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Local Climate in the Copper Basin of Tennessee as Modified by the Removal of Vegetation

By C. R. Hursh, *forest ecologist, Southeastern Forest Experiment Station, Forest Service*

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INTRODUCTION

Climate in the generally used sense is determined by physical conditions over which man has no control, namely: latitude, prevailing wind, topography, and nearness to the ocean or continental interior. Locally, certain elements of climate, such as temperature, wind, evaporation, and rainfall, are modified by altitude, topography, direction of exposure, bodies of water, and vegetation. The extent of these modifications defines and characterizes the local climate.[1]

As to how much the local climate can be altered by man's actions, little precise information has been published. Yet it has long been believed that large-scale activities such as the draining of swamps,

[1] In this circular the term "local climate" will be used in the same sense that Wallen (*26*) [2] and others have employed the term "microclimate." The writer prefers to restrict the latter term, if used at all to specify a minute climatic environment such as the canopy of a single cotton plant or the north side of a tree trunk, where very minor differences in environment are of major importance in the life of insects and parasites that cause plant diseases.

[2] Italic numbers in parentheses refer to Literature Cited, p. 37.

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irrigation projects, extensive tree planting, or clearing of forests for agriculture actually do modify the local climatic environment.

Suitable areas for making a study of the effects of vegetation on local climatic elements are not easy to find. It is rare to discover sizable land areas even approximately comparable in most respects, except for contrasting vegetative cover. Areas approaching this condition do occur, however, in different parts of the world adjacent to centers of ore-refining activity, where fumes have injured or destroyed the natural vegetation in a zone radiating from the smelters. One example of this kind of vegetation change in concentric zones is the Copper Basin (fig. 1) in the southeasternmost county of Tennessee. This area constitutes a suitable outdoor laboratory for studying the local climates associated with three vegetative cover conditions: forest, grass, and bare soil. Within each of these three cover condi-

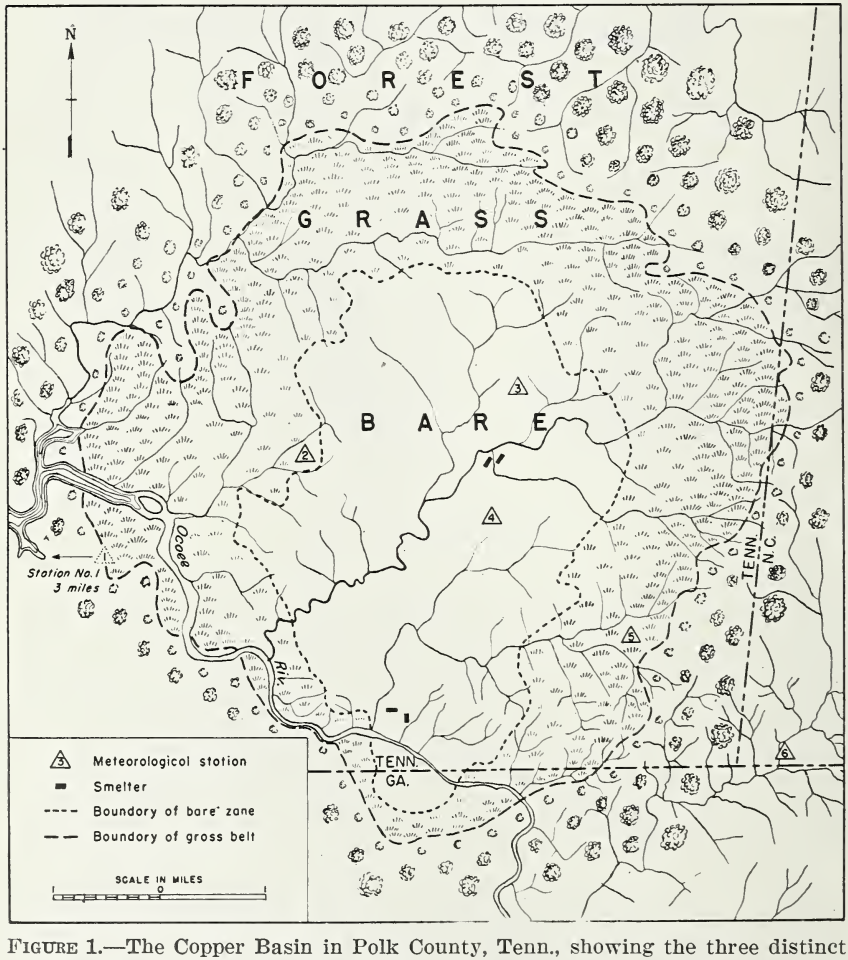

FIGURE 1.—The Copper Basin in Polk County, Tenn., showing the three distinct zones resulting from the destruction of vegetation by smelter fumes. The central bare zone, about 10½ square miles in extent, is the largest completely bare area in any semihumid region of the United States. Two meteorological stations were established in each zone for the study of local climate.

tions, continuous records of temperature, wind velocity, evaporation, and rainfall were taken for the 4-year period, 1936–39 inclusive. Summaries of these data are given in this circular.

With the Copper Basin as a laboratory, the present study was undertaken to obtain additional basic data contributing to our knowledge of how vegetation changes affect local climate. Information of this kind is required to understand local climate, and to find solutions to problems such as revegetation of denuded land, prevention and behavior of forest fires, erosion control, water conservation on agricultural land, and the use of trees as windbreaks and protection of dwellings from the sun.

DESCRIPTION OF THE EXPERIMENTAL AREA

The Copper Basin presents a landscape as unusual as any that can be found in the eastern United States. The central area, covering about 7,000 acres, is completely bare. This bare central area is surrounded by a belt of grassland from 1 to 2 miles wide; and beyond that stretches dense hardwood forest.

The bare zone (fig. 2) has been greatly eroded since it was stripped of vegetation. The appearance of some herbaceous plants in silt beds along streams in the bare area gives rise to a belief that the central part of the basin is becoming revegetated naturally. However, the bare area is still spreading, through the rapid expansion of hundreds of thousands of deep erosion gullies.

The belt of grassland (fig. 3) surrounding the bare zone comprises approximately 17,000 acres, and here the vegetation is almost entirely broomsedge, principally *Andropogon scoparius* L. Erosion gullies at the edge of the bare zone are constantly undercutting the grass and are eating their way farther into the grass belt.

Between the grass belt and the forest lies a transition zone of indefinite boundaries, comprising approximately 30,000 acres, now partly in grass and partly in trees. The original trees in this zone were once injured in varying degrees by smelter fumes. Some injured trees have died; others have recovered since the period of greatest damage. Some locations have become almost completely restocked with a young growth of hardwoods and pine.

Surrounding the Copper Basin and lying beyond the damaging effects of smelter fumes, the forest (fig. 4) is today very much as it was before mining activity began. Tree species are those characteristic of the southern Appalachian Mountain region at elevations between 1,500 and 2,500 feet: principally mixed oaks, dogwood, sourwood, and black tupelo. There are also occasional trees of shortleaf and pitch pine; and yellow-poplar, ash, and black walnut occur in coves. Chestnut was originally present only on the upper north-facing slopes. White pine was also present in the original forest, but being particularly susceptible to smelter fumes, it was one of the first species to disappear. Fume injury to white pine has been reported 15 to 20 miles from the center of the basin.

No records are available as to the nature of successive vegetation changes over the years since mining activity began about 1850. At first most of the ore was transported out of the basin for smelting. Later open-hearth furnaces were used directly at the mine locations. It was during this period that trees were cut for fuel in the smelting

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Figure 2.—The bare central area of the Copper Basin is characterized by extensive sheet and gully erosion that have already washed away several feet of the original soil profile. *A*, Extensive gullies on exposed slope; *B*, soil from the slopes deposited as alluvial fill in a stream valley; *C*, valley bottom scoured down to rock by floodwaters from bare slopes.

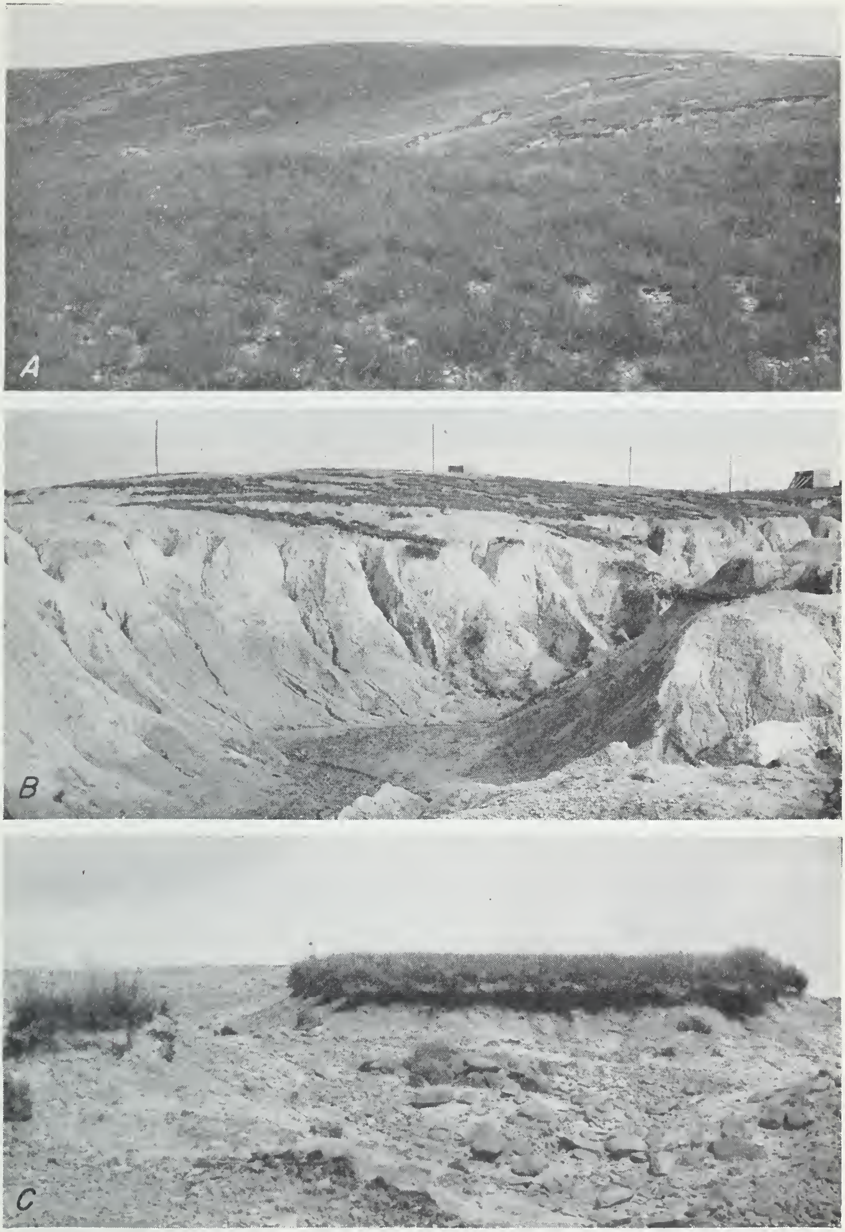

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Figure 3.—*A*, A belt of grassland, chiefly broomsedge, encircles the bare zone; *B*, in the transition area between the bare zone and the grass belt deep gullies underdrain the broomsedge and erosion eats into the exposed slopes; *C*, remnants of broomsedge found in isolated patches are subject to progressive desiccation by frost action and erosion.

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FIGURE 4.—A dense mixed hardwood forest cover surrounds the Copper Basin. Before smelting activities began, forest like this covered the entire basin.

process. The greatest activity in open-hearth smelting was in the years 1890–95, when, it is said, the air was constantly filled with smoke and sulfur dioxide fumes from the furnaces. Old settlers do not agree as to the length of time since vegetation disappeared. Low shrubs are reported to have persisted even in the denuded center of the basin until as late as 1895.[3] In any case, it is generally believed that all vegetation adjacent to the smelters had disappeared shortly after 1900. By 1910, the denuded zone was about as extensive as it is today. The broomsedge belt was at its maximum extent between 1915 and 1925.

Regardless of these minor changes, the three distinct vegetative zones in which records were taken of the Copper Basin have quite definite boundaries, and there was no difficulty in locating meteorological stations within areas principally influenced by a single vegetative cover condition.

The general climatic and physiographic features of the Copper Basin are favorable to a study of vegetation effects on local meteorological phenomena. A mean annual rainfall of 54 inches is well distributed throughout the year. Seasons are sharply defined. Plant growth starts in the latter half of April, but full foliage does not appear in the forest until the middle of May. Leaf fall takes place chiefly in late October and November. The winters are open, with little snow, and the ground stays frozen only a few days at a time. Repeated freezing and thawing occur during the winter and spring months, and erosion is severe on unprotected soil throughout the year. According to Thornthwaite's climatic pattern of the United States (*21*, *22*) the Copper Basin falls within a humid climatic region, lying in close proximity to the superhumid region of the southern Appalachian Mountains.

The center of the basin is located 35° 0′ latitude, 84° 22′ longitude, at an elevation of 1,600 to 1,800 feet, and lies in a region of generally

[3] Summaries of the history of the Copper Basin and descriptions of its present appearance have been recently published by Seigworth (*20*) and Penfound (*17*). Court records (*14*) of damage claims add very little to the history of the area.

westerly winds. As a whole, the basin exhibits a much dissected but fairly uniform topography of low rolling hills, with broad ridges 100 to 200 feet higher than the streams.

Considered altogether, the Copper Basin is probably one of the few areas in the world that is preeminently suitable for making a scientific study of the effect of vegetation destruction in modifying the elements of the general climate. World travelers agree that the basin presents a unique opportunity for carrying out scientific studies relating to the presence and absence of vegetation. However, because of the limitations of equipment and personnel under which the work described here was carried out, it must be considered to be an indicative and exploratory study only, rather than an exhaustive research in the field of vegetation effects on the elements of the local climate. This report serves as an introduction to the possibilities for further climatic research within the Copper Basin area.

METHODS OF STUDY

Data for this study were gathered during a period of four consecutive years, 1936–39. To collect these data, six meteorological stations were established in the Copper Basin. Each station was operated within a fenced enclosure 40 by 40 feet (fig. 5).

Stations 1, 2, and 3 were located in a line that crossed the bare zone from the southwest-by-west, and will be referred to as the west series. Stations 4, 5, and 6 were in a line that crossed the basin from southeast-by-south, and will be called the east series. The associated topo-

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FIGURE 5.—One of the six meteorological stations. The instruments and shelters, reading from left to right, are: Wind vane, soil pit, evaporation pan, soil the mograph shelter, standard rain gage, recording rain gage, anemometer, class A Weather Bureau evaporation pan, minimum-maximum thermometer and hygrothermograph shelter, and microbarograph shelter. Other stations were similarly equipped.

graphic conditions are given in table 1. Each series had a station in each of the three vegetative zones; so there were two representative stations in each zone. The two forest stations were 8.1 miles apart; the two grass stations were 3.9 miles apart; and the bare zone stations 1.4 miles apart. Location of the stations is shown in figure 1.

TABLE 1.—*Comparison of topographic features associated with each station*

Station	Cover condition	Aspect	Slope[1]	Elevation
West Series:			*Percent*	*Feet*
Station 1	Forest, second-growth	NE	5	1, 698
Station 2	Grass, chiefly broomsedge	E	5	1, 633
Station 3	Bare	NE	5	1, 821
East Series:				
Station 4	Bare	NE	10	1, 710
Station 5	Grass, chiefly broomsedge	NE	10	1, 740
Station 6	Forest, old-field	NE	10	1, 720

[1] The slope of the ground adjacent to each station was uniform rather than concave or convex.

In each series the three stations were established at locations of similar physiographic characteristics. It was impossible to locate stations with identical topographic positions, but the station sites were sufficiently alike to reduce physiographic differences to a minimum.

Of the two stations in the bare zone, station 3 was slightly more exposed to wind from all directions than station 4, and was 111 feet higher in elevation. Station 3 was within ½ mile of the border of the grass zone, whereas station 4 was about 1 mile from the nearest grass.

The principle difference between the two grass belt stations was that station 2 was slightly more exposed than station 5 in regard to adjacent topography, and was 107 feet lower in elevation. Vegetation was similar at both grass stations. The broomsedge did not form a sod. Grass clumps covered about 60 percent of the ground surface, but during the period of maximum growth the foliage shaded about 90 percent of the ground. As the leaves dried out the amount of surface shade was reduced to as low as 70 percent.

Tree growth at the two forest stations differed considerably with regard to age and density. Station 1 was located within a second-growth hardwood stand with occasional old-growth cull trees; station 6 on farm land that had been abandoned and allowed to return to trees. The size of trees was about the same at both stations, but there were fewer trees per acre at station 6. The upper canopy of foliage was completely closed at station 1, whereas at station 6 it had a density of 80 percent.

Air temperatures were recorded at a height of 4 feet above the ground by means of standard maximum-minimum thermometers within regulation shelters (fig. 5). Readings were taken twice daily.

Soil temperatures were recorded in 5-inch vitrified sewer tile inserted horizontally into the side of a pit at depths of 6, 12, and 18 inches. Each tile was kept closed with a padded wooden plug. Ten-inch immersion thermometers were placed so that the mercury bulb was in contact with the soil at the back open end of the tile. The soil pit itself was 3 by 4 feet, and 2 feet deep. It was kept covered with a heavy insulated trap door except while records were being taken. An additional soil reading was taken at the depth of 0.5 inch by means of a 10-inch immersion thermometer placed in the mineral soil at an angle of 15°, with the mercury bulb just covered. Daily readings were taken at approximately 8 a. m. and 5 p. m. In addition to the pit readings, recording soil thermographs were maintained at stations 1 and 4 for a period of 2 years, 1938–39.

Relative differences in wind velocity at the different stations were measured by three-cup Weather Bureau anemometers. They were operated at a height of 2 feet above the soil surface and at the location of the evaporation pans in order to correlate wind with evaporation.

Evaporation records for the entire period were obtained from pans 36 inches in diameter and 18 inches deep, set 14 inches into the soil. Height of water in the pan was held at soil level so far as possible. Measurements were made by means of a micro-hook gage, operated within a stilling well 5 inches in diameter. In addition, class A Weather Bureau land pan records also were obtained at stations 4, 5, and 6 for a part of the period under observation. This type of pan is 48 inches in diameter, 10 inches deep, ventilated on all sides and at the bottom, and was set on a rack 4 inches above the ground surface. Water temperatures were read from an immersion thermometer hung horizontally 1 inch below the surface and shaded from the sunlight.

Rainfall was recorded in standard Weather Bureau 8-inch unshielded rain gages located so that no surrounding objects intercepted a 45° angle from the gage. At forest stations, rain gages were placed 200 feet from the main meteorological stations, and the tree canopy was removed sufficiently so as not to interfere with obtaining a satisfactory measurement. Since practically all the precipitation in the Copper Basin area occurs as rain, no attempt was made to separate snow from rainfall in this study.

MODIFICATIONS OF LOCAL CLIMATES

Air Temperature

It has been generally believed that forest cover has a moderating effect throughout the year on both extremes of temperature. Comparative records taken in the forest and in the bare zone of the Copper Basin do not entirely bear out this belief.

When the leaves were off the trees (November to May) the daily range of air temperature (taken as the difference between the daily maximum and the daily minimum temperature) was found to be greater in the forest than in either the bare or grass zones (fig. 6 and table 2). For example, the daily temperature range in the forest in April was 25.2° F.; this was 4.1° F. more than in the bare zone and 2.8° F. more than in the grass belt.

However, with the appearance of foliage, air temperature in the forest became more stable than in either of the open zones, and remained so until leaf fall. In July and August, for example, the forest temperature fluctuated (daily average) 1.95° F. less than the grass belt temperature. The bare zone was intermediate.

In general, when the trees were bare, the forest showed the greatest range in air temperature, the bare zone the least, and the grass belt was intermediate. When the trees were in leaf, the grass belt showed the greatest range, the forest the least, and the bare zone was intermediate.

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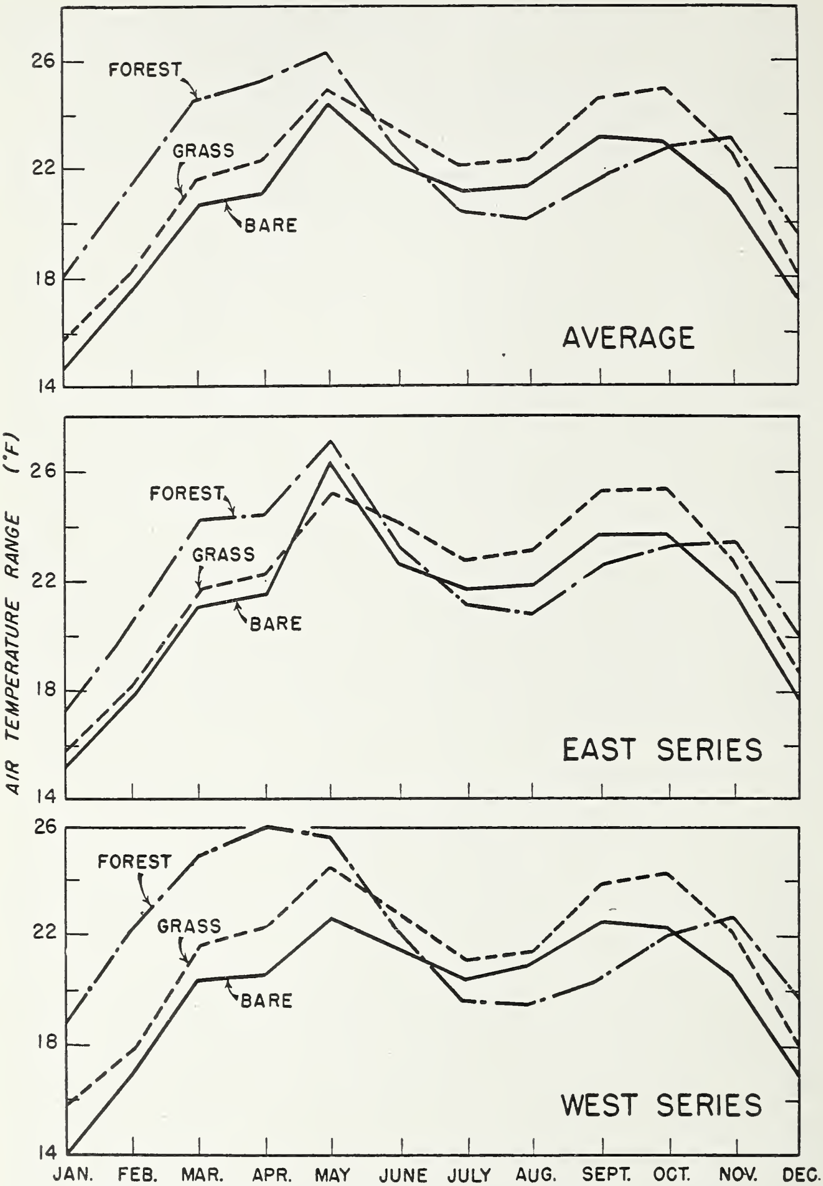

FIGURE 6.—Daily range of air temperature, monthly average.

These results do not agree with the findings of other workers. Zon (*27*) tabulated the findings of European investigations, from which he concluded that "In the forest the maximum temperature is always lower and the minimum temperature higher than outside." Burger (*2*), working in the spruce forest near Thun, Switzerland, found that in every month daily range of air temperature in the forest was always less by 2° to 3° F. than in the open. The findings of Schubert (*19*) in the spruce-and-beech type forests of northern and central Germany also indicate that the forest has a modifying effect on both extremes of air temperature.

Differences in latitude and the fact that the European studies were made in forests partly or wholly coniferous offer a possible explanation for the differences between the Copper Basin and the European findings. Below 35° north latitude the absence of canopy shade during the winter is probably the major factor influencing local air temperature in hardwood forests. From November through April the sun's rays reach the forest floor directly, except for scattered patches shaded by evergreen growths. Consequently, instead of being reflected away by foliage, the sunlight is absorbed by the forest floor and is radiated as heat. Moreover, because there is less wind movement in the forest than in the open, the radiated heat tends during the daytime to accumulate in the forest more than in the open. Thus higher maxima occur in the hardwood forest, and this is the principal reason for the wider temperature range.

Table 2.—*Monthly average of mean daily range of air temperature for vegetation zones, 1936–39* [1]

Zone	January	February	March	April	May	June
Forest:	°F.	°F.	°F.	°F.	°F.	°F.
Average of stations 1 and 6	17. 8	21. 4	24. 6	25. 2	26. 4	22. 8
Grass:						
Average of stations 2 and 5	15. 6	18. 0	21. 7	22. 4	25. 0	23. 1
Difference [2]	−2. 2	−3. 4	−2. 9	−2. 8	−1. 4	+0. 3
Bare:						
Average of stations 3 and 4	14. 6	17. 5	20. 8	21. 1	23. 4	22. 2
Difference [2]	−3. 2	−3. 9	−3. 8	−4. 1	−3. 0	−0. 6

Zone	July	August	September	October	November	December
Forest:	°F	°F.	°F.	°F.	°F.	°F.
Average of stations 1 and 6	20. 4	20. 2	21. 6	22. 6	23. 1	19. 7
Grass:						
Average of stations 2 and 5	22. 1	22. 4	24. 3	24. 9	22. 6	18. 2
Difference [2]	+1. 7	+2. 2	+2. 7	+2. 3	−0. 5	−1. 5
Bare:						
Average of stations 3 and 4	21. 2	21. 4	23. 2	23. 0	21. 0	17. 2
Difference [2]	+0. 8	+1. 2	+1. 6	+0. 4	−2. 1	−2. 5

[1] Monthly averages of daily means rounded off to one decimal point. Individual mean daily range may not always be in exact agreement in the decimal place with values derived as averages of the maximum-minimum air temperature data given in table 3.

[2] Difference as compared with average of forest stations.

In coniferous forests the foliage prevents the sun from reaching the forest floor and heating it. And because of the difference in latitude between the Copper Basin and the European forests, the incidence of the sun's rays is relatively higher in the Copper Basin during late spring before foliage appears. These factors help to account for the much higher air temperatures and the wider temperature range recorded in the hardwood forests of the Copper Basin.

MINIMUM AIR TEMPERATURE

Trends in range of air temperature in the different zones of the Copper Basin are further explained by a separate analysis of minimum and maximum temperatures. Minimum air temperatures were

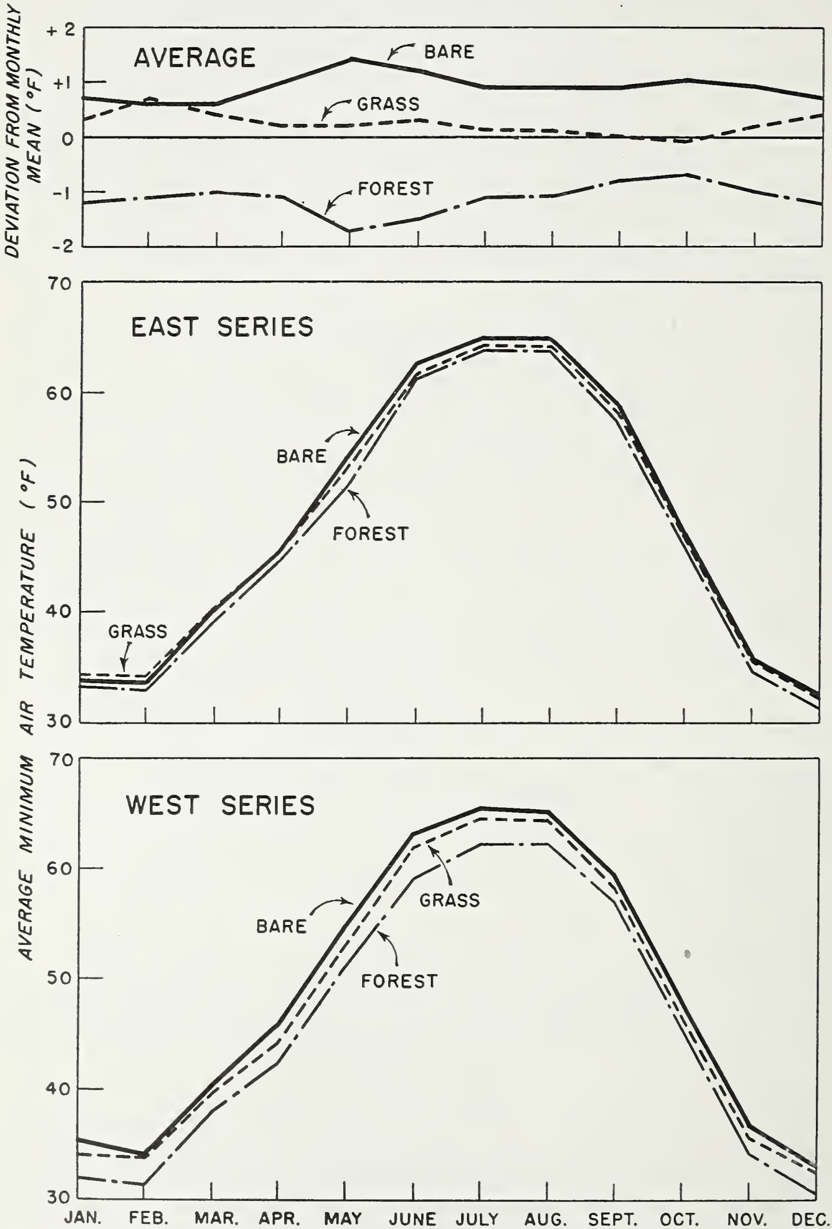

FIGURE 7.—Average daily minimum air temperature expressed as the monthly mean, January 1936–December 1939.

found to be always lower at forest stations than at either grass or bare zone stations in every month of the year (fig. 7 and table 3). These differences between zones ranged from 0.6° to 3.1° F. The grass zone temperatures were between those of the forest and bare zones. The relative position of the temperature curves of the three zones remained essentially the same throughout the year.

TABLE 3.—*Average maximum and minimum daily air temperature, by zone, expressed as the monthly mean, 1936–39*

Zone	January	February	March	April	May	June
Forest:						
Station 1:	°F.	°F.	°F.	°F.	°F.	°F.
Maximum	50. 5	53. 6	62. 8	68. 3	76. 8	81. 4
Minimum	32. 0	31. 3	38. 0	42. 4	51. 1	59. 2
Station 6:						
Maximum	50. 4	53. 3	63. 2	69. 0	78. 9	84. 8
Minimum	33. 4	33. 0	39. 1	44. 6	51. 7	61. 3
Grass:						
Station 2:						
Maximum	49. 7	51. 6	61. 4	66. 9	77. 7	84. 7
Minimum	34. 1	33. 7	39. 8	44. 4	53. 2	62. 0
Station 5:						
Maximum	50. 1	52. 2	62. 1	67. 6	78. 9	86. 1
Minimum	34. 4	34. 2	40. 3	45. 2	53. 4	61. 9
Bare:						
Station 3:						
Maximum	49. 1	51. 2	60. 8	66. 6	77. 6	84. 9
Minimum	35. 3	34. 0	40. 4	45. 9	54. 9	63. 2
Station 4:						
Maximum	49. 5	51. 5	61. 2	66. 8	80. 4	85. 4
Minimum	34. 0	33. 8	40. 0	45. 2	54. 1	62. 6

Zone	July	August	September	October	November	December
Forest:						
Station 1:	°F	°F.	°F.	°F.	°F.	°F.
Maximum	82. 1	82. 0	77. 4	67. 4	56. 7	50. 0
Minimum	62. 4	62. 4	56. 9	45. 4	34. 0	30. 4
Station 6:						
Maximum	85. 1	84. 6	79. 9	69. 3	58. 1	51. 0
Minimum	63. 9	63. 7	57. 4	46. 0	34. 6	31. 3
Grass:						
Station 2:						
Maximum	85. 9	85. 9	81. 9	70. 8	57. 7	50. 4
Minimum	64. 6	64. 4	58. 0	46. 3	35. 4	32. 4
Station 5:						
Maximum	87. 2	87. 2	83. 3	71. 8	58. 3	50. 8
Minimum	64. 3	64. 0	57. 9	46. 3	35. 6	32. 5
Bare:						
Station 3:						
Maximum	86. 1	86. 3	81. 8	70. 0	57. 1	49. 8
Minimum	65. 6	65. 2	59. 2	47. 7	36. 6	32. 9
Station 4:						
Maximum	86. 5	86. 6	82. 4	70. 7	57. 3	50. 0
Minimum	64. 8	64. 8	58. 6	47. 0	35. 8	32. 5

These findings do not agree with those reported by Ebermayer (*4*), who found that in the Bavarian forests minimum air temperatures averaged 3° F. higher inside the forest than in the open. The different results in the Copper Basin are conceivably due to surface conditions unusually favorable for rapid air drainage away from the recording stations in the bare and grass zones (fig. 8). Because of rapid radiation of heat from bare soil, it could naturally be expected that the night temperature in the bare zone would fall below that of surrounding areas having vegetative cover. However, when cooler air

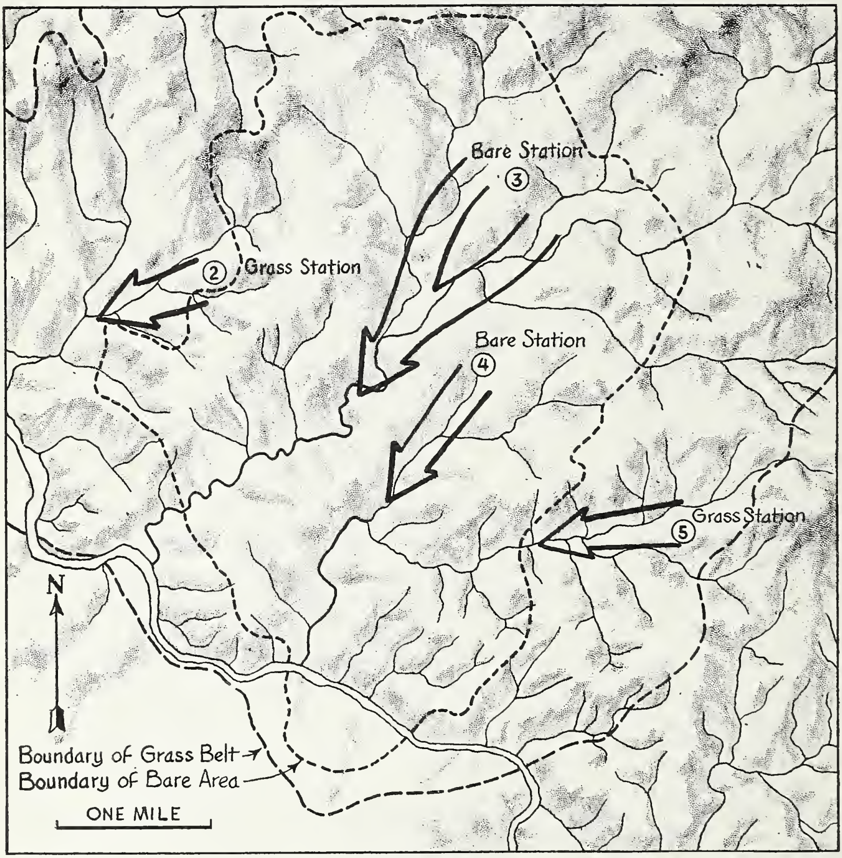

FIGURE 8.—Assumed drainage at night of near-surface air away from the bare zone and grass zone stations, shown diagrammatically. The heavier cooled air can be expected to flow down the bare slopes toward the natural stream channels. This occurs at night only. During the day the direction is reversed because rapid heating of the soil tends to create an upslope air movement.

at the ground surface has a favorable opportunity to drain away rapidly and to be replaced by warmer air from above, thermometers read 4 feet above the ground will be influenced by the air above the station rather than by the air that is being cooled at the ground surface. It can be seen that because of the bare surface and rolling topography in the bare zone, air drainage from the bare slopes will be rapid. It is reasonable to believe that cold air drains away from the bare stations at the ground surface much more easily than from the forest stations where mechanical obstructions (low vegetation on the forest floor) retard its movement.

MAXIMUM AIR TEMPERATURE

Whereas minimum air temperatures in the three vegetative zones maintained the same relative position for all months, maximum air temperatures of the different zones showed a complete change in relative position during the year. During the leafless period (December through April) the mean maxima in the forest ranged from 0.6° to 2.0° F. higher than the bare zone; but during the period of foliage (June through October) it was from 2.1° to 3.5° lower (table 3). In September and October grass station maximum air temperatures were 3.5° higher than the forest stations, and 0.8° higher than the bare zone stations (fig. 9).

Although these data do not agree with the usual findings reported for northern coniferous forests, they agree with observations that have been made elsewhere within hardwood stands. Burger (*2*) reported that in Switzerland average air temperature in the hardwood forest during April was about the same as in open country, whereas for other months the forest recorded a definitely lower temperature. In other words, Burger found that the hardwood forest reaches its maximum temperature in relation to outside temperatures during the month of April. Similarly, Pavari (*15*) reports that the air temperature in the Mediterranean pine forests reaches its maximum in relation to outside temperatures during April.

Explanation of the relative change in position of the maximum air temperatures of the three zones of the Copper Basin involves a number of factors. The air is definitely warmer in the forest from January through April, than in the contiguous grass or denuded zones. During May the forest stations change from highest to lowest air temperature maxima, retaining this position throughout the summer and during September and October. During this period (May through October) the foliage of the hardwood forest has its maximum effectiveness in shading the forest floor. Thus in a general way it may be said that during the months of full foliage the forest tends to insulate the air at the forest floor against becoming heated by the sun. Furthermore, the transpiration of water by trees and other plants has some cooling effect on the atmosphere immediately surrounding them, and so helps to produce relatively lower temperatures in the forest.

TEMPERATURE CHANGES IN PASSING AIR CURRENTS

A further analysis of maximum air temperatures at all six stations in the Copper Basin shows that those of the west series recorded lower daily maxima than corresponding stations in the east series. The single exception was the two forested stations during the winter months. To explain the higher maxima for the east series necessitates a consideration of the position of the stations with regard to air movements across the bare and grass zones of the Copper Basin.

The question arises whether or not the east stations are influenced by flowing air that has been warmed in passing over the grass and bare zones. If this is a valid hypothesis, it should be possible to show that the east series of stations lies on the side of the bare zone away from the direction of the prevailing wind.

The obervation stations were spaced across the Copper Basin roughly in an east-west direction (fig. 1). Any regular flow of sur-

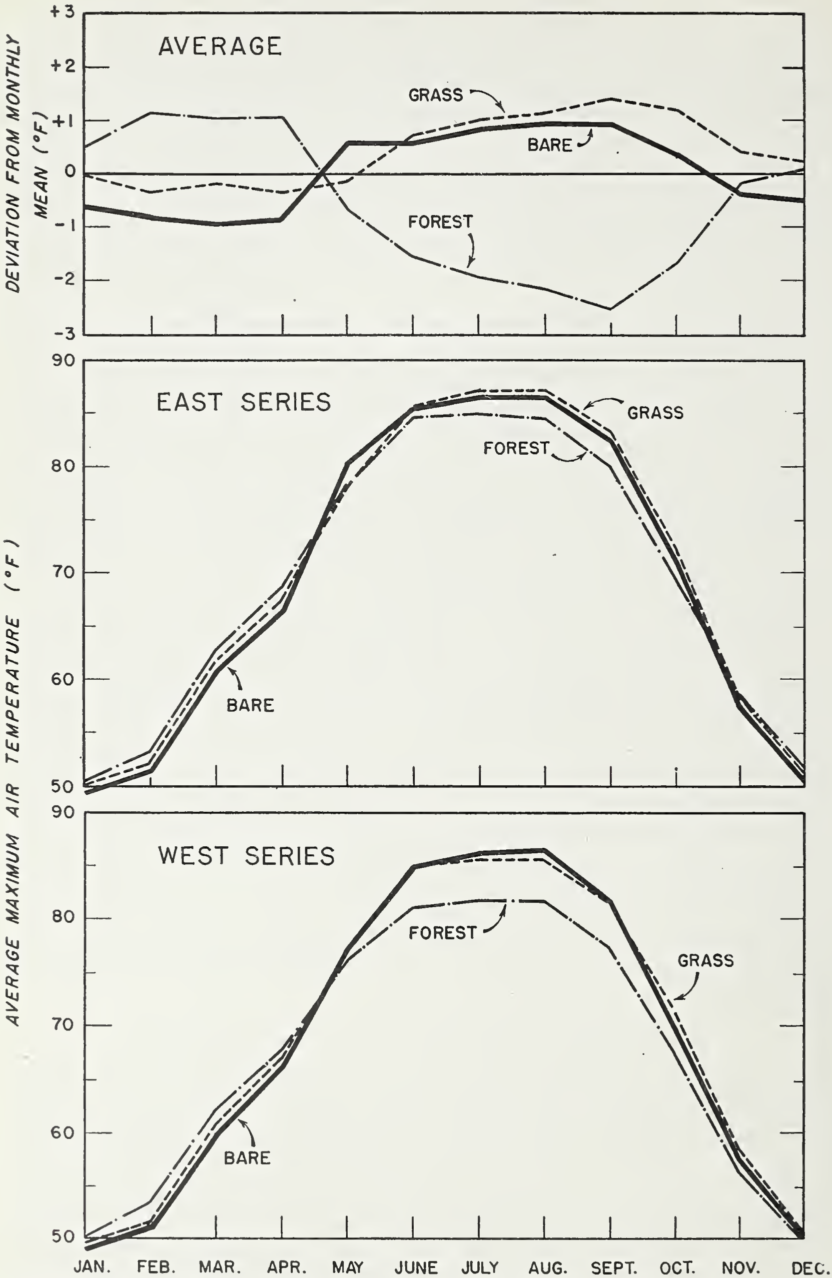

FIGURE 9.—Average daily maximum air temperature expressed as the monthly mean, January 1936–December 1939.

face air across the basin would subject the stations away from the wind to an afternoon maximum that was influenced not only by the topography, vegetation, and aspect of the station itself, but also by the effect of passing air that was heated as it drifted across the cleared areas.

Records (*23*,[4] *24*, *25*) indicate that the Copper Basin lies in the path of the westerly winds. Consequently general wind movements would cross the denuded areas toward the grass and forest stations 5 and 6 in the east series. As a specific example, observations at grass station 5, which was in the east series, showed that from June through September the prevailing wind was from a westerly direction in 53 percent of the daily afternoon recordings; that is, from the west, northwest, and southwest. The temperature maxima differed most between stations on clear days, when the wind was more likely to be westerly. On the other hand, these differences tended to disappear on days of overcast or rain. Hence, the differences in mean maxima were due to clear (fair) weather differences. In fair weather the winds were usually the prevailing westerlies for the region undisturbed by storm areas (cyclones).

General topography is characterized by a slight rise in elevation across the basin from west to east. Rising slopes begin on the east side of the basin just inside the boundary of the grass zone. Because they are exposed to the south and southwest, these slopes have the general topographic effect of inducing an upward flow of air along the heated surface during the afternoon. In addition, westerly flow of winds might be further strengthened by the effect of topography associated with the major stream-drainage pattern of the Copper Basin area, because westerly winds would naturally tend to follow the Ocoee River (touching the basin on the south), which flows from the east to the west. During the daytime there might thus be an added tendency for up-canyon breezes to move up the river and consequently across the Copper Basin from the west.

Thus it would appear that relatively cool air actually flows off the forest from the western side of the basin and is heated as it flows over the grass and bare zones toward the east. This west to east movement of heated air explains the warmer temperatures at the east series of stations during hot summer months. All the data so far collected in the Copper Basin substantiate this hypothesis.

[4] The 42-year Weather Bureau record taken at Chattanooga, Tenn., is given below in comparison with the 4-year record at Station 5 in the Copper Basin:

Prevailing Wind Direction

	Jan.	Feb.	Mar.	Apr.	May	June	July
Chattanooga	NW.	NW.	NW.	SW.	SW.	SW.	SW.
Copper Basin	NW.	SE.	NW.	NW.	NW.	NW.	NW.

	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Chattanooga	NE.	NE.	NW.	NW.	SW.	SW.
Copper Basin	SE.	SW.	N.	N.	NW.	NW.

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Another explanation is needed for the fact that both stations in the grass zone showed higher relative temperatures than the forest stations. This may conceivably be found in the changing soil temperatures associated with the seasonal ratio of daylight to darkness, changing hours of sunshine, and relative value of denuded, grassed, and forested surfaces as absorbers and radiators of radiant energy.[5] The retarding effect of vegetation on near-surface air movement permits a given layer of air to remain longer in contact with the heated surface. Soil temperatures corroborate this possible explanation and a discussion of these soil records follows.

Soil Temperature

Soil temperatures are related to air temperatures in that they both derive from solar energy. However, because temperature changes take place more slowly in soil than in air, the daily fluctuation of soil temperature presents a pattern different from that of air temperature. Penman (*18*) has pointed out that although there is a definite interdependence of surface soil and air temperatures, it is only when air temperature maxima are below 52° F. that the daily range of soil surface temperature is approximately the same as that of the air temperature.

EFFECT OF VEGETATION

Soil temperatures in the three zones, measured at 0.5-inch depth at 5 p. m., were found to differ (fig. 10 and table 4) by less than ±1° F. during the period when the leaves were off the trees and the grass was dead (November through April). During this period the trees and the grass blades evidently interfered very little with the penetration to earth of the soil-heating solar energy. Any shading effect of the vegetation was compensated because the vegetation also obstructed radiation from the soil and reduced air movement at the soil surface; this counteracted two processes by which the soil surface is cooled. Thus it might be anticipated that near noon, when the sun is high in the sky and vegetation has its minimum shading effect, soil surface temperatures in the vegetated zones would even exceed temperatures in the open.

On the other hand, during the months (May to October) when the fully leaved trees and the green grass afforded more shade, soil temperatures in the forest were from 5.1° (October) to 10° F. (June) lower than in the bare zone. Corresponding soil temperatures in the grass zone were from 0.5° (May) to 3.9° (August) lower than in the bare zone; and from 2.4° (October) to 8.2° (June) greater than in the forest.

Soil temperatures measured in the forest at 8 a. m. at 0.5-inch depth showed a smooth annual fluctuation from a minimum 8.5° to 9.5° F. less than the bare zone (May through August) to a maximum 1.8°

[5] No attempt has been made in the present study to measure the relative value of different vegetative covers in absorbing and radiating energy of sunlight during different seasons of the year.

greater than the bare zone (November). Grass zone temperatures showed a similar but smaller fluctuation, varying from 1.6° to 2.2° lower than the bare zone (May through August) to 1.9° higher than the bare zone (November and December).

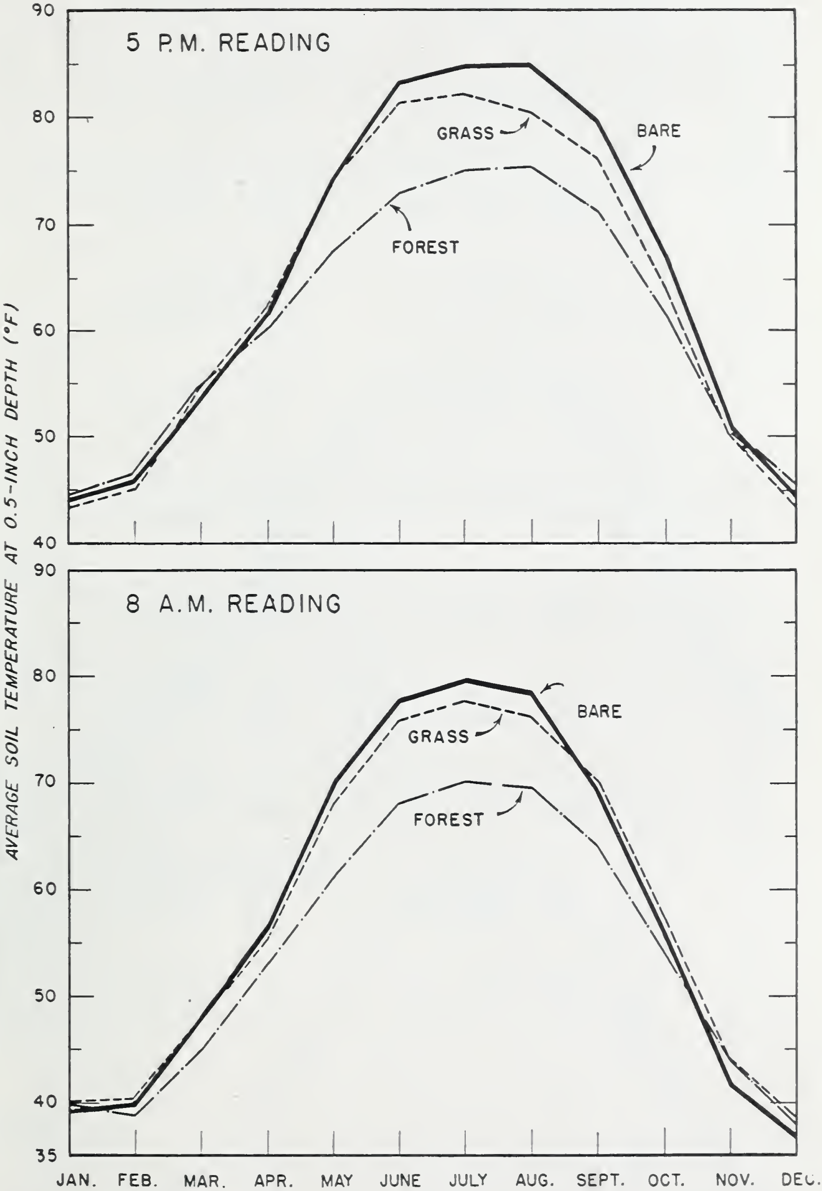

FIGURE 10.—Monthly mean of daily soil temperature readings, 0.5-inch depth.

TABLE 4.—*Average daily soil temperature at 0.5-inch depth, by zone, expressed as the monthly mean, 1936–39*

MORNING READINGS—8 A. M.

Zone and station	January	February	March	April	May	June	July	August	September	October	November	December
Forest:	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Station 1	38. 5	37. 6	44. 4	52. 3	60. 6	67. 2	69. 6	68. 9	63. 2	52. 2	42. 9	36. 6
Station 6	41. 0	41. 2	46. 6	55. 1	63. 5	70. 0	71. 6	71. 0	66. 2	56. 4	45. 7	40. 4
Grass:												
Station 2	40. 6	40. 8	48. 5	55. 6	67. 9	75. 0	78. 8	77. 0	70. 4	58. 4	45. 6	39. 7
Station 5	39. 8	39. 8	46. 6	56. 2	70. 1	78. 2	77. 3	75. 8	70. 2	56. 2	43. 2	37. 8
Bare:												
Station 3	39. 4	39. 8	48. 2	56. 7	69. 7	78. 0	79. 8	79. 0	71. 0	57. 3	43. 4	38. 0
Station 4	39. 7	40. 0	47. 8	57. 2	71. 6	78. 3	79. 4	78. 1	68. 3	54. 8	41. 6	36. 2

AFTERNOON READINGS—5 P. M.

Zone and station	January	February	March	April	May	June	July	August	September	October	November	December
Forest:												
Station 1	44. 2	46. 2	56. 1	62. 6	67. 4	71. 8	73. 8	74. 8	70. 8	60. 6	49. 0	44. 2
Station 6	44. 5	46. 2	53. 3	58. 7	68. 6	75. 1	76. 8	76. 3	71. 8	62. 7	51. 8	45. 0
Grass:												
Station 2	44. 5	45. 8	52. 7	60. 9	72. 5	80. 3	81. 6	79. 9	74. 6	63. 9	50. 4	43. 7
Station 5	43. 6	45. 0	55. 2	63. 0	75. 8	83. 1	83. 5	81. 9	78. 2	64. 1	49. 9	43. 2
Bare:												
Station 3	44. 6	45. 4	53. 4	61. 6	74. 6	83. 0	84. 1	84. 0	77. 6	64. 6	50. 4	44. 5
Station 4	44. 2	46. 1	54. 0	61. 8	74. 7	83. 9	85. 5	85. 6	81. 5	68. 9	52. 0	44. 0

In order to obtain a measure of actual maximum soil temperatures for a 24-hour period, readings were made hourly from 8 a. m. to 6 p. m. during a special 14-day period in July 1937. The absolute maximum usually occurred at 2 p. m. on bright summer days at a depth of 0.5 inch. The highest temperature recorded in the forest was 82° F.; in the grass zone, 105°; and in the bare zone, 127°. These surface-soil temperatures were not so high as those reported for extremely sandy soils. The Copper Basin soils contain very little sand; but they do contain large quantities of mica, which may tend to insulate the bare soil.

At a depth of 6 inches, there were among the three zones practically no differences among the soil temperatures taken at 5 p. m. during the months of dormant vegetation (fig. 11 and table 5). During the

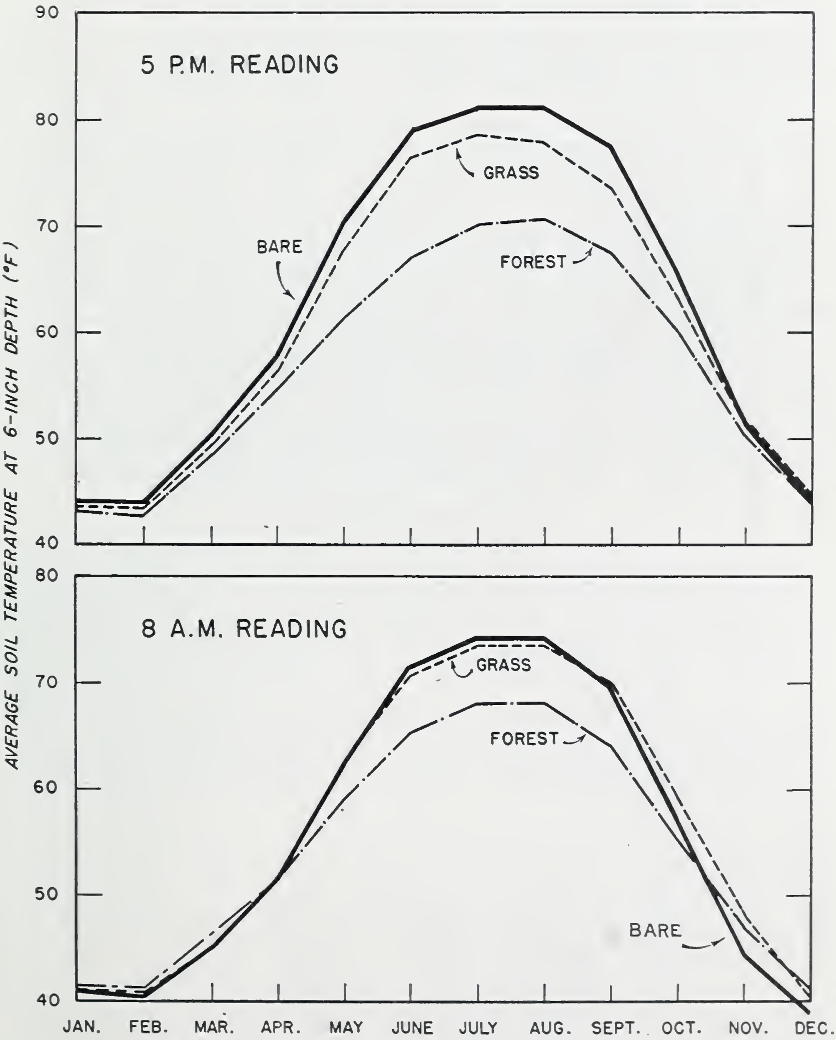

FIGURE 11.—Monthly mean of daily soil temperature readings, 6-inch depth.

TABLE 5.—*Average daily soil temperature at 6-inch depth, expressed as the monthly mean, 1936–39*

MORNING READINGS—8 A. M.

Zone and station	January	February	March	April	May	June	July	August	September	October	November	December
Forest:	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
Station 1	41.0	40.8	46.4	51.8	58.6	64.3	67.0	67.8	63.1	55.0	46.6	41.4
Station 6	42.1	41.8	46.2	51.9	60.2	66.4	69.5	69.9	65.8	57.0	47.8	41.4
Grass:												
Station 2	41.6	40.9	45.5	51.6	61.5	69.8	72.6	72.8	69.0	59.5	48.2	41.4
Station 5	42.0	41.0	45.9	52.2	63.2	72.4	75.0	74.9	70.4	58.9	47.6	41.1
Bare:												
Station 3	41.8	41.2	46.5	53.2	64.2	72.6	75.6	75.4	71.6	59.1	46.4	39.7
Station 4	40.5	39.5	44.4	50.7	60.6	70.5	72.9	72.5	67.6	55.7	43.2	39.0

AFTERNOON READINGS—5 P. M.

Zone and station	January	February	March	April	May	June	July	August	September	October	November	December
Forest:												
Station 1	44.2	43.7	49.0	55.1	60.4	66.4	69.2	69.9	66.8	59.4	50.6	44.6
Station 6	42.9	42.8	48.5	54.9	62.5	68.4	71.2	71.6	68.2	60.1	50.2	43.2
Grass:												
Station 2	44.2	43.7	49.5	56.1	66.8	75.4	77.4	76.4	72.2	62.8	51.4	44.0
Station 5	43.2	43.1	49.7	57.0	69.2	77.6	79.8	79.3	74.6	63.4	50.8	43.5
Bare:												
Station 3	43.0	42.5	49.4	56.4	69.0	77.4	80.1	80.1	76.7	64.0	50.2	42.7
Station 4	44.8	45.0	52.0	59.1	71.4	79.9	81.8	81.5	78.3	65.7	51.9	44.5

period of foliage, the bare zone recorded the highest temperature and the forest the lowest, with the grass zone intermediate. Maximum differences occurred in June, when the forest recorded 11.2° F. less than the bare zone and 9.1° less than the grass zone.

Eight a. m. temperatures at the 6-inch soil depth in the forest were higher than those in the bare zone when the leaves were down, and were lower during the foliar period. Greatest differences occurred in November when the forest soil at the 6-inch depth was warmer than the bare zone by 2.4° F., and in June when the forest soil was colder by 6.2°. The grass zone temperatures, on the other hand, did not differ from the bare zone by more than ±1° except from October to December when they were from 1.8° to 3.1° higher.

In general, the temperatures in the vegetated zones tended to exceed those in the bare zone in the late fall and early winter months when the 8 a. m. readings represented true nightly minima (the sun had not risen enough at 8 a. m. to be effective), but tended to be markedly lower than the bare zone in summer. In the summer the sun had already warmed the denuded soil surface materially by 8 a. m., but warmed the vegetated zones more slowly because of the effective shading of the soil.

It is apparent that vegetation provides an insulating effect that insures a more equable temperature in the forest and grass zone soils. In those months when the hours of sunlight exceeded the hours of darkness, the bare soil absorbed a greater amount of heat and remained warmer throughout the night. The bare zone stations then recorded a higher 8 a. m. temperature than the vegetated stations. But when the hours of darkness exceeded those of sunlight, the net loss of heat was greater in the bare zone than in the forest or grass zones. On the whole, in terms of local climate, removal of the forest cover has subjected the soil to much higher summer temperatures and to a greater fluctuation in temperature throughout the year.

RANGE OF SOIL TEMPERATURE

Supplementary data on soil temperatures were obtained from soil thermographs operated during the period December 1936–February 1940.[6] As these records furnished a more accurate maximum and minimum temperature than the pit readings [7] for each day, they provide a basis for computing the actual daily range at two stations: forest station 1 and bare station 4.

From the thermograph records it was found that the maximum soil temperature in the forest at the depth of 1.2 inches was less than that of the bare zone during every month of the year, the difference being large during the foliar period, and small when the leaves were down.

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[6] One element was set at the depth of 6 inches below the surface of the mineral soil, and the other at a depth as close to the mineral soil surface as the element could be operated. The recorder elements were of the extra sensitive grid type with a diameter of 2⅛ inches. For the surface reading, the element was buried and completely covered with soil to a depth of 0.5 inch. Temperatures recorded are therefore considered to represent the average depth of the element, or about 1.2 inches below the surface of the mineral soil. No continuous records were taken in the litter, or at the soil surface.

[7] Soil thermograph records served as a check on pit readings from soil temperatures. Satisfactory agreement was found between monthly mean minimum and maximum thermograph records at 6 inches, and the thermometer pit readings at 8 a. m. and 5 p. m. for the same depth (table 6). There was less agreement between the thermograph reading at 1.2 inches and the thermometer reading at 0.5 inch.

The difference ranged from a high of 22.2° F. in July to a low of 2.4° in January (table 6). At this depth the minimum soil temperature was always higher in the forest, ranging from 0.7° in April to as much as 5.9° in November. The thermographically recorded maxima and minima agreed reasonably well with the 5 p. m. and 8 a. m. measurements at the same depth in the pits.

TABLE 6.—*Average daily soil temperature of forest and bare zones, expressed as the monthly mean, 1938–39* [1]

Item	1.2-inch depth			6-inch depth		
	Forest—station 1	Bare—station 4	Difference—station 4 from station 1	Forest—station 1	Bare—station 4	Difference—station 4 from station 1
January:	°F.	°F.	°F.	°F.	°F.	°F.
Maximum	43. 4	45. 8	+2. 4	43. 4	41. 7	−1. 7
Minimum	36. 2	33. 1	−3. 1	39. 5	37. 0	−2. 5
Range	7. 2	12. 7	5. 5	3. 9	4. 7	. 8
February:						
Maximum	47. 2	51. 4	+4. 2	44. 0	44. 7	+. 7
Minimum	36. 3	33. 8	−2. 5	38. 5	38. 0	−. 5
Range	10. 9	17. 6	6. 7	5. 5	6. 7	1. 2
March:						
Maximum	60. 5	64. 4	+3. 9	53. 5	52. 0	−1. 5
Minimum	41. 9	40. 0	−1. 9	45. 0	43. 4	−1. 6
Range	18. 6	24. 4	5. 8	8. 5	8. 6	. 1
April:						
Maximum	70. 2	75. 8	+5. 6	59. 6	60. 0	+. 4
Minimum	45. 8	45. 1	−. 7	48. 9	49. 8	+. 9
Range	24. 4	30. 7	6. 3	10. 7	10. 2	. 5
May:						
Maximum	70. 6	84. 6	+14. 0	64. 1	69. 7	+5. 6
Minimum	56. 6	54. 9	−1. 7	56. 6	59. 4	+2. 8
Range	14. 0	29. 7	15. 7	7. 5	10. 3	2. 8
June:						
Maximum	74. 7	96. 4	+21. 7	68. 8	79. 0	+10. 2
Minimum	64. 3	63. 5	−. 8	63. 8	69. 0	+5. 2
Range	10. 4	32. 9	22. 5	5. 0	10. 0	5. 0
July:						
Maximum	76. 4	98. 6	+22. 2	71. 0	81. 5	+10. 5
Minimum	66. 3	65. 5	−. 8	66. 0	71. 5	+5. 5
Range	10. 1	33. 1	23. 0	5. 0	10. 0	5. 0
August:						
Maximum	79. 2	99. 7	+20. 5	72. 6	81. 9	+9. 3
Minimum	67. 7	66. 3	−1. 4	67. 4	72. 0	+4. 6
Range	11. 5	33. 4	21. 9	5. 2	9. 9	4. 7
September:						
Maximum	72. 7	94. 4	+21. 7	68. 3	77. 4	+9. 1
Minimum	61. 6	59. 4	−2. 2	62. 7	66. 7	+4. 0
Range	11. 1	35. 0	23. 9	5. 6	10. 7	5. 1
October:						
Maximum	61. 5	79. 0	+17. 5	59. 0	64. 7	+5. 7
Minimum	50. 3	46. 1	−4. 2	53. 4	54. 5	+1. 1
Range	11. 2	32. 9	21. 7	5. 6	10. 2	4. 6
November:						
Maximum	50. 0	59. 5	+9. 5	49. 4	50. 5	+1. 1
Minimum	41. 8	35. 9	−5. 9	44. 5	42. 2	−2. 3
Range	8. 2	23. 6	15. 4	4. 9	8. 3	3. 4
December:						
Maximum	43. 9	48. 1	+4. 2	44. 4	43. 5	−. 9
Minimum	36. 3	32. 2	−4. 1	40. 1	37. 8	−2. 3
Range	7. 6	15. 9	8. 3	4. 3	5. 7	1. 4

[1] Data from thermograph readings taken at station 1 and station 4.

During the growing season (May–October) the daily range of soil temperature in the open exceeded that in the forest by 21.4° F. (fig. 12 and table 6). The daily range at 1.2-inch depth in the forest was about 10° for all except the spring months. It was found that the daily range in the forest soil temperature increased rapidly during February and March, and reached a maximum range of 24.4° in April. The range then decreased after tree foliage appeared.

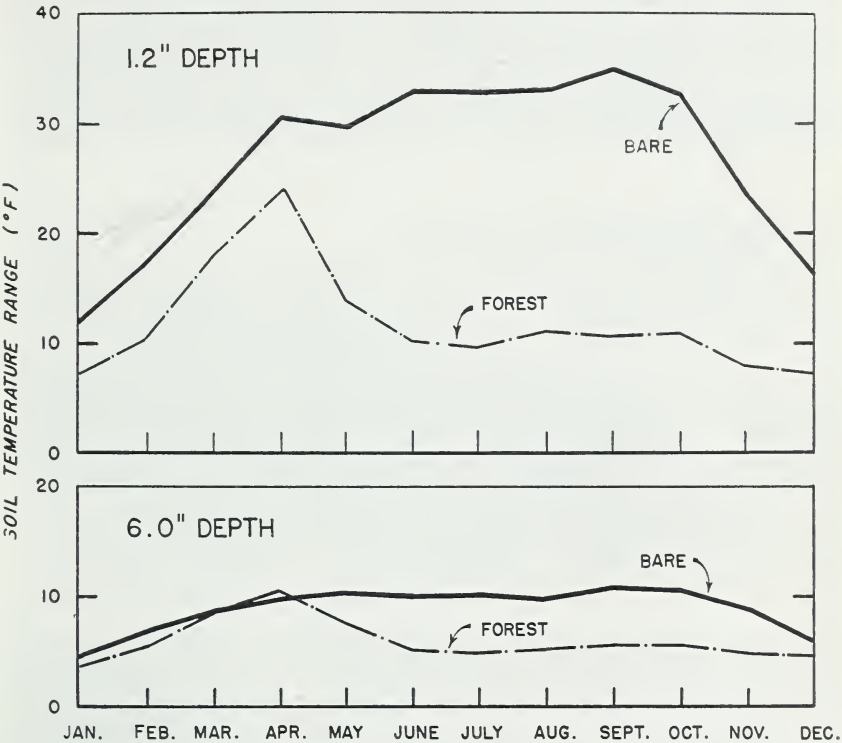

FIGURE 12.—Range of soil temperature, monthly mean of daily records for January 1936–December 1939 inclusive.

The differences in soil temperature among the zones of the Copper Basin may be assigned largely to the presence of absence of shade by vegetation canopy and to the insulation afforded by organic litter and debris on the ground. Soil temperature records in this study bear out the general conclusions reached by MacKinney (*12*), Korstian (*9*), and Li (*11*) principally for New England forest conditions, and by Pearson (*16*) for the timbered areas of western yellow pine forests in the Southwest. All of these workers found that the forest litter has a highly insulating effect on the soil; and that the soil is relatively cooler inside the forest than outside. However, they did not encounter the relatively high winter and spring soil temperatures found in the hardwood forests of the Copper Basin.

The Copper Basin records demonstrate the nature of soil temperature changes that have resulted from removal of the hardwood forest in this locality. An increase during the growing season of more than

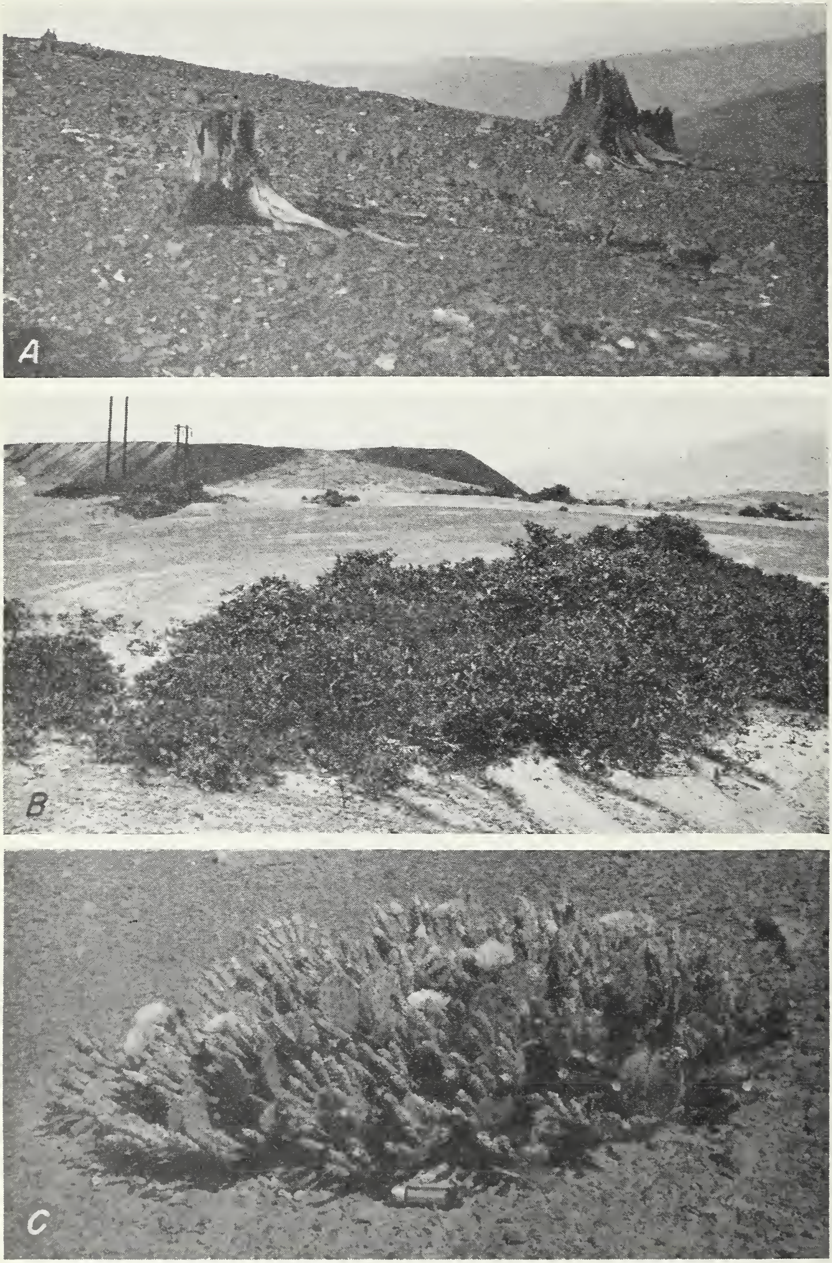

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FIGURE 13.—Changing conditions in the Copper Basin have resulted in changes in vegetation: *A*, A few chestnut stumps are the only remaining evidence of the hardwood forest that once covered the bare zone; *B*, smilax, which has a deep fleshy rootstock that can survive unfavorable surface soil conditions, is now the only green vegetation in many locations; *C*, pricklypear cactus, with its ability to withstand high soil temperatures and desiccation from the wind and evaporation, is one of the few plants able to survive on exposed positions in the bare zone.

21° F. in the daily temperature range, and of nearly 20° in the daily maxima of soil temperatures (1.2-inch depth) affected other elements of the local climate—for example, soil moisture and evaporation. The resulting difficult conditions for plant growth in the bare central zone are borne out concretely by results of tree-planting experiments: entire plantations have failed completely. These soil temperature conditions doubtless contribute to the slow rate at which vegetation is now reestablishing itself within the bare zone. They also explain the rigorous conditions of local climate with which the existing vegetation now has to contend (fig. 13).

Wind Velocity

Wind movements exert a definite influence on evaporation, drying out of the soil, and heating of the air layers near the ground. For this reason, efforts were made to measure wind velocity inside and outside the forest as a factor in determining the influence of tree growth on the local climate.

The highest wind velocities in the Copper Basin were found to occur during February, March, and April (table 7). Beginning in May wind velocities gradually decreased until the end of September, and then rose (fig. 14) until the end of March.

Table 7.—*Average monthly wind velocity and evaporation on forest, grass, and bare zones, 1936–39*

Wind Velocity

Month	Forest		Grass		Bare	
	Station 1	Station 6	Station 2	Station 5	Station 3	Station 4
	M. p. h.	*M. p. h.*	*M. p. h.*	*M. p. h.*	*M. p. h.*	*M. p. h.*
January	0. 9	1. 3	6. 2	3. 8	7. 3	5. 1
February	1. 0	1. 4	7. 0	4. 4	7. 7	5. 4
March	1. 1	1. 5	7. 2	4. 2	7. 8	5. 4
April	1. 0	1. 6	6. 8	4. 4	7. 7	5. 5
May	. 4	. 7	4. 4	2. 6	5. 4	4. 3
June	. 2	. 5	3. 5	2. 0	4. 7	3. 9
July	. 1	. 4	2. 6	1. 7	4. 0	3. 5
August	. 1	. 5	2. 3	1. 7	3. 9	3. 4
September	. 1	. 5	2. 7	1. 6	4. 1	3. 3
October	. 4	. 7	3. 8	2. 2	5. 3	3. 9
November	. 7	. 9	4. 6	2. 7	5. 7	4. 3
December	. 7	. 9	4. 4	2. 7	5. 6	4. 1

Evaporation

Month	Station 1	Station 6	Station 2	Station 5	Station 3	Station 4
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
January	0. 83	0. 98	1. 66	1. 44	1. 72	1. 68
February	1. 00	1. 31	2. 17	2. 26	2. 65	2. 35
March	1. 86	2. 02	3. 78	3. 32	4. 18	3. 50
April	2. 26	2. 74	5. 08	4. 80	6. 00	5. 40
May	1. 83	2. 53	5. 90	5. 52	7. 41	6. 51
June	1. 23	1. 94	6. 06	5. 95	8. 17	7. 08
July	1. 05	1. 86	5. 46	5. 43	7. 45	6. 80
August	. 80	1. 65	4. 73	5. 06	7. 01	6. 23
September	. 84	1. 54	4. 16	4. 15	5. 98	5. 29
October	1. 14	1. 66	3. 76	3. 37	4. 81	4. 14
November [1]	1. 19	1. 46	2. 61	2. 34	3. 23	2. 81
December [1]	. 77	1. 03	1. 61	1. 77	1. 82	1. 68
Annual average	14. 80	20. 72	46. 98	45. 41	60. 43	53. 47

[1] Three-year averages.

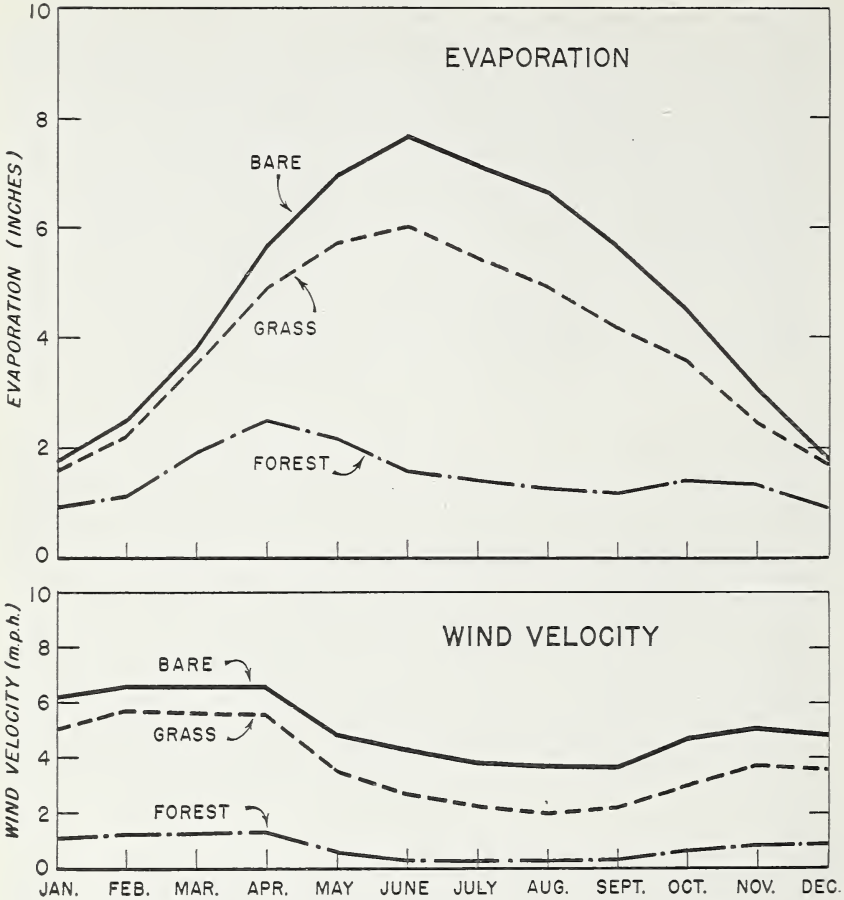

FIGURE 14.—Wind velocity and evaporation, monthly averages.

The forested areas showed considerably less wind movement (measured 2 feet above the ground) in every month of the year than the open areas. The average wind velocity measured in the forest in February, March, and April was about 1 mile per hour compared with 6 m. p. h. in the grass zone and 7 m. p. h. in the bare area.[8] In

[8] The seasonal change in wind velocities recorded in the Copper Basin is similar to the 42-year record kept by the Weather Bureau at Chattanooga, Tenn., the closest continuous wind record available (*23*). The Chattanooga record, taken from the top of a 60-foot building without obstructions, in comparison with the Copper Basin record:

	Jan.	Feb.	Mar.	Apr.	May	June	July
Chattanooga (true velocity m. p. h.)	8. 2	8. 7	8. 9	8. 7	7. 1	6. 7	6. 5
Copper Basin (station 3)	7. 3	7. 7	7. 8	7. 7	5. 4	4. 7	4. 0

	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Chattanooga (true velocity m. p. h.)	6. 2	6. 2	6. 7	7. 5	7. 9	7. 4
Copper Basin (station 3)	3. 9	4. 1	5. 3	5. 7	5. 6	5. 8

summer the wind in the forest was almost imperceptible; an average of only 0.3 m. p. h. was recorded, contrasted with 3 to 4 m. p. h. outside the forested area. In other words, during the summer the forest recorded only one-thirteenth of the wind movement measured in the denuded area, and one-eighth of that in the grass zone. In July, wind velocity in the forest was only 7 percent of that in the denuded zone, and in June, 8 percent.

These results indicate that at all seasons of the year the forest with its dense mass of foliage and tree growth has a retarding effect on wind movement and air drainage along the ground surface.

Evaporation

Records of evaporation revealed one of the most striking differences between the forest and the open areas. Monthly evaporation in the bare zone (measured from partially buried pans) was five times greater than evaporation in the forest during the summer months (table 7). During winter months evaporation in the bare zone was about twice that in the forest.[9] Evaporation in the grass belt was similar to but less than that in the bare zone (fig. 14).

In the forest the highest evaporation occurred in April, and then decreased after foliage appeared. In the bare and grass areas the greatest evaporation took place in June.

Maximum evaporation is doubtless related more directly to the radiant energy of sunlight (intensity and length of day) than to any other climatic factor. Byram and Jemison (*3*), studying solar radiation in the southern Appalachian Mountains in relation to the drying of the forest floor, found that the greatest solar radiation occurs in June, which was the month of maximum evaporation in the grass and bare zones of the Copper Basin. Within the forest, the greatest amount of radiant energy of sunlight reached the evaporation pans during April before the appearance of foliage, thus accounting for maximum evaporation during that month.

Rainfall

Of all the elements that make up local climate, precipitation is generally considered the least likely to be influenced by vegetation. However, an analysis of 4-year precipitation records indicates that like temperature, wind velocity, and evaporation, the amounts of rainfall in the three vegetative zones of the Copper Basin also differ. For example, in any 6-month period of the entire 4 years of record, regardless of the season, more rainfall was measured in the forest than in the grass or bare regions (table 8). Rainfall in the grass area was intermediate, and the bare area recorded the lowest amounts. Ten years of records taken independently by the Tennessee Valley Authority also indicate that the lowest precipitation for the Copper Basin area has consistently been recorded in the bare zone.[10]

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[9] The class O Weather Bureau pans gave 18.0 percent greater evaporation than the partially buried pan at bare station 4, and 15.5 percent and 15.8 percent respectively at grass station 5 and forest station 6. Water temperatures taken at 8 a.m., 1 inch below the water surface, showed the same general trend as minimum air temperatures, and did not correlate directly with monthly evaporation.

[10] TENNESSEE VALLEY AUTHORITY, WATER PLANNING DEPARTMENT. PRECIPITATION IN THE TENNESSEE RIVER BASIN. 1937–47. [Processed reports.]

During the 6 months beginning May 1, the average amounts of rainfall recorded for the three vegetative zones were: Forest, 23.9 inches; grass zone, 22.5 inches; bare area, 21.1 inches. During the 6 months beginning November 1, the corresponding figures were: Forest, 33.4 inches; grass zone, 30.3 inches; bare area, 29.2 inches.

Consistent differences in rainfall recorded in the Copper Basin zones are also apparent in mean monthly records (fig. 15) plotted as a 3-month moving average. (A moving average more nearly simulates a seasonal pattern to be expected over a longer period than the actual 4 years of observation.) The forest stations always recorded the highest rainfall, with the exception of September and October when

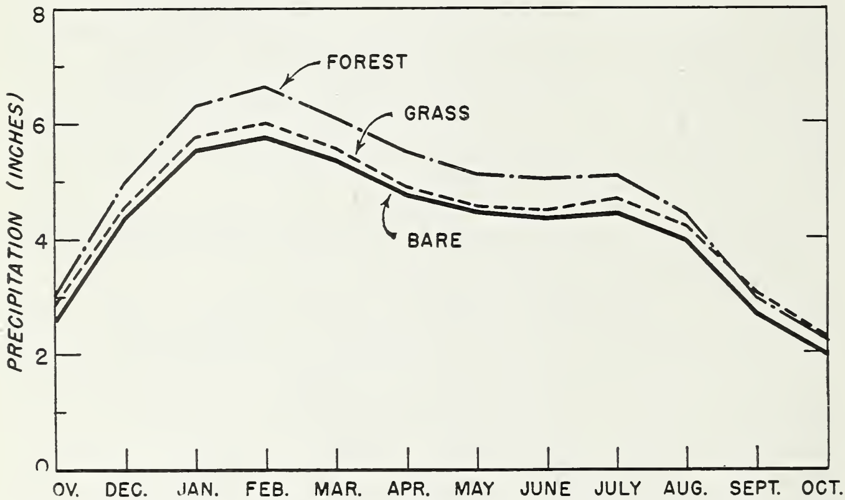

FIGURE 15.—Average monthly total precipitation from January 1936–December 1939 inclusive, shown for the water year beginning November 1. The plotted points are a moving average of 3 months.

TABLE 8.—*Average monthly precipitation on forest, grass, and bare zones, 1936–39*

Month	Forest		Grass		Bare	
	Station 1 (elev. 1,700 ft.)	Station 6 (elev. 1,720 ft.)	Station 2 (elev. 1,630 ft.)	Station 5 (elev. 1,740 ft.)	Station 3 (elev. 1,820 ft.)	Station 4 (elev. 1,710 ft.)
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
January	9. 02	7. 72	7. 70	7. 36	7. 34	7. 11
February	6. 67	5. 49	5. 58	5. 62	5. 34	5. 48
March	5. 74	5. 13	4. 64	4. 89	4. 73	4. 58
April	7. 36	6. 32	6. 39	6. 13	6. 10	5. 96
May	4. 66	3. 62	3. 30	3. 96	3. 90	3. 38
June	4. 90	3. 95	3. 72	3. 83	3. 86	3. 65
July	6. 14	6. 99	5. 61	6. 49	5. 83	5. 63
August	4. 64	4. 04	4. 64	3. 80	3. 89	3. 83
September	2. 24	2. 25	2. 45	2. 30	2. 25	2. 18
October	2. 42	2. 07	2. 62	2. 28	1. 96	1. 92
November	2. 32	2. 09	1. 85	1. 96	1. 76	1. 82
December	4. 83	4. 22	4. 21	4. 22	4. 10	4. 00
Annual average	60. 94	53. 89	52. 71	52. 84	51. 06	49. 54

the grass zone slightly exceeded the forest. The grassed area had more rain than the bare zone in every month of the year.

During the 4 years of the Copper Basin study, no unusually wet or dry years occurred. The mean annual rainfall of about 54 inches in 1936–40 at station 6 was about the same as that recorded in 17-year records (1914–30) at the smelter plant, near Copper Hill, 2 miles away. (This record furnishes the only available rainfall data ever taken in the locality prior to the Copper Basin study.) It is probable, therefore, that the rainfall data (table 8) are fairly representative of the locality.[11]

This remarkable consistency in rainfall in the different zones of the Copper Basin raises the important question whether it is due to the effects of vegetative cover, or to other factors. Examined statistically, rainfall records show that the variation due to the vegetative cover of the three zones is highly significant (table 9) ; this analysis lends support to the argument that the differences in rainfall at the six stations are due to factors other than chance.

TABLE 9.—*Analysis of variance of rainfall within forest, grass, and bare zones, 1936–39*

Source of variation	Degrees of freedom	Sum of squares	Mean square	F: Observed [1]	F: Expected 1 percent	F: Expected 5 percent
Months (M)	11	853. 7354	77. 6123	**171. 1407	2. 55	------
Cover (zones) (C)	2	17. 3726	8. 6863	**19. 1539	4. 94	------
Position (P) [2]	1	3. 9974	3. 9974	**8. 8146	7. 04	------
Years (Y)	3	46. 5882	15. 5294	**34. 2434	4. 09	------
C×P	2	4. 7001	2. 3500	**5. 1819	4. 94	------
M×C	22	6. 0869	. 2767	(1. 6390)	------	------
M×P	11	5. 6801	. 5164	1. 1387	3. 60	2. 40
C×Y	6	2. 2967	. 3828	(1. 1847)	------	------
M×Y	33	1560. 6790	47. 2933	**104. 2851	1. 56	------
P×Y	3	. 8218	. 2739	(1. 6557)	------	------
M×C×P	22	7. 5956	. 3453	(1. 3134)	------	------
M×C×Y	66	27. 4457	. 4158	(1. 0907)	------	------
P×C×Y	6	. 2905	. 0484	**(9. 3698)	6. 88	3. 67
P×M×Y	33	15. 4828	. 4692	1. 0346	1. 94	1. 59
P×M×C×Y (remainder)	66	29. 9314	. 4535	----------	------	------
Total	287	2582. 7042	--------	----------	------	------

[1] **indicate highly significant results. Parentheses indicate that the mean square shown is smaller than the error mean square.

[2] East (stations 4, 5, 6), West (stations 1, 2, 3).

[11] A 4-year record of rainfall is considered too short to justify anything but tentative conclusions. In addition to the shortness of the record, it should be pointed out that any comparative study of rainfall on small areas brings out difficulties of measurement and interpretation. In a region of frequent summer thunderstorms, it is not at all unusual for a sizable storm to miss completely one or another station. In spite of these recognized limitations in rainfall measurements, scattered occurrence of storms on the whole seems to have balanced out well for all stations, and records for different zones of the Copper Basin have all been of the same general magnitude.

Aside from vegetation, the factors most likely to influence rainfall locally are the immediate topography, exposure, elevation of individual stations, and the presence of mountain ridges in the proximity of the basin. Topography and elevation influence the amount and distribution of rainfall in the southern Appalachian Mountains, and whether topography at the different stations in the Copper Basin is a determining factor cannot be definitely proved from the present data. It is quite possible that surrounding topography, even at some distance from the station, may be of greater importance in rainfall distribution at different observation stations than the nature and extent of the bare zone itself. This would appear to be especially true for forest station 1, which recorded the highest rainfall; it lies near slopes rising gradually to a height of 1,400 feet above the station. However, forest station 6, which recorded the next highest rainfall, cannot be influenced by topography because it is not associated with any distinctive orographic features.

The grass and bare stations were so located that they were influenced in about the same manner by the general topography of the basin. Consequently, precipitation differences among these four stations were less likely to result from topographic effects. However, rainfall variance among these four stations, examined independently of the forest records, showed a highly significant statistical difference with regard to vegetative cover (table 10).

TABLE 10.—*Analysis of variance of rainfall within grass and bare zones, 1936–39*

Source of variation	Degrees of freedom	Sum of squares	Mean square	F: Observed [1]	F: Expected 1 percent	F: Expected 5 percent
Months (M)	11	517. 1369	47. 0124	**271. 5910	2. 86	------
Cover (zones) (C)	1	2. 0582	2. 0582	**11. 8902	7. 48	------
Position (P) [2]	1	. 1692	. 1692	(1. 0230)	------	------
Years (Y)	3	26. 7280	8. 9093	**51. 4691	4. 44	------
C×P	1	. 2271	. 2271	1. 3120	7. 48	4. 14
M×C	11	. 9551	. 0868	(1. 9942)	------	------
M×P	11	2. 9229	. 2657	1. 5350	2. 86	2. 06
C×Y	3	1. 4340	. 4780	2. 7614	4. 44	2. 89
M×Y	33	1065. 3489	32. 2833	**186. 5009	1. 94	------
P×Y	3	. 7353	. 2451	1. 4159	4. 44	2. 89
M×C×P	11	2. 3559	. 2142	1. 2374	2. 86	2. 06
M×C×Y	33	9. 9219	. 2007	*1. 7371	1. 94	1. 59
P×C×Y	3	. 0864	. 0288	(6. 0104)	------	------
P×M×Y	33	9. 9407	. 3012	*1. 7500	1. 94	1. 59
P×M×C×Y (remainder)	33	5. 7110	. 1731	----------	------	------
Total	191	1645. 7315	--------	----------	------	------

[1] **indicate highly significant results—*significant results. Parentheses indicate that the mean square shown is smaller than the error mean square.
[2] East, stations 5 and 6; West, stations 3 and 4.

The effect of forests on rainfall has been extensively discussed in forestry literature. Numerous investigators have reported that a higher local rainfall is associated with forest cover. For example, 30 years of observation near Nancy, France, led Huffel (*7*) to conclude that stations operated at small openings within the forest recorded 30 percent more precipitation than stations operated in the open country 5 kilometers from the edge of the forest. Burger (*2*) and others criticized these findings on the grounds that the differences were probably caused by insufficient protection of the recording gages from wind in the open country. Huffel (*7*), however, was not inclined to agree with this criticism. More recently, Nicholson (*13*) pointed out the error in attempting to generalize regarding forest rainfall relations; he insisted upon the necessity of considering specific forest types and physiographic regions. However, he concluded from his own observations that in Kenya and Uganda, East Africa, "total rainfall is likely to be affected by changes in the covering of vegetation, not only appreciably, but possibly enormously."

After making a comprehensive review of the world literature on the subject, Zon (*27*) concluded that in general forests not only increase local rainfall, but they also tend to "relay" moisture from near the ocean to the continental interior by a process of temporary storage and reevaporation of moisture into the air during the growing period.

Higher wind velocities in the denuded and grassed zones were conceivably an appreciable factor in reducing the amount of rain caught in standard rain gages. However, it was during clear days that greatest wind velocity differences between stations were recorded. During storm periods there was generally much less difference in wind velocity among stations than is shown by table 7. When storms in which there was little or no wind movement were analyzed separately they showed the same degree of difference as did storms with more wind movement. The influence of wind in reducing the amount of rainfall recorded in standard gages did not appear to be the principal reason for differences among stations for the following reasons.

Grass stations 2 and 5 were located on opposite sides of the bare zone, about 4 miles apart. They recorded almost identical rainfall totals for the 4 years: 210.8 inches at station 2 on the west side of the bare zone, and 211.3 inches at station 5 on the east side. Station 4 in the bare zone recorded 198.1 inches for the 4-year period following January 1936, or about 13 inches less than either of the grass stations. At station 3, also within the bare zone, but much closer to the grass area on the northern border, 204.2 inches were recorded, or about 7 inches less than either of the grass stations. Standard gages at the grass stations had about the same opportunity to be influenced by wind as those at the bare stations; yet the latter consistently recorded less rainfall. In both zones the gages were free of interference except for enclosure fences, and were equally exposed to the wind in all directions. Thus for the grass and bare zones, wind velocity can be considered as of only minor importance in contributing to the rainfall differences recorded.

The fact that the rain gages in the forests were located in clearings surrounded by trees presents a possibility that vertical eddies in these openings drew down more rain than would otherwise be deposited there, as is the case with snow. There was no possibility of testing the effects of small openings on rain catch in this study. Forest rain station 6 was in an opening about 180 feet in diameter, whereas forest rain station 1 was in an opening measuring 600 feet by 300 feet. The surrounding tree height was about 60 feet. The amount of rain for any 6-month period was always greater in the larger opening.

As previous sections of this publication have shown, the manner in which the vegetative cover in the Copper Basin influences local air and soil temperature, wind velocity, and evaporation may be explained reasonably in terms of known physical processes. The nature of the effect of the vegetative zones on local rainfall is more difficult to interpret. However, a number of explanations may be considered.

Vegetated surfaces reflect a larger proportion of the sun's rays than does bare soil, which absorbs relatively more sunlight and radiates it back into the lower atmosphere as heat. This greater heating of the air above a denuded locality conceivably may produce a difference in air density and turbulence. The local effect would then be a vertical movement in the disturbed air layer, which reaches its maximum thickness in midafternoon on bright sunny days. On clear days, according to Gregg (*5*), this effect of land surface heating has been noticed to a height of 3,000–4,000 feet (900–1,200 meters) in summer, and 2,000–3,000 feet (600–900 meters) in winter. Pavari (*15*) found in Italy a measurable influence of local vegetation up to a height of 500 meters or more.

Conditions in the Copper Basin provide an almost ideal opportunity for producing a localized heating and turbulence of the air directly over the denuded zone. Soil and air temperatures recorded at ground surface indicate that formation of columns of heated air over the bare zone is possible. This could have an effect on local rainfall, because concentration of heat over the bare and grass zones might be sufficient on some days to start a convection movement that would result in a convective type of storm. Thus, with conditions favorable for a convective type of storm, moist warm air converging over the heated bare zone would tend to rise rapidly and to be cooled. Condensation from this effect would produce extremely localized rainfall centered around the bare zone. Observers in the Copper Basin have reported that small convection storms of limited extent sometimes occur only in the central part of the basin. In fact, records show that the only periods in which the bare zone exceeded the forest zone in amount of rainfall were those with very low total precipitation, not exceeding 1 to 2 inches for the entire month, all of which came from local convection storms.

A heated column of air over the bare zone might also exert some effect on rainfall at the approach of a warm-front type of storm, but this possible effect is believed to be slight. In this case, the warm moist air mass may be considered as overrunning, on a gentle gradient, a mass of relatively cooler dry air. Under these conditions, condensation is caused by the cooling of the moist air mass due to a gradual rise along the incline of colder air. Any condition that would influence the floor of this incline (such as a slightly warmer localized air mass from below) might tend to delay slightly the start of rainfall in that particular spot. Thus heat radiated upward from the bare and grass zones in excess of that radiated from the surrounding cooler forest areas would in theory influence the floor of this incline directly over the bare zone, and would tend to delay the starting of rain. Similarly, the fact that the air directly associated with the denuded zone is drier than the air over the surrounding forest area may affect the floor of the approaching warm air mass. Thus, if the bare and grass zones remained relatively warmer and drier than the forest area, less rain could conceivably fall within the cleared portion of the basin at the time of warm-front storms. Records to date are inadequate for any positive conclusions.

In the opinion of the writer, records indicate that vegetative zones of the Copper Basin have a slight effect upon local rainfall, but that the nature and direction of this effect is not always the same, depending upon inherent characteristics of the air mass conditions present.

Regardless of difficulty in establishing a positive or negative effect of vegetation on precipitation, it is generally agreed that the absence of vegetation does affect the relative amount of air moisture. Short-time records of relative humidity or air-moisture-saturation deficit were obtained at two stations by means of Friez hygrothermographs. From these values mean daily saturation deficit was computed by using mean relative humidity for the 24-hour period from midnight to midnight. Monthly averages of daily saturation deficit as expressed in inches of mercury at forest station 1 and bare station 3 for the 12-month period following December 1934 are given in table 11.

These show that the forest had a lower monthly average of air-moisture-saturation deficit than the grass or bare areas throughout the period of observation. The greatest contrast was found in June, July, August, and September. Comparable values of specific humidity are significantly less within the bare zone even when adjusted for higher mean temperatures at station 3. As previously mentioned, these differences in moisture present in the air might influence the beginning of condensation preceding a particular storm period. However, measurements of air moisture were taken close to the ground surface and are only indicative rather than representative of actual conditions at higher atmospheric levels.

TABLE 11.—*Monthly average of mean daily deficit in air moisture saturation,*[1] *and air temperature as monthly average of daily mean, December 1934 to November 1935*

Year and month	Forest—station 1		Bare—station 3	
	Air temperature	Moisture saturation deficit	Air temperature	Moisture saturation deficit
	°F.	*Inch mercury*	*°F.*	*Inch mercury*
1934:				
December	35. 8	0. 043	38. 4	0. 050
1935:				
January	39. 8	. 048	41. 1	. 070
February	39. 8	. 052	41. 4	. 079
March	53. 1	. 101	54. 3	. 130
April	54. 9	. 102	56. 6	. 152
May	63. 3	. 114	66. 0	. 190
June	66. 7	. 099	71. 2	. 242
July	71. 8	. 094	75. 8	. 237
August	71. 6	. 097	76. 0	. 264
September	66. 2	. 106	70. 1	. 229
October	55. 9	. 110	59. 6	. 187
November	48. 4	. 067	49. 9	. 096

[1] Values given are the monthly average of the mean daily record. They were obtained by planimetering the hygrothermograph chart to obtain an average percent saturation for the day. Air temperature was then averaged for every 6 hours beginning at 6 a. m. These average records were converted into a single daily value of moisture saturation deficit expressed in terms of inches of mercury.

As pointed out in the foregoing discussion, the influence of forest growth on local rainfall is indirect and can probably be explained only through such factors as temperature and air-moisture-saturation deficit. These factors have been shown to be characteristically different inside and outside the forest. Whether or not such differences are sufficiently great to modify the local precipitation enough to be of practical importance, or whether the modification is so slight as to be of only academic interest, remains to be determined. If the results of the Copper Basin study are even tentatively accepted to indicate that presence or absence of forest can exert a slight positive effect on rainfall, it still remains to be determined what will be the effect for areas of larger size and other cover conditions.

SUMMARY

Meteorological records were collected for three contiguous land areas that once supported a uniform hardwood forest, but now are characterized by three distinctive vegetative conditions: Forest, grass, and bare soil. Differences in air and soil temperature, wind, evaporation, air-moisture-saturation deficit, and rainfall show that each vegetative zone now possesses a distinctive local climate.

The seasonal trend of the elements of the local climate has been modified as the original forest has given way to grassland and to complete denudation. For example, during the months when vegetation is in full foliage (June through October), the mean monthly maximum air temperature was found to be from 2.1° to 3.5° F. higher in the bare zone than in the forest. During the months when the deciduous forest was not in leaf, the bare zone recorded a mean monthly maximum air temperature lower by 0.6° to 2.0°. Records also indicate that on clear summer days relatively cooler air flowing from the forest was heated as much as 2.9° as it flowed over the grass and bare zones.

Soil temperatures recorded in the bare zone and in the forest show a still greater difference than do air temperatures. During the months of full foliage the mean daily range of soil temperature at 1.2-inch depth was found to be 33.5° F. in the bare area as compared with 10.9° F. in the forest.

Wind movement, measured at the height of 2 feet above the ground, has increased from 5 to 15 times in the open as compared with the forest.

Evaporation from free-water surfaces has also increased outside the forest. During June, the month of greatest evaporation in the open, the bare area recorded 7.62 inches, the grass zone 6.00 inches, and the forest 1.58 inches. Total yearly evaporation for the three zones was found to be as follows: Bare zone, 56.95 inches; grass zone 46.19 inches; forest, 17.76 inches.

Rainfall recorded was consistently less in the bare zone than in the surrounding vegetated areas. Other more detailed monthly differences have been given in the discussion of the individual climatic elements.

These findings are useful in understanding the local climate associated with different vegetative cover conditions. As pointed out by Kotok (*10*), Hayes (*6*), Jemison (*8*), and others, one useful application of local meteorological data relates to the control of forest and grass fires by explaining local conditions that create high potential fire danger. Another application can be found in emphasizing critical climatic difficulties in revegetating bare and eroding soil in the Southern States. Techniques of planting and special measures to insure better growing conditions for plants can be developed only with full recognition of critical soil temperature ranges and of the severity of local climatic stress existing on exposed soil. The results have practical application to a number of other realistic problems of land management relating to forestry and agriculture, and to the useful employment of vegetation in modifying the local climate to man's best interest. As early as 1911, Bates (*1*) called attention to the desirability of windbreaks and shade tree plantings to improve dwelling sites and habitations in the Southeastern States. The practicability of this suggestion has been emphasized by the findings in this study.

Observations made in this study provide a permanent record of meteorological conditions as they now exist within the Copper Basin. With improved manufacturing and smelting processes, escaping fumes will possibly be eliminated in the future; and this will permit vegetation to become established again throughout the Copper Basin. The present records of meteorological conditions will then serve as a basis for future comparisons.

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