Soil Temperatures in Indiana[1]

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Abstract

Soil temperatures were summarized from an Indiana network of 12 stations. Soil temperature observations were begun in 1960 by the Agronomy Department of Purdue University and the National Oceanic and Atmospheric Administration, formerly the Weather Bureau. Temperature relationships were shown for the day-month-year, at various locations, to depths of 40 inches. Comparisons were made between major soil textures in Indiana including the muck and sandy loam soils near Wanatah where like weather conditions prevail. The Palmer Model 35E, mercury-in-tube driven, maximum-minimum dial-type thermometers were read daily to obtain diurnal temperature extremes.

Introduction

In the application of science to agriculture it is important that temperature levels be understood in detail at the earth-atmosphere interface. The environmental temperatures a few inches below the soil surface, as well as a few inches above, are of paramount importance in the understanding of total biological activity. Soil temperatures are particularly important in determining plant growth, insect activities, and the development of diseases. To advance our knowledge in these areas a network of soil temperature stations was started in 1960. The Purdue University Department of Agronomy purchased and installed the instruments. The National Weather Service agreed to review the reports and publish them in *Climatological Data—Indiana* (3) along with other meteorological data originating at the same sites. A portion of the data was also published in the Indiana Weekly Weather and Crop Report (4) during the growing season. In the first state network the Palmer dial-type thermometers were exposed at a depth of 4 inches under grass. A later expansion of the network resulted in thermometers at depths of 1, 2, 4, 8, 20, and 40-inch depths under bare soil. These expanded soil temperature stations were and are located at Purdue Agricultural Research Centers. The selected depths conform to the choices of the World Meteorological Organization. Table 1 lists the stations and data pertinent to them.

Soil temperature data are used by various interests both in and outside of Agriculture. The most obvious application is in providing information on freeze depth and duration with respect to location and time of year. Another concerns the freeze-thaw cycle near the surface.

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Alternate freezing and thawing is very destructive to wintering crops, particularly alfalfa. The plant roots are often heaved out of the ground, particularly in unglaciated Southern Indiana. Trafficability over the soils in the winter can also be estimated from knowledge of duration and depth of soil freezing. The volatility of nitrogen fertilizers in soils above 50°F (20°C) can be minimized by spreading only when soil temperatures are below this temperature. Soil temperatures in the spring control seed germination and are important considerations for determining planting times.

TABLE 1. *Soil temperature stations.*

Station	Latitude	Longitude	Elevation in Feet	Soil Type
Columbia City	41°08′	85°29′	854	Blount Silt Loam
Culver	41°10′	86°28′	730	Coloma Sandy Loam
Dubios	38°27′	86°42′	690	Zanesville Silt Loam
Farmland	40°15′	85°09′	965	Pewamo Silty Clay Loam
Johnson	38°16′	87°45′	440	Oaktown Loamy Fine Sand
New Augusta	39°54′	86°16′	875	Crosby Silt Loam
Oolitic	38°53′	86°33′	650	Bedford Silt Loam
Terre Haute	39°21′	87°25′	555	Vincennes Silty Clay Loam
Wanatah (Sand)	41°26′	86°56′	735	Tracy Sandy Loam
Wanatah (Muck)	41°26′	86°56′	715	Edwards Muck
W. Lafayette	40°28′	87°00′	706	Russell Silt Loam

Soil temperatures at depths greater than 20 inches are of interest to those wanting to utilize the soil as heat sinks for cooling and heating houses, piping heat or cooling fluids through pipes placed in the soil. Another example concerns the storage of fluids in tanks at depths where soil temperature must be taken into account. Many other applications of soil temperatures are assured as environmental control technology develops.

This paper summarizes some relationships between soil temperature depth, station location and soil type as related to diurnal and seasonal temperature changes. As in air temperature there is more interest in the daily highs and lows than in the daily mean. A daily average limits much of the utility of soil temperature applications.

The work of Carson and Moses (1, 2) at the Argonne National Laboratory has considerable application to soils in Indiana. Newman has shown how soil temperatures follow seasonal patterns and that weekly normals of temperature can be obtained from relative short length of records using Fourier analyses in an unpublished progress report entitled "Predicting Diurnal and Seasonal Temperatures at Varying Depths Within Soil Profiles."

Methods

The Palmer soil thermometer, Model 35B, is used throughout the state. The dial-type thermometer has a pointer activated by a mercury filled sensor about a foot long. The rod-shaped sensor is buried horizontally in the ground at the proper depth. As the pointer moves to the left with falling temperature another pointer is moved and remains at the lowest value during the period. With rising temperature, a third pointer is pushed to the right and remains to show the maximum value during the period. The pointers for the lowest and highest are reset to the drive pointer at each daily reading. The thermometers are housed in a wooden box at a level convenient for opening and reading.

In this paper, daily minimum temperatures were averaged for each month. The values for each month were then averaged for a length of record mean. The same was done with daily maximum temperatures. The period of record used in this summary ranged from 5 to 10 years with the record for 4-inch depths under grass being the longest.

Discussion of Results

The location and description of stations for which soil temperatures are reported are given in Table 1. The daily maximum and daily minimum temperatures, respectively, at a depth of 4 inches under grass at stations in northern and central Indiana are compared in Figure 1, A and B. Wanatah in the NW area of the state was 1 to 4°F cooler than stations farther south. The warmest station was Columbia City despite its northerly location. The unexpected warmth may be due to greenhouses a few yards on the west and south. The exposure is more sheltered than are other stations studied. The same comparison is made in Figure 2, A and B, for central and southern stations. As expected, southern stations are the warmest in the state. From north to south then, average daily maximum temperatures at the 4-inch depth under grasses ranged from 74°F at Wanatah to 84°F at Evansville in July, and from 30 to 36°F in January. The range of average daily minimum temperatures was from 68 to 79°F in the summer and from 29 to 35°F in late winter. Note that Johnson is somewhat warmer than Dubois. At Johnson, thermometers are in Oaktown loamy fine sand, while at Dubois, thermometers are in Zanesville silt loam. Also, there is an elevation difference of 250 feet. Dubois is higher with an elevation of 690 feet above mean sea level.

A comparison of temperatures at different depths at Johnson and Dubois is depicted in Figure 2, C and D. The most obvious observation is the warmth of the sandy soils at Johnson particularly in the shallow depths. The daily maximum temperature in summer at Dubois averaged 88°F at the 2-inch depth under bare soil while Johnson averaged 98°F. At the 8-inch depth, temperatures were about 10°F lower and differences between the two stations were of the same magnitude. There was a great spread of the maximum temperatures from the shallow 2-inch level to the deeper 8-inch level, compared with the minimum temperatures during the summer months. Minimum temperatures were more similar. Sandy soils warm much faster in the spring. At these southern stations neither the minimums nor the maximums averaged 32°F or less during any one winter month except the minimum at the 2-inch depth at Dubois.

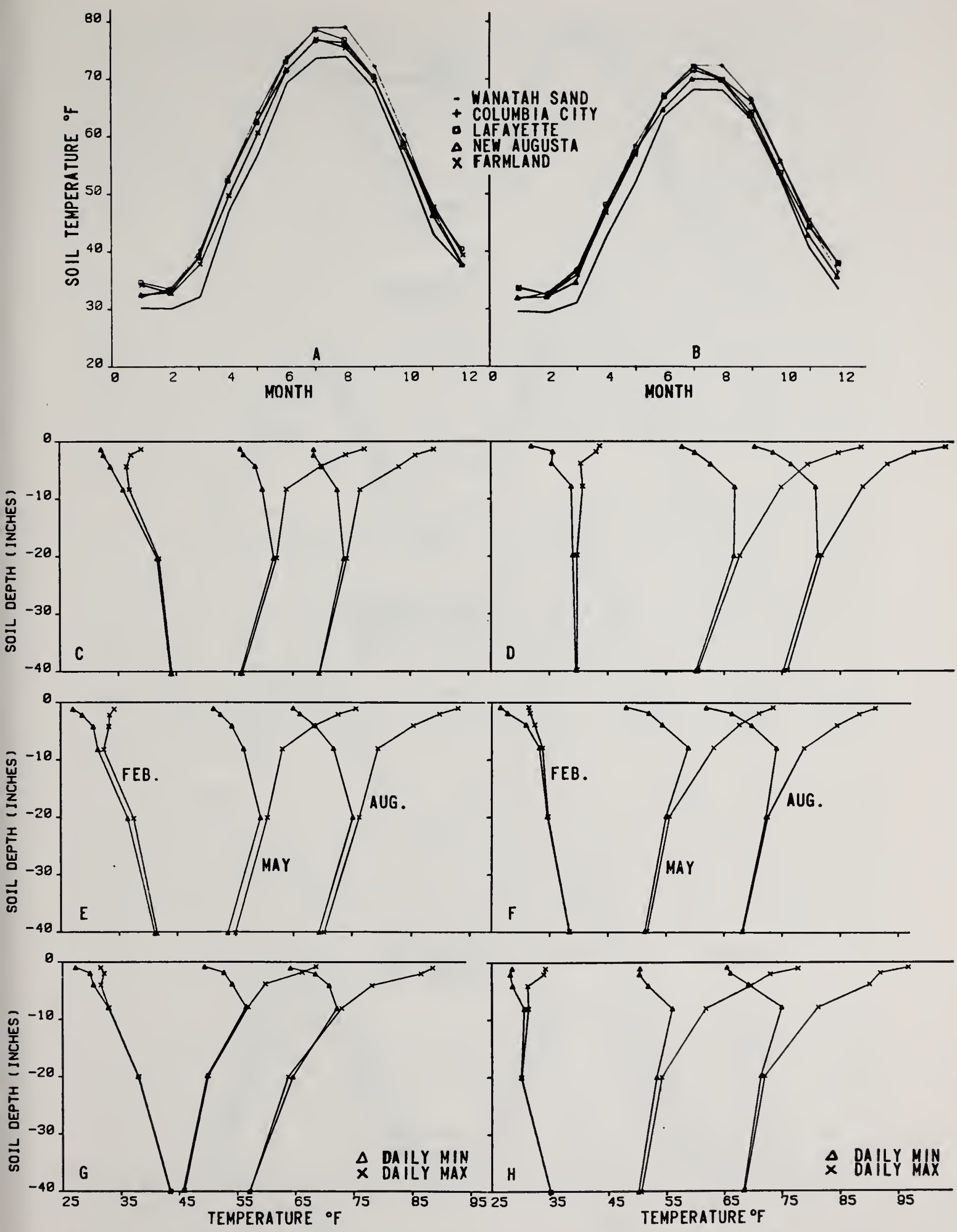

FIGURE 1. *Soil temperatures. A. Daily maximums, 4-inches deep under grass. B. Daily minimums, 4-inches deep under grass. C. Dubois temperatures in bare soil. D. Johnson temperatures in bare soil. E. Lafayette temperatures in bare soil. F. Farmland temperatures in bare soil. G. Wanatah temperatures in bare muck soil. H. Wanatah temperatures in bare sandy loam.*

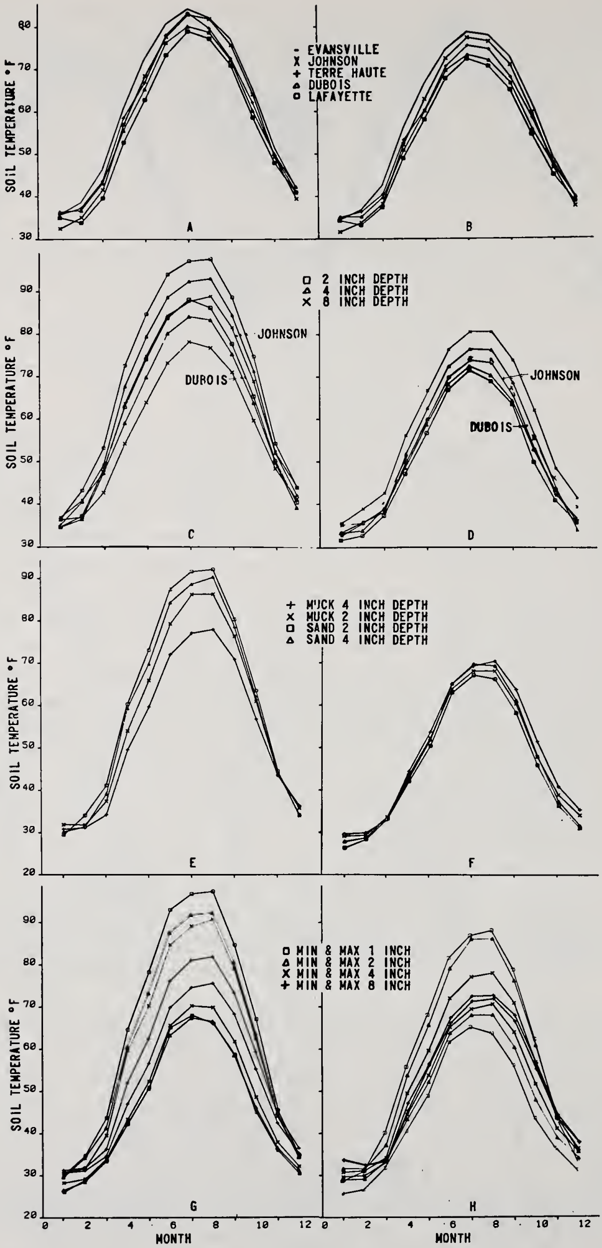

FIGURE 2. *Soil temperatures. A. Daily maximums, 4-inches under grass. B. Daily minimums, 4-inches under grass. C. Daily maximum in bare soil. D. Daily minimum in bare soil. E. Daily maximum in bare soil. F. Daily minimum in bare soil. G. Wanatah, bare sandy soil. H. Wanatah, bare muck soil.*

Another type of temperature presentation is shown in Figure 1, D for Johnson and Figure 1, C for Dubois. A dominant feature was the increase of the diurnal temperature range at the shallow depths from February to August. The increase was less in the soils at Dubois. At the depth of 40 inches the sands at Johnson were warmer by 6°F in August and cooler in February by about 5°F than the soils at Dubois. This reflects the fact that sands are better conductors of heat and their thermal capacity is less so they warm or cool deeper and faster.

In Figure 1, E and F, the bare soil temperatures for the months of February, May and August for Lafayette and Farmland are shown. These months were selected because of their importance in applications. Farmland has a higher and "tighter" soil known as Pewamo silty clay loam. At Lafayette the thermometers are in Russell silt loam. Bare soil temperatures at the 20 and 40-inch depths are a little lower at Farmland which is in keeping with climatic differences. The daily range at the 8-inch depth is greater at Lafayette than Farmland while the minimums are cooler at Lafayette.

The importance of microclimates and drainage is demonstrated at the two soil temperature stations at Wanatah in the northwest area of Indiana near Lake Michigan. These stations are located at the Pinney-Purdue Agricultural Center. They are only 360 yards apart but have quite different soils. The two soils are Edwards muck and Tracy sandy loam. The muck station is 20 feet lower in elevation. When comparing soil temperature at these two stations it can be assumed the macro and meso scale weather was uniform at the two sites. This leaves the microclimatic effects, caused by terrain drainage and soil differences, to explain the variations of soil temperature at the two locations.

In Figure 1, G, the muck soils are seen to remain warm in the winter and cool in the summer compared to the sandy loam soils a short distance away, Figure 1, H. The maximum temperatures of the sands were also higher, giving greater daily ranges of temperature than in the muck soils, particularly in the summer. At 40 inches in August, the sand was 68°F and the muck soil was 57°F; in February the muck was 43 and the sands were 35°F, primarily because the thermometers are in the water table at the muck station.

Temperatures at the shallow depths at these two stations are shown in Figure 2, E and F. As to be expected the sands were warmed in midsummer during the afternoon (maximum temperatures), but at night the minimums were slightly lower. The maximums at 2-inches in sand were 14°F higher than the maximums at 4-inches in muck. Truly a remarkable difference in soil temperature environment a few yards away and in a different soil. In January or February they all converged in the range of 25 to 32°F.

The fluctuation of temperatures at all four shallow depths (1, 2, 4, and 8 inches) is depicted in Figure 2, G and H. In summer the sands had tremendous daily temperature ranges while temperature ranges in the muck soils were much more conservative. The smaller daily range in the muck soil was evident for any given depth. The minimums were lower at shallow depths compared to those at greater depths, a fact long recognized by builders in planning depth of footings.

Concluding Remarks

In these charts the radiational heat flow into the soil in summer and from the soil in winter can be seen in the convergence of the temperatures in the late winter and temperature divergence in the spring and summer. Measuring soil temperatures allows one to quantify the development of spring as well as to determine how the growing season is progressing relative to normal.

The mean duration of frozen soils at various depths in the winter can be estimated by noting the 32°F level on many of the charts. Soil temperatures in Indiana at shallow depths remain in the low 30's much of the winter. Latent heat, as soil water changes from liquid to solid and back, accounts for persistence in temperatures near 32°F. Indirectly some indications of trafficability of the soils can be obtained by noting the depth of freeze and duration, however, a much more complete analysis of these data is required to answer such questions.

The general dates for any threshold temperature can be estimated from the seasonal temperature marches. For example, from Figure 2, E, at Wanatah the daily high of soil temperature at 2-inches averaged less than 50°F beginning the second week of November when liquid fertilizer can be spread without great loss. Determination of threshold dates critical for farm operations will become more common as we learn more about environmental-biological response mechanisms.

Acknowledgements

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