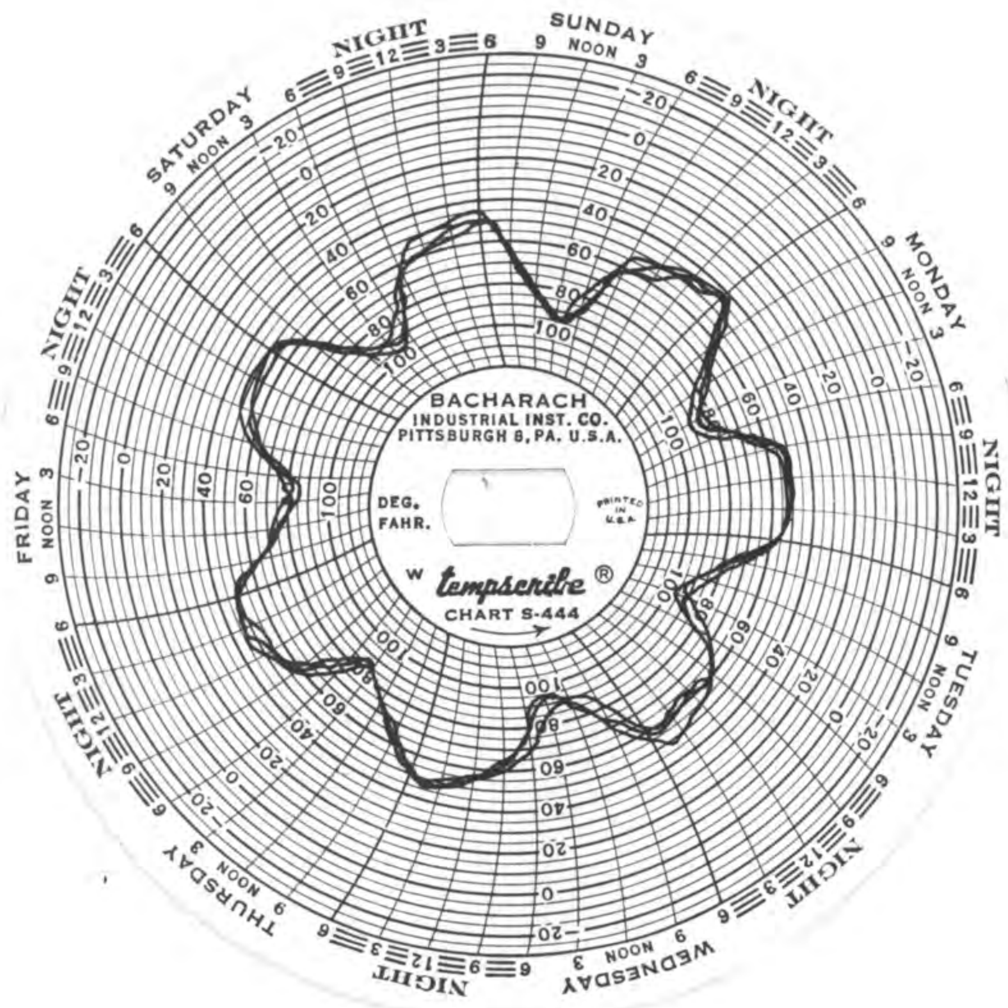

Figure 9. Thermograph records showing similarity in an air temperature pattern on the three clear-cuts sampled (#44, #12, #31 superimposed) taken during a seven-day period from July 24 to July 31, 1961.

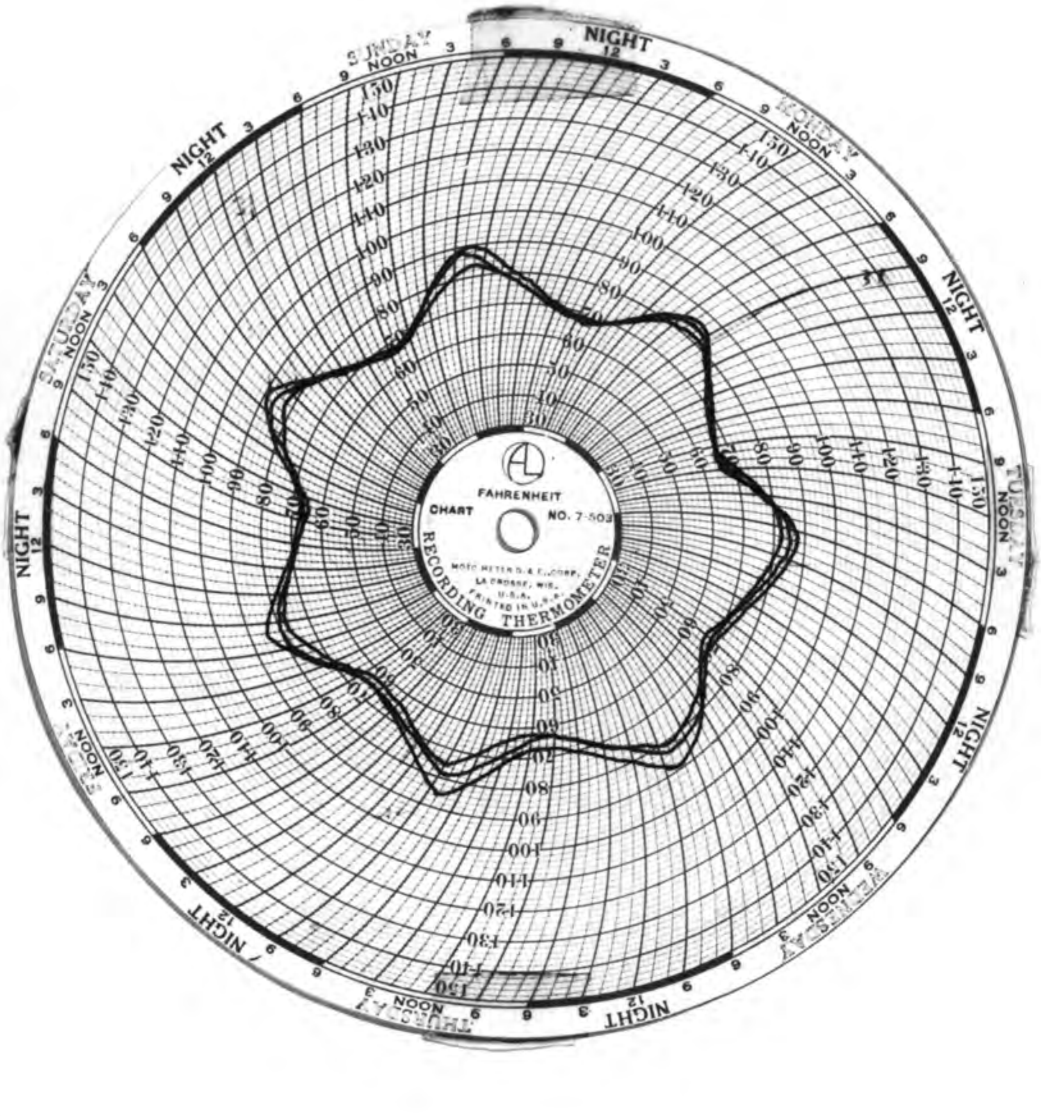

Figure 10. Thermograph records showing similarity in a soil temperature pattern on the three clear-cuts sampled (#44, #12, #31 superimposed) taken during a seven-day period from July 24 to July 31, 1961.

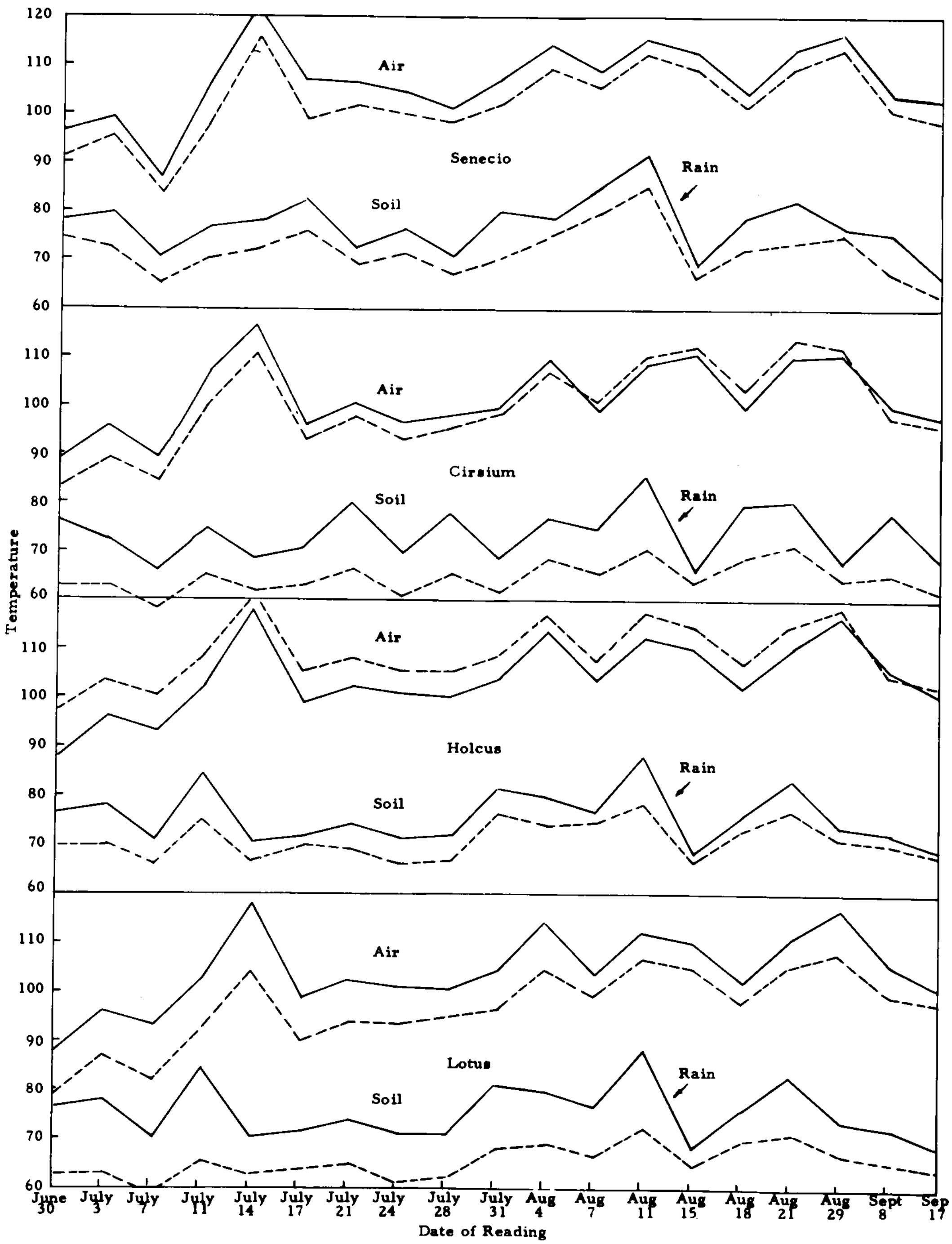

Figure 11. Seasonal changes in air temperature recorded in pure stands of Senecio, Cirsium, Holcus and Lotus. Dashed lines show mean air and soil temperature associated with vegetation. Solid lines show comparable bare ground temperatures.

is indicated by the small, solid bars in Figures 15, 16. Between the three Senecio replications, the range of maximum air temperatures averaged 4.7^{o}F. during the first summer. During the course of the summer, average maximum Senecio air temperatures were approximately five degrees below those occurring on bare ground (Table 1, Figure 11). The actual average maximum temperature for all Senecio stations during the course of the summer was 103 1/2^{o}F. but on the warmest day the temperature averaged as high as 115^{o}F. Soil temperature variation was calculated in the same way as for air temperatures. Between the three replications, the average range in soil temperatures was 3.2^{o}F. Senecio soil temperatures were about five degrees below those occurring on bare ground. The average soil temperature for the summer was 73^{o}F., but on the warmest day reached a peak average of 80^{o}F.

Between the three replications in Cirsium cover, the average range in maximum air temperature was 4.6^{o}F. Cirsium air temperatures averaged only one and one-half degree below those occurring on bare ground during the course of the summer (Table I. Figure 11). However, a closer look at the data shows that during approximately the first half of the summer, Cirsium air temperatures read five degrees below bare ground, and during the course of the summer steadily rose until by the beginning of August the temperatures in Cirsium were actually reading higher than those occurring on bare ground (Figure 11). Also it was found that the amount of variation occurring between bare-ground areas increased as the summer progressed. During the first half of the summer the average range in variation between bare-ground areas was only 2.8°F., but increased to 6.4°F. during the second half of the summer (Figures 17, 18). In this case, the air temperature relationships of *Cirsium* made a marked shift during the course of the summer. The average maximum air temperature for *Cirsium* during the course of the summer was 101°F.; however, it reached a high average of 114°F. on the warmest day.

The three replications of soil temperatures taken under *Cirsium* showed a low average variation of only 1.6°F. during the course of the summer (Figures 17, 18). *Cirsium* soil temperatures averaged 65°F. during the summer, which was nine degrees below that recorded on bare ground (Table 1, Figure 11). On the warmest day the soil temperatures in *Cirsium* averaged 71°F.

Between the three replications in *Lotus* cover during the first summer, the average range in maximum air temperature was 3.8°F. (Figures 19, 20). Maximum air temperatures in *Lotus* averaged seven and one-half degrees below those occurring on bare ground (Table 1, Figure 11). The average maximum air temperature for the first summer was 98°F., but reached 105°F. on the warmest day. *Lotus* was noted to show a seasonal pattern of temperature influence. This species depresses maximum temperatures most during the early portion of the summer, with temperature readings averaging eight and nine degrees below those occurring on bare ground. However, during the latter portion of the summer, Lotus depressed maximum air temperature only about five degrees (Figure 11).

The three replications of soil temperatures taken under Lotus, showed an average variation of 3.4°F. during the course of the summer (Figures 19, 20). Soil temperature under Lotus averaged 66°F. for the first summer (Table I). This was eleven degrees below average temperatures occurring on bare-ground areas. On the warmest day during the first summer, soil temperature under the Lotus reached 71°F.

During the second summer maximum air temperature readings in Lotus followed a pattern similar to the first summer (Figures 21, 22). However, the air temperature averaged only four degrees below those on bare ground, as opposed to seven and one-half degrees during the first summer (Table I).

The maximum air temperature averaged 98 1/2°F. during the second summer, but reached a peak average of 112°F. on the warmest day. During the second summer soil temperatures under Lotus averaged 18°F. below those occurring on bare ground. These temperatures were obtained with maximum thermometers instead of the current reading thermometers used to measure soil temperatures the previous summer. The average soil temperature as read by maximum thermometers was 66 1/2°F., and reached a peak of 74°F. on the warmest day.

The three replications in _Holcus_ cover during the first summer showed an average range in maximum air temperature of 5.9°F. (Figures 19, 20). _Holcus_ was the only species to have maximum air temperatures which averaged above those occurring on bare-ground areas. During the first summer the _Holcus_ air temperatures averaged five degrees above those occurring on bare ground (Table I, Figure 11). The average maximum air temperature for _Holcus_ during the first summer was 111°F. During the second summer maximum air temperatures sampled in _Holcus_ averaged five and one-half degrees above those on bare ground on clear-cut #12, and averaged four degrees higher on clear-cut #31 (Figures 21, 22, 23, Table I). The average maximum air temperature during the second summer was 106 1/2°F. on clear-cut #12 and only 101 1/2°F. on clear-cut #31. The maximum air temperature during the second summer for _Holcus_ on the warmest day averaged 119°F. on clear-cut #12 and 117°F. on clear-cut #31.

Between the three replications during the first summer, the average range in soil temperature was 3.3°F. (Figures 19, 20). Soil temperatures under _Holcus_ averaged 71 1/2°F., which was five degrees below the average soil temperature on bare ground (Table I). On the warmest day the soil temperature under Holcus averaged 79°F. Soil temperatures for the second summer as measured with maximum thermometers averaged nine degrees below bare-ground temperatures on clear-cut #12 and eleven degrees below bare-ground temperatures on clear-cut #31. The average soil temperature over the course of the second summer was 75 1/2°F. on clear-cut #12 and 72 1/2°F. on clear-cut #31. On the warmest day soil temperature rose to 86°F. on clear-cut #12 and 78°F. on clear-cut #31.

One might easily expect the temperature relationships for a species to vary, depending on whether the day was relatively hot or unusually cool. For air temperatures no such relationship was apparent for any of the species studied, except for Holcus (Figures 11, 15-23). In the cases of Senecio, Cirsium, and Lotus, it was found that each of these species depressed the air temperature about the same amount on a warm day or on a cool day (Figure 11). The difference between bare ground and the Holcus cover was less on warm days. Soil temperatures under plant cover tended to read slightly closer to bare-ground temperatures on cool days. This appears to be especially true after a rain, in which case the soil temperatures under the vegetation may average within two or three degrees of those occurring under bare-ground areas (Figure 11).

The minimum temperature data collected during the summer of 1962 show that, at a height of one and one-half inches above the ground, temperatures tend to read a few degrees higher in both *Holcus* and *Lotus* than over bare-ground areas (Figure 12). It was found that *Holcus* minimum temperatures averaged 1.88°F. above those occurring on bare ground, and that *Lotus* minimum temperatures averaged 2.3°F. higher than those occurring on bare ground.

The thermograph data for all nine bare-ground areas showed some general daily patterns of air and soil temperatures (Figures 13, 14). During the night and up until sunrise the temperature would reach its lowest point, usually about 45°F. to 60°F. From sunrise the air temperature steadily increased until late afternoon. The maximum temperature for the day usually lasts for a period of roughly an hour and occurs between three and five o'clock. From about five until sunset the temperature drops rapidly, and then continues to drop slowly until just before sunrise.

The thermograph data for soil showed a temperature lag of several hours, when compared to air temperatures. In this case the lowest temperatures occur between nine and ten in the morning. From this time the temperature steadily increases until about six or seven in the evening when the temperature reaches its peak for the day. From about seven until nine the next morning the temperature decreases steadily, reaching a low of about 60°F. to 70°F.

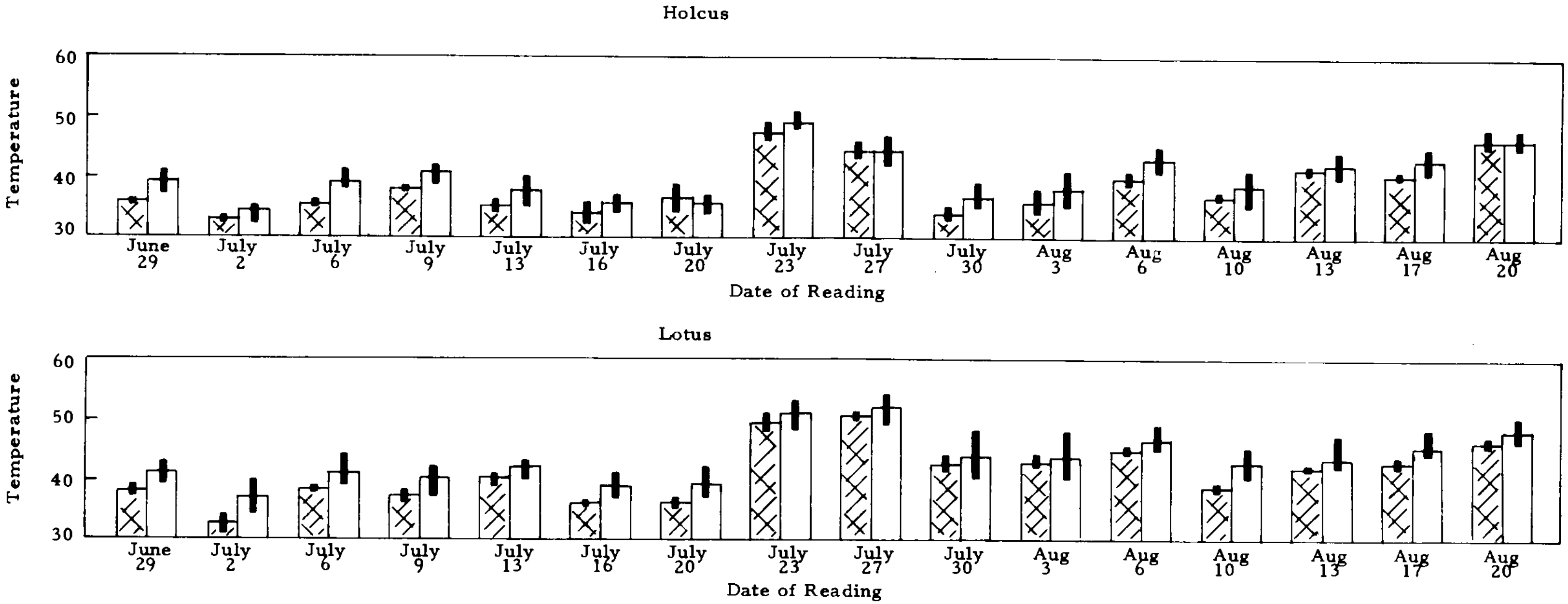

Figure 12. Mean minimum air temperatures recorded in Holcus and Lotus cover and on adjacent bare-ground areas during the summer of 1962 from June 29 to Aug. 20. Hatched bars refer to bare ground, unhatched to cover type. Solid bars indicate range of values.

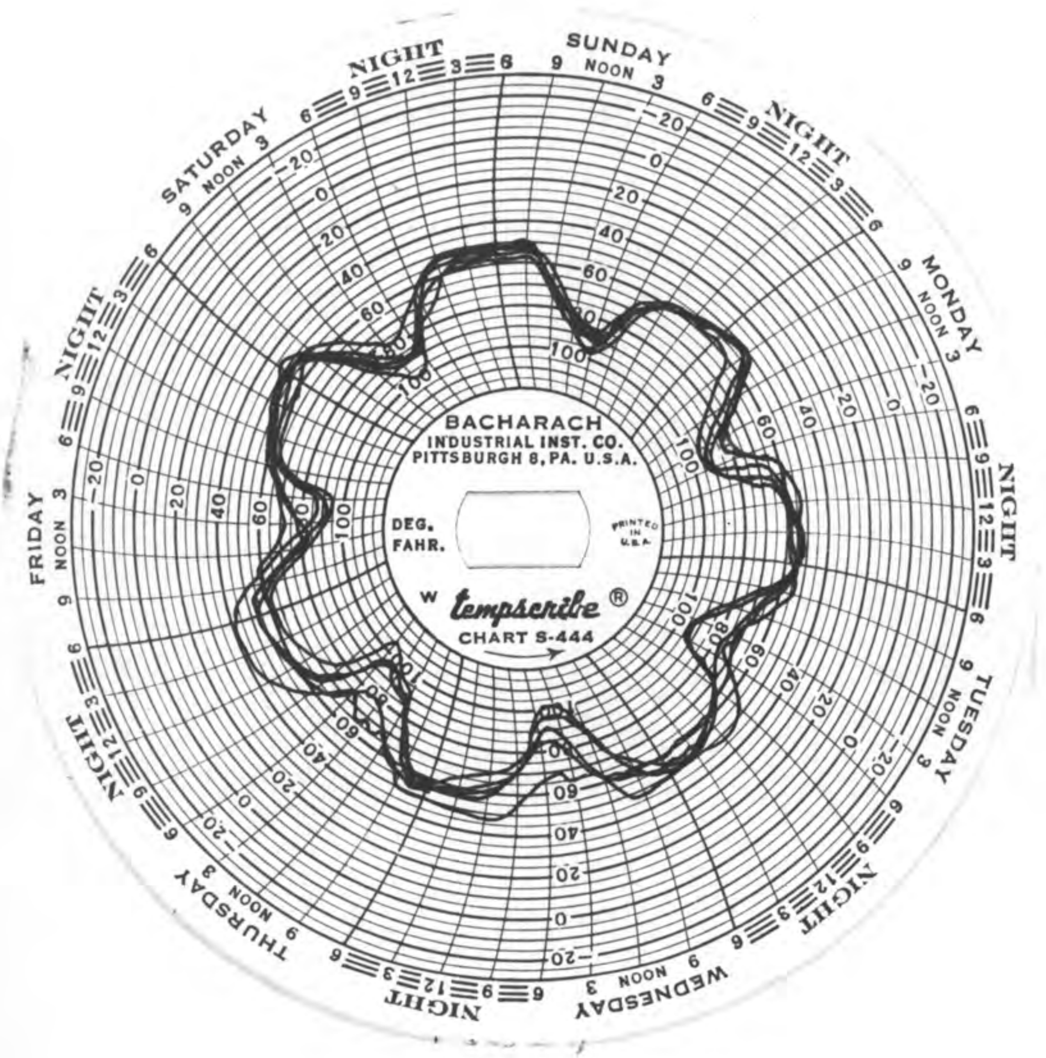

Figure 13. Superimposed thermograph records for air temperatures showing characteristic diurnal pattern observed during alternate weeks from July 3 to Sept. 8, 1961.

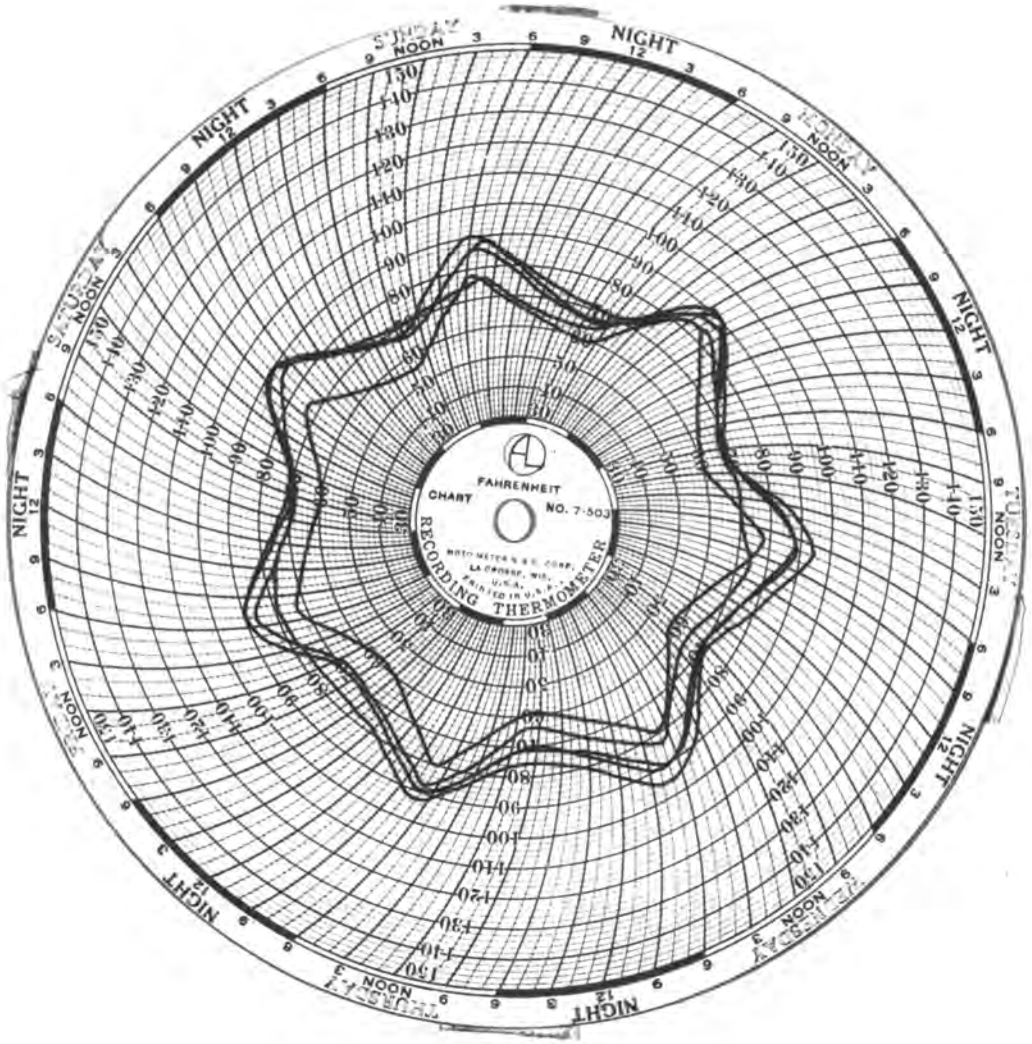

Figure 14. Superimposed thermograph records for soil temperatures showing characteristic diurnal pattern observed during alternate weeks from July 3 to Sept. 8, 1961.

V. DISCUSSION

The data analyzed show a certain amount of inherent variability. This is to be expected, since a clear-cut is by its very nature a rugged, broken, even a chaotic area. The ground is usually broken into many irregularities and covered by old stumps and partially burned, downed logs. The soil is usually rocky and covered at least in part with a certain amount of debris such as burned wood and bark. Any of these factors may have an effect on a temperature station reading. However, in spite of these difficulties, the data show certain trends which are highly consistent throughout the work of both summers.

In the species studied, a relationship can be found between the physical form of the plant and the effect of the plant on maximum air temperatures. Lotus is characterized by a dense canopy of leaves one or two feet above ground level. Since only a small amount of light is able to penetrate this canopy and because most of the heat exchange takes place at least a foot from the soil surface, the microclimate of Lotus near the soil surface is characterized by a low amount of light and cool temperatures. As the summer progresses the leaves of Lotus turn from green to yellow and finally wither. As a result the leaves become less effective in reducing light from reaching the ground level and the maximum temperature becomes correspondingly higher under the Lotus. For this reason Lotus shows a tendency to exhibit higher temperature in comparison to bare ground as the summer progresses.

Holcus has a life form and a characteristic microclimate which is different from Lotus. Being a grass, it has no thick canopy of leaves to prevent light from reaching close to ground level. Instead, a comparatively large amount of light penetrates almost to ground level before it is converted to heat. This situation results in temperatures which are normally higher than those occurring on bare ground. High temperatures found under Holcus are caused not only by better light penetration but also by the matting of dead grass leaves under the grass stems on the soil surface. Much of the light which is able to penetrate through the stalks will be stopped when reaching this mat of leaves and will at this point be converted to heat. In this way the upper portion of the grass-leaf mat becomes an important area of heat exchange. Since in many cases this heat exchange surface is close to the level where temperature measurements were taken, the temperatures tend to run higher than they would otherwise. The importance played by the grass-leaf mat in heat exchange was demonstrated with a simple experiment by the author. A one-inch layer of grass-leaf mat was placed on a portion of a bare-ground area. It was found that the grass-leaf mat alone was sufficient to raise maximum air temperatures eight degrees above those occurring on bare ground at the one and one-half inch level. At the same time the insulation properties of the artificial grass mat lowered the soil temperature five degrees at the three-inch level.

Senecio and Cirsium, both members of the composite family, have similar physical forms and similar temperature relationships, which are intermediate between those of Holcus and Lotus. Neither of these species produces a thick canopy of leaves associated with low temperatures near the soil surface as in the case of Lotus. On the other hand, they do not allow a large amount of light to reach close to the ground, producing high temperatures as in the case of Holcus. Cirsium showed that a plant may modify its temperature environment significantly during the course of a season. The change in temperature relationships of Cirsium apparently corresponds to the dissemination of large amounts of seeds by the thistle plant. These seeds are characterized by a long, white, many bristled pappus, which, when concentrated into a small area, forms a dense white mat. As in the case of the leaf-mat formed by Holcus, the mat made of Cirsium seed pappus also raised temperatures significantly. On some occasions temperature stations located in areas of dense pappus mats averaged readings of more than ten degrees higher than similar areas without pappus mats. Senecio, as in the case of Lotus, showed a tendency to exhibit higher temperatures in comparison to bare ground as the summer progresses. This tendency was also correlated with the plants turning yellow and drying up.

Because vegetation acts as a heat insulation layer, soil temperatures are always cooler under the vegetation than under bare-ground areas. The temperature relationship seems to be mostly a matter of the amount of light reaching the soil surface. Bare-ground areas which have no vegetation on them, and therefore a mimimum of insulation, also have the highest soil temperatures. *Lotus*, which allows the least amount of light to reach the soil surface, also has the lowest soil temperatures. *Cirsium*, *Senecio*, and *Holcus* fall between these extremes.

Although the temperature data collected for *Holcus* and *Lotus* during the summer of 1962 are similar to that collected in 1961, there are some consistent differences. In part these differences are because the summer of 1962 was a cooler summer than in 1961. Temperature data for Corvallis showed the mean temperature for the summer of 1962 averaged 3.4^{o}F. below that for the summer of 1961 during the months of June, July, and August (Table 2). The cooler summer of 1962 would partially account for the lower air temperatures found in *Holcus* the second year. During the first summer *Holcus* averaged 111^{o}F. as compared to only 104^{o}F. the second summer. However, it is interesting to note that during both summers Holcus consistently read five degrees above bare-ground temperatures.

Although the summer of 1962 was somewhat cooler than the first summer, Lotus air temperatures averaged slightly higher during the second summer, 98.5°F. compared to 98.0°F. This can be explained on the basis that Lotus was beginning to decrease as succession advanced during the second year. It is significant that during the second year it only depressed air temperatures four degrees below those occurring on bare ground as compared to seven and a half degrees during the first summer.

A noticeable difference occurs in the soil temperature data taken during the two summers. During the second summer Holcus averaged ten degrees below those occurring on bare ground, compared to only five degrees the first summer. Also Lotus soil temperatures averaged 18°F. below those occurring on bare ground the second summer as compared to only eleven degrees for the first summer. It is very likely that these differences occurred as a result of the differences in method used in taking temperatures during the two summers. The temperatures taken during the first summer were read by means of current reading thermometers, while those taken the second summer were read by means of maximum thermometers. It is reasonable to believe that bare-ground temperatures fluctuate more than temperatures taken under vegetation. The maximum

TABLE II. UNITED STATES WEATHER BUREAU TEMPERATURE DATA FOR THE CITY OF CORVALLIS DURING THE SUMMER OF 1961 AND 1962.

Month	Mean Maximum Temperature		Mean Minimum Temperature		Mean Temperature		Departure From Long Term Means	
	61	62	61	62	61	62	61	62
June	77.3	72.6	49.6	45.5	63.5	59.1	+1.7	-2.5
July	81.7	80.5	50.9	45.7	66.3	64.6	-0.2	-2.0
August	84.8	78.2	52.6	50.0	68.7	61.1	+2.0	-2.3
September	72.1	76.1	45.1	48.5	58.6	62.3	-4.3	-0.4

thermometers would tend to emphasize the temperature extremes which occur on bare ground. On the other hand, current reading thermometers would only emphasize the maximum difference between bare ground and temperature taken in the vegetation when readings were taken in the early part of the afternoon at the hottest part of the day. Since many of the soil temperatures were taken early in the morning, the difference between bare-ground temperatures and temperatures taken under the vegetation would not be as great with current reading thermometers as with maximum thermometers.

The early stages of plant succession create a temperature environment over the clear-cut which is highly changeable. During the first stage of succession, when the clear-cut is occupied by *Senecio*, there are many open areas and patches of bare ground. *Senecio* does not survive the second year, and is replaced by *Cirsium*, a biennial, which may or may not grow in the same space occupied by the *Senecio* the former year. As the annuals and biennials shift populations rapidly during the first few years, many areas of the clear-cut are subjected to a changing temperature environment. An area which is covered by vegetation one year may be bare the next, only to be covered by vegetation again at a slightly later date. In contrast to this, the later stages of succession made up of *Holcus* and *Lotus* (both perennials) are relatively stable. The cover formed by these two species are relatively uniform and remain in a more or less fixed position for several years. Also the temperature environment produced by these two species is more pronounced and consistant than that produced by the former two species.

From the above information it can be seen that any species established after clear-cutting will be subjected to different temperature environments, depending on how soon it germinates after the cut is made. A species which germinates soon after clear-cutting will grow in a temperature environment which is highly changeable, but at the same time neither as warm as that found under Holcus nor as cool as that found under Lotus. As succession occurs the temperature environment will become less and less like that occurring on bare ground. For this reason, the time of germination after cutting should be of great importance to the survival of a species. This is particularly true for trees which are more susceptible to heat damage in the early stages of seedling establishment than later on after the tree is relatively well established. For example, on hot days the temperature in Holcus cover has averaged as high as 120°F., and individual cases obtain readings as high as 130°F. These figures represent temperatures taken in the shade one and one-half inches above the ground. Temperatures taken in areas directly exposed to the sun would probably read considerably higher. Both Hermann (11) and Silen (23) have shown that the lethal temperature for Douglas-fir in this area is about 130°F. at the soil surface. It would appear from this information that the temperatures occurring under Holcus may reach sufficiently high levels to kill Douglas-fir seedlings.

Of the four plants studied, Lotus is the least likely to kill plants because of overheating. However, the dense shade produced by Lotus may also be a limiting factor to many plants.

It would seem from the foregoing discussion that tree seedlings such as Douglas-fir would have the best chance for survival when planted soon after clear-cutting. At this time the environment is still not made abnormally hot by Holcus, nor heavily shaded by Lotus.

VI. SUMMARY AND CONCLUSIONS

The influence of four successional dominant species on modifying both air and soil temperatures was investigated during the summers of 1961 and 1962. The study was carried out on the Marys Peak watershed, where a consistent pattern of succession has been found to occur on burned Douglas-fir clear-cuts. The early stages of succession are characteristically dominated by *Senecio sylvaticus* in the second year after cutting, *Cirsium vulgare* in the third, and *Holcus lanatus* and *Lotus stipularis* for several years following.

Maximum air temperatures one and one-half inches above the ground and soil temperatures three inches below the soil surface were measured in each of the four dominating species. All temperatures occurring in the vegetation were compared to associated areas of comparable exposure denuded of all plant life. Each bare-ground area was surrounded by five to eight temperature stations in the vegetation. At each temperature station both maximum air temperatures and soil temperatures were taken. The bare-ground areas contained in addition to maximum thermometers, two thermographs for recording soil and air temperatures. All temperature measuring equipment was shaded from direct sunlight, and replicated three times on each clear-cut.

A relationship was found between the physical form of the species studied and its effect on maximum air temperatures. Lotus is characterized by a dense canopy of leaves one or two feet above the ground. This canopy reduces light sharply at the soil surface, causing maximum air temperatures to read about seven degrees below those occurring on similar bare-ground areas.

Holcus has a life form and a characteristic microclimate which differs from Lotus. Due to a combination of having no canopy of leaves, but processing a dense mat of grass leaves at the soil surface, this species raises rather than lowers maximum air temperature when compared to bare-ground areas. Maximum air temperatures under Holcus were found to average five degrees above those occurring on bare ground.

Senecio and Cirsium, both members of the composite family, have similar life forms and similar temperature environments, which fall in between the extremes found in Lotus and Holcus. Both species depress maximum air temperatures about five degrees. Cirsium by producing large amounts of white seed pappus, showed that a species may significantly change its temperature pattern over the course of a season.

Soil temperatures are always cooler under vegetation than under bare ground. The amount of temperature difference seems to be correlated with the amount of plant material to act as a heat insulating layer.

The early stages of plant succession (_Senecio_ and _Cirsium_) create a temperature environment over the clear-cut which is highly changeable. As annuals and biennials shift populations rapidly during the first few years, many areas of the clear-cut are subjected to a changing temperature environment. The later stages of succession made up of mostly perennials (_Holcus_ and _Lotus_) are relatively stable.

Any species attempting to become established after clear-cutting will be subjected to different temperature environments, depending on how soon it germinates after the clear-cut is made. The present study suggests that tree seedlings such as Douglas-fir would have the best chance of survival when planted within three years after clear-cutting.

BIBLIOGRAPHY

1. Aikman, J. M. and A. W. Smelsen. The structure and environment of forest communities in central Iowa. Ecology 19:141-150. 1938.

2. Broadbent, L. The microclimate of potato crop. Quarterly Journal of the Royal Meteorological Society 76:439-454. 1950.

3. Brunt, D. Some factors in microclimatology. Quarterly Journal of the Royal Meteorological Society 71:1-10. 1945.

4. Brunt, D. Some factors in microclimatology. Quarterly Journal of the Royal Meteorological Society 72:185-188. 1946.

5. Champness, S. Stella. Effect of microclimate on the establishment of timothy grass. Nature 165:325-326. 1950.

6. Chilcote, W. W., Successional patterns of Douglas-fir clear-cuts in the Oregon Coast Range. Bulletin of the Ecological Society of America 43:58-59. 1962.

7. Cornford, C. E. Katabatic winds and prevention of forest damage. Quarterly Journal of the Royal Meteorological Society 64:553-584. 1938.

8. Fritts, Harold C. An analysis of maximum summer temperatures inside and outside a forest. Ecology 42:436-439. 1961.

9. Geiger, Rudolf. The climate near the ground. Cambridge, Harvard University Press, 1959. 494 p.

10. Grainger, John. Climate, host and parasite in crop diseases. Quarterly Journal of the Royal Meteorological Society 81: 80-88. 1955.

11. Hermann, Richard. The influence of seedbed microenvironment upon the establishment of Douglas fir (pseudotsuga menziesii (Mirb.) Franco) seedlings. Ph. D. thesis. Corvallis, Oregon State University, 1960. 202 numb. leaves.

12. Hirst, J. M., I. F. Long and H. L. Penman. Micrometeorology in the potato crop. In: Proceedings of the Toronto Meteorological Conference. London, Royal Meteorological Society, 1954. p. 233-237.

13. Kittredge, Joseph. Forest influences. New York, McGraw-Hill, 1948. 394 p.

14. Larsen, J. A. Effects of removal of the virgin white pine stand upon the physical factors of site. Ecology 3:302-305. 1922.

15. Molga, M. Agricultural meteorology. Part II. Outline of agrometeorological problems. Warsaw, Poland, Panstwowe Wydawnictwo Rolnicze i Lesne, 1958. (Translated for the U. S. National Science Foundation and the Dept. of Agriculture. U. S. Office of Technical Services. OTS 60-21419)

16. Montieth, J. L. and G. Szeicz. The radiation balance of bare soil and vegetation. Quarterly Journal of the Royal Meteorological Society 87:159-170. 1961.

17. Monteith, J. L. and G. Szeicz. Radiative temperature in heat balance of natural surface. Quarterly Journal of the Royal Meteorological Society 88:496-507. 1962.

18. Penman, H. L. and I. F. Long. Weather in wheat: an essay in micro-meteorology. Quarterly Journal of the Royal Meteorological Society 86:16-50. 1960.

19. Raschke, K. Heat transfer between the plant and the environment. Annual Review of Plant Physiology 11:111-126. 1960.

20. Rider, N. E. and G. D. Robinson. A study of the transfer of heat and water vapour above a surface of grass. Quarterly Journal of the Royal Meteorological Society 77:375-401. 1951.

21. Salisbury, E. J. Ecological aspects of meteorology. Journal of the Royal Meteorological Society 65:337-358. 1939.

22. Selleck, G. W. and K. Schuppert., Some aspects of microclimate in a pine forest and in an adjacent prairie. Ecology 38:650-653. 1957.

23. Silen, Roy R. Lethal surface temperatures and their interpretation for Douglas-fir. Ph. D. thesis. Corvallis, Oregon State University, 1960. 170 numb. leaves.

24. Sparkes, C. H. and M. F. Buell. Microclimatological features of an old field and an oak-hickory forest in New Jersey. Ecology 36:363-365. 1955.

25. Waterhouse, F. L. Microclimatological profiles in grass cover in relation to biological problems. Journal of the Royal Meteorological Society 81:63-71. 1955.

APPENDIX

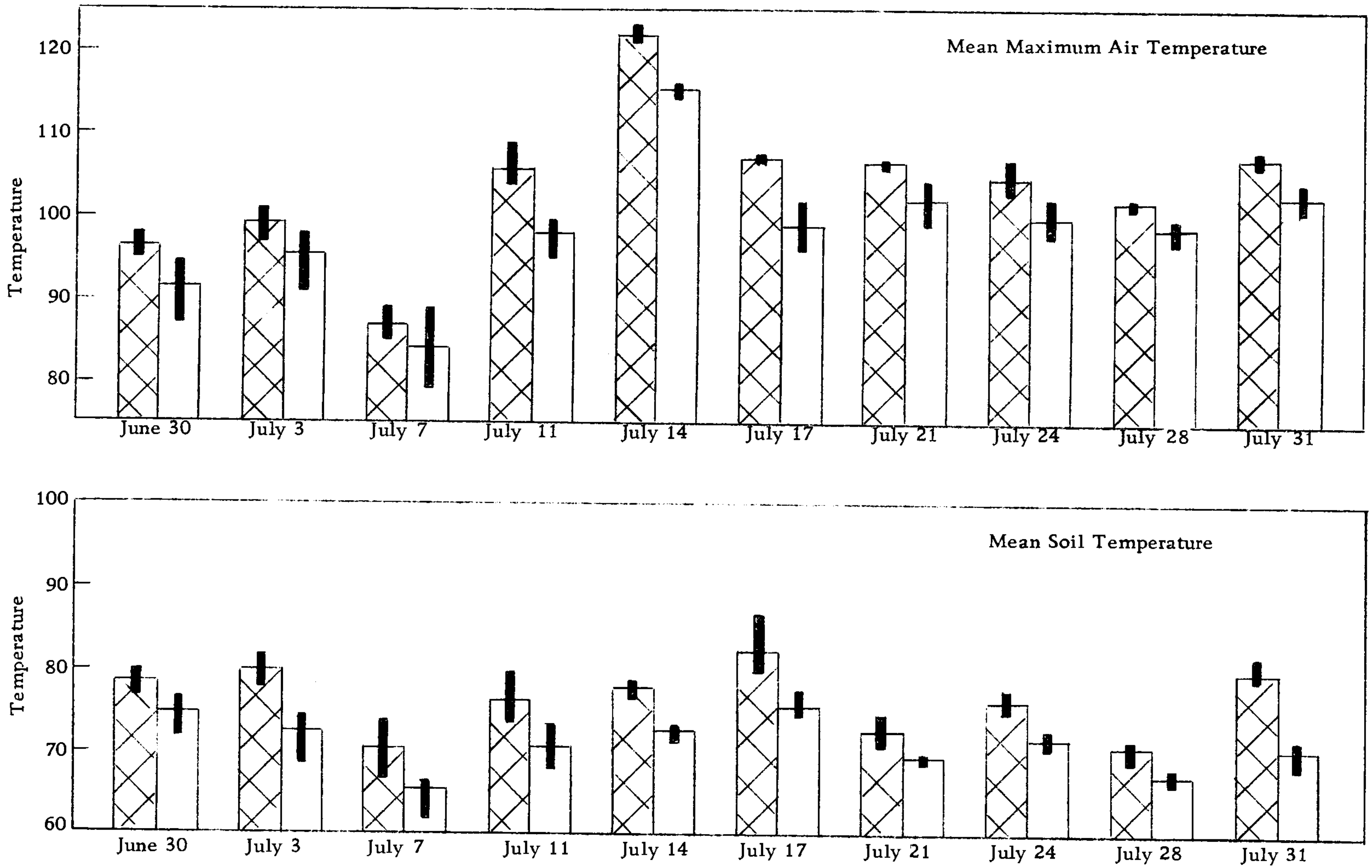

Figure 15. Mean air and soil temperatures recorded in Senecio cover and on adjacent bare-ground areas during the summer of 1961 from June 30 to July 31. Hatched bars refer to bare ground, unhatched to Senecio cover. Solid bars indicate range of values.

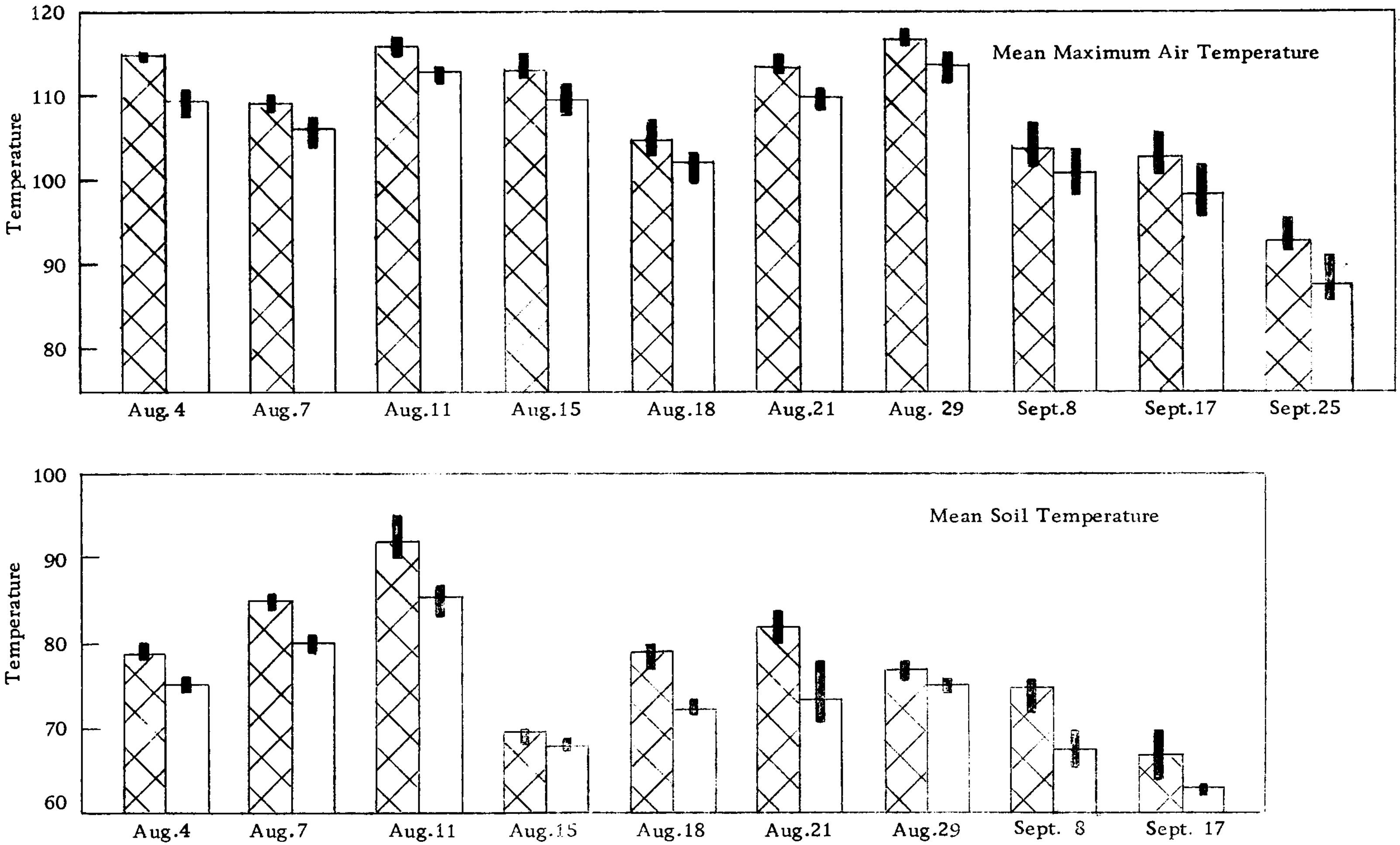

Figure 16. Mean air and soil temperatures recorded in Senecio cover and on adjacent bare-ground areas during the summer of 1961 from Aug. 4 to Sept. 25. Hatched bars refer to bare ground, unhatched to Senecio cover. Solid bars indicate range of values.

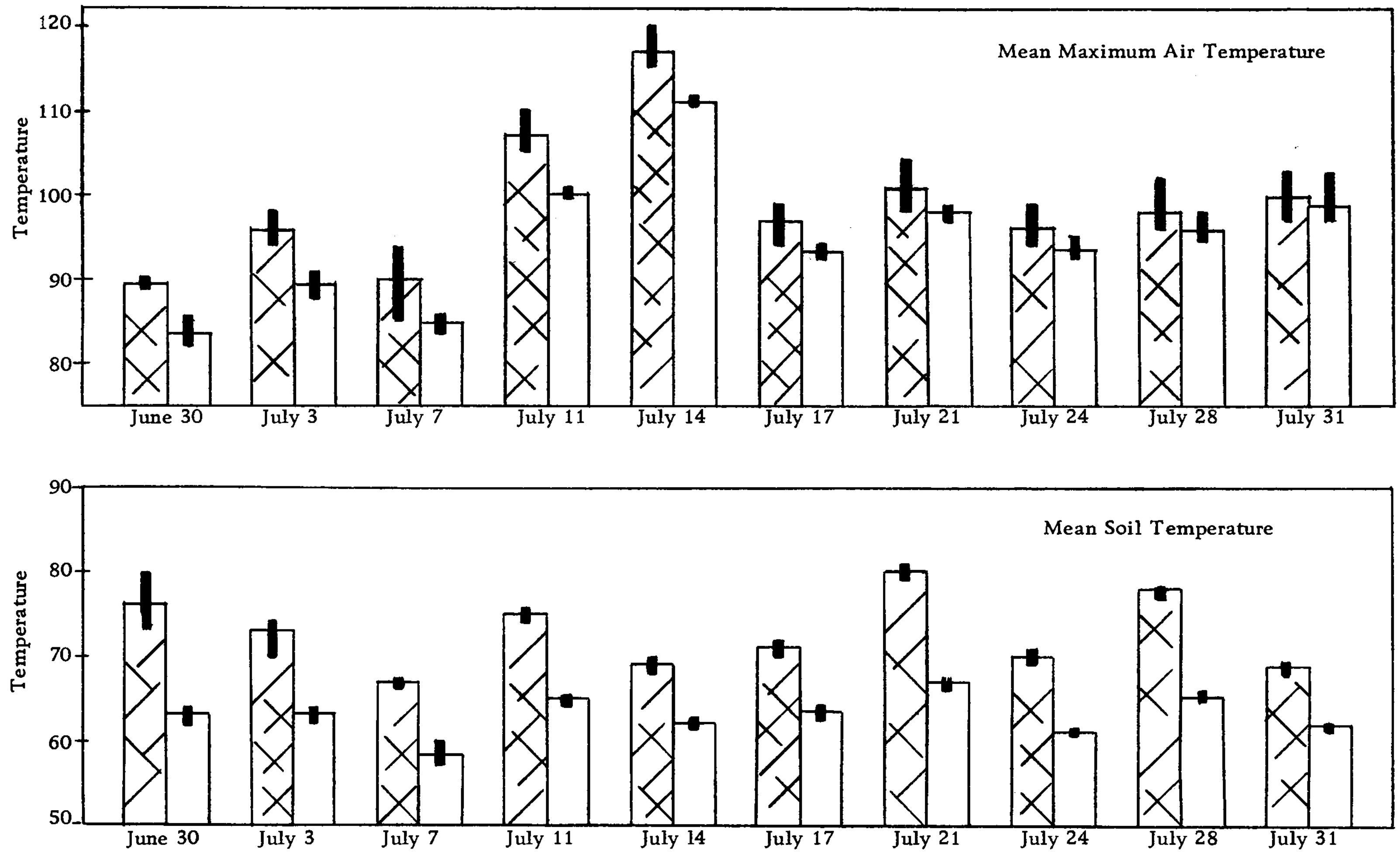

Figure 17. Mean air and soil temperatures recorded in Cirsium cover and on adjacent bare-ground areas during the summer on 1961 from June 30 to July 31. Hatched bars refer to bare ground, unhatched to Cirsium cover. Solid bars indicate range of values.

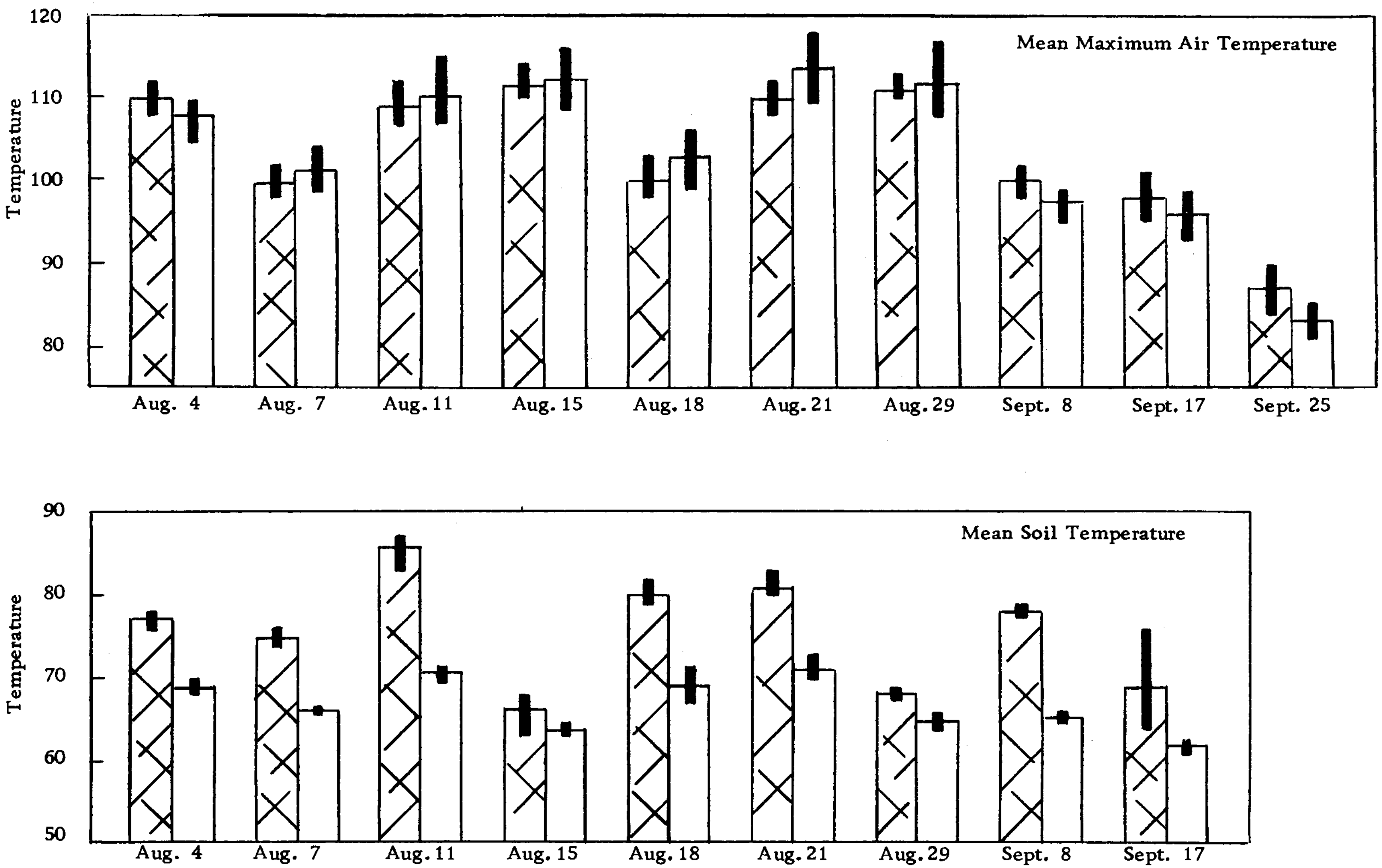

Figure 18. Mean air and soil temperatures recorded in Cirsium cover and on adjacent bare-ground areas during the summer of 1961 from Aug. 4 to Sept. 25. Hatched bars refer to bare ground, unhatched to Cirsium cover. Solid bars indicate range of values.

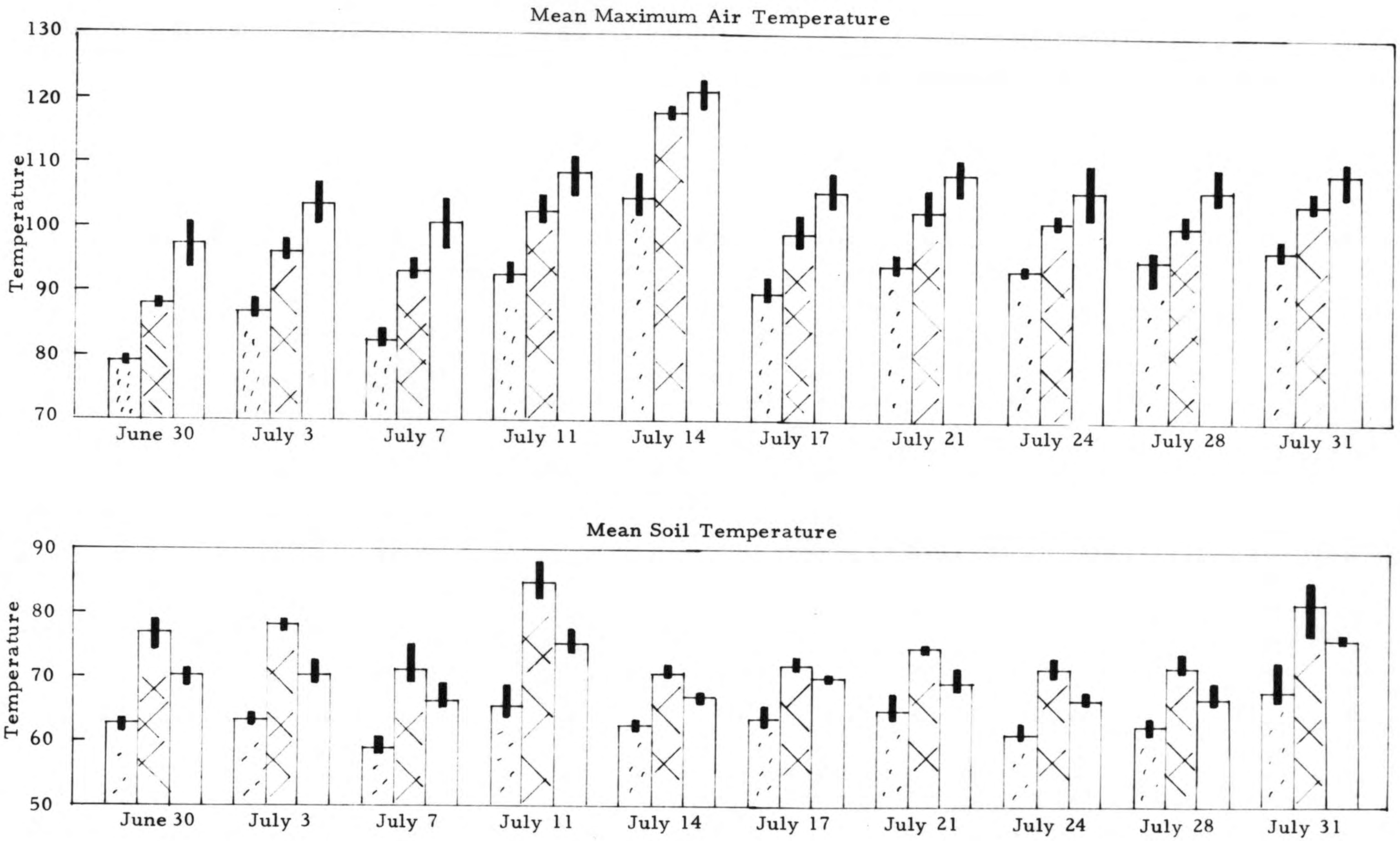

Figure 19. Mean air and soil temperatures recorded in Holcus and Lotus cover and on adjacent bare-ground areas during the summer of 1961 from June 30 to July 31. Hatched bars refer to bare ground, unhatched to Holcus cover, dotted to Lotus cover. Solid bars indicate range of values.

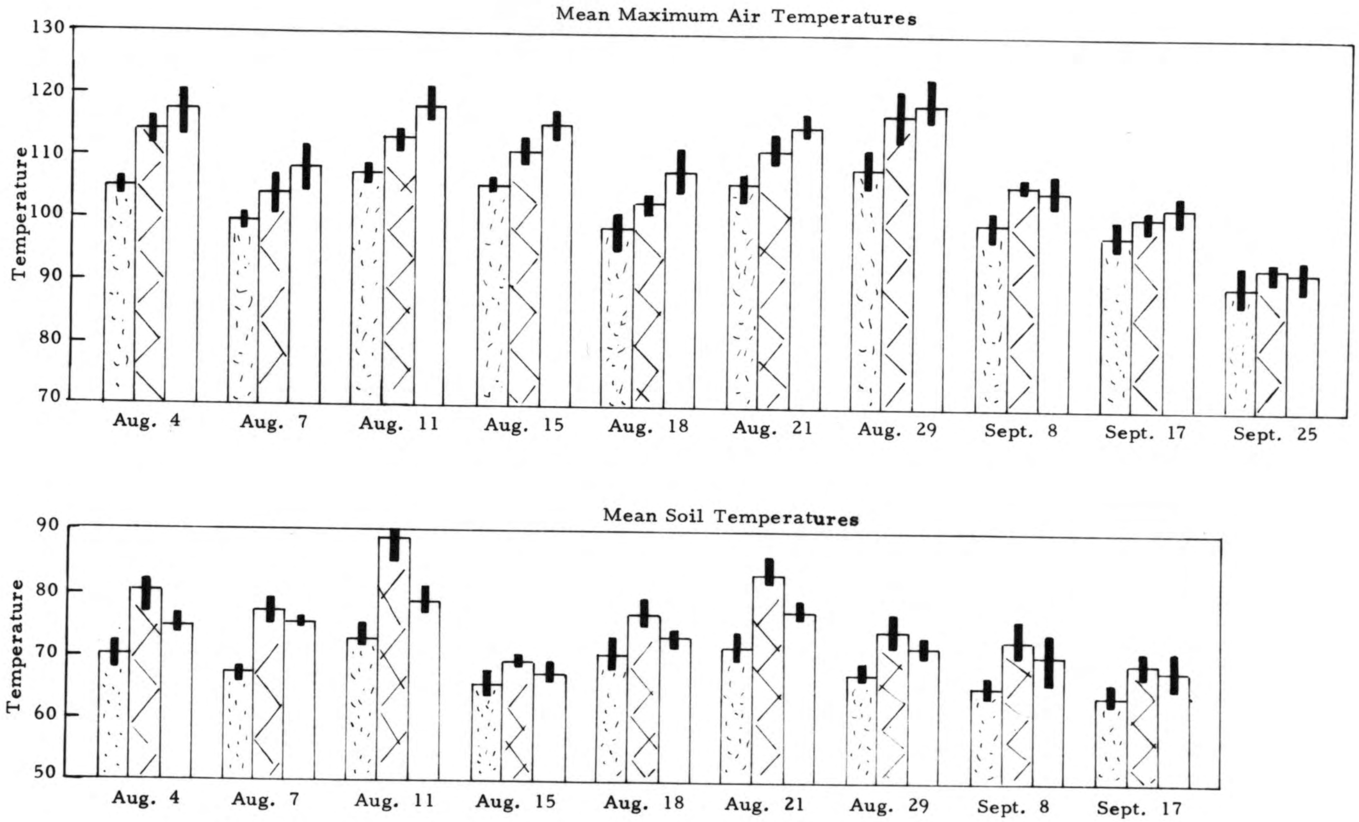

Figure 20. Mean air and soil temperatures recorded in Holcus and Lotus cover and on adjacent bare-ground areas during the summer of 1961 from Aug. 4 to Sept. 25. Hatched bars refer to bare ground, unhatched to Holcus cover, dotted to Lotus cover. Solid bars indicate range of values.

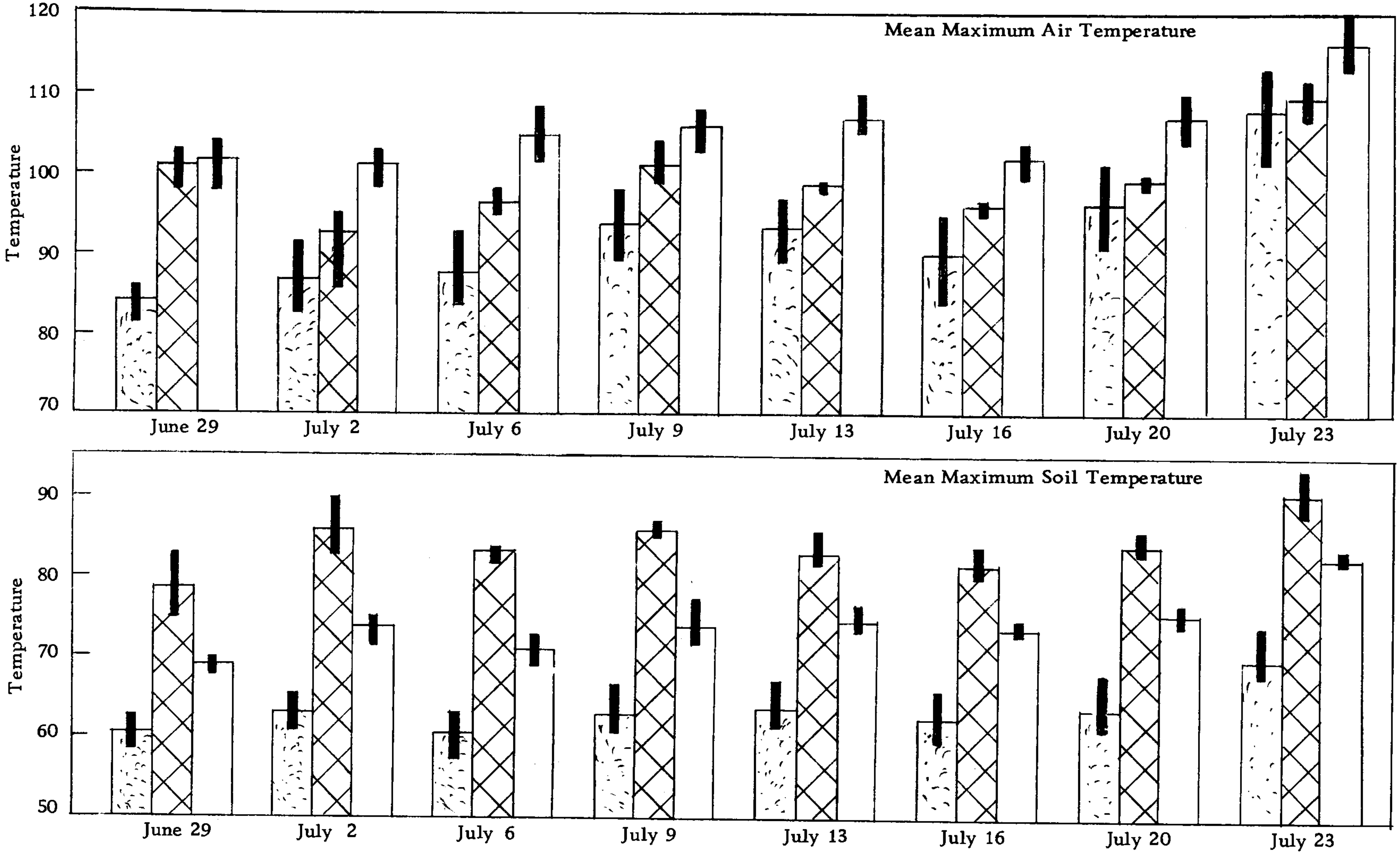

Figure 21. Mean air and soil temperatures recorded in Holcus and Lotus cover and on adjacent bare-ground areas during the summer of 1962 from June 29 to July 23 on clear-cut # 12. Hatched bars refer to bare ground, unhatched to Holcus cover, dotted to Lotus cover. Solid bars indicate range of values.

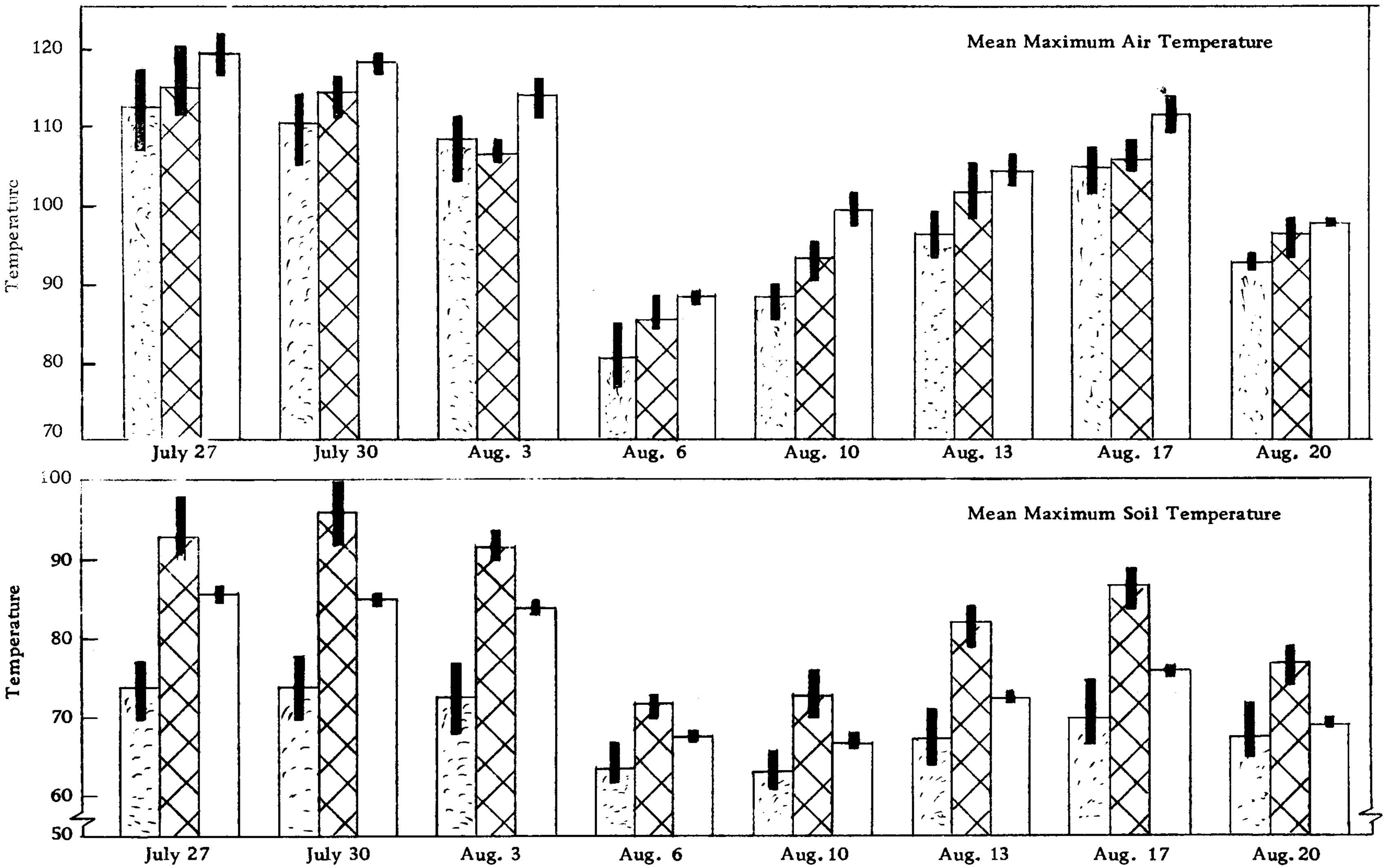

Figure 22. Mean air and soil temperatures recorded in Holcus and Lotus cover and on adjacent bare-ground areas during the summer of 1962 from July 27 to Aug. 20 on clear-cut #12. Hatched bars refer to bare ground, unhatched to Holcus cover, dotted to Lotus cover. Solid bars indicate range of values.

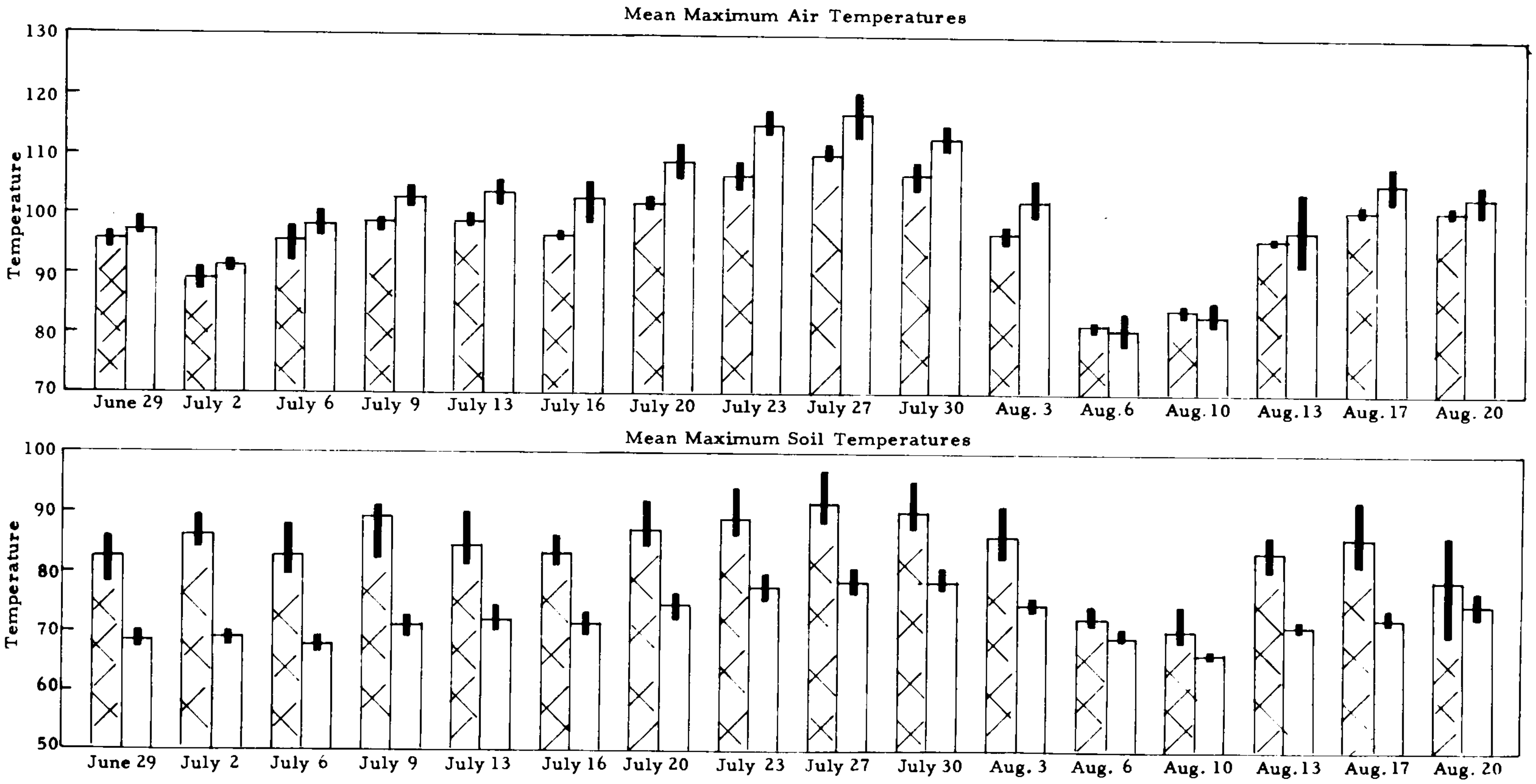

Figure 23. Mean air and soil temperatures recorded in <u>Holcus</u> cover and on adjacent bare-ground areas during the summer of 1962 from June 29 to Aug. 20 on clear-cut No. 31. Hatched bars refer to bare ground, unhatched to <u>Holcus</u> cover. Solid bars indicate range of values.