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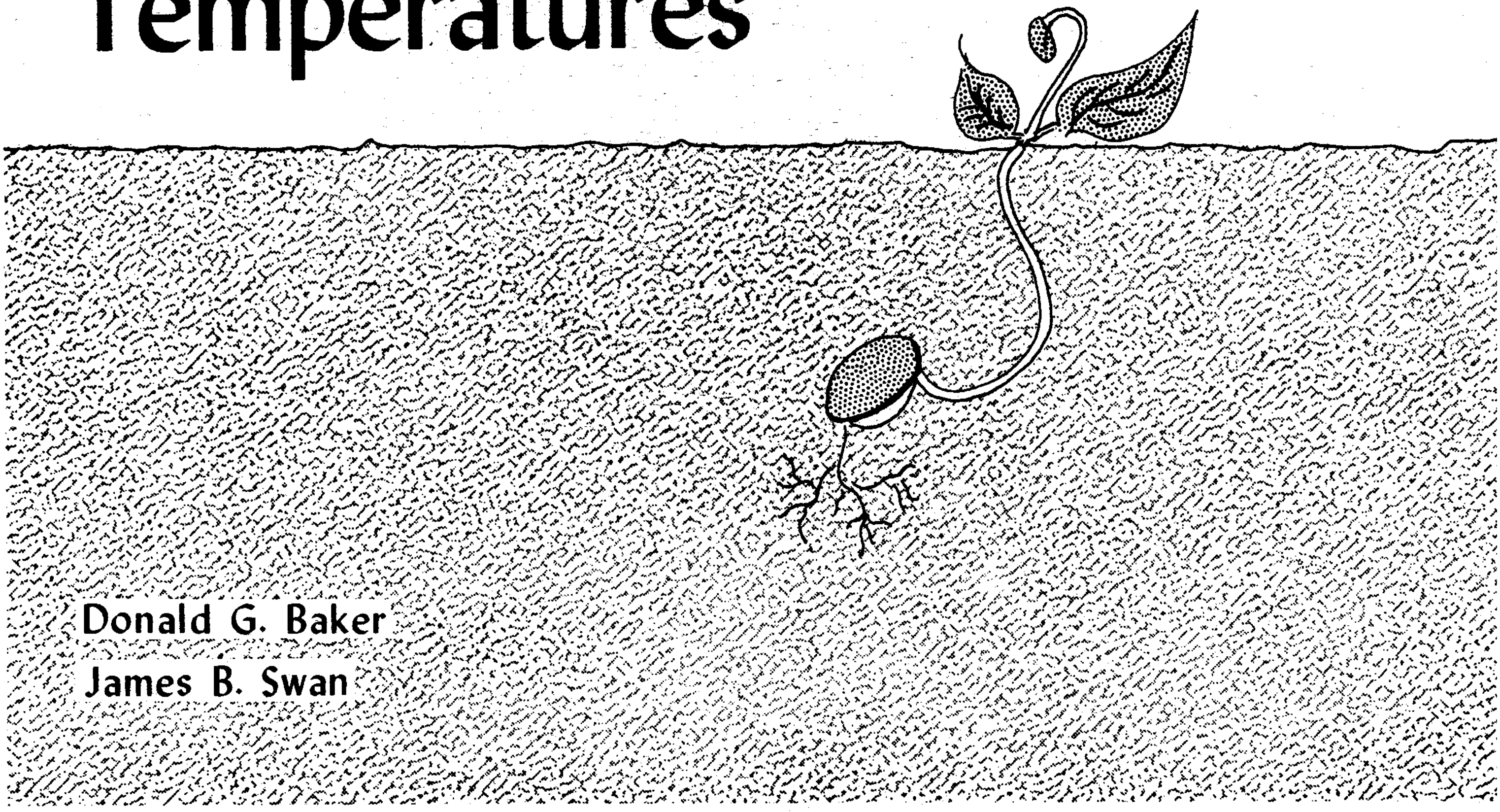
CLIMATE OF MINNESOTA

Part IV. Spring Soil Temperatures



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Climate of Minnesota

PART IV. SPRING SOIL TEMPERATURES

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SPRING SOIL TEMPERATURES ARE of great importance to agriculturists. Until the soil heats sufficiently, planting may be delayed. Seed germination and plant growth also are delayed by low spring soil temperatures. In effect, low spring temperatures shorten the spring period, decreasing the length of the growing season. A short spring is a serious matter for crops requiring a long growing period.

Furthermore, because low temperatures retard microbial activity within the soil, a temporary shortage of soil nitrogen is created. To make up for this lack, extra nitrogen fertilizer should be applied in cool springs. Retarded plant metabolism resulting from low temperatures apparently reduces nutrient uptake; therefore, applications of phosphorus and potassium are advisable also (3, 8).

Soil temperatures in Minnesota ordinarily are well below the optimum for plant growth, nutrient absorption by plants, and nutrient availability within the soil. In addition to correcting low fertility, high starter fertilizer rates are suggested to counteract low soil temperatures. Spring soil temperature probably is the most common factor in retarding plant growth in Minnesota.

Approximate optimum ranges of soil temperatures for crop growth and yield are shown in table 1. The medium temperature range (70-79° F.), on the average, first occurs only in late May in southern Minnesota. The very high temperature range (86-90° F.) ordinarily does not occur until summer.

Table 1. Optimum soil temperature ranges for growth and yield of various crops (4)*

Low temperature, 65-69° F.	Medium temperature, 70-79° F.	High temperature, 80-85° F.	Very high temperature, 86-90° F.
Barley	**Oats**	**Sudangrass**	**Corn****
Ryegrass	**Sugar beets**	**Bromegrass**	**Soybeans**
Timothy	**Wheat**	**Alfalfa**	**Sorghum§**
Peas	**Turnips‡**	**Beans**	
Potatoes	**Cabbage**	**Rice**	
Turnips†	**Tomatoes**	**Corn**[11]	

* Within each category, crops are arranged from top to bottom in approximate order of increasing temperature requirement.

† Low light period—fall and winter.

‡ High light period—spring and summer.

§ The optimum for sorghum may be greater than 90° F.

[11] Field results with varying temperature.

**Greenhouse results with constant temperature.

Since spring temperatures in Minnesota are normally below the optimum for most crops, above average spring soil temperatures usually do not create any problem. The uptake of plant nutrients generally increases with high soil temperatures. Even the increased soil evaporation and plant transpiration seldom present serious consequences because soil moisture usually can support plant growth throughout spring. To be sure, above normal temperatures can be serious but, ordinarily, not until later in the season.

Temperature variation between soils with the same cover, slope, and location is due generally to differing moisture contents. Because of water's high heat capacity, which on a weight basis is about five times greater than that of soil, water greatly influences the heat economy of soil. This influence is so tremendous that, under most circumstances, differences in color, texture, and structure can be neglected. Soil temperature usually indicates relative soil moisture content.

Soil temperature is not a common measurement. But, fortunately, it has been measured for several years at four Minnesota stations (table 2). This study is based essentially upon data from these four stations in southern Minnesota: Fairmont, Faribault, Lamberton, and St. Paul. Data for the first two were obtained from a U.S. Department of Commerce Weather Bureau publication (6). The Lamberton data were obtained through Wallace W. Nelson, superintendent of the Southwest Agricultural Experiment Station. St. Paul data were obtained from the University of Minnesota's agricultural weather station. The other material indicated in table 2 is either too brief or not available. Regrettably, no records of similar detail and duration are available from central and northern Minnesota.

Data from 4 years, 1961-64, are presently available at the Fairmont and Faribault stations; 5 years' data, 1961-65, are available at Lamberton and St. Paul. Because numerous periods of missing data exist in the Fairmont record, the degree of confidence is less in the Fairmont

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The authors wish to acknowledge the assistance of Harley J. Otto, professor and extension agronomist, University of Minnesota.

Table 2. Soil temperature data in Minnesota*

Station	Observer	Site	Instrument	Observation depth	Time of observation	Commencement date	Termination date	Data published
Blue Earth, Faribault County	Green Giant Co., Le Sueur, Minn.	Bare soil	Taylor recorder (mercury in steel)	3 in.	Continuous	1950	1960	Unpublished, (7)
Crookston, Polk County	North Central Soil and Water Conservation Research Center, ARS, USDA	Fall plowed, harvested sugar beets and alfalfa plots	Thermocouple	4-in. intervals to 5 ft. and 6-in. intervals to 7 ft.	Weekly	Oct. 15, 1964	June 15, 1965	Unpublished
Fairmont, Martin County	Radio station KSUM	Sod	Soil thermometers (glass)	3, 6, 12, 24, 36, and 48 in.	1800	Mar. 1959	To date	(6)
Faribault, Rice County	Radio station KDHL	Sod	Soil thermometers (glass)	3, 6, 12, 24, 36, and 48 in.	0700	Oct. 1960	To date	(6)
Farmington, Dakota County	Green Giant Co., Le Sueur, Minn.	Bare	Taylor recorder (mercury in steel)	3 in.	Continuous	1955	1960	Unpublished, (7)
Glencoe, McLeod County	Green Giant Co., Le Sueur, Minn.	Bare	Taylor recorder (mercury in steel)	3 in.	Continuous	1950	1960	Unpublished, (7)
Lamberton, Redwood County	Southwest Agricultural Experiment Station	Bare	Palmer dial type	2 and 12 in.	Daily maximum and minimum	Jan. 1961	To date	(6)
		Alfalfa	Thermocouple	4 and 12 in.	0800 and 1600	June 21, 1965†	Sept. 16, 1965†	Unpublished
		Barley	Thermocouple	4 and 12 in.	0800 and 1600	June 21, 1965†	July 20, 1965†	Unpublished
		Corn	Thermocouple	4 and 12 in.	0800 and 1600	June 21, 1965†	Sept. 16, 1965†	Unpublished
		Soybean (in row)	Thermocouple	4 and 12 in.	0800 and 1600	June 21, 1965†	Sept. 16, 1965†	Unpublished
		Soybean (between row)	Thermocouple	4 and 12 in.	0800 and 1600	June 21, 1965†	Sept. 16, 1965†	Unpublished
		Wheat	Thermocouple	4 and 12 in.	0800 and 1600	June 21, 1965	July 27, 1965†	Unpublished
Le Sueur, Le Sueur County	Green Giant Co., Le Sueur, Minn.	Bare soil	Taylor recorder (mercury in steel)	3 in.	Continuous	1941	1960	Unpublished, (7)
Madison, Lac Qui Parle County	North Central Soil and Water Conservation Research Center, ARS, USDA	Sod	Thermocouple	2-in. intervals to 3 ft. and 4-in. intervals to 5 ft.	0930	Oct. 26, 1964	May 24, 1965	Unpublished
Marcell Experimental Forest, Itasca County	Forest Service, Lake States Forest Experiment Station, USDA	Spruce bogs	Rüeger bimetal dial type	6 in.	Weekly	June 1961	Dec. 1962 (intermittent observations since)	Unpublished
Montgomery, Le Sueur County	Green Giant Co., Le Sueur, Minn.	Bare soil	Taylor recorder (mercury in steel)	3 in.	Continuous	1951	1960	Unpublished, (7)
Morris, Stevens County	North Central Soil and Water Conservation Research Center, ARS, USDA	Sod	Thermocouple	2-in. intervals to 1 ft., 6-in. intervals to 6 ft., and 12-in. intervals to 12 ft.	0800 except weekends and holidays	Nov. 15, 1964	May 9, 1965	Unpublished
Norcross, Traverse County	North Central Soil and Water Conservation Research Center, ARS, USDA	Bromegrass	Thermocouple	2-in. intervals to 3 ft. and 4-in. intervals to 5 ft.	Weekly	July 1962	May 30, 1965	Annual report of North Central Soil and Water Conservation Research Center, ARS, USDA
St. Paul, Ramsey County	Dept. of Soil Science, Univ. of Minn.	Bare soil	Thermocouple	0.4, 2, 4, 8, 16, 32, and 48 in.	Hourly	Oct. 1960	To date	(6)
		Soybean	Thermocouple	0.4, 2, 4, 8, 16, 32, and 48 in.	Hourly	July 1962	To date	(6)
		Sod	Thermocouple	0.4, 2, 4, 8, 16, 32, and 48 in.	Hourly	Oct. 1960	To date	(6)
				5.2, 10.5, 15.7, 21, 26.2, 31.5, 36.7, and 42 ft.	1700	1961-62	To date	(6)
St. Paul (Lake Vadnais City Water Dept. Pumping Station), Ramsey County	School of Forestry, Univ. of Minn.	Sod	Thermistors (in soil moisture unit)	6, 12, 24, 36, 48, 60, and 72 in.	Weekly	Aug. 1958 Apr. 1959 Mar. 1960	Dec. 1958 Dec. 1959 Aug. 1960	Unpublished
		Oak woods	Thermistors (in soil moisture unit)	6, 12, 24, 36, 48, 60, and 72 in.	Weekly	Aug. 1958 Apr. 1959 Mar. 1960	Dec. 1958 Dec. 1959 Aug. 1960	Unpublished
		Pine woods	Thermistors (in soil moisture unit)	6, 12, 24, 36, 48, 60, and 72 in.	Weekly	Aug. 1958 Apr. 1959 Mar. 1960	Dec. 1958 Dec. 1959 Aug. 1960	Unpublished
Stewart, McLeod County	Green Giant Co., Le Sueur, Minn.	Bare soil	Taylor recorder (mercury in steel)	3 in.	Continuous	1955	1960	Unpublished, (7)
Waseca, Waseca County	Southern Agricultural Experiment Station	Bare soil	Thermocouple	2.4 and 8 in. 20 and 40 in.	Continuous Daily maximum and minimum	Sept. 1964	To date	(6)

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* Sources of information are both personal communications and references indicated. Published data seldom begin with observation commencement date. Only the 1700 hour observations of the St. Paul data are published.

† All plots are expected to be continued in succeeding years and for a longer period during the growing season.

results than in results from the other stations. Temperature data of shallow soil depths at all stations had to be smoothed for the illustrations because a 4- or 5-year period is insufficient for eliminating the excessive daily variation that masks the general trend.

In all references to hours of the day in this report, the 24 hour clock is used. The first two figures refer to the hour, the second two to the minutes. For example, midnight is 0000 hours, 9:30 a.m. is 0930 hours, and 6:00 p.m. is 1800 hours.

Average Hourly Soil Temperatures

Hourly soil temperatures, presently available only at St. Paul, are shown in figure 1. Under bare soil, average daily temperature ranges at the 2-inch depth are 2° F., 12° F., and 18° F. for March, April, and May, respectively. Under sod the daily fluctuation averages only about 1° F., 6° F., and 10° F. for the same 3 months. Therefore, sod, never more than 4 inches in height, effectively reduces the average daily temperature range by nearly one-half. Temperature fluctuation within soil has been observed to decrease as height of cover increases.

At the 2-inch depth, 95 percent of the hourly temperature fluctuations should fall within limits shown in figure 2. Variation greater than shown would occur just 5 percent of the time. Although figures 1 and 2 are based upon only 2 years' data, they illustrate the 3-month period and give a good estimate of what may be expected.

Assume that a temperature of at least 40° F. is necessary for the growth of a particular crop. Then, on the average, this temperature is reached or exceeded under a bare soil in April during about 9½ hours of the day—from 1030 to 2000 hours (figure 2). In comparison, this temperature occurs under sod from about 1330 to 1930 or only 6 hours. Soil temperature under sod compared to under bare soil averages about 3° F. cooler in April.

The range in hourly temperatures at the 2-inch depth, as shown in figure 2, is ordinarily greatest in early afternoon and least in early morning hours.

Average Daily Soil Temperatures

The average daily progression of spring soil temperatures at the Fairmont, Faribault, Lamberton, and St. Paul stations is shown in figures 3-6, respectively. Several typical spring features are illustrated. One feature is the temperature difference between depths: (a) a small difference occurring in early March, becoming (b) even smaller in late March, succeeded by (c) an increase in the temperature difference between depths which continues until a maximum is reached in midsummer. The small temperature variation in March is also evident in figures 1 and 2.

The feature referred to in (b), the reduction in the temperature differences between various soil depths, occurs during spring thaw. Indeed, in some years, little or no temperature difference may occur to an extended depth; the soil is then virtually isothermal (of equal temperature) for 3, 4, or even 5 feet. This situation exists when the soil is thawing and melt water is standing in or draining through it. Obviously, the soil temperature of about 32° F. is nearly uniform throughout much of the soil profile.

Note the pause in the spring soil temperature increase that occurs when the soil reaches about 32° F. This lull represents the phase change from ice to water. The change requires an additional amount of heat known as the heat of fusion.

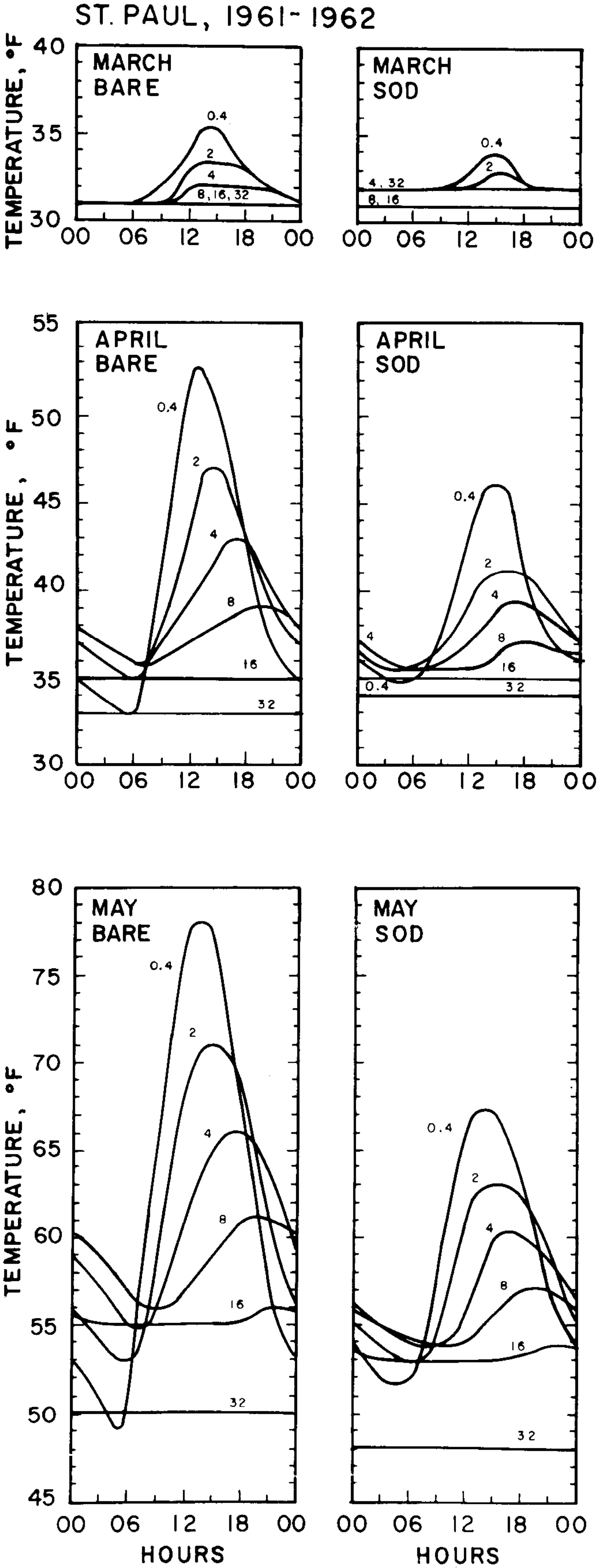

Figure 1. Average hourly March, April, and May temperatures under a bare and a sod covered soil at indicated depths in inches, St. Paul, 1961-62.

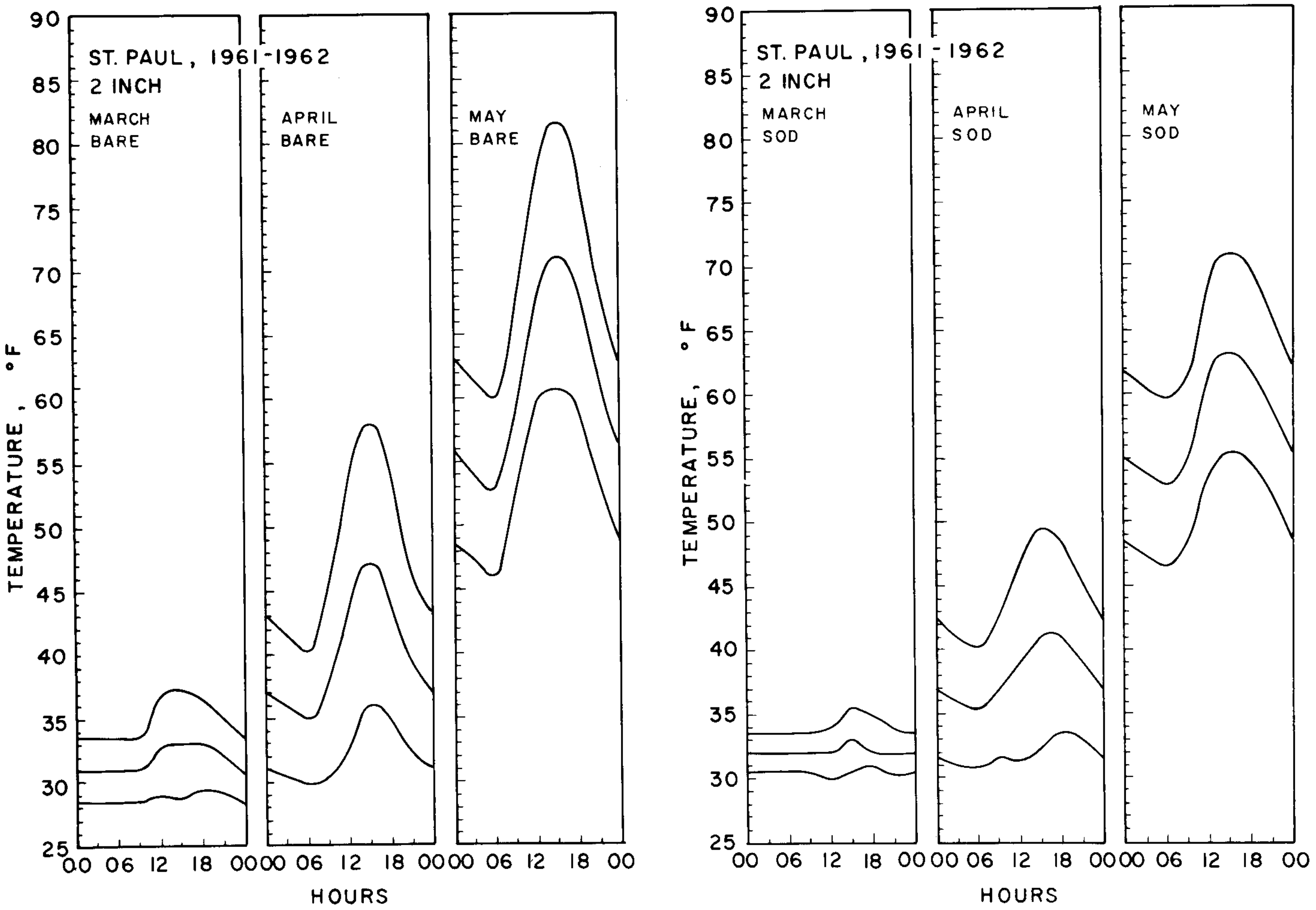

Figure 2. Average hourly 2-inch depth soil temperatures (middle line) and the 95-percent probability temperature range (top and bottom lines), under bare (left) and sod covered soil (right), March, April, and May, St. Paul, 1961-62.

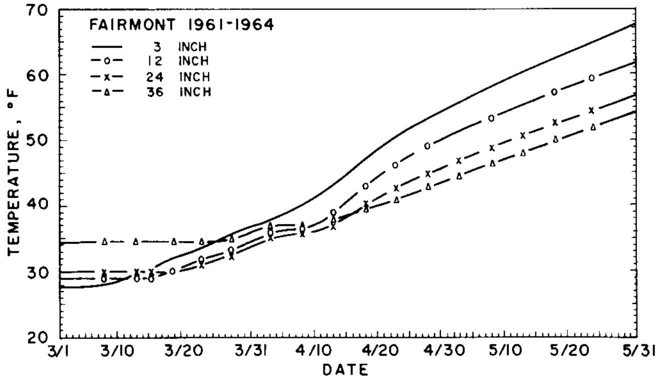

Figure 3. Average daily 1800 hour soil temperatures under sod, Fairmont, 1961-64.

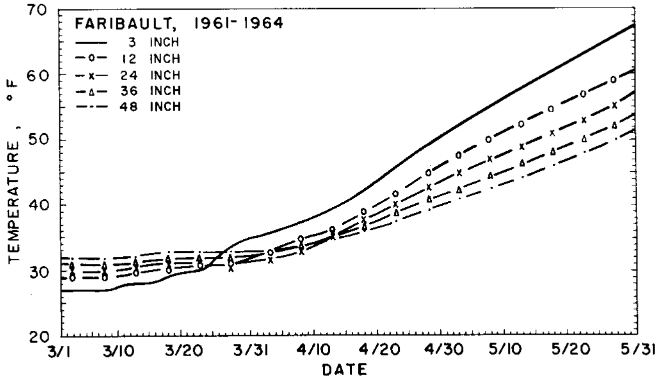

Figure 4. Average daily 0700 hour soil temperatures under sod, Faribault, 1961-64.

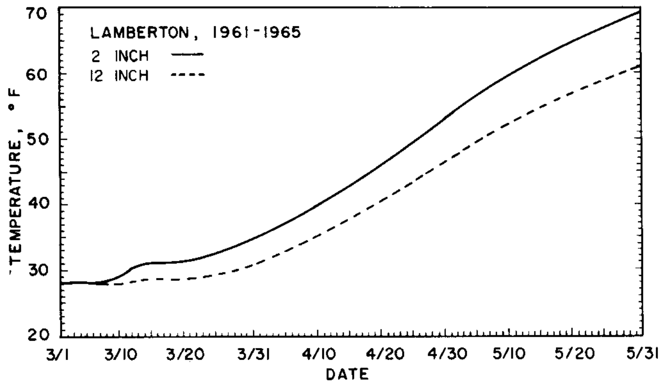

Figure 5. Average daily soil temperatures under bare soil, Lamberton, 1961-65.

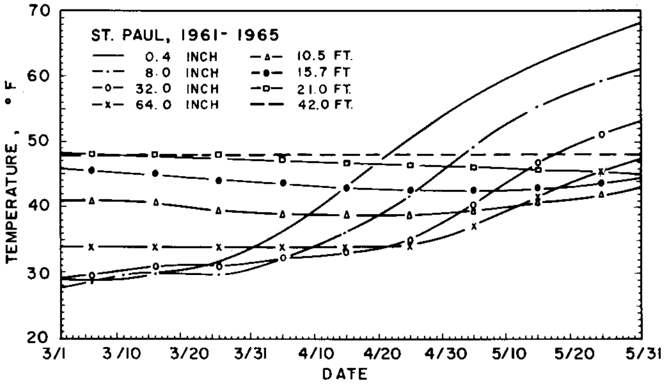

Figure 6. Average daily soil temperatures under sod, St. Paul, 1961-65.

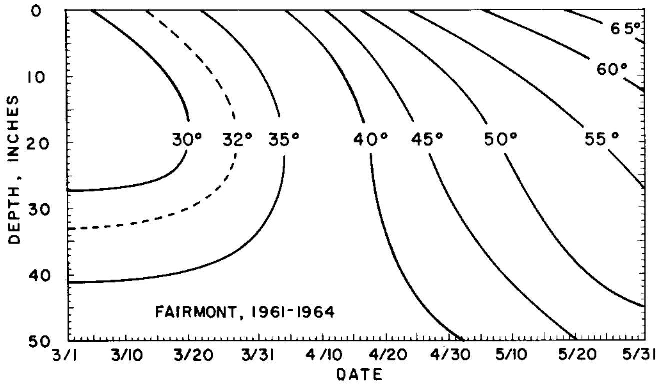

Figure 7. Average daily 1800 hour soil temperatures under sod, Fairmont, 1961-64.

Under dry soil conditions and in the presence of soil salts, the thawing or freezing point of soils may be lower than 32° F. However, measurements indicate that 32° F. is ordinarily the freezing or thawing temperature of most Minnesota soils. Once the soil thaws, an abrupt temperature increase is normal.

Another feature to observe is the temperature "overturn" that generally occurs between mid and late March. During winter and into early March, soil temperature increases with depth due to the cold and usually frozen surface soil (figures 7-9). With the appearance of spring and the warming that begins at the surface, an "overturn" occurs in the soil temperature. The upper part of the soil now remains warmer than the subsoil until a second and reverse "overturn" takes place due to the earth's cooling in autumn and winter's approach.

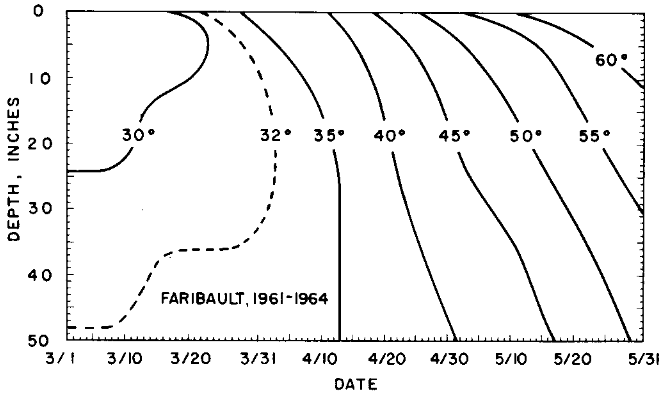

Figure 8. Average daily 0700 hour soil temperatures under sod, Faribault, 1961-64.

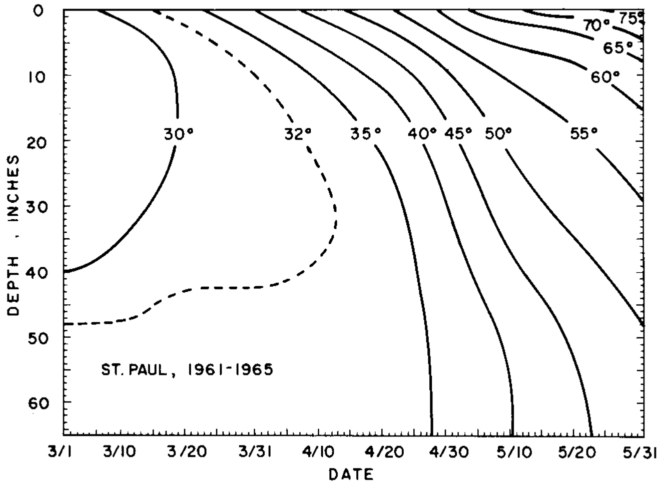

Figure 9. Average daily soil temperatures under bare soil, St. Paul, 1961-65. Temperatures below 32 inches are from sod covered soil.

The "overturn" is due simply to the temperature change in the shallow depths because temperatures at deep depths change little during a season (figure 6). The temperature at 42 feet, for example, remains nearly constant at 48° F., plus or minus about 0.5° F., throughout the year. The shallow depth is by turn warmer in summer and colder in winter.

Because figures 3-6 represent average conditions, and because the thaw period varies from year to year, some details mentioned are partially masked. They are more evident when only one season is considered.

Figures 7-9 show the average daily position of the isotherms (lines connecting points of equal temperature) within the soil at Fairmont, Faribault, and St. Paul. This method of illustration permits a ready interpolation of the temperature for depths other than those measured. These three figures show an important and useful method of illustrating the same data shown in figures 3, 4, and 6. The Lamberton record is omitted because measurements are only to the 12-inch depth.

The average date on which soils are completely thawed, assuming thawing coincides with the 32° F. isotherm, is March 24, April 4, and April 14 at Fairmont, Faribault, and St. Paul, respectively. Not until then can the snowmelt, melted soil moisture, or rainwater drain into the subsoil. As a result, soils are more susceptible to surface erosion until completely thawed. Due to the forced runoff of both snowmelt and rainwater, flooding also is a hazard. Therefore, the above dates represent the times when a flood hazard is greatly reduced.

Because the 1965 spring was so unusual, a comparison of it with average conditions at St. Paul is shown in figure 10. Shortly before the general thaw occurred in early April 1965, 4 inches of ice and approximately 9 inches of snow were on the soil surface. The water content of the ice and snow equaled more than 6 inches. Soil temperatures obviously were greatly lower than the average.

At the 0.4-inch depth the soil did not reach 32° F. until April 11—26 days later than usual. And not until May 2, 18 days later than average, did the temperature of the entire soil profile exceed 32° F. By about April 30, soil temperatures in upper levels were nearly back to normal. However, an unrelated meteorological situation developed which prevented temperatures at depths less than 6 inches from reaching the shallow soil average of 75° F. normally reached by late May.

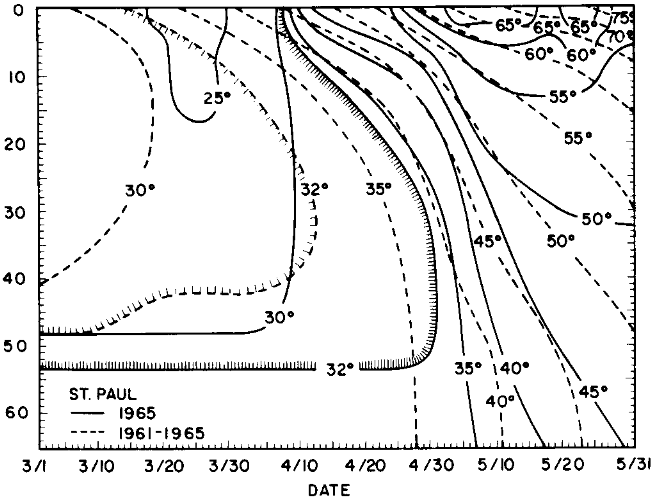

Figure 10. Average daily soil temperatures under bare soil, St. Paul, 1965, (solid lines) compared to the 1961-65 average (dashed lines). Temperatures below 32 inches are from sod covered soil.

Freezing Depth

The soil's freezing depth depends upon three main factors:

1. The winter air temperature.

2. The soil itself which includes moisture content, physical condition, and the presence or absence of vegetative cover.

Table 3. Average and extreme frozen soil depths at three stations

Station	Cover	Years	Depth (inches) Maximum	Depth (inches) Average	Depth (inches) Minimum
Fairmont	Sod	1961-64	50	33	24
Faribault	Sod	1961-64	52	45	30
St. Paul	Bare	1961-65	64	48	32
St. Paul	Sod	1961-65	60	44	32

3. Snow cover, including its presence or absence, depth, and density.

Because a snow cover after the soil is frozen is of little benefit in conserving soil heat, the time of first snowfall is critical. An early snowfall, particularly if it persists, greatly retards loss of soil heat. Freezing depth data are shown in table 3; average conditions at Fairmont, Faribault, and St. Paul are shown in figures 7-9. Since every depth was not sampled, freezing levels ordinarily were determined by interpolation between depths where temperature measurements were made.

Not until successive "shock waves" of cold air above the surface decrease with the approach of spring does the frozen soil front ordinarily stagnate or retreat. The retreat usually is gradual until about mid-April when soil temperatures change relatively rapidly. As is apparent in figure 11 and in figures 7-9, the major heat source is external; thawing proceeds essentially from the surface downward. However, a minor thawing may proceed from the base of the frozen layer upward as the configuration of the 32° F. isotherm indicates (figures 8 and 9). The 32° F. isotherm persists longest on the average at a depth of 20 inches at Fairmont, 24 inches at Faribault, and 33 inches at St. Paul (figures 7, 8, and 9).

The probable maximum depths to which soils freeze are shown in figure 12. Data upon which this figure is based are mid-February estimates and measurements from diverse sources such as gravediggers (6). Although

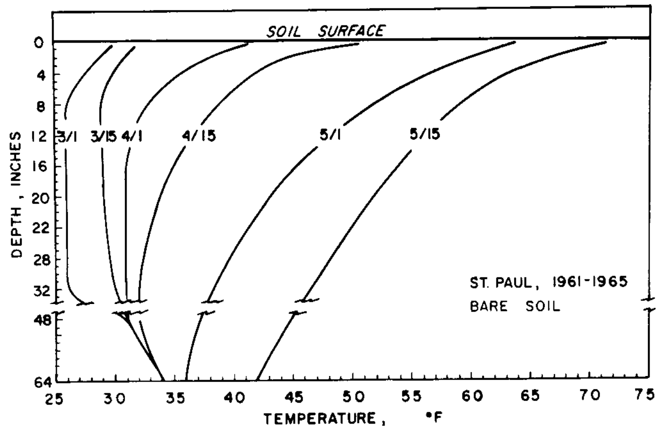

Figure 11. Average soil temperature profile at 2-week intervals under a bare soil, St. Paul, 1961-65. Note particularly the increase between April 15 and May 1. Temperatures below 32 inches are from sod covered soil.

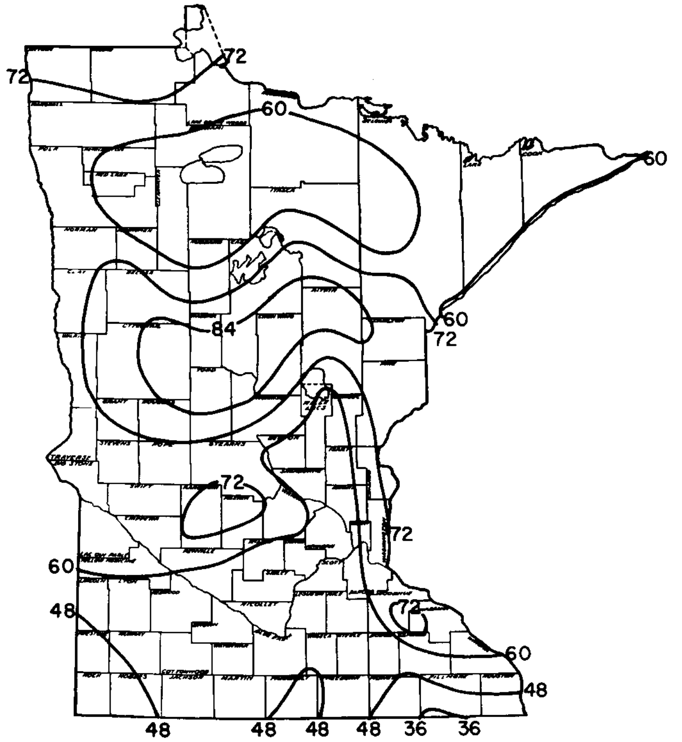

Figure 12. Maximum depths of frozen soil in inches, Minnesota, 1959-65.

some data are estimates, they agree with the Fairmont, Faribault, and St. Paul data (table 3). Extremes in the north and south also coincide with measurements at Winnipeg, Manitoba (5), and Ames, Iowa (2), where average freezing depths are about 66 and 24 inches, respectively. Minnesota data indicate that at most stations the average freezing depth is about 18 inches shallower than the maximum depth.

Because no reason can be suggested for the projection of relatively shallow freezing depths north of the Twin Cities in Mille Lacs and neighboring counties, these data should be accepted with caution. Deep depths of frozen soil in central and southeastern Minnesota coincide with regions of low winter and spring air temperatures (1).

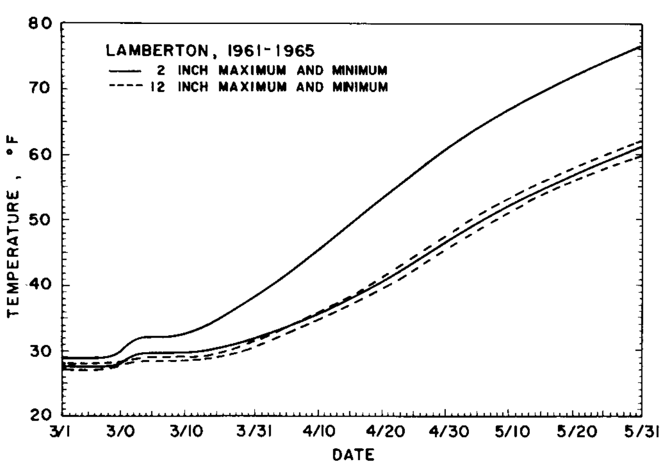

Figure 13. Average daily maximum and minimum soil temperatures under bare soil at 2- and 12-inch depths, Lamberton, 1961-65.

Temperature Lag

A feature typical of soil temperature, and not merely a spring phenomenon, is the lag in temperature with depth (see figures 1 and 6). The time interval between the surface's gain or loss of heat progressively increases with depth. In unfrozen, well drained soils, only the first 16-20 inches are affected by the daily heating and cooling cycle. The average diurnal variation in May temperatures at Lamberton decreases, for example, from about 16° F. at the 2-inch depth to only 2° F. at 12 inches (figure 13).

At a 0.4-inch depth, daily maximum and minimum temperatures lag behind the surface maximum and minimum by about 30 to 60 minutes. At 4 inches the lag is about 4 to 5 hours after noon for the maximum and 1 to 2 hours after dawn for the minimum. Beyond about a 16- to 20-inch depth the lag behind the surface temperature increases from days to even months. For example, at a 5-foot depth, the maximum temperature occurs in early September and the minimum in early April compared to late June or early July for the surface maximum and January for the surface minimum.

That there is a temperature lag with depth is of great importance when daily observations are made at depths shallower than 16-20 inches (figure 1). Only at the surface does the maximum occur shortly after noon and the minimum at sunrise. This schedule may, of course, be altered due to cloudiness and precipitation. A great disadvantage with many soil temperature measurements is that an average temperature or the maximum and minimum temperatures are not obtained. What is obtained is the temperature at a particular hour of the day. As a result, a valid comparison is difficult unless other stations take observations at the same time and the same depth.

An approximate average range of the daily bare soil temperature at 0.4 inch during spring for 8 different hours of the day is shown in figure 14. While based upon a well drained, level soil (Waukegan silt loam) at St.

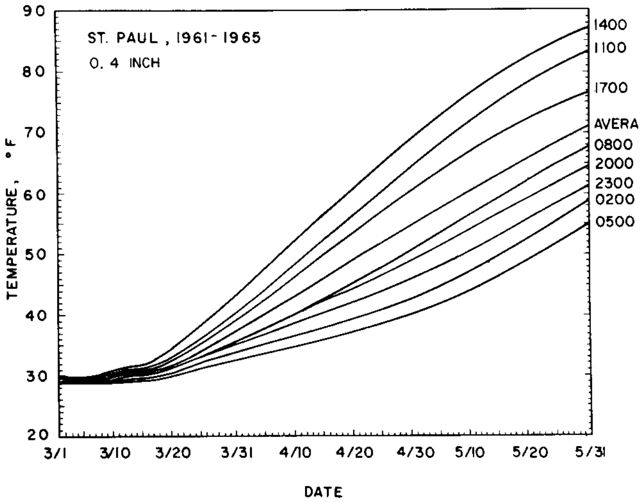

Figure 14. Average 3-hour soil temperatures at 0.4-inch depth under a bare, well drained soil, St. Paul, 1961-65.

Paul, findings probably apply to a similar situation almost anywhere in Minnesota. Figure 14 may be used to estimate the correction necessary for obtaining the average bare soil temperature when an observation is made at any hour of the day.

For example, on May 10, an observation made at 1400 hours averages about 18° F. higher than the mean. Moreover, by interpolation, the average temperature for the day can be obtained by taking a measurement at about 0900 or 2000 hours. Additional details for other depths are shown in table 4. Of course, times shown are only approximate; the deeper the depth the less critical is the time factor. On a warm spring day the surface maximum should be taken within a few minutes of 1300 hours. At the 2-inch depth, a tolerance of 15-30 minutes before or after the indicated time is usually satisfactory. At the 12-inch depth, the daily temperature variation is so slight that a tolerance of several hours is permissible.

Table 4. Approximate time of occurrence of maximum, average, and minimum temperatures in a well drained, bare soil at St. Paul

Depth	Maximum temperature occurrence	Average temperature occurrence	Minimum temperature occurrence*
inches		hours	
Surface	1300	0830, 1830	0500
0.4	1400	0900, 1900	0530
2	1530	1000, 2000	0600
4	1700	1130, 2100	0700
8	1900	1430, 0000	0900
12	2300	1800, 0300	1200

* The minimum surface temperature normally occurs at about dawn. From March 1 to May 31, sunrise varies from 0650 to 0430. For simplicity, sunrise is assumed constant at 0500.

Influence Of Cover And Precipitation

The influence of vegetative cover upon spring soil temperatures is shown in figures 1 and 15. Evidently, vegetation has a cooling effect upon soil. In late winter and very early spring, snow, if present, remains longer on soil covered with vegetation than on bare soil because vegetation traps more snow. Snow also insulates the soil and greatly retards soil heating. Once snow disappears the vegetation itself acts as an insulator and retards soil heating. The vegetation also absorbs a large proportion of the incident radiation—radiation reaching the absorbing surface. Most of the absorbed radiation is then consumed in evapotranspiration and the remainder is used to heat the air and soil. In comparison, the energy incident upon bare soil is consumed almost entirely in heating the air and soil. Therefore, a greater share of energy is available to heat bare soil than a soil covered with vegetation.

As the spring season progresses, the temperature difference between the two different covers increases (figure 15). The depth to which the difference in cover affects the soil temperature also increases. By late May, this difference can be measured to a depth greater than 32 inches between even a bare and a sod covered soil (figure 1). The kind, density, and height of vegetation greatly affect these differences.

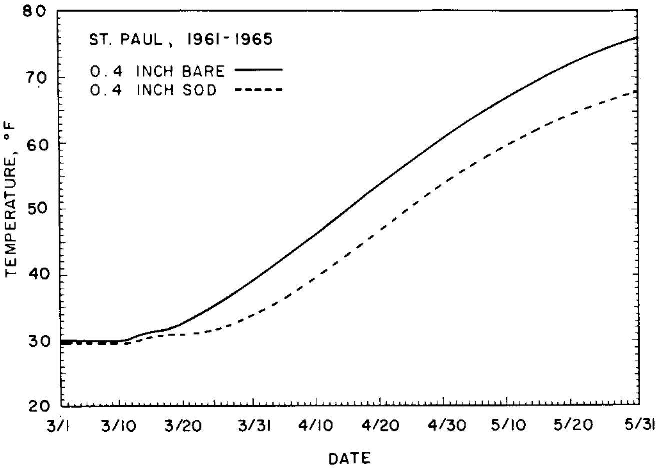

Figure 15. Average daily soil temperature at 0.4-inch depth under bare and sod covered soil, St. Paul, 1961-65.

As indicated earlier, snow is an effective insulator of both heat and cold. As long as snow is present, the soil can warm only gradually and cannot rise higher than 32° F. This situation is evident in figure 16—the ground was snow covered through March 30 and again from April 12 to 16.

Of course, snow also acts as an insulator in the other direction and greatly retards heat loss (figure 17). On the morning of March 1, 1962, approximately 9 inches of fairly fresh snow were on the ground. The measured air temperature was —21° F.; within the snow 4 inches

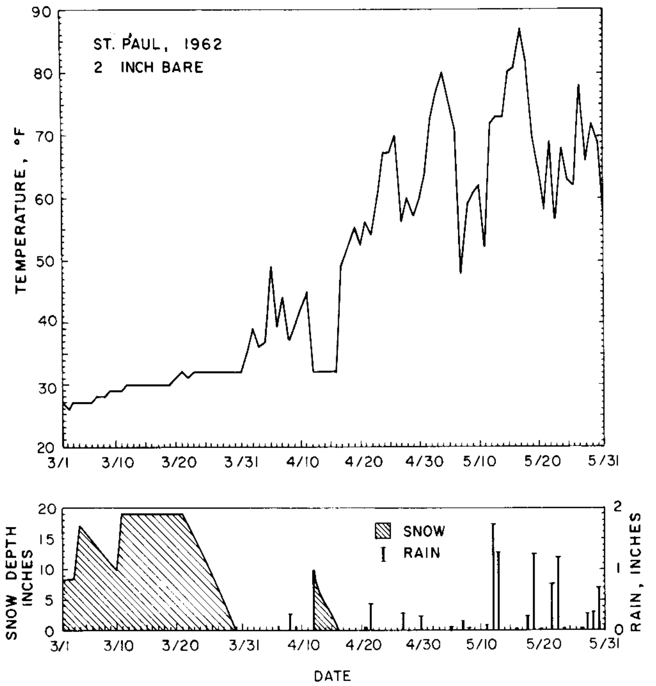

Figure 16. Daily temperature at 2-inch depth under bare soil (top) with the snow depth and rainfall as indicated (bottom), 1700 hours, St. Paul, 1962.

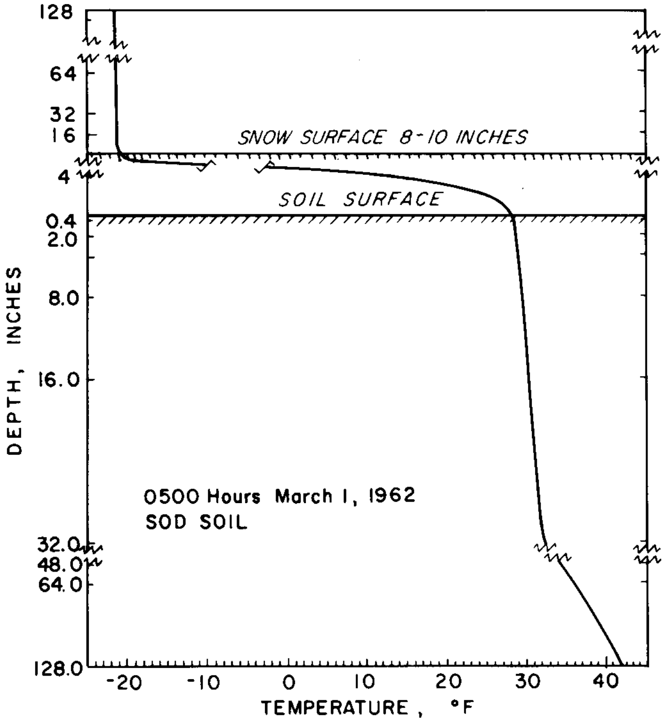

Figure 17. Soil (under sod) and air temperatures at 0500 hours, St. Paul, March 1, 1962.

above ground, the temperature was 12° F. At 0.4 inch below the soil surface the temperature was nearly 29° F. Temperature gradually increased with depth to 42° F. at 10.5 feet. Between the air above the snow surface and 0.4 inch below the soil surface—a distance of only 9.4 inches—there was a temperature differential of about 50° F. Incidentally, due to the early and heavy snowfall of the 1961-62 winter, soil temperatures at St. Paul never dropped below 21° F., the highest shallow soil winter temperature observed in 5 years.

Figure 16 illustrates the influence of both snow and rain upon soil temperatures. Note how daily temperature fluctuations result from rainfall once snow disappears. The cooling effect of rain is due to two things:

- The temperature of the rain itself, normally much lower than soil temperature.
- The evaporation from the soil surface that occurs after rainfall.

The latter, although not as immediate in effect, is the major cooling factor.

Estimating Soil Temperature

Estimating soil temperature from air temperature is perhaps less difficult during spring, once the soil thaws, than at any other season. Figure 18 shows the relationship between the average daily air temperature and an average daily 3-inch depth temperature under bare soil at Faribault. Figures 19 and 20 illustrate this relationship with the 2-inch average daily temperature at Lamberton and St. Paul, respectively. At all three stations the air temperature is several degrees colder than the soil temperature at the 2- and 3-inch depths during early March and May but warmer during late March and April.

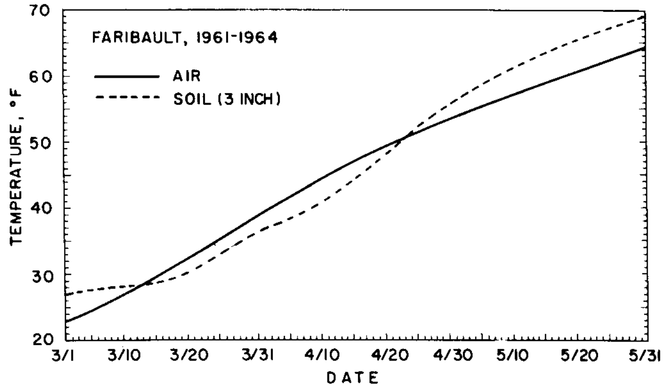

Figure 18. Average daily soil (3-inch depth under sod) and air temperatures, Faribault, 1961-64.

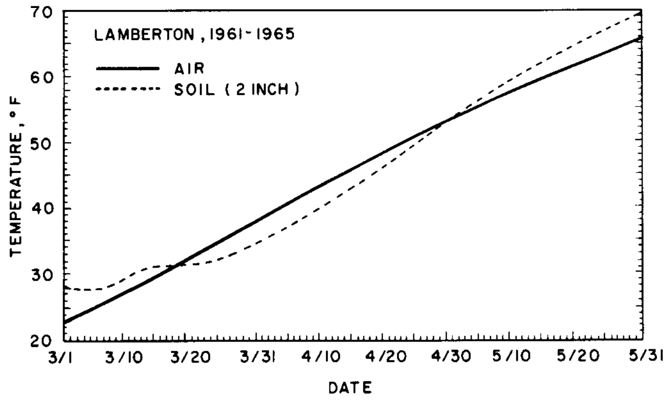

Figure 19. Average daily soil (2-inch depth under bare soil) and air temperatures, Lamberton, 1961-65.

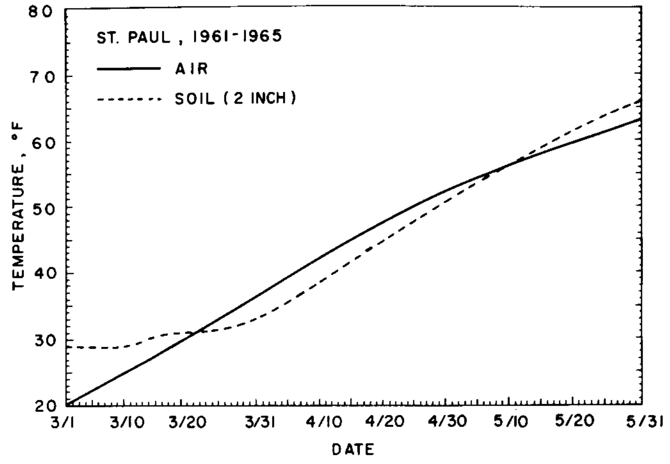

Figure 20. Average daily soil (2-inch depth under sod) and air temperatures, St. Paul, 1961-65.

But averages can mask real differences. Figure 21 shows that after the soil thaws, the correlation between air and soil temperatures remains high. However, on any single day the difference may be great. Therefore, a better estimate of soil temperature is made if the mean

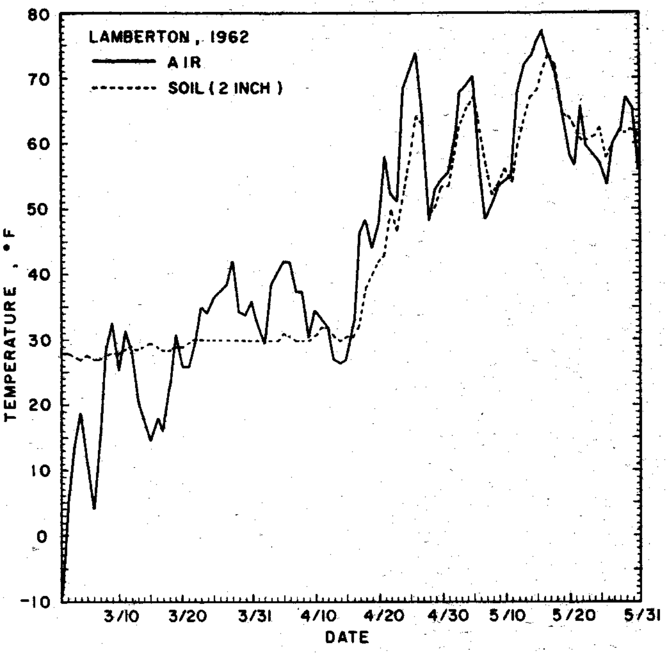

Figure 21. Average daily soil (2-inch depth under bare soil) and air temperatures, Lamberton, 1962.

air temperature of several days is obtained and then averaged.

Figure 21 also shows the damping effect of soil upon temperature change. The variation of the average temperature from 1 day to another at the 2-inch depth is usually several degrees less than the variation in the air. This situation also is true concerning hourly soil and air temperature variations. Under a vegetation covered soil the damping effect upon temperature variation, of course, is even greater than with a bare soil (figure 1).

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