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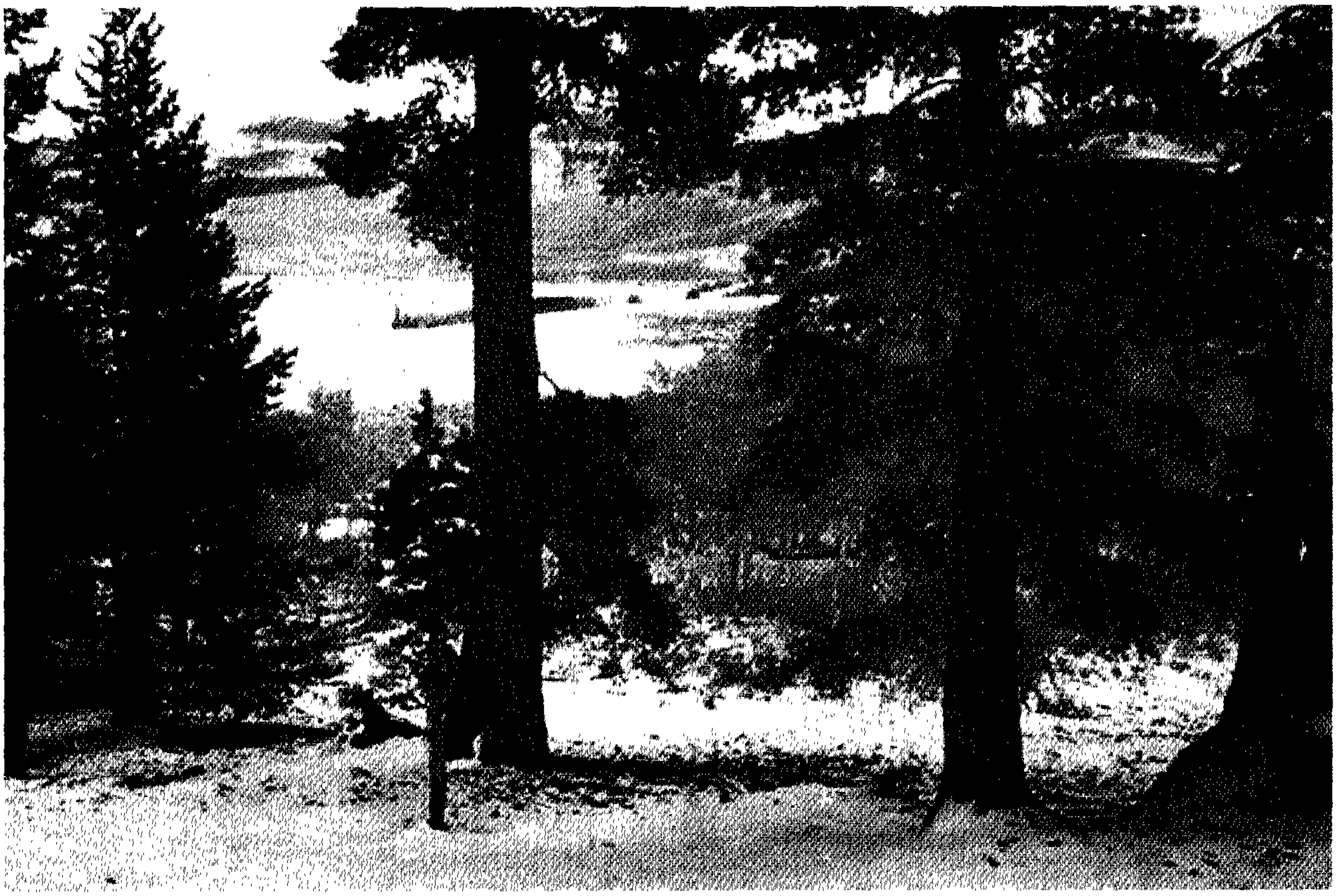
The Temperature Regime for Selected Soils in the United States

National Soil Survey Center, Lincoln, Nebraska



Soil Survey Investigations Report No. 48

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Cover photo: The vegetative cover near a temperature site in Mono County, California. The soil in the aspen thicket is at an elevation of 2,645 meters (8,675 feet) and has a cryic temperature regime.

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Foreword

The National Soil Survey Center (NSSC) has actively pursued the collection of soil temperature data since 1990. The Global Change Initiative of 1990 authorized research authorities in two arenas for NRCS soil scientists: 1) Organic carbon and its sequestration and 2) Soil climate, including moisture and temperature.

Studies in this investigations report ran from 1 to 2 years. For instance, the eight-station network on Edisto Island, South Carolina, began in 1996 and closed in 1998. The mean annual soil temperature during the second year was within 0.1 ºC of the first year. This research effort reinforces our current belief that scientists do not need to collect soil temperature data for long periods of time to understand most seasonal and annual temperature relationships.

This soil survey investigations report summarizes results from 33 studies in the United States and its territories. These studies resulted in many important findings. In addition to this report, complete metadata with air and soil temperature summaries for 200 sites can be found on the NSSC Web site at www.statlab.iastate.edu/soils/nssc/temperature/rstn1.htm.

As scientists, we seek to understand fundamental relationships, i.e., the relationship of air temperature to soil temperature, the relationship of elevation to soil temperature, etc. Valid interpretation of soil temperature data, like that of any laboratory data, requires detailed analysis of nonbiased samples by well tested methods.

Many scientists in the Soil Survey Division assisted in the site selection and installation of data loggers for this report. These include scientists from the National Soil Survey Center, NRCS soil scientists from 25 states, NCSS cooperators from state universities, scientists from the U.S. Forest Service and the National Biological Survey, Long-Term Ecological Research staff scientists at Niwot Ridge, and the South Dade County Soil and Water Conservation District in Homestead, Florida. The extra effort by these employees is a testimony to the pursuit of science as we begin the new millennium.

Berman Hudson
Director
Soil Survey Division

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Chapter 1

The Importance of Soil Climate

Early Russian scientists, including A.I. Voikov, V.V. Dokuchaev, I.V. Michurin, V.R. Vil'yams, and K.A. Timiryazev, believed that humans could modify natural processes, including the climate of the air layer near the ground and of the surficial layers of the soil itself. Though this did not come about in Russia, such modification is feasible. The Russian scientists of the 1930s introduced the term "soil climate." Many pedologists and climatologists use this term to refer either to the moisture and temperature regimes of soils in the narrow sense or to climate in the broader sense (Shul'gin, 1965).

Soil climate has much in common with atmospheric climate: it is similarly characterized by temperature, humidity, daily and annual fluctuations of both indexes, spatial distribution, and changes in space and time. Nevertheless, soil climate has its own specific traits as compared with the climate of the atmosphere and that of the air layer near the ground. Therefore, we need a special branch of climatology—soil climatology.

One of the distinguishing features of soil climate is the environment where it forms. While atmospheric climate consists of the physical phenomena of the earth's air envelope, soil climate has its seat in a bio-organo-mineral system, with its own laws of development and thermodynamics. Taken as a whole, the atmosphere is more or less uniform over great distances, whereas soil climate is not homogenous in composition even within a fairly small area. Soil climate can also be strongly influenced by human activity.

Soil climate has great variability. This variability is historically conditioned, arising with the formation of the soil itself and with the growth of plants, animals, and micro-organisms. Close connection with these most active components of nature determines the great variability of soil climate in time. In the 19th and 20th centuries, humans, by clearing the Eastern woodland and plowing the virgin prairie of the Midwest, modified vegetation and soil climate, while atmospheric climate was changing much less within the same regions. Drainage of swamps, irrigation of deserts, and artificial forestation considerably modify the soil climate within even shorter periods of time. Such variability of soil climate opens wide prospects of further changes.

Soil climate consists of such elements as temperature, moisture, air composition, pressure, and light penetration. Among these, the first two have strong influence, while the others are much less important and not so well known.

The principal formative conditions of soil climate are 1) atmospheric climate; 2) physical soil properties; 3) plant cover, snow carpet, and other coverings; 4) biological activity; and 5) human activity. In addition, soil climate is influenced by 6) slope geometry, relief, and exposure; 7) water table and level of surface waters; 8) nearby rivers, other bodies of water, and irrigation or drainage systems; 9) nature of the parent rock; 10) geological structure; and 11) altitude above sea level. All of these conditions are interrelated. They change in space and time, thus transforming the soil climate and themselves being modified by it. Soil climate thus is a constituent of the environment of physical geography and forms under its influence. It is influenced by all those conditions of the physical-geographical setting. The climate of a soil in turn affects many natural phenomena as well as economic production. Indeed, it influences the life and productivity of soils, plants, and micro-organisms as well as the development of microclimate.

Soil climate is most closely related to soil-forming processes. Beginning with V.V. Dokuchaev, pedologists considered climate as one of the "soil formers." Soil climate greatly affects the rate of soil biological and biochemical processes and largely determines the soil's fertility. The warmth, moisture, and air within the soil itself influence humus formation and the activity of micro-organisms and other soil fauna. A close relationship should exist between patterns of soils on the landscape and soil climate (Shul'gin, 1965).

The geographical distribution of plants is influenced by soil climate. These are the hydrophytes, mesophytes, and xerophytes growing, respectively, in environments of excess moisture, sufficient moisture, and deficit moisture. These three categories are distributed not only according to geographical region but also within limited areas differing in relief and in moisture content. Soil temperature likewise affects plant geography to some extent.

Soil climate is important to agriculture. The germination of most cultivated crops depends on soil temperature and moisture. The formation and regeneration of tillering nodes in grain crops and the intensity and duration of their tillering are affected by the temperature and moisture content of the soil's uppermost layers. The moisture content of a soil plays a decisive role in the survival of winter crops and perennial grasses. Root system growth and the overground vegetal bulk largely depend upon elements of soil climate. Soil climate strongly affects the growth rate of plants, the formation of subsidiary ears, plant mortality, the development of several stories, and other cultivated plant growth phenomena. The availability of soil nutrients, sufficient soil moisture, proper temperature, and access to air ensure normal plant growth, high yields, and good-quality crops (Shul'gin, 1965).

The role of soil climate is particularly evident in drought years. Even then, good crop yields may be obtained if farming practices have created favorable combinations of the various elements of soil climate, namely, high moisture content in deep soil layers and a reasonably moderate soil temperature. Soil climate is no less important in winter. During years marked by particularly harsh conditions of atmospheric climate, the soil climate of snow-covered soil may be sufficiently favorable for the normal wintering of plants. Proper cultivation and the timing of farming practices depend directly upon soil climate in many ways.

Chapter 2

Principles Regulating the Soil's Temperature Regime*

1. Thermal Properties of Soil

Solar radiation is the primary source of heat entering the soil. The soil surface transforms radiation into thermic energy and transmits it deeper into the soil. When soil radiates, the expenditure of heat exceeds the intake; the surface cools, and the cooling is transmitted downward. Thus, the soil's surface, by absorbing and radiating heat, regulates the thermic energy and therefore also the thermic regime of the soil. Early Russian climatologists called this surface "external active surface," thus stressing its importance in heat exchange.

The intake and expenditure of radiant energy at the earth's surface (R) are expressed in the following equation of radiation balance:

$$R = Q - S - U,$$

wherein Q is total solar radiation; S, the reflected solar radiation; and U, the earth's effective radiation, i.e., the difference between earth radiation proper and counter-radiation by the atmosphere.

The positive balance of radiant energy results in a warming of soil and air. Heat also is expended on evaporation from the surface of soil and vegetation, on the melting of snow in spring, and on biological processes. The thermic balance of the soil's surface is as follows:

$$R = M + V + \beta + \Delta,$$

wherein M is amount of heat expended on warming the air; V, the amount of heat expended on warming the mineral soil; β, the amount of heat expended on evaporation; and Δ, the amount of heat expended on other processes.

The warming and cooling of soil depend on many factors: temperature differences between soil layers, the thermal conductivity of soil, its heat capacity, and therefore also its temperature conductivity. The greater the difference of temperature between the soil's surface and its deep layers, the greater the amount of heat entering or leaving the soil. The degree of warming of a soil depends on its thermal conductivity, i.e., on its ability to transfer heat from the warmer to the cooler layers. Thermal conductivity is defined by the amount of heat, in calories, flowing in 1 second through a 1-cm^2 layer of homogenous substance 1 cm thick, when the temperature on the two sides of such a layer differs by 1 ºC, i.e., when the temperature difference is 1 ºC per 1 cm.

A soil's thermal conductivity depends on its physical properties, i.e., on the content of soil solids, air, and moisture, as well as on porosity. The thermal conductivity of soil solids is greater than that of the soil air by a factor of about 100; the conductivity of water exceeds that of air by a factor of about 24; and the conductivity of soil solids exceeds that of soil water by a factor of about 5.

As a soil becomes moister, i.e., as its air becomes replaced by water, its conductivity increases, though not in proportion to humidity. When the latter is low, conductivity increases sharply at first; then, as the soil becomes more humid, the increase in conductivity is less marked. When humidity is low, the difference between the thermal conductivity of water and that of soil particles is great; as the soil becomes moister, its conductivity gradually approaches that of water.

Thermal conductivity is greatly influenced by soil porosity, which is measured as the ratio between volume of soil pores and total volume of soil and is expressed in percent. Cultivation increases soil

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* Much of the theory in this chapter was extracted from A.M. Shul'gin, 1965, *The temperature regime of soils*. USDA and National Science Foundation, Washington, D.C.

porosity. Porosity of a "pristine" soil ranges from 30 to 40 percent, and that of cultivated soils ranges from 40 to more than 60 percent. As porosity increases, thermal conductivity decreases. The thermal conductivity of soil fluctuates daily and annually, because soil humidity also shows diurnal and annual fluctuations. During the day conductivity usually decreases, but at night it increases again. When a soil becomes moister, conductivity increases; as the soil desiccates, conductivity decreases.

The warming and cooling of soils also depend on heat capacity. One distinguishes between gravimetric heat capacity (i.e., specific heat) and volumetric heat capacity. The former is the amount of heat, in calories, necessary to warm 1 g soil by 1 ºC; the latter is the amount needed to warm 1 cm^3 soil by 1 ºC The heat capacity of a soil depends on its humidity, content of air, and porosity and also on its mineralogical composition. As the heat capacity of water is twice that of the solid mineral parts of soil, the volumetric heat capacity of the soil increases with humidity, and the greater the porosity, the greater the increase. Conversely, a higher content of air reduces the soil's heat capacity. Specific heats of various materials that are common in soils are given in table 2.1.

Table 2.1.—Mean specific heats of various solids (32-212 °F, 273-373K) from Avallone and Baumeister, 1987.

Material	°C ($kJ\ kg^{-1}\ K^{-1}$)	Material	°C ($kJ\ kg^{-1}\ K^{-1}$)
Alumina	0.77	Limestone	0.91
Gneiss	0.75	Marble	0.88
Granite	0.84	Quartz	0.96
Graphite	0.84	Sand	0.82
Gypsum	1.10	Sandstone	0.92
Hornblende	0.84	Serpentine	1.05
Humus (soil)	1.80	Silica	0.80
Kaolin	0.94	Talc	0.87

The volumetric heat capacity of peat relative to other soils (sand and clay) is least in the dry state and highest in the moist state and is determined by the peat's greater porosity. Conversely, the heat capacity of sand relative to other soils is highest in dry conditions and least in moist conditions. The heat capacity of clay is less than that of sand when the soil is fairly dry and greater than that of sand when the moisture content is higher.

Diurnal oscillations of temperature in a moist soil are less than those in a dry soil. Also, there is less difference in temperature between layers in a moist soil. Moist soils warm and cool more slowly. The reverse is true of dry soils. Therefore, clayey soils with greater heat capacity and limited moisture content will warm up less in daylight than sandy soils and cool off less at night. In spring, clayey soils are usually colder than sandy soils, whereas in autumn, assuming greater moistening, the clayey soils are warmer than the sandy soils. The thermal condition of a soil is expressed not only in absolute magnitudes, i.e., calories, but also in relative units, i.e., degrees. Changes of soil temperature in time and with depth are determined by the soil's temperature conductivity.

For this purpose one uses the thermal diffusivity, which equals the coefficient of thermal conductivity divided by the volumetric heat capacity of the soil:

$$K = \lambda \div C_p,$$

where K is the thermal diffusivity; λ, the coefficient of thermal conductivity; and C_p, the volumetric heat capacity.

K is the increase of temperature of a unit of soil-volume (1 cm^3) when there is inflow of heat = λ per unit time. In soils where K is small, the daily and annual fluctuations of temperature are damped out at lesser depths than in soils with a high K value. In deep soil layers, the temperature requires more time to increase; it also decreases more slowly. When the temperature conductivity is small in surficial layers, however, one observes wide oscillations of temperature: the temperature rises more rapidly but drops just as swiftly. The daily and annual amplitudes of temperature in soils with a low *K* value are observable at lesser depths than in soils with a high *K* value.

Thermal diffusivity depends on the humidity and content of air in the soil. The temperature conductivity of air is much greater than that of water. *K* is 0.16 for air but is only 0.0013 for water. When a soil's humidity is low, its *K* increases, but the increase becomes gradually less marked as humidity rises because changes in temperature conductivity depend on simultaneous changes in temperature conductivity and in heat capacity. Volumetric heat capacity increases with increased humidity. Temperature conductivity also rises as long as the degree of humidity remains moderate, but when the latter becomes high, the increase of temperature conductivity decreases. Therefore, in the first stages of moistening, the increase in a soil's temperature conductivity is faster than that of its heat capacity and the *K* must increase. As the soil becomes still moister, however, the rise in thermal conductivity becomes relatively less, so that temperature conductivity decreases.

2. Heat Exchange in the Soil

A process of heat exchange takes place in the soil during the year. It proceeds from the surface downward or in the opposite direction. Over a period of 24 hours, one observes considerable changes in heat exchange in daylight and very small changes at night. During daylight hours the variations of heat exchange follow those of solar radiation. The time when heat exchange becomes nil coincides more or less with sunrise and sunset. The diurnal course of heat exchange in the soil depends on the presence or absence of plant cover, on the height and character of the plants, and on the velocity of the wind.

The seasonal course of heat exchange in soil shows certain peculiarities. The greatest positive heat exchange normally occurs in spring and in the first half of summer; the greatest negative heat exchange occurs in early winter.

The cover of the soil—plant cover in summer, snow carpet in winter—greatly influences its heat exchange. Investigations carried out over many years by G.A. Lyuboslavskii at Lesnoe in a soil remaining bare throughout the year and in a soil covered with grass in summer and with snow in winter have resulted in the following findings. The greatest differences are observable in winter, from the time when the snow carpet becomes established in December and stops the cooling of soil, and in spring, when the snow carpet, and later the plant cover, slow down the intake of heat by the soil and therefore its warming (Shul'gin, 1965).

The downward transmission of heat occurs chiefly through molecular thermal conductivity in the soil, but also through heat exchange by convection and radiation. Heat spreads by thermal conductivity between the upper and lower soil layers. The magnitude characterizing the change of temperature with depth is known as the vertical temperature gradient, which indicates the change of soil temperature per unit of depth.

The main regularities in the downward propagation of temperature oscillations through the soil are as follows:

1. The period of temperature oscillations (24 hours and 1 year) remains constant at all depths.
2. The amplitudes decrease with depth. As depth increases in arithmetic progression, the amplitude decreases in geometric progression and is damped at a certain depth.
3. The times of the maxima and minima of temperature are retarded with depth. The retardation is proportional to depth.
4. The depths of constant daily temperature and of constant annual temperature are in the ratio of the square root of oscillation periods. As these periods are 24 hours and 1 year, the depth

of damping of annual oscillation exceeds the depth of damping of diurnal oscillation by a factor of 19.

In reality, the propagation of heat in the soil is much more complicated, because a soil's thermal conductivity depends on its moisture content, and the latter changes with depth as well as in time. Moreover, during the warm season, the distribution of temperatures in the soil is determined by the thermic properties of the upper soil layer, which is a poor conductor of heat. During winter in the North, however, the distribution is determined by the thermic properties of the snow carpet, which limits heat transfer.

3. Daily Course of the Soil's Temperature

Soil temperature has a diurnal and an annual periodicity. The daily course of temperature in the soil is determined chiefly by diurnal variation of solar and the earth's surface radiation. The daily course of the temperature at the soil's surface is characterized by one maximum (at about. 13 h [1 p.m.]) and by one minimum (before sunrise).

In daylight, it is the soil's surface which is warmest and warmth decreases with depth. At night, the soil's surface is coldest and cooling decreases with depth. Thus, the diurnal amplitude of soil temperature is greatest at the surface, decreasing with depth.

The damping of diurnal soil temperature oscillations occurs at a depth of 35 to 100 cm. At this depth, the diurnal temperature remains constant but changes can be detected on a weekly basis.

During daylight hours at southern latitudes in summer, the temperature at the surface of a strongly insolated soil reaches 50 to more than 60 ºC. Because of low thermal conductivity in the upper soil layers, however, the downward penetration of heat is very slow. Therefore, there is rapid decrease of temperature within the surficial soil layer. At a depth of 10 to 20 cm, the temperature is often almost 30 ºC lower than the temperature at the surface.

The vertical gradient of soil temperature decreases with depth mainly because the upper layers absorb most of the heat, so that the downward flow is reduced. During dry periods, however, the increased gradient within the surficial soil layer may be the result of decreased temperature conductivity in this layer, caused by less compactness and a lower moisture content.

In some days the diurnal course of soil temperature can show considerable deviations, determined largely by cloudiness, precipitation, winds, etc.

The amplitude of soil temperature oscillations according to depth also depends on the composition of soils. In granitic soils, which have the highest temperature conductivity, this amplitude is least at the surface and greatest at a depth of 60 cm. In sand, which has much lower temperature conductivity, the amplitude is greatest at the soil's surface. It is less marked in peat because of high expenditure on evaporation.

The amplitude of diurnal temperature oscillations in the upper soil layers is greatly influenced by the plant cover in summer and by a snow carpet in winter. The surface of a bare soil is warmer than that of a soil under natural cover. In summer the plant cover increases reflection, evaporation, and heat losses by radiation. It has been established that the highest temperatures occur in soils which are not quite bare, i.e., on surfaces with sparse burned-out grassy vegetation. Such a discontinuous grassy cover expends less heat on evaporation and therefore enhances the strong warming of the soil's surface.

4. Annual Course of the Soil's Temperature

The annual course of soil temperature at temperate latitudes usually has a maximum in July or August and a minimum in January or February. At these latitudes the amplitude of annual temperature oscillations at the surface of bare soil remains approximately the same, i.e., approximately 30 ºC. Amplitudes of annual temperature oscillations in the soil decrease with depth; the time of maximum and minimum temperatures is retarded.

According to Fourier's theoretical calculations, the depth of penetration of annual fluctuations in soil temperature should exceed the depth of penetration of diurnal oscillations of temperature by a factor of about 19. The actual ratio is greater, however, because thermal conductivity increases with depth; soil humidity also varies with depth and time, and soil porosity is less in the deep layers. On the average, the depth of penetration of annual fluctuations of temperature ranges from 8 to 25 m, but in some places it reaches 30 m.

The depth of penetration of annual temperature oscillations is about 25 m at northern latitudes, 15 to 20 m at temperate latitudes, and about 10 m at southern latitudes. Below these depths there is a layer of constant annual temperature, i.e., a layer that does not vary either daily or annually. On the average, the time of maximum and minimum temperature is delayed by 20 to 30 days per meter of soil depth.

There are seasonal differences in the changes of soil temperature with depth because of variations in the annual course of temperatures at different depths. In summer temperature decreases with depth; in winter it increases with depth. In the transitional seasons peculiarities are observed in the distribution of soil temperatures. In autumn the temperature is highest in a layer at a certain depth and decreases both upward and downward from that layer. Conversely, in spring the coolest layer is "sandwiched" between upper and lower layers which are warmer.

The annual course of soil temperature greatly depends on the plant cover, its character, and its changing height throughout the year. The greatest differences are observable in winter, when cooling is reduced by a snow carpet with a low thermal conductivity and a high reflective capacity. The greatest amplitudes of annual temperature oscillations occur in bare soils. The natural surface of a soil that is snow covered in winter and grass covered in summer has a greatly reduced amplitude of temperature oscillation. In summer a bare soil is warmer than a soil under natural cover; in winter (within temperate latitudes), a bare soil is much colder than a soil under a snow carpet.

5. Relationship Between the Temperatures of Air and Soil

Annual averages of soil temperatures remain nearly equal at different depths, down to 3 m, and differ by only a few tenths of a degree. The mean annual air temperature is lower, however, and differs from that of the soil by a greater amount, ranging from a few tenths of 1 to more than 5 ºC (Shul'gin, 1965).

The difference between mean annual air temperature and mean annual soil temperature varies in amount according to climatic zones. Studies in the former Soviet States indicate that this difference ranges from ±1 to 3.5 ºC (Shul'gin, 1965).

In the United States, recent studies have verified that the mean annual air temperature can be warmer than the mean annual soil temperature in areas of air drainage phenomena. Table 2.2 shows the relationship between mean annual soil temperature (MAST) and mean annual air temperature (MAAT) at selected sites across the United States (Mount, 1998 and 1999).

Table 2.2.—Relationship between MAST and MAAT (ºC).

Location	MAST	MAAT	MAST - MAAT
Pima County, AZ	19.2	18.0	+1.2
Nunn, CO	10.4	7.5	+2.9
Watkinsville, GA	17.2	15.1	+2.1
Parker Ranch, HI	14.3	12.7	+1.6
Henderson County, IL	9.9	9.4	+0.5
Ellicott City, MD	12.2	11.1	+1.1
Crescent City, MN	7.3	5.9	+1.4
Tidewater, NC	16.3	15.6	+0.7
Lincoln, NE	11.2	9.4	+1.8
Mandan, ND	7.1	4.3	+2.8
Molly Caren, OH	11.7	9.5	+2.2
Mascoma Research Area, NH	7.6	5.9	+1.7
Edisto Island, SC	18.9	18.2	+0.7
Smoky Mountains, TN	11.8	11.4	+0.4
Bushland, TX	21.2	19.4	+1.8
Culpepper County, VA	12.9	12.6	+0.3
St. John Island, USVI	27.9	26.6	+1.3
Wabeno, WI	6.1	4.0	+2.1
Greenbrier County, WV	8.5	10.0	-1.5
Lind, WA	11.1	9.4	+1.7
Wycola, WY	10.0	7.6	+2.4

The site in West Virginia is not unique in its air and soil temperature relationship. Tennessee and Arizona have documented similar sites where the mean annual air temperature is warmer than the mean annual soil temperature. Problems arise when soil temperature is modeled solely on the basis of the mean annual air temperature.

6. Influence of Relief on Soil Temperature

Relief has a considerable effect on soil temperature. The latter depends largely upon slope exposure. South-facing slopes receive the greatest amount of heat, north-facing slopes the least amount. West-facing slopes receive about as much sunshine as east-facing slopes, and yet they are warmer because during the first half of the day, when east-facing slopes are insolated, much of the heat is expended on evaporation, whereas during the latter half of the day, when the west-facing slopes are insolated, evaporation decreases strongly because of soil desiccation.

M.M. Filatov (1945) observed, in Transbaikalia in daylight, a temperature of 12 ºC at the surface of a north-facing slope as against 29 ºC on the south-facing slope. Topographic shape is also of importance. A.I. Voekov showed that as a rule daylight warming and night cooling are strongest in concave areas (valleys) and least in convex areas (heights) because of the intensity of air mixing. The temperature regime of soils is not the same on slopes of different exposure. Intake of solar radiation, soil moisture, luxuriance of grassy cover, and velocity of winds determine the differences. South-facing slopes usually receive more heat from solar radiation, and they are drier than north-facing slopes.

According to S.A. Sapznikova (Shul'gin, 1965), soil temperatures differ because of solar radiation input and moist soil on north-facing slopes. When slopes are not very steep, soils and covers on slopes are similar, and especially when the wind blows from the south, the difference in soil temperature between slopes is to 0.2 to 1.5 ºC in the vicinity of Leningrad. A field slope facing only 1º north will be like a level field situated 100 km farther north, with respect to heat intake. Therefore, the choice of a slope may be of decisive importance in agriculture, especially when southern crops are being grown in more northerly regions.

V.P. Mosolov (1949) made observations in the Tatar USSR on June 22 and 24, 1940, showing that, on northwest- and south-facing slopes of similar gradient, the difference in soil temperature was 5 to 7 ºC at the 1-cm depth. The south-facing slope warms up faster and loses almost twice as much water through evaporation.

Measurement of the combined influence of slope gradient and exposure upon temperature show that the south-facing slopes have the highest soil temperatures, followed by the east- and west-facing slopes; north-facing slopes have the lowest temperatures. As the gradient increases, temperature rises on south- and east-facing slopes but drops on north- and west-facing slopes. Differences in soil temperature on south- and north-facing slopes increase with increasing gradient, whereas on east- and west-facing slopes the contrast decreases. In such conditions, west-facing slopes of moderate grades (15º) are usually warmer than east-facing slopes. The reverse is true for steeper slopes (30º). The greatest oscillations of temperature occur on south-facing slopes; they become more and more reduced on slopes approaching northern exposure.

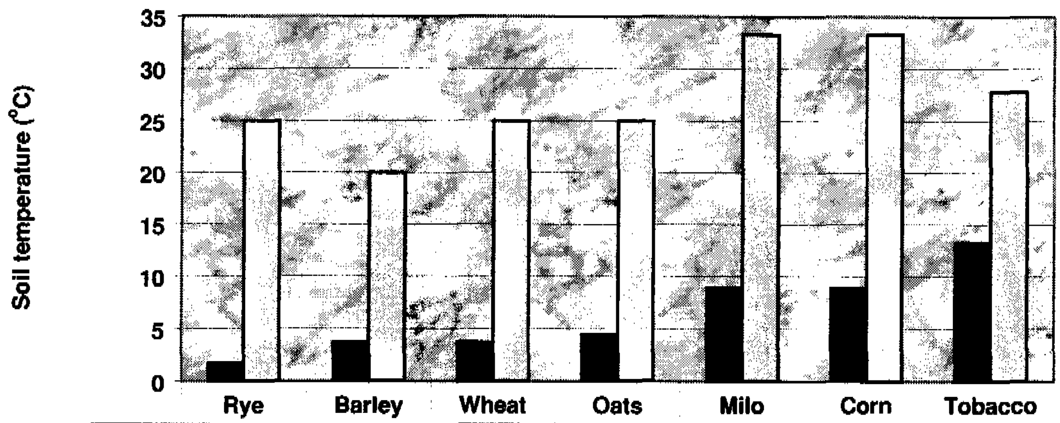
The surface form of a soil influences its temperature. According to Wollny's observations, a soil with a horizontal surface warms up more rapidly than a soil on a slope, except for the south-facing slope. The difference reaches 0.3 to 0.5 ºC (Loske, 1911). Moreover, the slightest ruggedness of relief will considerably increase the soil's temperature.

Local altitude strongly affects the temperature of soils. On the strength of lengthy observations at meteorological stations in Bavaria, at elevations ranging from 136 to 1,136 m, Ebermayer concluded that mean soil temperature decreases with increasing altitudes above sea level. He also remarked that the greatest drop in soil temperature occurs at moderate elevations, i.e., 600 to 800 m (Loske, 1911).

Mountain regions are characterized by great differences between air temperature and the temperature of the upper soil layer. Tien Shan observed the soil temperature in the Pamirs in 1913. In the Samarkand region, on May, 21-30, 1913 at 1300 h, the temperature of the soil was 47 ºC at the foot of mountains (at an elevation of 1,360 m), but that of the air was only 24 ºC; on a south-facing slope (at an elevation 2,000 m) the corresponding figures were 54 ºC and 13 ºC. On the Peter-the-First Range, on October 22, 1913, at 13 h, the temperature of the soil surface on a plateau (at an elevation of 3,150 m) reached 45 ºC and that of the air was merely 20 ºC; at the summit (at an elevation of 5,020 m), the respective temperatures were 42 ºC and 8 ºC. Therefore, the difference between air temperature at a height of 2 m above the soil and that of the soil itself increases with elevation. At the foot of mountains and on plateaus, the difference is to 23 to 25 ºC, while on south-facing slopes it is 41 ºC and on the summit of mountains it is 34 ºC. Despite very great differences in altitude (elevations ranging from 1,360 to 5,020 m), the temperature of a sunlit soil surface may not change at all, or it may even increase on slopes as compared with the plains, because of the intensity of solar radiation on mountains. Similarly, observations in the Swiss Alps have shown that the average temperature of the soil surface exceeds the air temperature by 2.4 ºC at an elevation of 1,600 m, by 3 ºC at an elevation of 1,900 m, and by 3.6 ºC at an elevation of 2,200 m (Berg, 1938).

7. Temperature Effects on Germination of Seeds

Soil temperature at a depth of about 10 cm strongly affects seed germination in spring. Figure 2.1 shows the minimum and optimum temperature for seed germination of rye, barley, wheat, oats, sorghum, corn, and tobacco (Joffe, 1949).



	Rye	Barley	Wheat	Oats	Milo	Corn	Tobacco
■ Minimum	1.7	3.7	3.7	4.4	8.9	8.9	13.3
□ Optimum	25	20	25	25	33.3	33.3	27.8

Crop

Figure 2.1.—Minimum and optimum soil temperature for germination of various crops.

Through technology transfer from generation to generation, farmers plant on dates somewhere between the minimum and optimum soil temperature for each of the plants listed. They plant during the minimum end of the soil temperature threshold only on level fields of somewhat uniform sandy soils. Since most fields have forces modifying uniform soil temperature (slope gradient and aspect, water table level, etc.), the farmers tend to plant somewhere between the minimum and optimum soil temperature.

Chapter 3

The Calibration Question

Certification of the accuracy of data from electronic loggers and storage modules is always recommended. Most temperature sensors are factory calibrated and have an accuracy threshold of a few tenths of a degree C. Errors for electronic sensors include thermistor errors, quantization errors (step errors in the digital representation of the temperature), and a small residual error remaining after all other errors have been calibrated out. Individual loggers do not have exactly the same step values, so that two loggers exposed to the same temperatures may report different values. Each one, however, will be correct within its accuracy limits.

Another calibration concern is the internal clocks in data loggers. At room temperature, the logger's idea of time can vary from the actual time by as much as 1 hour per year. For soil temperature studies, where data are off-loaded each year, this is not a major concern. Unless data are collected each hour, precise time is not critical.

Thermistors will hold their calibration for a variable period of time. Most vendors claim that the thermistors will hold their calibration for 5 years under optimal conditions. Mount et al. (1995) identified drifting of soil temperature data from St. John Island in the U.S. Virgin Islands after 2 years of study from multiple sensors at the same soil depth. Consequently, it is advised that all long-term soil temperature studies replace their thermistors after 2 years of data collection.

It is impractical to recheck all of the factory-calibrated sensors in the laboratory, especially for temperature networks using hundreds of sensors. Consequently, only a random spot check of thermistors is deemed necessary. One way to spot check the calibration is to place a thermistor in an ice cube tray with tap water. Cool the water down to near freezing inside a refrigerator. Take the ice cube tray from the refrigerator and activate a data logger for a 15-minute test (figure 3.1).

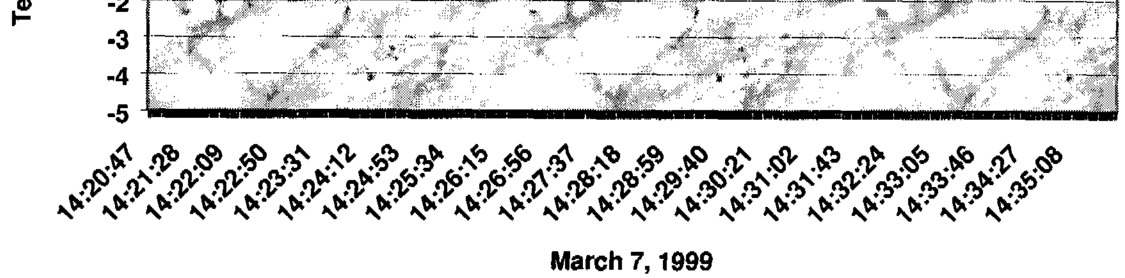
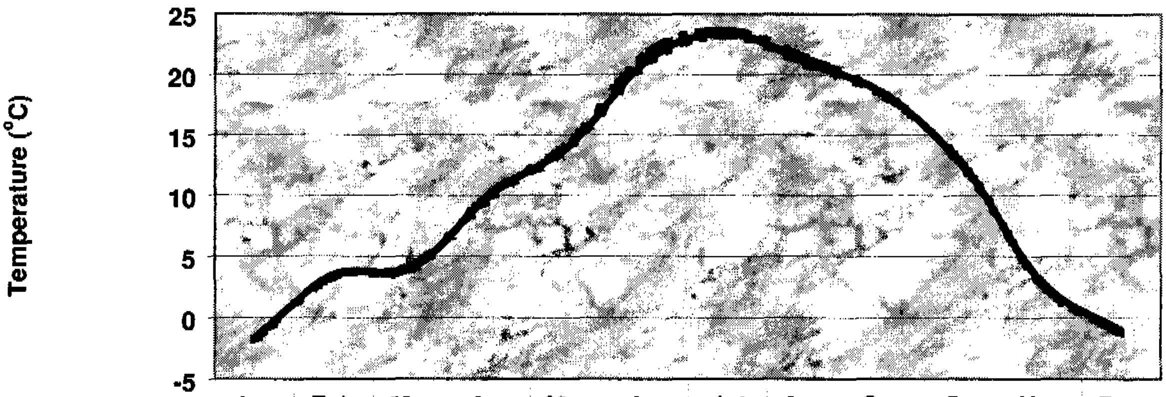


Figure 3.1.—Calibration test on a StowAway XTI sensor.

The mean temperature of 1,800 readings for the ice cube test was -0.1 ºC. The sensor ranged from +0.1 to –0.4 ºC for this 15-minute test. The sensor was accurate enough for the intended purpose. Where greater accuracy is desired, however, two or more temperatures may be checked.

Another way to judge sensor calibration is by inference. For example, a study was designed in a western Illinois ecosystem to ascertain the temperature differences between a site in an open glade, a site under cedar, and a site under locust trees. The three sites have a horizontal surface, are within 100 m of each other, and should have similar air temperature readings. The air temperature values for each site were averaged by month and graphed (figure 3.2). Calibration of the sensors was accepted, although the three sensors may all have the same degree of error.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cedar	-1.7	3.5	4.0	10.1	14.2	21.3	23.4	21.0	18.3	12.4	2.9	-1.0
Glade	-1.8	3.4	4.2	10.1	14.4	21.9	23.6	21.3	18.3	12.4	2.7	-1.3
Locust	-1.9	3.3	4.0	9.8	14.0	21.0	23.2	20.8	18.1	12.2	2.6	-1.3

Month (1997-1998)

Figure 3.2.—Air temperature signatures and monthly averages at three sites within 100 m of each other in western Illinois.

Graphing data can help to ascertain calibration uniformity and problems. One example where graphing was used to determine accuracy of calibration is from St. John Island in the U. S. Virgin Islands. During 1996, a site on the north side of St. John was targeted for installation of sensors to measure soil temperature. Factory-calibrated sensors were used at 10 locations within 100 m of each other. When data were off-loaded, then graphed for a 1-day representation of soil temperature, a problem was discovered (figure 3.3.). Soil temperature readings for the 10-cm depths (series 1-10) as graphed for December 17 were incorrect. The hourly fluctuation at a given location and its relationship to the other sites were not probable. The sensors were not accurate and were replaced during 1997.

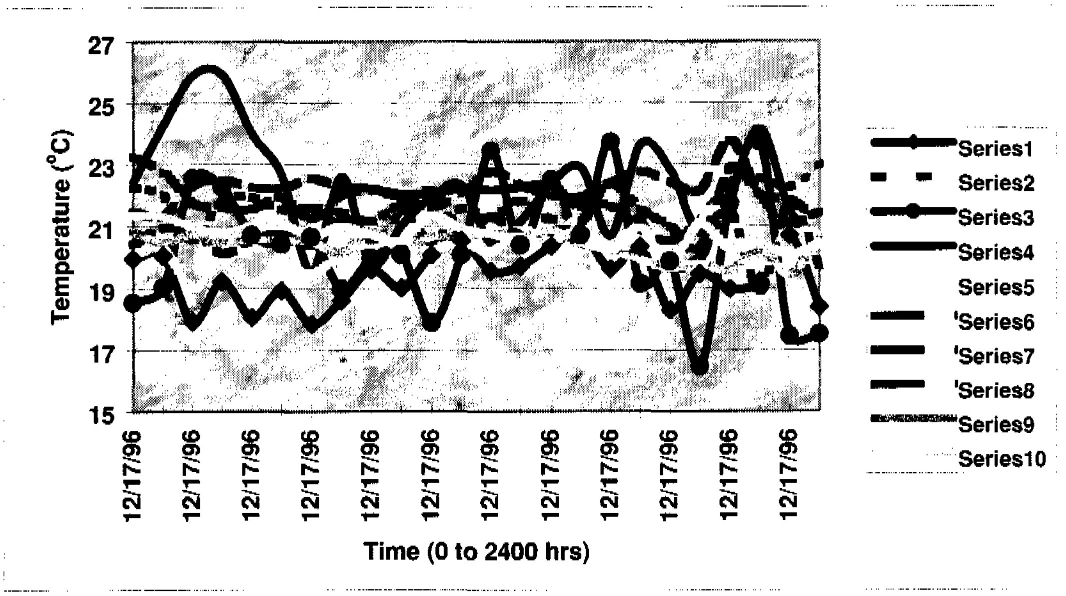


Figure 3.3.—Inaccurate soil temperature readings at 10 cm for 10 sites on St. John Island.

Occasionally, a spike will appear in the raw data set (figure 3.4). An initial view of the data spikes will often indicate inaccurate readings. Spiking of temperature data should be examined in detail. It might be a calibration problem.

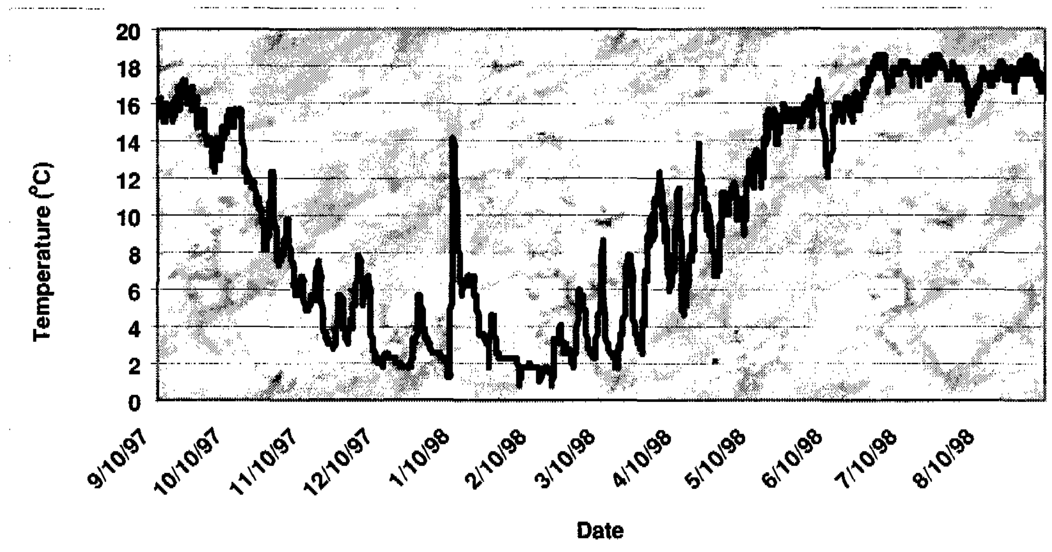


Figure 3.4.—A troublesome spike at the 10-cm soil depth on a site in the Great Smoky Mountains of Tennessee.

To make any determination of the quality of data based on visual analysis, scientists should examine the data a little more closely. When the data from figure 3.4 are examined in detail and the air temperature data from the same site are overlain, a different picture emerges (figure 3.5).

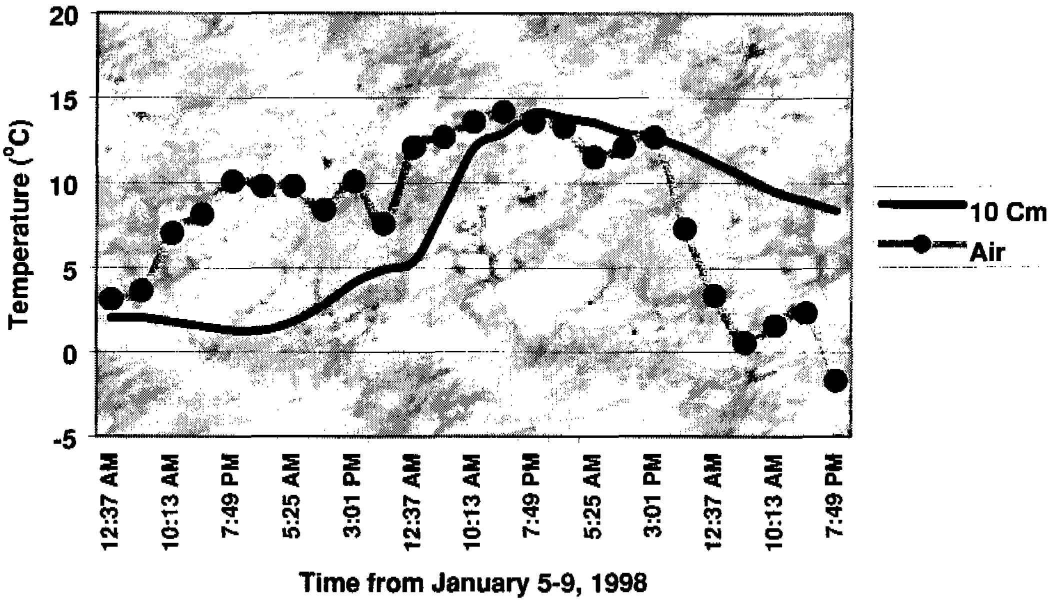


Figure 3.5.—Same data from figure 3.4 examined in closer detail. The period from January 5-9, 1998, looks valid after scrutiny of the air and soil temperature data. This is a winter thaw phenomenon.

Spiking of soil temperature data should to be examined in detail. In most cases, data that appear inaccurate are, in fact, only obeying the physical laws of soil temperature. It is imperative that soil temperature data not be deemed inaccurate before an investigation of the possible reasons for aberrant behavior.

In summary, sensor accuracy and calibration are a fundamental part of a valid soil temperature study. Consequently, data should be evaluated each year and thermistors should be replaced after 2 years. Though statistical rules exist for rejecting certain types of aberrant behavior of data, it is best if a scientist examines these data before eliminating any of the data pool.

Chapter 4

Evaluation of Temperature Data

1. Background

Soil temperature data can be examined visually in graphs, analytically through software functions, and comparatively (two or more sites concurrently) through visual and/or analytical means.

The period of data collection, or "period of record," should be specified in a soil temperature study. Since soil temperature is time dependent, it is imperative that all collected data have a time and date stamp. This is most critical for soil studies involving data collection at soil depths of less than 30 cm, where diurnal fluctuation is most prevalent.

The evaluation of temperature data varies with the period of record. Data from short-term studies of less than 1 year are evaluated in a different manner than annual or long-term data. With current data-logging technology, it is possible to have as much, if not more, data from a short-term study as from a long-term study. For all analyses in this report, at least 150 readings were collected for each month during the period of record.

2. Short-Term Temperature Data

The type of analysis for short-term temperature data varies with the interval and number of collected points. Figure 4.1 displays a 2-day study in Nebraska. The period of record was February 20-22, 1998. The total number of readings was 1,796, and the capture interval was one reading every 96 seconds.

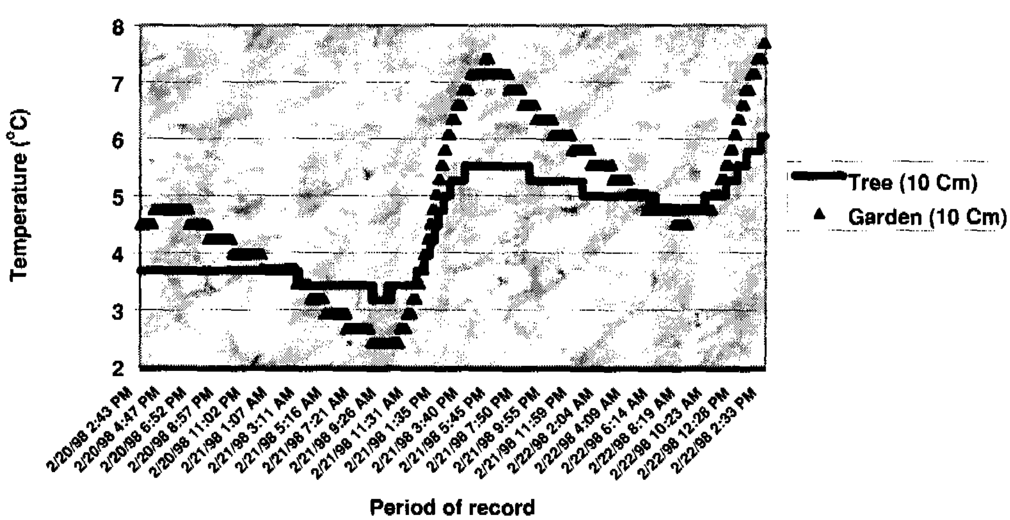
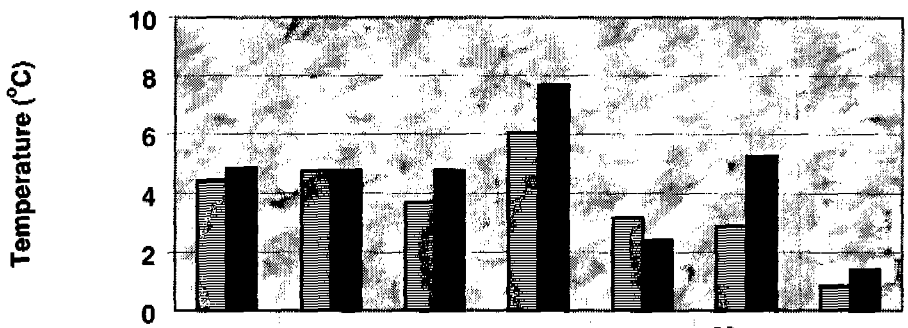


Figure 4.1.—Short-term study of soil temperature at a depth of 10 cm in Lincoln, Nebraska.

Figure 4.1 tells a story but includes no analysis. Analysis of this example presents a quandary. Though the study is 2 days in length, only February 21 is totally captured; February 20 and 22 are only partially captured. Consequently, the period of record is 2 days, but it encompasses parts of 3 individual days. How should one proceed with the analysis of this 2-day study?

Start by looking at the big picture. Analyze the entire period of record. For these data, we will calculate the average, median, and mode values as well as the maximum and minimum values for the period of record. Next, graph the data for visual and analytical review (figure 4.2).



	Mean	Median	Mode	Max	Min	Max - Min	StDev
Tree	4.4	4.7	3.7	6.1	3.2	2.9	0.8
Garden	4.8	4.8	4.8	7.7	2.4	5.3	1.4

Figure 4.2.—Summary of soil temperature data for the 2-day study in Lincoln, Nebraska.

The data analyzed by the mean, median, and mode approach show that the soil temperature in the garden was warmer than that under the tree during the period of record. The extreme changes in soil temperature are more expressed in the garden soil, as is indicated by the values for the maximum temperature minus the minimum (5.3 °C vs. 2.9 °C) and by the standard deviation (1.4 °C vs. 0.8 °C). Finally, the analysis shows that the representative temperature value for the garden soil is 4.8 °C, the same as the average, median, and mode values.

Additional detailed analysis could entail calculating the standard deviation for a data set. The standard deviation is a measure of the variability of data. Soil temperature, especially at shallow depths, constantly rises and falls throughout the day. Thus, the standard deviation is generally high. In figure 4.2, it is 0.8 °C for the soil under the tree and 1.4 °C for the garden soil.

3. Annual Temperature Data

Soil Taxonomy requires monthly averages of soil temperature for determinations of a temperature regime (Soil Survey Staff, 1999). Before automated collection systems were available, scientists would take one mid-month reading for an entire year or for a set of years. Consequently, one reading represented the monthly average. With the ability to collect large amounts of data for an entire year, calculation of the average monthly and mean annual soil temperature is a little more complicated.

Since most studies do not start exactly on 12:01 a.m. on January 1 and end at midnight on December 31 of the same year, monthly averages need to be calculated. From these averages, a mean annual soil temperature (MAST), a mean summer soil temperature (MST), and a mean winter soil temperature (MWT) are calculated. Table 4.1 gives data collected during 1996 and 1997 from Greenbrier County, West Virginia.

Table 4.1.—Average monthly soil temperature at 50 cm for a soil in West Virginia.

Month	Mean 50 cm (°C)
Jan 97	3.6
Feb 97	2.8
Mar 97	5.0
Apr 97	6.0
May 97	8.2
Jun 97	11.9
Jul 97	15.0
Aug 97	15.0
Sep 96 & 97	13.5
Oct 96	10.2
Nov 96	6.9
Dec 96	4.3
MAST	8.5
MST	14.0
MWT	3.6
MS-MW	10.4

With a MAST of 8.5 °C, this soil has a mesic soil temperature regime, according the rules of *Soil Taxonomy*. The raw soil temperature signature, however, indicates that the 50-cm depth is quite active (figure 4.3).

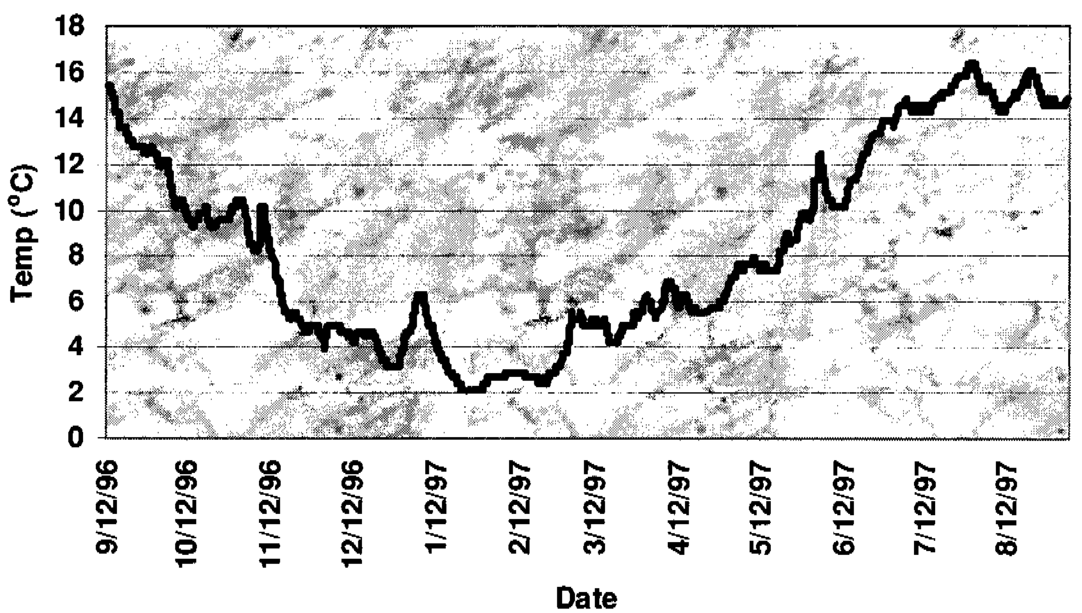
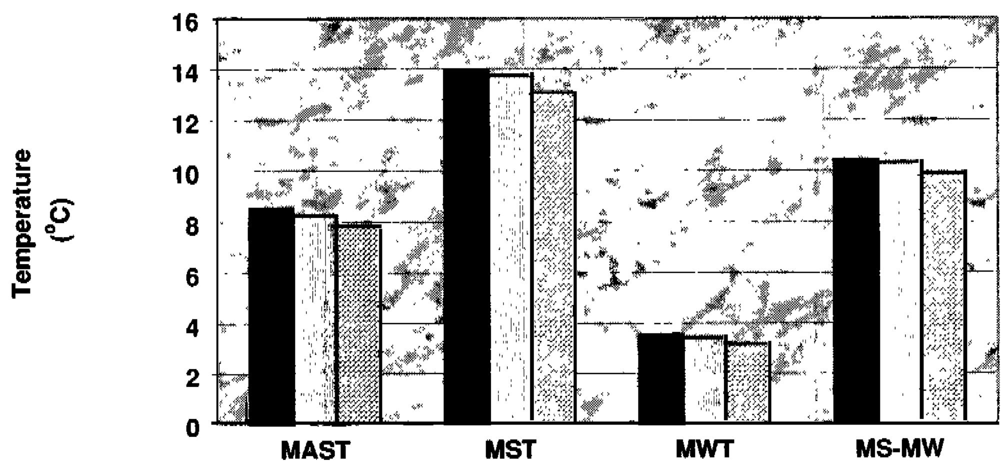


Figure 4.3.—Annual soil temperature at 50 cm for a site in West Virginia.

Whereas most temperature signatures at the 50-cm depth show a consistent seasonal trend, this one in West Virginia is in a constant movement phase. Perhaps, we ought to examine the monthly median and mode values. The monthly values for mean, median, and mode are shown in table 4.2 and displayed graphically in figure 4.4.

Table 4.2.—Average monthly mean, median, and mode values (°C) at 50 cm for a soil in Greenbrier County, West Virginia.

Month	Mean (50 cm)	Median (50 cm)	Mode (50 cm)
Jan	3.6	3.2	2.2
Feb	2.8	2.7	2.7
Mar	5.0	5.0	5.0
Apr	6.0	5.8	5.8
May	8.2	7.7	7.4
Jun	11.9	11.6	10.2
Jul	15.0	14.8	14.5
Aug	15.0	14.8	14.5
Sep	13.5	13.0	12.8
Oct	10.2	9.9	9.6
Nov	6.9	6.3	5.0
Dec	4.3	4.5	4.7
Annual	8.5	8.3	7.9
Summer	14.0	13.8	13.1
Winter	3.6	3.4	3.2
Sum-Win	10.4	10.3	9.9



	MAST	MST	MWT	MS-MW
Mean (50 Cm)	8.5	14.0	3.6	10.4
Median (50 Cm)	8.3	13.8	3.4	10.3
Mode (50 Cm)	7.9	13.1	3.2	9.9

Figure 4.4.—The annual mean, median, and mode for a site in West Virginia.

These analyses indicate that if the mode, or the most frequently occurring monthly temperature value, were used to depict the annual soil temperature, this site would have a frigid soil temperature regime.

4. Regression Equations

Attempting to solve the mystery of soil temperature across a study area often leads scientists to look for a quick solution. Mean annual soil temperature (MAST) commonly is thought to have a linear or at least a curvilinear relationship with altitude. This relationship can be regressed into an equation with the aid of software programs. Table 4.3 shows an example of the relationship between MAST and altitude.

Table 4.3.—MAST and altitude data from nine sites on the Big Island of Hawaii.

Site	Alt. (m)	MAST (°C)
7	183	21.5
3	457	27.0
5	518	18.7
8	518	18.7
4	798	18.8
2	1,082	18.1
1	1,090	18.7
6	1,585	14.3
9	3,566	12.3

The annual results from these nine sites in Hawaii can be regressed into an equation (figure 4.5).

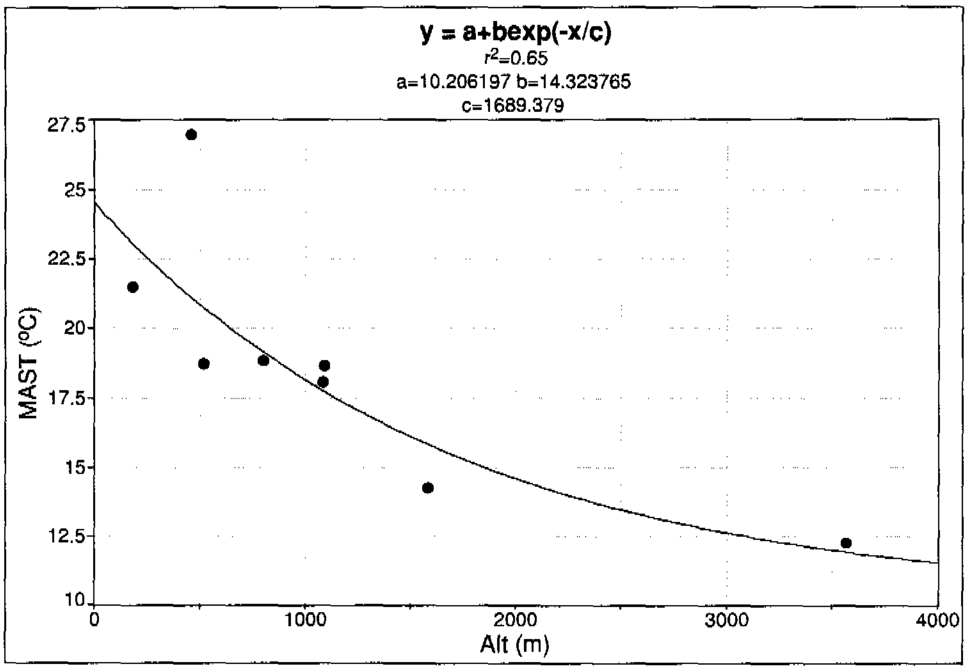


Figure 4.5.—Regression equation for nine sites on the Big Island of Hawaii.

The r^2 value of only 0.65 in figure 4.5 does not indicate a good relationship between MAST and altitude for these nine sites. If site 3 (MAST of 27 °C) is determined to be an outlier and we recalculate the regression without the data from that site, the r^2 value improves (figure 4.6).

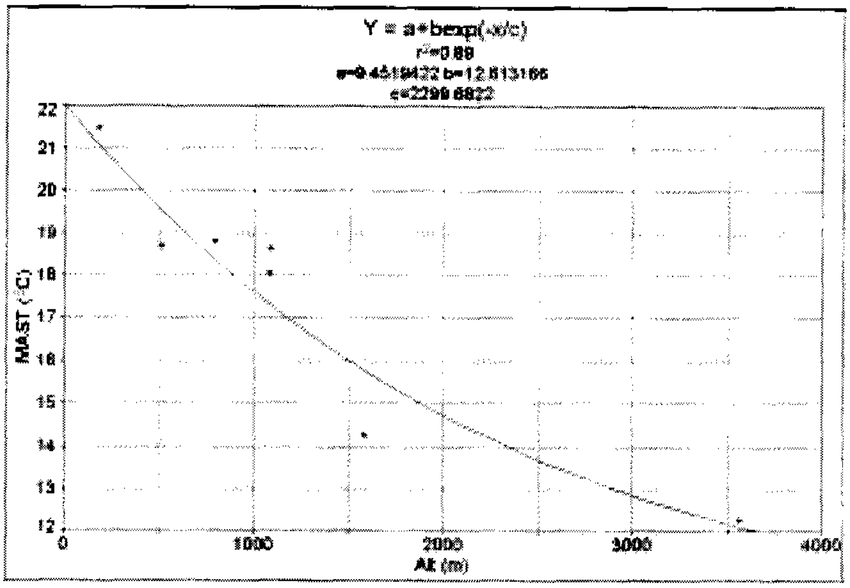


Figure 4.6.—Regression equation for eight sites on the Big Island of Hawaii.

The r^2 value is now increased to 0.89. This is much better, but it shows that there are factors other than altitude that impact soil temperature on the Big Island of Hawaii.

Measurements of soil temperature under one type of vegetation in a given location can be used to predict the soil temperature at the same depth under a different vegetation. In figure 4.7, for example, measurements at a depth of 50 cm in a meadow are highly correlated with measurements on a nearby dune.

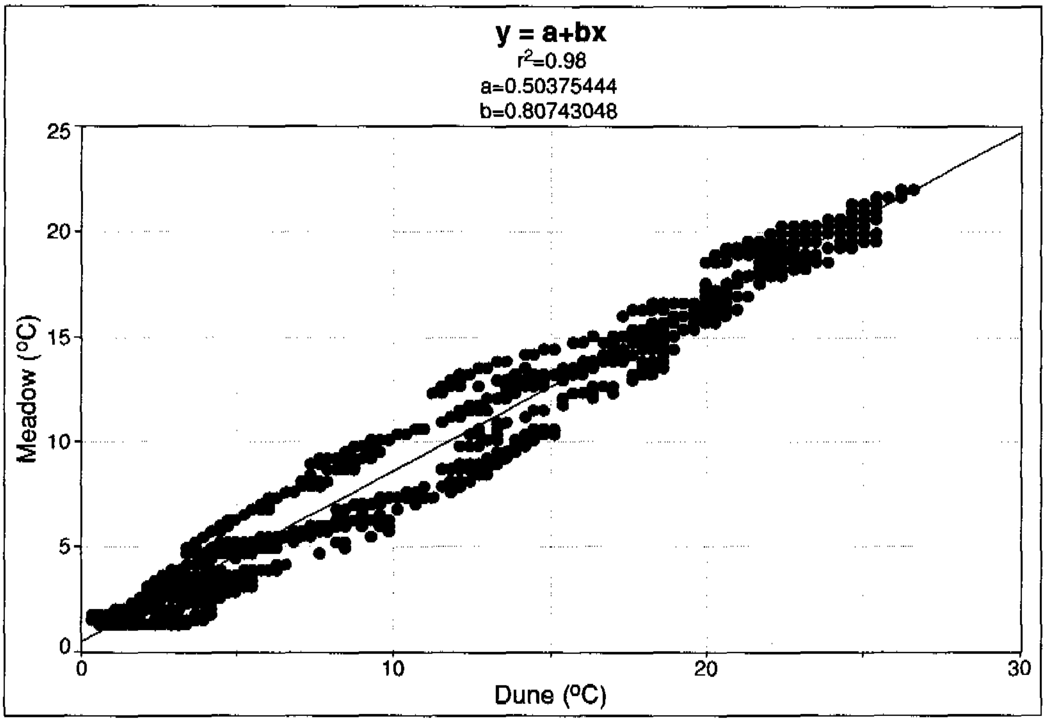


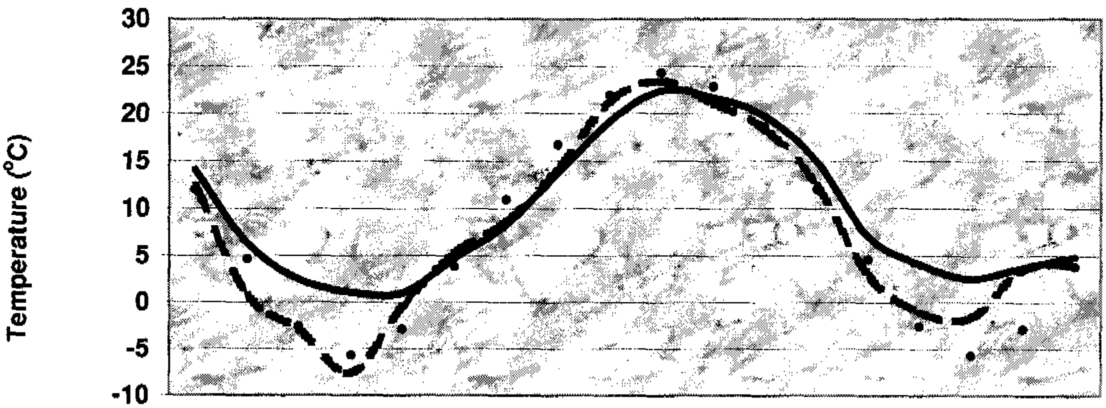
Figure 4.7.—Correlation of the 50-cm soil temperature at two sites in the Sand Hills of Nebraska.

The high r^2 value (0.98) in figure 4.7 confirms that there is a strong correlation between 50-cm soil temperature values at sites in close proximity.

5. Shift Analysis

In an attempt to find the meaning of short-term data and the relationship of these data to long-term (30-year normal) data, shift analysis is useful. Soil scientists cannot collect data for 30 years in most locations in the U.S. Therefore, we are limited to data collection periods that range from 1 to 5 years. Attempts must be made to ascertain whether data collected during these short-term studies imply long-term worthiness.

The concept of shift implies that with incrementally downward shifting from a period of monthly data, there will eventually be a period that corresponds with the 30-year normal air temperature data. Consequently, soil temperature studies require an air temperature component. Both air temperature data from a shielded sensor and soil temperature data were collected, for example, during an ecosystem study for a 17-month period from 1996 to 1998 in Henderson County, Illinois. These data are shown in figure 4.8 and table 4.4.



	Oct-96	Nov-96	Dec-96	Jan-97	Mar-97	Apr-97	May-97	Jun-97	Jul-97	Aug-97	Sep-97	Oct-97	Dec-97	Jan-98	Feb-98	Mar-98
• 30-Yr Air	12.0	4.6	-2.6	-5.7	3.8	10.9	16.7	21.9	24.3	22.8	18.6	12.0	-2.6	-5.7	-2.9	3.8
Air	12.4	0.7	-2.9	-7.6	5.3	8.6	14.1	21.3	23.4	21.0	18.3	12.4	-1.0	-1.7	3.5	4.0
50-cm Soil	14.1	6.3	2.5	1.1	4.7	8.2	13.8	19.2	22.4	21.6	19.6	14.9	4.1	2.5	3.7	4.8

Month

Figure 4.8.—Short-term data used to effect shift analysis.

Table 4.4.—Shift analysis from October 1996 to March 1998.

Month	Burlington 30-yr. air (°C)	Measured air (°C)	Measured 50-cm soil (°C)
Oct-96	12.0	12.4	14.1
Nov-96	4.6	0.7	6.3
Dec-96	-2.6	-2.9	2.5
Jan-97	-5.7	-7.6	1.1
Feb-97	-2.9	-0.4	1.0
Mar-97	3.8	5.3	4.7
Apr-97	10.9	8.6	8.2
May-97	16.7	14.1	13.8
Jun-97	21.9	21.3	19.2
Jul-97	24.3	23.4	22.4
Aug-97	22.8	21.0	21.6
Sep-97	18.6	18.3	19.6
Oct-97	12.0	12.4	14.9
Nov-97	4.6	2.9	7.0
Dec-97	-2.6	-1.0	4.1
Jan-98	-5.7	-1.7	2.5
Feb-98	-2.9	3.5	3.7
Mar-98	3.8	4.0	4.8

Shift Period	MAAT	MAST
Oct 96 – Sep 97	9.5	11.2
Nov 96 – Oct 97	9.5	11.3
Dec 96 – Nov 97	9.7	11.3
Jan 97 – Dec 97	9.9	11.5
Feb 97 – Jan 98	**10.3**	**11.6**
Mar 97 – Feb 98	10.7	11.8
Apr 97 – Mar 98	10.6	11.8

The 30-year MAAT, measured at a weather station in Burlington, Iowa, is 10.4 °C. This weather station is within 10 km of the site in Henderson County, Illinois. Table 4.4 shows that a possible approximation of the theoretical 30-year MAAT occurred from February 1997 to January 1998, when the MAAT was 10.3 °C. The MAST at 50 cm during this period of record was 11.6 °C. Since it is assumed that approximating a 30-year MAAT during a study will approximate the MAST during the same period, the suggested benchmark MAST for Henderson County, Illinois, is 11.6 °C.

This type of evaluation is useful in approximating the 30-year MAST for an individual site that is a rather short distance from a long-term monitoring air temperature station.

6. Data Gaps

Annual analysis requires data for a 12-month period. When data from one month are missing, estimating monthly values on the basis of the existing data can be attempted. The danger of attempting to populate missing values will be explained by an example. A south-facing sand dune in the Sand Hills of Nebraska has 12 average monthly readings at a depth of 50 cm based on about 150 readings per month (table 4.5). Based on the monthly averages, the MAST is 12 °C. If data are missing during all of February, for instance, how would one attempt to add the missing value and what would be the impact on the MAAT?

Table 4.5.—Matrix of soil temperature data (°C) with missing monthly values.

Month	All	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Jan	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Feb	3.5	??	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Mar	3.7	3.7	??	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
Apr	9.8	9.8	9.8	??	9.8	9.8	9.8	9.8	9.8	9.8	9.8
May	15.9	15.9	15.9	15.9	??	15.9	15.9	15.9	15.9	15.9	15.9
Jun	18.7	18.7	18.7	18.7	18.7	??	18.7	18.7	18.7	18.7	18.7
Jul	24.0	24.0	24.0	24.0	24.0	24.0	??	24.0	24.0	24.0	24.0
Aug	23.5	23.5	23.5	23.5	23.5	23.5	23.5	??	23.5	23.5	23.5
Sep	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	??	22.4	22.4
Oct	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	??	12.5
Nov	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	??
Dec	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Mean	12.0	??	??	??	??	??	??	??	??	??	??

The missing monthly average temperature could be calculated as a value halfway between the average temperature of the previous month and that of the following month. Though not always reliable, this calculation might approximate the missing value rather well. For the missing value in February, for instance, we take the midpoint value between January and March. This calculates to 2.5 °C, exactly 1 °C colder than the average of measured values throughout the month (table 4.6). The impact on the MAST is also shown in table 4.6. In the case of February, estimating the monthly average resulted in an error of 0.1 °C (11.9 vs. 12.0 °C). Severe problems are encountered with attempts to estimate the soil temperature average for March. The estimate of 6.6 °C is nearly 3 °C warmer than the measured value of 3.7 °C.

Table 4.6.—Impact of estimating missing data on the MAST (°C).

Month	All	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Jan	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Feb	3.5	(2.5)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Mar	3.7	3.7	(6.6)	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
Apr	9.8	9.8	9.8	(9.8)	9.8	9.8	9.8	9.8	9.8	9.8	9.8
May	15.9	15.9	15.9	15.9	(14.2)	15.9	15.9	15.9	15.9	15.9	15.9
Jun	18.7	18.7	18.7	18.7	18.7	(19.9)	18.7	18.7	18.7	18.7	18.7
Jul	24.0	24.0	24.0	24.0	24.0	24.0	(21.1)	24.0	24.0	24.0	24.0
Aug	23.5	23.5	23.5	23.5	23.5	23.5	23.5	(23.2)	23.5	23.5	23.5
Sep	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	(18.0)	22.4	22.4
Oct	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	(14.1)	12.5
Nov	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	(7.7)
Dec	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Mean	12.0	11.9	12.3	12.0	11.9	12.1	11.8	12.0	11.6	12.1	12.2

Table 4.6 paints a bleak picture for attempting to back-populate missing values. Only the months of April and August resulted in no impact on the MAST. The estimation for March skewed the MAST by +0.3 °C, and the estimation for September skewed the MAST by -0.4 °C. These differences are very important, especially in ecosystems bordering on two soil temperature regimes.

In summary, every temperature study should evaluate data in a statistical manner, by calculating mean, maximum, minimum , and maximum minus minimum values. Statistics verify hypotheses and add value to the total presentation of the study.

Chapter 5

Temperature Regimes Defined by *Soil Taxonomy*

Within limits, soil temperature controls the possibilities for plant growth and for soil formation. Below the freezing point, there is very little biotic activity, water no longer moves as a liquid and, unless there is frost heaving, time stands still for the soil. Between temperatures of 0 and 5 ºC, the root growth of most plants and the germination of most seeds are impossible. A horizon as cold as 5 ºC is a thermal pan to roots of most of the higher plants.

Biological processes in the soil are controlled in large measure by soil temperature and moisture. Each plant species has its own temperature requirements. In the Antarctic, for example, there is a microscopic plant that grows only at temperatures below 7 ºC, temperatures at which most other plants are inactive. At the other extreme, seed germination of many tropical plants requires a soil temperature of 24 ºC or higher. Plants have one or more soil-temperature requirements that are met by the soils of their native environment. Similarly, soil fauna have temperature requirements for survival. Soil temperature, therefore, has an important influence on biological, chemical, and physical processes in the soil and on the adaptation of introduced plants (Richards et al., 1952).

At any moment the temperature within a soil varies from horizon to horizon. The temperature near the surface fluctuates with the hours of the day and with the seasons of the year. The fluctuations may be very small or very large, depending on the environment. Because temperature is so variable, or perhaps because it is not preserved in samples, some pedologists have thought that it is not a property of the soil. Most of us who work with soils in a limited geographical area take soil temperature for granted because the temperatures of all the soils in a limited area are similar. We are all inclined to notice the properties that differ among soils and to focus our attention on them.

Each pedon has a characteristic temperature regime that can be measured and described. The temperature regimes are defined in *Soil Taxonomy* in terms of the mean annual soil temperature, the average seasonal fluctuations from that mean, and the mean warm or cold seasonal soil temperature at a point within the root zone.

In theory, every soil pedon has a mean annual temperature that is essentially the same in all horizons at all depths in the soil and at depths considerably below the soil. The measured mean annual soil temperature is seldom the same in successive depths at a given location, but the differences are so small that it seems valid and useful to take a single value as the mean annual temperature of a soil.

The mean annual soil temperature is related most closely to the mean annual air temperature, but this relationship is affected to some extent by the amount and distribution of rainfall and the amount of snow, the protection provided by shade and by the O horizons in forests, the slope aspect and gradient, and irrigation. Other factors, such as soil color, texture, and amount of organic matter, can also affect the soil temperature to a small degree (Soil Survey Staff, 1975).

Following is a description of the soil temperature regimes used in defining classes at various categoric levels in *Soil Taxonomy*. The temperature classes of Gelisols are excluded.

Cryic.—Soils in this temperature regime have a mean annual temperature lower than 8 ºC but do not have permafrost.[†]

1. In mineral soils the mean summer soil temperature (June, July, and August in the Northern Hemisphere and December, January, and February in the Southern Hemisphere) either at a depth of 50 cm from the soil surface or at a densic, lithic, or paralithic contact, whichever is shallower, is as follows:

    a. If the soil is not saturated with water during some part of the summer and

[†] *Soil Taxonomy* defines each soil temperature regime and temperature class to the nearest whole unit. Thus, because of rounding, a temperature described as less than 8 °C is actually less than 7.5 ºC. It can be argued that soil temperature should be defined to the nearest tenth of a degree C.

(1) If there is no O horizon: lower than 15 ºC; or
(2) If there is an O horizon: lower than 8 ºC; or

b. If the soil is saturated with water during some part of the summer and

(1) If there is no O horizon: lower than 13 ºC; or
(2) If there is an O horizon or a histic epipedon: lower than 6 ºC.

2. In organic soils the mean annual soil temperature is lower than 6 ºC.

For the most part, cryic soils in the conterminous United States occur at high altitudes. Soils with cryic temperature regimes in wooded ecosystems commonly have isotivity values (mean summer soil temperature minus mean winter soil temperature) of less than 6 ºC. Conversely, soils with cryic temperature regimes in alpine grass or sagebrush ecosystems commonly have isotivity values greater than 6 ºC. The monthly temperature signature of a cryic soil in Wyoming is shown in figure 5.1. For ease of comparison, this and all other graphic representations of temperature regimes are shown with a constant Y-axis of 0 to 35 ºC.

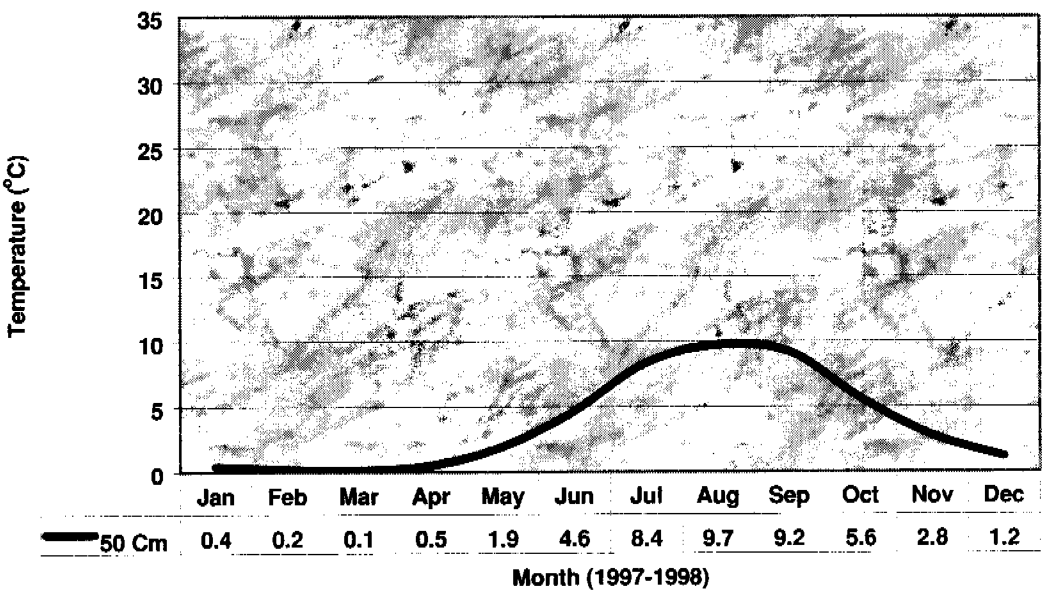


Figure 5.1.—A cryic temperature regime in a soil in Wyoming.

The concepts of the soil temperature regimes described below are used in defining classes of soils in the lower categories of *Soil Taxonomy.*

Frigid.—A soil with a frigid temperature regime is warmer in summer than a soil with a cryic regime, but its mean annual temperature is lower than 8 ºC and the difference between mean summer and mean winter (December, January, and February) soil temperatures is more than 6 ºC either at a depth of 50 cm from the soil surface or at a densic, lithic, or paralithic contact, whichever is shallower. An example of a soil with a frigid temperature regime from New Hampshire is shown in figure 5.2.

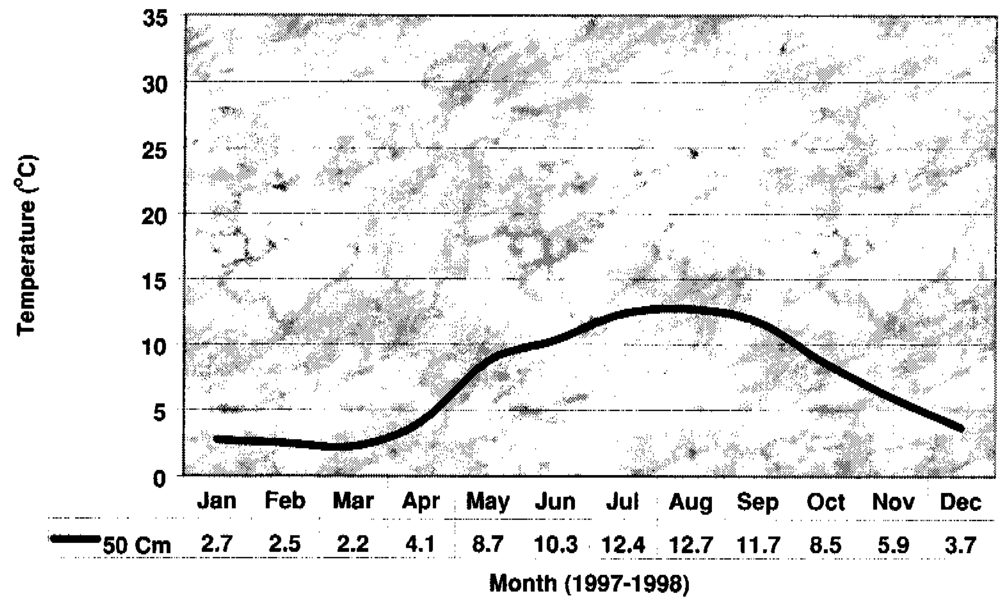


Figure 5.2.—A frigid temperature regime in a soil in Grafton County, New Hampshire.

Mesic.—The mean annual soil temperature is 8 ºC or higher but is lower than 15 ºC, and the difference between mean summer and mean winter soil temperatures is more than 6 ºC either at a depth of 50 cm from the soil surface or at a densic, lithic, or paralithic contact, whichever is shallower. An example from the Nebraska Sand Hills is shown in figure 5.3.

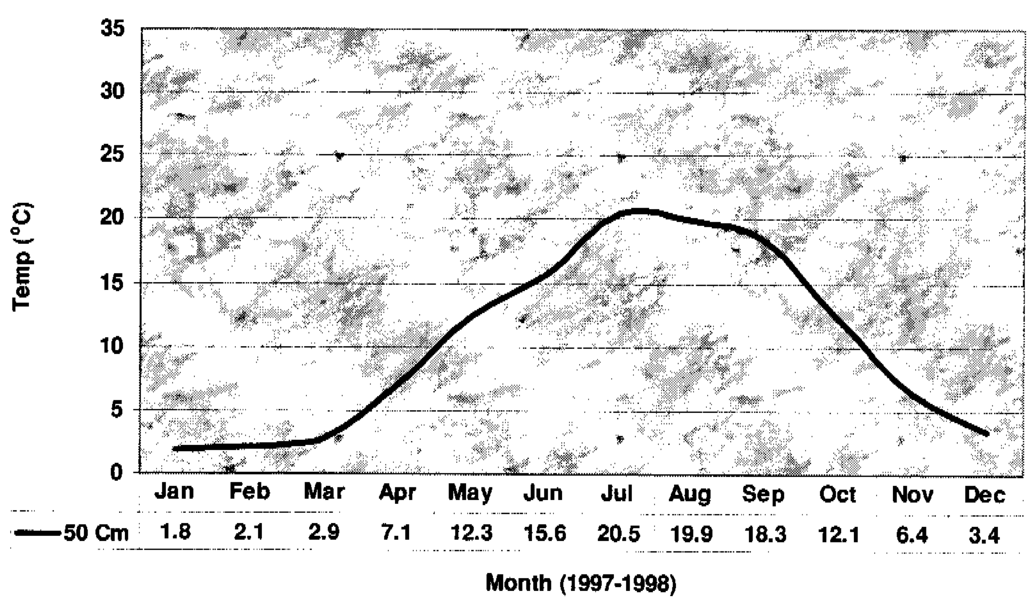


Figure 5.3.—A mesic temperature regime in a soil in the Sand Hills of Nebraska.

Thermic.—The mean annual soil temperature is 15 ºC or higher but is lower than 22 ºC, and the difference between mean summer and mean winter soil temperatures is more than 6 ºC either at a depth of 50 cm from the soil surface or at a densic, lithic, or paralithic contact, whichever is shallower. Soils with a thermic temperature regime are pervasive throughout the Southeast, including South Carolina (figure 5.4)

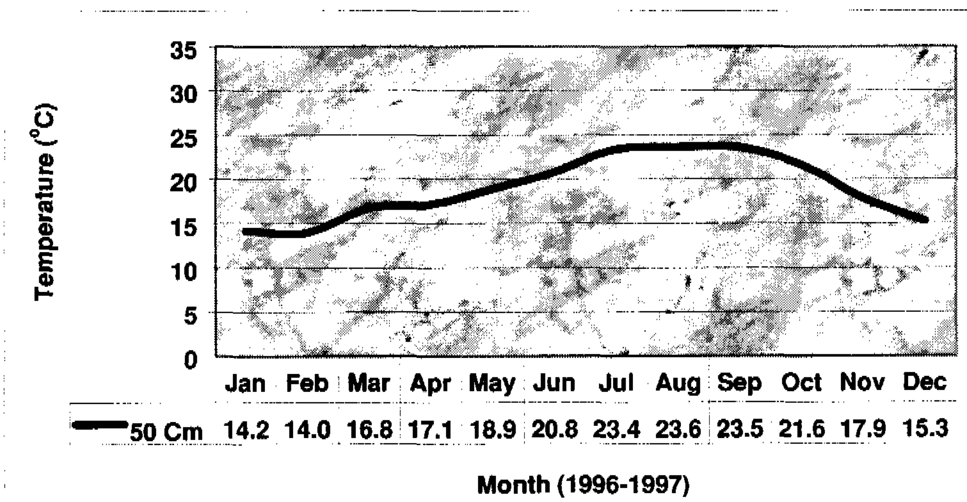


Figure 5.4.—A thermic temperature regime in a soil on Edisto Island, South Carolina.

Hyperthermic.—The mean annual soil temperature is 22 ºC or higher, and the difference between mean summer and mean winter soil temperatures is more than 6 ºC either at a depth of 50 cm from the soil surface or at a densic, lithic, or paralithic contact, whichever is shallower. An example of an Arizona soil with a hyperthermic temperature regime is shown in figure 5.5.

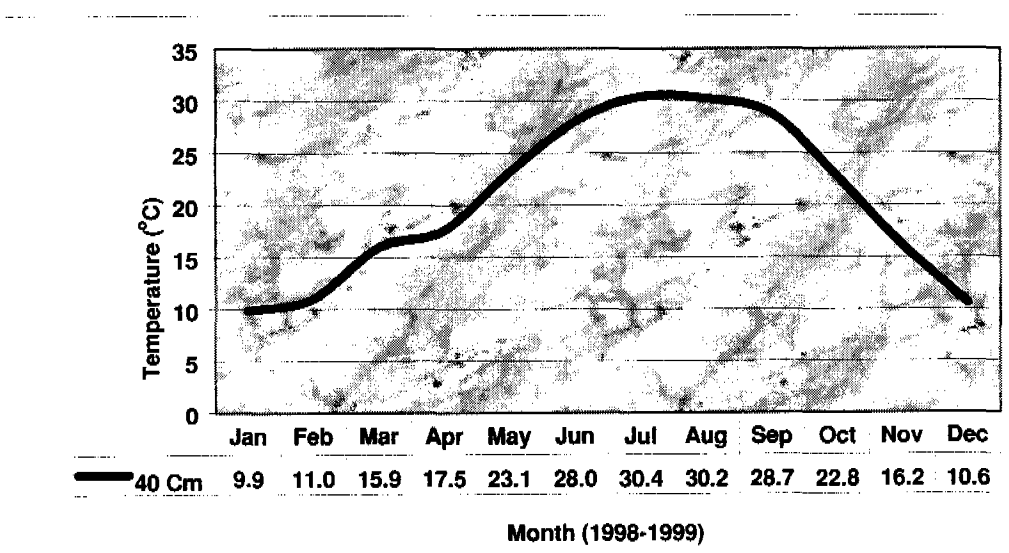


Figure 5.5.—A hyperthermic temperature regime in a soil in the Grand Canyon in Arizona.

Isofrigid.—The mean annual soil temperature is lower than 8 ºC. Isofrigid soils that do not meet the definition of cryic are rare. The only isofrigid site fully documented in the United States is in Idaho (figure 5.6).

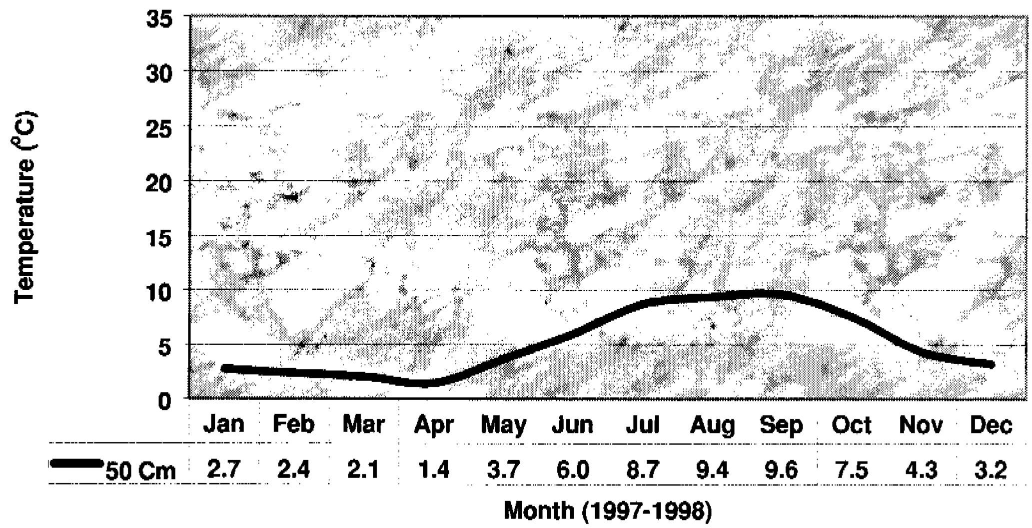


Figure 5.6.—Isofrigid temperature signature in a soil in Clearwater County, Idaho.

Isomesic.—The mean annual soil temperature is 8 ºC or higher but is lower than 15 ºC. Soils with an isomesic temperature regime are most common in the Tropics, though a few occur on the West Coast of the U.S. and one area occurs in eastern Tennessee. An example from Hawaii is shown in figure 5.7.

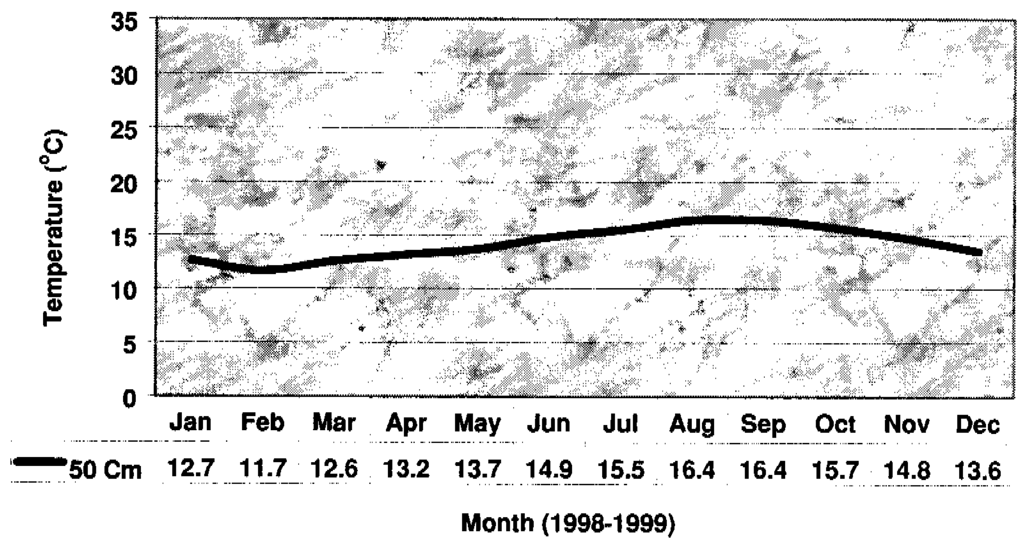


Figure 5.7.—Isomesic temperature signature of a soil on the Big Island of Hawaii.

Isothermic.—The mean annual soil temperature is 15 ºC or higher but is lower than 22 ºC. An example of the isothermic regime is shown in figure 5.8.

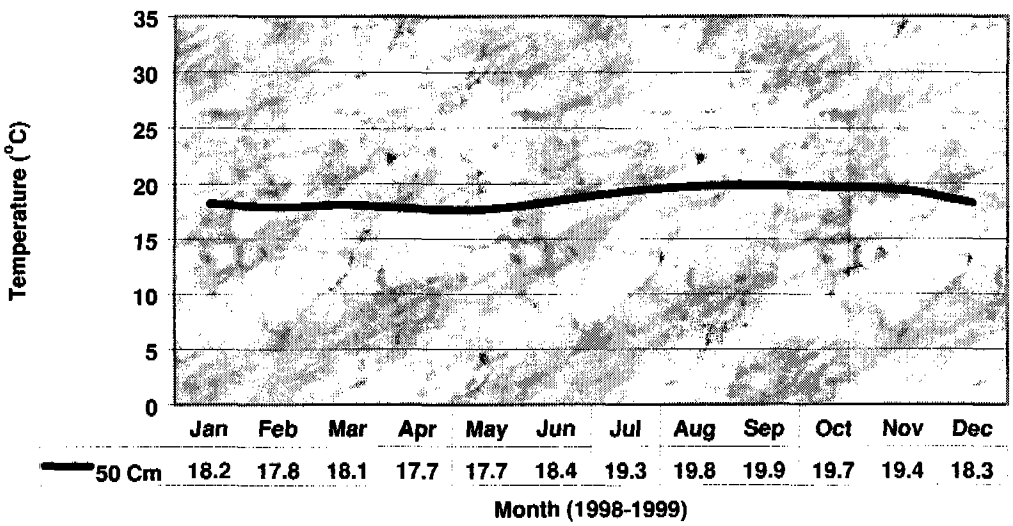


Figure 5.8.—Isothermic temperature signature of a soil in a rain forest on the Big Island of Hawaii.

Isohyperthermic.—The mean annual soil temperature is 22 ºC or higher. This temperature regime is most common in the Tropics (figure 5.9). The example of an isohyperthermic temperature regime in figure 5.9 is one where bedrock is at a depth of 30 cm. Consequently, that depth is the zone for determining the soil temperature regime.

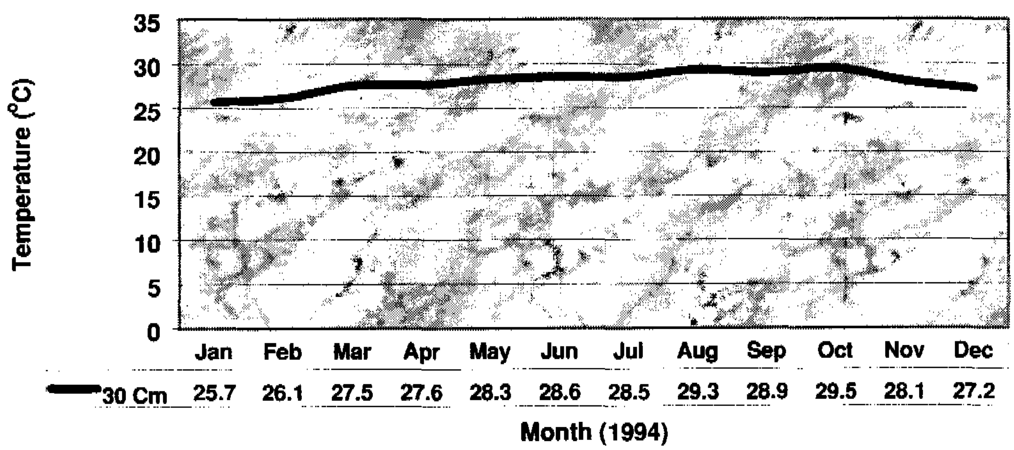


Figure 5.9.—Isohyperthermic temperature signature of a soil on St. John Island, Virgin Islands.

The monthly and seasonal differences among these examples are quite variable. The most extreme example is the soil with a mesic temperature regime from the Sand Hills of Nebraska. It is well known that the soils of the Midwest and High Plans have large isotivity values. Consequently, their soil temperature signatures exhibit these strong differences. *Soil Taxonomy* adequately provides for these differences.

Chapter 6

Soil Temperature Networks

Fully functional soil temperature networks, once rare in the United States, are now becoming commonplace. Currently, there are two noteworthy networks, one operated at by NRCS National Climate and Data Center in Portland, Oregon, and one operated by the National Soil Survey Center (NSSC) in Lincoln, Nebraska. The NSSC network is called the Remote Soil Temperature Network (RSTN).

For a network to be truly functional, it must have the following qualities—1) integration of all technology, 2) a collection interval of more than four times each day, 3) data available in database format and accessible in summarized format on the Internet, 4) documented soil and site information, and 5) site locations georeferenced in either latitude and longitude or UTM coordinates.

In 1995, the United States had 1,677 climate stations (NRCS Soil Climate Team, 1995). Attaining data from these sites is difficult. Some data are lost; other data are proprietary. Much of the collected data is suspect because of a lack of thermistor calibration.

The RSTN was established in 1996 as a part of the NRCS Global Change Initiative. The first application of the StowAway/Hobo temperature technology was in Finland during 1996. One PVC unit with loggers for air temperature and soil temperature was installed in Finnish Lapland during July 1996.

Other projects followed, including studies in Tennessee, South Carolina, West Virginia, New York, St. John Island in the Virgin Islands, Iowa, and Illinois in 1996; Idaho, Missouri, Nebraska, New Hampshire, western and central New York, New York City, North Carolina, Vieques Island off of Puerto Rico, Wyoming, and Virginia in 1997; Arizona, Arkansas, California, Colorado, the Big Island of Hawaii, Illinois, Nebraska, New Jersey, New York, North Carolina, Pennsylvania, Nevada, Florida, Tennessee, and Washington in 1998; and California, Connecticut, south Florida, northern Maine, southern Illinois, eastern Washington, and Nevada in 1999 (figure 6.1).

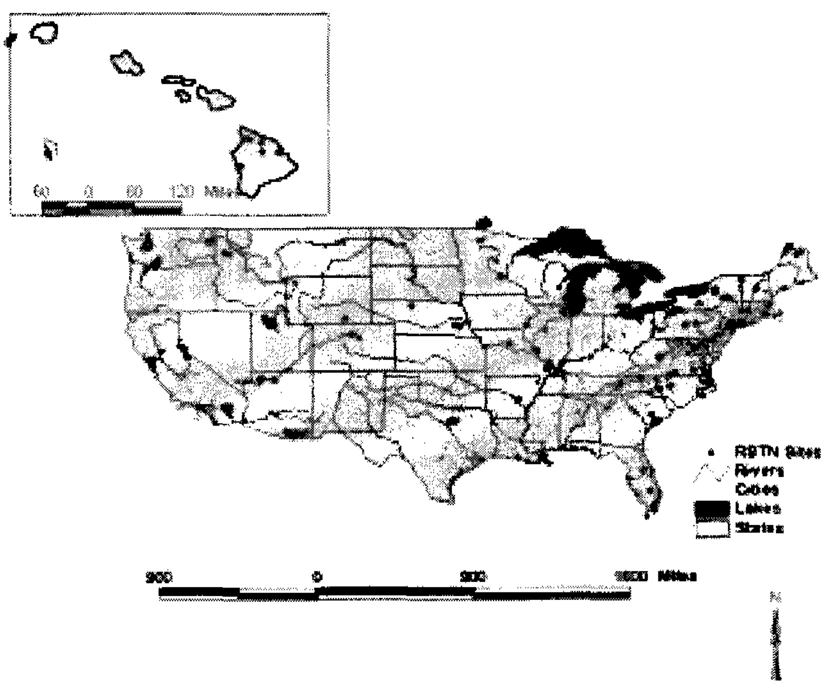


Figure 6.1.—Location of sites in the Remote Soil Temperature Network.

Before a study was initiated, its purpose was identified in consultation with scientists from the study area. Many of the studies were initiated to resolve soil temperature regime problems, but the technology transcends taxonomic classification purposes.

In addition to identifying the mean annual soil temperature at each site, the studies support other activities of the National Cooperative Soil Survey. These include:

1) *Major Land Resource Area coordination.*—The soil scientists in NRCS Major Land Resource Area Office 13 are using the data to correlate mesic and frigid soils in New York, Pennsylvania, West Virginia, and Tennessee.
2) *Documentation for scientific papers.*—NRCS soil scientists in Tennessee and South Carolina presented temperature data at meetings of the American Society of Agronomy in Baltimore during October 1998 (Mount et al., 1998, and McMillen et al., 1998).
3) *Training.*—Examples of the temperature data from the RSTN are presented to students at the Soil Correlation Course in Lincoln, Nebraska.
4) *NASIS data population.*—Within 2 years, enough soil temperature data will be collected to develop reliable rules for populating NASIS at each MO office.
5) *Information marketing.*—A brief paper on the RSTN was presented in the fall 1998 issue of *Soil Survey Horizons* (Mount, 1998). A more extended paper was presented in 1999 (Mount, 1999). Metadata and temperature summaries for 200 sites in the RSTN can be accessed on the NSSC home page under the Global Change selection of *National soil temperature tables* (www.statlab.iastate.edu/soils/nssc/temperature/rstn1.htm).
6) *Temperature definitions.*—Data collected in the RSTN will help define soil temperature regimes for the International Committee on Moisture and Temperature Regimes.

StowAway temperature loggers store a maximum of 1,800 data points during periods ranging from 15 minutes to 360 days. Prior to installation at most of the sites in the RSTN, StowAway temperature loggers were programmed to collect data every 4 hours and 48 minutes for 360 days. This frequency is the same as five times each day. The certified temperature accuracy of these temperature loggers is ±0.4 °C (±0.7 °F).

At each site, a 23-cm (9-in) PVC pipe with a 10-cm (4-in) diameter houses three StowAway temperature loggers and a desiccant pack to absorb excess moisture. Holes drilled in the PVC pipe allow 1.8-m (6-ft) sensor leads to exit outside while the temperature loggers are protected from the weather elements. A high-grade sealant is applied to the caps of the units to keep water from entering.

Site installation is initiated when a hole is dug with a sharpshooter to a depth of 50 cm (20 in). Site data are collected, and the soils are briefly examined for information that affects taxonomic classification. One temperature sensor lead is tied to a bush or sapling to capture air temperature. It is generally placed 0.9 to 1.2 m (3 to 4 ft) above the soil surface. Care is taken to position the sensor so that it is never exposed to direct sunlight and has free flow of air around it. Two soil temperature sensor leads are installed at each site, one at the 10-cm (4-in) soil depth and one at the 50-cm (20-in) soil depth. Finally, the PVC pipe is buried at about 10 cm and covered with soil.

After retrieval of the temperature loggers, data are off-loaded either near the study area or at the NSSC in Lincoln, Nebraska. Once off-loaded, the temperature signatures are examined for each of the sites (figure 6.2).

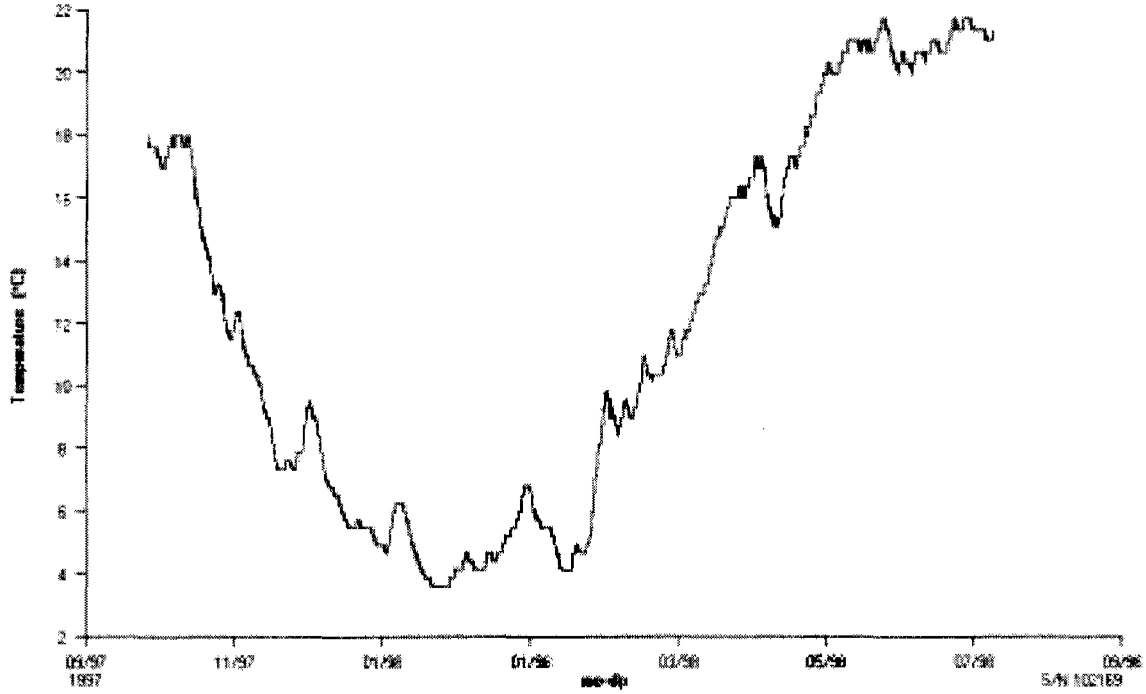


Figure 6.2.—Data are off-loaded into OnSet "dtf" files before being exported to Excel format. This example is from a soil in central Missouri.

Temperature measurements are time dependent. Consequently, they require a scientist to examine the data in a manner that differs from the method of examining data collected for depth to bedrock or thickness of an Ap horizon. The temperature data can be summarized through use of the statistics described in the following paragraphs.

We commonly use the average (mean) for a defined period of record. This record is normally 1 year. A standard deviation around the average can be calculated. In some cases, however, it has limited value.

The median, or calculated midpoint value for a data set, indicates if the data are skewed in any way. The median value is often used where the data are slightly skewed to the cool or warm side in the collection of all points.

The maximum value resolves the question of how warm the 50-cm soil depth gets, and the minimum value resolves the question of how cool the 50-cm soil depth gets.

Subtracting the minimum temperature value from the maximum temperature value allows a scientist to ascertain the maximum fluctuation of the soil temperature.

Air and soil temperature data for the RSTN are averaged by month, and an annual average is then determined and graphed in Microsoft Excel software (figure 6.3).

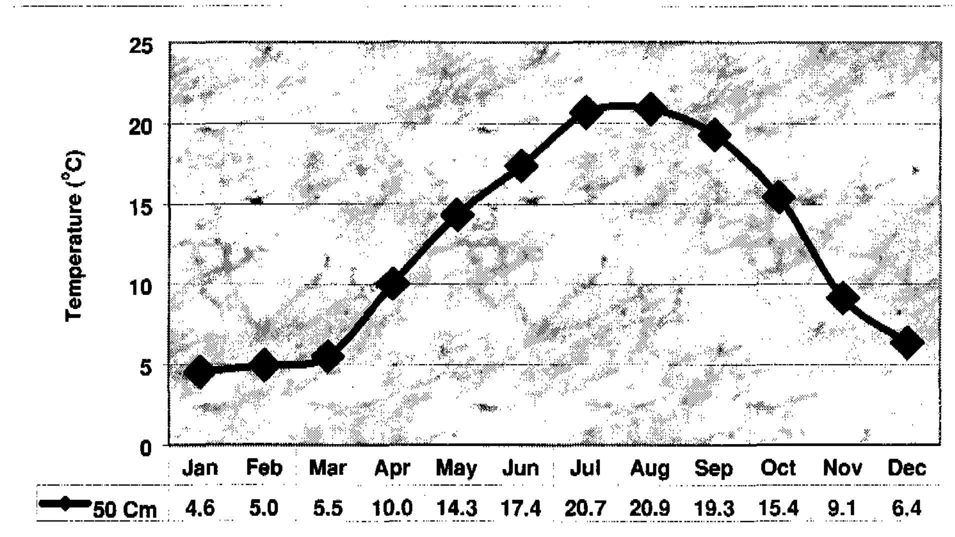


Figure 6.3.—Monthly soil temperature averages at 50 cm for a site in Missouri.

In addition to mean annual air temperature (MAAT) and mean annual soil temperature (MAST), a mean summer temperature (MST) and a mean winter temperature (MWT) are calculated for all sites in the RSTN (figure 6.4).

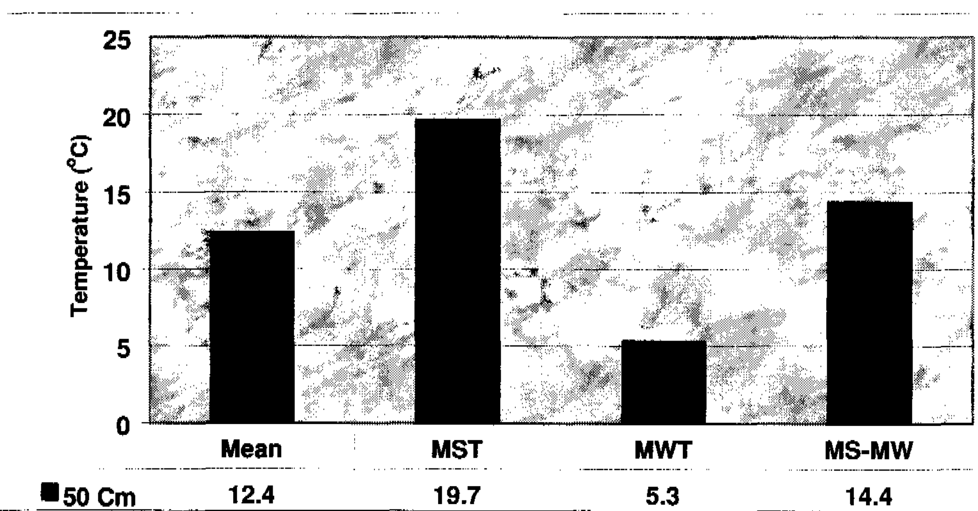


Figure 6.4.—An example of annual and seasonal analysis for soil temperature at 50 cm from a site in Missouri.

The MST is the average for all the readings during June, July, and August (in the Northern Hemisphere), while the MWT is the average for all the readings during December, January, and February. An *isotivity value*, or the difference between MST and MWT, is determined at each of the sites in the RSTN.

A consistent method is imperative for any soil temperature network. Each article in chapter 7 used methods and materials similar to those described in this chapter (chapter 6).

Chapter 7.01

The Influence of Aspect on Soil Temperature at Two Sites in Southern Arizona* †

ABSTRACT

Two sites at similar altitudes in southern Arizona were monitored for air and soil temperature during 1998 and 1999. The soil temperature at a depth of 50 cm was warmer for the south aspect than for the north aspect during each month of the study. Moreover, this difference was about the same amount for each month. The soil on the south aspect had a mean annual soil temperature that was 6.7 °C warmer at a depth of 10 cm and 6.0 °C warmer at a depth of 50 cm than the soil on the north aspect. This finding does not support the original field conjecture that the difference in mean annual soil temperature at 50 cm would be no more than 3.9 °C. The isotivity value (difference between mean summer and mean winter soil temperatures) is more expressed at 10 cm than at 50 cm. The maximum and minimum air temperature values were nearly the same at each site. The maximum air temperature was 37.78 °C (100.0 °F) for the north aspect and 37.83 °C (100.1 °F) for the south aspect. The minimum air temperature was -8.1 °C for the north aspect and -7.7 °C for the south aspect. It is presumed that the nominal difference in mean annual air temperature between the sites (11.9 vs. 13.4 °C) is a function of refractive heat bouncing off the soil surface and interacting with the sensor on the south aspect.

1. Background and Purpose

Aspect has been well documented as a major site factor influencing soil temperature (Soil Survey Staff, 1999, and Shul'gin, 1965). In studies of the East and Midwest regions of the United States, north-south aspect comparisons of mean annual soil temperature (MAST) reveal a difference of 0.5 to 2.2 °C (Mount, 1999).

In the Western United States, however, the differences in MAST for paired aspect sites can be large. On paired aspect sites in California, the difference in MAST is as much as 6.1 °C when the sites are examined with limited readings over a 2-year period (Arroures et al. 1999).

The primary purpose of this study in Arizona was to measure and analyze soil temperature at 10 sites during 1998 and 1999. These sites reflect the dominant climatic areas of Cochise, Santa Cruz, and Pima Counties. During this study, sites 5 and 6 were paired for MAST comparisons based on aspect. We expected that the difference in MAST could be as much as 3.9 °C. The aspect study at sites 5 and 6 was selected for formal presentation in this paper.

2. Study Area

Cochise County is in southeastern Arizona. It borders Mexico to the south and New Mexico to the east. Figure 7.01.1 shows the sites in the study area.

* Studies in chapter 7 are arranged alphabetically by state. Thirty-three studies from the United States and the Caribbean Area (Puerto Rico and the United States Virgin Islands) are presented.

† Phil Camp, NRCS State Soil Scientist in Phoenix, Arizona, and Don Breckenfeld, Cathy McGuire, and Bill Svetlik, NRCS Soil Scientists in Tucson, Arizona, helped prepare this section.

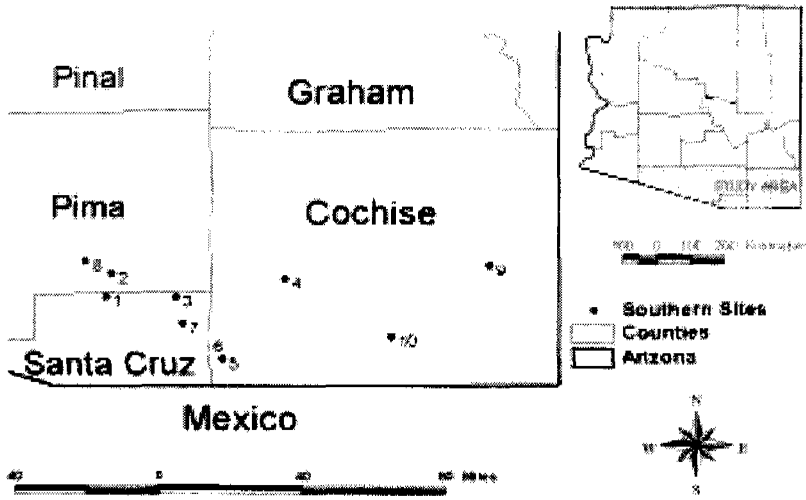


Figure 7.01.1.—Location of temperature sites in the study area.

Sites 5 and 6 are in the Coronado National Forest of Arizona. Site 5 is in forest land, and site 6 is in rangeland. The latitude of each site is about 31°27' north, and the longitude of each site is about 110°24' west. The elevation of the sites is 1,853 meters. Site 5 is on a 42 percent slope with a north aspect (figure 7.01.2). Site 6 is on a 24 percent slope with a south aspect (figure 7.01.3). The soil at site 5 is a fine-loamy, mixed, superactive, thermic Lithic Haplustalf, and the soil at site 6 is a loamy-skeletal, mixed, superactive, thermic Aridic Haplustalf (Soil Survey Staff, 1999). The vegetation on site 5 includes silverleaf oak (*Quercus spp. L.*), alligator juniper (*Juniperus spp. L.*), and Chihuahua pine (*Pinus spp. L.*) with a ground cover of bullgrass. The vegetation on site 6 includes Emory oak (*Quercus spp. L.*), pinyon pine (*Pinus spp. L.*), and Chihuahua pine with a ground cover of beargrass. Incoming solar radiation reaching the soil surface is estimated to be 50 percent at site 6. Moreover, the soil at site 6 does not have a leaf or needle litter and has about 50 percent cobbles and gravel at the soil-air interface.

Figure 7.01.2.—Site 5 has a north aspect and is covered with trees.

Figure 7.01.3.—Site 6 has a south aspect and is covered with grass and scrub vegetation.

3. Results

The annual temperature signature for the 10-cm depth at site 5 (figure 7.01.4) was averaged by month for figure 7.01.5.

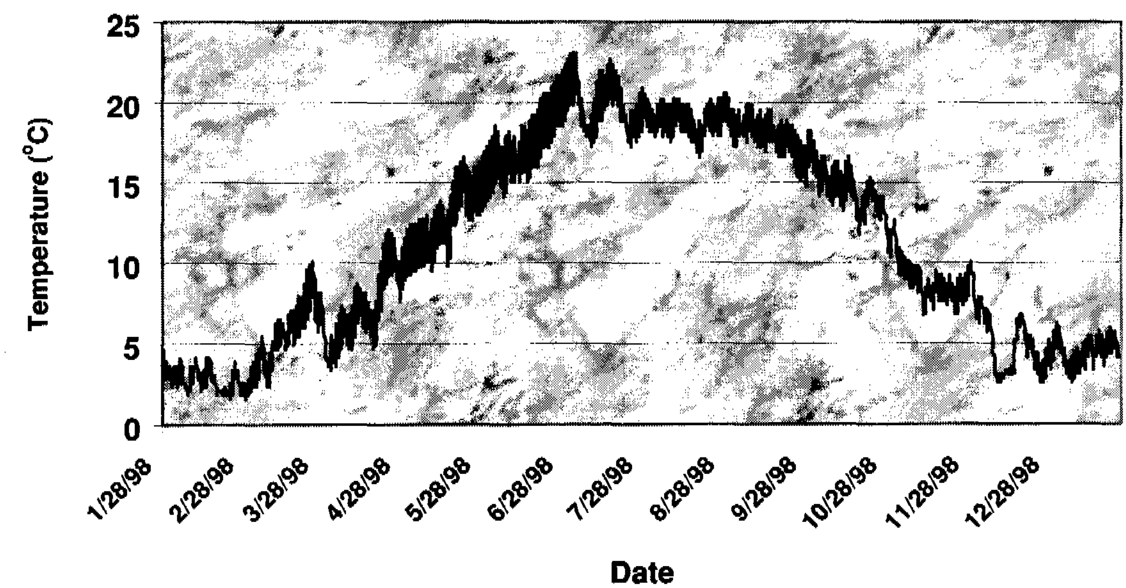


Figure 7.01.4.—Soil temperature signature of the 10-cm depth at site 5.

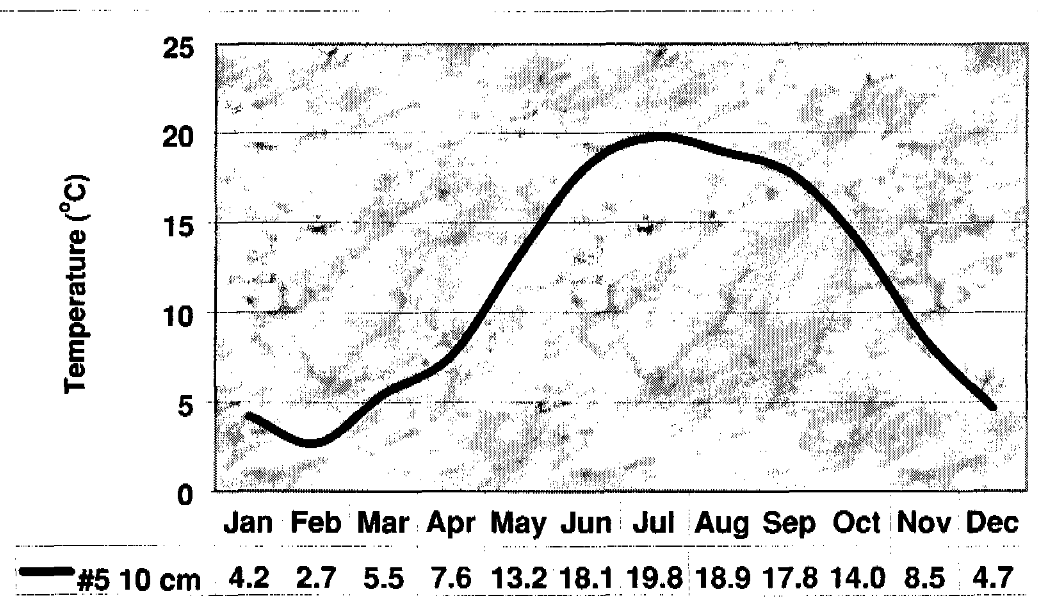


Figure 7.01.5.—Average monthly soil temperature for the 10-cm depth at site 5.

In addition to calculations of monthly and annual means for air temperature (MAAT) and soil temperature (MAST), a mean summer temperature (MST) and a mean winter temperature (MWT) were calculated so that the extreme seasonal variation at each of the sites can be determined (figure 7.01.6).

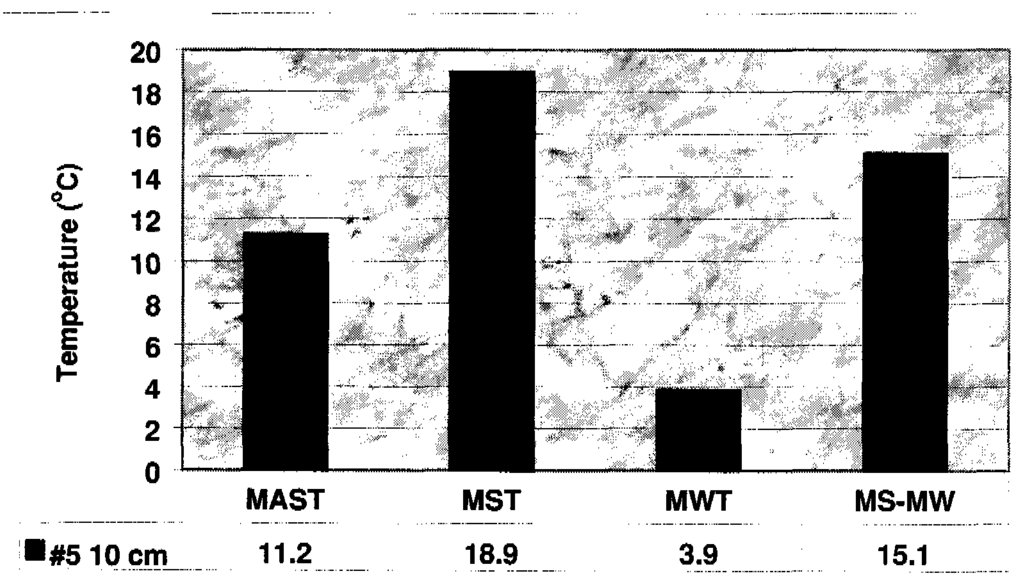
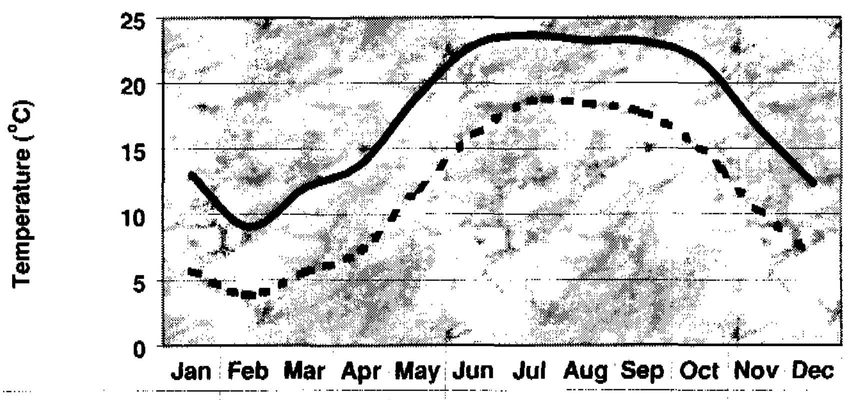


Figure 7.01.6.—Seasonal and annual analysis for the 10-cm depth at site 5.

The 50-cm monthly soil temperature analyses for sites 5 and 6 are shown in figure 7.01.7. The seasonal and annual analyses for both air and soil temperature are shown in table 7.01.1.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North #5	5.7	3.9	5.6	7.2	11.9	16.0	18.6	18.4	17.7	15.0	10.5	6.9
South #6	13.0	9.0	12.0	13.8	19.0	22.8	23.7	23.3	23.2	21.7	16.8	12.3

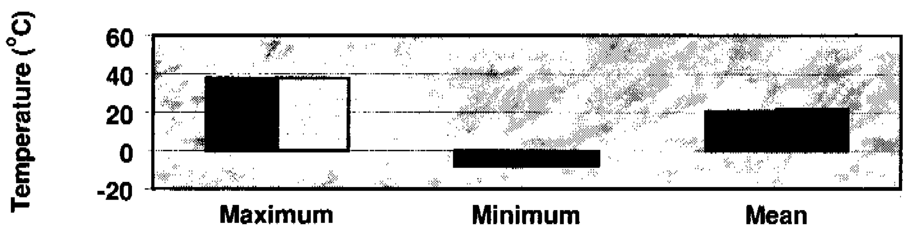
Figure 7.01.7.—*Comparison of monthly soil temperature averages between north and south aspect sites.*

Site 6 is warmer than site 5 for each month of the study (figure 7.01.7). Moreover, this difference is about the same amount for each month. Table 7.01.1 indicates that the south aspect (site 6) has a MAST that is 6.7 °C warmer at a depth of 10 cm and 6.0 °C warmer at a depth of 50 cm than the north aspect (site 5).

Table 7.01.1—Seasonal and annual temperature analysis (°C) for sites 5 and 6 in southern Arizona.

Analysis	Site 5 10 cm	Site 6 10 cm	Site 5 50 cm	Site 6 50 cm	Site 5 Air	Site 6 Air
Mean	11.2	17.9	11.5	17.5	11.9	13.4
MST	18.9	24.8	17.7	23.3	20.8	21.7
MWT	3.9	11.7	5.5	11.4	2.8	4.9
Isotivity	15.1	13.1	12.2	11.8	18.0	16.7

The difference between MAST and MAAT at site 5 is unusual. Normally, the MAAT is less than the MAST at any site (Soil Survey Staff, 1999). At site 5, the reverse was true. The maximum and minimum air temperature values, however, were nearly the same at sites 5 and 6. The maximum air temperature was 37.78 °C (100.0 °F) at site 5 and 37.83 °C (100.1 °F) at site 6 (figure 7.01.8).



	Maximum	Minimum	Mean
Site 5	37.8	-8.1	20.8
Site 6	37.8	-7.7	21.7

Figure 7.01.8.—Comparison of mean annual air temperatures for sites 5 and 6.

The minimum air temperature was -8.1 °C at site 5 and -7.6 °C at site 6. The reasons for the difference between the MAAT at sitès 5 and 6 (11.9 vs. 13.4 °C) are not known. In addition, more data are needed to assess the relationship between air and soil temperatures in southern Arizona.

Contrary to an original field hypothesis, the MAST at site 6 (on a south aspect) is more than 3.9 °C warmer than the MAST at site 5 (on a north aspect). The MAST for site 6 is 6.1 °C warmer at a depth of 50 cm than the MAST for site 5. The isotivity values are more expressed at 10 cm than at 50 cm. It is presumed that the nominal difference in MAAT between the sites is a function of refractive heat bouncing off the soil surface and interacting with the sensor at site 6.

Acknowledgment

Chuck Peacock, NRCS Soil Scientist in Globe, Arizona, provided assistance during the installation phase of the study.

Chapter 7.02

Quantification of Soil Temperature Extremes for Arizona's Grand Canyon*

ABSTRACT

Ten sites were monitored in the Grand Canyon of Arizona for air and soil temperature during 1998 and 1999. Three sites were shaded by forest species, and seven were in the desert ecosystem of Whitmore Canyon. Altitudes ranged from 500 to 2,793 meters, and slopes ranged from 1 to 20 percent. Air temperature signatures indicate that snow cover did not impact air temperature readings at sites 1 to 3. Air temperature was warmer at sites 4 to 10 in Whitmore Canyon on a monthly, seasonal, and annual basis. Sites 1 and 2 averaged below 0 °C during the winter months. The air temperature at 1,890 m is transitional to the forested soils at 2,793 and 2,539 m and to the desert soils in Whitmore Canyon. For the 10-cm soil depth, site 4 at 500 m had the warmest single reading (46.9 °C). The soil at 2,793 m is the coldest in the study area. With a MAST of 4.9 °C, it has a frigid temperature regime. With an isotivity of 9.6 °C, it also has the lowest isotivity value (difference in mean summer and mean winter soil temperatures). The soil at 2,539 m is 1.9 °C warmer than the soil at 2,793 m but also is frigid. With a MAST of 9.1 °C, the soil at 1,890 m is mesic. The soils at 500 and 774 m are hyperthermic because their MAST is more than 22 °C. They also have the warmest summer soil temperatures. The soil at 1,049 m has a MAST that is 0.9 °C warmer than that of the soil at 1,042 m. Both soils have a thermic temperature regime. The soils at three sites ranging from 1,170 to 1,558 m are thermic. Analysis of extreme temperatures showed that the minimum reading at 10 cm was -2.4 °C at site 9, followed by -1.9 °C at site 1. The soils on 6 of the 10 sites froze at 10 cm during the period of record. The highest isotivity value at 10 cm was 47.9 °C for the soil at 1,475 m in Whitmore Canyon. The deepest soil temperature summaries show that the soil at 774 m had the warmest temperature (37.0 °C) while the soil at 2,793 m had the coldest temperature (0.2 °C). Curiously, the extreme isotivity value occurred for the soil at 1,170 m (29.8 °C). Six of the ten sites exhibited large variations in air and soil temperatures. Results of field hypotheses were mixed. Onsite estimates require temperature data to confirm annual soil temperature regimes. The results of sine wave analysis suggest that the soil temperature at sites 2, 3, and 10 cycle in a mathematical order from year to year. This order helps scientists to approximate temperatures at these sites.

1. Background and Purpose

Designing a study to monitor the essential factors that affect mean annual soil temperature is difficult. In addition to aspect, altitude, and slope, such factors as vegetative cover, particle-size class, and the presence or absence of a water table should be considered. Combination and/or interdependency of all these factors should be considered before a study can be designed to capture the pattern of soil temperature across a soil survey area. Such was the challenge of the temperature study for the Grand Canyon National Park in Arizona. This study was funded as part of the NRCS Global Change Initiative.

The primary purpose of this study was to measure and analyze soil temperature during 1998 and 1999 at 10 sites reflecting the dominant climatic areas of the Grand Canyon National Park. The sites were selected to maximize the extreme differences in altitude and aspect in the park. Temperature data were deemed necessary to quantify the soil temperature extremes for Arizona's Grand Canyon and to assist in correlation of the soil temperature regimes for the ongoing NRCS soil survey.

* Phil Camp, NRCS State Soil Scientist, Phoenix, Arizona, helped prepare this section.

2. Study Area and Hypotheses

The study area is within the confines of the Grand Canyon National Park. The park is in parts of Coconino and Mohave Counties in northwest Arizona and borders Utah to the north and Nevada to the west. Sites 1 and 2 are in Coconino County, and sites 3 to 10 are in Mohave County. Extensive metadata were collected at each site (table 7.02.1).

Table 7.02.1.—Site and soil information for the study area.

Site no.	Latitude (north)	Longitude (west)	Elevation (m)	Slope (%)	Aspect (°)	Surface rocks (%)	Bedrock depth (cm)
1	36°19'45"	112°06'05"	2,793	1	90	1	>50
2	36°12'47"	112°03'41"	2,539	4	180	10	>50
3	36°21'21"	112°07'14"	1,890	2	135	80	>50
4	36°09'06"	113°11'59"	500	1	180	0	>50
5	36°09'08"	113°12'15"	774	1	180	70	40
6	36°09'08"	113°12'15"	1,049	18	290	75	40
7	36°11'30"	113°13'45"	1,042	6	110	65	45
8	36°12'07"	113°10'35"	1,558	20	180	80	>50
9	36°12'02"	113°11'29"	1,475	15	180	75	40
10	36°12'43"	113°12'48"	1,170	4	90	30	35

Site 1 is on the Little Park Lake USGS Quad. It is near a fire tower and is 21 meters from the edge of a cabin. The vegetation on this site consists of Douglas-fir (*Pseudotsuga spp. L.*) and quaking aspen (*Populus tremuloides L.*) with a ground cover of dryland sedge (*Carex spp. L.*). The soil is a coarse-loamy, mixed, active, frigid Typic Haplustept (Soil Survey Staff, 1999). The texture is fine sandy loam throughout the profile, and the soil has a 2-cm-thick, very dark brown (10YR 2/2) humus layer overlying mineral soil. This site was thought to be the coldest of the sites in the study area. The mean annual soil temperature (MAST) was expected to be above 0 °C, and the mean summer soil temperature (MST) was presumed be more than 7 °C.

Site 2 is on the Bright Angel Point USGS Quad. It is 34 meters east of the adjacent ranger station. The vegetation on this site consists of blue spruce (*Picea spp. L.*), quaking aspen (*Populus tremuloides L.*), and ponderosa pine (*Pinus ponderosa L.*) with a ground cover of squirreltail. The soil is a coarse-loamy, mixed, active, frigid Typic Haplustoll and is covered with a thin layer of litter. It was expected to be frigid.

Site 3 is on the Mt. Trumbull Southeast USGS Quad and is adjacent to an Indian kiva ruin. The vegetation on this site consists of pinyon pine (*Pinus spp. L.*) with a ground cover of penstamon (*Penstamon spp. L.*), pricklypear (*Opuntia spp. L.*), big sage (*Artemisia spp. L.*), and birdbeak. The soil is an ashy over fragmental, mixed, superactive, mesic Vitrandic Haplocambid. It was expected to be mesic.

Site 4 is on the Whitmore Rapids USGS Quad. It is at the bottom of the Grand Canyon and about 15 meters above the Colorado River. The vegetation on this site is 80 percent pricklypear (*Opuntia spp. L.*), creosotebush (*Larrea tridentata L.*), and sixweeks fescue (*Festuca spp. L.*). The soil is a calcareous, superactive, hyperthermic Fluventic Torripsamment. It was expected to be the warmest soil in the study area and to have a hyperthermic soil temperature regime (Soil Survey Staff, 1999).

Site 5 is also on the Whitmore Rapids USGS Quad. It is in Whitmore Canyon and within 17 meters of the escarpment of the North Rim. The vegetation on this site is creosotebush (*Larrea tridentata L.*), sixweeks fescue (*Festuca spp. L.*), beavertail cactus, blackbrush, and barrel cactus (*Ferocactus spp. L.*). The soil is a loamy-skeletal, carbonatic, superactive, thermic Petrocalcic Haplocalcid. It was expected to have a MAST of about 22 °C.

Site 6 is on the Whitmore Rapids USGS Quad and is in Whitmore Canyon. The vegetation on this site is creosotebush (*Larrea tridentata L.*), bursage, black ratany, snakeweed, and barrel cactus

(*Ferocactus spp. L.*). The soil is a loamy-skeletal, calcareous, superactive, thermic Calcic Petrocalcid. Site 6 was paired with site 7 and was expected to be 1 °C warmer.

Site 7 is within 180 meters of site 6. The vegetation on site 7 is green ephedra (*Ephedra spp. L.*), Nevada ephedra (*Ephedra spp. L.*), and broom snakeweed. Catsclaw acacia (*Acacia spp. L.*) is within 30 meters of the site. The soil is a loamy-skeletal, calcareous, superactive, thermic Calcic Petrocalcid. It has violent effervescence when hydrochloric acid is added.

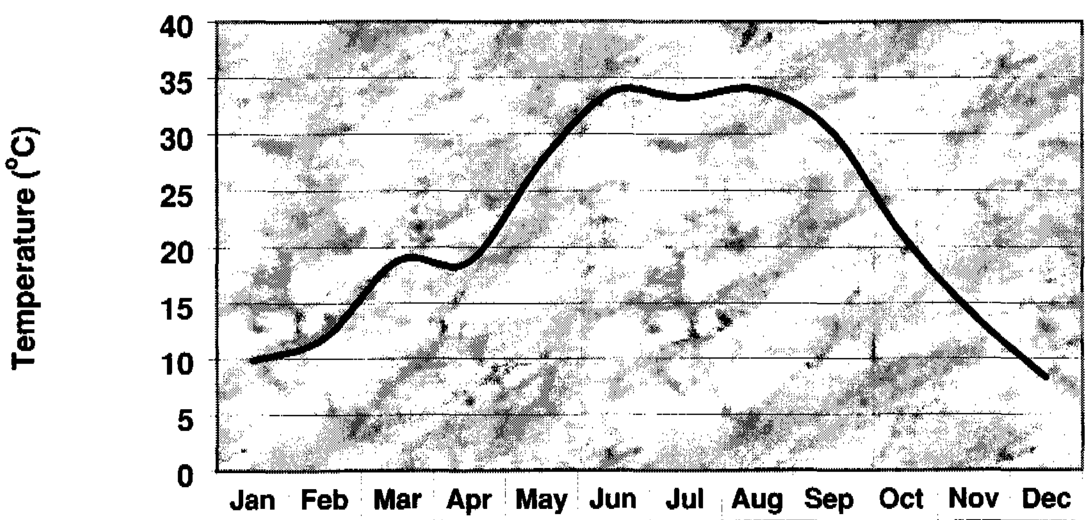
Site 8 is on the Whitmore Rapids USGS Quad and in Whitmore Canyon. It is on a prominent cinder cone. The vegetation on this site is Wyoming big sage (*Artemisia spp. L.*), banana yucca (*Yucca spp. L.*), Nevada ephedra, and fluffgrass. The soil is an ashy-skeletal over fragmental, mixed, superactive, mesic Vitrandic Haplocambid. This site was thought to be mesic.

Site 9 is on the Whitmore Rapids USGS Quad and in Whitmore Canyon. The vegetation on this site consists of banana yucca, beavertail cactus, broom snakeweed, tubosa grass, and wire grass. The soil is a loamy-skeletal, carbonatic, superactive, mesic Typic Haplocambid with a yellowish brown color (10YR 5/4) throughout. This site was thought to be mesic.

Site 10 is also on the Whitmore Rapids USGS Quad and in Whitmore Canyon. The vegetation on this site is agave (*Agave spp. L.*), oak (*Quercus spp. L.*), and stipa grass. The soil is a coarse-loamy, mixed, active, thermic Lithic Haplocambid. About 80 percent of the site is rock outcrop. This site was thought to have a thermic temperature regime.

3. Results

Figure 7.02.1 shows the average monthly soil temperature for the 10-cm depth at site 5. Figure 7.02.2 shows the seasonal and annual analysis.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10 cm	9.8	11.9	18.8	18.7	27.5	33.8	33.2	34.0	30.4	21.2	13.9	8.2

Figure 7.02.1.—Average monthly soil temperature for the 10-cm depth at site 5.

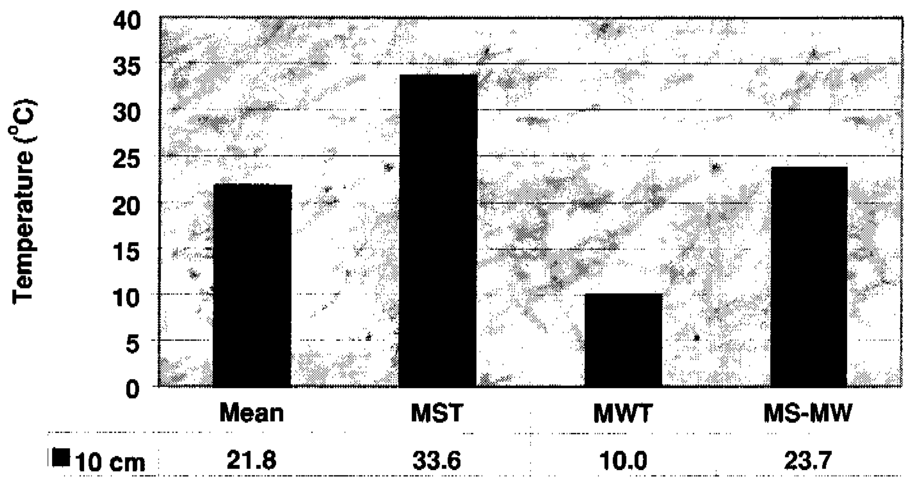


Figure 7.02.2.—Seasonal and annual analysis for the 10-cm depth at site 5.

Air temperature.—Monthly, seasonal, and annual air temperature summaries are shown in table 7.02.2. Snow cover did not impact air temperature readings at sites 1 to 3. Air temperature was warmer at sites 4 to10 in Whitmore Canyon on a monthly, seasonal, and annual basis. Sites 1 and 2 averaged below 0 °C during the winter months. The air temperature at site 3 is transitional to the forested soils at sites 1 and 2 and the desert soils in Whitmore Canyon.

Table 7.02.2.—Monthly, seasonal, and annual air temperatures (°C) for the study area.

Analysis	Site 1	Site 2	Site 3	Site 5	Site 6	Site 7	Site 10
Jan 99	-2.3	-1.2	0.7	9.5	6.7	6.1	6.7
Feb 99	-1.7	-0.8	1.7	11.6	9.2	8.6	8.7
Mar 99	1.8	3.3	6.4	17.9	15.0	14.4	13.3
Apr 99	0.4	1.6	6.0	16.7	13.3	13.8	12.6
May 99	8.1	8.7	14.8	25.7	23.0	22.4	21.4
Jun 99	12.9	13.9	20.5	31.6	29.0	28.4	27.5
Jul 99	14.4	15.5	21.5	31.9	28.9	28.7	27.7
Aug 99	13.4	14.6	20.3	32.4	29.3	28.5	27.8
Sep 99	11.1	11.6	16.6	28.9	26.0	26.0	24.1
Oct 98	3.7	5.2	7.5	19.6	16.7	16.0	16.1
Nov 98	0.0	1.0	2.4	12.8	10.4	9.3	9.5
Dec 98	-3.6	-2.7	-1.2	7.9	5.0	4.5	4.6
Mean	4.8	5.9	9.8	20.5	17.7	17.2	16.7
MST	13.5	14.7	20.7	32.0	29.1	28.5	27.7
MWT	-2.5	-1.6	0.4	9.7	7.0	6.4	6.7
Isotivity	16.1	16.2	20.3	22.3	22.1	22.1	21.0

Soil temperature at 10 cm.—Table 7.02.3 shows that the soil at site 1 was the only soil that had freezing MWT values (-0.1 °C) and was marginally colder than the soil at site 2 (0.0 °C). Sites 4 to 10 in Whitmore Canyon averaged 6 to 10 °C warmer than sites 1 and 2 during the winter months and also were warmer during the summer months.

Site 4 at the bottom of the Grand Canyon was the warmest soil and had the greatest diurnal activity (figure 7.02.3). This soil warmed considerably during the daylight hours and reached a maximum at 47.0 °C.

Table 7.02.3.—Monthly, seasonal, and annual soil temperatures (°C) for the 10-cm depth.

Analysis	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Jan 99	-0.4	-0.3	0.8	8.4	9.8	8.8	6.9	6.3	7.2	8.9
Feb 99	-0.1	-0.1	0.9	12.1	11.9	11.0	9.6	8.0	8.2	10.4
Mar 99	-0.1	2.1	5.2	20.3	18.8	18.8	16.2	13.9	13.7	16.5
Apr 99	0.8	3.3	5.4	20.3	18.7	17.9	16.4	13.2	12.4	15.6
May 99	5.6	8.9	11.4	29.2	27.5	26.6	25.4	20.5	20.0	23.4
Jun 99	9.5	12.8	16.8	36.2	33.8	31.4	30.7	25.9	25.7	28.8
Jul 99	13.0	16.1	19.7	34.7	33.2	31.6	30.5	27.6	26.4	30.1
Aug 99	12.8	16.0	18.4	34.8	34.0	32.4	31.1	28.2	27.6	30.8
Sep 99	11.0	13.9	15.6	31.9	30.4	29.6	27.5	25.4	25.0	27.9
Oct 98	5.2	6.9	8.8	22.1	21.2	20.7	18.5	16.7	17.2	19.1
Nov 98	1.4	2.0	2.9	13.7	13.9	13.0	10.9	9.8	10.6	12.2
Dec 98	0.2	0.3	0.1	7.4	8.2	7.4	5.6	4.7	5.8	7.3
Mean	4.9	6.8	8.8	22.6	21.8	20.8	19.1	16.7	16.7	19.2
MST	11.8	15.0	18.3	35.2	33.6	31.8	30.8	27.2	26.6	29.9
MWT	-0.1	0.0	0.6	9.3	10.0	9.0	7.4	6.3	7.1	8.8
Isotivity	11.9	15.0	17.7	25.9	23.7	22.8	23.4	20.9	19.5	21.1

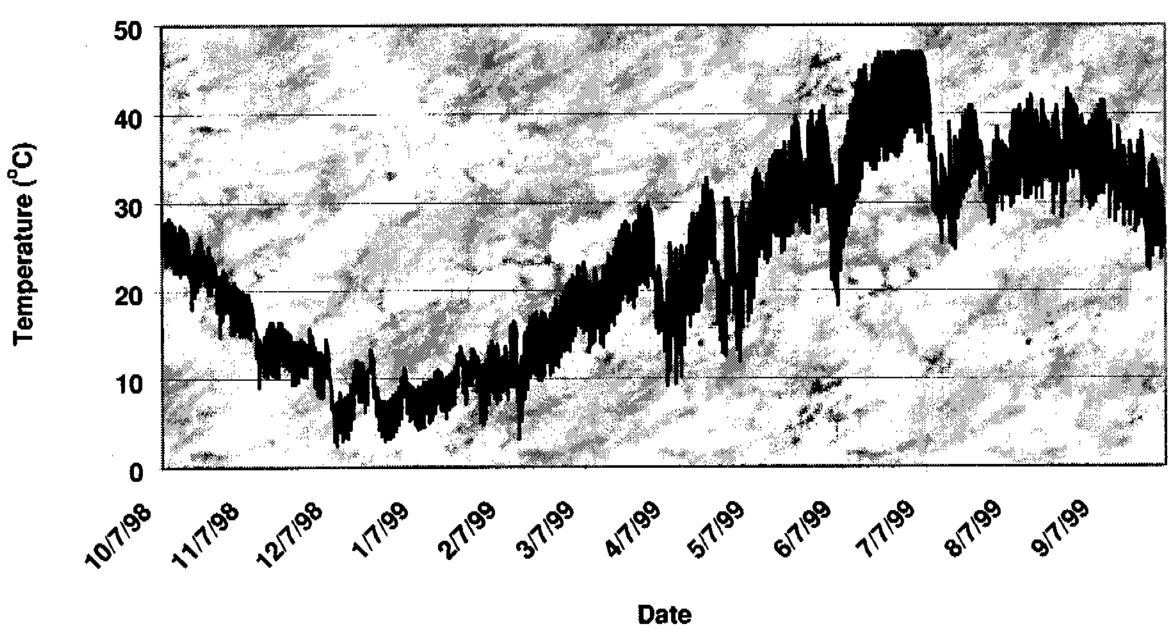


Figure 7.02.3.—Annual signature displaying maximum readings of the 10-cm depth at site 4 during July.

Soil temperature at deepest measured depth.—Monthly, seasonal, and annual soil temperature summaries for the deepest measured depth are shown in table 7.02.4. This depth is either 50 cm or the depth to bedrock.

Table 7.02.4.—Monthly, seasonal, and annual soil temperatures (°C) for the deepest measured depth.

Analysis	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Jan 99	0.5	1.1	2.5	11.1	11.6	9.9	8.4	9.6	9.2	9.2
Feb 99	0.3	1.1	2.2	13.2	12.9	11.0	9.9	9.7	9.6	10.4
Mar 99	0.4	1.9	4.6	18.5	18.7	15.9	15.2	13.6	14.1	16.1
Apr 99	1.0	3.4	5.7	20.5	19.8	17.5	16.8	14.4	14.8	16.7
May 99	4.2	6.9	9.1	25.1	26.1	23.0	22.7	18.4	19.7	22.6
Jun 99	7.9	10.6	13.3	29.8	31.7	28.0	27.8	22.9	24.7	28.1
Jul 99	11.4	14.1	17.6	32.5	33.3	30.4	30.0	26.2	27.6	29.7
Aug 99	11.7	14.5	17.2	31.9	33.5	30.2	29.9	26.5	27.9	30.2
Sep 99	10.9	13.5	16.0	30.6	31.5	28.7	28.1	25.7	27.1	28.1
Oct 98	6.3	8.4	11.3	23.8	23.8	22.8	21.1	19.9	20.6	19.1
Nov 98	2.7	3.9	6.5	17.4	16.9	16.2	14.4	14.6	14.7	12.2
Dec 98	1.3	2.1	3.3	11.9	11.1	10.6	8.8	9.9	9.6	8.0
Mean	4.9	6.8	9.1	22.2	22.6	20.3	19.4	17.6	18.3	19.2
MST	10.3	13.0	16.1	31.4	32.8	29.5	29.2	25.2	26.7	29.4
MWT	0.7	1.4	2.7	12.1	11.9	10.5	9.0	9.7	9.5	9.2
Isotivity	9.6	11.6	13.4	19.3	20.9	19.0	20.2	15.5	17.2	20.2

The soil at site 1 was the coldest in the study area. With a MAST of 4.9 °C, it has a frigid temperature regime. It also has the lowest measured isotivity value (9.6 °C). The soil at site 2 is 1.9 °C warmer but also has a frigid temperature regime. With a MAST of 9.1 °C, the soil at site 3 is the only one to have a mesic temperature regime. Sites 4 and 5 are hyperthermic. They also have the warmest MST. The MAST of the soil at site 6 is 0.9 °C warmer than that of the soil at site 7. The soils at both sites have a thermic temperature regime. The soils at sites 8, 9, and 10 also have a thermic temperature regime.

Air and soil temperature extremes for the Grand Canyon.—Monthly, seasonal, and annual soil temperature summaries for the deepest measured depth are shown in table 7.02.5. This depth is either 50 cm or the depth to bedrock.

Table 7.02.5.—Monthly, seasonal, and annual soil temperature extremes (°C) for the deepest depth.

Analysis	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Air max	29.7	28.9	37.8	---	***47.0***	46.9	44.0	---	---	43.9
Air min	***-18.1***	-16.5	-16.5	---	-2.4	-6.8	-7.4	---	---	-7.3
Max-min	47.7	45.4	***54.3***	---	49.4	53.7	51.4	---	---	51.2
10 cm max	17.0	21.4	27.2	***46.9***	45.5	45.5	44.8	39.1	45.5	37.8
10 cm min	-1.9	-0.9	-3.8	2.4	2.7	0.9	-0.6	-0.2	***-2.4***	2.4
Max-min	18.9	22.3	31.1	44.5	42.8	44.6	45.5	39.3	***47.9***	35.4
Deep max	12.5	15.4	18.3	34.3	***37.0***	32.9	33.4	28.0	30.1	34.3
Deep min	***0.2***	0.8	1.9	9.8	8.8	8.5	6.6	8.0	7.2	4.5
Max-min	12.4	14.6	16.4	24.5	28.2	24.4	26.8	20.0	23.0	***29.8***

Because of vermin activity, seasonal and annual air temperature summaries were not available for sites 4, 8, and 9. Of the remaining sites, site 5 had the warmest single reading (47.0 °C). Site 1, at an altitude of 2,793 meters, had the lowest single air temperature reading (-18.1 °C). The difference between the maximum and minimum air temperature readings (the maximum minus the minimum) was greatest (54.3 °C) at site 3.

For the 10-cm soil depth, site 4 had the warmest reading (46.9 °C). The minimum reading at 10 cm was -2.4 °C at site 9, followed by -1.9 °C at site 1. Data confirm that 6 of the 10 sites froze at 10 cm during the period of record. The extreme isotivity value at 10 cm was 47.9 °C at site 9 in Whitmore Canyon.

Summaries of the deepest soil temperature show that site 5 had the warmest temperature reading (37.0 °C) while site 1 had the coldest temperature reading (0.2 °C). Curiously, the extreme isotivity value occurred for the soil at site 10 (29.8 °C). Table 7.02.5 shows that 6 of the 10 sites had extreme air and soil temperature values.

During the installation phase of this study, we predicted some results for each site. We expected site 1 to be the coldest in the study area. With a MAST of 4.9 °C, this site is the coldest. We predicted that the MAST at site 2 would be about 8 °C. The MAST was only 6.8 °C. Since soil mapping had followed this predicted pattern, there could be more hectares of soil with a frigid temperature regime than was originally thought.

The soil at site 3 was expected to have a MAST of about 11 °C. The MAST was only 9.1 °C. This site is mesic.

The temperature prediction for site 4 was partially true. We expected this site to have a hyperthermic temperature regime (true) and the warmest MAST in the study area (false). Site 5 has the warmest MAST in the study area (22.5 °C). The expected MAST (22.6 °C) at this site is within ±1 °C of the measured MAST.

Predictions for site 6 were better because the soil at site 6 was 0.9 °C warmer than that at site 7. Data from these paired sites show aspect dependency of soil temperature between east-and west-facing slopes but not nearly as great as that between north- and south-facing slopes.

At site 8, the MAST was 17.6 °C, which is 3.6 °C warmer than the estimated 14 °C. This site has a south aspect. It is possible that the north-facing slope of this cinder cone is mesic. Site 9 was predicted to have a MAST of 14 °C. Its MAST is 18.3 °C, more than 4 °C warmer than was expected. We expected that the soil at site 10 would have a thermic temperature regime (MAST >15 °C). The MAST at site 10 was 19.2 °C, much warmer than was expected.

4. Sine Wave Analysis

All soils have a distinct annual temperature signature at the 50-cm depth or at a shallower depth if bedrock is within 50 cm. Soil temperature fluctuates slowly at 50 cm, and changes normally require a few days to increase or decrease. For the 10 sites in the study area, evaluations of soil temperature signatures at 50 cm were made to ascertain if the sites fit a sine wave formula. TableCurve 2D version 5 was used for this analysis. An Excel file containing annual temperature data was imported into TableCurve. The Julian date was selected for the X-axis, and soil temperature at 50 cm was selected for the Y-axis.

Site 3 has a sine wave soil temperature signature. Fifty-eight soils with mesic temperature regimes throughout the United States were similarly evaluated. Data from nine sites with mesic temperature regimes in the Midwest Corn Belt have 50-cm temperature signatures that fit a sine wave trend. These data are from two sites in eastern Nebraska, six sites in central Illinois, and one site in east-central Ohio. Moreover, soils with mesic temperature regimes at one site in California, site 3 in the Grand Canyon of Arizona, one site in Hawaii, two sites in Pennsylvania, three sites in Tennessee, eight sites in Maryland, and six sites in West Virginia also had 50-cm temperature signatures that fit a sine wave trend. A total of 22 sites with soils having a mesic temperature regime had annual data showing temperature signatures that fit a sine wave trend. A total of 35 sites with mesic temperature regimes, however, had annual data showing signatures that did not fit a sine wave function. These include soils at 3 sites in southern Arizona, soils at 20 sites in New York, soils at 4 sites in Pennsylvania, soils at 2 sites in Maryland, soils at 5 sites in Tennessee, and a soil at 1 site in West Virginia.

The results of plotting the soil temperature signature for site 3 in this study area to determine if it fit a sine wave trend are shown in figure 7.02.4.

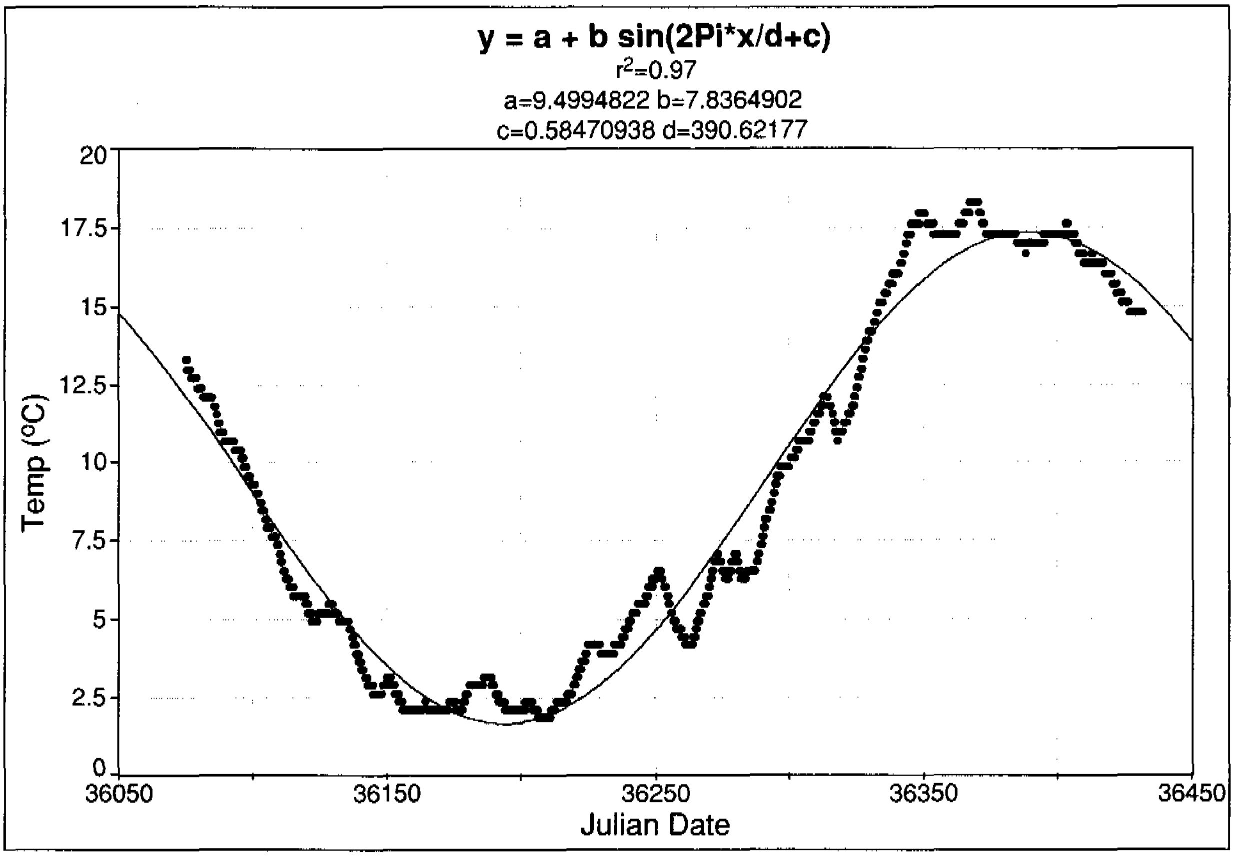


Figure 7.02.4.—Sine wave nature of the temperature signature at 50 cm for site 3.

The results of sine wave analysis (r^2=0.97) imply that the soil temperature signature at site 3 cycles in a mathematical order from year to year. This finding aids scientists in approximating the temperature at the site at any point in its past or future.

5. Conclusion

The Grand Canyon National Park temperature study is an important addition to the body of knowledge about soil temperature. Key sites for monitoring temperatures were identified. Data from these key sites can be used to assess the influence of slope, altitude, aspect, and vegetative cover on soil temperature. Once these factors are understood, the division of the temperature regimes within the park can be determined.

Acknowledgment

Rick Strait and Fred Fisher, NRCS Soil Scientists in Flagstaff, Arizona, provided assistance during the installation and data recovery phase of this study.

Chapter 7.03

Integrating Soil Temperature Data Into a Site-Specific Management Study in Lonoke County, Arkansas

ABSTRACT

Addressing the relationship between biological activity and crop yields is one way to integrate soil temperature data for site-specific management (SSM) activities. Applied research indicates that 5 °C is the temperature at which the biological activity of a soil is reduced to the 5-percent level. The soil temperature signature for the 10-cm depth during the period of record was examined for a soil at a wet site in Lonoke County, Arkansas. Except for a 1-month period in December 1998 and January 1999, the soil remained biologically active at 10 cm. At 25.2 °C, the MST was optimal for the production of the crops in Arkansas. There was a large decrease in soil temperature during the period June 4 to June 6, 1998. The driving force that results in these swings of soil temperature at 10 cm normally is air temperature. The air temperature decreased from 32.3 °C on June 4 at 3:54 p.m. to 14.8 °C on June 6 at 6:18 a.m. This is a net decrease of 17.5 °C in less than 48 hours. During that same period of record, the 10-cm soil temperature decreased from 26.0 to 16.5 °C, or a net decrease of 9.5 °C. The relationship of the shift in air temperature to the resulting soil temperature at 10 cm implies that soil temperature can change rapidly but that soil temperatures are more buffered than air temperature. We assume that air temperature was primarily responsible for the drop in soil temperature at 10 cm. Many crops are impacted by shifts in air and soil temperature. An adverse shift in soil temperature at 10 cm affects plant vigor, the susceptibility to disease, the effectiveness of herbicides, and crop yields.

1. Background and Purpose

Site-specific management (SSM), despite lofty attempts at a precise definition, is simply doing the right thing at the right place at the right time. During the SSM investigations of two 16-ha fields in Arkansas in March 1998, three temperature loggers were installed to collect data for an assessment of the impact of soil temperatures on cropping systems (Mount, Hoover, and Lightle, 1999)

Soil temperature data from Lonoke County, Arkansas, are an important addition to current soil temperature research. Temperature loggers collected data in 1998 and 1999. The Lonoke County soil temperature study was funded by the NRCS Global Change Initiative.

2. Study Area

The study area is near Allport, Arkansas, a small town in the southern part of Lonoke County. Lonoke County is in east-central Arkansas, east of Little Rock. The principal crops grown in the county are rice, soybeans, wheat, and corn.

The Lonoke County site is about 15 meters south of A2 marker in a SSM field and 91 cm north of an open drainage ditch. Its GPS location is 34°32'24" north and 91°45'00" west. The soil at the site is in the Perry series. It is a poorly drained, clayey soil with more than 60 percent clay in the Bg horizon. It is a very-fine, smectitic, thermic Chromic Epiaquert (Soil Survey Staff, 1999). A water table is near the soil surface throughout the year. Elevation of the site is 66 m, and the vegetation consists of water-loving hardwood trees, including overcup oak (*Quercus spp. L.*).

3. Results

After signatures for annual temperature were viewed, data were averaged by month, then graphed in Microsoft Excel software (figure 7.03.1), and the extreme seasonal variation was determined (figure 7.03.2).

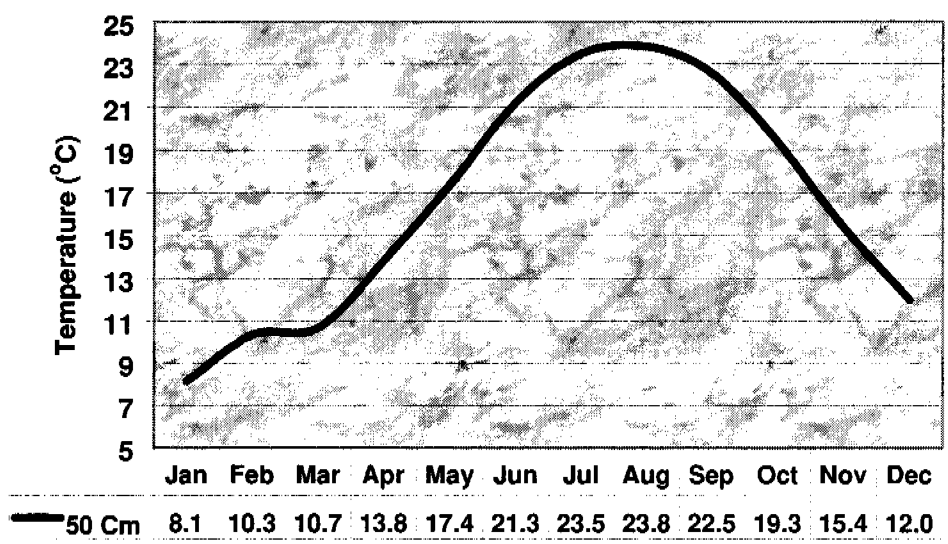


Figure 7.03.1.—Average monthly soil temperatures at a depth of 50 cm.

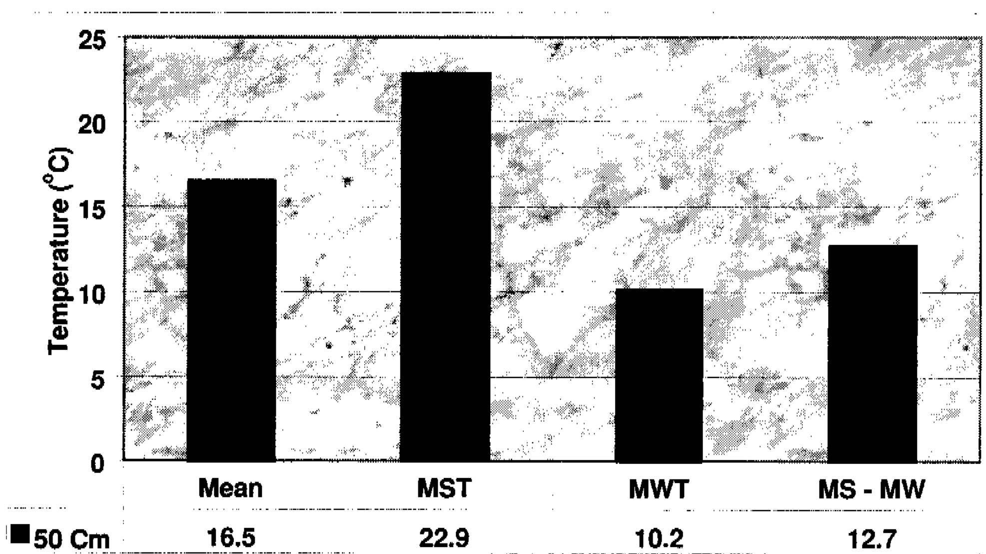


Figure 7.03.2.—An example of annual and seasonal analysis of soil temperature for the 50-cm depth.

The soil temperature regime is thermic (table 7.03.1). The MAST of the 10-cm depth is 0.6 °C (1.0 °F) warmer than the MAST of the 50-cm depth. The MAAT is 17.9 °C, or 1.5 °C warmer than the 30-year normal (figure 7.03.3). The average monthly air temperature at the SSM site was 2.3 °C warmer in January and 3.7 °C warmer in February of 1999 than the 30-year normal air temperature for these months. It was 2.5 °C warmer in June, 1.7 °C warmer in July, and 0.6 °C warmer in August than the 30-

year normal air temperature. Water at this site may have tempered the air temperature, thus reducing the warming effect. Normally, the MAST at 50 cm is expected to be 1 °C warmer than the MAAT. During the period of record for this study, the MAST was 1.4 °C colder than the MAAT (16.5 vs. 17.9 °C).

Table 7.03.1.—Monthly, seasonal, and annual analysis of temperature data (°C) from the study area.

Analysis	10 cm	50 cm	Site air	Keo air
Jan 99	7.6	8.1	6.4	4.1
Feb 99	10.5	10.3	10.5	6.8
Mar 98 & 99	11.7	10.7	12.4	11.9
Apr 98	14.8	13.8	16.4	17.1
May 98	20.4	17.4	23.6	21.3
Jun 98	24.2	21.3	27.8	25.3
Jul 98	26.3	23.5	28.6	27.0
Aug 98	25.0	23.8	26.7	26.1
Sep 98	23.3	22.5	25.1	22.7
Oct 98	17.9	19.3	17.9	17.0
Nov 98	13.5	15.4	12.3	11.3
Dec 98	9.3	12.0	6.9	6.2
Mean	17.0	16.5	17.9	16.4
MST	25.2	22.9	28.2	26.1
MWT	9.1	10.2	8.0	5.7
Isotivity	16.1	12.7	20.3	20.4

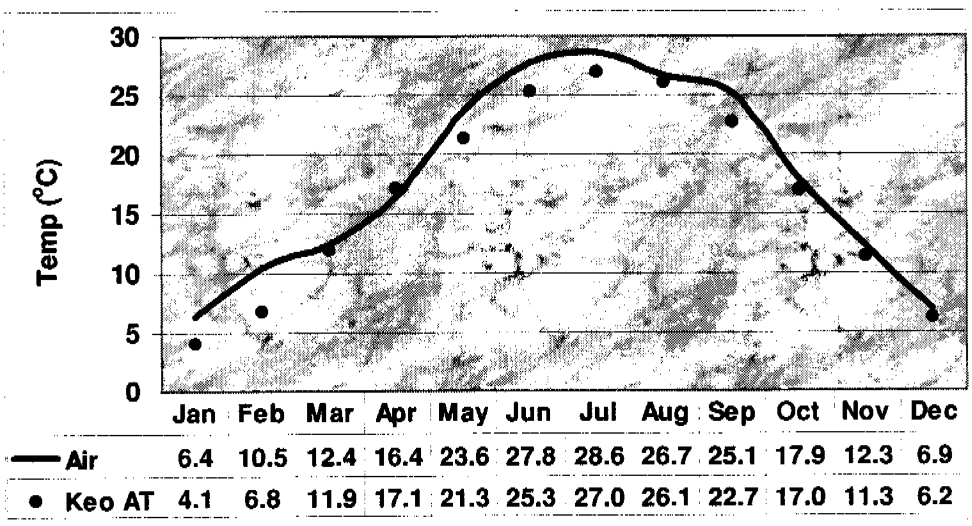


Figure 7.03.3.—Comparison of 1998-1999 air temperature data to the 30-year normal at Keo.

4. Discussion

Relating biological activity to crop yields is one way to integrate the soil temperature data into SSM. Applied research indicates that the temperature at which the biological activity of a soil is reduced to the 5-percent level is 5 °C. Most measurements relating microbial activity to temperature show growth stopping at 0 °C. Some phychrophilic bacteria are capable of growth below the freezing point, providing that the osmotic concentration of the ambient solution or of the organism's cytoplasmic constituents is sufficiently high to permit the cell structures to remain unfrozen (Paul and Clark, 1989).

The soil temperature signature for the 10-cm depth during the period of record was examined (figure 7.03.4). Except for a 1-month period in December 1998 and January 1999, the soil in Arkansas remained biologically active at 10 cm. At 25.2 °C, the MST is optimal for the production of crops in Arkansas.

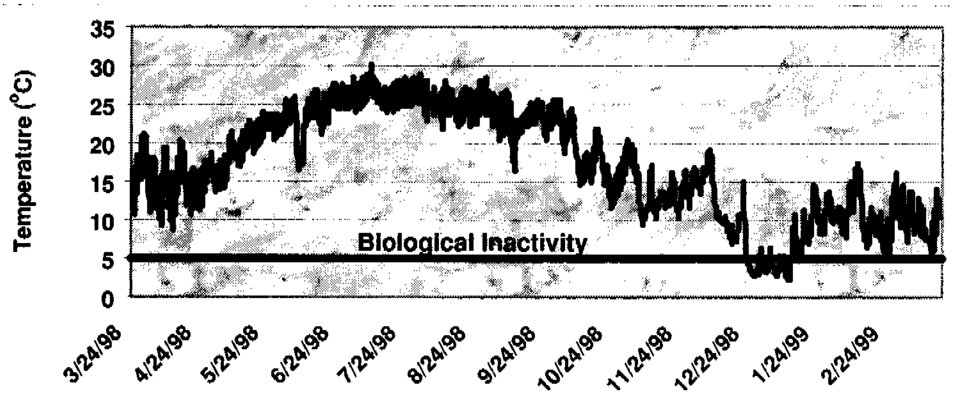


Figure 7.03.4.—Dates of biological activity for the 10-cm soil depth in Arkansas.

Figure 7.03.5 shows a large decrease in soil temperature during the period June 4 to June 6, 1998. The driving force that results in these swings of soil temperature at 10 cm is normally air temperature. The 10-cm and air temperature readings from June 4 to June 6, 1998 (nine readings each) are shown in figure 7.03.5.

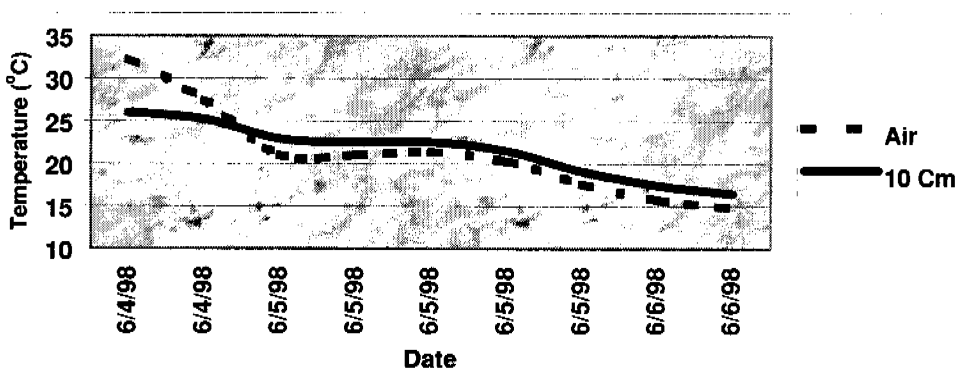


Figure 7.03.5.—Relationship of air temperature to 10-cm soil temperature from June 4 to June 6, 1998.

The air temperature decreased from 32.3 °C on June 4 at 3:54 p.m. to 14.8 °C on June 6 at 6:18 a.m. This is a net decrease of 17.5°C in less than 48 hours. During that same period of record, the 10-cm soil temperature decreased from 26.0 to 16.5 °C, or a net decrease of 9.5 °C.

All crops are impacted by shifts in air temperature. An adverse shift in soil temperature at 10 cm can affect plant vigor, the susceptibility to disease, the effectiveness of herbicides, and crop yields. The relationship of the Arkansas shift in air temperature to the corresponding soil temperature at 10 cm implies that soil temperature can change radically. The measured data for the site in Arkansas should provide a good working model on dramatic shifts in soil temperature during a short-term period.

Acknowledgments

Paul Benedict, NRCS Soil Scientist in California, and Dave Hoover, NRCS State Soil Scientist in Idaho, assisted in collecting metadata and installing soil temperature loggers for this study.

Chapter 7.04

Interpretation of Soil Temperature Data From Five Sites in California's Joshua Tree National Park*

ABSTRACT

Most of the soils in California's Joshua Tree National Park are thought to have thermic or hyperthermic temperature regimes. The vegetation includes Joshua trees (*Yuca bervifolia L.*) and grasses as well as low-growing desert plants. We measured soil temperatures to help explain some of the differences in ecological communities. At elevations above 1,585 meters, temperature regimes are thermic on south aspects and mesic on north aspects. This finding may have implications for other studies in the Mojave Desert, which have assumed that lower elevations are the upper boundary of the thermic temperature regime. The upper boundary of the hyperthermic temperature regime had been assumed to be less than 610 meters, but we found that hyperthermic temperatures occur at 640 m. The mean summer temperature at site 2 (35.4 °C) is the warmest of any site. Soil isotivity values (the difference between mean summer temperature and mean winter temperature) at 10 cm are highest at site 1 (22.9 °C) and site 5 (22.8 °C) and lowest at site 4 (16.4 °C) with a south aspect. The mean winter temperature exceeded 10 °C, except for the soil at 1,585 m, which has a mean annual soil temperature of 4.0 °C at 50 cm. The soils at sites below at least 640 m are hyperthermic, the soils above about 640 m and below 1,585 m are thermic, and the soils that have north aspects and are above 1,585 m are mesic.

1. Joshua Tree Project Study Area

Joshua Tree National Park is in Riverside County in southeastern California. Two desert systems are in the park. The Colorado Desert dominates the eastern part of the park, and the Mojave Desert occupies the western part. The differences between the two desert systems are largely a result of elevation. The Colorado Desert typically is lower, drier, and marginally hotter than the Mojave Desert. While there may appear to be little difference to the casual observer, there are numerous differences in the plant and animal species in the desert. Traditionally, the soils in the Colorado Desert have been considered hyperthermic (MAST of more than 22.0 °C), whereas those in the Mojave Desert have been considered thermic. Small, local areas at the higher elevations may better fit a mesic temperature regime (Soil Survey Staff, 1999).

The soils in the study area are Typic Torriorthents (Soil Survey Staff, 1999). The sites above 1,158 m support of a variety of desert grasses, shrubs, and Joshua trees (*Yuca bervifolia L.*); the sites below 1,158 m support low-growing desert plants that leave the soil surface exposed to solar radiation (table 7.04.1). About 25 percent of the soil surface is exposed to solar radiation at site 5, and 80 percent is exposed at site 2.

Table 7.04.1.—Site metadata for the study area.

Site number	Latitude (north)	Longitude (west)	STR (name)	Slope (%)	Aspect (°)	Elevation (m)
1	33°56'04"	115°42'34"	Hyperthermic	1	320	446
2	33°41'35"	115°48'07"	Hyperthermic	5	180	640
3	33°00'10"	116°01'20"	Thermic	3	60	1,158
4	33°55'40"	116°11'11"	Thermic	45	180	1,585
5	33°56'00"	116°11'18"	Mesic	42	2	1,585

* Peter Fahnestock, NRCS Soil Scientist in Apple Valley, California, helped write this section.

2. Methods

After retrieval of the temperature loggers, data were off-loaded in Lincoln, Nebraska, and the temperature signatures were examined for each of the sites. Data for the study area were averaged by month, then graphed in Microsoft Excel software (figure 7.04.1).

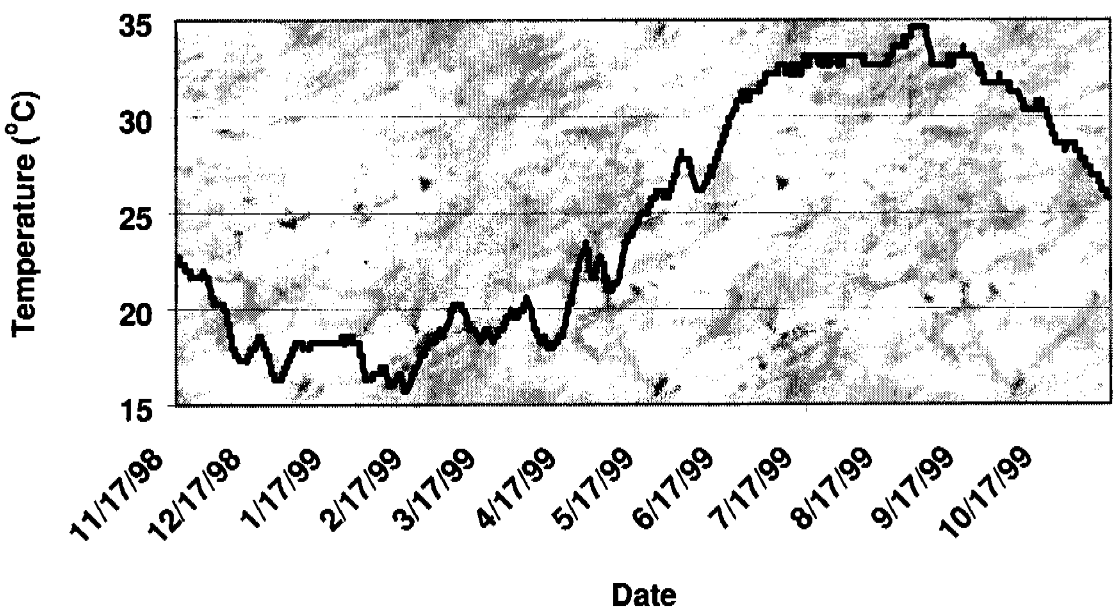


Figure 7.04.1.—Soil temperature signature at 50 cm for site 2.

In addition to calculations of monthly and annual means for air temperature (MAAT) and soil temperature (MAST), calculations of the mean summer temperature (MST) and the mean winter temperature (MWT) were made to ascertain the extreme seasonal variation at each of the sites. The MST is the average soil temperature for June, July, and August, and the MWT is the average soil temperature for December, January, and February. An isotivity value, or the difference between MST and MWT, was determined at each site (Soil Survey Staff, 1999).

3. Results

Following are four tables and one graph that show monthly, seasonal, and annual analyses for the five sites. Dashed lines for an individual month indicates that the sensor was inoperative because of vermin damage or battery failure. The tables are arranged by depth to allow for comparison of soil and air temperatures.

Site 1.—Table 7.04.2 shows the MAST at 50 cm for site 1 in the Mojave Desert part of the park. The soil at this site is hyperthermic (Soil Survey Staff, 1999). The MST for the 50-cm soil depth averaged 32.8 °C and is one of the warmest MST averages in the Remote Soil Temperature Network.

Table 7.04.2.—Monthly, seasonal, and annual analysis (°C) for site 1.

Analysis	10 cm	50 cm
Jan 99	12.4	14.2
Feb 99	13.9	14.6
Mar 99	18.8	18.0
Apr 99	21.0	20.6
May 99	28.9	26.0
Jun 99	34.3	30.3
Jul 99	36.0	33.8
Aug 99	35.6	34.2
Sep 99	32.6	32.5
Oct 99	26.0	27.7
Nov 98& 99	17.5	20.4
Dec 98	10.8	14.6
Mean	24.0	23.9
MST	35.3	32.8
MWT	12.4	14.5
Isotivity	22.9	18.3

Site 2.—This site is in the Colorado Desert and has a hyperthermic soil temperature regime (table 7.04.3). Though the MST at 50 cm is less at site 2 than at site 1 (31.7 vs. 32.8 °C), the MAST is warmer (24.9 vs. 23.9 °C), most likely because of the MWT averages. The winter average is 17.7 °C at site 2 and 14.5 °C at site 1. The south aspect of site 2 may have modified the winter soil temperatures. The coldest single reading at 10 cm for site 2 was 4.9 °C, compared to 2.7 °C for site 1. Both sites are well above the minimum MAST criteria for hyperthermic (22 °C).

Table 7.04.3.—Monthly, seasonal, and annual analysis (°C) for site 2.

Analysis	10 cm	50 cm
Jan 99	15.7	18.0
Feb 99	16.2	17.2
Mar 99	19.1	19.4
Apr 99	20.6	20.4
May 99	28.3	24.7
Jun 99	33.3	29.0
Jul 99	36.1	32.7
Aug 99	36.7	33.4
Sep 99	33.7	32.7
Oct 99	29.3	29.8
Nov 98& 99	20.9	23.9
Dec 98	13.9	18.0
Mean	25.3	24.9
MST	35.4	31.7
MWT	15.3	17.7
Isotivity	20.1	14.0

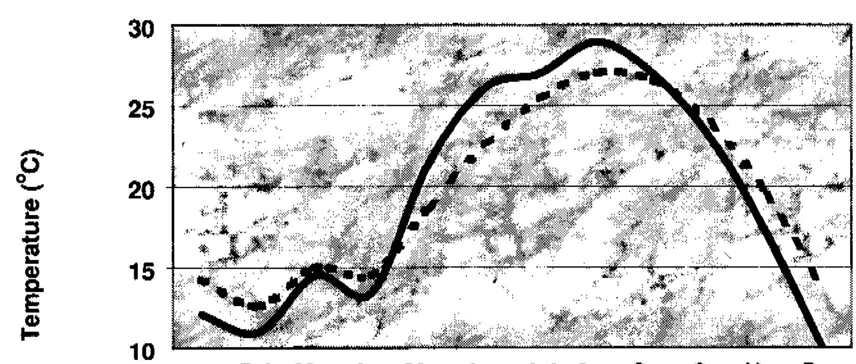
Site 3.—This site is in the Mojave Desert. It has a thermic soil temperature regime. At 50 cm, it has a MAST of 20.2 °C (table 7.04.4), which is 4.7 °C colder than the MAST at site 2 and 3.7 °C colder than the MAST at site 1 (23.9 °C).

The 10-cm depth froze twice during December 1998 and once during February 1999. The period of reduced biological activity in which the 10-cm soil temperature is less than 5 °C is essentially from December through February. This is contrasted by the warmest readings at 10 cm of 38.4 °C during late June and early July of 1999.

Table 7.04.4.—Monthly, seasonal, and annual analysis (°C) for site 3.

Analysis	10 cm	50 cm
Jan 99	11.5	11.8
Feb 99	11.6	11.6
Mar 99	14.4	14.5
Apr 99	15.4	16.1
May 99	22.7	20.9
Jun 99	28.4	25.9
Jul 99	30.7	29.5
Aug 99	30.9	29.8
Sep 99	27.9	28.3
Oct 99	22.7	24.0
Nov 98& 99	15.7	17.7
Dec 98	9.0	11.7
Mean	20.1	20.2
MST	30.0	28.4
MWT	10.7	11.7
Isotivity	19.3	16.7

Site 4.—The soil at site 4 has a thermic soil temperature regime. The monthly analysis is shown in figure 7.04.2. Presumably, the south exposure of this site kept the 10-cm depth from freezing throughout the period of record. Site 4, which has an elevation of 1,585 meters, has a MAST of 19.5 °C, which is only 0.7 °C colder than the MAST of site 3 (20.2 °C), which has an elevation of 1,158 meters. South-facing slopes in Joshua Tree National Park appear to greatly impact the MAST.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#4 10 cm	12.1	11.0	14.5	13.4	21.4	26.1	27.0	28.9	26.9	23.0	17.1	9.8
#4 50 cm	14.2	12.6	15.0	14.5	18.7	22.5	25.4	27.0	26.5	23.9	19.5	13.5

Figure 7.04.2.—Monthly analysis of soil temperature at site 4.

Site 5.—The soil at site 5 was paired with the soil at site 4 so that the influence of aspect in Joshua Tree National Park could be measured. Both sites are at 1,585 meters. With a 50-cm MAST of 14.9 °C, site 5, which has a north aspect, is 4.6 °C colder than the MAST at site 4 (19.5 °C), which has a south aspect. We expected the soil at site 5 to have a frigid temperature regime, but it barely qualified for a mesic temperature regime (table 7.04.5). It can now be stated with some certainty that there are no soils with frigid soil temperature regimes in Joshua Tree National Park. Sensors at this site captured air temperature for the entire period of record. Usually, the mean annual air temperature (MAAT) is colder than the MAST at 50 cm. At site 5, this was not the case. At this site, the MAAT was 14.9 °C, compared to a MAST at 50 cm of 14.3 °C. This relationship is similar to findings of an aspect study in southern Arizona (Mount, 1999).

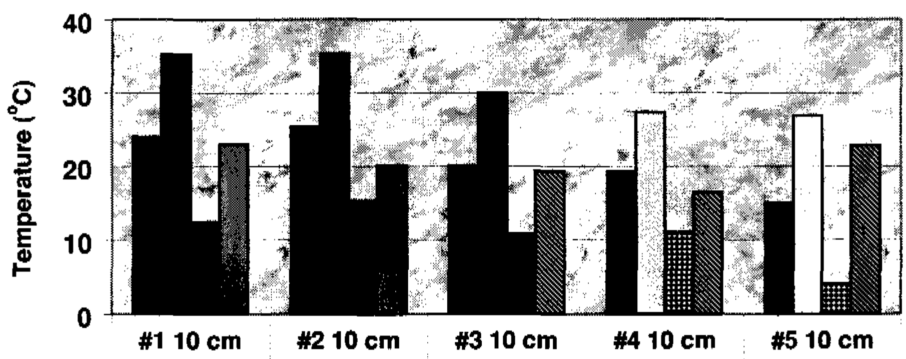
Table 7.04.5.—Seasonal and annual analysis (°C) for site 5.

Analysis	10 cm	50 cm	Air
Jan 99	4.9	7.5	6.9
Feb 99	4.5	6.2	7.2
Mar 99	9.2	8.3	8.9
Apr 99	10.9	9.8	9.3
May 99	19.8	15.2	18.4
Jun 99	26.1	20.2	23.2
Jul 99	27.1	23.3	25.4
Aug 99	27.4	23.7	25.1
Sep 99	23.0	21.8	22.5
Oct 99	16.0	17.1	17.8
Nov 98& 99	8.8	11.8	10.1
Dec 98	2.5	7.1	4.2
Mean	15.0	14.3	14.9
MST	26.9	22.4	24.6
MWT	4.0	6.9	6.1
Isotivity	22.8	15.4	18.5

4. Discussion

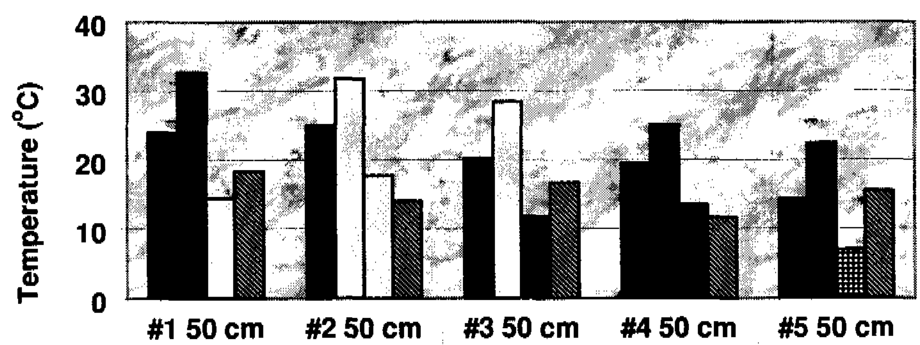
Most of the soils in California's Joshua Tree National Park have thermic temperature regimes. A few have hyperthermic temperature regimes. Site 5 is an example of the mesic temperature regime on north aspects at the highest elevations in the park. This is confirmation of the existence of a separate major land resource area (MLRA 29) at the higher elevations in the park (SCS, 1981). The cooler soil temperatures account for some of the differences in ecological communities at these high elevations. The data at site 4 suggest that the thermic temperature regime, particularly on south aspects, occurs at altitudes of more than 1,524 meters. This finding may have implications for other studies in the Mojave Desert, which have assumed that lower elevations are the upper boundary of the thermic temperature regime. Sites 1 and 2 were shown to be hyperthermic. Site 2, like site 5, may have implications for past studies, which had assumed that the upper boundary of the hyperthermic temperature regime was less than 610 meters. The data will also allow for researchers to tentatively assign elevational and aspect breaks to the soil temperature regimes in the park.

There were measurable differences among seasonal and annual averages for soil temperature during this 1-year study (figures 7.04.3 and 7.04.4). Isotivity values at 10 cm indicate that site 1 (22.9 °C) and site 5 (22.8 °C) had the most difference between summer and winter soil temperatures (MS-MW), and site 4, which has a south aspect, had the least difference (16.4 °C). The MWTs exceed 10 °C, except for site 5, which has an average of 4.0 °C. Readings of mean soil temperature at 50 cm indicate that the soils at sites 1 and 2 are hyperthermic, the soils at sites 3 and 4 are thermic, and the soil at site 5 has a "warm" mesic soil temperature regime. The MST at site 2 (35.4 °C) is one of the warmest of the 200 sites in the Remote Soil Temperature Network.



	#1 10 cm	#2 10 cm	#3 10 cm	#4 10 cm	#5 10 cm
Mean	24.0	25.3	20.1	19.3	15.0
MST	35.3	35.4	30.0	27.3	26.9
MWT	12.4	15.3	10.7	10.9	4.0
MS-MW	22.9	20.1	19.3	16.4	22.8

Figure 7.04.3.—Seasonal and annual soil temperature averages for the 10-cm depth.



	#1 50 cm	#2 50 cm	#3 50 cm	#4 50 cm	#5 50 cm
Mean	23.9	24.9	20.2	19.4	14.3
MST	32.8	31.7	28.4	25.0	22.4
MWT	14.5	17.7	11.7	13.4	6.9
MS-MW	18.3	14.0	16.7	11.6	15.4

Figure 7.04.4.—Seasonal and annual soil temperature averages for the 50-cm depth.

Since the soils in the study area with a mesic temperature regime do not occur at elevations below about 1,585 meters on north aspects, there may be a minor temperature regime that marginally warrants consideration for classification purposes.

Acknowledgments

Leon Latto, NRCS Soil Scientist at Las Vegas, Nevada, Ed Tallyn, NRCS Soil Scientist at Davis, California, and John Rule, NRCS Soil Scientist at Twentynine Palms, California, provided assistance during the installation phase of this project.

Chapter 7.05

Interpretation of Soil Temperature Data From the Niwot Ridge in Colorado*

ABSTRACT

Commonly, aspect influences the mean annual soil temperatures at the higher altitudes in the conterminous United States. Measurements of soil temperatures at three sites on the Niwot Ridge in Colorado were made to determine the influence of aspect on soil temperatures at elevations around 3,500 m. The mean annual soil temperature for the north aspect was 2.2 °C colder than that for the south aspect (-0.7 vs. 1.5 °C). The 50-cm mean annual soil temperature for the neutral aspect was 0.0 °C. The soil isotivity value (the difference in mean summer and mean winter temperatures) at 50 cm was greater than 11 °C at the neutral site (12.6 °C). It was less than 11 °C at the other sites. These cryic soils on Niwot Ridge exhibit a greater isotivity value at 50 cm than cryic soils in Idaho, where snow covers the surface throughout the winter months. The 10-cm soil depth at the north aspect was biologically active (>5 °C) for about 80 days. In areas of alpine grass vegetation, soil temperature at 10 cm rises rather quickly in June and stays above 5 °C until late September. The lowest soil temperature readings are at 10 cm during the winter (-12.1 °C at the south aspect, -14.3 °C at the neutral aspect, and -13.6 °C at the north aspect). The lack of winter snowfall allowed soil temperature to drop lower than was expected. The 50-cm mean winter temperatures of the soils at the neutral aspect and the north aspect are within 0.1 °C of each other (-6.4 vs. -6.3 °C). The 50-cm mean winter temperature of the soil at the south aspect, however, is -4.0 °C. Therefore, the mean winter temperatures among the three sites differ by 2.4 °C. Prior to this study, most scientists thought that it is not possible for a soil to have a mean annual soil temperature of less than 0 °C without having permafrost. Site 3 has a 50-cm mean annual soil temperature of -0.7 °C but does not have permafrost within 2 meters. Though frozen at the 50-cm depth for about 7½ months of the year, it is thawed for the remainder of the year. The 10- and 50-cm mean annual soil temperatures of site 3 set the current NRCS standard for cold soil temperature in the conterminous United States. The cold climate on Niwot Ridge occurs throughout the high-elevation reaches of Colorado. There may be tens of thousands of hectares with similar cold soil temperatures in these areas.

1. Background and Hypotheses

Monitoring soil temperature at sites with cold climatic conditions is challenging. Most sites with extremely cold climatic conditions are difficult to access and nearly impossible to visit during winter months. It is in these remote areas where automated data-capture systems are most needed for assessments of daily, monthly, seasonal, and annual soil temperatures.

Temperature loggers were installed at the three sites in the Niwot Ridge Long-Term Ecological Research Area (LTER) on September 2, 1998. These sites are part of the Remote Soil Temperature Network (RSTN). The RSTN is a network of sites using the same StowAway data-logger technology to collect air and soil temperature data across the United States. The RSTN was established in 1996 as a part of the USDA-NRCS Global Change Initiative.

Six hypotheses were formed during the September 1998 installation of data loggers at the three sites:

1. The soil temperature on the north aspect would be colder than that on the south aspect.
2. The 50-cm mean annual soil temperature at two of the three sites would be less than 0.6 °C.
3. The difference between mean summer and mean winter soil temperatures would be more than 11 °C.

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* Ronald F. Bauer, Emeritus Soil Scientist, USDA-NRCS, National Soil Survey Center, Lincoln, Nebraska, assisted in preparing this section.

4. There would be more than 300 days of biological inactivity (soil temperature of less than 5 °C at the 10-cm depth) on the north aspect.
5. The single coldest soil temperature reading would not be less than -6.7 °C.
6. The mean winter soil temperatures at a depth of 50 cm on the three sites would be within 0.3 °C of each other.

These hypotheses were based on results from other studies within the RSTN. Though general in nature, they represent valid conjectures that could be tested with measured soil temperature data from the Niwot Ridge LTER.

2. Niwot Ridge Study Area

The LTER on Niwot Ridge is administered by the University of Colorado's Mountain Research Station (MRS). It is located in Boulder County, Colorado. The MRS is an interdisciplinary research facility devoted to the advancement of study of montane environmental science. It supports research in biology, geography, and geology. It is one of the best known sites for alpine research in the world. Its reputation stems from decades of research on Niwot Ridge. The alpine research area of Niwot Ridge was designated as an Experimental Ecological Reserve by the Institute of Ecology in 1975 and as a Biosphere Reserve by UNESCO in 1979.

In 1980, Niwot Ridge was selected by the National Science Foundation as the alpine tundra component of the Long-Term Ecological Research (LTER) program.

On September 2, 1998, temperature loggers were installed at three sites for measurement of air and soil temperatures on the Niwot Ridge. Each site is under alpine grass vegetation in the windswept reaches of the LTER. The percentage of the surface covered by cobbles, stones, and boulders ranges from 3 percent at site 1 to 15 percent at sites 2 and 3. The geology at each site is acid crystalline granitic rocks. Patterned ground in the form of frost polygons, cryoturbated soils, and sorted cobble and stone troughs are evident at each site. The well drained soil at each site is a loamy-skeletal, mixed, superactive Humic Dystrocryept (Soil Survey Staff, 1998). Table 7.05.1 gives additional information about each site.

Table 7.05.1.—Site information for the Niwot Ridge LTER study area.

Site number	Latitude (north)	Longitude (west)	Slope (%)	Aspect (°)	Elevation (m)
1	40°03'13"	105°35'14"	20	180	3,490
2	40°03'19"	105°35'14"	5	Neutral	3,566
3	40°03'25"	105°35'11"	22	320	3,505

3. Methods

StowAway temperature loggers store 1,800 data points during periods ranging from 15 minutes to 360 days. Their certified temperature threshold is ±0.4 °C. Before being installed at the three sites on Niwot Ridge, the temperature loggers were programmed to collect data every 4 hours and 48 minutes for 360 days. This frequency is the same as five times each day.

At each site, a 23-cm PVC pipe with a 10-cm diameter housed three StowAway temperature loggers and a desiccant pack to absorb excess moisture. Holes drilled in the PVC pipe allow 1.8-meter sensor leads to exit outside while the temperature loggers are protected from the weather elements. These PVC pipes were installed at sites in the study area on June 18, 1998. A hole was dug with a sharpshooter to a depth of 50 cm at each site. Site data were then collected, and a brief examination of the soils was made to ascertain a taxonomic classification. One sensor lead was affixed to a metal bar about 10 cm above the soil surface to collect air temperature data. Two soil temperature sensors were installed at each site—one at the 10-cm soil depth and one at the 50-cm soil depth. Finally, the PVC pipe was buried at about 10 cm and covered with soil.

After retrieval of the temperature loggers, data were off-loaded in Denver, Colorado, and the temperature signatures were examined for each of the sites (figure 7.05.1).

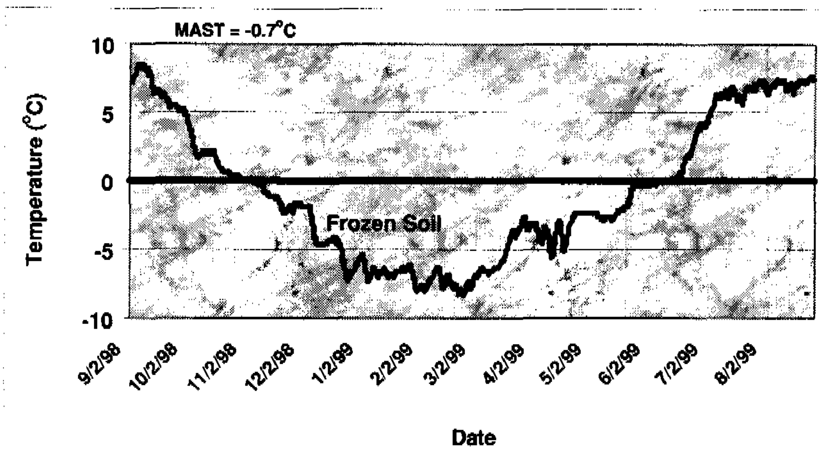


Figure 7.05.1.—Soil temperature signature for the 50-cm depth at site 3. This is a very cold soil with more than 7 continuous months below freezing.

4. Results

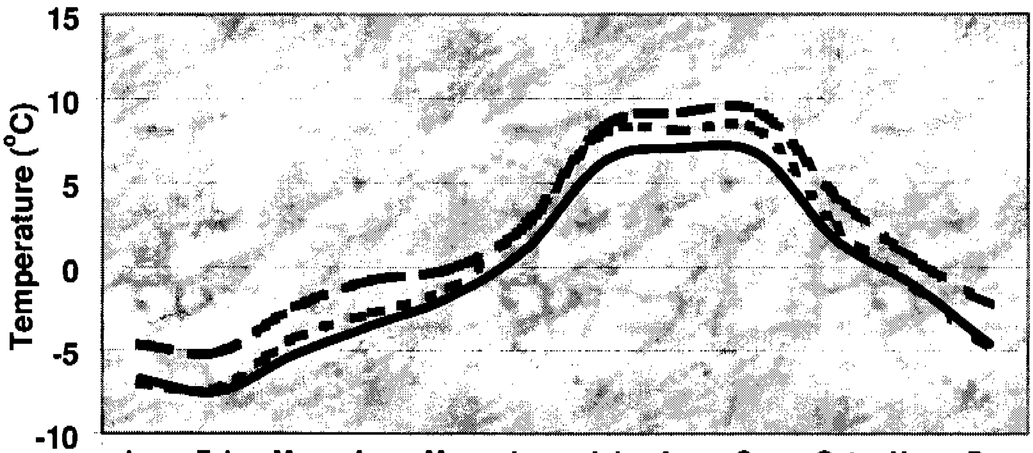
One hundred percent of the possible air and soil temperature data were collected at all the sites on the Niwot Ridge LTER. This success rate meets the optimum standard for extreme climatic monitoring.

Soil temperature at 10 cm.—Analyses for the 10-cm depth are given in table 7.05.2. Site 3, on a north aspect, has the coldest MAST (-0.8 °C), followed by the ridgetop at site 2 (0.2 °C), and then the south aspect at site 1 (1.3 °C). The 10-cm depth at site 3 has the coldest MAST (-0.8 °C) in this report.

Table 7.05.2.—Monthly, seasonal, and annual analyses of soil temperature (°C) for the 10-cm depth.

Analysis	Site 1	Site 2	Site 3
Jan 99	-7.2	-8.8	-8.9
Feb 99	-7.1	-8.5	-9.0
Mar 99	-2.4	-3.7	-5.1
Apr 99	-1.1	-2.6	-3.5
May 99	0.4	-1.0	-1.6
Jun 99	5.9	5.9	4.1
Jul 99	11.0	11.2	9.6
Aug 99	10.5	9.8	8.8
Sep 98	9.9	9.1	7.3
Oct 98	2.5	1.3	0.4
Nov 98	-2.0	-3.2	-3.9
Dec 98	-5.6	-7.4	-7.8
MAST	1.3	0.2	-0.8
MST	9.1	8.9	7.5
MWT	-6.6	-8.2	-8.6
Isotivity	15.7	17.2	16.0

Soil temperature at 50 cm.—Figure 7.05.2 shows the average monthly soil temperatures for the three sites in the study area, and table 7.05.3 gives the seasonal and annual data for the 50-cm depth in the soils on the three sites.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Site 1	-4.6	-5.1	-2.4	-0.8	-0.1	2.5	8.3	9.1	9.2	4.2	0.5	-2.3
Site 2	-7.0	-7.3	-4.3	-2.8	-1.3	2.7	7.9	8.1	8.1	2.4	-1.1	-4.9
Site 3	-6.7	-7.5	-5.3	-3.5	-1.8	1.1	6.2	7.0	6.7	1.6	-1.1	-4.6

Figure 7.05.2.—Average monthly soil temperatures for the Niwot Ridge study area.

Table 7.05.3.—Seasonal and annual analyses of soil temperature (°C) for the 50-cm depth.

Analysis	Site 1	Site 2	Site 3
MAST	1.5	0.0	-0.7
MST	6.6	6.2	4.8
MWT	-4.0	-6.4	-6.3
Isotivity	10.7	12.6	11.0

The MAST of the north aspect location at site 3 is 0.7 °C colder than the ridgetop location at site 2 and 2.2 °C cooler than the south aspect location at site 1. The soil temperature regime at each site is cryic (Soil Survey Staff, 1999). The isotivity value is about 11.0 °C at each site. It ranges from 10.7 to 12.6 °C.

Air temperature.—The air temperature sensors used in this study were placed 10 cm above the ground at all of the sites. The monthly, seasonal, and annual air temperature data are shown in table 7.05.4.

Table 7.05.4.—Monthly, seasonal, and annual air temperature (°C) data.

Analysis	Site 1	Site 2	Site 3
Jan 99	-10.3	-10.6	-10.5
Feb 99	-9.2	-9.7	-9.6
Mar 99	-3.8	-4.3	-4.7
Apr 99	-3.2	-4.4	-4.2
May 99	1.4	0.2	-0.5
Jun 99	7.7	7.9	7.8
Jul 99	12.1	12.1	12.0
Aug 99	10.8	10.5	10.5
Sep 98	10.5	9.4	9.3
Oct 98	0.6	-0.2	-0.4
Nov 98	-5.3	-5.9	-5.7
Dec 98	-9.4	-10.0	-9.8
MAST	0.2	-0.4	-0.5
MST	10.2	10.2	10.1
MWT	-9.6	-10.1	-9.9
Isotivity	19.8	20.3	20.0

Air temperatures are slightly mitigated by snow cover at each site during April and May (figure 7.05.3). Consequently, the spring and annual air temperature averages are conjectured to be somewhat different from the ones shown in table 7.05.4. Snowfall, covering the sensor at site 3, "flat-lined" the readings to near 0 °C for about 1 month from April 20 to May 22, 1999. On May 23, the air temperature readings displayed the normal oscillations of daily temperature. The snow covering the air temperature sensor at site 3 lasted 1 week longer than the snow at the ridgetop location on site 2 and the south aspect location on site 1.

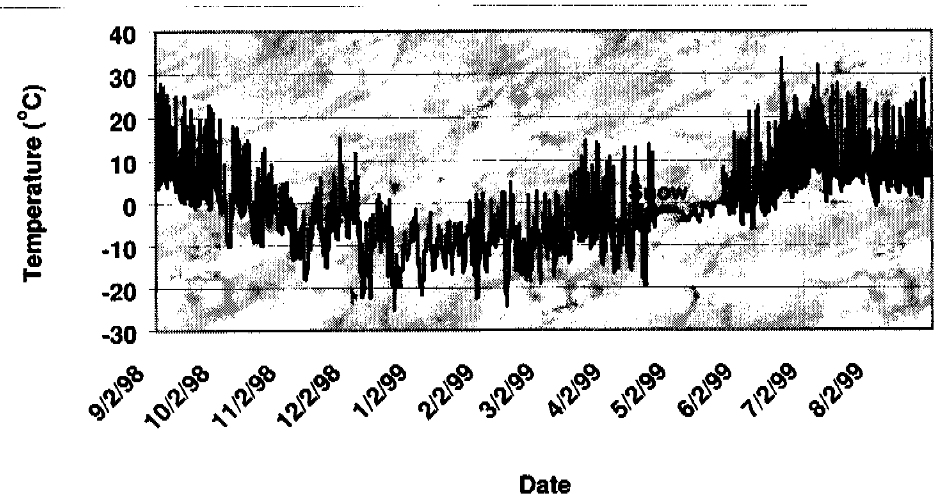


Figure 7.05.3.—Impact of snowfall on the air temperature signature at site 3.

Time analysis and autocorrelation.—The StowAway data loggers captured data five times each day. The average trend for each time sequence at site 2 is shown in figure 7.05.4.

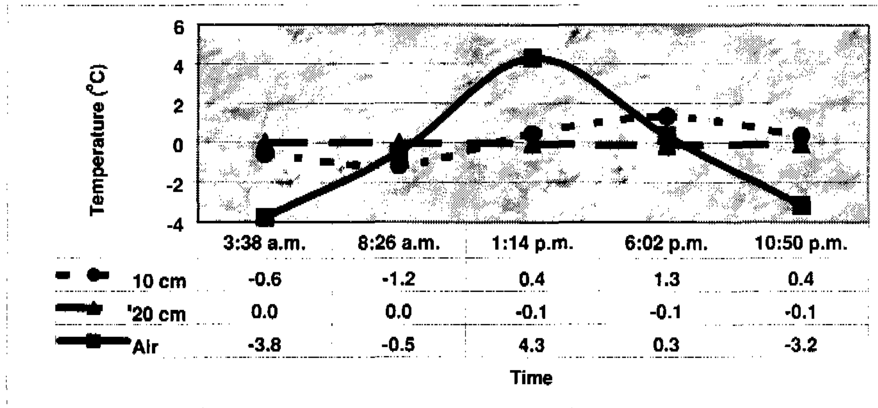


Figure 7.05.4.—Time analysis for air and soil temperatures at site 2.

Data from this study reveal that air and soil temperatures are sensitive to the time of day they are collected. Though the average soil temperature at 50 cm is nearly the same at all five times during the day it was collected, the average reading is coldest at 6:02 p.m. (-0.1 °C). At the 10-cm depth, the average reading is coldest at 8:26 a.m. (-1.2 °C). The average air temperature reading is warmest at 1:14 p.m. (4.3 °C) and coldest at 3:38 a.m. (-3.8 °C).

Data from the ridgetop location at site 2 show that, over time, the soil temperature measured at 10 cm is highly correlated with the soil temperature measured at 50 cm (figure 7.05.5). Even though the r^2 is 0.90, accurately predicting the 50-cm soil temperature based on measured data at 10 cm can yield results that are less than adequate.

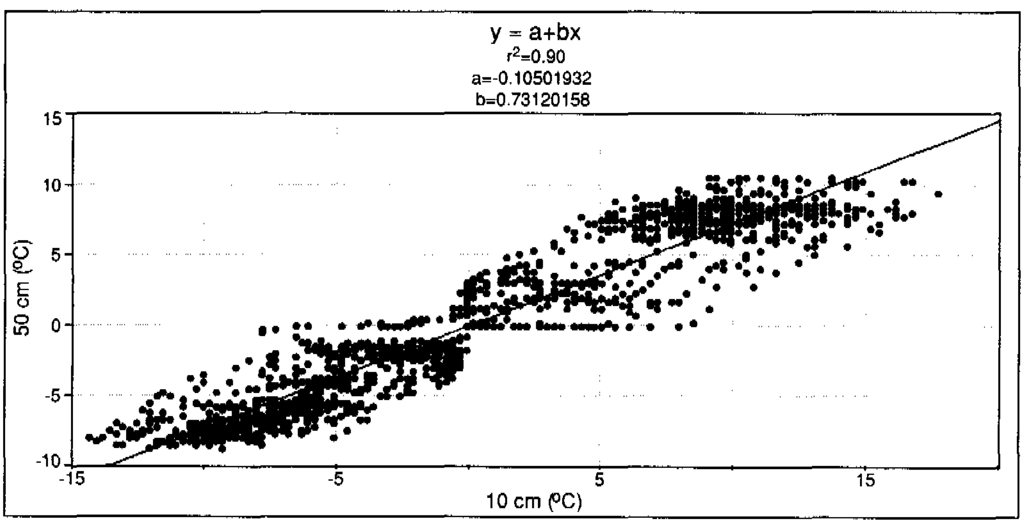
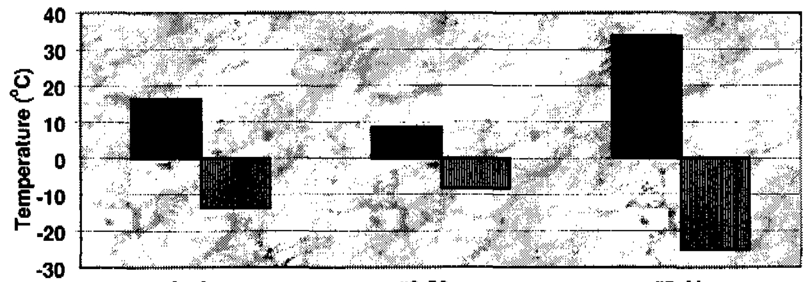


Figure 7.05.5.—Correlation of soil temperatures at 10 cm and 50 cm for site 2.

Extremes.—There are extreme differences between the minimum and maximum air and soil temperature readings for the period of record. Figure 7.05.6 shows these extremes for the north aspect location at site 3.

One might not expect extreme differences between maximum and minimum soil temperatures at high elevations. The difference between the extreme maximum and minimum air temperatures is 59.0 °C. The difference between the maximum and minimum soil temperatures at 10 cm is 30.0 °C, or about half that of the air temperature. These extremes are further suppressed at 50 cm, where the difference between the maximum and minimum soil temperatures is only 16.8 °C.



	#3 10 cm	#3 50 cm	#3 Air
Max	16.4	8.5	33.7
Min	-13.6	-8.3	-25.3

Figure 7.05.6.—Maximum and minimum extremes for air and soil temperatures at site 3.

5. Discussion

This study confirms that aspect influences the MAST at 50 cm for altitudes above 3,350 m in the conterminous United States. The MAST for the north aspect at site 3 is 2.2 °C colder than that of the south aspect at site 1 (-0.7 vs. 1.5 °C). The MAST at 50-cm for sites 2 and 3 was less than 0.6 °C and thus supported the second hypothesis. The isotivity value was greater than 11 °C at site 2. It was less than 11 °C at the other sites. Therefore, the third hypothesis is false. These cryic soils on Niwot Ridge exhibit a greater isotivity value at 50 cm than the cryic soils in Idaho, where snow covers the surface throughout the winter months. In Clearwater County, Idaho, the isotivity values for three cryic sites were less than 6.0 °C (Mount, 1999). The 10-cm depth at site 3 was biologically inactive for about 285 days. Consequently, the fourth hypothesis is false. In areas of alpine grass vegetation, soil temperature at 10 cm rises rather quickly in June and stays above 5 °C until late September. The fifth hypothesis, which anticipated that the coldest soil temperature reading would not be less than -6.7 °C, is false. The lowest soil temperature readings at the 10-cm depth during the winter months are -12.1 °C at site 1, -14.3 °C at site 2, and -13.6 °C at site 3. The lack of winter snowfall allowed soil temperature to drop lower than was expected. Thus, the sixth hypothesis is false. The 50-cm MWT at sites 2 and 3 are within 0.1 °C of each other (-6.4 vs. -6.3 °C), but the 50-cm MWT of the south aspect at site 1 is -4.0 °C. Therefore, the difference in MWT among the three sites is 2.4 °C.

Prior to this study, most NRCS scientists in the soil temperature monitoring community thought that it was not possible for a soil to have a MAST of less than 0 °C without having permafrost. Site 3 has a 50-cm MAST of -0.7 °C but does not have permafrost within 2 m. Though frozen at the 50-cm depth for about 7½ months of the year, the soil at this site is thawed during the rest of the year. The 10- and 50-cm MAST values at site 3 set the current NRCS standard for cold soil temperature in the conterminous United States.

The cold climate on the Niwot Ridge occurs in areas throughout the high-elevation reaches in Colorado. These areas have tens of thousands of hectares with similar cold soil temperatures. To confirm this observation, two additional sites were installed at similar elevations, southwest of Denver in Guanella Pass, during September 1999.

Acknowledgment

Mark Losleban, Meteorologist at MRS, assisted in site selection, collection of metadata, and installation of soil temperature loggers for this study.

Chapter 7.06

Interpretation of Soil Temperature Data From Guanella Pass, Colorado*

ABSTRACT

It is commonly believed that vegetative cover can influence soil temperatures, even at elevations above 3,350 meters in the conterminous United States. Soil temperatures were measured at five sites in the Guanella Pass in Clear Creek County, Colorado. Temperature sensors were installed at these sites on September 8, 1999, and collected data for 1 year. Unexpectedly, the soil at 3,505 m has the coldest mean annual soil temperature at 10 cm (1.3 °C), followed by soils at 3,545 m, 3,140 m, and 3,377 m. The isotivity value (the difference in mean summer and mean winter temperatures) for a site at 3,545 m (14.6 °C) is the highest in the study area, while that of the south aspect at 3,377 m (12.7 °C) is less than was expected. The soil at 3,545 m is the only one with temperature data at 25 cm. Its mean annual soil temperature is nearly identical to that of the 10-cm depth (2.3 vs. 2.4 °C). The isotivity value at 25 cm is 1.6 °C less than that at the 10-cm depth (13.0 vs. 14.6 °C). The soil was frozen at both 10 cm and 25 cm for an average of 5 months during the period of record (December 1999 through April 2000). None of the soils came close to having a mean annual soil temperature of 0 °C or less at any depth. Unexpectedly, the mean annual soil temperature at 50 cm for the soil at 3,140 m (1.4 °C) is the coldest in the study area. The mean annual soil temperatures for the soils at 3,545 m are warmer and also the inverse of the original hypothesis. The soil at 3,377 m has the warmest annual average (4.2 °C). With an annual average of 4.0 °C and a mean summer temperature of 9.8 °C, the soil at 3,140 m has a frigid temperature regime. The soil temperature regimes at the remaining sites are cryic. The isotivity values range from 7.2 to 11.0 °C. These values are somewhat lower than those expected. Snow cover from January to May mitigates the air temperature at 3,545 m. Snow covering the sensor "flat-lined" the readings for 4 months from January 10 to May 10, 2000. On May 11, the air temperature readings displayed the normal oscillations of daily temperature. Conversely, snow covering the air temperature sensor at site 5 lasted less than 1 month and likely had little impact on monthly and annual temperature values. One could conclude that since sites 4 and 5 are at similar elevations and in close proximity, the impact of snow cover is about 0.4 °C.

1. Background and Hypotheses

Soil temperature data from high-elevation sites in Colorado are limited. Most sites with extreme climatic conditions are difficult to access and nearly impossible to visit during winter months. It is in these remote areas where automated data-capture systems are most needed for assessments of daily, monthly, seasonal, and annual soil temperatures.

Temperature sensors were installed at the five sites in the Guanella Pass area on September 5, 1999, as part of a research effort to assess soils with cold soil temperatures. During September 2000, the MLRA Office in Lakewood, Colorado, incorporated these sites into a network of temperature sites throughout Colorado. Six hypotheses were formed during the September 1999 installation in the Guanella Pass. These hypotheses were based on results from the Niwot Ridge LTER study. Though general in nature, they could be tested with measured soil temperature data from this study. They are as follows:

1. Sites 1, 2, and 5 would have a cryic soil temperature regime.
2. Sites 3 and 4 would have a cryic soil temperature regime with a MAST of <0 °C.
3. The difference between mean summer and mean winter soil temperatures would be less than 11 °C at all sites.

* Steve Park and Alan Price, NRCS Data Quality Specialists at the MLRA Office in Lakewood, Colorado, helped prepare this section.

4. There would be more than 250 days of biological inactivity at a depth of 10 cm in the soil on site 3.
5. Site 3 would be colder than site 4.
6. Sites 3 and 4 would not be as cold as the sites on the Niwot Ridge LTER in Boulder County, Colorado.

2. Guanella Pass Study Area

The five sites are located in Clear Creek County, Colorado, which is about 100 km west and south of Denver. Sensors were installed at these sites on September 8, 1999, to measure air and soil temperature. Site 1 is in a grove of aspen (*Populus spp. L.*). Site 2 is in a forest of Engelmann spruce (*Picea engelmannii L.*) with some subalpine fir (*Abies spp. L.*). Site 3 is in the windswept reaches of Guanella Pass and is vegetated with alpine grass and forbs. Site 4 also is in the windswept reaches of Guanella Pass. It is vegetated with stunted Engelmann spruce and low-growing alpine willow. Site 5 is in a forest of Engelmann spruce and bristlecone pine (*Pinus spp. L.*) with about 50 percent canopy. The percentage of the surface covered by cobbles, stones, and boulders ranges from less than 0.1 percent at site 3 to 10 percent at site 1. The well drained soils at sites 1, 2, and 5 are loamy-skeletal, mixed, superactive Typic Eutrocryepts (Soil Survey Staff, 1999). The well drained soils at sites 3 and 4 are loamy-skeletal, mixed, superactive Typic Eutrocryepts. Table 7.06.1 gives additional information about each site.

Table 7.06.1.—Site information for the temperature study in the Guanella Pass.

Site number	Latitude (north)	Longitude (west)	Elevation (m)	Slope (%)	Aspect (°)
1	39°39'03"	105°42'31"	3,140	40	90
2	39°36'24"	105°42'49"	3,505	70	30
3	39°35'43"	105°42'44"	3,545	9	240
4	39°35'29"	105°42'57"	3,545	30	300
5	39°34'24"	105°43'29"	3,377	47	180

3. Results

Soil temperature at 10 cm.—The soil temperatures for the 10-cm depth at the five sites are given in table 7.06.2. Unexpectedly, site 2 had the coldest MAST at 10 cm (1.3 °C), followed by site 3, site 4, site 1, and site 5. The isotivity value at site 3 (14.6 °C) is the highest in the study area, while that of the south aspect at site 5 (12.7 °C) is less than was expected.

Table 7.06.2.—Monthly, seasonal, and annual soil temperatures (°C) for the 10-cm depth.

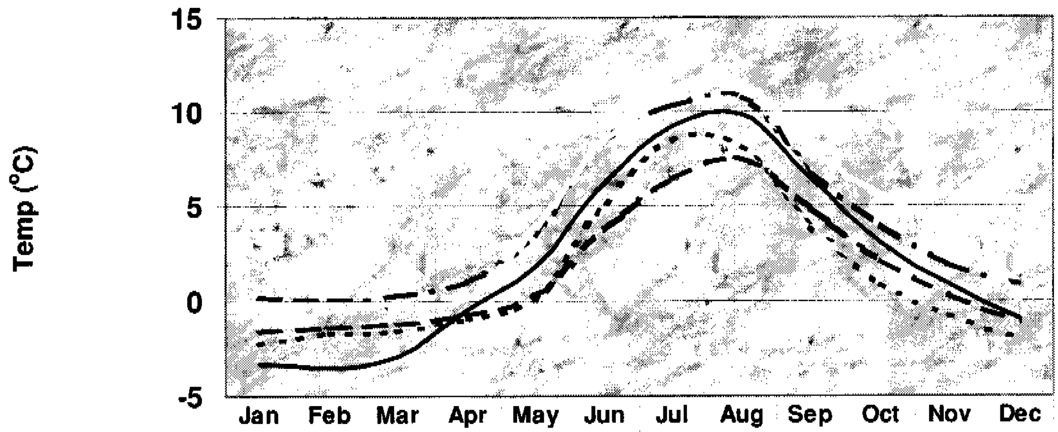
Analysis	Site 1	Site 2	Site 3	Site 4	Site 5
Jan 00	-1.5	-4.0	-4.6	-2.4	-1.7
Feb 00	-1.6	-3.0	-4.2	-1.8	-0.2
Mar 00	-1.3	-2.7	-3.2	-1.6	0.6
Apr 00	-0.1	-1.2	-0.1	-0.8	1.0
May 00	3.0	1.4	4.6	1.4	5.7
Jun 00	8.4	9.3	8.4	6.4	10.2
Jul 00	10.8	11.3	11.4	8.5	12.5
Aug 00	12.0	9.4	12.3	8.6	12.5
Sep 99&00	5.6	2.6	5.7	4.4	7.8
Oct 99	2.1	-0.8	1.8	1.2	5.2
Nov 99	0.0	-3.2	0.1	-0.5	3.3
Dec 99	-0.8	-4.1	-2.7	-2.6	-1.1
Mean	3.0	1.3	2.4	1.7	4.7
MST	10.4	10.0	10.7	7.8	11.8
MWT	-1.3	-3.7	-3.9	-2.3	-1.0
Isotivity	11.7	13.7	14.6	10.1	12.7

Soil temperature at 25 cm.—Site 3 is the only site with temperature data at 25 cm (table 7.06.3). The MAST is nearly identical to that of the 10-cm depth (2.3 vs. 2.4 °C). The isotivity value at site 3 is 1.6 °C less for the 25-cm depth than for the 10-cm depth (13.0 vs. 14.6 °C). The soil was frozen for an average of 5 months during the period of record. This period is similar to that of the 10-cm depth.

Table 7.06.3.—Monthly, seasonal, and annual soil temperatures (°C) for the 25-cm depth at site 3.

Analysis	Site 3
Jan 00	-4.2
Feb 00	-4.1
Mar 00	-3.2
Apr 00	-0.3
May 00	3.1
Jun 00	7.5
Jul 00	10.4
Aug 00	10.8
Sep 99&00	6.3
Oct 99	2.6
Nov 99	0.5
Dec 99	-2.1
Mean	2.3
MST	9.5
MWT	-3.5
Isotivity	13.0

Soil temperature at 50 cm.—Complete data were captured for the 50-cm soil depth at each site. Figure 7.06.1 shows monthly data for the five sites in the study area, and table 7.06.4 shows seasonal and annual data.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 50 cm	0.2	0.1	0.2	0.9	3.4	8.5	10.3	10.8	6.8	4.0	1.9	0.9
2 50 cm	-2.2	-1.7	-1.6	-0.9	0.1	5.2	8.5	8.1	3.8	0.8	-0.8	-2.0
3 50 cm	-3.3	-3.5	-2.9	-0.5	1.8	6.2	9.2	9.8	6.5	3.0	0.8	-0.9
4 50 cm	-1.6	-1.4	-1.2	-0.7	0.3	3.8	6.4	7.4	4.9	2.1	0.2	-1.1
5 50 cm	-1.2	-0.6	-0.1	0.1	3.9	8.5	10.9	11.5	8.1	5.6	3.7	0.1

Figure 7.06.1.—Average monthly soil temperatures at 50 cm for the Guanella Pass study area.

Table 7.06.4.—Seasonal and annual soil temperatures (°C) at 50 cm.

Analysis	Site 1	Site 2	Site 3	Site 4	Site 5
Mean	4.0	1.4	2.2	1.6	4.2
MST	9.8	7.3	8.4	5.9	10.3
MWT	0.4	-2.0	-2.6	-1.4	-0.6
Isotivity	9.4	9.2	11.0	7.2	10.8

Unlike the soils on the Niwot Ridge LTER in Colorado, none of the soils in Guanella Pass came close to having a MAST of less than 0 °C. Unexpectedly, the MAST at 50 cm for the soil at site 2 (1.4 °C) is the coldest in the study area. The MAST for the soils at sites 3 and 4 are warmer than was conjectured and also the inverse of the original hypothesis. The soil at site 5 has the warmest MAST (4.2 °C). With a MAST of 4.0 °C and a MST of 9.8 °C, the soil at site 1 has a frigid temperature regime. The soil temperature regimes at the remaining sites, as defined by *Soil Taxonomy*, are cryic (Soil Survey Staff, 1999). Soil isotivity values ranged from 7.2 to 11.0 °C. These values are lower than was expected.

Air temperature.—Except for site 3, where no air temperature data were collected, air temperature sensors used in this study were placed about 10 cm above the ground. The monthly, seasonal, and annual air temperature data are shown in table 7.06.5.

Table 7.06.5.—Monthly, seasonal, and annual air temperatures (°C).

Analysis	Site 1	Site 2	Site 4	Site 5)
Jan 00	-6.3	-9.5	-7.2	-8.5
Feb 00	-3.9	-7.1	-5.0	-5.1
Mar 00	-4.0	-7.0	-3.7	-3.2
Apr 00	1.4	-0.8	-1.1	-0.5
May 00	7.6	5.1	4.9	5.3
Jun 00	10.7	9.5	10.0	8.6
Jul 00	12.4	12.2	12.1	11.1
Aug 00	11.4	10.6	10.5	9.7
Sep 99&00	5.4	4.0	4.8	4.5
Oct 99	2.5	0.9	1.8	1.6
Nov 99	0.1	-2.0	-0.5	-1.4
Dec 99	-7.2	-9.7	-9.2	-8.9
Mean	2.5	0.5	1.5	1.1
MST	11.5	10.8	10.9	9.8
MWT	-5.8	-8.8	-7.1	-7.5
Isotivity	17.3	19.5	18.0	17.3

Data for air temperature are mitigated by snow cover at site 4 from January to May (figure 7.06.2). Consequently, the spring and annual air temperature averages for this site are conjectured to be somewhat different than those shown in table 7.06.5. Snowfall, covering the sensor at site 3, "flat-lined" the readings for 4 months from January 10 to May 10, 2000. On May 11, the air temperature readings displayed the normal oscillations of daily temperature. Snow covering the air temperature sensor at site 5 lasted less than 1 month and likely had little impact on its monthly and annual temperature values. One could infer that since sites 4 and 5 are at similar elevations and in close proximity, the impact of snow cover was about 0.4 °C (the MAAT of site 5 minus the MAAT of site 4).

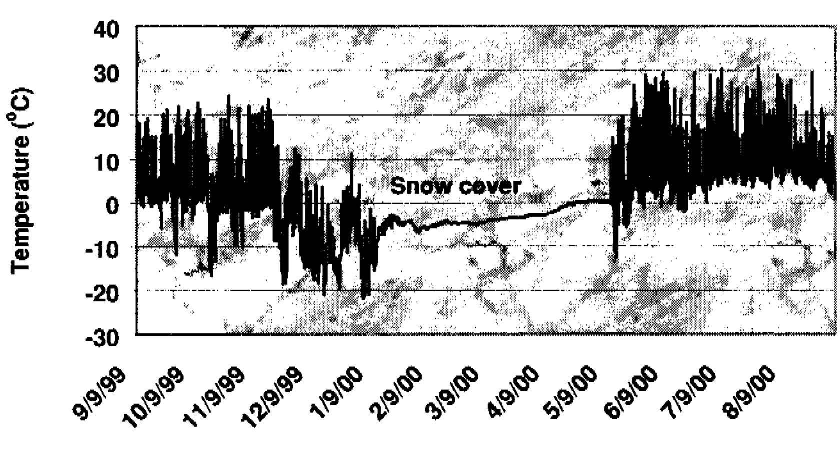
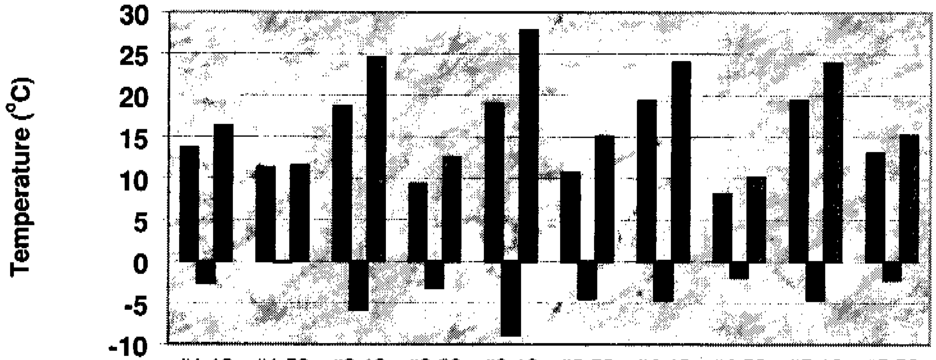


Figure 7.06.2.—Impact of snowfall on the air temperature signature at site 4.

Soil temperature extremes.—On each site in the study area, there are extreme differences between the minimum and maximum soil temperature readings at both 10 cm and 50 cm for the period of record (figure 7.06.3).



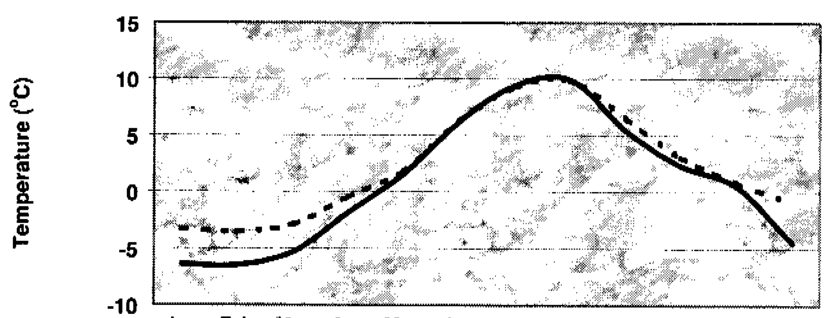
	#1 10 cm	#1 50 cm	#2 10 cm	#2 50 cm	#3 10 cm	#3 50 cm	#4 10 cm	#4 50 cm	#5 10 cm	#5 50 cm
Max	13.6	11.2	18.6	9.3	19.0	10.7	19.3	8.2	19.3	13.0
Min	-2.7	-0.2	-5.8	-3.1	-8.8	-4.4	-4.6	-1.9	-4.6	-2.2
Max-Min	16.3	11.4	24.5	12.4	27.8	15.1	23.9	10.1	23.9	15.2

Figure 7.06.3.—Maximum and minimum soil temperature extremes at 10 cm and 50 cm.

The soil on each site froze at all depths during the study. Soil temperature extremes at high elevations are most pronounced at the 10-cm depth. The difference between maximum and minimum soil temperatures at 10 cm ranges from 16.3 °C at site 1 to 27.8 °C at site 3 on the windswept alpine grasslands of Guanella Pass. The pattern changes for the 50-cm soil depth. For these extremes, site 4 had the lowest value (10.1 °C), whereas site 5 had the highest extreme value (15.2 °C). The extremes at 50 cm are similar to those at the Niwot Ridge LTER.

4. Discussion

The soils at sites 2, 3, 4, and 5 have cryic soil temperature regimes, and the soil at site 1 has a frigid regime. Consequently, hypothesis 1 is incorrect. Neither site 3 nor site 4 had a MAST at 50 cm of 0 °C or less. Figure 7.06.4 contrasts data from this study with data from the Niwot Ridge LTER during the same period of record.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Guanella	-3.3	-3.5	-2.9	-0.5	1.8	6.2	9.2	9.8	6.5	3.0	0.8	-0.9
Niwot	-6.4	-6.5	-5.3	-1.9	1.6	6.2	9.4	9.9	5.4	2.3	0.5	-4.5

Figure 7.06.4.—Average monthly temperatures for site 3 in Guanella Pass and site 2 on Niwot Ridge.

Hypothesis 1 is incorrect most likely because of appreciable snow cover on the alpine grasses of Guanella Pass. The summer temperatures warm much more quickly at Guanella Pass than on Niwot Ridge, resulting in a warmer MAST at 50 cm.

Hypothesis 2 is incorrect. Air temperature for the period of record at Guanella Pass was warmer than that of the 1998-1999 period of record. Even when this continental warming pattern is taken into account, it is suspected that neither soil would have been subpergelic.

Hypothesis 3 is incorrect; none of the sites had isotivity values of less than 11 °C. The frigid and cryic soils at Guanella Pass exhibit a greater isotivity value at 50 cm than cryic soils in Idaho, where snow covers the surface throughout the winter months. In Clearwater County, Idaho, the isotivity values for three cryic sites were less than 6.0 °C (Mount, 1999).

Hypothesis 4 stated that site 3 would be biologically inactive for more than 250 days. Biological inactivity occurs when the soil temperature is <5 °C (Paul and Clark, 1989). The 10-cm soil depth at site 3 was biologically inactive for about 270 days. Consequently, hypothesis 4 is true. In areas of alpine grass vegetation, soil temperature at 10 cm rises rather quickly in June and stays above 5 °C until late September.

Hypothesis 5 stated that site 3 would have a colder MAST than site 4. This conjecture was based on data from Niwot Ridge that showed soil temperatures in the krummholz to be warmer than in the adjacent alpine grass. This hypothesis is false in Guanella Pass, where the MAST at site 4 was 0.6 °C colder than the MAST at site 3 (1.6 vs. 2.2 °C).

The final hypothesis is true. Data show that the soils at sites 3 and 4 in Guanella Pass are not as cold as the soil on site 2 on the Niwot Ridge during the same period of record.

The climate in Guanella Pass occurs throughout the high-elevation reaches of Colorado. In these areas, there are tens of thousands of hectares with similar cold soil temperatures. The MLRA office in Lakewood, Colorado, is encouraged to monitor additional sites throughout these areas to quantify the extent of these cold soils.

Chapter 7.07

Subtropical Soil Temperature Study in Florida*

ABSTRACT

Soils at seven sites in south Florida were monitored for air and soil temperature during 1999 and 2000. The soils are hyperthermic at three sites and isohyperthermic at four sites where the isotivity values (the difference between mean summer and mean winter soil temperatures) were less than 6 °C. This study confirms the presence of "iso" temperature regimes in the subtropical zone of south Florida. Microvariations in air temperature were detected on the five sites in and around Homestead, Florida. The soils at two of the five sites had an identical mean annual air temperature of 23.2 °C. The lychee nut plantation displays a different monthly air temperature signature than the other three sites in Homestead. The soil at the lychee nut plantation is warmer during the winter months and cooler during the spring months. On average, this soil is the same as the soil at the Pine Island Nursery (23.2 °C). The 5-cm depth for a soil in grass vegetation in Homestead averaged over 37.8 °C for the months of August and September 1999. The 10-cm depth for this soil averaged 37.2 and 35.6 °C for the same months. The mean annual soil temperature for the 28-cm depth (26.7 °C) was the warmest of the sites in the Homestead area. The soils at the Almond Tree Nursery and the Pine Island Nursery near Homestead had isotivity values of less than 6 °C and are isohyperthermic. Data from two soils in the Florida Keys suggest a latent heat effect on the mean annual soil temperature. The soils in Key Largo and in Key Vaca are 43 cm to bedrock and have isohyperthermic soil temperature regimes with isotivity values of less than 4 °C. The monthly values for the 43-cm depth in these two soils show a displacement of unexplainable high temperature values, especially during October and November.

1. Background and Purpose

A soil temperature study for south Dade and Monroe Counties, Florida, was initiated during February 1999. This study was a cooperative effort among NRCS and the South Dade County Conservation District in Homestead, Florida, and the National Soil Survey Center in Lincoln, Nebraska. The NRCS Global Change Initiative provided funding for this study. One purpose of the study was to determine the soil temperature regimes according to the classification system in *Soil Taxonomy*. Another purpose was to supply temperature data to cooperators in the study area for their farming ventures.

2. Study Area

Southernmost Florida is subtropical, and Key West has the warmest mean annual air temperature (MAAT) in the conterminous United States (25.4 °C). Data from a 33-year period (1961 to 1990) indicate that the mean annual rainfall averages slightly more than 1,000 mm. Occasional hurricane events cause rather high deviations from year to year. Elevation is less than 4 meters above sea level in the study area. The sites are on nearly level soils. The soils are typically shallow (<50 cm) to oolitic bedrock (Hurt et al., 1995).

Site 1 is at the University of Florida Tropical Research and Education Center in Homestead (NE¼SE¼ sec. 27, T. 56 S., R. 38 E.). Its latitude is 25º31'16" north, and its longitude is 80º30'06" west. The vegetation at the site consists of grasses and weeds less than 10 cm tall and mowed throughout the year to a height of 5 cm. The soil at this site is Krome very gravelly loam (map unit symbol 7), a loamy-skeletal, carbonatic, hyperthermic Lithic Udorthent (Hurt et al., 1995). The typical pedon has an Ap horizon from 0 to 18 cm and an R layer at 18 cm consisting of hard, porous oolitic bedrock. There is no indication that this site is affected by irrigation practices.

* Linda Meeder from the South Dade County SWCD Office in Homestead, Florida, assisted in preparing this section.

Site 2 is in Dade County, at the private residence of Andres Mejides, an organic producer in Homestead (figure 7.07.1). The site is in the NE¼NE¼ sec. 34, T. 56 S., R. 38 E. It is along a north-south metal fence line. Its latitude is 25º31'34" north, and its longitude is 80º30'39" west. Mr. Mejides uses the area for organic farming of tropical plants, including tree orchids and chenille shrubs, and the ground cover consists of Boston fern (*Nephrolepsis exaltata bostoniensis L.*). A Krome soil is at this site. Because of good management, it is darker than is defined as the range for the Krome series and is probably a Lithic Haprendoll (Soil Survey Staff, 1999). The soil was moist when the temperature sensors were installed, and the temperature of the irrigation water is about 23.9 °C (75 ºF).

Figure 7.07.1—Site 2 is in a rather dense subtropical forest ecosystem in Homestead, Florida.

Site 3 is on the property of Noble Hendrix, Chair for the South Dade County Soil and Water Conservation District. The site is in sec. 28, T. 56 S., R. 39 E. It is along a north-south metal fence line. Its latitude is 25º31'56" north, and its longitude is 80º26'29" west. The site is at a lychee nut (*Litchi chinensis L.*) grove with a height of about 4.3 meters (figure 7.07.2). The ground cover is decomposing lychee nut leaves. Because of good management, the soil at this site is darker than is defined for the Krome series and is probably a Lithic Rendoll. The irrigation water is suspected to be about 1 °C cooler than that at site 2.

Figure 7.07.2.—Site 3 is in a lychee nut plantation.

Site 4 is at the Almond Tree Nursery owned by Steve Garrison. The site is west of Homestead, in the town of Redlands in sec. 8, T. 57 S., R. 38 E. More specifically, it is in an east-west live oak border. Its latitude is 25º29'04" north, and its longitude is 80º31'27" west. The site has an overstory of live oak (*Quercus spp. L.*) trees. About 10 percent of the soil surface is sporadically covered with about 10 percent dead live oak leaves. The soil at the site is like Krome very gravelly loam (map unit symbol 7), a loamy-skeletal, carbonatic, hyperthermic Lithic Udorthent. It is too deep for the Krome series and classifies as a Lithic Rendoll (Hurt et al., 1995). This site represents a transition between the irrigated nursery to the north and the plowed field to the south.

Site 5 is at the Pine Island Nursery. The site is north of Homestead, in sec. 5, T. 56 S., R. 39 E. More specifically, it is in the second citrus row west of a palm tree nursery (figure 7.07.3). Its latitude is 25º35'18" north, and its longitude is 80º27'26" west. This nursery has raised beds about 38 cm high. The overstory consists of a 1.8-meter-tall Persian lime (*Citrus spp. L.*) tree. The understory is bare with about 10 percent limestone gravel. The soil at the site is like Krome very gravelly loam (map unit symbol 7). Because of the raised beds, it is too deep for the Krome series and classifies as a Typic Haplustoll (Soil Survey Staff, 1999). This site is not irrigated.

Figure 7.07.3.—The soil surface exposed beneath the lime tree at site 5.

Site 6 is in Monroe County, Florida, on Key Largo. The site is in a residential area south of mile marker 102 on Mahogany Drive. Its latitude is 25º07'12" north, and its longitude is 80º24'47" west. The vegetation consists of gumbo limbo (*Bursera simaruba L.*), passion fruit, mahogany, oyster plant (*Tragopogon porrifolius L.*), banana, and other tropical ornamentals. The soil is Pennekamp gravelly muck, 0 to 2 percent slopes, extremely stony (map unit symbol 2) and is a loamy-skeletal, carbonatic, isohyperthermic Lithic Rendoll. The *Soil Survey of Monroe County, Keys Area, Florida*, indicates that the Pennekamp series makes up 6,980 acres (10.6 percent) in the survey area (Hurt et al., 1995). Soil moisture from adjacent sprinkler systems is suspected to have minimum impact on soil temperature at site 6.

Site 7 is in Monroe County, Florida, in the town of Marathon on Key Vaca. The small island of Rachel Key lies to the north. The site is at the northern end of the Florida Keys National Marine Sanctuary. Its latitude is 24º43'27" north, and its longitude is 81º04'40" west. Site 7 is the southernmost site in the United States that is monitored for soil temperature. This research site has an overstory of 3.7-meter-tall gumbo limbo (*Bursera simaruba L.*), 4-meter-tall poisonwood (*Metopium toxiferum L.*), and buttonwood. The ground cover consists of oyster plant (*Tragopogon porrifolius L.*) and unidentified grasses. The soil at this site was mapped as Keylargo muck, tidal (Hurt et al., 1995), but it is closer to Keyvaca soils, which are loamy-skeletal, carbonatic, isohyperthermic Lithic Haprendolls. The soil has 10 cm of slightly moist hemic material over fractured coral bedrock we excavated to 40 cm. Keyvaca soils are dry enough to have an ustic moisture regime (Soil Survey Staff, 1999).

3. Results

Table 7.07.1 shows air and soil temperature results for each site in the study area.

Table 7.07.1.—Air and soil temperature averages (°C) for the deepest soil depth.

Site no.	Mean air	MAST	MST	MWT	Isotivity value
1	---	26.7	30.8	22.2	8.6
2	23.3	23.3	26.2	19.7	6.4
3	23.2	25.8	29.9	23.7	6.1
4	22.8	23.9	26.3	21.2	5.1
5	23.2	25.3	27.7	22.1	5.6
6	24.5	31.9	34.1	30.5	3.6
7	25.7	29.1	31.5	27.8	3.7

Tropical research center in Homestead.—The soil at site 1 is hyperthermic. Data at site 1 are consistent with its setting. The 5-cm depth averaged over 37.8 °C for the months of August and September 1999. The 10-cm depth averaged 37.2 °C for the same months. The MAST at the 28-cm depth (26.7 °C) was the warmest of the five sites in the Homestead area. The 5- and 10-cm depths are warmer than the 28-cm depth during every month of this study. This finding is unusual. Normally, the MWT is warmer at deep depths than at shallow depths. Another peculiarity at site 1 was the gradient of mean annual soil temperature with depth. The 5-cm depth averaged 31.7 °C, the 10-cm depth averaged 30.1 °C, and the 28-cm averaged 26.7 °C. In nontropical systems, the difference between shallow and deep depths is much less. Studies in South Carolina show this difference to be less than 0.6 °C in wooded and dunal ecosystems (Mount et al., 1998).

Organic farmstead in Homestead.—The soil at site 2 has a hyperthermic temperature regime. The results in the wooded ecosystem at site 2 are much different from the results in the grassy location at site 1. At 22.6 °C, the MAAT was the coldest of any site in the study area. The warmest month was July (26.8 °C), and the coldest was February (17.0 °C). The minimum air temperature of 3.1 °C was recorded at 6:47 a.m. on January 27, 2000. The MAST at 10 cm was 23.0 °C, and the MAST at 20 cm was 23.3 °C. This consistency is typical of densely forested ecosystems throughout the United States. Contrary to onsite conjecture, the soil at this site had an isotivity value of more than 6.0 °C at 20 cm. In all other regards, however, this site displayed typical soil temperatures for a subtropical ecosystem.

Lychee nut plantation in Homestead.—The results at site 3 were somewhat similar to those at site 2 in that the soil is hyperthermic. At 23.2 °C, the MAAT was 0.7 °C warmer than that of site 2 and within 0.1 °C of the 30-year mean for Homestead (23.3 °C). This average strongly suggests that the air temperature at site 3 was within the definition of a normal year for Homestead, Florida. At 27.0 °C, the warmest month was July, but August was nearly as warm at 26.7 °C. The coldest monthly air temperature was in March (18.4 °C). The minimum air temperature of 3.4°C was recorded at 6:49 a.m. on March 2, 1999. The MAST at 10 cm was 22.9 °C, and the MAST at 20 cm was 25.8 °C. The 2.9 °C increase in MAST at 20 cm is suspected to reflect the irrigation practices at the lychee nut plantation. The 20-cm soil depth at this site had an isotivity value of 6.1 °C and is marginal to isohyperthermic. Moreover, the monthly soil temperature at 20 cm was warmer than the air temperature during all months except April. The soil temperature at 20 cm averages 29.2 °C from June through October. This 5-month average at site 3 is precisely 1.7 °C warmer than the soil temperature at 20 cm at a tropical site on St. John Island in the Caribbean—strong evidence of the tropical environment in Homestead, Florida. The coldest soil temperature (18.8 °C) and the coldest air temperature (18.4 °C) occurred in March.

Almond Tree Nursery west of Homestead.—At 22.8 °C, the MAAT at this site was 0.4 °C colder than the MAAT at site 3 and 0.3°C warmer than the MAAT at site 2. The warmest months were July and August, each averaging 26.7 °C. The monthly air temperature was coldest (17.8 °C) in February. The minimum air temperature of 4.4 °C was recorded at 5:38 a.m. on January 27, 2000—the same day as the minimum at site 2. The MAST at 10 cm was 23.3 °C, and the MAST at 41 cm was 23.9 °C. This similarity in averages between the two depths is consistent with the ecosystem at site 4. The 41-cm soil depth at this site had an isotivity value of 5.1 °C. Consequently, the soil is isohyperthermic (Soil Survey Staff, 1999). Unlike the lychee nut plantation at site 3, the soil temperature at 41 cm for site 4 averaged less than 26.7 °C from June through October. This difference is thought to result from the lack of irrigation at this site. August had the warmest monthly mean for both the 10- and 41-cm soil depths, and February had the coldest. The coldest monthly average at 10 cm was 18.8 °C, and the coldest monthly average at 41 cm was 20.1 °C.

Pine Island Nursery north of Homestead.—At 23.2 °C, the MAAT at site 5 was identical to that of the lychee nut plantation at site 3. The warmest months were July, August, and September, which averaged 27.6 °C, 27.1 °C, and 26.7 °C, respectively. February had the coldest monthly air temperature (17.9 °C). The minimum air temperature of 2.9 °C was recorded at 5:43 a.m. on December 27, 1999. The low reading on January 27, 2000, was 4.5 °C. In this study area, the diurnal fluctuation of soil temperature at 10 cm was the most expressed at site 5 (figure 7.07.4). The amplitude of daily lows and highs is consistent with a farmed ecosystem.

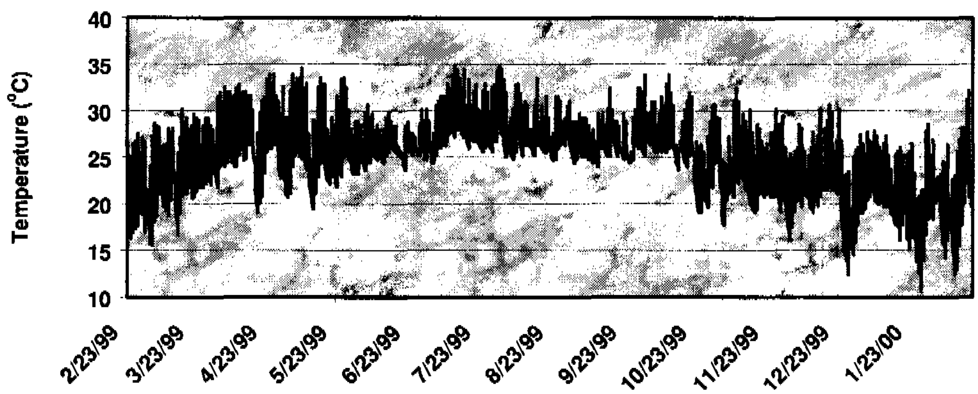


Figure 7.07.4.—Soil temperature signature at 10 cm for site 5.

The MAST at 10 cm was 25.2 °C, and the MAST at 50 cm was 25.3 °C. This similarity in averages between the two depths is consistent with the results at sites 2 and 4. The isotivity values at 10 and 50 cm are less than was hypothesized. Unexpectedly, the 50-cm soil depth at this site had an isotivity value of only 5.6 °C. Consequently, the soil at the site is isohyperthermic. The soil temperature at 50 cm averaged more than 26.7 °C from May through September. July had the warmest monthly mean for both the 10-cm (28.2 °C) and 50-cm (28.9 °C) soil depths, and January and February had the coldest.

Key Largo.—Site 6 is the first of two sites in the Florida Keys to verify the most tropical soil temperature in Florida. At 24.5 °C, the MAAT at site 6 is warmer than the MAAT of any other location in Homestead, Florida. The 30-year air temperature normal at nearby Tavernier, Florida, is 25.2 °C. Therefore, the mean at Key Largo is slightly cooler than the 30-year normal. The warmest months in this study were July and August, averaging 28.6 °C and 28.2 °C, respectively. The coldest monthly air temperature (19.2 °C) occurred in February. The minimum air temperature of 7.4 °C was recorded at 5:05 a.m. on December 27, 1999. The MAST at 10 cm was 24.4 °C, and the MAST at 43 cm was 31.9 °C. This 7.5 °C dissimilarity in averages between the two depths is the largest of any documented site in the United States. However, the 43-cm soil depth at this site has an isotivity value of only 3.6 °C and is isohyperthermic. August had the warmest monthly mean for the 10-cm depth (28.6 °C). The 43-cm depth, however, was warmest during October (39.1 °C) and November (37.8 °C). These high temperature values on Key Largo cannot be explained by solar inputs and may result from exothermic activities. The February average of 18.3 °C was the coldest monthly average for the 10-cm depth, and the March average of 22.3 °C was the coldest monthly average for the 43-cm depth.

Key Vaca.—The soil at site 7 is somewhat near the southernmost point in Florida. At 25.7 °C, the MAAT at site 6 is 1.2 °C warmer than the MAAT at site 6, in Key Largo, Florida. The 30-year air temperature normal at nearby Key West, Florida, is 25.4 °C. Therefore, the mean at Key Largo is 0.3 °C warmer than the 30-year normal. The warmest months in this study were July and August, which averaged 29.4 °C and 29.3 °C, respectively. The coldest monthly air temperature (20.9 °C) occurred in February. The minimum air temperature of 11.6 °C was recorded at 5:07 a.m. on January 27, 2000. The MAST at 10 cm was 26.8 °C, and the MAST at 43 cm was 29.1 °C. This 2.3 °C dissimilarity in MAST between the two depths is more than was originally expected. However, the 43-cm soil depth at this site has an isotivity value of only 3.7 °C and is isohyperthermic. July had the warmest monthly mean for the 10-cm depth (30.2 °C). However, the 43-cm soil depth was warmest during August and September (32.9 °C). Like the values at site 6, these high values cannot be explained by air temperature inputs and are conjectured to result from exothermic activities at the site. The February average of 22.3 °C was the coldest monthly average for the 10-cm depth. The March average of 23.4 °C was the coldest monthly average for the 43-cm depth.

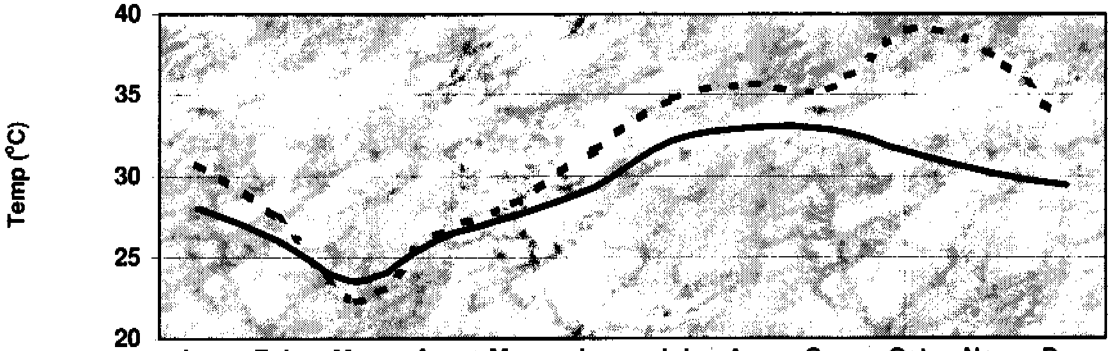
4. Discussion

The variation in air and soil temperatures in the Florida subtropical temperature study (especially those at Homestead) is called a microclimate effect. To expect all the air temperature stations at Homestead to have the same MAAT is not realistic. Two of the five stations, however, did have the same MAAT.

The lychee nut plantation at site 3 displays a different momthly air temperature signature than the other three sites in Homestead. Site 3 is warmer during the winter months and cooler during the spring months. On average, however, it has the same MAAT as site 5 (23.2 °C).

There appears to be a latent heat phenomena in the Florida Keys. The point of measurement for the classification of the soil temperature is either 50 cm or the contact of soil and rock if a soil is shallower than 50 cm. At site 6, on Key Largo, and site 7, on Key Vaca, the depth to bedrock is 43 cm. The sensor was carefully placed on top of the bedrock, then covered with soil material from the residential garden. Data for both depths did not display any spiking, which implies electronic interference and hence problems with the sensor technology.

The resulting monthly values for the 43-cm depth at sites 6 and 7 show a displacement of unexplainable high temperatures. Though more understandable at site 7, on Key Vaca (considering the air temperature inputs), the deep temperatures on Key Largo defy normal analysis. Figure 7.07.5 graphs the monthly temperatures at 43 cm for sites 6 and 7.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#6	30.7	27.4	22.3	26.3	28.3	31.6	34.8	35.8	35.4	39.1	37.8	33.3
#7	27.9	26.1	23.4	26.0	27.5	29.3	32.2	32.9	32.9	31.4	30.2	29.4

Figure 7.07.5.—Average monthly soil temperatures for the 43-cm depth at sites 6 and 7.

Data frequently raise more questions than answers. In the case of the Florida Keys, the primary question revolves around the latent heat of soil. Additional data from sites in the Florida Keys are needed before we can fully understand the complexity of soil temperature in this part of the United States.

Chapter 7.08

Soil Temperature Gradients on the Island of Hawaii*

ABSTRACT

The mean annual air temperature lapse rates, or the decrease in air temperature per 1,000 meters rise in altitude, were calculated from sites on both the dry side and the wet side of Hawaii. At 6.3 °C, the lapse rate from the Parker HQ site to the Hanaipoie site on the dry side of Hawaii is nearly identical to the 6.5° C lapse rate mentioned by previous researchers on the Big Island of Hawaii. However, the wet Hamakua sites northwest of Hilo have a larger lapse rate (9.7 °C) than was predicted by previous researchers. It is presumed that the rapid increase in the precipitation gradient with altitude contributes to the increase in the lapse rate. Mean annual soil temperature lapse rates have a larger range on the dry side (1.0 to 23.7 °C) than on the wet side (2.1 to 8.2 °C). From these measured data, it is concluded that one fixed mean annual soil temperature lapse rate will not work very well in Hawaii. The relationship of the mean annual air temperature lapse rate to the mean annual soil temperature lapse rate was examined for transect on both the dry side and the wet side. The lapse rate ratio of mean annual air temperature to mean annual soil temperature is 1.1:1.0 on the dry side and 1.2:1.0 on the wet side. The ratios are similar and imply that the decrease in mean annual soil temperature with altitude will occur at a slower rate than the decrease in mean annual air temperature. In other words, changes in soil temperature with increasing altitude are not proportional to changes in air temperature with increasing altitude. An experienced soil scientist can predict the soil temperature regime at a specific location in Hawaii with a fair degree of accuracy. The measured soil temperature regimes agreed with field predictions at five of the six sites in this study. However, prediction of the exact mean annual soil temperature at an individual site is much more difficult. Many attempts have been made to approximate mean annual soil temperature on the basis of mean annual air temperature, altitude, and lapse rates. Some studies in tropical environments have presented high r^2 values for their regression equations. Unfortunately, most of these studies reflect data from a specific ecosystem. When equations are taken from any one of these studies, they do not "fit" well with measured soil temperature data. Consequently, simple mathematical models designed to predict mean annual soil temperature in Hawaii do not work well. With annual data from additional sites throughout the Big Island, a better understanding of the mean annual soil temperature may evolve. It is suggested that a workable model for accurate prediction of mean annual soil temperature in Hawaii should integrate mean annual air temperature, altitude, slope percent and geometry, aspect, percent vegetative cover, and precipitation.

1. Background and Purpose

Soil scientists have been measuring the temperature of soils for nearly 100 years. From periodically collected data, early scientists concluded that one mid-month reading approximated the monthly average and the average of 12 monthly readings approximated the mean annual soil temperature (MAST) (Soil Survey Staff, 1975). From these monthly readings, seasonal variations were calculated. Soils of the Tropics were found to have less seasonal variation than soils on the continental U.S. The term "iso" was developed for those soils that differed less than 5 °C between mean summer (the average of June, July, and August) and mean winter (the average of December, January, and February) temperatures.

Prior to about 1991, measurements of soil temperature in Hawaii were restricted to one reading each month, primarily because of lengthy time requirements. Previous studies required a soil scientist to drive to each site near the middle of each month, dig down to 50 cm, measure the temperature, record the data, and then backfill the hole. Data from these short-term studies then were usually graphed; a MAST was

* Robert T. Gavenda, NRCS Soil Survey Project Leader, Kealakekua, Hawaii, Saku Nakamura, NRCS Assistant State Soil Scientist, Honolulu, Hawaii, and Christopher Smith, NRCS State Soil Scientist, Honolulu, Hawaii, assisted in preparing this section.

determined, then filed for later use. Some of these early data have been lost. After about 1985, various vendors began to market data loggers, resistance thermistors, and software that automatically collect soil temperature data. These loggers automatically record temperature data five times a day and free field soil scientists from the necessity of visiting the sites every month. This revolution in data collection allows for concerted soil temperature studies with multiple purposes.

The primary purpose of this study on the island of Hawaii was to measure and analyze soil temperature at nine sites reflecting the dominant climatic areas of the island. Six of these sites that approximate a dry to wet transect line are summarized in this report. Another purpose was to verify the measured data with the hypothesized soil temperature regime to support the ongoing soil survey. A third purpose was to identify lapse rates for soil temperature along a transect line that runs from the dry desert in northwest Hawaii, across Mauna Kea, and down to the wet sites near Hilo.

2. Previous Climate Research on Hawaii

As early as 1937, it was well known by researchers that the high relief of the Hawaiian Islands, coupled with the prevalence of the northeast trade winds during most of the year, compresses a wide variety of climatic zones within a relatively small area (Jones and Bellaire, 1937).

The Department of Land and Natural Resources of the State of Hawaii published air temperature summaries in 1983 showing the minimum and maximum monthly temperatures. The mean annual air temperature (MAAT) on the coastal plains of the Big Island is about 24 ºC. The maximum air temperature occurs between 1 and 2 p.m., and the minimum occurs just before sunrise. The coldest reporting site is the 3,962-meter-elevation station on Mauna Kea, which has a MAAT of 2.2 ºC. Measured data indicate that the MAAT decreased at a rate of about 5.4 ºC per 1,000-meter increase in elevation (Meteorological Staff, 1983).

From their work on the Island of Maui during 1982, Ikawa and Kourouma reported that soil temperature is one of the important soil properties and that, as one of the climatic factors, it influences not only soil formation but also plant growth (Ikawa and Kourouma, 1985). Thus, soil temperature is expressed as one of the modifiers at the soil family level (Soil Survey Staff, 1999). Besides air temperature, some of the other factors believed to affect soil temperature are kinds and amounts of insulating cover, slope and/or aspect, elevation, soil color, and texture of the surface horizon. The relationship of air and soil temperatures on Maui was expressed by equations indicating that the MAST of the 10-cm depth is the same as the MAST of the 50-cm depth. Ikawa and Kourouma concluded in their report that, depending on the latitude, the difference between the MAST at the 50-cm depth and the MAAT can range from about 5 ºC at the lower elevation on Maui to about 2 or 3 ºC at the higher elevations (Ikawa and Kourouma, 1985).

Mauna Kea is the only mountaintop in the tropical mid-Pacific Ocean Basin to show evidence of glaciation (Porter, 1979). Here, there is evidence to support a hypothesis for four glacial sheets. The oldest and largest of these glaciations began about 280,000 years ago and covered an area of nearly 150 km^2. Glaciation on Mauna Kea may have been caused by an increase in winter snowfall and a decrease in ablation rates resulting from lower air temperatures and increased cloudiness.

Juvik and Nullet (1994) showed that annual variation in average monthly air temperature is quite small at each of four sites in Hawaii (5 to 6 ºC). For the period of record covered (1992-1993), the range of average daily, maximum, and minimum temperatures remained fairly constant with elevation. The lapse rate of MAAT equates to 6.5 ºC per 1,000 meters. Soil temperatures follow a somewhat different pattern. The average range of soil temperature at 1 cm is less than the average of air temperature at the two lower sites but greater at the upper site by 1 ºC. The small range at the two lower sites could be attributed to continuously wet and shaded soils, while the high range at the upper site results from a generally drier lava substrate and higher radiation exposure near the inversion level. The average soil temperature at 1 cm is somewhat higher than the average annual air temperature.

Juvik and Juvik (1998) noted that Hawaii's climate is notable for its low day-to-day and month-to month variability. The annual variability in mean monthly temperatures at sea level is only about 5º C. A trade wind inversion exists on Hawaii at an elevation around 1,800 meters. This is verified with measurements transmitted from balloon-borne instruments launched twice daily by the National Weather Service from Hilo, Hawaii and Lihue, Kauai airports. The inversion itself is a relatively shallow layer (less than 1,000 meters thick) in which temperature increases rather than decreases with elevation. Lapse rates of air temperature per gradient of elevation rise have been studied and documented throughout the past 50 years on Hawaii. Currently, the lapse rate decreases at 6.5 ºC per 1,000 meters to an elevation of 1,500 meters. Thereafter, the lapse rates fall less rapidly to about 4.0 ºC per 1,000 meters.

From 1975 to 1998, soil temperature regimes with less than 5° C difference between average summer and winter soil temperatures at the 50-cm depth were designated as "iso" (Soil Survey Staff, 1975). During the 1980s, research from a climate-monitoring network on Haleakala, a mountain on the island of Maui, showed that 3 out of 19 stations differed more than 5° C at the 50-cm depth and these sites are thus hyperthermic (Nullet et al., 1990). As a result of this study, the "iso" definition in *Soil Taxonomy* was amended to allow isotivity values (difference in mean summer and mean winter soil temperatures) to range to 6 ºC (Soil Survey Staff, 1999).

3. Study Area

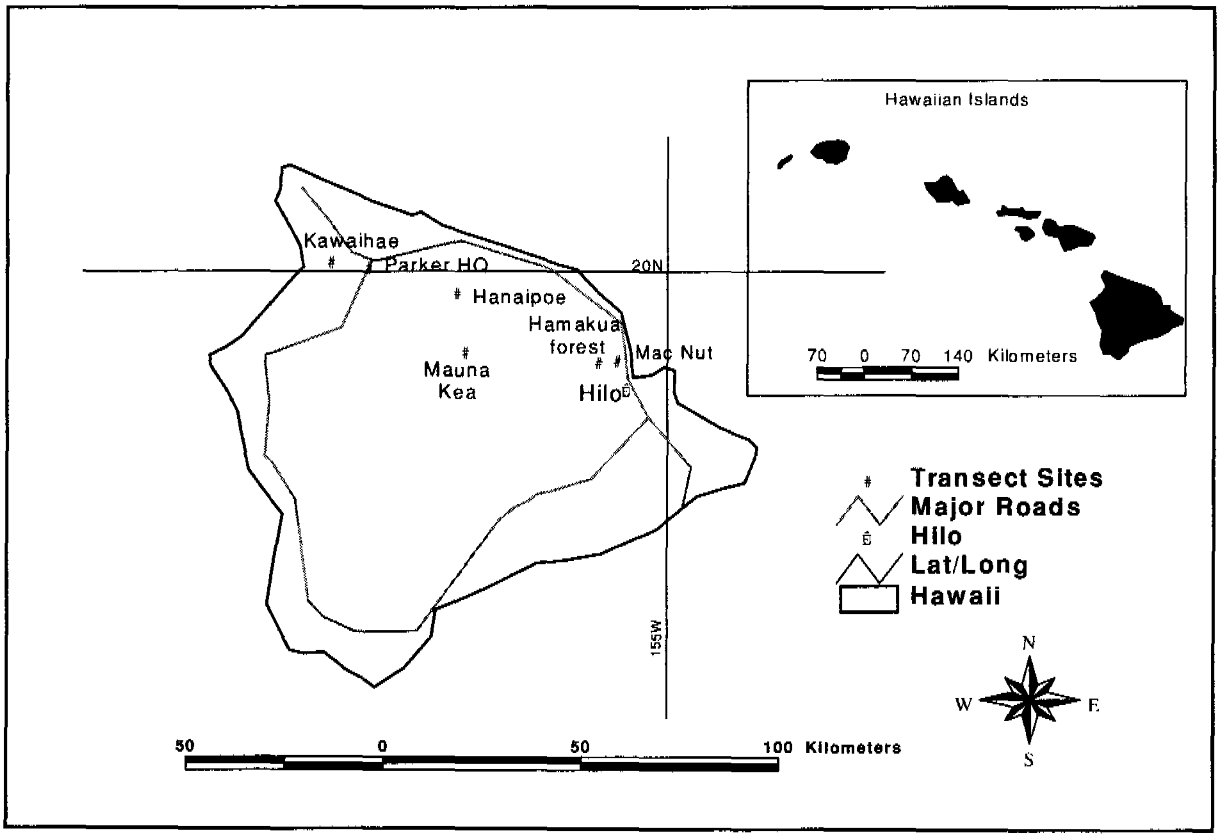


Figure 7.08.1.—Location of temperature sites in the study area.

The Big Island of Hawaii is located in the Tropics, the zone between the Tropic of Cancer and the Tropic of Capricorn. Hawaii is between 18° and 21° north of the Equator and is about 155° west of the Prime Meridian (figure 7.08.1). Big Island, with a surface area of only 10, 455 km^2, exhibits a wide range of climatic diversity comparable with that on continents. The three major factors that contribute to this climatic diversity are topographic relief (0 to 4,205 m elevation), a large-scale synoptic wind field, and a local circulation resulting from differential heating and cooling of the land, water, mountain, and lowland areas. Above the 3,200-meter level on Mauna Kea and Mauna Loa volcanoes, all months have a mean air temperature below 10 ºC and the climates are classified as periglacial. Nighttime freezing is common throughout the year (Juvik et al., 1978).

The mean annual precipitation at the six sites ranges from 250 mm at the Kawaihae site to over 5,400 mm at the rain forest site near Hilo (Juvik et al., 1992). The Kawaihae site is in an area of range, the Parker HQ and Hanaipoe sites are in areas of pasture, the Hamakua site is in an area of forest and macadamia nut trees, and the Mauna Kea site is on barren glacial mountain land. The soil at the Mauna Kea site formed in glaciated volcanic material that has been sorted through frost action. The resulting soil has a cobble pavement overlying sand. The soils at the other sites formed in volcanic ash (table 7.08.1).

Table 7.08.1.—Soil and site information for the study area.

Site name	Latitude (north)	Longitude (west)	Elevation (m)	Slope (%)	Aspect (°)	Annual precip. (mm)
Kawaihae	20°01'26"	155°45'38"	472	7	280	255
Parker HQ	20°00'37"	155°40'35"	764	2	270	585
Hanaipoe	19°56'41"	155°28'30"	1,585	13	0	585
Mauna Kea	19°47'31"	155°27'26"	3,566	5	0	380
Hamakua Forest	19°46'01"	155°09'10"	518	25	70	5,460
Hamakua Mac Nut	19°46'13"	155°06'40"	183	5	90	4,065

4. Results

Air temperature.—At 17.7 ºC, the MAAT for the Parker HQ site in Waimea is similar to long-term data indicating an average of 18.2 ºC (Meteorological Staff, 1983). (See table 7.08.2.) Using the daily low and daily high values collected during this study shows a MAAT at the Parker HQ site of 18.8 ºC. Both of the methods used to determine a MAAT at the Parker HQ site in Waimea resulted in averages that approximate the long-term average.

Table 7.08.2.—Monthly, seasonal, and annual air temperature averages (°C).

Analysis	Parker HQ	Hanaipoe	Hamakua Forest	Hamakua Mac Nut
Jan 99	16.1	11.3	16.7	20.0
Feb 98	16.1	11.2	16.8	20.4
Mar 98	16.9	12.1	17.2	20.6
Apr 98	16.6	11.8	16.9	20.2
May 98	17.1	11.9	16.8	20.3
Jun 98	18.3	13.6	17.9	21.5
Jul 98	19.0	14.1	18.6	21.9
Aug 98	19.9	15.0	19.5	22.5
Sep 98	19.4	13.8	18.6	22.0
Oct 98	18.8	13.3	18.7	21.7
Nov 98	17.9	13.1	18.1	20.9
Dec 98	16.0	11.3	16.9	19.7
MAAT	17.7	12.7	17.7	21.0
MST	19.1	14.2	18.7	22.0
MWT	16.1	11.3	16.8	20.0
MST-MWT	3.0	3.0	1.9	1.9

Soil temperature.—The soils at all sites but Kawaihae and Mauna Kea have isotivity values of less than 6 ºC (table 7.08.3). These data imply that most of Hawaii would classify as "iso" even if bedrock terminated the soils at 10 cm. This finding is valuable to scientists working on the Big Island soil survey.

Table 7.08.3.—Monthly, seasonal, and annual soil temperature averages (°C) for the 10-cm soil depth.

Analysis	Kawaihae	Parker HQ	Hanaipoe	Mauna Kea	Hamakua Forest	Hamakua Mac Nut
Jan 99	24.4	16.1	10.8	5.5	17.7	20.1
Feb 98	25.2	15.5	10.1	10.6	17.1	21.3
Mar 98	27.7	16.4	11.7	11.5	17.8	22.9
Apr 98	26.0	16.1	12.3	12.4	17.5	20.7
May 98	28.3	16.8	12.7	15.4	17.4	20.3
Jun 98	29.1	18.1	14.3	16.9	18.5	21.7
Jul 98	32.8	18.6	14.8	16.2	19.4	21.8
Aug 98	33.0	19.2	15.6	15.4	20.0	22.6
Sep 98	30.7	19.0	15.0	14.1	19.7	22.8
Oct 98	28.7	18.7	14.1	11.2	19.6	22.4
Nov 98	25.1	17.9	13.0	8.3	19.1	21.2
Dec 98	24.4	16.3	11.3	6.1	17.8	20.2
MAST	27.9	17.4	13.0	12.0	18.5	21.5
MST	31.6	18.6	14.9	16.2	19.3	22.0
MWT	24.7	16.0	10.7	7.4	17.5	20.5
Isotivity	7.0	2.7	4.2	8.8	1.8	1.5

For the 20-cm depth, data imply borderline "iso" conditions for the soil at Kawaihae but not for the soil on Mauna Kea (table 7.08.4). The MAST at 20 cm is similar to the MAST at 10 cm for both soils. However, the temperature at the Kawaihae site decreases with depth (27.9 vs. 27.4 ºC), whereas the temperature at the Mauna Kea site increases with depth (12.0 vs. 12.2 ºC). The high soil temperature at Kawaihae might reflect what happens in tropical ecosystems after deforestation (Potter et al., 1975).

Table 7.08.4.—Monthly, seasonal, and annual soil temperature averages (°C) for the 20-cm soil depth.

Analysis	Kawaihae	Mauna Kea
Jan 99	24.4	6.5
Feb 98	24.6	11.0
Mar 98	26.9	11.7
Apr 98	25.6	12.1
May 98	27.4	15.1
Jun 98	28.2	16.6
Jul 98	31.3	15.8
Aug 98	32.0	15.1
Sep 98	30.1	14.2
Oct 98	28.5	12.0
Nov 98	25.5	9.2
Dec 98	24.2	7.2
MAST	27.4	12.2
MST	30.5	15.8
MWT	24.4	8.2
Isotivity	6.1	7.6

Monthly and annual summaries for the 50-cm soil depth show that the Kawaihae site is isohyperthermic, the Parker HQ site and the Hamakua forest and macadamia nut tree sites are isothermic, the Hanaipoe site is isomesic, and the Mauna Kea site is mesic (Soil Survey Staff, 1999). (See table 7.08.5.) The temperature gradient from the Kawaihae site to the Parker HQ site is quite sharp. It is only 8.9 km between these sites, but the MAST drops 8.2 ºC. This equates to a 0.9 ºC decrease in MAST for every 1,000 meters of horizontal distance between these sites.

Table 7.08.5.—Monthly, seasonal, and annual soil temperature averages (°C) for the 50-cm soil depth.

Analysis	Kawaihae	Parker HQ	Hanaipoe	Mauna Kea	Hamakua Forest	Hamakua Mac Nut
Jan 99	24.8	17.9	12.7	7.8	18.2	20.1
Feb 98	24.6	17.4	11.7	10.6	17.8	21.4
Mar 98	26.3	18.0	12.6	11.4	18.1	22.5
Apr 98	25.5	17.8	13.2	11.5	17.7	21.5
May 98	26.5	18.2	13.7	14.2	17.7	20.4
Jun 98	27.3	19.1	14.9	15.6	18.4	21.6
Jul 98	29.3	19.5	15.5	15.5	19.3	21.8
Aug 98	30.5	20.1	16.4	14.9	19.8	22.4
Sep 98	29.4	20.1	16.4	14.3	19.9	22.9
Oct 98	28.3	20.0	15.7	12.7	19.7	22.2
Nov 98	26.5	19.5	14.8	10.4	19.4	21.2
Dec 98	24.7	18.4	13.6	8.4	18.3	20.0
MAST	27.0	18.8	14.3	12.3	18.7	21.5
MST	29.0	19.6	15.6	15.3	19.2	21.9
MWT	24.7	17.9	12.6	8.9	18.1	20.5
Isotivity	4.4	1.7	3.0	6.4	1.1	1.4

Except for the Mauna Kea site, soil temperature data for this study support the hypothesized temperature regimes. Long-term air temperature data from a weather station on Mauna Kea had suggested that this site would be frigid or perhaps isofrigid (Meteorological Staff, 1983). We did not expect the unvegetated soil surface to accentuate the daily highs, resulting in isotivity values at 10 cm, 20 cm, and 50 cm that are more than 6 ºC.

Soil temperature signatures and isotivity values.—For the soil at the Mauna Kea site, the 10-cm isotivity value is 8.8 ºC (table 7.08.3). The 50-cm depth on Mauna Kea has a temperature signature exhibiting the largest isotivity value of any site in the study (figure 7.08.2). Here, the isotivity value is 6.4 ºC. Consequently, the soil at this site has a mesic soil temperature regime (Soil Survey Staff, 1999).

In contrast to the Mauna Kea site, the Hamakua forest site, which is northwest of Hilo, has a much reduced temperature signature and a small isotivity value at the 50-cm depth (figure 7.08.3 and table 7.08.5). The isotivity value at this site (1.1 ºC) is the lowest for the study area and for any soil in this report.

We suggest that the definition of "iso" needs to be reexamined. In the Northern Hemisphere we have assumed that June, July, and August have the highest soil temperature readings and December, January, and February have the lowest soil temperature readings (Soil Survey Staff, 1975). At the Hamakua forest site, this assumption does not hold true. There is a 2-month shift in the extreme temperatures. Consequently, the three warmest months for soil temperature at 50 cm are August, September, and October and the three coldest months are February, April, and May (table 7.08.5). The difference between the average of the three coldest and the three warmest months is 2.1 ºC, compared with 1.1 °C using the standard method to determine isotivity. These analyses support the general climate of Hawaii, where the warmest months are not June and July, when the sun is the highest, but August and September, and the coolest month is not December, when the sun is farthest south and days are shortest, but February and March, reflecting the seasonal lag in the ocean's temperature (Price, 1982).

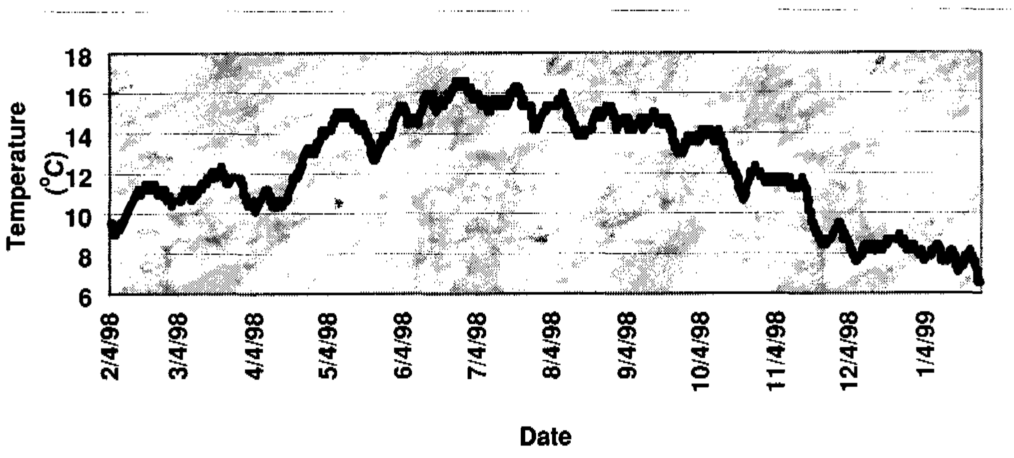


Figure 7.08.2.—Temperature signature of the 50-cm soil depth on Mauna Kea.

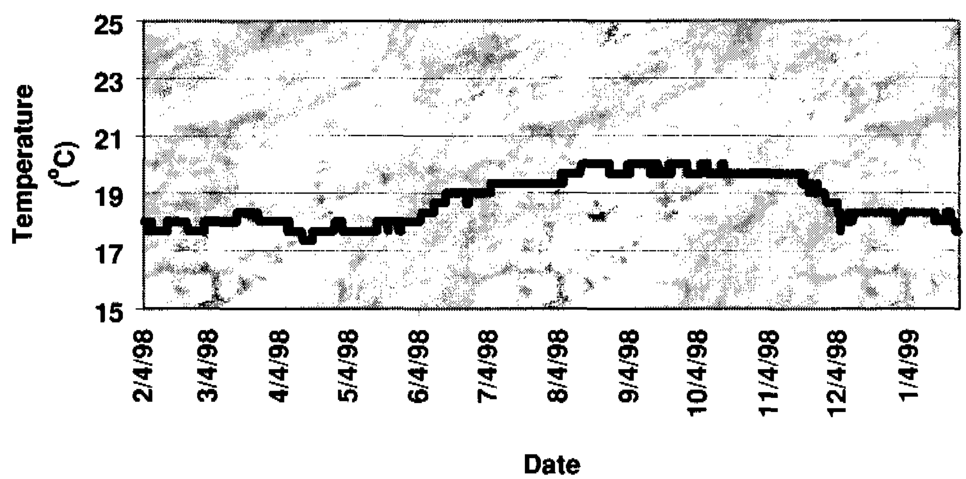


Figure 7.08.3.—Temperature signature of the 50-cm soil depth at the Hamakua forest site.

Relationship of MAST to altitude.—For the tropics, it has been documented in at least two studies that MAST and altitude can have a high r^2. A 10-point transect study in the Caribbean National Forest conducted by the U.S. Forest Service during 1985 and 1986 showed an r^2 of 0.93 between MAST and altitude (Huffaker, 1999). Embrechts and Tavernier (1986) reported an r^2 of 0.86 between MAST and altitude for a study in Cameroon, Africa, from 15 scattered sites within 10º north of the Equator.

The low r^2 value of 0.65 for the regression analysis of MAST and altitude for the sites in Hawaii verifies that, in Hawaii, there is no precise mathematical model for accurately determining the MAST solely on the basis of altitude (figure 7.08.4).

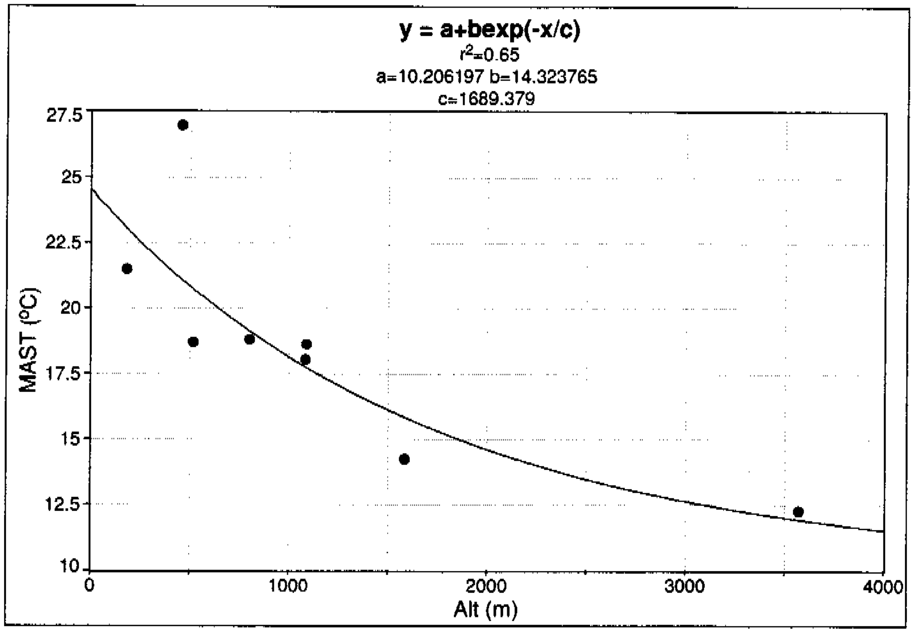


Figure 7.08.4.—Regression analysis comparing MAST and altitude for sites on the Island of Hawaii.

Relationship of MAST to MAAT.—Smith et al. (1964) reported that in humid oceanic climates, where soils receive large amounts of annual rainfall, the MAST at 50 cm is cooler than the MAAT. They consider this a result of the lack of solar radiation or the effect of evaporation. The two Hamakua sites with high precipitation and low amounts of solar radiation northwest of Hilo do not fit this pattern.

In their work on Maui during the 1980s, Ikawa and Kourouma (1985) developed equations to calculate MAST from MAAT at both the 10-cm and 50-cm soil depths for relatively dry sites. Figure 7.08.5 compares measured data from the relatively dry location at the Parker HQ site in Waimea, Hawaii, with their equations. While the results are encouraging, it appears that the equations to determine MAST work better on Maui.

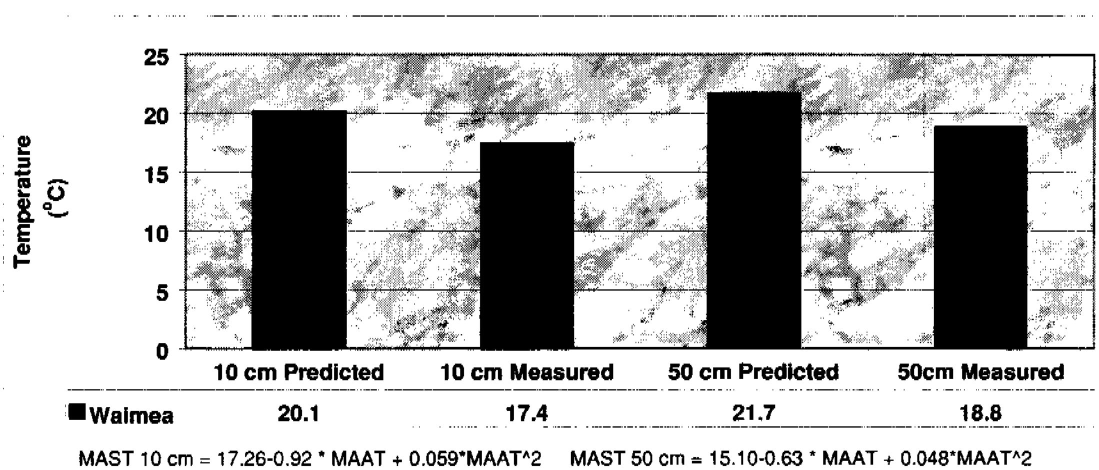


Figure 7.08.5.—Comparison of predicted MAST and measured data from the Parker HQ site near Waimea, Hawaii.

Lapse rates.—The MAST lapse rates, or the decrease in MAAT per 1,000 meters rise in altitude, were calculated from two points on both the dry side and the wet side of Hawaii. The lapse rate from the Parker HQ site to the Hanaipoie site on the dry side of Hawaii (6.3 ºC) is nearly identical to the rate of 6.5 ºC presented by Juvik and Juvik (1998). However, the wet Hamakua sites northwest of Hilo have a larger lapse rate (9.7 ºC) than was predicted by previous researchers. It is presumed that the rapid increase in the precipitation gradient with altitude contributes to the increase in the lapse rate.

MAST lapse rates for both the dry and wet sides of Hawaii are shown in table 7.08.6. The lapse rates have a larger range on the dry side (1.0 to 28.1 ºC) than on the wet side (2.1 to 8.4 ºC). From these measured data, it is concluded that one fixed MAST lapse rate will not work very well in Hawaii.

Table 7.08.6.—Mean annual soil temperature lapse rates calculated from measured data.

Site names (Transect ID and Moisture)	Altitude change (m)	Decrease in lapse rate (°C/1,000 m)
Kawaihae to Parker HQ - Dry	292	28.1
Parker HQ to Hanaipoe - Dry	821	5.5
Hanaipoe to Mauna Kea - Dry	1,981	1.0
Kawaihae to Mauna Kea - Dry	3,094	4.7
Hamakua Mac Nut to Forest - Wet	335	8.4
Hamakua Forest to Mauna Kea – Wet to Dry	3,048	2.1
Hamakua Mac Nut to Mauna Kea – Wet to Dry	3,383	2.7

The relationship of the MAAT lapse rate to the MAST lapse rate was examined for a two-point transect line on both the dry side and the wet side. The lapse rate ratio of MAAT to MAST is 1.1:1.0 on the dry side and 1.2:1.0 on the wet side. The ratios are similar and imply that the decrease in MAST with altitude will occur at a slower rate than the decrease in MAAT. In other words, changes in soil temperature with increasing altitude are not proportional to changes in air temperature with increasing altitude.

5. Summary and Discussion

An experienced soil scientist can predict the soil temperature regime at a specific location in Hawaii with a fair degree of accuracy. The measured soil temperature regimes agreed with field predictions at five of the six sites in this study. However, prediction of the MAST at an individual site is less accurate.

Many attempts have been made to approximate MAST on the basis of MAAT, altitude, and lapse rates. Some studies in tropical environments have presented high r^2 values for their regression equations. Unfortunately, most of these studies reflect data from a specific ecosystem (Huffaker, 1999). When equations are taken from any one of these studies, they do not "fit" well with measured soil temperature data in Hawaii.

Annual data from a minimum of 20 additional sites throughout the Big Island could result in a better understanding of the MAST. A workable model for accurately predicting MAST in Hawaii should integrate MAAT, altitude, slope and its geometry, aspect, vegetative cover, and precipitation.

Acknowledgments

We would like to thank Mr. Frank Hess at Parker Ranch and Mr. John Cross at Mauna Kea Agribusiness for their cooperation in this study. Mike Kolman, NRCS Soil Scientist at Kealakekua, provided special assistance during the installation phase of the study.

Chapter 7.09

Soil Temperature Fluctuations in the Kikuyu Grasslands of Hawaii*

ABSTRACT

From 1975 to 1998, soil temperature regimes with less than 5 °C difference between mean summer and mean winter temperatures at the 50-cm depth were designated as "iso." During the 1980s, research from a climate-monitoring network on Haleakala, a mountain on the island of Maui, showed that 3 out of 19 stations differed more than 5° C at 50 cm, indicating a hyperthermic temperature regime. All of the sites are aridic (Soil Survey Staff, 1999). As a result of this study, the definition of "iso" in *Soil Taxonomy* was amended to allow isotivity values (difference in mean summer and mean winter soil temperatures) to range to 6 °C. Isotivity values approaching 5 °C were reported in studies of the U.S. Virgin Islands during the mid-1990s. These studies imply that soils of the Tropics have more seasonal variation than was expected by the founders of *Soil Taxonomy*. For the 1998-1999 temperature study on Hawaii, the sites under kikuyugrass exhibited low isotivity values for both the 10- and 50-cm depths. Their isotivity values averaged 3.2 °C at 10 cm and 2.1 °C at 38 cm and 50 cm. These data suggest that in the Tropics the soils beneath a thick carpet of grass are well below the 6.0 °C isotivity value required for "iso" temperature regimes. In many parts of the continental U.S., the mean annual soil temperatures at the 10- and 50-cm depths are about the same. In a few cases, the difference attains 0.5 °C. At four sites in Hawaii, the soils under kikuyugrass are consistently 1.2 °C warmer at 50 cm than at 10 cm. The kikuyugrass is deep rooted and probably keeps the lower soil depths under high water tension (>10 bars), while the near surface is replenished with precipitation throughout most of the year. Since more units of heat are needed to warm a wet soil than a dry soil, this difference is manifested throughout the year. Big Island, the youngest of the Hawaiian island chain, is volcanically active. The heat from geologic activity upwells toward the soil surface. Thus, the lower depths are always warmer on a mean annual basis than the upper depths under conditions where kikuyugrass thrives. This exothermic activity is suspected at each site in Hawaii.

1. Background and Purpose

The island of Hawaii, with a surface area of only 10,455 km^2, exhibits a wide range of climatic diversity equivalent with that of larger continents. The soil temperatures at 10 cm near the summit of Mauna Kea, at an elevation of 3,510 meters, approach 0º C during the winter months, whereas those in the coastal areas less than 42 km away are 23 °C warmer.

It is well known that soil temperature responds differently beneath different kinds of vegetation (Smith et al., 1964). The primary purpose of this study was to measure and analyze soil temperature at 10 sites during 1998 and 1999. These sites reflect the dominant climatic areas of the island. This report summarizes data from four of the sites with a thick carpet of kikuyugrass (*Pennisetum clandestinum*). Another purpose was to verify the measured data with the hypothesized soil temperature regimes.

2. Study Area

The Big Island of Hawaii is in the Tropics. Hawaii is between 18°56' and 21°16' north of the Equator and is between 154°48' and 156°02' west of the Prime Meridian.

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* Robert T. Gavenda, NRCS Soil Scientist, Kealakekua, Hawaii, Saku Nakamura, NRCS Assistant State Soil Scientist, Honolulu, Hawaii, and Christopher Smith, NRCS State Soil Scientist, Honolulu, Hawaii, assisted in preparing this section.

The study is an analysis of four sites that support kikuyugrass. NRCS soil scientists in Hawaii selected these as the best sites for gathering data that answer questions about daily, monthly, seasonal, and annual soil temperatures. The mean annual precipitation at these sites ranges from 600 mm at the Parker HQ site, near the town of Waimea, to over 1,500 mm at the KDC 1 and KDC 2 sites, southeast of Captain Cook (Juvik et al., 1992).

The soils at each site formed in volcanic ash over lava. The soil at the KDC 1 site is shallow to pahoehoe, smooth volcanic bedrock material that is 1,500 to 2,000 years old. This soil is an isothermic Udifolist. The soil at KDC 2 site is moderately deep to a'a, which is coarse volcanic bedrock material. This soil is a medial-skeletal, isothermic Typic Hydrudand. At the Parker HQ site, the soil is a medial-skeletal, amorphic, isothermic Pachic Haplustand. The soil at the Hanaipoe site is as a medial, amorphic, isomesic Dystric Haplustand and is deep to hard bedrock (Soil Survey Staff, 1999). The georeferenced locations of the sites are shown in figure. 7.09.1, and additional site characteristics are given in table 7.09.1.

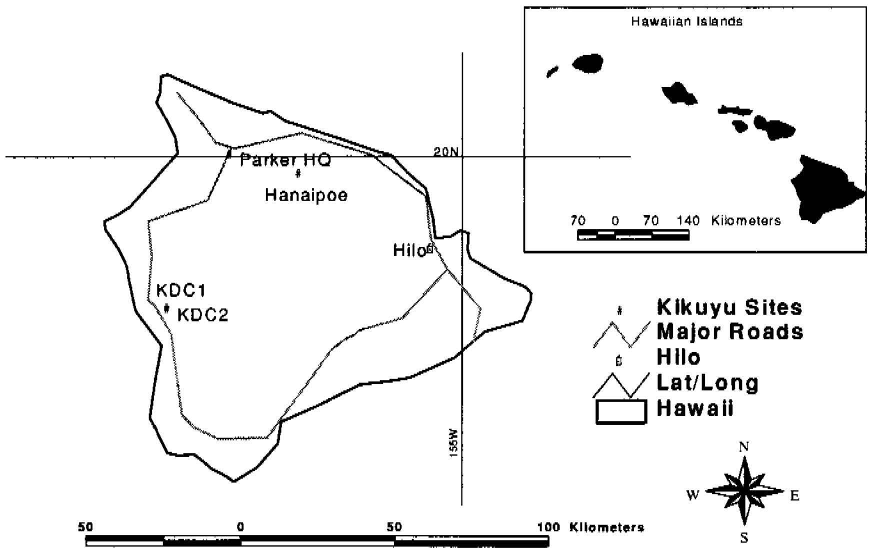


Figure 7.09.1.—Location of the temperature sites in the study area.

Table 7.09.1.—Soil and site information for the study area.

Site name	Latitude (north)	Longitude (west)	Elevation (m)	Slope (%)	Aspect (°)	Annual Precip. (mm)
KDC 1	19°30'07"	155°51'23"	1,089	5	40	1,400
KDC 2	19°29'41"	155°51'25"	1,082	5	40	1,400
Parker HQ	20°00'37"	155°40'35"	764	2	270	585
Hanaipoe	19°56'41"	155°28'30"	1,585	13	0	585

Kikuyugrass and other tropical grasses occupy more than 412,000 ha in Hawaii and more than 200,000 ha on the Big Island (NRCS NRI Data. 1994, 1992 *National Resources Inventory*, http: www/nhq.nrcs.usda.gov/NRI/tables). Kikuyugrass is the preferred species for the ranch managers on the Big Island. Prior to this study, the daily, seasonal, and annual responses of soil temperature beneath these grasslands were not known. Kikuyugrass, a native of Kenya in Africa, is a warm-season, mid-green, coarsely textured grass imported from Australia (figure 7.09.2). Being hardy and easily controlled by withholding water and fertilizer, it grows well in Hawaii below elevations of 1,050 m.

Figure 7.09.2.—Typical area of kikuyugrass near the Parker HQ site.

3. Results

Air temperature.—Data for MAAT are given in table 7.09.2 for three sites. Data capture at the KDC 2 site, southeast of Captain Cook, was terminated by vermin activity during late-August 1998. Thus, data are given for only 7 months. The partial data suggest that the MAAT at this site will be colder than the MAAT at the Parker HQ site.

Table 7.09.2.—Monthly, seasonal, and annual air temperature averages (°C).

Analysis	KDC 2	Parker HQ	Hanaipoe
Jan 99	---	16.1	11.3
Feb 98	13.6	16.1	11.2
Mar 98	14.2	16.9	12.1
Apr 98	15.5	16.6	11.8
May 98	15.8	17.1	11.9
Jun 98	16.8	18.3	13.6
Jul 98	17.3	19.0	14.1
Aug 98	17.5	19.9	15.0
Sep 98	---	19.4	13.8
Oct 98	---	18.8	13.3
Nov 98	---	17.9	13.1
Dec 98	---	16.0	11.3
MAAT	---	17.7	12.7
MST	17.2	19.1	14.2
MWT	---	16.1	11.3
MST-MWT	---	3.0	3.0

At 17.7 ºC, the MAAT for the Parker HQ site in Waimea is similar to long-term data indicating an average of 18.2 ºC (Meteorological Staff, 1983). When divided by 2, the average daily low and high values collected during this study at Waimea is calculated to be 18.8 ºC.

Soil temperature.—The MAST at 10 cm shows that all the isotivity values are less than 5 ºC (table 7.09.3). These data imply that the soils beneath the kikuyu grasslands in Hawaii would classify as "iso" even if bedrock terminated the soils at 10 cm. The three isothermic sites at KDC and Parker HQ have a MAST within 0.5 ºC, though they differ in elevation and mean annual precipitation.

Table 7.09.3.—Average monthly, seasonal, and annual soil temperatures (°C) at 10 cm.

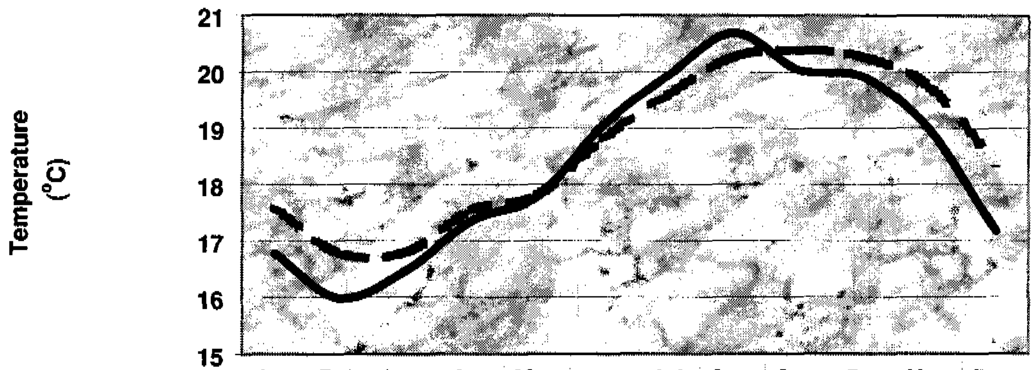
Analysis	KDC 1	KDC 2	Parker HQ	Hanaipoe
Jan 99	16.8	16.3	16.1	10.8
Feb 98	16.0	15.7	15.5	10.1
Mar 98	16.5	16.1	16.4	11.7
Apr 98	17.4	16.5	16.1	12.3
May 98	17.8	16.8	16.8	12.7
Jun 98	19.1	17.8	18.1	14.3
Jul 98	19.9	18.8	18.6	14.8
Aug 98	20.7	19.2	19.2	15.6
Sep 98	20.0	19.1	19.0	15.0
Oct 98	19.9	19.3	18.7	14.1
Nov 98	19.0	18.2	17.9	13.0
Dec 98	17.2	16.5	16.3	11.3
MAST	17.0	17.5	17.4	13.0
MST	19.9	18.6	18.6	14.9
MWT	16.6	16.2	16.0	10.7
Isotivity	3.3	2.5	2.7	4.2

Table 7.09.4.—Average monthly, seasonal, and annual soil temperatures (°C) for the deeper depths.

Analysis	KDC 1	KDC 2	Parker HQ	Hanaipoe
Jan 99	17.6	17.0	17.9	12.7
Feb 98	16.8	16.2	17.4	11.7
Mar 98	16.8	16.5	18.0	12.6
Apr 98	17.5	17.0	17.8	13.2
May 98	17.8	17.3	18.2	13.7
Jun 98	18.8	18.2	19.1	14.9
Jul 98	19.6	19.0	19.5	15.5
Aug 98	20.3	19.5	20.1	16.4
Sep 98	20.4	19.5	20.1	16.4
Oct 98	20.3	19.5	20.0	15.7
Nov 98	19.7	19.0	19.5	14.8
Dec 98	18.4	17.7	18.4	13.6
MAST	18.7	18.0	18.8	14.3
MST	19.6	18.9	19.6	15.6
MWT	17.6	17.0	17.9	12.6
Isotivity	2.0	1.9	1.7	3.0

The soil at KDC 1 has bedrock at a depth of 38 cm. Monthly temperature averages and annual summaries for the 38- and 50-cm soil depths show that all sites are isothermic, except for the Hanaipoe site, which is isomesic (table 7.09.4). The annual averages for the KDC sites and the Parker HQ site are similar. The higher altitude site at Hanaipoe averages more than 4 ºC colder.

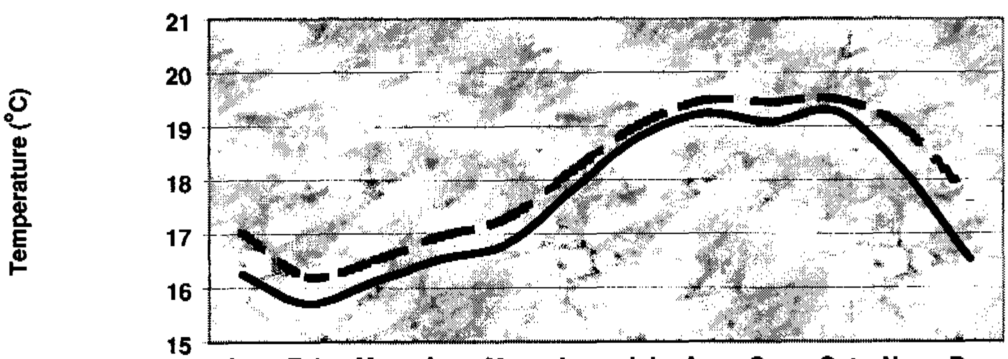
Relationship of MAST at 10 cm to MAST at 38 and 50 cm.—Figure 7.09.3 shows the relationship of the 10-cm depth to the 38-cm depth contact with volcanic bedrock for the KDC 1 site.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10 cm	16.8	16.0	16.5	17.4	17.8	19.1	19.9	20.7	20.0	19.9	19.0	17.2
38 cm	17.6	16.8	16.8	17.5	17.8	18.8	19.6	20.3	20.4	20.3	19.7	18.4

Figure 7.09.3.—Monthly soil temperature averages for the KDC 1 site.

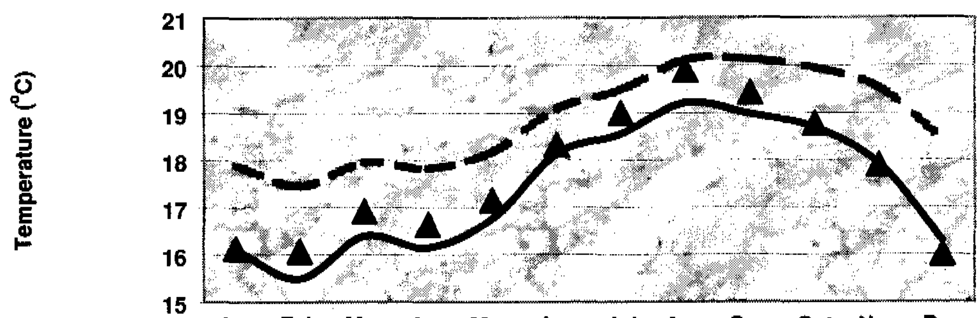
The monthly soil temperature for the 10-cm depth at KDC 1 is colder than the 38-cm depth for all months, except for June, July, and August. The KDC 2 site shows a more interesting relationship between the two soil depths (figure 7.09.4).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10 cm	16.3	15.7	16.1	16.5	16.8	17.8	18.8	19.2	19.1	19.3	18.2	16.5
50 cm	17.0	16.2	16.5	17.0	17.3	18.2	19.0	19.5	19.5	19.5	19.0	17.7

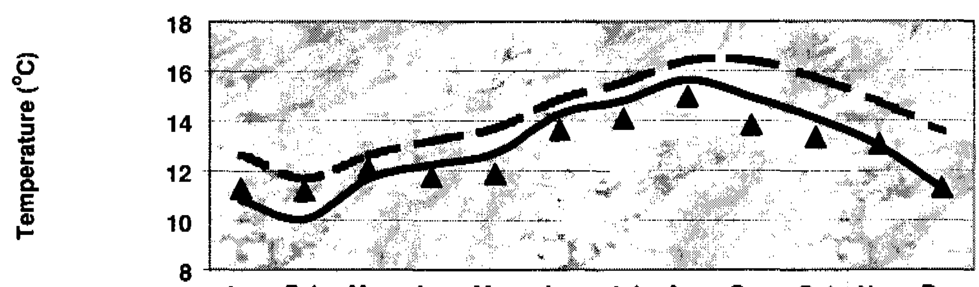
Figure 7.09.4.—Monthly soil temperature averages for the KDC 2 site.

At the KDC 2 site, the 10-cm depth is colder than the 50-cm depth for every month of the year. The same relationship occurred beneath kikuyugrass at the Parker HQ and the Hanaipoe sites (figures 7.09.5 and 7.09.6). These graphs also show the relationship of air temperature to soil temperature.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10 cm	16.1	15.5	16.4	16.1	16.8	18.1	18.6	19.2	19.0	18.7	17.9	16.3
50 cm	17.9	17.4	18.0	17.8	18.2	19.1	19.5	20.1	20.1	20.0	19.5	18.4
▲ Air	16.1	16.1	16.9	16.6	17.1	18.3	19.0	19.9	19.4	18.8	17.9	16.0

Figure 7.09.5.—Relationship of monthly air and soil temperatures at the Parker HQ site near Waimea.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10 cm	10.8	10.1	11.7	12.3	12.7	14.3	14.8	15.6	15.0	14.1	13.0	11.3
50 Cm	12.7	11.7	12.6	13.2	13.7	14.9	15.5	16.4	16.4	15.7	14.8	13.6
▲ Air	11.3	11.2	12.1	11.8	11.9	13.6	14.1	15.0	13.8	13.3	13.1	11.3

Figure 7.09.6.—Relationship of monthly temperatures at the Hanaipoe site.

Examination of the soils beneath kikuyugrass reveals a consistent pattern. For all months the 10-cm soil depth is colder than the 50-cm depth.

Relationship of MAST to MAAT.—According to Smith et al. (1964), when soils in humid oceanic climates receive large amounts of annual rainfall, the MAST at 50 cm is cooler than the MAAT, generally because of a lack of solar radiation or the effect of evaporation. The semiarid (ustic soil moisture regime) Parker HQ site, with a MAAT of 17.7 °C and a MAST of 18.8 °C, contradicts Smith et al. The MAST for the 10-cm depth at the Parker HQ site under kikuyugrass was cooler than the MAAT.

The kikuyugrass, which has a thick, fibrous root system, may eliminate the effect of solar radiation on the 10-cm depth. This part of the Parker Ranch is irrigated during the droughty summer months, slightly lowering the soil temperature at 10 cm.

Relationship of MAST to altitude.—For the Tropics, it has been documented in a least two studies that MAST and altitude are highly correlated. A 10-point transect study in the Caribbean National Forest conducted by the U.S. Forest Service during 1985 and 1986 showed an r^2 of 0.93 between MAST and altitude (Huffaker, 1999). Embrechts and Tavernier (1986) reported an r^2 of 0.86 between MAST and altitude in Cameroon, Africa, on 15 scattered sites within 10º north of the Equator.

Regression analysis of MAST and altitude for the Hawaiian sites in kikuyugrass is shown in figure 7.09.7. The r^2 value of 0.86 verifies that, in Hawaii, there is no precise mathematical model to accurately determine the MAST solely on the basis of altitude. This straight-line regression does accurately indicate that the KDC sites are warmer than was hypothesized. Prior to this study many scientists would have predicted that the MAST of the KDC sites would be 2º C lower than it proved to be when measured.

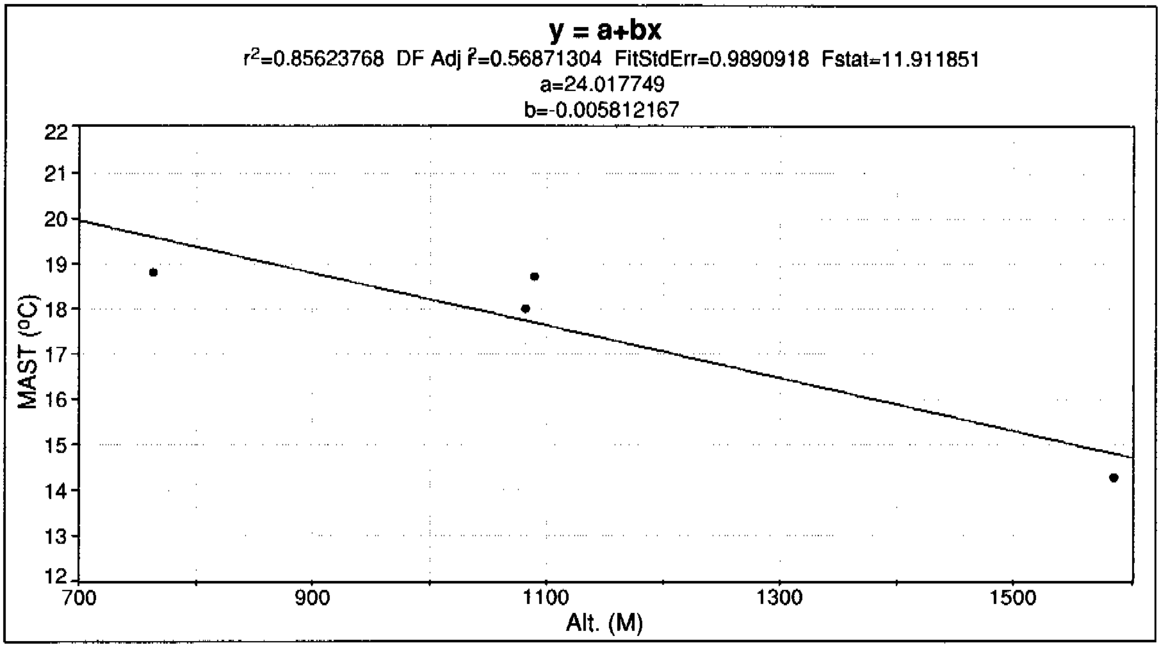


Figure 7.09.7.—A straight-line regression formula for the sites in kikuyugrass.

Isotivity values.—From 1975 to 1998, soil temperature regimes with less than 5° C difference between average summer and winter soil temperatures at the 50-cm depth were designated as "iso" (Soil Survey Staff, 1975). During the 1980s, research from a climate-monitoring network on Haleakala, a mountain on the island of Maui, showed that 3 out of 19 stations differed more than 5° C at 50 cm, indicating a hyperthermic temperature regime (Nullet et al., 1990). All of the sites are aridic. As a result of this study, the definition of "iso" in *Soil Taxonomy* was amended to allow isotivity values to range to 6 ºC (Soil Survey Staff, 1999).

Isotivity values approaching 5 ºC were reported in the U.S. Virgin Islands during the mid-1990s (Mount et al., 1995). Hourly air and soil temperature data on the semiarid Lameshur Bay Watershed on St. John Island showed isotivity values ranging from 2.5 to 4.8 ºC under dry tropical woodlands. Another study on St. John Island revealed an isotivity value of 5.1 ºC on north-facing slopes (Mount, Henry R. 1999. *National air and soil temperature tables.* National Soil Survey Center (NSSC) homepage: www.statlab.iastate.edu/soils/nssc/temperature/rstn1.htm). This study confirmed the previous work by Nullet in that soils of the Tropics proved to have more seasonal variation than was expected (Soil Survey Staff, 1975).

For the 1998-1999 temperature study on Hawaii, the sites under kikuyugrass exhibited low isotivity values for both the 10- and 50-cm soil depths. The isotivity values averaged 3.2 ºC for the 10-cm depths and 2.1 ºC for the 38- and 50-cm depths. These data suggest that in the Tropics soils beneath a thick carpet of grass are well below the 6.0 °C isotivity value required for "iso" temperature regimes.

4. Summary and Discussion

In many parts of the continental United States, the MAST at the 10- and 50-cm soil depths are about the same. In a few cases the difference is as much as 1 ºC (Mount, 1999.) At four sites in Hawaii, the temperature of the soils under kikuyugrass is consistently 1.2 ºC warmer at the 50-cm depth than at the 10-cm depth.

We offer two possible reasons for this unusual difference. The kikuyugrass is deep rooted and probably keeps the lower soil depths under high water tension (>10 bars), while the near surface is replenished with precipitation throughout most of the year. Since more units of heat are needed to warm a wet soil than a dry soil, this difference is manifested throughout the year.

Big Island, the youngest of the Hawaiian island chain, remains volcanically active. With the heat of geologic activity upwelling toward the soil surface, the lower depths are always warmer on a mean annual basis than the upper depths under conditions where kikuyugrass thrives. This exothermic activity is suspected at each of the sites in Hawaii.

Acknowledgment

Mike Kolman, NRCS Soil Scientist at Kealakekua, provided special assistance during the installation phase of this study.

Chapter 7.10

Soil Temperature Signatures for Three Hydrous Soils in Hawaii*

ABSTRACT

Three soils with a hydrous substitute of a particle-size class were monitored for air and soil temperature in 1998 and 1999. Data confirmed that these soils have isothermic temperature regimes. The soil temperature signatures at 50 cm for a eucalyptus site at Honokaa and a rain forest site at Hamakua support the traditional concept of slow temperature changes at this depth. The soil temperature signatures at 50 cm for these sites differ from the 50-cm soil temperature signature at the macadamia orchard site. At the macadamia orchard site, there are intermittent exothermic spikes from August through October for the 50-cm soil depth. When all the data for the 10- and 50-cm soil depths are displayed on the same chart, the period of exothermic spiking at 50 cm is more evident. Though spiking also occurred at the 10-cm depth, the 50-cm soil temperature signature masks it. These signatures show little evidence of spiking from February 4, 1998, until August 21, 1998. Inputs of water may have caused these temperature spikes. Though the soil temperature signatures at 10 cm and 50 cm are different at the macadamia orchard site, the mean annual soil temperature is the same (21.5 °C). Despite intermittent exothermic spikes, the isotivity values (difference in mean summer and mean winter soil temperatures) of hydrous soils in Hawaii are less than about 2.0 °C. These values are similar to what was reported in the rain forest of Puerto Rico. The measured soil temperature regimes agreed with field predictions at all three sites in this study. The isothermic soil temperature regime for the macadamia orchard site occurs at an altitude of 183 meters. For the two sites near Hilo, the upper isohyperthermic boundary is lower in altitude than a similar ecosystem in Puerto Rico.

1. Background and Purpose

Nearly all of the soils on Hawaii Island (Big Island) are derived from or influenced by volcanic activity. Many of these soils are shallow to either a'a or pahoehoe lava. The deep hydrous soils in the northwest part of Big Island have properties unlike those of other mineral soils. They are smeary and are classified as hydrous, ferrihydritic, isothermic Acrudoxic Hydrudands. In normal moist field conditions, the topsoil holds about 125 percent water and the subsoil holds about 250 percent water. These hydrous soils produce an exothermic reaction when water is added to them during a dry state. The daily temperature signatures of hydrous soils were unknown prior to this study.

The primary purpose of the 1998-1999 study in Hawaii was to measure and analyze soil temperature at 10 sites reflecting the dominant climatic areas of Big Island. Three of these sites have hydrous soils and are summarized in this report. Another purpose was to compare the measured data with the hypothesized soil temperature regime.

2. Study Area

The Big Island of Hawaii is in the Tropics (figure 7.10.1). Hawaii is between 18° and 21° north of the Equator and is about 155° west of the Prime Meridian.

Big Island, with a surface area of only 10,455 km^2, exhibits a wide range of climatic diversity comparable to that on continents. The three major factors that contribute to this climatic diversity are topographic relief (0 to 4,205 m elevation), a large-scale synoptic wind field, and a local circulation

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resulting from differential heating and cooling of the land, water, mountain, and lowland areas. Above the 3,200-meter level on Mauna Kea and Mauna Loa volcanoes, all months have mean air temperatures below 10 ºC (50 ºF) and the periglacial climates. Nighttime freezing is common throughout the year (Juvik et al., 1978).

The mean annual precipitation at the three sites ranges from 2,032 mm at the eucalyptus site to over 5,400 mm at the rain forest site, near Hilo (Juvik et al., 1992). One site supports eucalyptus (*Eucalyptus spp. L.*), another supports species of rain forest trees, and the third supports macadamia nut trees (*Macadamia integrifolia L.*). The georeferenced locations of the three sites are shown in figure. 7.10.1, and additional site characteristics are given in table 7.10.1. The soils are Hydrudands (Soil Survey Staff, 1999).

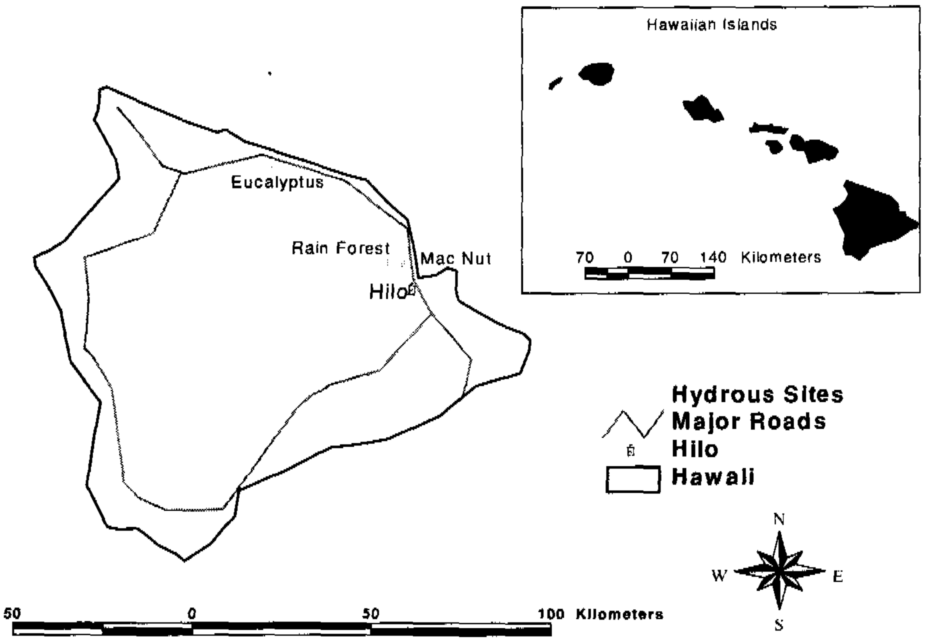


Figure 7.10.1.—Location of temperature sites in the study area.

Table 7.10.1. —Soil and site information for the study area.

Site name	Latitude (north)	Longitude (west)	Elevation (m)	Slope (%)	Aspect (°)	Annual Precip. (mm)
Eucalyptus	20°03'11"	155°26'37"	518	20	350	2,032
Hamakua Forest	19°46'01"	155°09'10"	518	25	70	5,460
Hamakua Mac Nut	19°46'13"	155°06'40"	183	5	90	4,065

3. Results

Air temperature.—The eucalyptus site at Honokaa and the rain forest site at Hamakua are each at an altitude of 518 m. However, their MAAT differs by more than 1 ºC (19.0 vs. 17.7 ºC), as is indicated in table 7.10.2. The high precipitation levels at the rain forest site may dampen the air temperature. The higher MAAT at the macadamia orchard site is the result of a relatively low elevation.

Table 7.10.2.—Monthly, seasonal, and annual air temperature (°C) averages.

Analysis	Honokaa	Hamakua Forest	Hamakua Mac Nut
Jan 99	17.6	16.7	20.0
Feb 98	18.2	16.8	20.4
Mar 98	18.8	17.2	20.6
Apr 98	17.8	16.9	20.2
May 98	18.2	16.8	20.3
Jun 98	19.4	17.9	21.5
Jul 98	20.2	18.6	21.9
Aug 98	20.4	19.5	22.5
Sep 98	20.4	18.6	22.0
Oct 98	19.8	18.7	21.7
Nov 98	19.0	18.1	20.9
Dec 98	18.1	16.9	19.7
MAAT	19.0	17.7	21.0
MST	20.0	18.7	22.0
MWT	17.9	16.8	20.0
MST-MWT	2.1	1.9	1.9

Soil temperature.—The MAST at 10 cm and 50 cm supports the hypothesized soil temperature regime at each site (table 7.10.3). All soils have isotivity values of less than 2.5 ºC and are isothermic (Soil Survey Staff, 1999). The data imply that the soils would classify as "iso" even if bedrock were at 10 cm. The difference in MAST between the 10- and 50-cm depths is only 0.1 °C at the eucalyptus site (20.0 vs. 19.9 °C). The MAST at the rain forest site is 0.2 °C warmer at 50 cm than at 10 cm (18.7 vs. 18.5 °C), and the macadamia site has the same MAST at both depths (21.5 °C). These data imply that an accurate MAST can be approximated for the hydrous soils by measuring at any depth between 10 and 50 cm.

Table 7.10.3.—Monthly, seasonal, and annual soil temperature averages at 10 cm and 50 cm (°C).

Analysis	Honokaa (10 cm)	Honokaa (50 cm)	Hamakua Forest (10 cm)	Hamakua Forest (50 cm)	Hamakua Mac Nut (10 cm)	Hamakua Mac Nut (50 cm)
Jan 99	18.2	18.5	17.7	18.2	20.1	20.1
Feb 98	19.3	18.8	17.1	17.8	21.3	21.4
Mar 98	20.6	19.7	17.8	18.1	22.9	22.5
Apr 98	19.1	19.1	17.5	17.7	20.7	21.5
May 98	19.3	19.2	17.4	17.7	20.3	20.4
Jun 98	20.6	20.2	18.5	18.4	21.7	21.6
Jul 98	21.1	20.8	19.4	19.3	21.8	21.8
Aug 98	21.3	21.2	20.0	19.8	22.6	22.4
Sep 98	21.1	21.1	19.7	19.9	22.8	22.9
Oct 98	20.7	20.9	19.6	19.7	22.4	22.2
Nov 98	20.0	20.4	19.1	19.4	21.2	21.2
Dec 98	18.3	18.9	17.8	18.3	20.2	20.0
MAST	20.0	19.9	18.5	18.7	21.5	21.5
MST	21.0	20.8	19.3	19.2	22.0	21.9
MWT	18.6	18.8	17.5	18.1	20.5	20.5
Isotivity	2.4	2.0	1.8	1.1	1.5	1.4

Exothermic activity.—Soil temperature measurements at 50 cm were chosen because, in concept, the diurnal fluctuation at this depth is essentially nonexistent (Soil Survey Staff, 1975). The temperature signatures for the eucalyptus site at Honokaa and the rain forest site at Hamakua support the traditional concept of slow changes at this depth. The time-scale graph for the 50-cm soil depth at the rain forest site is shown in figure 7.10.2.

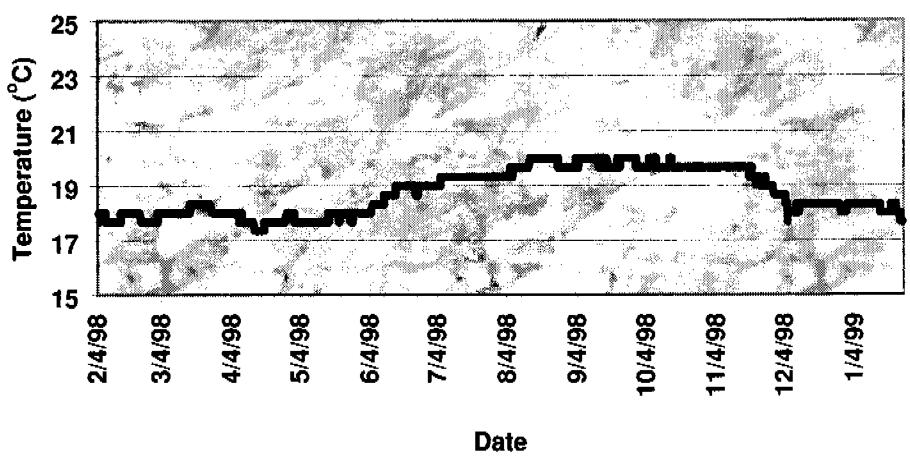


Figure 7.10.2.—Soil temperature signature at 50 cm for the rain forest site at Hamakua.

The soil temperature signature at 50 cm for the rain forest site differs from that of the macadamia orchard site (figures 7.10.2 and 7.10.3). At the macadamia orchard site, there are intermittent exothermic spikes from August through October for the 50-cm soil depth.

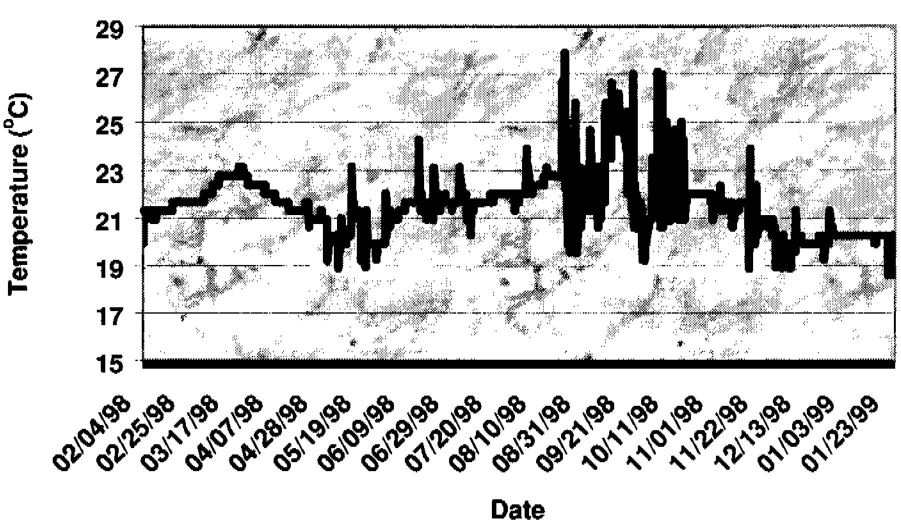


Figure 7.10.3.—Exothermic spikes at the 50-cm soil depth for the macadamia orchard site near Hamakua.

When all the data for the 10- and 50-cm soil depths are displayed on the same chart, the period of exothermic spiking at 50-cm is more evident (figure 7.10.4). Though spiking also occurred at the 10-cm depth, the 50-cm soil temperature signature masks it. These signatures show little evidence of spiking from February 4, 1998, until August 21, 1998. Though these soil temperature signatures are uniquely different, the MAST for the 10- and 50-cm soil depths is the same (21.5 °C).

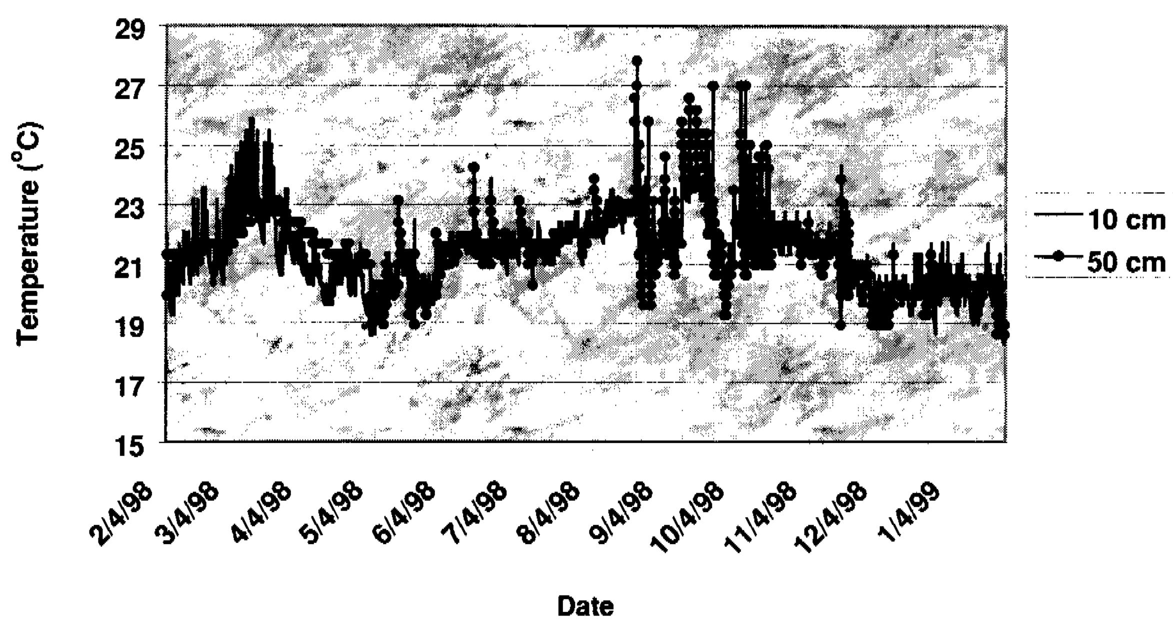


Figure 7.10.4.—Coincident exothermic spiking at 10 cm and 50 cm for the macadamia orchard site in Hawaii.

Isotivity values.—Despite intermittent exothermic spikes, the isotivity values of hydrous soils in Hawaii are less than about 2.0 °C. These values are similar to what Huffaker reported in the rain forest of Puerto Rico (Huffaker, 1999).

4. Summary and Discussion

The measured soil temperature regimes agree with field predictions at all three sites in this study. The isothermic soil temperature regimes for the macadamia orchard site occurs at an altitude of 183 meters. The isothermic-isohyperthermic boundary is lower in altitude than a similar ecosystem in Puerto Rico (Huffaker, 1999).

Hydrous soils at the macadamia orchard site in Hawaii exhibited temperature spikes from August through October 1998. These occurred at both the 10- and 50-cm soil depths. Verification negates the possibility of electronic spiking. Inputs of water may have precipitated these temperature spikes.

Acknowledgments

We would like to thank Mr. John Cross at Mauna Kea Agribusiness for his cooperation in this study. Mike Kolman, NRCS Soil Scientist at Kealakekua, provided special assistance during the installation phase of the study.

Chapter 7.11

Relationship of Frigid and Cryic Soil Temperature Regimes in Clearwater County, Idaho*

ABSTRACT

Five sites in northern Idaho were monitored for air and soil temperature in 1997 and 1998. Soils with cryic temperature regimes were found to have isotivity values (difference in mean summer and mean winter temperatures) of less than 6 °C. These results are most likely indicative of many cryic soils at northern latitudes in the United States. In Idaho soils with cryic temperature regimes are covered with snow for 7 or more months during the year. The snow cover may impact the number of months that the soils are biologically inactive (<5 °C). Soils with cryic temperature regimes are biologically inactive at the 10- and 50-cm depths for about 8 months during the year. The habitat types used to separate soil series and soil temperature regimes worked well in the study area, but we are uncertain whether it is the soil temperature regimes that dictate the vegetative communities or the habitat types that dictate the soil temperature regimes. A soil in a cutover area at an elevation of 1,600 m (site 3) is 0.7 °C warmer than a nearby forested soil at a similar elevation (site 5). These sites are identical, except for the successional stage of the habitat type. The soil in the cutover area is the first soil with an isofrigid soil temperature regime to be monitored in the United States. Its isotivity value is 5.2 °C. Cryic sites in northern Idaho exhibit low isotivity values. The two cryic soils on Bertha Hill (sites 4 and 5) each exhibited an isotivity value of less than 6 °C. These sites received the most snowfall in the study area and had the lowest values for mean summer temperature.

1. Background

Frigid and cryic soil temperature regimes are ubiquitous in northern Idaho. Their separation is conveniently based on habitat types and elevation. In general, the frigid-cryic separation occurs at elevations of 1,372 meters on north aspects and 1,494 meters on south aspects. These sites tend to be remote and cannot be monitored easily.

The frigid soil temperature regime occurs where the mean annual soil temperature at 50 cm ranges from 0 to 8 °C and the mean summer soil temperature for June, July, and August is more than 8 °C for soils with a humus layer (Soil Survey Staff, 1999). For soils with a humus layer, the cryic class is colder and the mean summer soil temperature for June, July, and August is less than 8 °C. If the soil has no humus layer, then the mean summer soil temperature is allowed to range to 15 °C. To complicate the frigid-cryic definition further, soils that have an aquic moisture regime (redoximorphic conditions) have a different set of criteria and soils that are Histosols have yet another set of criteria. Moreover, the allowance of isofrigid classes within the frigid soil temperature regime mandates even closer attention to temperature studies. The isofrigid class is one in which the difference between mean summer and mean winter soil temperatures (isotivity value) is less than 6 °C (Soil Survey Staff, 1999).

Before this study was initiated in November 1997, several vintages of intermittent studies had been conducted to verify the frigid and cryic soil temperature regimes in Idaho. Most of the data from these studies remain unpublished. In many cases spike thermometers calibrated to about 0.6 °C were used to measure summer soil temperatures at 50 cm during mid-June, mid-July, and mid-August. Hence, three temperature measurements were used to verify the cryic soil temperature regime. Because of extreme snowfall accumulations and the inaccessibility of the remote sites, the winter temperature signatures of

* Glenn Hoffman, Eileen Rowan, and Brian Gardner, NRCS Soil Scientists, Orofino, Idaho, and Neil Peterson NRCS Soil Scientist, Boise, Idaho, assisted in preparing this section.

the soils either were not known or were not presented to the scientific community prior to the culmination of this study.

2. Objectives and Hypotheses

The Idaho soil temperature study was funded through the NRCS Global Change Initiative. For this study, three objectives were defined. One was to verify mean annual soil temperature differences as stratified by the different habitat types in Clearwater County, Idaho. Another was to evaluate the mean annual soil temperature differences between a cutover site and an adjacent uncut site. A third objective was to evaluate the mean annual soil temperature and habitat type for a site hypothesized as having a frigid soil temperature regime. During the installation phase of the study, it was hypothesized that the mean annual soil temperature would be lowest at site 4, second lowest at site 5, third lowest at site 3, fourth lowest at site 2, and highest at site 1. A second hypothesis was that sites 3, 4, and 5 would prove to be cryic. The third hypothesis was that sites 1 and 2 would have a frigid soil temperature regime.

3. Study Area

Clearwater County is in the southern part of the Idaho panhandle. The Major Land Resource Area is 43E, the Northern Rocky Mountains. The study area is in the central part of the county. Five sites were selected during November 1998 for data collection intended to verify the hypothesized frigid-cryic temperature regimes. The different soil and site characteristics are summarized in table 7.11.1. The study area receives 1,143 to 1,270 mm of precipitation annually, of which 914 to 3,658 mm is snow. The elevation of the sites ranges from 1,128 to 1,661 meters. The latitude ranges from 46°44'35.12" to 46°45'51.07" north, and the longitude ranges from 115°46'04.72" to 115°47'40.60" west. Slope ranges from 20 to 35 percent, and aspect ranges from 180° to 278° (south to west).

Table 7.11.1.—Site and soil information for the study area.

Site (#)	Soil series (name)	Latitude (north)	Longitude (west)	Elevation (m)	Slope (%)	Aspect (°)
1	Hobo	46°44'35"	115°46'05"	1,128	20	225
2	Flumecreek	46°45'03"	115°47'27"	1,265	30	205
3	Bertha Hill	46°45'44"	115°47'37"	1,600	35	195
4	Bertha Hill	46°45'51"	115°47'38"	1,665	23	278
5	Bertha Hill	46°45'43"	115°47'41"	1,600	25	180

The soils are Andisols and have layers of humus 2 to 5 cm thick and mantles of volcanic ash 40 to 60 cm thick. The soils on sites 3, 4, and 5 formed in quartzite colluvium, and those on sites 1 and 2 formed in slope alluvium and quartzite colluvium. All of the sites are forested. Site 1 is a western redcedar (*Cedrus spp. L.*)-queen cup beadlily habitat type, site 2 is a grand fir (*Abies spp. L.*)-wild ginger habitat type, and site 3 is in an open and slightly diseased stand of the subalpine fir (*Abies spp. L.*)-beargrass (*Xerophyllum tenax L.*) habitat type (Cooper et al., 1991). Site 4 is a mountain hemlock (*Tsuga spp. L.*)-beargrass habitat type, and site 5 is a subalpine-beargrass habitat type.

4. Results

Soil temperature at 50 cm.— Table 7.11.2 shows, for the 50-cm depth, the monthly averages, MAST, MST, MWT, isotivity values, and temperature regimes for the five sites in the study area.

Table 7.11.2.—Soil temperature averages (°C) at 50 cm and temperature regimes.

Analysis	Site 1	Site 2	Site 3	Site 4	Site 5
Nov 1997	6.6	5.7	4.3	3.4	3.3
Dec 1997	4.4	3.9	3.2	2.4	2.2
Jan 1998	3.1	3.1	2.7	2.0	1.8
Feb 1998	2.7	2.5	2.4	1.6	1.4
Mar 1998	2.7	2.1	2.1	1.5	1.2
Apr 1998	3.5	2.5	1.4	1.3	1.0
May 1998	6.1	5.5	3.7	1.6	2.6
Jun 1998	7.6	6.8	6.0	4.0	4.9
Jul 1998	10.5	9.7	8.7	7.1	8.4
Aug 1998	11.9	11.0	9.4	8.4	9.5
Sep 1998	12.0	11.0	9.6	8.3	9.4
Oct 1998	10.4	9.2	7.5	6.6	6.9
MAST	6.8	6.1	5.1	4.0	4.4
MST	10.0	9.2	8.0	6.5	7.6
MWT	3.4	3.2	2.8	2.0	1.8
Isotivity	6.6	6.0	5.2	4.5	5.8
Regime	Frigid	Frigid	Isofrigid	Cryic	Cryic

The results confirmed hypothesis number 1. Site 4 is the coldest site, followed by 5, 3, 2, and 1. Sites 4 and 5 are cryic, and site 3 is isofrigid. However, with a MST of at 8.0 °C, site 5 marginally missed being cryic by a fraction of a degree. Hypothesis number 3 was confirmed; sites 1 and 2 proved to be frigid. Another significant finding of the study was that sites 3, 4, and 5 exhibit isotivity values of less than 6 °C. These values were not hypothesized. Site 4 has the lowest isotivity value (4.5 °C). If *Soil Taxonomy* provided a class for isocryic, then sites 4 and 5 would fit that category. The relatively small differences between MST and MWT are attributed to the snowfall at high elevations.

The linear trend of MAST and elevation for sites 1, 2, 4, and 5 has an r^2 of 0.99 (figure 7.11.1). This analysis indicates a positive correlation to the dampening of the MAST with increasing elevation.

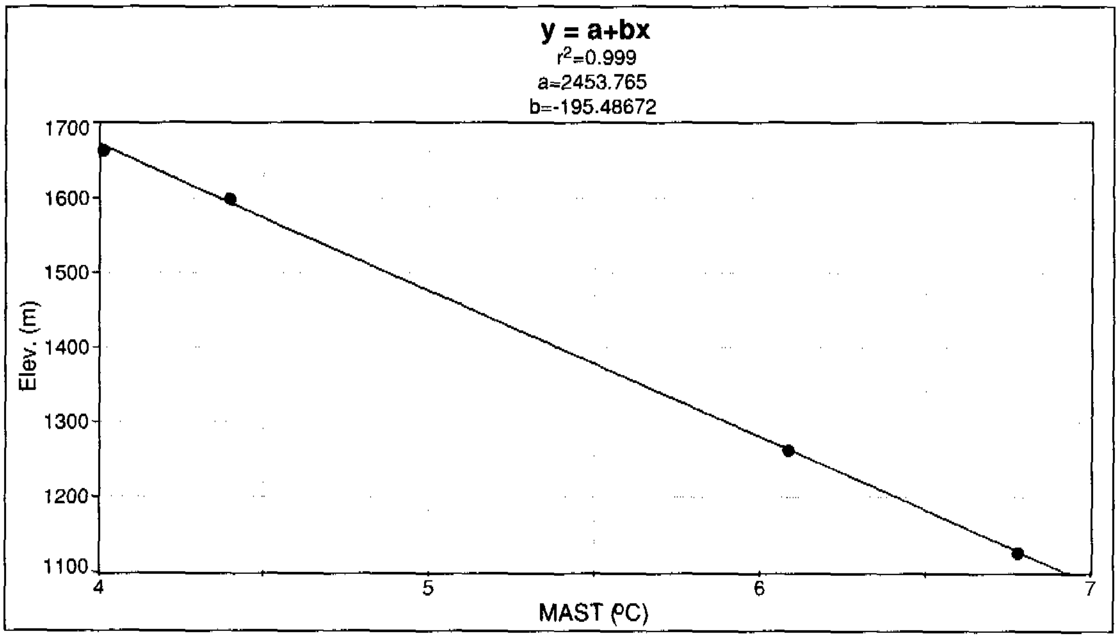


Figure 7.11.1.—Regression of elevation and mean annual soil temperature.

The relationship of MST and elevation for the same sites resulted in an r^2 value of 0.96 (figure 7.11.2). This regression indicates that the frigid-cryic temperature break occurs at about 1,465 m.

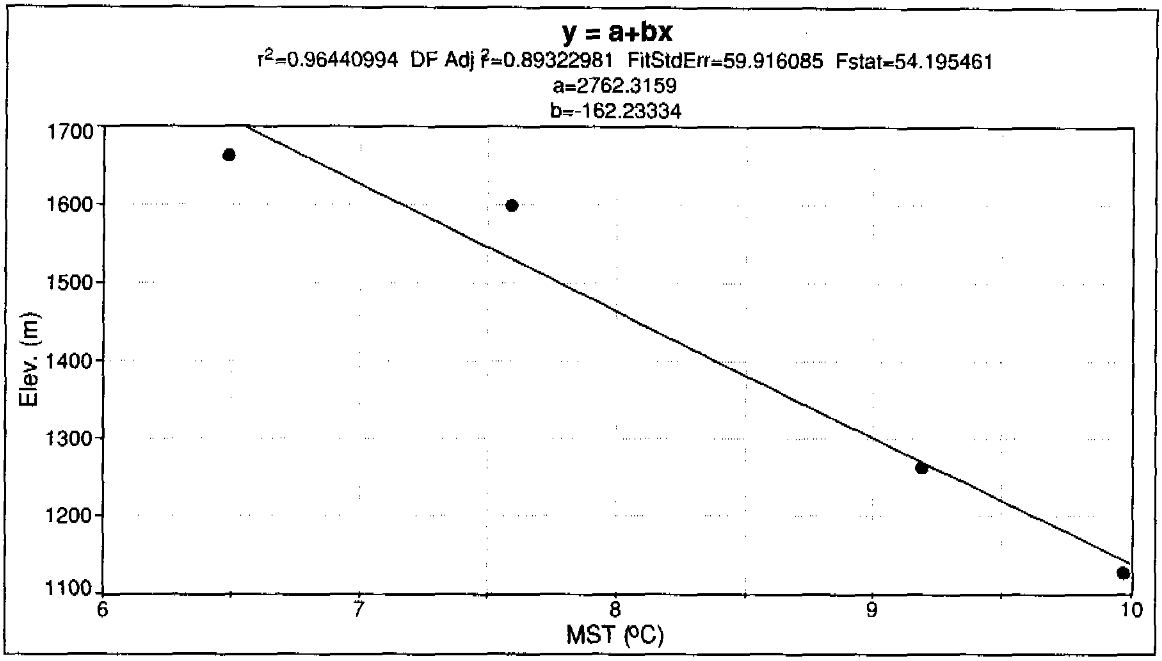


Figure 7.11.2.—Regression of elevation and mean summer soil temperature.

Soil temperature at 10 cm.—The MAST is slightly warmer at 10-cm soil depths than at the 50-cm depths. It is was about the same (6.9 vs. 6.8 °C) for the two depths at site 1, but it differed by 0.7 °C at site 5. These analyses are contrary to soil temperature data from other temperature studies in the United States. For instance, a recent temperature study of 10 sites in South Carolina that had humus layers with a thickness similar to that of the humus layers in the Idaho soils showed that the 10-cm soil depth averaged 0.3 °C colder than the 50-cm depth (Mount et al., 1998). It is conjectured that had hourly data been collected in both Idaho and South Carolina, these differences would have been less pronounced. Table 7.11.3 contrasts the MAST for the 10- and 50-cm soil depths for the sites in the study area.

Table 7.11.3.—Comparison of MAST (°C) at 10 and 50 cm.

Site number	MAST (10 cm)	MAST (50 cm)
1	6.9	6.8
2	6.6	6.1
3	Missing data	5.1
4	4.5	4.0
5	5.1	4.4

Air temperature.—Attempts to gather air temperature data at the study area were generally successful. Table 7.11.4 presents the annual findings. Although annual data were collected at three sites, the air temperature sensors were suspected to have been covered by snow at sites 4 and 5.

Table 7.11.4.—Comparison of MAAT and MAST (°C) at 50 cm.

Site (#)	MAAT	MAST 50 cm
1	---	6.8
2	6.8	6.1
3	---	5.1
4	5.2	4.0
5	4.8	4.4

Modeling air temperature values during the winter months was not deemed to be a worthwhile effort. Previous attempts to empirically model the diurnal air temperature curves from measured daily extremes have not been successful in Idaho. Sadler and Schroll (1997) determined that mountainous Idaho sites had the lowest r^2 value (0.47) in the eight-state area of interest.

The MAAT at all sites is slightly higher than the MAST at 50 cm. Snow is suspected to have covered the air temperature sensors at sites 4 and 5 during the winter months (figure 7.11.3), resulting in an apparently skewed air temperature signature. A Snow Telemetry (SNOTEL) site near site 5 collects air temperature data using MET 1 standards. From October 1996 to September 1997, the MAST at this SNOTEL site was 3.2 °C, or about 1.2 °C colder than the air temperature collected at site 5 from November 1997 to October 1998 with StowAway technology. When air temperature data become available for 1997 and 1998, a comparison of the air temperature at site 5 will commence to verify any skewing caused by snow covering the air temperature sensor.

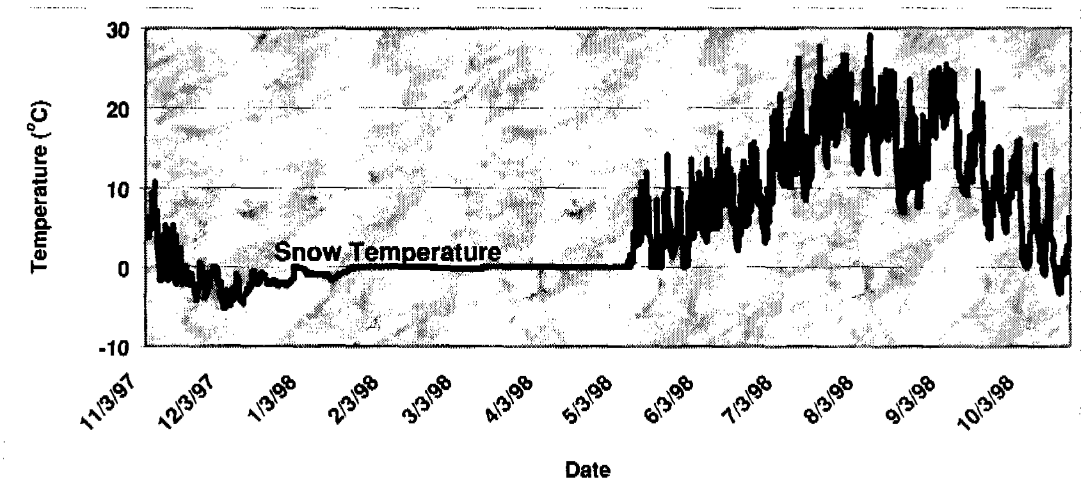


Figure 7.11.3.—Air temperature signature for Idaho site 4.

5. Biological Zero

Less than 5 percent biological activity in the soil is referred to as biological zero (Paul and Clark, 1989). This occurs at soil temperatures below 5 °C. For the 50-cm soil depth, sites 4 and 5 each had about 8 months of biological zero, site 3 had about 7 months, and sites 1 and 2 had about 5 months. The 10-cm soil depth exhibits biological zero for about the same amount of time as the 50-cm depth. Figure 7.11.4 shows the biological activity for the 10-cm depth at site 4. Considering the amount of time when the soil is too cold for biological activity to stimulate plant growth, the biomass productivity of the soils in the study area clearly compensates for this inactivity.

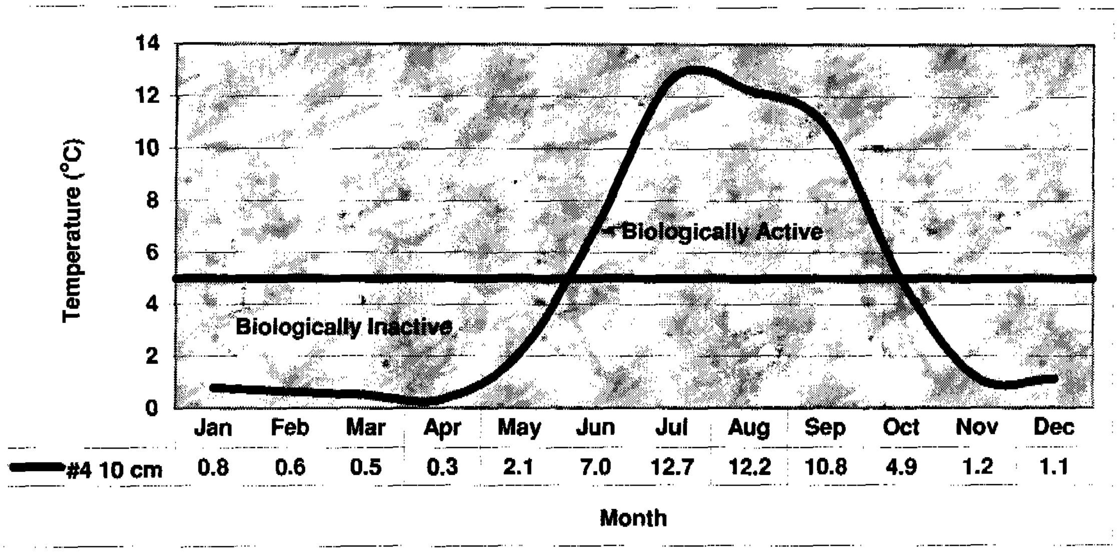


Figure 7.11.4.—Biological activity at 10-cm for Idaho site 4.

6. Discussion

It is not the purpose of this publication to initiate a more easily understood definition of frigid and cryic soil temperature regimes. Additional data from other cryic areas are needed to refine the present definitions. Instead, this study facilitates evaluation of these regimes in northern Idaho, specifically in Clearwater County. The fact that the results of the five sites in this study essentially verify each hypothesis is a testimony to the skill and intuitive knowledge of the NRCS field soil scientists in Idaho.

Isotivity values of less than 6 °C, which the cryic soils in this study area exhibited, are most likely indicative of most cryic soils at northern latitudes in the United States. Data from the Medicine Bow National Forest in Wyoming indicate low isotivity values (Mount, 1999). Nearly all soils with a cryic soil temperature regime are covered with snow for many months of the year. The snow cover influences the number of months when the soils are below biological zero. Cryic sites in both Wyoming and Idaho are below biological zero at the 50-cm soil depth for about 8 months during any one year.

Habitat types differ by soil series and soil temperature regime in Clearwater County. We are uncertain whether it is the soil temperature regimes that dictate the vegetative communities or the habitat types that dictate the soil temperature regimes.

The Idaho study resulted in three important findings. 1) The cutover soil at site 3 is slightly warmer (0.7 °C warmer) than the forested soil at site 5. These sites are identical, except for the successional stage of the habitat type. 2) The first isofrigid soil has been identified. Site 3 has the first soil with an isofrigid soil temperature regime to be fully documented in the U.S. Its isotivity value is 5.2 °C. 3) Cryic sites have low isotivity values. Sites 4 and 5 each have an isotivity value of less than 6 °C. These sites received the most snowfall and had the lowest MST values.

Acknowledgment

Ed Haagen, Resource Soil Scientist for the NRCS in Moscow, Idaho, provided assistance during the installation phase of this study.

Chapter 7.12

Findings From a 2-Year Soil Temperature Study in Northern Idaho*

ABSTRACT

Ten sites in Clearwater County, Idaho, were monitored for soil temperature from 1997 to 1999. These soils had either a frigid or cryic soil temperature regime during the 1998-1999 period of the study. Three sites that had frigid soil temperature regimes during the 1997-1998 period had cryic temperature regimes during the 1998-1999 period. The mean winter temperature at 50 cm averaged 0.3 °C warmer in the second year than in first year. During the second year, the mean annual soil temperature at 50 cm averaged 0.9 °C cooler, the mean summer temperature averaged 1.9 °C cooler, and the isotivity value (difference between mean summer and mean winter soil temperatures) averaged 2.1 °C cooler. The shifting of mean summer temperature during this study is troublesome. *Soil Taxonomy* defines the cryic soil temperature regime on the basis of its mean summer temperature. A great shift in mean summer temperature within 2 years makes the definition suspect. The mean annual soil temperature at 50 cm was colder during the second year of the study. Shift analysis for a soil at an elevation of 1,661 m indicates that the first shift, from November 1997 to October 1998, had a mean annual soil temperature of 4.3 °C. The thirteenth and final shift, from November 1998 to October 1999, had a mean annual soil temperature of 3.4 °C. This downward shift in is in contrast to studies in New York, West Virginia, and Pennsylvania indicating a 0.6 °C increase in mean annual soil temperature over a similar 2-year period.

1. Background

The presence and duration of snowpack can have an important effect on soil temperature. Previous soil temperature studies documented that Western soils with a lengthy snowpack do not freeze during the winter months (Mount, 1999). Moreover, the winter soil temperatures of these soils are warmer than those of cold soils with a limited snowpack in Colorado.

The frigid soil temperature regime occurs where the mean annual soil temperature at 50 cm ranges from 0 to 8 °C and the mean summer soil temperature for June, July, and August is more than 8 °C for soils with a humus layer. For soils with a humus layer, the cryic class is colder and the mean summer soil temperature for June, July, and August is less than 8 °C (Soil Survey Staff, 1999).

Before this study was initiated in November 1997, several vintages of intermittent studies had been conducted to verify the frigid and cryic soil temperature regimes in Idaho. Most of the data from these studies remain in file cabinets. In many cases spike thermometers calibrated to about 0.6 °C were used to measure summer soil temperatures at 50 cm during mid-June, mid-July, and mid-August. Hence, three temperature measurements were used to verify the cryic soil temperature regime. Because of extreme snowfall accumulations and the inaccessibility of the remote sites, the winter temperature signatures of these soils either were not known or were not presented to the scientific community prior to the culmination of this study.

2. Objectives and Hypotheses

The Idaho soil temperature study was funded through the NRCS Global Change Initiative. It is part of a network of sites funded through the NRCS Global Change Initiative that collects data at remote locations. Data loggers from this network have collected air and soil temperature data at 200 sites in 25

* Glenn Hoffman, NRCS Soil Scientist, Orofino, Idaho, assisted in preparing this section.

states, including areas at an elevation of 3,566 meters in Hawaii and Colorado, the valley floor of the Grand Canyon, and areas near sea level in South Carolina.

For this study, four objectives were defined. One was to verify mean annual soil temperature differences as stratified by the different habitat types in Clearwater County, Idaho. Another was to evaluate the mean annual soil temperature differences between a cutover site and an adjacent uncut site. A third objective was to evaluate the mean annual soil temperature and habitat type for a site hypothesized as having a frigid soil temperature regime. The last objective was to gather measured data for the frigid and cryic soil temperature regimes and populate monthly values in the National Soil Information System (NASIS) database.

During the installation phase of the study, it was hypothesized that, for sites 1 to 5, the mean annual soil temperature would be lowest at site 4, second lowest at site 5, third lowest at site 3, fourth lowest at site 2, and highest at site 1. A second hypothesis was that sites 3, 4, and 5 would prove to be cryic. A third hypothesis was that sites 1 and 2 would have a frigid soil temperature regime.

3. Study Area

Clearwater County is in the southern part of the Idaho panhandle. The Major Land Resource Area is 43E, the Northern Rocky Mountains. The study area is in the central part of Clearwater County. Ten sites were selected during November 1998 for data collection intended to verify the hypothesized frigid-cryic temperature regimes. The latitude of the sites ranges from 46°44'35" to 46°45'51" north, and the longitude ranges from 115°46'05" to 115°47'41" west. All of the sites are vegetated and fit into a documented habitat type described by the U.S. Forest Service (Cooper et al., 1991). See table 7.12.1.

Table 7.12.1.—Site and soil information for the study area.

Site number	Soil series	Vegetation (habitat type)	Elevation (m)	Slope (%)	Aspect (°)
1	Hobo	Western redcedar-queencup beadlily	1,128	20	225
2	Flumecreek	Grand fir-wild ginger	1,265	30	205
3	Bertha Hill	Subalpine fir-beargrass	1,600	35	195
4	Bertha Hill	Mountain hemlock-beargrass	1,661	23	278
5	Bertha Hill	Subalpine fir-beargrass	1,600	25	180
6	Jury	Grand fir-wild ginger	1,600	32	228
7	Jury	Western redcedar-wild ginger	1,600	23	278
8	Jury	Western redcedar-wild ginger	1,450	50	228
9	Vaywood	Subalpine fir-queencup beadlily	1,600	40	90
10	Hucberit	Mountain hemlock-beargrass	1,661	26	192

The study area receives 1,143 to 1,270 mm of precipitation annually, of which 914 to 3,658 mm is snow. The elevation of the sites ranges from 1,128 to 1,661 meters. Slope ranges from 20 to 50 percent, and aspect ranges from 180° to 278° (south to west). The soils are Andisols, each with a humus layer 2 to 5 cm thick and a mantle of volcanic ash 40 to 60 cm thick.

4. Results

Site 1.—Performance of the StowAway data loggers at site 1 was 68 percent during the first year of the study and 100 percent during the second year. Site 1 had a frigid soil temperature regime during both years. The MAST at 50 cm was colder during the second year than during the first year (table 7.12.2). The mean summer temperature (MST) at 50 cm was 1.2 °C colder during the second year than during the first year. However, the MST at 50 cm is still more than 8.0 °C. Consequently, the soil at this site has a frigid soil temperature regime (Soil Survey Staff, 1999).

Table 7.12.2.—Average air and soil temperatures (°C) for site 1.

Analysis	10 cm	50 cm	Air	Analysis	10 cm	50 cm	Air
Jan 98	0.8	3.1	---	Jan 99	0.6	3.3	-1.5
Feb 98	1.0	2.7	---	Feb 99	1.1	3.1	-1.5
Mar 98	1.5	2.7	---	Mar 99	1.0	2.6	0.4
Apr 98	4.0	3.5	---	Apr 99	1.7	2.6	2.9
May 98	8.3	6.1	---	May 99	5.6	4.0	7.2
Jun 98	10.1	7.6	---	Jun 99	9.6	6.8	11.6
Jul 98	15.3	10.5	---	Jul 99	12.3	8.8	16.0
Aug 98	15.1	11.9	---	Aug 99	14.8	10.8	17.5
Sep 98	13.9	12.0	---	Sep 99	11.5	10.5	11.6
Oct 98	8.2	10.4	---	Oct 99	8.1	9.3	6.5
Nov 97	3.8	6.6	2.7	Nov 98	3.8	7.4	1.1
Dec 97	0.9	4.4	---	Dec 98	1.2	4.6	-4.0
Mean	6.9	6.8	---	Mean	5.9	6.1	5.6
MST	13.5	10.0	---	MST	12.2	8.8	15.0
MWT	0.9	3.4	---	MWT	1.0	3.6	-2.3
Isotivity	12.6	6.6	---	Isotivity	11.3	5.2	17.3

Site 2.—This was the only site in the study area where performance of the StowAway loggers was less effective during the second year of the study than during the first year. Vermin activity negated complete success. Enough data were collected to determine the mean summer soil temperatures at this site (table 7.12.3). These data clearly show that the soil at this site had a frigid temperature regime during both years of the study (Soil Survey Staff, 1999). The MST at 50 cm was 0.5 °C colder during the second year than during the first year (8.7 vs. 9.2 ° C). This difference is more pronounced (11.7 vs. 13.2 °C) at the 10-cm depth. This finding implies that, among other factors, snow lasted longer during the spring of 1999 than during the spring of 1998.

Table 7.12.3.—Average air and soil temperatures (°C) for site 2.

Analysis	10 cm	50 cm	Air	Analysis	10 cm	50 cm	Air
Jan 98	1.4	3.1	-2.1	Jan 99	---	---	---
Feb 98	0.9	2.5	-0.2	Feb 99	---	---	---
Mar 98	0.7	2.1	0.4	Mar 99	---	---	---
Apr 98	2.9	2.4	4.4	Apr 99	---	---	---
May 98	7.9	5.5	9.2	May 99	---	---	---
Jun 98	9.8	6.8	11.4	Jun 99	9.3	7.2	11.0
Jul 98	15.0	9.7	19.3	Jul 99	11.8	8.4	16.4
Aug 98	14.7	11.0	18.6	Aug 99	14.0	10.5	18.1
Sep 98	13.4	11.0	15.4	Sep 99	10.9	10.3	12.6
Oct 98	7.4	9.2	5.4	Oct 99	7.6	8.7	7.6
Nov 97	3.7	5.7	2.1	Nov 98	2.6	5.9	0.6
Dec 97	1.8	3.9	-2.2	Dec 98	1.5	3.9	-4.7
Mean	6.7	6.1	6.8	Mean	---	---	---
MST	13.2	9.2	16.4	MST	11.7	8.7	15.2
MWT	1.4	3.2	-1.5	MWT	---	---	---
Isotivity	11.8	6.0	17.9	Isotivity	---	---	---

Site 3.—Vermin activity at site 3 was high during the first year, but 100 percent of the soil temperature data were captured during the second year. The MST at 50 cm was 2.5 °C colder during the second year than during the first year (table 7.12.4). The soil at this site had an isofrigid temperature

regime during the first year and a cryic temperature regime during the second year. At 3.8 °C, the MAST during the second year was 1.3 °C colder than during the first year. The length of the 1999 spring snowpack may have accentuated the difference in MAST.

Table 7.12.4.—Average air and soil temperatures (°C) for site 3.

Analysis	10 cm	50 cm	Air	Analysis	10 cm	50 cm	Air
Jan 98	---	2.7	---	Jan 99	0.7	2.3	---
Feb 98	---	2.4	---	Feb 99	0.6	1.9	---
Mar 98	---	2.1	---	Mar 99	0.4	1.7	---
Apr 98	---	1.4	---	Apr 99	0.4	1.4	---
May 98	---	3.7	---	May 99	0.4	1.0	---
Jun 98	---	6.0	---	Jun 99	7.7	3.6	9.4
Jul 98	---	8.7	---	Jul 99	9.7	5.8	13.3
Aug 98	---	9.4	---	Aug 99	12.2	7.5	15.3
Sep 98	---	9.6	---	Sep 99	9.7	7.2	10.6
Oct 98	---	7.6	---	Oct 99	6.8	6.0	6.8
Nov 97	4.3	4.3	3.4	Nov 98	1.7	3.9	2.1
Dec 97	---	3.2	---	Dec 98	0.9	2.8	---
Mean	---	5.1	---	Mean	4.3	3.8	---
MST	---	8.1	---	MST	9.9	5.6	12.7
MWT	---	2.8	---	MWT	0.7	2.3	---
Isotivity	---	5.3	---	Isotivity	9.1	3.3	---

Site 4.—Sensor performance was 100 percent successful on this site (table 7.12.5). The MAST at 50 cm was 0.4 °C colder during the second year than during the first year (3.6 vs. 4.0 °C). The MAAT was colder during the second year than during the first year (figure 7.12.1). Snow covered the air temperature sensor until May 8, 1998, during the first year and until May 31, 1999, during the second year. This 3-week difference in the length of the snowpack may have accentuated the colder soil temperatures.

Table 7.12.5.—Average air and soil temperatures (°C) for site 4.

Analysis	10 cm	50 cm	Air	Analysis	10 cm	50 cm	Air
Jan 98	0.8	2.0	-0.5	Jan 99	0.8	2.3	-2.6
Feb 98	0.7	1.7	0.0	Feb 99	0.7	2.1	-2.4
Mar 98	0.5	1.4	0.0	Mar 99	0.7	1.9	-0.7
Apr 98	0.3	1.3	0.1	Apr 99	0.6	1.7	0.1
May 98	2.1	1.6	3.8	May 99	0.4	1.5	0.4
Jun 98	6.9	3.9	8.9	Jun 99	1.1	1.4	7.9
Jul 98	12.7	7.1	17.7	Jul 99	8.8	5.1	14.2
Aug 98	12.2	8.4	17.3	Aug 99	11.3	7.6	15.9
Sep 98	10.8	8.3	13.7	Sep 99	7.6	6.7	10.1
Oct 98	4.9	6.6	3.6	Oct 99	5.0	5.7	5.8
Nov 97	1.2	3.4	0.4	Nov 98	1.4	4.1	-1.2
Dec 97	1.1	2.4	-2.3	Dec 98	1.0	2.9	-6.8
Mean	4.6	4.0	5.2	Mean	3.3	3.6	3.4
MST	10.6	6.5	13.1	MST	7.1	4.7	12.7
MWT	0.8	2.0	-0.9	MWT	0.8	2.4	-3.9
Isotivity	9.8	4.5	14.1	Isotivity	6.3	2.3	16.1

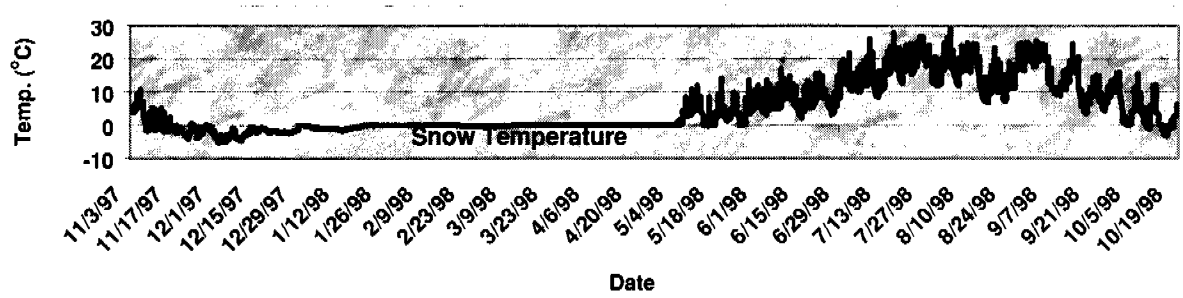


Figure 7.12.1.—Influence of snowpack on air temperature at site 4.

Site. 5.—Sensor performance at site 5 was 100 percent (table 7.12.6). Figure 7.12.2 shows the soil temperature signature for the 50-cm depth during the second year. The soil at site 5 has a cryic soil temperature regime. The MST at 50 cm was 6.1 °C during the second year and 7.6 °C during the first year. The MAST at 50 cm was 0.5 °C colder during the second year than during the first year (3.9 vs. 4.4° C).

Table 7.12.6.—Average air and soil temperatures (°C) for site 5.

Analysis	10 cm	50 cm	Air	Analysis	10 cm	50 cm	Air
Jan 98	0.9	1.8	-3.6	Jan 99	1.0	2.2	-2.2
Feb 98	0.7	1.4	-2.1	Feb 99	1.0	2.0	-2.1
Mar 98	0.6	1.2	-2.1	Mar 99	0.7	1.7	-0.7
Apr 98	0.4	1.0	2.1	Apr 99	0.6	1.4	-0.1
May 98	4.6	2.6	7.0	May 99	0.5	1.0	2.5
Jun 98	7.5	4.9	9.6	Jun 99	5.0	2.9	8.7
Jul 98	13.0	8.4	17.5	Jul 99	9.9	6.5	13.9
Aug 98	12.7	9.5	16.4	Aug 99	12.5	8.8	16.0
Sep 98	11.2	9.4	13.2	Sep 99	8.4	7.6	9.9
Oct 98	5.7	6.9	3.6	Oct 99	5.3	6.0	5.5
Nov 97	2.1	3.3	0.3	Nov 98	1.7	3.9	-0.9
Dec 97	1.2	2.2	-3.9	Dec 98	1.2	2.7	-6.5
Mean	5.1	4.4	4.8	Mean	4.0	3.9	3.7
MST	11.1	7.6	14.5	MST	9.1	6.1	12.9
MWT	0.9	1.8	-3.2	MWT	1.1	2.3	-3.6
Isotivity	18.3	5.8	17.7	Isotivity	8.1	3.8	16.5

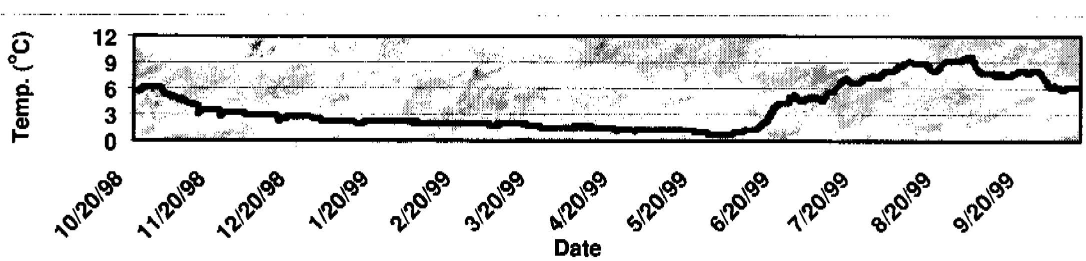


Figure 7.12.2.—Soil temperature signature at 50 cm for site 5.

The soil temperature signature at 50 cm shows little variation between summer and winter temperatures (figure 7.12.2). At 3.8 °C, this difference was 2.0 °C less during the second year than during the first year.

Site 6.—At this site sensor performance was 70 percent during the second year and 40 percent during the first year. It was not possible to use data from the first year to assess the temperature regime of the soil. The MST was successfully collected during the second year (table 7.12.7). With a MST of 7.5 °C, this soil had a cryic soil temperature regime during the second year. Assuming that the MST was 1 °C colder during the second year, the soil likely had a frigid soil temperature regime during the first year.

Table 7.12.7.—Average air and soil temperatures (°C) for site 6.

Analysis	10 cm	50 cm	Air	Analysis	10 cm	50 cm	Air
Jan 98	---	---	-3.1	Jan 99	---	---	-3.0
Feb 98	---	---	-0.9	Feb 99	---	---	-2.5
Mar 98	---	---	-0.3	Mar 99	----	---	-0.6
Apr 98	---	---	3.8	Apr 99	---	---	1.0
May 98	---	---	7.9	May 99	---	---	4.3
Jun 98	---	---	10.6	Jun 99	8.8	5.7	9.6
Jul 98	---	---	18.3	Jul 99	10.3	7.2	7.0
Aug 98	---	---	18.0	Aug 99	13.2	9.5	---
Sep 98	---	---	14.3	Sep 99	9.7	8.7	---
Oct 98	---	---	4.3	Oct 99	6.7	7.2	6.0
Nov 97	5.6	5.2	1.2	Nov 98	2.5	5.5	-0.3
Dec 97	---	---	-3.1	Dec 98	---	---	-5.8
Mean	---	---	5.9	Mean	---	---	---
MST	---	---	15.6	MST	10.8	7.5	---
MWT	---	---	-2.3	MWT	---	---	-3.7
Isotivity	---	---	17.9	Isotivity	---	---	---

Site 7.—More data were collected at site 7 during the second year of the study than during the first year (table 7.12.8). The soil at this site had a cryic soil temperature regime during the second year. Figure 7.12.3 shows the average monthly soil temperature at 10 cm for the second year.

Table 7.12.8.—Average air and soil temperatures (°C) for site 7.

Analysis	10 cm	50 cm	Air	Analysis	10 cm	50 cm	Air
Jan 98	1.2	2.7	-2.9	Jan 99	1.2	---	-1.0
Feb 98	---	---	-0.3	Feb 99	1.5	---	-1.1
Mar 98	---	---	-0.3	Mar 99	1.6	----	-0.2
Apr 98	---	---	3.2	Apr 99	1.6	---	-0.2
May 98	---	---	8.4	May 99	3.5	---	3.3
Jun 98	---	---	10.7	Jun 99	8.8	6.4	10.0
Jul 98	---	---	19.0	Jul 99	12.3	7.6	15.0
Aug 98	---	---	18.6	Aug 99	14.6	9.8	17.1
Sep 98	---	---	15.6	Sep 99	11.5	9.5	11.6
Oct 98	---	---	4.8	Oct 99	8.1	8.4	6.8
Nov 97	3.3	5.2	1.4	Nov 98	2.9	---	-0.4
Dec 97	1.6	3.4	-3.2	Dec 98	1.6	---	-6.0
Mean	---	---	6.2	Mean	5.8	---	4.6
MST	---	---	16.1	MST	11.9	8.0	14.0
MWT	---	---	-2.2	MWT	1.4	---	-2.7
Isotivity	---	---	18.3	Isotivity	10.5	---	16.7

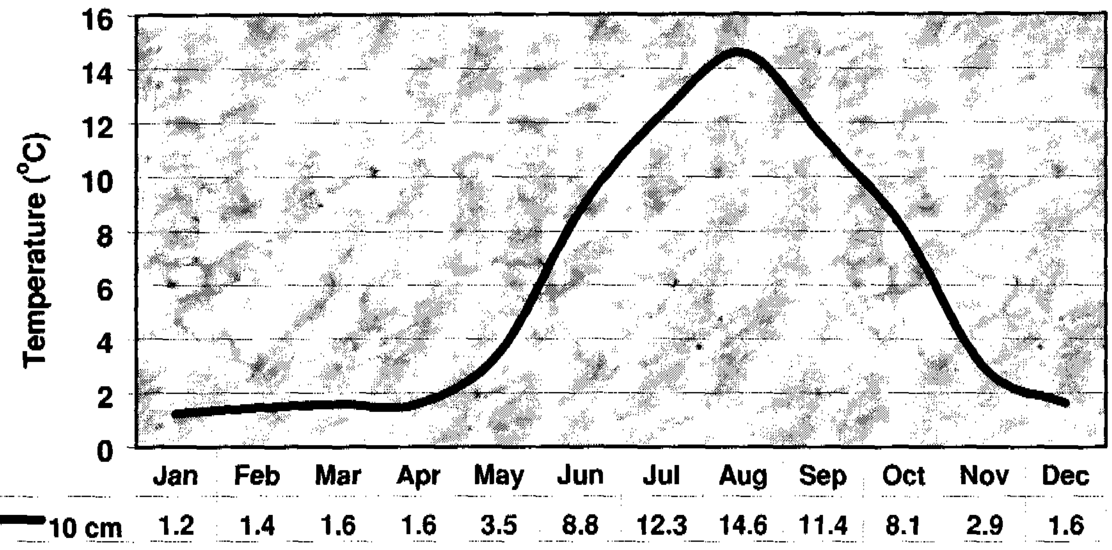
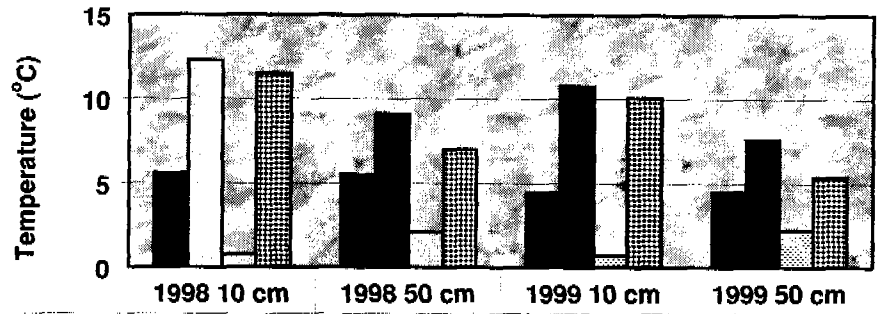


Figure 7.12.3.—Monthly soil temperature averages at 10 cm for site 7 during the second year of the study.

Site 8.—Table 7.12.9 shows average air and soil temperatures for site 8. Data capture was 100 percent during both years of the study. The soil at this site had a frigid soil temperature regime during the first year and a cryic soil temperature regime during the second year. Figure 7.12.4 shows the soil temperature relationships.

Table 7.12.9.—Average air and soil temperatures (°C) for site 8.

Analysis	10 cm	50 cm	Air	Analysis	10 cm	50 cm	Air
Jan 98	0.7	2.1	-3.2	Jan 99	0.6	2.0	-3.0
Feb 98	0.6	1.6	-1.1	Feb 99	0.6	1.8	-2.0
Mar 98	0.4	1.4	-0.6	Mar 99	0.4	1.5	-0.1
Apr 98	0.7	1.3	3.2	Apr 99	0.3	1.2	-0.1
May 98	6.2	4.7	7.9	May 99	0.9	1.1	4.2
Jun 98	8.8	6.7	10.2	Jun 99	7.9	5.0	9.3
Jul 98	14.2	10.4	18.2	Jul 99	11.0	7.7	14.3
Aug 98	13.8	11.5	17.3	Aug 99	13.5	10.1	16.4
Sep 98	12.3	11.1	14.1	Sep 99	9.5	9.1	10.7
Oct 98	6.1	8.1	4.1	Oct 99	6.4	7.3	6.0
Nov 97	2.4	4.2	1.1	Nov 98	1.8	4.4	-0.4
Dec 97	1.1	2.7	-3.4	Dec 98	0.9	2.8	-5.9
Mean	5.6	5.5	5.7	Mean	4.5	4.5	4.1
MST	12.3	9.1	15.2	MST	10.8	7.6	13.3
MWT	0.8	2.1	-2.6	MWT	0.7	2.2	-3.6
Isotivity	11.5	7.0	17.8	Isotivity	10.1	5.4	16.9



	1998 10 cm	1998 50 cm	1999 10 cm	1999 50 cm
■MAST	5.6	5.5	4.5	4.5
□MST	12.3	9.1	10.8	7.6
⊞MWT	0.8	2.1	0.7	2.2
⊞MS-MW	11.5	7.0	10.1	5.4

Figure 7.12.4.—Soil temperature relationships at site 8 during the 2-year study.

Site 9.—Table 7.12.10 summarizes average temperatures for site 9. The soil at this site had a cryic temperature regime during the second year. Not enough data were captured to categorically determine the soil temperature regime during the first year. Examination of the MST at 10 cm indicates that the soil was warmer during the first year. The MST at 10 cm was 12.3 °C during the first year and 10.9 °C during the second year. The MAAT was 5.6 °C during the first year and 4.2 °C during the second year.

Table 7.12.10.—Average air and soil temperatures (°C) for site 9.

Analysis	10 cm	50 cm	Air	Analysis	10 cm	50 cm	Air
Jan 98	1.0	2.2	-3.1	Jan 99	1.4	2.6	-2.4
Feb 98	0.8	---	-1.1	Feb 99	1.6	2.2	-2.0
Mar 98	0.7	---	-0.7	Mar 99	1.5	1.9	-0.5
Apr 98	0.7	---	3.0	Apr 99	1.3	1.6	0.8
May 98	6.1	---	7.9	May 99	1.3	1.4	4.0
Jun 98	8.5	---	10.2	Jun 99	7.5	4.0	9.7
Jul 98	14.0	---	18.2	Jul 99	11.4	7.4	14.9
Aug 98	14.6	---	17.4	Aug 99	13.8	10.0	16.7
Sep 98	---	---	14.1	Sep 99	10.4	9.3	10.7
Oct 98	---	---	4.1	Oct 99	7.0	7.7	5.2
Nov 97	2.6	4.3	1.1	Nov 98	2.4	4.9	-0.5
Dec 97	1.3	2.8	-3.4	Dec 98	1.7	3.3	-5.9
Mean	---	---	5.6	Mean	5.1	4.7	4.2
MST	12.3	---	15.3	MST	10.9	7.1	13.8
MWT	1.0	3.1	-2.6	MWT	1.6	2.7	-3.4
Isotivity	11.4	---	17.8	Isotivity	9.3	4.4	17.2

Site 10.—This site has the second coldest soil in the study area (figure 7.12.5). Data capture was 100 percent during both years (table 7.12.11). The MAST at 50 cm was 0.9 °C colder during the second year than during the first year (3.4 vs. 4.3°C). The snowpack may have been heavy at this site. The MST at 50 cm was 3.0 °C colder during the second year than during the first year (4.6 vs. 7.6 °C). The soil at this site usually has a cryic soil temperature regime.

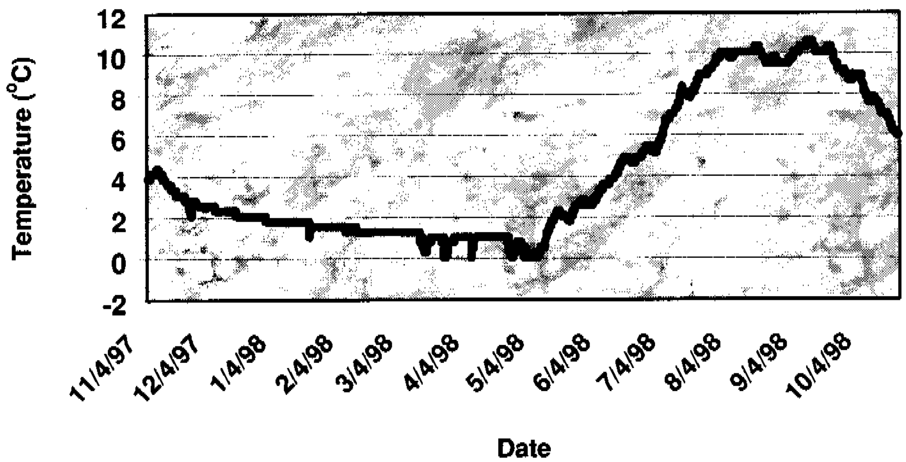


Figure 7.12.5.—Soil temperature signature at 50 cm for site 10 during the first year.

Table 7.12.11.—Average air and soil temperatures (°C) for site 10.

Analysis	10 cm	50 cm	Air	Analysis	10 cm	50 cm	Air
Jan 98	0.8	1.7	-3.6	Jan 99	0.6	1.9	-0.9
Feb 98	0.7	1.4	-0.8	Feb 99	0.6	1.7	-1.4
Mar 98	0.4	1.0	-0.9	Mar 99	0.5	1.5	-0.6
Apr 98	0.3	0.8	0.6	Apr 99	0.4	1.2	-0.1
May 98	2.6	1.7	5.9	May 99	0.3	0.8	-0.1
Jun 98	6.9	4.6	9.2	Jun 99	2.1	1.0	4.3
Jul 98	12.7	8.3	17.6	Jul 99	9.3	4.9	13.7
Aug 98	12.6	9.8	16.9	Aug 99	12.1	7.8	15.8
Sep 98	11.4	9.8	13.7	Sep 99	8.6	7.6	10.1
Oct 98	5.6	7.5	3.4	Oct 99	5.7	6.3	5.5
Nov 97	1.9	3.3	0.2	Nov 98	1.7	4.0	-1.6
Dec 97	1.1	2.2	-4.3	Dec 98	0.9	2.4	-6.0
Mean	4.8	4.3	4.8	Mean	3.6	3.4	3.2
MST	10.7	7.6	14.6	MST	7.8	4.6	11.2
MWT	0.8	1.8	-2.9	MWT	0.7	2.0	-2.7
Isotivity	9.9	5.8	17.4	Isotivity	7.1	2.6	14.0

5. Shift Analysis

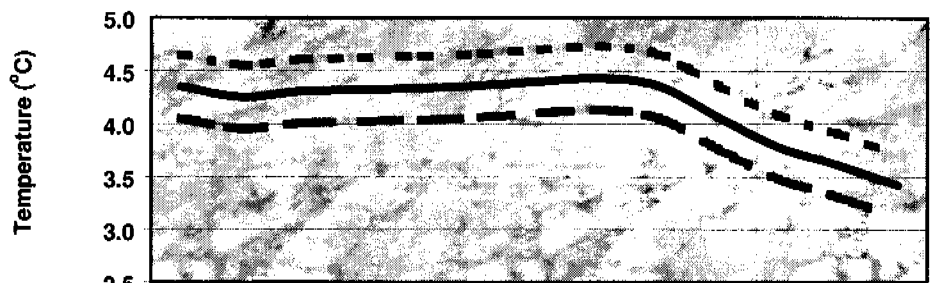
The cooling trend for soil temperatures at 50 cm is summarized in table 7.12.12. Cooler temperatures during the second year of the study are shown with a negative value, e.g., –1.5 °C. Warmer temperatures during the second year are shown with a positive value, e.g., +0.4 °C. Because of vermin activity, data are available for only six sites.

Table 7.12.12.—Soil temperature trends (°C) at 50 cm for six sites in Idaho.

Analysis	Site 1	Site 3	Site 4	Site 5	Site 8	Site 10
MAST	-0.6	-1.3	-0.4	-0.5	-1.0	-1.3
MST	-1.2	-2.4	-1.8	-1.6	-1.5	-3.0
MWT	+0.2	-0.4	+0.4	+0.4	+0.1	+0.2
Isotivity	-1.4	-2.0	-2.2	-2.0	-1.6	-3.2

The winter period (MWT) at 50 cm was warmer during the second year than during the first year. The MWT averaged about 0.3 °C for the sites with data. The MAST at 50 cm averaged 0.9 °C cooler during the second year than during the first year. Also, the MST averaged 1.9 °C cooler during the second year, and the isotivity values averaged 2.1 °C cooler during the second year.

The shifting of MST during this study is troublesome. *Soil Taxonomy* defines the cryic soil temperature regime on the basis of its MST. If the MST can shift so greatly within 2 years, it is imperative that data be collected for more years. Shift analysis for the 50-cm depth at site 10 is shown in figure 7.12.6.



	1	2	3	4	5	6	7	8	9	10	11	12	13
Shift 50 cm	4.4	4.3	4.3	4.3	4.3	4.4	4.4	4.4	4.4	4.1	3.8	3.6	3.4
+0.3 C	4.7	4.6	4.6	4.6	4.6	4.7	4.7	4.7	4.7	4.4	4.1	3.9	3.7
-0.3 C	4.1	4.0	4.0	4.0	4.0	4.1	4.1	4.1	4.1	3.8	3.5	3.3	3.1

MAST at Shift

Figure 7.12.6.—Shift analysis for the 50-cm soil depth at site 10.

The inference from figure 7.12.6 is clear. During this 2-year study in Idaho, mean annual soil temperatures got colder. Shift 1, from November 1997 to October 1998, has a MAST of 4.3 °C. The thirteenth and final shift, from November 1998 to October 1999, has a MAST of 3.4 °C. This downward shift is in contrast to studies in New York, West Virginia, and Pennsylvania indicating a 0.6 °C increase in MAST over a similar 2-year period (Mount, Pyle, et al., 1999).

Acknowledgments

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Chapter 7.13

Soil Temperature Study in Tazewell County, Illinois

ABSTRACT

The soils at four sites in Tazewell County, Illinois, had a mesic temperature regime during 1998 and 1999. There were measurable differences among average monthly, seasonal, and annual soil temperatures during this study in central Illinois. Analysis shows that the mean annual soil temperature for the soil in a flower garden was the warmest (13.6 °C), followed by the soil in an orchard (12.6 °C), and then a somewhat poorly drained soil with a grass cover (12.3 °C). The isotivity values (difference between mean summer and mean winter soil temperatures) are representative for mid-continental locations in the United States. Each site froze at 10 cm for only a few days during the winter.

1. Background

Central Illinois has some of the best soils in the world for the production of corn and soybeans. Plano and Drummer soils each yield more than 150 bushels of corn per acre during a normal year (Teater, 1996). Data on the physical and chemical properties of numerous soils in central Illinois are available. However, no soil temperature data were available prior to April 1998. The purpose of this study was to attain baseline soil temperature data for an assessment of the diurnal, monthly, and annual variation at four sites in Tazewell County. This study was funded through the NRCS Global Change Initiative.

2. Study Area

Tazewell County is in central Illinois. The four sites are located in section 22 of Dillon Township. The study area is about 10 km south of the Mackinaw River (figure 7.13.1).

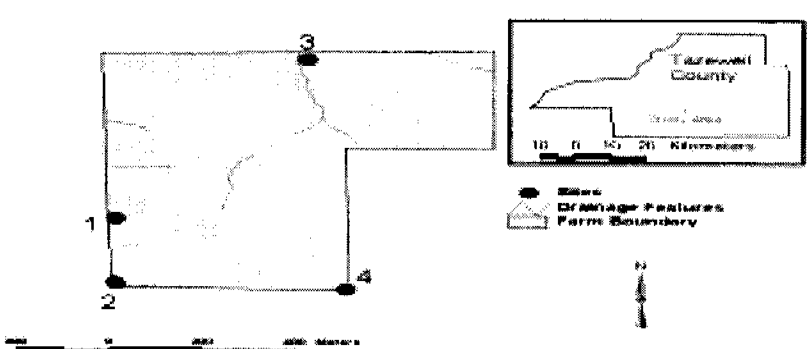


Figure 7.13.1.—Location of the sites in the study area.

Site 1 is in a flower garden southeast of the house. Its latitude is 40°25'31" north, and its longitude is 89°32'20" west. The moderately well drained soil at this site is Rozetta silt loam, which is a fine-silty, mixed, superactive, mesic Typic Hapludalf (Soil Survey Staff, 1999). It is on a 2 percent slope with a west aspect. The garden is periodically bare. Flowers are grown in the garden during the spring and summer months.

Site 2 is in an orchard in the southwest corner of the farm. It might be affected by cold air drainage. Its latitude is 40°25'24" north, and its longitude is 89°32'23" west. The well drained soil at this site is Fayette silt loam, which is a fine-silty, mixed, superactive Typic Hapludalf. It is on a 10 percent slope with a southwest aspect. The site is covered with grass throughout the year. It is mowed during the summer months.

Site 3 is in the northern part of a pasture directly south of the Winkler property line. Its latitude is 40°25'49" north, and its longitude is 89°32'07" west. The soil at this site is Fayette silt loam. It is on a 5 percent slope with a west aspect. The vegetation is pasture grass that is mowed periodically during the year.

Site 4 is at the southeast junction of the Troyer property line, adjacent to Long Road. Its latitude is 40°25'23" north, and its longitude is 89°32'04" west. The somewhat poorly drained soil at this site is Stronghurst silt loam, which is a fine-silty, mixed, superactive, mesic Aeric Endoaqualf. It is on a 1 percent slope with a north aspect. This site is covered with annual grasses.

3. Results

Monthly, seasonal, and annual soil and air temperatures are shown in tables 7.13.1, 7.13.2, 7.13.3, and 7.13.4. Dashes for an individual month indicate that the sensor was inoperative.

Site 1.—The MAST at 50 cm on this site was 13.6 °C (table 7.31.1), which was warmer than was hypothesized (12.2 °C). The warm winter temperatures are a reflection of the La Niña effect. The 10-cm mean is approximated from summer and winter readings. Its true MAST during the period of record is not known.

Table 7.13.1.—Temperature summary (°C) for site 1.

Analysis	10 cm	50 cm	Air
Jan 99	0.1	3.2	---
Feb 99	---	3.9	---
Mar 99	---	6.6	---
Apr 98	12.0	10.4	12.5
May 98	19.7	16.2	20.6
Jun 98	22.5	19.5	20.5
Jul 98	26.0	23.2	---
Aug 98	25.9	23.6	---
Sep 98	23.3	22.4	---
Oct 98	14.7	16.1	---
Nov 98	8.2	10.4	----
Dec 98	4.2	7.3	---
Mean	13.2	13.6	---
MST	24.8	22.1	---
MWT	---	4.8	---
Isotivity	---	17.3	---

Site 2.—This site reflects an ecosystem difference from site 1. With a MAST of 12.6 °C, it is 1.0 °C cooler at 50 cm than site 1 (table 7.13.2). The MAST of the 10-cm depth was slightly cooler than that of the 50-cm depth. It was thought that site 2 might show evidence of cold air drainage. Though colder than site 1, it is warmer than site 4. Consequently, there was no clear evidence of cold air drainage impacting the MAST at site 2.

Table 7.13.2.—Temperature summary (°C) for site 2.

Analysis	10 cm	50 cm
Jan 99	0.0	2.3
Feb 99	2.4	3.7
Mar 99	3.3	7.4
Apr 98	11.9	11.0
May 98	19.7	17.0
Jun 98	21.0	19.4
Jul 98	22.7	21.6
Aug 98	22.3	21.4
Sep 98	20.0	20.0
Oct 98	13.4	15.3
Nov 98	7.5	10.1
Dec 98	3.8	7.0
Mean	12.3	12.6
MST	22.0	20.8
MWT	2.1	4.3
Isotivity	20.0	16.4

Site 3.—Sensor performance at site 3 was the worst of any site in the study area. Mice chewed off the 50-cm soil temperature sensor and the air temperature sensor during June of 1998. The 10-cm MAST (12.9 °C) indicates that the soil is mesic (table 7.13.3). This is the second warmest site in the study area, after the garden site.

Table 7.13.3.—Temperature summary (°C) for site 3.

Analysis	10 cm	Air
Jan 99	0.9	---
Feb 99	2.7	---
Mar 99	3.0	---
Apr 98	11.7	12.7
May 98	18.5	16.4
Jun 98	21.1	---
Jul 98	23.8	---
Aug 98	23.8	---
Sep 98	21.7	---
Oct 98	14.8	---
Nov 98	8.9	---
Dec 98	4.6	---
Mean	12.9	---
MST	22.9	---
MWT	2.7	---
Isotivity	20.2	---

Site 4.—The monthly, seasonal, and annual soil temperatures for site 4 are shown in table 7.13.4. The sensors at this site performed well in spite of a high water table. Mice chewed off the air temperature sensor. It is conjectured that the water table impacted the difference in mean annual soil temperature between the 10- and 50-cm depths. The MAST values of site 4 at 10 and 50 cm are the

lowest in the study area. Evidently, the water table slightly impacts the MAST in central Illinois. This was not found to be true in a paired wet-dry soil temperature study in Virginia and North Carolina (Mount, 1999).

Table 7.13.4.—Temperature summary (°C) for site 4.

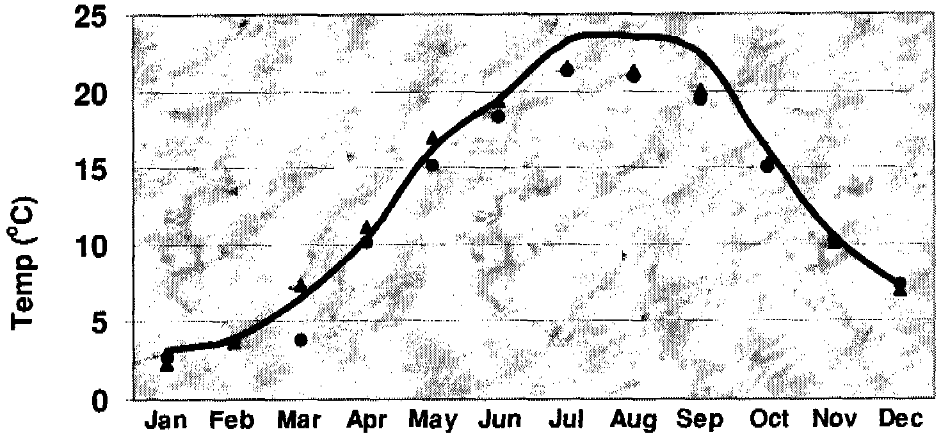
Analysis	10 cm	50 cm
Jan 99	0.4	2.7
Feb 99	2.4	3.7
Mar 99	2.6	3.8
Apr 98	10.6	10.0
May 98	17.3	15.2
Jun 98	20.0	18.4
Jul 98	22.6	21.3
Aug 98	22.1	20.9
Sep 98	19.4	19.5
Oct 98	13.1	15.0
Nov 98	7.7	10.2
Dec 98	4.0	7.3
Mean	11.9	12.3
MST	21.6	20.2
MWT	2.3	4.6
Isotivity	19.3	15.6

4. Discussion

There were measurable differences among the average monthly, seasonal, and annual soil temperatures during this 1-year study (figures 7.13.2 and 7.13.3).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
▲ Orchard	-0.1	2.4	3.3	11.9	19.7	20.9	22.7	22.3	20.1	13.4	7.5	3.8
— Pasture	0.9	2.7	3.1	11.7	18.5	21.2	23.8	23.8	21.7	14.8	8.9	4.6
● Troyer	0.4	2.4	2.7	10.6	17.3	20.1	22.7	22.1	19.4	13.1	7.7	4.0

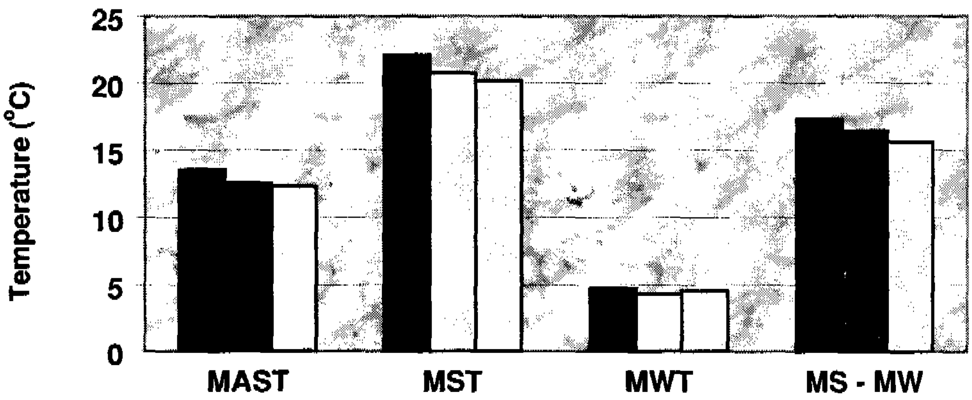
Figure 7.13.2.—Average monthly soil temperatures for the 10-cm depth in the study area.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
━ House	3.2	3.9	6.6	10.4	16.2	19.5	23.2	23.6	22.4	16.1	10.4	7.3
▲ Orchard	2.3	3.7	7.4	11.1	16.9	19.4	21.6	21.3	20.1	15.3	10.1	7.0
● Troyer	2.7	3.7	3.8	10.1	15.2	18.4	21.3	20.9	19.4	15.0	10.2	7.3

Figure 7.13.3.—Average monthly soil temperatures for the 50-cm depth.

Of the four sites, three had annual data for comparing the 50-cm depths (figure 7.13.4). These analyses show that the MAST at site 1 (house) was the warmest at 13 6°C, followed by site 2 (orchard) at 12.6 °C, and then by the somewhat poorly drained site 3 (Troyer) at 12.3 °C. Each of these sites has a mesic temperature regime. The isotivity values are representative of mid-continental locations in the United States.



	MAST	MST	MWT	MS - MW
■ House	13.6	22.1	4.8	17.3
■ Orchard	12.6	20.8	4.3	16.4
□ Troyer	12.3	20.2	4.6	15.6

Figure 7.13.4.—Seasonal and annual analysis of the 50-cm soil depth in the study area.

Evidence from studies in the Northeast indicates that the temperature during the period of record for this study was warmer than normal (Mount, Pyle, et al., 1999). Studies in New York and Pennsylvania indicate that the MAST for 1998 and 1999 was 0.8 °C warmer than that for 1997 and 1998. It is conjectured that the same is true for the Illinois study area.

Acknowledgment

Harley Mount, proprietor of the study area, assisted in site selection and in the installation and retrieval of data loggers.

Chapter 7.14

The Nature of Soil Temperature in Southern Illinois*

ABSTRACT

The soils of southern Illinois have historically been correlated to mesic temperature regimes. Soils at nine sites were monitored for soil temperature during 1999 and 2000. Six of the sites were in woodland, and three sites were in grassland. Air temperatures were very uniform throughout the study area. The mean annual air temperature ranged from 14.0 °C in Jackson County to 15.0 °C in Pulaski and Hardin Counties. Seasonal and annual soil temperatures at 10 cm varied widely and cannot be explained by air temperature inputs alone. Two sites with a grass cover in Jackson and Pulaski Counties were instrumented for the collection of soil temperature at 25 cm. The soils at both sites are thermic. The soil with a grass cover in Pulaski County has a larger isotivity value (difference in mean summer and mean winter soil temperatures) than the soil with a grass cover in Jackson County (20.7 vs. 17.2 °C). The reasons for this phenomenon are unclear. Examination of the 50-cm soil temperature averages indicates that seven of the nine sites are thermic and two sites are mesic. The isotivity value for site 2 (7.1 °C) is about half that of the other sites. Various attempts have been made to model soil temperature on the basis of 30-year normal air temperature inputs. A model developed at the National Soil Survey Center predicted soil temperature each month using measured air temperature data. Data were arrayed for over 100 sites from previous temperature studies. The r^2 for this relationship is 0.91. Regression equations were derived for each month by land use. The r^2 values ranged from 0.73 to 0.96. This model worked well at sites in Alexander and Hardin Counties, Illinois, but not very well in Jackson County.

1. Background

The soil temperature regime in southern Illinois has been in question for many years. For soil survey purposes, the soil temperature regime in Illinois was generally considered mesic throughout the State. However, a few soils with thermic temperature regimes were correlated on the bottom land along the Ohio and Mississippi Rivers. A mesic soil temperature regime is one that has a mean annual soil temperature (MAST) between 8 and 15 °C and an isotivity value (difference in mean summer and mean winter soil temperatures) of more than 6 °C. A thermic soil temperature regime is one that has a MAST between 15 and 22 °C and an isotivity value of more than 6 °C (Soil Survey Staff, 1999).

A study was designed at nine sites in Illinois and one site in Kentucky to identify the soil temperature regimes of grassland and forest sites. The study was funded by the NRCS Global Change Initiative. Air and soil temperature results for the sites in southern Illinois are presented in this report.

2. Study Area

The study area consists of nine sites in southern Illinois (figure 7.14.1). Elevation ranges from 90 to 170 meters. The soils in the study area are considered to have mesic temperature regimes bordering on thermic temperature regimes. The moderately well drained Hosmer soils are fine-silty, mixed, active, mesic Oxyaquic Fragiudalfs. The somewhat poorly drained Stoy soils are fine-silty, mixed, superactive, mesic Fragiaquic Hapludalfs. The poorly drained Darwin soils are fine, smectitic, mesic Fluvaquentic Vertic Endoaquolls. The poorly drained Jacob soils are very-fine, smectitic, acid, mesic Vertic Endoaquepts. The Menfro soils are fine-silty, mixed, superactive, mesic Typic Hapludalfs. The moderately well drained Sciotoville soils are fine-silty, mixed, active, mesic Aquic Fragiudalfs. The well drained Alford soils are fine-silty, mixed, superactive, mesic Ultic Hapludalfs (Soil Survey Staff, 1999). Table 7.14.1 gives additional site information

* Sam Indorante and Dewayne Williams, NRCS Soil Scientists, Carbondale, Illinois, helped prepare this section.

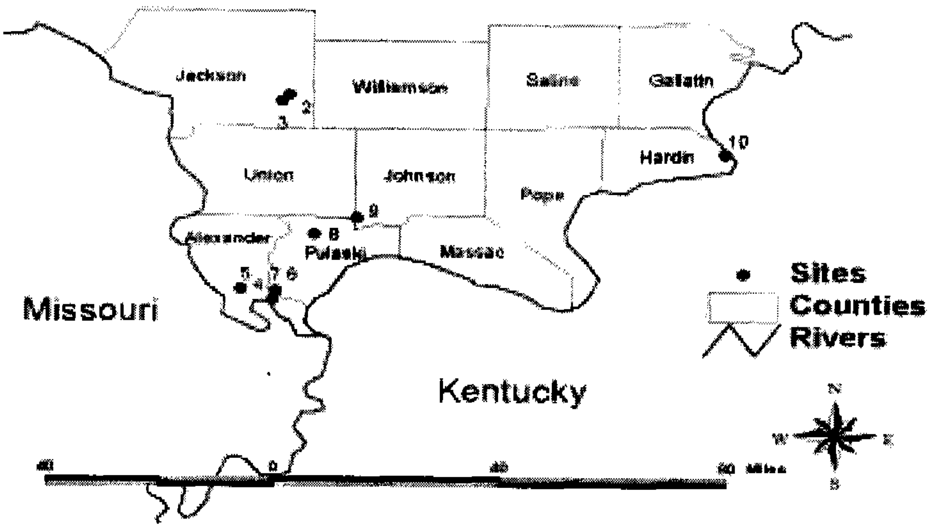


Figure 7.14.1.—Location of the sites in the soil temperature study area.

Table 7.14.1.—Site information for the southern Illinois temperature study.

Site no.	County name	Latitude (°N)	Longitude (°W)	Soil name	Slope (%)	Ecosystem (type)
2	Jackson	37°42'00"	89°13'00"	Hosmer	0	Forest
3	Jackson	37°41'01"	89°14'01"	Stoy	0	Grass
4	Alexander	37°05'28"	89°15'28"	Darwin	0	Forest
5	Alexander	37°07'21"	89°20'18"	Jacob	0	Forest
6	Pulaski	37°07'08"	89°14'54"	Menfro	0	Grass
7	Pulaski	37°07'09"	89°14'57"	Menfro	22	Forest
8	Pulaski	37°17'00"	89°09'03"	Sciotoville	0	Grass
9	Johnson	37°20'01"	89°02'27"	Sciotoville	5	Forest
10	Hardin	37°31'41"	88°06'32"	Alford	0	Forest

3. Results

NRCS soil survey office in Carbondale.—Data from site 2 are the most compelling evidence yet that the soils in southern Illinois are thermic. Once data were off-loaded, a check of the sensors confirmed that they had not lost their calibrations. The reason this site is warmer than was expected cannot be fully explained. Average monthly, seasonal, and annual temperatures are presented in table 7.14.2.

Table 7.14.2.—Average air and soil temperatures (°C) for site 2.

Analysis	10 cm	50 cm	Air
Jan 00	---	13.2	1.4
Feb 00	---	12.7	6.4
Mar 00	---	16.0	10.0
Apr 99 & 00	13.1	13.6	14.1
May 99	16.2	14.7	17.9
Jun 99	20.4	18.5	22.4
Jul 99	23.1	21.4	25.7
Aug 99	21.8	22.4	22.8
Sep 99	18.9	22.2	19.4
Oct 99	14.5	19.7	13.7
Nov 99	12.7	18.8	10.7
Dec 99	9.7	15.3	3.7
Mean	---	17.4	14.0
MST	21.8	20.8	23.6
MWT	---	13.7	3.8
Isotivity	---	7.1	19.8

The 10-cm depth thermistor developed problems on December 19, 1999, and quit logging. The 3.4-degree difference between MAAT and MAST at 50 cm suggests exothermic activity. The soil temperature values at 50 cm cannot be explained by air temperature inputs alone. The low isotivity value at 50 cm (7.1 °C) is the least of any site in the study area. This suggests that something other than air temperature is buffering the mean winter temperatures.

SIU ARS research area in Carbondale.—Data capture for site 3 was 100 percent (table 7.14.3). The sensors held their calibration. Data support a thermic soil temperature regime. The MAST at 50 cm for site 3 is warmer than was expected and is about the same as that for site 2. Again, exothermic activity is suspected.

Table 7.14.3.—Average soil temperatures (°C) for site 3.

Analysis	10 cm	25 cm	50 cm
Jan 00	9.2	6.7	10.4
Feb 00	10.5	7.3	11.1
Mar 00	15.5	11.3	16.5
Apr 99 & 00	15.0	13.5	14.2
May 99	18.5	17.7	16.6
Jun 99	23.7	22.4	20.9
Jul 99	30.1	26.6	24.8
Aug 99	28.5	25.6	24.9
Sep 99	25.3	23.0	23.1
Oct 99	21.1	17.5	18.7
Nov 99	17.4	14.2	16.5
Dec 99	11.7	9.0	12.3
Mean	18.9	16.2	17.5
MST	27.4	24.9	23.5
MWT	10.5	7.7	11.3
Isotivity	17.0	17.2	12.2

The differences in MAST among the 10-, 25-, and 50-cm soil depths are peculiar. Normally, the MAST will not differ by more than 1 °C at multiple depths for any soil during the same period of record (see the results for site 8). Here, at site 3, the difference in MAST is 2.7 °C between the 10-cm and 25-cm depths and 1.4 °C between the 10-cm and 50-cm depths. The isotivity value at 50 cm (12.2 °C) is nearly twice that of site 2 (7.1 °C).

Wes Vaco sweetgum plantation in Alexander County.—Capture of soil temperature data was 100 percent at site 4 (table 7.14.4). In a previous study gathering limited data, this site had a MAST of about 14.8 °C (Workman et al., unpublished data). During the 1999-2000 period, the soil at site 4 had a thermic temperature regime.

Table 7.14.4.—Average air and soil temperatures (°C) for site 4.

Analysis	10 cm	50 cm	Air
Jan 00	5.9	8.4	---
Feb 00	6.8	7.6	---
Mar 00	11.1	11.2	---
Apr 99 & 00	13.9	13.1	14.9
May 99	17.3	16.0	18.7
Jun 99	21.2	20.0	22.6
Jul 99	24.0	22.6	24.7
Aug 99	22.3	22.2	---
Sep 99	19.0	20.1	---
Oct 99	15.1	17.1	---
Nov 99	12.9	15.0	---
Dec 99	7.8	10.7	---
Mean	14.8	15.3	---
MST	22.5	21.6	---
MWT	6.8	8.9	---
Isotivity	15.6	12.7	---

The high isotivity value at 50 cm (12.7 °C) suggests that the water table did not impact the MAST at site 4. The 10-cm soil temperature signature indicates that this soil is usually warmer than 5 °C, thus suggesting that the soil is biologically active more than 11 months out of each year (figure 7.14.2).

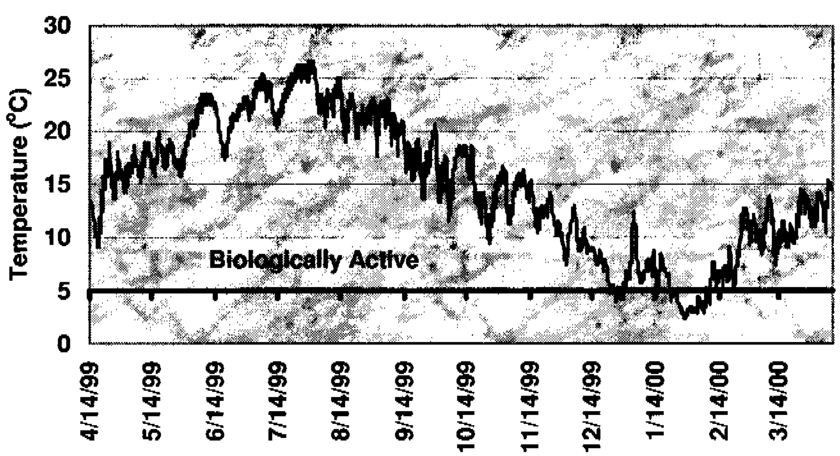


Figure 7.14.2.—Temperature data for the 10-cm soil depth at site 4.

Horseshoe Lake Wildlife Area in Alexander County.—The soil at site 5 was wet when the data loggers were installed. Water eventually got inside the PVC pipe. Because of the position of each data logger inside the PVC pipe, the air temperature logger was the least affected by internal water seepage (figure 7.14.3). Unfortunately, most of the data were lost for the 10- and 50-cm soil depths (table 7.14.5).

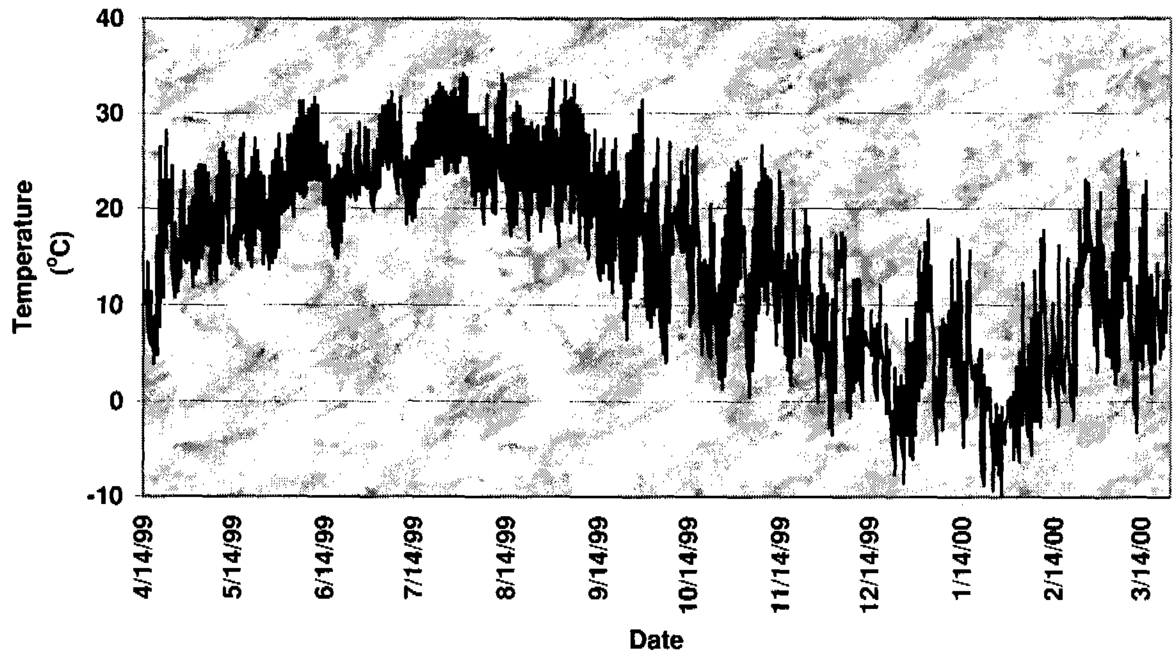


Figure 7.14.3.—Air temperature signature at the Horseshoe Lake Wildlife Area.

Table 7.14.5.—Average air and soil temperatures (°C) for site 5.

Analysis	10 cm	50 cm	Air
Jan 00	---	---	2.9
Feb 00	---	---	7.4
Mar 00	---	---	10.5
Apr 99 & 00	13.2	12.6	15.1
May 99	16.6	15.3	19.6
Jun 99	20.8	19.0	23.6
Jul 99	23.7	21.7	26.5
Aug 99	22.8	---	24.7
Sep 99	---	---	21.0
Oct 99	---	---	15.0
Nov 99	---	---	11.7
Dec 99	---	---	8.2
Mean	---	---	15.5
MST	22.5	---	25.0
MWT	---	---	6.2
Isotivity	---	---	18.8

The MAAT (15.5 °C) implies that the soil at site 5 is thermic. The MST at 10 cm (22.5 °C) for site 5 is identical to the MST at 10-cm for site 4, further implying that this soil is thermic.

Grassland surrounded by woodland in Pulaski County.—The air temperature at site 6 was not efficient in warming the soil. Though annual air temperature data can only be estimated (March is missing), the MAAT is about 58 °F. Air drainage might be the reason for this phenomenon. Data suggest that site 6 is mesic in most years (table 7.14.6).

Table 7.14.6.—Average air and soil temperatures (°C) for site 6.

Analysis	10 cm	50 cm	Air
Mean	14.2	14.3	---
MST	22.3	21.1	25.3
MWT	5.9	7.2	---
Isotivity	16.4	13.9	---

Site 6 is paired with site 7, which has a thermic temperature regime. There will be no easy separation of the mesic and thermic soil temperature regimes in southern Illinois. Temperature data from a sandy soil in Mason County, Illinois (1998-1999), had nearly the same MAST as this site. Consequently, the complexity of soil temperature does not seem to lend itself to precise breaks between mesic and thermic temperature regimes. However, on an operational basis (mapping and classification), there is a wide-open arena in which to apply these data for useful determinations.

Woodland in Pulaski County (paired with site 6).—Data capture at site 7 was 100 percent. In contrast to the soil on a neutral aspect at site 6, the soil on a south aspect at site 7 is thermic (figure 7.14.4 and table 7.14.7). A study in Nebraska (Mount, 1999) also indicates an aspect dependency for soil temperature.

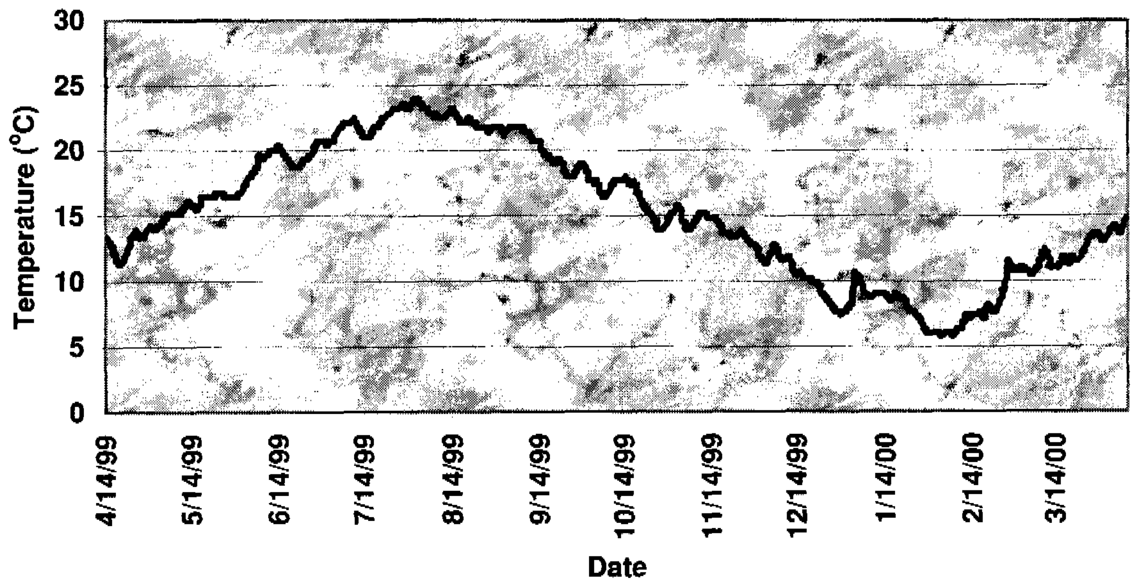


Figure 7.14.4.—The soil temperature signature at 50 cm for site 7.

Table 7.14.7.—Average air and soil temperatures for site 7.

Analysis	10 cm	50 cm	Air
Jan 00	6.8	8.3	2.5
Feb 00	8.0	7.7	7.2
Mar 00	13.1	11.8	11.6
Apr 99 & 00	14.5	13.3	14.9
May 99	17.5	15.8	18.8
Jun 99	21.5	19.4	22.9
Jul 99	24.6	22.2	26.0
Aug 99	23.8	22.4	24.3
Sep 99	20.1	20.0	20.1
Oct 99	15.7	16.4	14.8
Nov 99	13.6	14.1	11.8
Dec 99	8.7	10.2	4.8
Mean	15.7	15.1	15.0
MST	23.3	21.3	24.4
MWT	7.8	8.7	4.8
Isotivity	15.5	12.6	19.6

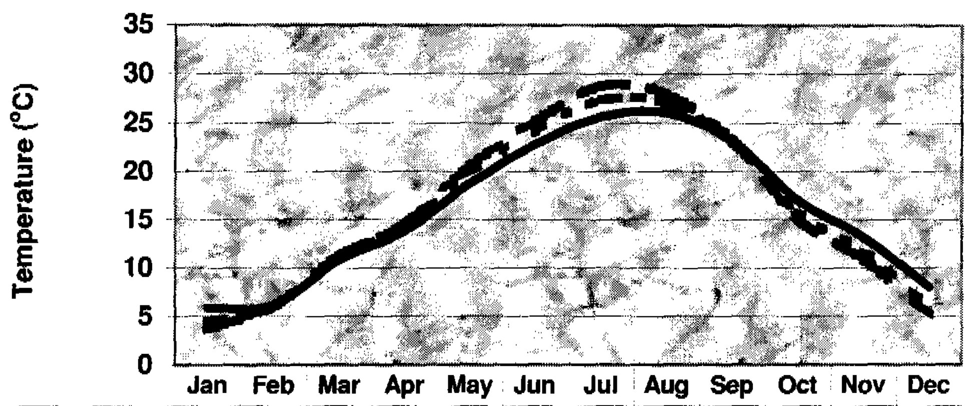
Data suggest that soils with south-facing slopes in Pulaski County are thermic while soils on neutral and north-facing slopes are mesic. Operationally, this finding will provide needed data to assist in updating the soil temperature regimes in southern Illinois.

Bellrose Waterfowl Reserve in Pulaski County.—Data capture was 100 percent at site 8 (table 7.14.8). The soil at this site was conjectured to have the warmest MAST in the study area. It does not. The MAST at 50 cm (15.9 °C) is several degrees cooler than that of the two sites in Jackson County to the north.

Table 7.14.8.—Average soil temperatures (°C) for site 8.

Analysis	10 cm	25 cm	50 cm
Jan 00	3.6	4.4	5.8
Feb 00	6.1	6.0	6.1
Mar 00	11.2	11.2	10.8
Apr 99 & 00	14.5	14.3	13.8
May 99	20.6	19.8	18.7
Jun 99	25.2	24.2	22.8
Jul 99	28.7	27.4	25.6
Aug 99	27.9	27.0	26.0
Sep 99	23.2	23.1	23.1
Oct 99	15.0	15.7	17.0
Nov 99	10.8	11.7	13.2
Dec 99	5.2	6.2	8.0
Mean	16.0	15.9	15.9
MST	27.3	26.2	24.8
MWT	4.9	5.5	6.7
Isotivity	22.4	20.7	18.1

The MAST is nearly identical at all three depths of measurement (16.0 and 15.9 °C). Data at site 8 support conceptual notions of soil temperature behavior (figure 7.14.5). The crossover of soil temperature during September is common in all studies in the Remote Soil Temperature Network (Mount, 1998).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10 cm	3.6	6.1	11.2	14.5	20.6	25.2	28.7	27.9	23.2	15.0	10.8	5.2
25 cm	4.4	6.0	11.2	14.3	19.8	24.2	27.4	27.0	23.1	15.7	11.7	6.2
50 cm	5.8	6.1	10.8	13.8	18.7	22.8	25.6	26.0	23.1	17.0	13.2	8.0

Figure 7.14.5.—Monthly soil temperatures at Bellrose Waterfowl Reserve.

Woodland in Johnson County.—The 10-cm data logger at site 9 started to "drift" during October 1999 and recorded improbably high measurements. Data are presented for the 10-cm depth for those months before questionable data were recorded (table 7.14.9). The MAST at 50 cm indicates that the soil on this site is marginally thermic. The soil has a south aspect, which might explain why the MAST is similar to that of site 7, in Pulaski County.

Table 7.14.9.—Average air and soil temperatures (°C) for site 9.

Analysis	10 cm	50 cm	Air
Jan 00	---	7.5	2.0
Feb 00	---	6.8	6.9
Mar 00	---	11.0	11.0
Apr 99 & 00	13.7	12.6	14.8
May 99	17.2	15.4	18.7
Jun 99	22.3	19.1	22.9
Jul 99	25.1	22.2	26.0
Aug 99	23.9	22.8	24.1
Sep 99	22.1	21.3	21.1
Oct 99	20.6	17.2	14.7
Nov 99	---	14.5	11.5
Dec 99	---	9.8	4.3
Mean	---	15.0	14.8
MST	23.8	21.3	24.3
MWT	---	8.0	4.4
Isotivity	---	13.3	20.0

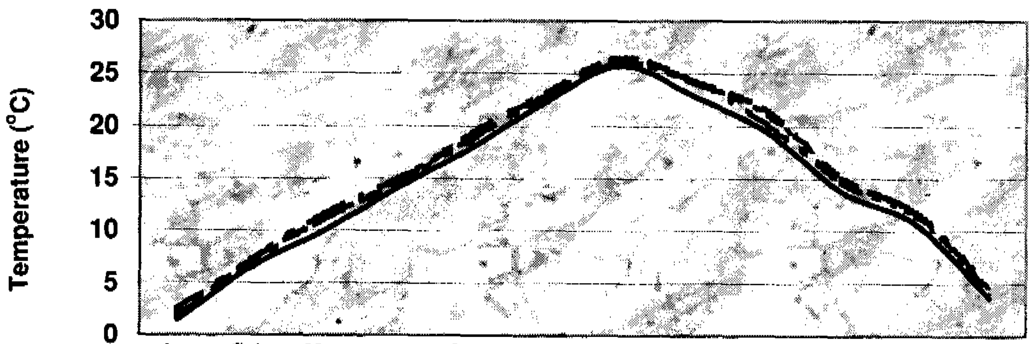
Woodland in Hardin County.—Data capture was 100 at site 10 (table 7.14.10). This site has a neutral aspect. The MAST for the 10-cm depth was 2.4 °C warmer than that for the 50-cm depth (17.0 vs. 14.6 °C). The behavior of the temperature at this site is similar to that of the temperature at site 6. Suppression of the monthly soil temperatures, particularly during the summer, is also similar to what occurred at site 6.

Table 7.14.10.—Average air and soil temperatures (°C) for site 10.

Analysis	10 cm	50 cm	Air
Jan 00	9.8	6.9	1.6
Feb 00	10.8	6.3	7.1
Mar 00	14.5	10.2	11.1
Apr 99 & 00	15.1	12.7	14.6
May 99	18.5	16.4	19.3
Jun 99	21.6	19.3	23.1
Jul 99	24.6	21.9	26.5
Aug 99	23.4	22.1	24.3
Sep 99	21.0	20.1	21.4
Oct 99	17.6	16.3	15.1
Nov 99	15.5	13.6	11.7
Dec 99	11.3	9.1	4.4
Mean	17.0	14.6	15.0
MST	23.2	21.1	24.6
MWT	10.6	7.4	4.4
Isotivity	12.6	13.7	20.2

The MAAT at site 10 was warmer than the MAST at 50 cm but less than the MAST at 10 cm. Perhaps the neutral aspect impacted the soil temperature. Data at this site suggest that soils on neutral and north aspects in southern Illinois are mesic.

Air temperatures.—Air temperatures were very uniform throughout the study area (figure 7.14.6).

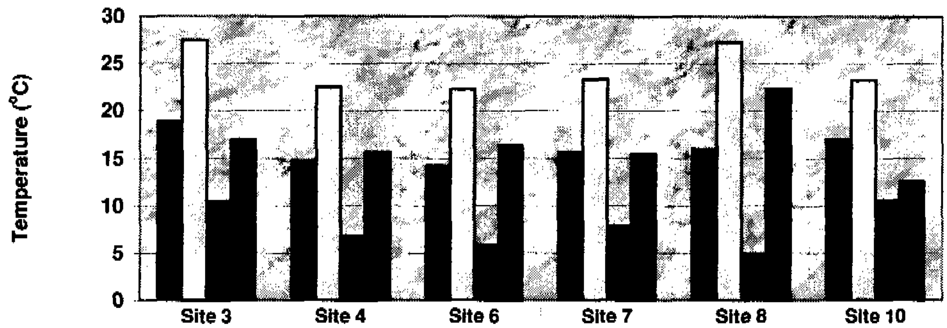


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Site 2	1.4	6.4	10.0	14.1	17.9	22.4	25.7	22.8	19.4	13.7	10.7	3.7
Site 7	2.4	7.2	11.6	14.9	18.8	22.9	25.9	24.3	20.1	14.8	11.8	4.8
Site 9	2.0	6.8	11.0	14.7	18.7	22.9	25.9	24.1	21.1	14.7	11.5	4.3
Site 10	1.6	7.1	11.1	14.6	19.3	23.1	26.5	24.3	21.4	15.1	11.7	4.4

Figure 7.14.6.—Monthly air temperature signatures for sites in Illinois.

MAAT ranged from 14.0 °C at site 2 to 15.0 °C at sites 7 and 10. Correlation of MAAT to MAST is complicated because of the many variables involved, i.e., slope, aspect, and vegetative cover.

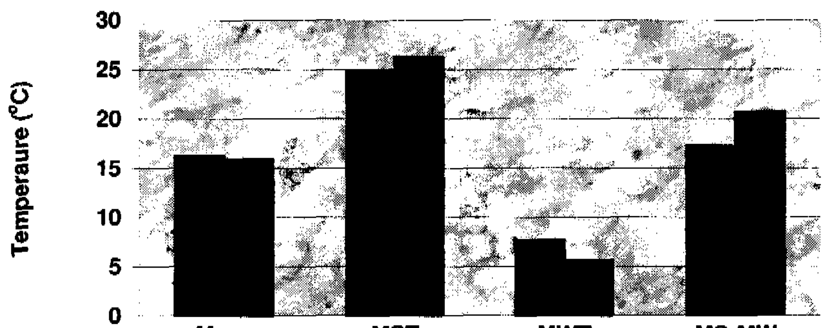
Soil temperature at 10 cm.—There was more unpredictability in seasonal and annual soil temperatures at 10 cm than can be explained by air temperature inputs alone (figure 7.14.7). The air temperature data did not indicate that there would be this variability among the 10-cm depths. Obviously, additional data are needed for more years before this variability can be adequately assessed.



	Site 3	Site 4	Site 6	Site 7	Site 8	Site 10
■Mean	18.9	14.8	14.2	15.7	16.0	17.0
□MST	27.4	22.5	22.3	23.3	27.3	23.2
■MWT	10.5	6.8	5.9	7.8	4.9	10.6
▨MS-MW	17.0	15.6	16.4	15.5	22.4	12.6

Figure 7.14.7.—Soil temperature at 10 cm for the study area.

Soil temperature at 25 cm.— Soil temperature at 25 cm was monitored at sites 3 and 8. Average seasonal and annual soil temperatures for the 25-cm soil depth are given in figure 7.14.8.

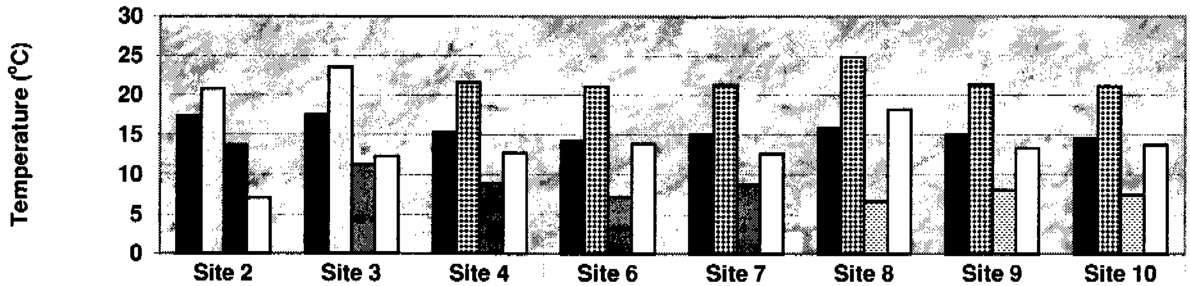


	Mean	MST	MWT	MS-MW
■Site 3	16.2	24.9	7.7	17.2
■Site 8	15.9	26.2	5.5	20.7

Figure 7.14.8.—Seasonal and annual soil temperatures for sites 3 and 8.

The soils at sites 3 and 8 have a thermic soil temperature regime. During the winter months site 8 averaged 2.2 °C colder than site 3. Site 8 also had a greater isotivity value (20.7 vs. 17.2 °C). The reasons for this phenomenon are unclear.

Soil temperature at 50 cm.—Examination of all the 50-cm average soil temperatures indicates that seven of the nine sites are thermic and two sites are mesic (figure 7.14.9). The isotivity value for site 2 (7.1 °C) is about half that of the other sites.



	Site 2	Site 3	Site 4	Site 6	Site 7	Site 8	Site 9	Site 10
■ Mean	17.4	17.5	15.3	14.3	15.1	15.9	15.0	14.6
□ MST	20.8	23.5	21.6	21.1	21.3	24.8	21.3	21.1
▩ MWT	13.7	11.3	8.9	7.2	8.7	6.7	8.0	7.4
□ MS-MW	7.1	12.2	12.7	13.9	12.6	18.1	13.3	13.7

Figure 7.14.9.—Average seasonal and annual soil temperatures for the 50-cm soil depth.

4. Modeling

Various attempts have been made to model soil temperature on the basis of 30-year normal air temperature inputs. One of the most commonly used models is the Newhall Simulation Model (Wambeke et al., 1991). A model at the NSSC was developed to predict soil temperature each month using measured air temperature data. Data were arrayed for over 100 sites from previous temperature studies (figure 7.14.10).

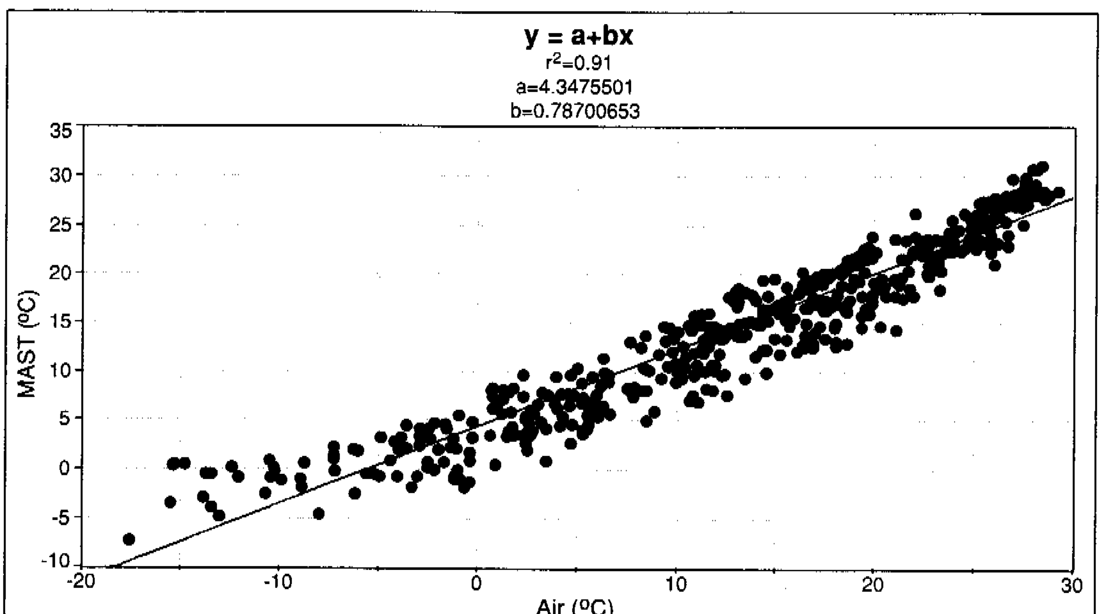


Figure 7.14.10.—Regression (autocorrelation) of air and soil temperatures from 100 sites in the U.S.

The r^2 for this relationship is 0.91. Regression equations were derived for each month by land use. The r^2 values ranged from 0.73 to 0.96. This model worked well at sites in Alexander and Hardin Counties, Illinois, but not very well in Jackson County (table 7.14.11).

Table 7.14.11.—Modeled soil temperature (NSSC model).

Analysis	Alexander Modeled forest soil (°C)	County Measured forest soil (°C)	Hardin Modeled forest soil (°C)	County Measured forest soil (°C)	Jackson Modeled grassland soil (°C)	County Measured grassland soil (°C)
Jan	5.3	8.4	4.7	6.9	3.4	10.4
Feb	5.9	7.6	5.0	6.3	4.3	11.1
Mar	9.9	11.2	9.2	10.2	8.4	16.5
Apr	14.8	13.1	13.0	12.7	13.8	14.2
May	18.5	16.1	16.0	16.4	22.6	16.6
Jun	22.5	19.9	19.9	19.3	23.7	20.9
Jul	24.3	22.6	22.1	21.9	24.7	24.8
Aug	23.7	22.2	22.3	22.1	24.1	24.9
Sep	23.8	20.1	22.4	20.1	22.3	23.2
Oct	18.1	17.1	16.4	16.3	16.3	18.7
Nov	13.1	15.1	12.3	13.6	11.1	16.6
Dec	8.3	10.7	7.4	9.1	6.4	12.3
Mean	15.7	15.3	14.2	14.6	15.1	17.5
MST	26.1	21.6	24.1	21.1	24.2	23.6
MWT	6.5	8.9	5.7	7.4	4.7	11.3
Isotivity	19.6	12.7	18.3	13.7	19.4	12.3

It is hoped that with additional soil temperature studies, the NSSC model will become a satisfactory estimation tool.

5. Discussion

The success rate for the temperature study in Illinois averaged less than in other studies coordinated by the National Soil Survey Center. However, it was similar to previous studies in Illinois using StowAway data logger technology.

Data for the period of record indicate the soil temperature regimes in southern Illinois are dominantly thermic. The soils at two of the sites are mesic. Data from this study should provide the Soil Survey Office in Carbondale and the MLRA Office in Indianapolis the opportunity to determine how they wish to separate the soil temperature regimes of southern Illinois.

Acknowledgments

Ed Workman, Conservationist at the Soil Survey Office in Carbondale provided assistance during the installation phase of this study. Mat McCauley, NRCS Soil Scientist, also provided assistance at several of the sites.

Chapter 7.15

Interpretation of Soil Temperature Data for Aroostook County, Maine

ABSTRACT

Air and soil temperatures were measured at six sites in northern Aroostook County, Maine, in 1999 and 2000. The mean annual air temperature at the sites ranged from 3.1 to 4.7 °C. The correlation of mean annual air temperature to mean annual soil temperature was low because of many variables, i.e., elevation, slope, aspect, snow, and vegetative cover. The active nature of the air temperature sensors implies that the snow cover was less than 1 meter deep during the period of record. Seasonal and annual soil temperatures at 10 cm are similar for the sites in this study. The mean summer temperature ranged from 13.0 °C for a soil at an elevation of 396 m to 14.6 °C for a soil at 320 m, and the mean winter temperature ranged from m -0.4 °C for a soil at 427 m to 3.3 °C for another soil at the same elevation. An isotivity value (difference in mean summer and mean winter temperatures) of 5.4 °C for a soil at 427 m and straddling the Canadian border is supported by the 50-cm soil temperature data. The isotivity values for this soil and for a soil near Perham (5.5 °C) are less than 6 °C, resulting in "iso" temperature regimes. Seasonal and annual averages for the 50-cm depth imply that the soil temperature regimes are frigid at four sites and isofrigid at two sites. None of the soils had a cryic temperature regime. The average of the six sites showed the 50-cm depth to have a mean annual soil temperature of 7.1 °C, a mean summer temperature of 11.4 °C, a mean winter temperature of 3.6 °C, and an isotivity value of 7.8 °C.

1. Background

Northern Maine has some of the coldest average annual air temperatures in the conterminous U.S. An investigation into the soil temperature in Aroostook County commenced during 1999. Funding for this study was provided by the NRCS Global Change Initiative. One purpose of the study was to determine if the soils at sites with a cover of mixed hardwoods and softwoods have cryic soil temperature regimes (Soil Survey Staff, 1999). Another purpose was to evaluate whether snowfall impacts the mean winter soil temperature, as it had been shown to do in a similar study in northern Idaho (Mount, 1999).

2. Study Area

The study area consists of six sites in northern Aroostook County, Maine (table 7.15.1).

Table 7.15.1.—Site information for the six locations in the study area.

Site number and name	Soil series name	Latitude (north)	Longitude (west)	Elevation (m)	Slope (%)	Aspect (°)
1.–Daigle	Daigle	47°03'05"	69°28'10"	320	5	180
2.–Fire Tower	Elliottsville	47°22'00"	69°18'05"	463	20	90
3.–Escourt Station	Elliottsville	47°26'05"	69°12'00"	427	10	0
4.–Hedgehog Mtn.	Tunbridge	46°56'00"	69°32'10"	427	10	60
5.–6-Mile Checkpoint	Elliottsville	46°39'05"	68°41'00"	396	7	240
6.–Perham	Perham	46°53'30"	68°20'00"	274	17	40

The somewhat poorly drained Daigle soils are fine-loamy, isotic, frigid, shallow Aquic Haplorthods. The moderately well drained Elliottsville and Tunbridge soils are coarse-loamy, isotic, frigid Typic Haplorthods. The moderately well drained Perham soils are fine-loamy, isotic, frigid Aquic Haplorthods

(Soil Survey Staff, 1999). Humus layers overlying mineral soil are 2 to 5 inches thick. Solar radiation hits 10 to 40 percent of the forest floor at each site. The vegetation consists of red and sugar maple (*Acer spp. L.*), balsam fir (*Abies spp. L.*), American beech (*Fagus spp. L.*), yellow and white birch (*Betula spp. L.*), and a ground cover of hazelnut, Solomons seal, striped maple (*Acer spp. L.*), and trillium.

3. Results

Daigle site.—Data capture for air and soil temperature was 100 percent at site 1 (table 7.15.2).

Table 7.15.2.—Average air and soil temperatures (°C) for site 1.

Analysis	10 cm	50 cm	Air
Jan 00	0.9	2.7	-13.1
Feb 00	1.1	2.4	-10.3
Mar 00	1.1	2.1	-1.3
Apr 00	1.9	2.1	1.7
May 99 & 00	8.6	6.0	10.0
Jun 99	13.7	10.3	16.8
Jul 99	15.5	12.3	17.8
Aug 99	14.7	12.6	15.8
Sep 99	14.1	12.6	15.0
Oct 99	6.2	8.5	3.0
Nov 99	3.3	5.6	-0.1
Dec 99	1.3	3.7	-7.5
Mean	6.9	6.8	4.0
MST	14.6	11.7	16.8
MWT	1.1	2.9	-10.3
Isotivity	13.5	8.8	27.1

The MAST at both 10 cm (6.9 °C) and 50 cm (6.8 °C) is about 3 °C warmer than the MAAT (4.0 °C). This difference is more than was shown in studies in Washington and Idaho (Mount, 1999). The results support a field conjecture that the soil at this site would have a MAST of about 4.0 °C and have a frigid soil temperature regime. The MST at 50 cm (11.7 °C) is too warm for the soil to be cryic (figure 7.15.1). Unlike cold soils in Idaho and Washington, this soil started to warm at the 50-cm depth in May (6.0 °C) and was too warm during June (10.3 °C), July (12.3 °C), and August (12.6 °C) to be cryic.

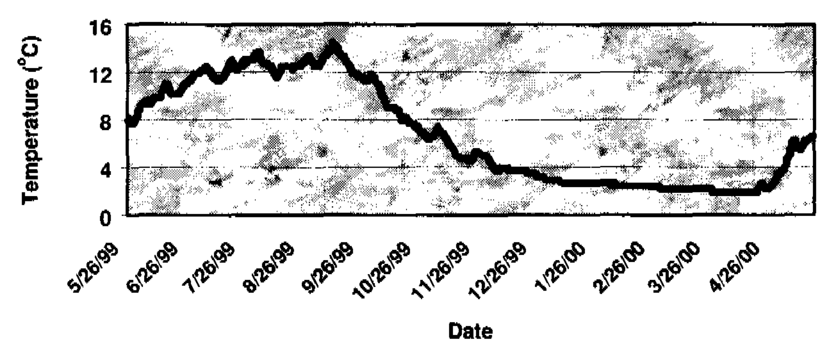


Figure 7.15.1.—Soil temperature signature at 50 cm for site 1.

Fire tower site.—Data capture at site 2 was 100 percent (table 7.15.3). The soil at site 2 was expected to be cryic. At 6.5 °C, the MAST of this soil is the coldest in the study area. Since the MST is 11.7 °C at 50 cm, this soil is frigid (Soil Survey Staff, 1999). At 3.1 °C, the MAAT is the coldest of any site in the study area. The difference between MAST and MAAT is 3.4 °C. This difference is unusual for forest soils in the conterminous United States. A soil temperature study at four sites in Grafton County, New Hampshire, showed a difference of only 1.3 °C between MAST and MAAT from July 1997 to June 1999 (Homer et al., unpublished data). For unknown reasons, the difference between MAST and MAAT in Aroostook County, Maine, is more than twice that of Grafton County, New Hampshire.

Table 7.15.3.—Average air and soil temperatures (°C) for site 2.

Analysis	10 cm	50 cm	Air
Jan 00	1.3	2.5	-13.9
Feb 00	1.2	2.1	-11.0
Mar 00	1.1	1.8	-2.3
Apr 00	1.0	1.6	0.8
May 99 & 00	6.5	4.6	9.1
Jun 99	13.0	10.0	16.0
Jul 99	14.9	12.4	16.9
Aug 99	14.4	12.8	15.0
Sep 99	14.0	12.9	14.1
Oct 99	6.6	8.5	2.0
Nov 99	3.6	5.3	-1.1
Dec 99	1.8	3.5	-8.2
Mean	6.6	6.5	3.1
MST	14.1	11.7	16.0
MWT	1.4	2.7	-11.0
Isotivity	12.7	9.0	27.0

Escourt Station site.—Data capture at site 3 was 100 percent (table 7.15.4).

Table 7.15.4.—Average air and soil temperatures (°C) for site 3.

Analysis	10 cm	50 cm	Air
Jan 00	3.0	5.0	-13.3
Feb 00	3.4	4.6	-10.2
Mar 00	3.9	4.4	-1.6
Apr 00	4.2	3.9	1.2
May 99 & 00	8.7	5.2	9.6
Jun 99	12.2	8.6	17.4
Jul 99	14.5	10.8	18.0
Aug 99	14.6	12.2	15.9
Sep 99	14.1	13.1	15.1
Oct 99	7.4	10.0	3.0
Nov 99	4.8	7.5	-0.1
Dec 99	3.4	5.9	-7.4
Mean	7.8	7.6	4.0
MST	13.7	10.5	17.1
MWT	3.3	5.2	-10.3
Isotivity	10.5	5.4	27.4

This site was suspected to be the coldest in the study area. With a MAST at 50 cm of 7.6 °C, the site is several degrees warmer than was expected. However, its isotivity value at 50 cm is only 5.4 °C. Consequently, the soil at this site is isofrigid. The MAST at 10 cm is slightly warmer than the MAST at 50 cm (7.8 vs. 7.6 °C). The reason the 10-cm depth remains well above freezing during the winter months is unclear (figure 7.15.2). More data are needed before a complete understanding of the unusual temperature signature of this site can be attained.

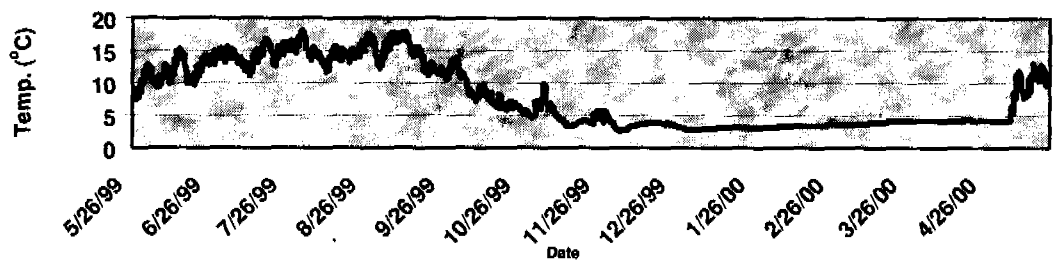


Figure 7.15.2.—Soil temperature signature for the 10-cm depth at site 3.

Hedgehog Mount site.—Data show that the soil at site 4 is frigid (table 7.15.5). At 9.0 °C, the isotivity value is the highest of any soil in the study area. The well drained nature of this soil might explain this temperature phenomenon. The difference between MAST and MAAT (2.7 °C) is nearly identical to that of site 1 (2.8 °C). One unusual event occurred from January through April 2000. The 10-cm depth froze for a total of 134 days. Forest soils with a vegetative cover typically have a humus layer that protects them from freezing at the 10-cm depth. This layer did not prevent freezing at site 4. Previous temperature studies revealed that forest soils with humus layers in Idaho and Washington did not freeze at 10 cm, despite having a colder MAST than the soils in Maine (Mount, 1999).

Table 7.15.5.—Average air and soil temperatures (°C) for site 4.

Analysis	10 cm	50 cm	Air
Jan 00	-0.6	2.6	-12.4
Feb 00	-0.5	2.2	-9.9
Mar 00	-0.2	2.2	-1.8
Apr 00	0.1	1.9	1.2
May 99 & 00	6.3	5.1	9.9
Jun 99	12.8	10.0	17.1
Jul 99	14.5	12.5	17.7
Aug 99	13.8	13.2	16.1
Sep 99	13.3	13.4	15.3
Oct 99	5.4	8.9	3.1
Nov 99	2.5	6.0	0.2
Dec 99	0.1	3.7	-7.3
Mean	5.6	6.8	4.1
MST	13.7	11.9	17.0
MWT	-0.4	2.9	-9.9
Isotivity	14.0	9.0	26.8

6-mile checkpoint site.—Data capture for air temperature and for soil temperature at 50 cm was 100 at site 5 (table 7.15.6).

Table 7.15.6.—Average air and soil temperatures (°C) for site 5.

Analysis	50 cm	Air
Jan 00	2.4	-11.7
Feb 00	2.0	-8.8
Mar 00	1.6	-0.5
Apr 00	1.6	2.5
May 99 & 00	5.2	10.6
Jun 99	9.6	17.0
Jul 99	12.0	17.9
Aug 99	13.1	15.9
Sep 99	13.4	15.4
Oct 99	9.3	3.8
Nov 99	6.1	0.9
Dec 99	3.8	-6.5
Mean	6.7	4.7
MST	11.5	16.9
MWT	2.7	-9.0
Isotivity	8.8	25.9

Since site 5 is 80 km south of the northernmost sites, it was expected to be 1 to 2 °C warmer than sites 2 and 3. Data reveal that the soil at site 5 is frigid, has nearly the same MAST as the soil at site 2, and is colder than the soil at site 3. The difference between MAST and MAAT (2.0 °C) is the least of any site in the study area. The signature for the air temperature is typical for the period of record of this study and suggests that the site was not covered by a blanket of snow (figure 7.15.3).

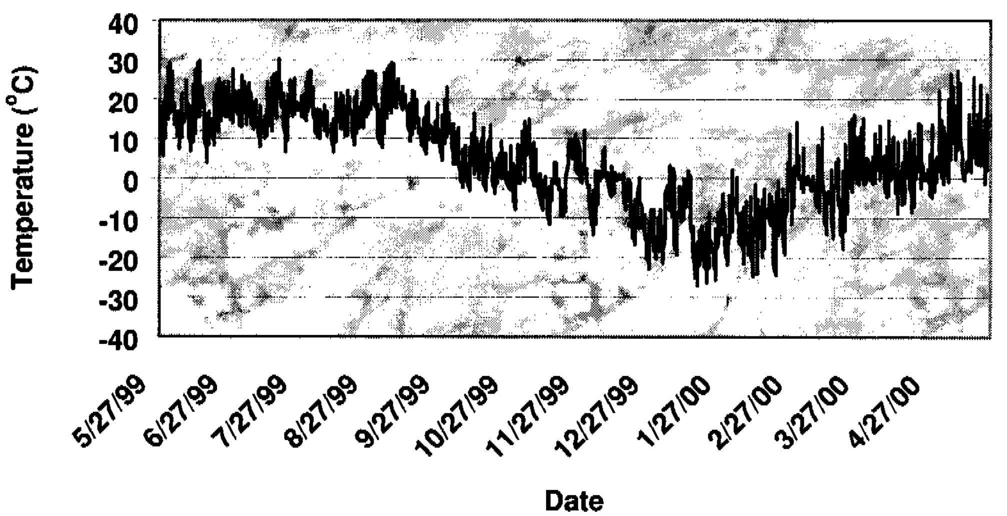


Figure 7.15.3.—The air temperature signature at site 5.

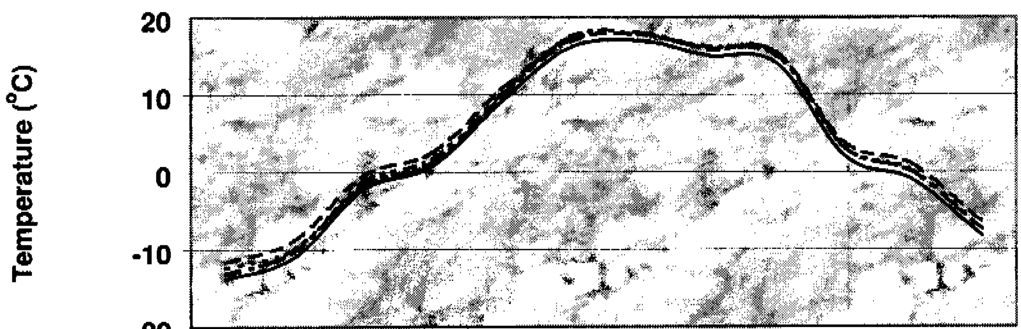
Perham site.—Capture of the soil temperature data was 100 percent at site 6 (table 7.15.7).

Table 7.15.7.—Average soil temperatures (°C) for site 6.

Analysis	10 cm	50 cm
Jan 00	0.0	5.0
Feb 00	0.3	4.5
Mar 00	0.6	4.2
Apr 00	1.2	3.9
May 99 & 00	8.6	4.8
Jun 99	11.2	8.0
Jul 99	13.8	11.6
Aug 99	14.1	13.2
Sep 99	14.0	14.2
Oct 99	8.0	11.7
Nov 99	5.1	9.2
Dec 99	2.2	6.8
Mean	6.6	8.1
MST	13.0	11.0
MWT	0.9	5.4
Isotivity	12.2	5.5

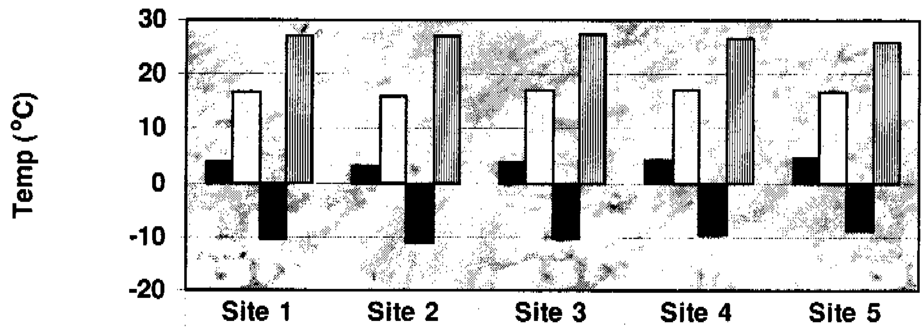
Data show that the soil at site 6 is frigid bordering on mesic. It also is isofrigid (Soil Survey Staff, 1999). The 10-cm MAST is 1.5 °C colder than the 50-cm MAST (6.6 vs. 8.1 °C). More data are needed for a determination of whether this difference occurs from year to year. The 10-cm depth froze for a total of 110 days. These data imply that the forest environments in Maine are not as effective in keeping cold air temperature from freezing soils as those in Idaho and Washington (Mount, 1999).

Air temperature.—Average monthly and seasonal air temperatures were uniform throughout the study area (figures 7.15.4 and 7.15.5).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#1 Air	-13.1	-10.3	-1.3	1.7	10.0	16.8	17.8	15.8	15.0	3.0	-0.1	-7.5
#2 Air	-13.9	-11.0	-2.3	0.8	9.1	16.0	16.9	15.0	14.1	2.0	-1.1	-8.2
#3 Air	-13.3	-10.2	-1.6	1.2	9.6	17.4	18.0	15.9	15.1	3.0	-0.1	-7.4
#4 Air	-12.4	-9.9	-1.8	1.2	9.9	17.1	17.7	16.1	15.3	3.1	0.2	-7.3
#5 Air	-11.7	-8.8	-0.5	2.5	10.6	17.0	17.9	15.9	15.4	3.8	0.9	-6.5

Figure 7.15.4.—Monthly air temperature signatures for sites in Maine.

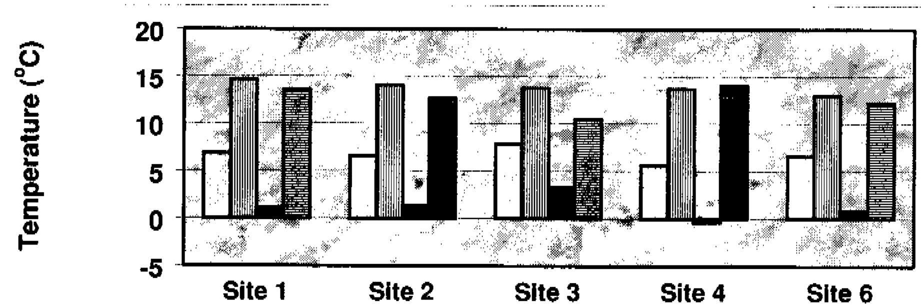


	Site 1	Site 2	Site 3	Site 4	Site 5
Mean	4.0	3.1	4.0	4.1	4.7
MST	16.8	16.0	17.1	17.0	16.9
MWT	-10.3	-11.0	-10.3	-9.9	-9.0
MS-MW	27.1	27.0	27.4	26.8	25.9

Figure 7.15.5.—Seasonal and annual summaries of air temperature in Maine.

The MAAT ranged from 3.1 °C at site 2 to 4.7 °C at site 5. Correlation of MAAT to MAST is complicated because of the many variables involved, i.e., elevation, slope, aspect, snow, and vegetative cover. The active nature of the air temperature sensors implies that the snow cover was less than the height of the air temperature sensors (1 m) during the period of record.

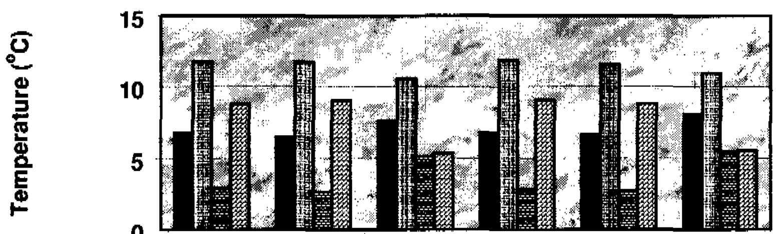
Soil temperature at 10 cm.—Seasonal and annual soil temperatures at 10 cm were fairly uniform throughout the study area (figure 7.15.6). The MST ranged from 13.0 °C at site 6 to 14.6 °C at site 1, and the MWT ranged from -0.4 °C at site 4 to 3.3 °C at site 3. The low isotivity value at site 3 (10.5 °C) is supported by the 50-cm soil temperature data.



	Site 1	Site 2	Site 3	Site 4	Site 6
Mean	6.9	6.6	7.8	5.6	6.6
MST	14.6	14.1	13.7	13.7	13.0
MWT	1.1	1.4	3.3	-0.4	0.9
MS-MW	13.5	12.7	10.5	14.0	12.2

Figure 7.15.6.—Average seasonal and annual soil temperatures at 10 cm for five sites in the study area.

Soil temperature at 50 cm.—The average seasonal and annual temperatures at 50 cm imply that the soil temperature regime in Aroostook County is frigid at four sites and isofrigid at two sites (figure 7.15.7). The isotivity values for site 3 (5.4 °C) and 6 (5.5 °C) are less than 6 °C, resulting in "iso" temperature regimes (Soil Survey Staff, 1999).



	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Mean	6.8	6.5	7.6	6.8	6.7	8.1
MST	11.7	11.7	10.5	11.9	11.5	11.0
MWT	2.9	2.7	5.2	2.9	2.7	5.4
MS-MW	8.8	9.0	5.4	9.0	8.8	5.5

Figure 7.15.7.—Average seasonal and annual soil temperatures for the 50-cm depth.

4. Summary

The percentage of data capture for this temperature study was comparable to that for other temperature studies in the Remote Soil Temperature Network. Capture of air temperature data was especially successful and indicates that snow did not modify the daily values.

Data for the period of record indicate that the soil temperature regimes are either frigid or isofrigid in the study area. None of the soils approached the cryic regime. The average of the six sites shows the 50-cm depth to have a MAST of 7.1 °C, a MST of 11.4 °C, a MWT of 3.6 °C, and an isotivity value of 7.8 °C. In order for the soils to be cryic, they would need to have a MST of less than 8 °C. A drop in MST of 3.4 °C does not seem likely in any year. Hence, it is concluded that the soils are frigid in most years.

In this study sites with O horizons were not compared to adjacent cultivated sites without O horizons. In soils without O horizons, the MST criterion increases from 8 to 15 °C (Soil Survey Staff, 1999). It remains possible that cultivated soils in Aroostook County are cryic. Comparisons of soil temperatures in cropland areas to those in forested areas is needed to complete the assessment of soil temperature regimes in northern Maine.

Scientists in Finland have monitored soil temperature for many years (Yli-Halla and Mokma, 1998). They have found that forested soils in their country are frigid, whereas the adjacent cultivated soils are cryic. Consequently, they have proposed a change in the cryic soil temperature criteria. They would like to raise the MST criterion in *Soil Taxonomy* from 8 to 11 °C. If this proposed change were accepted, the soils in Aroostook County would be in cryic temperature regimes.

Acknowledgment

Larry Flewelling, NRCS Soil Scientist in Maine, assisted in the installation of data loggers for this study.

Chapter 7.16

Soil Temperature Study in Cherry County, Nebraska

ABSTRACT

Soil temperatures from three depths were monitored at two sites in the Sand Hills of Cherry County, Nebraska, in 1997 and 1998. The soil with a south aspect (site 1) had a mean annual soil temperature at 50 cm that was 1. °C warmer than the soil with a neutral aspect (site 2) in a subirrigated meadow. The soils at both sites froze at 10 cm throughout January, and the mean winter temperatures at 50 cm were 2.6 °C for site 1 and 2.5 °C for site 2. The isotivity value (difference between mean summer and mean winter soil temperatures) was expected to be more than 16.7 °C for the study area, and it was at site 1 (19.5 °C). The soil with a neutral aspect had an isotivity value of 16.2 °C, which was 3.3 °C less than the value of the soil with a south aspect. These findings indicate that soil temperature is dependent on the aspect of the slope for soils in the Midwestern United States.

1. Background and Purpose

During mid-October of 1997, two temperature-monitoring sites were selected in Cherry County, Nebraska. This study was initiated in 1997 to provide temperature data that will supplement currently approved Global Change projects in the Caribbean area, Finland, Idaho, Illinois, Iowa, New Hampshire, New York, North Carolina, South Carolina, Tennessee, Virginia, West Virginia, and Wyoming (Mount, 1998).

The primary reasons for the Cherry County temperature study are:

1. To verify the mesic soil temperature regime in this part of the Nebraska Sand Hills.
2. To quantify the contrast between the annual temperature signature of a soil on a stabilized sand dune and the annual temperature signature of a soil in a subirrigated meadow.
3. To identify the dates when the 10-, 25-, and 50-cm soil depths are below biological zero, or 5 °C (Paul and Clark, 1989), during the period of record.
4. To quantify the difference between mean summer and mean winter soil temperatures at 50 cm in the Sand Hills of Nebraska.
5. To add to the growing collection of baseline soil temperature data for the United States.

One hypothesis for this study was that the mean annual soil temperature (MAST) at 50 cm for the stabilized sand dune (site 1) would be warmer than the MAST in the subirrigated meadow (site 2). A second hypothesis was that the isotivity values (difference between mean summer and mean winter soil temperatures) at 50 cm would be more than 16.6 °C at both sites.

2. Study Area

The study area is in Cherry County, which is in north-central Nebraska and is in the heart of the Sand Hills. Two sites were instrumented during October 1997. The two sites are in the Valentine National Wildlife Refuge. Their latitude is 42º25'54" north, and their longitude is 100º32'12" west. No shrubs were available to support the sensor lead for measuring air temperature. Consequently, all three leads were used to monitor the soil temperature.

Site 1 is on the south aspect of a sand dune with a slope of 17 percent and an elevation of 898 meters. The vegetation consists of little and sand bluestems (*Andropogon spp. L.*) and wild sunflowers (*Helianthus spp. L.*). The site is a rolling sand dune complex with native grasses that range in height from 0.2 to 0.8 meter. The soil at this site is an excessively drained Valentine soil, a mixed, mesic Typic Ustipsamment.

Site 2 is level, has a neutral aspect, and has an elevation of 893 meters. The vegetation consists of little and big bluestems (*Andropogon spp. L.*) and switchgrass. The ecosystem is a subirrigated Sand Hills meadow with grasses that range in height from 0.2 to 1.0 meter. The soil at this site is a somewhat poorly drained Els soil, a mixed, mesic Aquic Ustipsamment (Soil Survey Staff, 1999).

3. Results

The monthly, seasonal, and annual temperatures for sites 1 and 2 are given in table 7.16.1. The depths are arranged for comparison between the sites. The air temperature values reflect the 30-year normals at the Valentine Lakes Game Refuge.

Table 7.16.1.—Soil temperatures (°C) at two sites in Cherry County and 30-year air temperature (°C) for Valentine, Nebraska.

Analysis	Site 1 (10 cm)	Site 2 (10 cm)	Site 1 (25 cm)	Site 2 (25 cm)	Site 1 (50 cm)	Site 2 (50 cm)	Valentine air temperature
Jan 98	-0.2	-0.3	0.6	0.6	1.3	1.8	-4.7
Feb 98	3.1	1.4	3.3	1.8	3.5	2.1	-2.1
Mar 98	3.4	2.5	3.5	2.8	3.7	2.9	2.2
Apr 98	11.2	8.7	10.3	8.1	9.8	7.1	9.1
May 98	17.8	15.2	16.7	14.1	15.9	12.3	15.0
Jun 98	20.0	17.7	19.3	17.1	18.7	15.6	20.4
Jul 98	25.8	23.3	24.8	22.4	24.0	20.5	23.8
Aug 98	25.1	21.8	24.1	21.3	23.5	19.9	22.6
Sep 98	22.9	18.8	22.7	18.9	22.4	18.3	17.1
Oct 97&98	10.3	9.5	11.6	10.8	12.5	12.1	10.9
Nov 97	3.9	3.6	5.0	4.9	5.8	6.4	2.7
Dec 97	1.3	0.8	2.3	2.0	3.0	3.4	-3.3
Mean	12.0	10.2	12.0	10.4	12.0	10.2	9.5
MST	23.6	20.9	22.7	20.3	22.1	18.7	22.3
MWT	1.4	0.6	2.1	1.5	2.6	2.5	-3.4
Isotivity	22.3	20.3	20.7	18.8	19.5	16.2	25.6

The soil on the south aspect (site 1) was warmer at each depth than soil on the neutral aspect (site 2). The MAST for the 50-cm depth was 1.8 °C warmer at site 1 than at site 2. The findings in this study imply that soil temperature is dependent on the aspect of the slope in the Midwest. However, data from more sites in other Midwest States are needed to refine the concept of aspect dependency.

The isotivity values in this study are indicative of the soils throughout the Midwest. These values were thought to be more than 16.7 °C for both sites. Site 2 has an isotivity value of 16.2 °C, which is 3.3 °C less than the value at site 1 (19.5 °C).

Acknowledgment

Marja Liisa Räisänen, Geologist for the Geological Survey of Finland at Kuopio, assisted in collecting metadata and in installing the soil temperature loggers in the study area.

Chapter 7.17

The Nature of Soil Temperature for Dry Soils in Nevada and California*

ABSTRACT

Ten sites in Nevada and California were monitored for soil temperature from 1998 to 2000. The soil at an elevation of 2,670 m had a cryic soil temperature regime during both years of the study. At 5.9 °C, the mean annual soil temperature at 50 cm was 1.2 °C warmer in the second year of the study than in the first year. The mean summer temperature at 50 cm was less than 15.0 °C in both years. It was 1.5 °C warmer in the second year than in the first year (14.0 vs. 12.5 °C). The soil at 2,682 m showed an increase in soil temperature during the second year. Data imply that this soil was cryic in the first year and mesic in the second year. Though higher in elevation than the south aspect soil at site 2 (2,758 m vs. 2,682 m), the soil at site 3 is shallow to bedrock, supports a sparse cover of low sagebrush, is more open to solar radiation, and was mesic. At 2,763 m, the soil at site 4 has the highest elevation in the study area and is mesic. The soil at 2,219 m (site 5) was mesic. At 10.6°C, its mean annual soil temperature is too warm for a frigid or cryic temperature regime. The soil at 2,644 m in California is cryic, and its 10-cm depth has the coldest mean summer temperature in the study area (14.4 °C). The soil at 2,621 m in California has a mean annual soil temperature at 50 cm of 11.6 °C and is mesic. With a mean annual soil temperature of 7.6 °C and a mean summer temperature of 17.8 °C, the soil at 2,053 m has a frigid temperature regime. With a mean annual soil temperature of 6.7 °C and a mean summer temperature of 14.1 °C, the soil at 2,200 m in Nevada is cryic. The mean winter temperature for the 50-cm depth is 0.1 °C and is nearly identical to that of the air temperature (0.0 °C). The soil at 2,124 m in Nevada is mesic. At 9.4 °C, its mean annual soil temperature is too warm for the soil to be either frigid or cryic. Shift analysis shows that in the second year soils with a north aspect increase 1.2 °C and soils with a south aspect increase 2.5 °C. At the 10-cm depth, the soil at 2,053 m froze the most days (160), whereas the soil at 2,219 m froze only 1 day. At the deepest depth, the soil at 2,670 m froze the longest (99 days).

1. Background

The quantity of data from high-elevation desert soils has been limited for Nevada and California. Though much monthly data have been accumulated over the years in Nevada (Blake, NRCS Staff, unpublished data), data on the diurnal fluctuation of soils at elevations greater than 2,050 m are limited. Consequently, a study was designed to collect daily temperature data at 10 high-elevation sites in western Nevada and eastern California. All sites have an aridic or aridic-xeric soil moisture regime (Soil Survey Staff, 1999). This Nevada-California soil temperature study was funded in part through the NRCS Global Change Initiative. It is one of many projects that collect air and soil temperature data at remote locations.

2. Objectives

One objective of this study was to verify mean annual soil temperature differences as stratified by the different elevation and aspect dependencies in Nevada and California. A second objective was to evaluate the freeze dates at 10 cm and 50 cm for each of the sites.

* Ed Blake, NRCS Soil Scientist, Minden, Nevada, and Tom McKay, NRCS Data Quality Specialist at the MLRA Office in Reno, Nevada, assisted in preparing this section.

3. Study Area

The study area is in western Nevada and east-central California (figure 7.17.1). It covers parts of Douglas County in Nevada and Mono County in California. The Major Land Resource Area is 26, the Carson Basin and Mountains (SCS, 1981). Nine sites were selected for verification of soil temperature regimes. The differentiating soil and site characteristics are summarized in table 7.17.1.

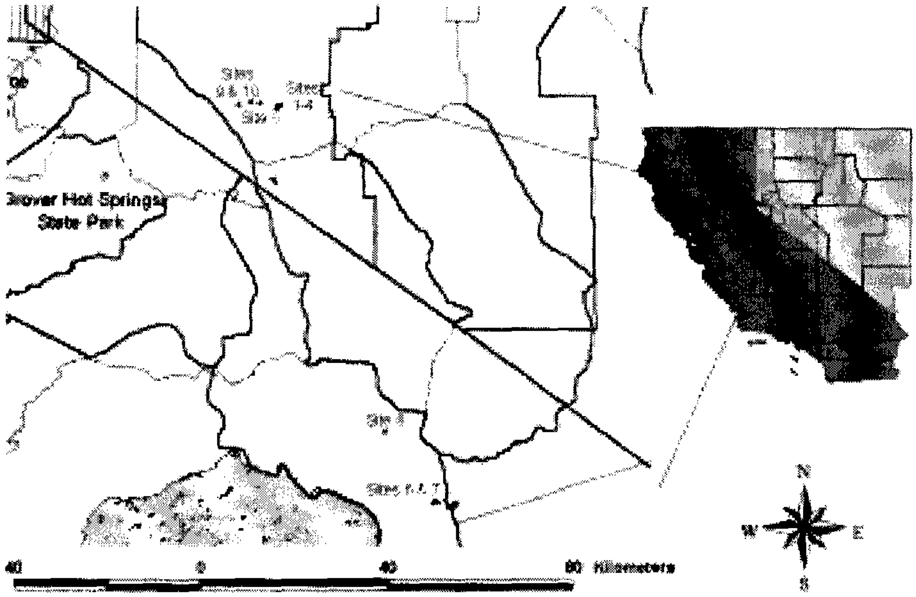


Figure 7.17.1.—Location of sites in the study area.

Table 7.17.1.—Site and soil information for the study area.

Site no.	Latitude (north)	Longitude (west)	County and State names	Land use	Surface rocks (%)	Elevation (m)	Slope (%)	Aspect (°)
1	38°49'58"	119°30'41"	Douglas, NV	Range	37	2,670	25	50
2	38°50'11"	119°30'37"	Douglas, NV	Range	53	2,682	28	220
3	38°50'14"	119°30'20"	Douglas, NV	Range	57	2,758	10	170
4	38°50'18"	119°30'15"	Douglas, NV	Range	60	2,763	12	40
5	38°50'28"	119°32'39"	Douglas, NV	Forest	35	2,219	36	200
6	38°05'02"	119°12'15"	Mono, CA	Forest	17	2,644	14	17
7	38°05'12"	119°11'52"	Mono, CA	Range	75	2,621	8	80
8	38°13'15"	119°17'57"	Mono, CA	Range	32	2,053	20	40
9	38°50'20"	119°35'01"	Douglas, NV	Forest	45	2,200	20	360
10	38°50'38"	119°33'37"	Douglas, NV	Forest	27	2,124	46	360

The soils at sites 1, 2, 3, 4, and 6 have a cryic soil temperature regime, the soils at sites 7 to 10 have a frigid temperature regime, and the soil at site 5 has a mesic temperature regime. The soils are shallow to very deep over bedrock. The soils at sites 1 to 4 and at site 6 are Argicryolls; the soils at sites 5, 7, 9, and 10 are Argixerolls; and the soil at site 8 is a Haploxeroll (Soil Survey Staff, 1999). Sites 1 to 4 have 430 mm of mean annual precipitation; sites 5, 9, and 10 have 355 mm; sites 6 and 7 have 635 mm; and site 8 has 510 mm.

4. Results

Nevada site 1.—Site 1 was cryic during both years of the study. At 5.9 °C, the MAST at 50 cm was 1.2 °C warmer during the second year of the study than during the first year (table 7.17.2). The MST at 50 cm was 1.5 °C warmer during the second year than during the first year (14.0 vs. 12.5 °C). Because the MST at 50 cm is less than 15.0 °C, this soil is cryic.

Table 7.17.2.—Average air and soil temperatures (°C) for Nevada site 1.

Analysis	10 cm	50 cm	Air	Analysis	10 cm	50 cm	Air
Jan 99	-1.2	-0.1	-1.2	Jan 00	-3.5	-1.8	-2.4
Feb 99	-0.7	-0.1	-2.4	Feb 00	-1.2	-0.5	-1.7
Mar 99	-0.5	-0.1	---	Mar 00	-0.4	0.1	-1.3
Apr 99	-0.2	0.0	---	Apr 00	2.2	1.4	4.8
May 99	3.8	1.8	---	May 00	10.9	7.3	8.9
Jun 99	13.9	9.5	---	Jun 00	17.3	12.4	14.7
Jul 99	19.4	14.3	---	Jul 00	19.5	14.4	16.7
Aug 99	16.0	13.6	---	Aug 00	17.9	15.1	16.4
Sep 98&99	9.4	10.5	7.9	Sep 99&00	11.9	11.8	12.3
Oct 98	3.3	5.1	3.1	Oct 99	6.7	8.3	8.9
Nov 98	-0.3	1.4	-0.8	Nov 99	0.7	3.7	4.5
Dec 98	-0.6	0.5	-4.3	Dec 99	-5.1	-0.9	-1.1
Mean	5.2	4.7	---	Mean	6.4	5.9	6.7
MST	16.5	12.5	---	MST	18.3	14.0	15.9
MWT	-0.8	0.1	-2.6	MWT	-3.3	-1.1	-1.7
Isotivity	17.3	12.3	---	Isotivity	21.5	15.0	17.7

Nevada site 2.—Site 2 (south aspect) was paired with site 1 (north aspect). Site 2 showed an increase in soil temperature in the second year (table 7.17.3). The soil at site 2 was cryic in the first year and mesic in the second year. The MST at 50 cm was 1.8 °C warmer in the second year than in the first year (16.2 vs. 14.4 ° C). From the first year to the second, the MAST increased 2.7 °C at 10 cm and 2.5 °C at 50 cm. The soil temperature at 50 cm increased the most during April, May, October, and November.

Table 7.17.3.—Average air and soil temperatures (°C) for Nevada site 2.

Analysis	10 cm	50 cm	Air	Analysis	10 cm	50 cm	Air
Jan 99	0.6	0.8	-0.7	Jan 00	0.5	2.1	-2.8
Feb 99	0.2	0.9	-4.0	Feb 00	0.5	1.9	-2.6
Mar 99	0.8	1.0	-1.5	Mar 00	1.6	1.9	-0.5
Apr 99	1.5	1.8	-1.0	Apr 00	7.9	6.7	4.7
May 99	8.8	6.7	6.7	May 00	11.4	10.0	7.7
Jun 99	14.1	11.5	10.9	Jun 00	16.8	14.4	13.7
Jul 99	19.7	16.1	15.9	Jul 00	19.3	16.4	15.8
Aug 99	17.6	15.5	13.7	Aug 00	19.7	17.8	16.1
Sep 98&99	12.7	13.0	8.8	Sep 99&00	16.9	15.2	12.1
Oct 98	8.5	8.8	4.9	Oct 99	14.0	12.9	10.0
Nov 98	2.1	3.7	-0.6	Nov 99	7.4	8.4	4.1
Dec 98	0.0	1.5	-3.2	Dec 99	2.4	3.7	-0.4
Mean	7.2	6.8	4.2	Mean	9.9	9.3	6.5
MST	17.2	14.4	13.5	MST	18.6	16.2	15.2
MWT	0.3	1.1	-2.6	MWT	1.1	2.6	-1.9
Isotivity	16.9	13.3	16.1	Isotivity	17.4	13.6	17.1

Nevada site 3.—Sites 3 and 4 were paired because they have similar elevations (2,758 and 2,763 m). Site 3 is mesic (table 7.17.4). Though higher in elevation than the south aspect soil at site 2, the soil at site 3 is more open to solar radiation. It is expected that during a normal year site 3 will be cryic. Its diurnal fluctuation at 10 cm averaged as high as 16.6 °C during July of 2000 (figure 7.17.2).

Table 7.17.4.—Average air and soil temperatures (°C) for Nevada site 3.

Analysis	10 cm	30 cm	Air
Jan 00	-1.6	0.0	-4.1
Feb 00	-0.6	0.3	-0.5
Mar 00	2.7	2.0	---
Apr 00	8.0	7.2	---
May 00	11.9	10.6	---
Jun 00	20.9	16.3	---
Jul 00	21.5	18.3	---
Aug 00	19.9	19.1	---
Sep 00	15.6	15.2	---
Oct 99 & 00	12.2	12.5	8.4
Nov 99	5.3	7.0	2.9
Dec 99	0.0	1.7	-2.9
Mean	9.6	9.2	---
MST	20.8	17.9	---
MWT	-0.7	0.7	-2.5
Isotivity	21.5	17.2	---

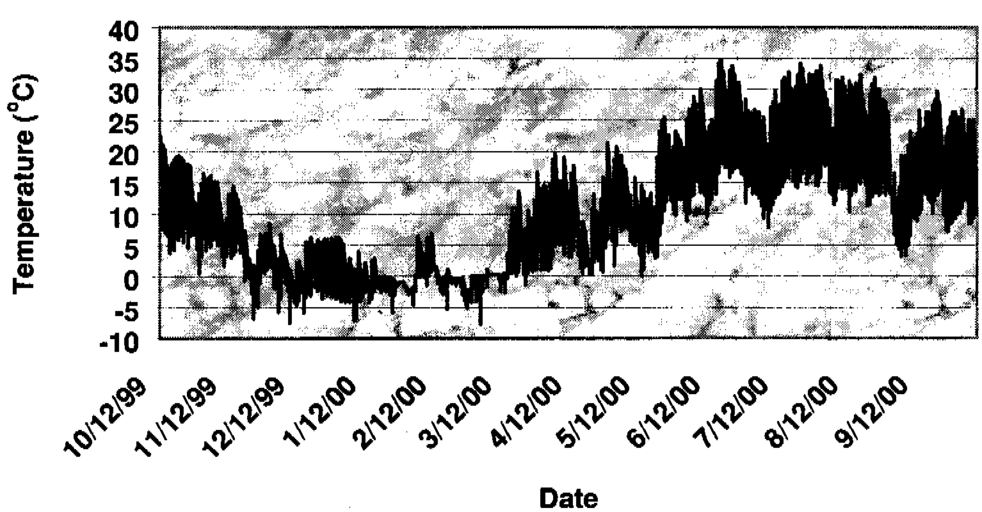


Figure 7.17.2.—The 10-cm soil temperature signature at site 3 showed extreme diurnal fluctuation during July.

Nevada site 4.—Site 4 (north aspect) was paired with site 3 (south aspect). At 2,763 m, the soil at site 4 has the highest elevation in the study area. It is mesic (table 7.17.5). The MAST at 30 cm was 1.0 °C colder than that of site 3 (8.2 vs. 9.2 °C). During a normal year, this site is expected to be cryic.

Table 7.17.5.—Average air and soil temperatures (°C) for Nevada site 4.

Analysis	10 cm	30 cm	Air
Jan 00	-2.4	-0.5	---
Feb 00	-1.4	-0.1	---
Mar 00	1.7	1.8	---
Apr 00	7.5	6.9	---
May 00	11.5	11.9	---
Jun 00	18.7	17.5	---
Jul 00	20.7	19.4	---
Aug 00	19.7	16.2	---
Sep 00	14.5	14.8	---
Oct 99 & 00	10.0	10.4	8.6
Nov 99	3.7	6.0	---
Dec 99	-1.7	0.8	---
Mean	8.5	8.2	---
MST	19.7	17.7	---
MWT	-1.8	0.1	---
Isotivity	21.5	17.6	---

Nevada site 5.—Sensor performance at site 5 was 100 percent (table 7.17.6). At 10.6 °C, the MAST is too warm for either a frigid or a cryic temperature regime. Data for this site support the original hypothesis of a mesic soil temperature regime.

Table 7.17.6.—Average air and soil temperatures (°C) for Nevada site 5.

Analysis	10 cm	40 cm	Air
Jan 00	2.4	4.4	-0.4
Feb 00	2.1	3.5	0.6
Mar 00	3.9	4.5	2.4
Apr 00	7.8	8.0	6.9
May 00	10.7	10.6	10.5
Jun 00	15.8	14.9	16.6
Jul 00	17.6	16.7	18.7
Aug 00	18.6	17.9	18.4
Sep 00	16.1	15.8	14.7
Oct 99 & 00	13.5	13.8	11.2
Nov 99	8.8	10.2	5.6
Dec 99	4.4	6.3	-0.3
Mean	10.1	10.6	8.7
MST	17.3	16.5	17.9
MWT	3.0	4.8	0.0
Isotivity	14.3	11.8	18.0

California site 6.—Sensor performance was 100 percent at this site (table 7.17.7). The relationship among MAST at 10-cm and 50-cm and mean annual air temperature is uniform (6.2 °C, 6.4 °C, and 6.5 °C, respectively). The 10-cm depth has the coolest MST (14.4 °C) in the study area. Had the soil at this site been terminated by bedrock at 10 cm, it would still be cryic because the MST is only 14.4 °C. This soil supports a dense stand of quaking aspen (*Populus tremuloides L.*) and is shaded during the summer months.

Table 7.17.7.—Average air and soil temperatures (°C) for California site 6.

Analysis	10 cm	50 cm	Air
Jan 00	-1.7	0.9	-1.5
Feb 00	0.1	1.6	-2.1
Mar 00	0.4	1.6	-0.3
Apr 00	2.9	2.2	4.6
May 00	10.4	7.2	9.5
Jun 00	12.8	10.1	13.9
Jul 00	15.0	11.6	15.9
Aug 00	15.5	14.3	15.4
Sep 00	12.6	12.3	11.8
Oct 99 & 00	8.1	8.5	8.7
Nov 99	1.8	5.4	3.0
Dec 99	-3.4	1.7	-1.1
Mean	6.2	6.4	6.5
MST	14.4	12.0	15.1
MWT	-1.6	1.4	-1.5
Isotivity	16.1	10.6	16.6

California site 7.—Site 7 is about 2 km from site 6 and is at nearly the same elevation (2,621 vs. 2,644 m). However, it sits on a ridgetop that is sparsely shaded with low sagebrush (*Artemisia spp. L.*) and has more exposure to solar radiation. The soil at site 7 has a high volume of rock fragments on the surface and throughout the profile. Table 7.17.8 gives monthly and annual temperature data for this site.

Table 7.17.8.—Average air and soil temperatures (°C) for California site 7.

Analysis	10 cm	50 cm	Air
Jan 00	0.1	1.9	-1.1
Feb 00	1.6	3.3	4.1
Mar 00	1.3	4.0	---
Apr 00	7.3	8.1	---
May 00	14.5	14.1	---
Jun 00	20.2	18.9	---
Jul 00	23.0	21.6	---
Aug 00	21.2	22.8	---
Sep 00	16.8	20.2	---
Oct 99 & 00	11.1	13.9	8.9
Nov 99	3.8	7.4	4.3
Dec 99	-0.9	2.5	-0.3
Mean	10.0	11.6	---
MST	21.5	21.1	---
MWT	0.3	2.6	---
Isotivity	21.2	18.5	---

Because vermin gnawed off the thermistor lead, air temperature data for site 7 are limited, but the site is presumed to be similar to site 6 (MAAT of 6.5 °C). The MAST at 50 cm for site 7 was 11.6 °C, compared to 6.4° C at nearby site 6. Consequently, the soil at site 7 is mesic. The MAST at 10 cm for site 7 was 10.0 °C, compared to 6.2 °C at site 6. The diurnal fluctuation of the 10-cm depth at site 7 is the greatest of the study area (figure 7.17.3). It was as much as 20 °C during July of 2000. It is expected that the soil at this site may be mesic during normal years.

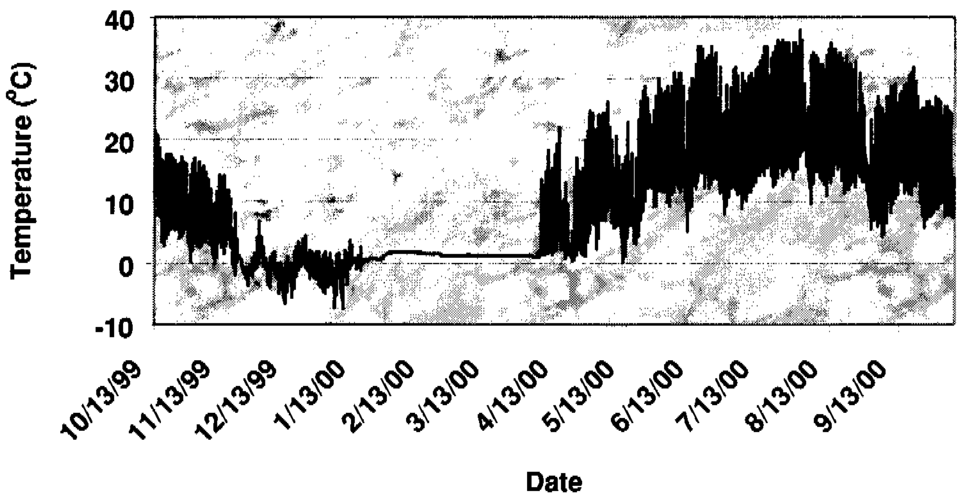


Figure 7.17.3.—Soil temperature signature at 10 cm for site 7 displaying extreme diurnal fluctuation during July.

California site 8.—Table 7.17.9 shows average air and soil temperatures for California site 8. Data capture was 100 percent for soil temperature and 92 percent for air temperature. With a MAST of 7.6 °C and a MST of 17.8 °C, the soil at this site is frigid. Its 10-cm depth had both the coldest and warmest one-time readings of any site in the study area. At -15.41 °C on January 6, 2000, this reading is the coldest ever recorded for any study in the NRCS Global Change Initiative. At 39.70 °C, the highest recording occurred on July 30, 2000. Figure 7.17.4 shows the soil temperature signature of the 10-cm depth.

Table 7.17.9.—Average air and soil temperatures (°C) for California site 8.

Analysis	10 cm	50 cm	Air
Jan 00	-3.4	-1.7	0.3
Feb 00	-0.6	0.4	1.2
Mar 00	0.2	0.8	3.2
Apr 00	7.6	5.5	9.0
May 00	14.6	11.1	13.9
Jun 00	21.3	16.2	18.6
Jul 00	24.0	18.8	21.3
Aug 00	20.8	18.4	20.1
Sep 00	12.3	13.8	---
Oct 99 & 00	4.0	8.0	8.7
Nov 99	-2.2	2.4	4.7
Dec 99	-7.7	-2.3	-1.3
Mean	7.6	7.6	10.0
MST	22.0	17.8	20.0
MWT	-3.9	-1.2	0.1
Isotivity	25.9	19.0	19.9

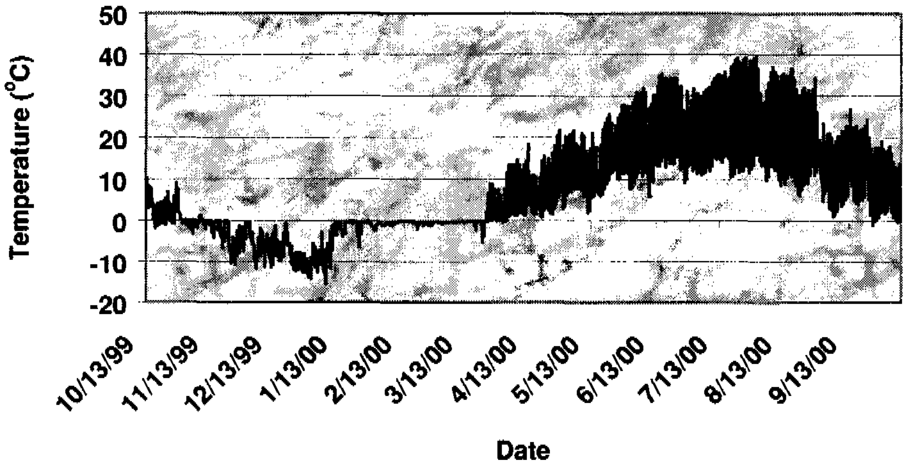


Figure 7.17.4.—Soil temperature signature for 10 cm at site 8 showing extreme highs and lows.

Nevada site 9.—Table 7.17.10 gives temperature results for Nevada site 9. Data capture was 100 percent for the 50-cm soil depth and for air temperature. The data logger for the 10-cm depth was defective. With a MAST of 6.7 °C and a MST of 14.1 °C, the soil at this site is cryic. The MWT at the 50-cm depth is 0.1 °C and is nearly identical to that of the air temperature (0.0 °C). However, the MAST at 50 cm averaged 1.7 °C lower than the MAAT (6.7 vs. 8.4 °C). The imbalance of MAAT to MAST in this study implies difficulty in modeling soil temperature solely on the basis of air temperature.

Table 7.17.10.—Average air and soil temperatures (°C) for Nevada site 9.

Analysis	50 cm	Air
Jan 00	-0.5	-0.2
Feb 00	1.0	0.8
Mar 00	1.1	2.5
Apr 00	4.3	6.8
May 00	8.3	10.2
Jun 00	12.6	16.2
Jul 00	14.6	17.9
Aug 00	15.0	17.6
Sep 00	12.1	13.2
Oct 99 & 00	8.4	10.4
Nov 99	4.0	5.6
Dec 99	-0.1	-0.7
Mean	6.7	8.4
MST	14.1	17.2
MWT	0.1	0.0
Isotivity	13.9	17.3

Nevada site 10.—Data capture was 100 percent for both soil and air temperatures at this site (table 7.17.11). The soil at site 10 is mesic. At 9.4 °C, its MAST is too warm for either frigid or cryic. The MAST at 10 cm was 0.8 °C colder than the MAST at 48 cm (8.6 vs. 9.4 °C). The temperature signature at 48 cm (the depth of bedrock) shows that the soil did not freeze during the period of record (figure 7.17.5.

Table 7.17.11.—Average air and soil temperatures (°C) for Nevada site 10.

Analysis	10 cm	48 cm	Air
Jan 00	0.6	2.4	-0.1
Feb 00	1.2	2.3	1.1
Mar 00	2.6	3.0	2.6
Apr 00	6.4	6.3	7.6
May 00	10.4	10.0	11.7
Jun 00	16.6	15.6	18.3
Jul 00	18.4	17.7	19.9
Aug 00	17.1	17.5	19.0
Sep 00	13.9	15.6	14.1
Oct 99 & 00	10.6	11.9	11.0
Nov 99	5.0	7.1	5.8
Dec 99	0.1	3.1	-0.4
Mean	8.6	9.4	9.2
MST	17.4	16.9	19.0
MWT	0.6	2.6	0.2
Isotivity	16.8	14.3	18.8

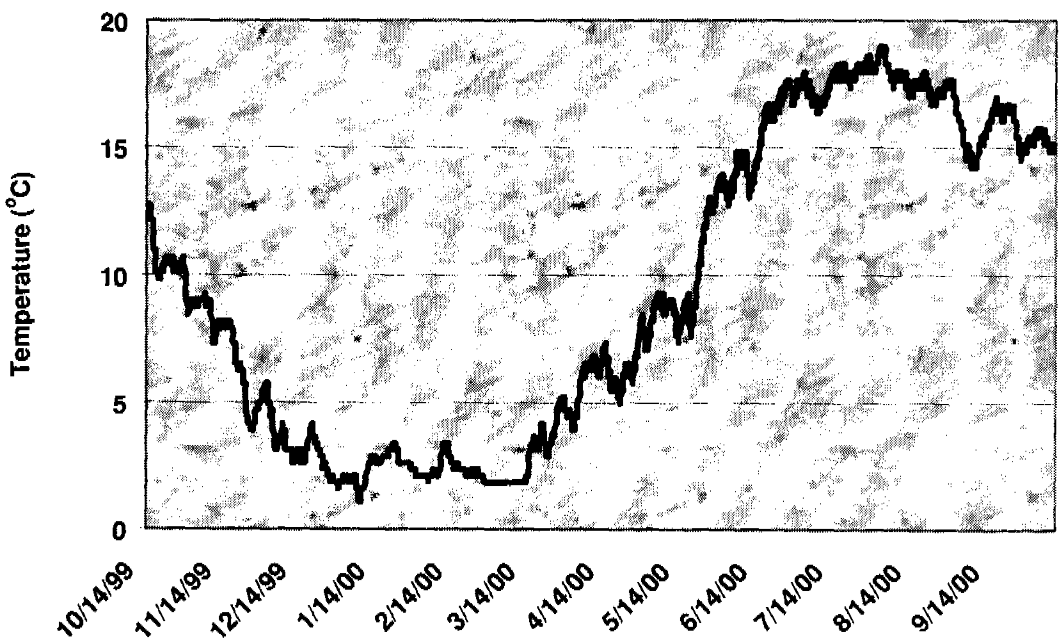


Figure 7.17.5.—Soil temperature signature for the 48-cm depth at site 10.

5. Shift Analysis

Shift analysis helps scientists to explain the effects that increases and decreases in air temperature have on MAST. Nevada sites 1 and 2 had data for 2 years. Computing a running average based on shift analysis can determine trending of the MAST (table 7.17.12). The first date is for the September 1998 through August 1999 period of record and is the first shift, and the last date represents the September 1999 through August 2000 period of record and is the thirteenth shift.

Table 7.17.12.—Soil temperature trends at 50-cm for Nevada sites 1 and 2.

Sift number	Date	Site 1 MAST (°C)	Site 1 MST (°C)	Site 1 soil temp. regime	Site 2 MAST (°C)	Site 2 MST (°C)	Site 2 soil temp. regime
1	Aug 99	4.7	13.2	Cryic	6.8	14.4	Cryic
2	Sep 99	4.8	13.2	Cryic	7.0	14.4	Cryic
3	Oct 99	5.1	13.2	Cryic	7.3	14.4	Cryic
4	Nov 99	5.3	13.2	Cryic	7.7	14.4	Cryic
5	Dec 99	5.1	13.2	Cryic	7.9	14.4	Cryic
6	Jan 00	5.0	13.2	Cryic	8.0	14.4	Cryic
7	Feb 99	5.0	13.2	Cryic	8.1	14.4	Mesic
8	Mar 99	5.0	13.2	Cryic	8.1	14.4	Mesic
9	Apr 99	5.1	13.2	Cryic	8.5	14.4	Mesic
10	May 99	5.6	13.2	Cryic	8.8	14.4	Mesic
11	Jun 99	5.8	13.4	Cryic	9.1	15.4	Mesic
12	Jul 99	5.8	13.5	Cryic	9.1	15.5	Mesic
13	Aug 00	5.9	14.0	Cryic	9.3	16.2	Mesic

The MAST at site 1, on a north aspect, increased from 4.7 °C during the first shift to a maximum of 5.9 °C during the thirteenth and final shift. The MST increased from 13.2 to 14.0 °C, or an increase of 0.8 °C for the period of record. The soil continued to be cryic throughout the thirteen 12-month shifts. The second year is acknowledged to be the warmest in local history, while the first year is average.

The MAST at site 2, on a south aspect, increased from 6.8 °C during the first shift to a maximum of 9.3 °C during the thirteenth shift. The MST increased from 14.4 °C to 16.2 °C, or an increase of 1.8 °C for the period of record. The soil at site 2 was cryic for the first six shifts and mesic for the final seven shifts. It is conjectured that, during average years, the soil will shift downward into a cryic soil temperature regime.

6. Frost Analysis

One common question that various customers ask soil scientists concerns frost dates and depths during the course of a winter season. Prior to this study, the answer to this question was a professional estimate. Table 7.17.13 shows, for sites 1 and 2, frost dates, the number of days when the soil is frozen, and minimum temperature readings for 1998 and 1999.

Table 7.17.13.—Frost dates for Nevada sites 1 and 2 in 1998 and 1999.

Site no.	Freeze dates (10 cm)	Days frozen	Minimum temp. (°C)	Freeze dates (50 cm)	Days frozen	Minimum temp. (°C)
1	11/06/98 to 05/19/99	194	-2.12	01/06/99 to 04/19/99	103	-0.35
2	12/05/98 to 04/09/99	105	-1.33	No frost	0	0.64

Sites 1 and 2 were paired, in part so that differences in frost frequencies could be discerned. The north-facing soil at site 1 was continuously frozen at both the 10- and 50-cm depths. The 50-cm depth was frozen 53 percent fewer days than the 10-cm depth (103 vs. 194 days). The maximum depth of freezing temperatures is not known. The south-facing soil at site 2 froze intermittently at 10 cm for 105 days between December 5, 1998, and April 9, 1999. This soil did not freeze at the 50-cm depth during the first year of this study. It was warmer than the soil at site 1. Therefore, its duration and depth of frost were considerably less than those of the north-facing soil at site 1.

Frost dates, the number of days when the soil is frozen, and minimum temperature readings for the 10-cm and deepest depths are shown in table 7.17.14. These analyses are for 1999 and 2000.

Table 7.17.14.—Frost dates for 1999 and 2000.

Site no.	Freeze dates (10 cm)	Days frozen	Minimum temp. (°C)	Freeze dates (deepest depth)	Days frozen	Minimum temp. (°C)
1	11/22/99 to 03/22/00	120	-8.57	01/06/99 to 04/19/99	99	-2.91
2	11/22/99 to 01/15/00	13	-3.93	No frost	0	1.36
3	11/18/99 to 03/13/00	70	-7.61	12/14/99 to 03/01/00	31	-2.65
4	10/29/99 to 03/22/00	92	-7.78	12/08/99 to 03/12/00	65	-2.14
5	12/08/99 to 01/06/00	1	-0.69	No frost	0	2.39
6	11/22/99 to 02/05/00	74	-7.31	No frost	0	0.10
7	11/18/99 to 01/14/00	40	-7.37	No frost	0	0.62
8	10/17/99 to 04/01/00	160	-15.41	11/24/99 to 01/24/00	59	-5.43
9	No data	---	---	12/15/99 to 01/18/00	34	-2.25
10	11/22/00 to 01/09/00	45	-3.88	No frost	0	1.09

At the 10-cm depth, site 8 froze the most days (160) and site 5 froze only 1 day. Data for site 9 were not available. Since the 50-cm depth froze for 34 days, however, it can be inferred that the 10-cm depth froze for a longer period. At the deepest depth, site 1 froze for 99 days and sites 2, 5, 6, 7, and 10 did not freeze. None of the sites were continuously frozen from the first to the last frost event. Minimum temperatures at both 10 and 50 cm for site 1 were greater during the second year than during the first year, although the number of days when the soil was frozen was less. While site 8 froze the most days at 10 cm, it froze fewer days than site 1 did at 50 cm.

The minimum soil temperature during the period of record is important. Site 8 had the lowest minimum temperature at both 10 cm and the deepest depth (50 cm). The 10-cm depth had a low of -15.41 °C, and the 50-cm depth had a low of -5.43 °C. Because of these extremes, special engineering features are needed if roads or single-dwelling homes are constructed in this area.

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Chapter 7.18

Findings From a 2-Year Soil Temperature Study in Cattaraugus County, New York

ABSTRACT

The soils at 11 forested sites in Cattaraugus County, New York, had a mesic or frigid temperature regime during this 2-year study, from 1997 to 1999. The soil temperature increased, on average, by 0.4 °C during the second year of the study. This increase is typical of studies in the Northeast from 1997 to 1999. The soil temperature increased equally on north and south aspects. Soil temperature shifted either up or down with each 12-month segment of capture. The soil at Bay site 4 started out frigid (<8 °C) during its first shift, migrated into mesic during the third shift, and continued to have a mesic soil temperature regime during the remainder of the period of record. Data from this study suggest that a soil temperature regime will shift with warming continental weather patterns—even during a short-term study.

1. Background

The findings in this study are an important addition to current soil temperature research. Data loggers were installed in late July of 1997 and collected data for 2 years. Funding for this study was provided by the NRCS Global Change Initiative. The purpose of the study was to verify the soil temperature regimes and establish an approximate elevation for soils with frigid temperature regimes.

2. Study Area

Cattaraugus County is in the western part of New York. The sites are in the southern part of the county, about 8 km south of the Ohio River. Table 7.18.1 gives metadata for each of the sites in the study area.

Table 7.18.1.—Soil and site information for the study area.

Site ID	Latitude (north)	Longitude (west)	Elevation (m)	Slope (%)	Aspect (°)	Soil series name	Drainage class
Lime 1	42°01'49"	78°41'45"	640	36	180	Kinzua	Well
Lime 2	42°01'40"	78°41'42"	579	23	180	Onoville	Moderately well
Lime 3	42°01'35"	78°41'34"	518	7	180	Portville	Somewhat poor
Lime 4	42°01'25"	78°41'28"	579	22	0	Onoville	Moderately well
Lime 5	42°01'06"	78°41'25"	640	40	0	Mandy	Well
Bay 1	42°05'04"	78°48'08"	579	25	180	Carrollton	Well
Bay 2	42°03'57"	78°48'14"	518	25	180	Buchanan	Moderately well
Bay 3	42°03'45"	78°48'25"	549	17	45	Onoville	Moderately well
Bay 4	42°03'30"	78°48'39"	610	43	45	Carrollton	Well
Olean 1	42°01'08"	78°25'04"	549	34	180	Carrollton	Well
Olean 2	42°01'03"	78°25'04"	518	24	180	Gilpin	Well

The four Limestone sites are in the Limestone Run area of Carrollton, New York. The vegetation is American beech (*Fagus spp. L.*), sugar maple (*Acer saccharum L.*), northern red oak (*Quercus spp. L.*), and white ash (*Fraxinus spp. L.*) and an understory of numerous hardwood species. The well drained

Kinzua soil at Limestone site 1 formed in residuum and is a fine-loamy, mixed, active, frigid Typic Hapludult (Soil Survey Staff, 1999). The moderately well drained Onoville soils at Limestone sites 2 and 4 formed in colluvium and are fine-loamy, mixed, subactive, frigid Aquic Fragiudults. The somewhat poorly drained Portville soil at Limestone site 3 formed in colluvium and is a fine-loamy, mixed, active, mesic Aeric Fragiaqualf. The well drained Mandy soil at Limestone site 5 formed in residuum and is a loamy-skeletal, mixed, active, frigid Typic Dystrudept.

The four Bay sites are in the Allegheny State Park of Carrollton, New York. The vegetation is American beech, sugar maple, northern red oak, and yellow birch (*Betula spp. L.*) and an understory of numerous hardwood species. The well drained Carrollton soil formed in residuum and is a fine-loamy, mixed, active, frigid Typic Hapludult. The moderately well drained Buchanan soil formed in colluvium and is a fine-loamy, mixed, semiactive, mesic Aquic Fragiudult.

The two Olean sites are near the town of Olean in Cattaraugus County. The vegetation is American beech, sugar maple, northern red oak, and yellow birch and an understory of numerous hardwood species. The well drained Gilpin soil at Olean site 2 formed in residuum and is a fine-loamy, mixed, semiactive, mesic Typic Hapludult.

3. Temperature Results

In the tables in this study, dashes for an individual month indicate that the sensor was inoperative because of vermin damage or battery failure.

Limestone site 1.—The soil at Limestone site 1 is mesic (table 7.18.2). The MAST at 10 cm increased 0.6 °C during the second year, while the MAST at 50 cm rose 0.5 °C. This trend continues with each site in this study. The period of record (1998 and 1999) was very warm, particularly from July to December in 1998. The air temperature was warmer in 1998 than in 1997.

Table 7.18.2.—Soil and air temperatures (°C) for Limestone site 1.

Analysis	'97-'98 10-cm	'98-'99 10-cm	'97-'98 50-cm	'98-'99 50-cm	'97-'98 Air	'98-'99 Air
Jan	2.5	1.7	3.4	2.9	0.4	-5.2
Feb	1.7	1.3	2.4	2.3	-0.9	-1.5
Mar	3.4	1.7	3.6	2.1	---	-0.5
Apr	7.8	7.4	7.5	6.7	---	7.9
May	12.8	12.4	11.4	10.9	---	14.7
Jun	13.9	14.9	12.8	13.4	---	17.5
Jul	16.3	17.7	15.3	16.1	16.3	20.4
Aug	15.1	17.1	14.6	16.3	16.1	18.0
Sep	13.3	15.3	13.4	15.0	13.1	15.9
Oct	10.1	11.0	10.9	11.7	8.6	9.2
Nov	4.9	6.4	6.3	7.6	2.5	4.0
Dec	2.4	4.9	3.7	6.0	0.5	0.7
Mean	8.7	9.3	8.8	9.3	---	8.4
MST	15.1	16.6	14.2	15.3	---	18.6
MWT	2.2	2.6	3.2	3.7	0.0	-2.0
Isotivity	12.9	14.0	11.1	11.5	---	20.7

Limestone site 2.—The loggers at this site were hampered by vermin activity and battery problems. Consequently, data were lost for soil temperature at each of the depths during June and July of 1999. Captured data indicate a significant increase in soil temperature during the month of December between 1997 and 1998 (table 7.18.3). The 10-cm depth increased from 3.1 to 5.8 °C, and the 50-cm depth increased from 3.9 to 6.6 °C. The December increase in soil temperature of 2.7 °C at 50 cm is attributed to the La Niña winter in New York in 1998-1999. The MAST at both 10 cm and 50 cm is about 0.4 °C warmer than the MAAT. This difference is thought to be typical of wooded ecosystems in the county.

Table 7.18.3.—Soil and air temperatures (°C) for Limestone site 2.

Analysis	'97-'98 10-cm	'98-'99 10-cm	'97-'98 50-cm	'98-'99 50-cm	'97-'98 Air	'98-'99 Air
Jan	3.0	2.5	3.5	3.4	-0.5	---
Feb	1.8	1.5	2.3	2.3	0.7	---
Mar	3.1	1.3	3.1	1.9	2.8	---
Apr	7.1	5.9	6.7	5.7	8.1	---
May	11.3	---	10.3	9.7	15.4	---
Jun	13.0	---	12.2	---	15.5	---
Jul	15.4	---	14.6	---	17.9	---
Aug	14.8	16.4	14.2	15.7	16.0	18.3
Sep	13.4	15.1	13.3	14.9	13.1	15.7
Oct	10.8	11.5	11.2	12.1	8.4	---
Nov	5.9	7.3	6.8	8.2	1.4	---
Dec	3.1	5.8	3.9	6.6	-1.5	---
Mean	8.6	---	8.5	---	8.1	---
MST	14.4	---	13.7	---	16.5	---
MWT	2.6	3.3	3.2	4.1	-0.4	---
Isotivity	11.8	---	10.4	---	16.9	---

Limestone site 3.—Data from this site suggest that the soil was mesic during both years of this study (table 7.18.4). At 1.3 °C, the increase in MAST at 10 cm during the 1998-1999 period is the highest of any site in the study area. The lone month of air temperature comparison shows that August of 1998 was warmer than August of 1997 (17.6 vs. 15.5 °C). This trend is indicative of all sites in the county.

Table 7.18.4.—Soil and air temperatures (°C) for Limestone site 3.

Analysis	'97-'98 10-cm	'98-'99 10-cm	'97-'98 50-cm	'98-'99 50-cm	'97-'98 Air	'98-'99 Air
Jan	2.7	3.5	3.7	4.0	-0.7	---
Feb	1.6	2.6	2.7	2.8	-0.2	---
Mar	3.0	2.4	3.2	2.4	2.1	---
Apr	7.1	7.1	6.6	5.7	7.5	---
May	11.1	11.3	9.7	9.1	14.3	---
Jun	12.9	13.6	11.3	---	---	---
Jul	15.3	16.6	13.5	---	14.6	---
Aug	14.5	16.8	13.3	14.7	15.5	17.6
Sep	13.2	15.6	12.8	14.1	12.6	---
Oct	10.5	12.2	11.0	12.0	7.7	---
Nov	5.8	8.1	7.2	8.6	1.1	---
Dec	3.2	6.6	4.5	7.0	-2.0	---
Mean	8.4	9.7	8.3	---	---	---
MST	14.2	15.7	12.7	NM	---	---
MWT	2.5	4.2	3.6	4.6	-1.0	---
Isotivity	-6.0	11.5	-8.7	---	---	---

Limestone site 4.—The soil at this site was frigid (8.0 °C) during the 1997-1998 period and mesic (8.4 °C) during the 1998-1999 period (table 7.18.5). The December 1998 increase over December 1997 is the greatest single-month difference. Curiously, the MAAT increased only 0.3 °C during the second year. It is surmised that the increase in air temperature during the summer and fall of 1998 versus 1997 more than offset the decrease in air temperature from January to March in 1999 over that of 1998. The soil temperatures at 50 cm from January to March in 1999 were colder than those during the same period in 1998. However, this difference was not enough to offset the warm summer, fall, and early winter of 1998.

Table 7.18.5.—Soil and air temperatures (°C) for Limestone site 4.

Analysis	'97-'98 10-cm	'98-'99 10-cm	'97-'98 50-cm	'98-'99 50-cm	'97-'98 Air	'98-'99 Air
Jan	2.0	---	2.5	2.1	-0.7	-5.2
Feb	0.6	---	1.2	1.2	0.0	-1.9
Mar	2.2	---	2.0	0.6	2.3	-1.0
Apr	6.3	---	5.8	4.7	7.5	7.4
May	11.4	---	10.0	9.2	14.9	13.7
Jun	13.5	---	12.3	12.3	15.7	17.0
Jul	16.1	---	15.0	15.4	18.0	20.2
Aug	15.0	---	14.3	16.1	15.9	18.1
Sep	13.4	---	13.2	15.0	13.0	15.5
Oct	10.2	---	10.7	11.6	8.0	9.0
Nov	5.0	---	5.8	7.1	1.3	3.7
Dec	2.2	---	2.8	5.4	-1.8	0.5
Mean	8.1	---	8.0	8.4	7.8	8.1
MST	14.9	---	13.9	14.6	16.5	18.4
MWT	1.6	---	2.2	2.9	-0.8	-2.2
Isotivity	13.3	---	11.7	11.7	17.4	20.6

Limestone site 5.—This site had a low percentage of success in data acquisition. The 50-cm soil temperature sensor may have been pulled out of the ground. Consequently, these data are presented only to show that this site, at an altitude of 640 m, was marginally frigid during the second year of this study (table 7.18.6).

Table 7.18.6.—Soil and air temperatures (°C) for Limestone site 5.

Analysis	'98-'99 10-cm	'98-'99 50-cm	'98-'99 Air
Jan	---	0.4	---
Feb	---	-0.1	---
Mar	---	0.0	---
Apr	---	5.2	---
May	---	11.2	---
Jun	---	14.6	---
Jul	---	16.5	---
Aug	16.9	16.0	18.3
Sep	15.3	15.0	15.9
Oct	---	9.7	---
Nov	---	4.6	---
Dec	---	2.9	---
MAST	---	8.0	---
MST	---	15.6	---
MWT	---	1.1	---
Isotivity	---	14.5	---

Bay site 1.—The 10- and 50-cm depths at Bay site 1 indicate that the soil is mesic (table 7.18.7). The decrease in MWT at 50 cm from the first to the second year is difficult to explain. The February and March 1998 averages of 8.6 °C and 6.0 °C are likely driven by phenomena other than air temperature.

Table 7.18.7.—Soil and air temperatures (°C) for Bay site 1.

Analysis	'97-'98 10-cm	'98-'99 10-cm	'97-'98 50-cm	'98-'99 50-cm	'97-'98 Air	'98-'99 Air
Jan	---	2.0	4.8	2.7	---	-3.9
Feb	---	1.0	8.6	1.1	---	-1.4
Mar	---	1.0	6.0	1.0	---	-0.5
Apr	---	6.1	6.7	4.6	---	8.2
May	---	10.7	10.5	---	---	15.0
Jun	---	13.8	12.3	---	---	18.0
Jul	---	16.6	14.9	---	18.2	20.9
Aug	---	16.9	14.8	15.8	17.4	18.5
Sep	---	15.6	13.8	14.9	---	16.1
Oct	---	11.9	11.4	12.0	---	9.6
Nov	---	7.8	6.9	8.3	---	4.4
Dec	---	6.2	3.7	6.6	---	1.7
Mean	---	9.1	9.5	9.6	---	8.9
MST	---	15.7	14.0	15.8	---	19.1
MWT	---	3.0	5.7	3.5	---	-1.2
Isotivity	---	12.7	8.3	12.3	---	20.3

Bay site 2.—Data capture at this site was 100 percent for the 50-cm soil temperatures and for the air temperatures (table 7.18.8). The increase in MAST at 50 cm during the second year was 0.6 °C (8.6 vs. 9.2 °C). The soil at this site was mesic during both years. The MAAT averages (8.5 and 9.0 °C) for this site, which has an elevation of 518 m and a south aspect, are too warm for the soil to be frigid.

Table 7.18.8.—Soil and air temperatures (°C) for Bay site 2.

Analysis	'97-'98 50-cm	'98-'99 50-cm	'97-'98 Air	'98-'99 Air
Jan	3.2	3.1	-0.3	-2.4
Feb	2.1	2.2	0.7	-0.2
Mar	2.9	1.8	2.7	-0.1
Apr	6.8	5.9	7.6	7.8
May	10.8	10.3	15.4	14.4
Jun	12.6	12.9	16.0	17.5
Jul	15.2	15.5	18.0	20.5
Aug	14.7	16.3	16.2	18.0
Sep	13.7	15.3	13.4	15.7
Oct	11.2	12.2	8.7	9.4
Nov	6.6	8.3	4.8	4.7
Dec	3.8	6.5	-1.3	2.1
Mean	8.6	9.2	8.5	9.0
MST	14.2	14.9	16.7	18.7
MWT	3.1	3.9	-0.3	-0.2
Isotivity	-6.7	11.0	-0.7	18.8

Bay site 3.—Results from Bay site 3 suggest that the soil at this site is on the cold side of mesic (table 7.18.9). The MAST at 50 cm increased 0.4 °C during the 1998-1999 period of record. This increase is consistent with most other sites in the county. Bay site 3 is expected to be frigid in some years.

Table 7.18.9.—Soil and air temperatures (°C) for Bay site 3.

Analysis	'97-'98 10-cm	'98-'99 10-cm	'97-'98 50-cm	'98-'99 50-cm	'97-'98 Air	'98-'99 Air
Jan	2.1	1.5	3.4	3.4	---	-5.2
Feb	0.9	0.9	2.2	2.5	---	-1.9
Mar	2.8	0.6	3.0	1.8	---	-1.2
Apr	6.6	5.5	6.2	4.9	---	7.6
May	11.8	10.7	10.0	9.0	---	14.4
Jun	13.6	14.2	12.0	12.1	---	17.2
Jul	15.8	17.1	14.5	14.8	---	20.2
Aug	14.9	16.8	13.9	15.7	---	17.9
Sep	13.2	15.0	13.1	14.7	---	15.4
Oct	9.6	10.5	10.6	11.6	---	8.9
Nov	4.4	5.9	6.3	7.8	---	4.0
Dec	2.0	4.6	3.8	6.4	---	0.4
Mean	8.1	8.6	8.3	8.7	---	8.1
MST	14.8	16.1	13.5	14.2	----	18.4
MWT	1.7	2.3	3.1	4.1	---	-2.3
Isotivity	13.1	13.7	10.4	10.1	---	20.7

Bay site 4.—The soil at this site was frigid during the first year and mesic during the second year (table 7.18.10). The MAST increased 0.5 °C at 50 cm during the second year. The soil temperature increased at equal rates between sites with north and south aspects in the county. This finding had not been documented in previous temperature studies. If repeated in other studies, the finding would suggest that warming weather patterns will warm forested soils at an equal rate, regardless of slope and aspect.

Table 7.18.10.—Soil and air temperatures (°C) for Bay site 4.

Analysis	'97-'98 10-cm	'98-'99 10-cm	'97-'98 50-cm	'98-'99 50-cm	'97-'98 Air	'98-'99 Air
Jan	2.0	1.5	2.7	3.0	---	22.0
Feb	0.7	0.9	1.4	1.9	---	27.7
Mar	1.9	0.6	1.8	1.3	---	30.1
Apr	5.6	5.5	5.0	3.6	---	45.3
May	11.1	10.7	9.2	8.2	---	58.2
Jun	13.0	14.2	11.5	11.6	---	68.8
Jul	15.6	17.1	14.3	14.5	18.3	68.8
Aug	14.9	16.8	13.9	15.7	17.9	64.5
Sep	13.1	15.0	12.9	14.7	---	60.0
Oct	10.0	10.5	10.6	11.6	---	48.1
Nov	4.9	5.9	6.3	7.4	---	38.1
Dec	2.2	4.6	3.4	5.7	---	31.8
Mean	7.9	8.6	7.7	8.3	---	47.0
MST	14.5	16.1	13.2	13.9	---	67.3
MWT	1.6	2.3	2.5	3.6	---	27.2
Isotivity	12.9	13.7	10.7	10.4	---	40.2

Olean site 1.—The soil at Olean site 1 is mesic (table 7.18.11). The MAST at the 10-cm depth increased 0.4 °C during the second year of the study (9.0 vs. 9.4°C). While the 50-cm depth is the point of precise measurement for a soil temperature regime, the MAST for the 10-cm depth approximates that of the 50-cm depth (Mount, 1999). Therefore, one can infer that the 50-cm depth at the Olean site 1 also increased by about 0.4 °C during the second year of the study.

Table 7.18.11.—Soil and air temperatures (°C) for Olean site 1.

Analysis	'97-'98 10-cm	'98-'99 10-cm	'97-'98 50-cm	'98-'99 50-cm	'97-'98 Air	'98-'99 Air
Jan	2.8	1.7	---	2.9	---	---
Feb	1.9	1.7	---	2.4	---	---
Mar	3.1	2.0	---	2.2	---	---
Apr	7.5	6.3	---	6.1	---	---
May	11.9	11.0	---	10.2	---	---
Jun	13.7	13.8	---	12.7	---	---
Jul	16.4	17.0	---	14.2	---	---
Aug	15.4	17.4	---	16.6	---	18.9
Sep	14.4	16.1	---	15.7	---	16.2
Oct	11.6	12.4	---	12.8	---	9.7
Nov	6.1	7.7	---	8.6	---	3.3
Dec	3.3	6.0	---	6.9	---	---
Mean	9.0	9.4	---	9.3	---	---
MST	15.2	16.1	---	14.5	---	---
MWT	2.7	3.2	---	4.1	---	---
Isotivity	12.5	12.9	---	10.5	---	---

Olean site 2.—Table 7.18.12 shows that the temperature sensors at Olean site 2 did not perform well during the 1997-1998 period. The success of data capture was similar to that of Olean site 1. The soil at Olean site 2 was mesic during both years of the study.

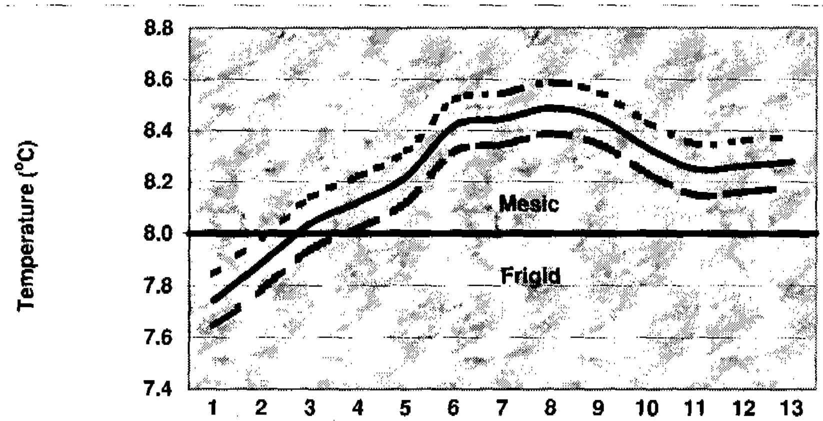
Table 7.18.12.—Soil and air temperatures (°C) for Olean site 2.

Analysis	'97-'98 10-cm	'98-'99 10-cm	'97-'98 50-cm	'98-'99 50-cm	'97-'98 Air	'98-'99 Air
Jan	---	1.3	3.0	3.0	---	---
Feb	---	0.6	1.6	1.4	---	---
Mar	---	0.7	2.7	1.2	---	---
Apr	---	6.1	6.4	4.8	---	---
May	---	11.7	10.1	9.7	---	---
Jun	---	14.7	---	12.3	---	---
Jul	---	18.4	---	15.9	---	---
Aug	16.5	18.1	15.7	16.9	---	20.8
Sep	---	16.1	14.7	15.9	---	15.8
Oct	---	11.7	12.1	13.0	---	---
Nov	---	6.8	6.6	8.9	---	---
Dec	---	5.1	3.2	7.0	---	---
Mean	---	9.3	---	9.2	---	---
MST	---	17.1	---	15.0	---	---
MWT	---	2.3	2.6	3.8	---	---
Isotivity	---	14.7	---	11.2	---	---

4. Discussion

The MAST at the 11 sites increased, on average, by 0.4 °C during the second year of the study. This increase is typical of studies in the Northeast from 1997 to 1999 (Mount, Pyle, et al., 1999). The MAST increased equally on north and south aspects.

Monitoring soil temperature is completely different from sampling a soil for characterization data. The percentage of sand, silt, and clay for an individual soil horizon remains constant for hundreds of years. Soil temperature is time-dependent, and it shifts either up or down with each 12-month segment of capture. Figure 7.18.1 shows the shift in 12-month segments between July 1998 and July 1999 at the 50-cm soil depth at Bay site 4.



	1	2	3	4	5	6	7	8	9	10	11	12	13
MAST Shift	7.7	7.9	8.0	8.1	8.2	8.4	8.4	8.5	8.4	8.3	8.2	8.3	8.3
Minus 0.1 deg C	7.6	7.8	7.9	8.0	8.1	8.3	8.3	8.4	8.3	8.2	8.1	8.2	8.2
Plus 0.1 deg C	7.8	8.0	8.1	8.2	8.3	8.5	8.5	8.6	8.5	8.4	8.3	8.4	8.4

Figure 7.18.1.—Shift analysis for the soil temperature at Bay site 4.

Figure 7.18.1 shows that the soil at Bay site 4 starts out frigid (<8 °C), migrates to mesic during the third shift, and continues to be mesic during the remainder of the period of record. Perhaps it will shift down and have a frigid soil temperature regime during late 1999. Summarized data in figure. 7.18.1 clearly indicate that a soil temperature regime will shift with global climate warming, even during a short-term study. So, how do we handle dramatic short-term changes for correlation purposes? Probably one of the best ways is to determine a latitude-elevation regression based on measured data.

On March 22, 1999, a linear regression equation was generated using TableCurve software (figure 7.18.2). The measured data were derived from a site in the Great Smoky Mountains in Tennessee; a site in western Greenbrier County, West Virginia; and a northern site in Cattaraugus County, New York. The elevation component is where the mesic-frigid break has been measured from nearby data. With a r^2 of 0.99, this equation can be used to approximate the mesic-frigid soil temperature break on north-facing slopes for any given latitude between 35° and 43º north.

The equation is as follows: Y (latitude in decimal degrees) = a + bx; where a = 46.204504; where b = -0.0075558256; and where x = elevation (m).

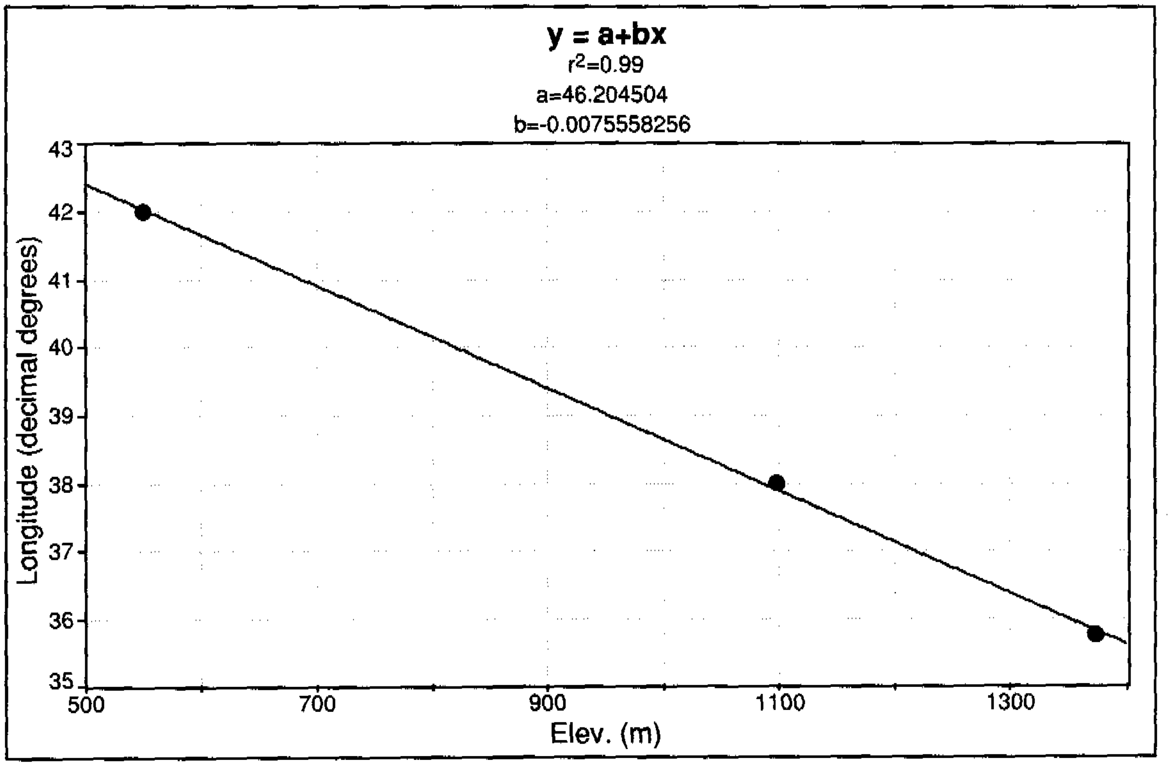


Figure 7.18.2.—Regression equation used to differentiate mesic and frigid soils in MO 13.

This regression equation will continue to be used for correlation purposes in the Major Land Resource Area 13 Office. It approximates conceptual temperature divisions as determined by short-term data from Cattaraugus County, New York.

Acknowledgments

Paul Puglia, NRCS Soil Scientist, Ellicottville, New York, helped to collect metadata for this study. Alex Topalanchik and Roy Pyle, MO 13 Soil Scientists, Morgantown, West Virginia, and Don Flegel, NRCS Soil Scientist, White Sulphur Springs, West Virginia, assisted in the installation of data loggers.

Chapter 7.19

Findings From a 2-Year Soil Temperature Study in Lewis County, New York*

ABSTRACT

A 2-year study was initiated in 1997 to verify the soil temperature regime in Lewis County, New York. The soil temperature of Lewis County has historically been considered to be mesic. The mean annual soil temperature at three sites increased, on average, by 0.4 °C during the second year of this study. Shift analysis for a grass-covered soil at an elevation of 381 m indicates that the mean annual soil temperature was coldest at the first shift, then migrated to over 8.9 °C during shifts 7 and 8. Shifts 12 and 13 indicate that the mean annual soil temperature is shifting downward to near 8.7 °C. It is presumed that air temperature increased during this study as a result of the current global warming patterns and is the primary factor responsible for warming the soils in Lewis County, New York. The mean annual air temperature was normal during a La Niña winter, but the summer and autumn air temperature of 1998 more than compensated for this normality. Therefore, it is not how warm or cold an individual year is during a soil temperature study that drives an increase in soil temperature. Warm summer, fall, and early winter air temperatures more than offset cold winter and spring air temperatures. This phenomenon increased the mean annual soil temperature during the second year and indicates a mesic soil temperature regime.

1. Background

Upstate New York is in the transition zone between mesic and frigid soil temperature regimes. Data loggers were installed at three sites in Lewis County, New York, during late July in 1997 and collected data for 2 years. The purpose of this study was to verify that the soils are frigid. A frigid temperature regime is one that has a mean annual soil temperature (MAST) of less than 8 °C. In addition, the isotivity value (difference between mean summer and mean winter temperatures) is more than 6 °C, and the mean summer temperature is less than 8 °C where soils have an O horizon (Soil Survey Staff, 1999).

2. Study Area

Lewis County is in north-central New York. The three sites in the study area are in the southern part of the county. They are near five other sites where data loggers collected data for 2 years. Information about the sites in the study area is given in table 7.19.1. Site 1 is along a fence by a cemetery in rural Glenfield, New York. The vegetation on this site consists of a single cherry tree (*Prunus spp. L.*) and periwinkle ground cover. The soil at site 1 is similar to Pinckney soils, which are coarse-loamy, mixed, active, frigid Typic Dystrudepts (Soil Survey Staff, 1999). Site 2 is on the Benedict Dairy Farm. The vegetation on this site consists of annual grasses and weeds. Site 3 is on the Riverside Farm, operated by Ed Patterson. The vegetation on this site consists of grasses and annual weeds. The soil on site 3 is similar to Salmon soils, which are coarse-silty, isotic, frigid Typic Haplorthods. The surface of this soil has been over-thickened because of the activity of roadside maintenance.

* Ed Stein, NRCS Soil Scientist at Lowville, New York, helped prepare this section.

Table 7.19.1.—Soil and site information for the study area.

Site number	Latitude (north)	Longitude (west)	Elevation (m)	Slope (%)	Aspect (°)	Soil series name
1	43°37'53"	75°26'53"	579	6	190	Pinckney
2	43°39'33"	75°24'38"	381	0	Neutral	SND
3	43°41'32"	75°21'47"	241	0	Neutral	Salmon

3. Results

Site 1.—The soil temperature regime was thought to be frigid during the first year. Data indicate that the regime was mesic during the second year. During the months running from July to December, the 50-cm soil depth was colder in first year than in the second year (table 7.19.2). August was 1.3 °C warmer at 50 cm in the second year than in the first year.

Table 7.19.2.—Temperatures (°C) for site 1.

Analysis	'97-'98 10-cm	'98-'99 10-cm	'97-'98 50-cm	'98-'99 50-cm	'97-'98 Air	'98-'99 Air
Jan	1.4	1.7	3.4	3.7	-1.6	-7.8
Feb	---	1.3	---	3.0	---	-2.8
Mar	---	1.0	---	2.5	---	-2.0
Apr	---	4.2	---	3.6	---	6.0
May	---	11.6	---	8.7	---	---
Jun	16.5	15.1	12.6	12.0	20.3	---
Jul	16.4	17.3	13.6	14.5	17.7	19.0
Aug	16.4	17.2	14.3	15.6	16.4	18.6
Sep	13.9	15.2	13.5	14.6	12.2	14.9
Oct	8.9	10.2	10.5	11.5	6.5	8.5
Nov	4.0	4.5	6.6	7.2	-0.8	1.7
Dec	1.8	3.1	4.2	5.3	-4.3	-1.5
Mean	---	8.5	---	8.5	---	7.4
MST	16.4	16.5	13.5	14.0	18.1	18.8
MWT	---	2.0	---	4.0	---	-4.0
Isotivity	---	14.5	---	10.1	---	22.8

Since the data suggest that the MAST at 50 cm rose during the second year, shift analysis was used to determine the various increments of change. The modeled shift is shown in figure 7.19.1.

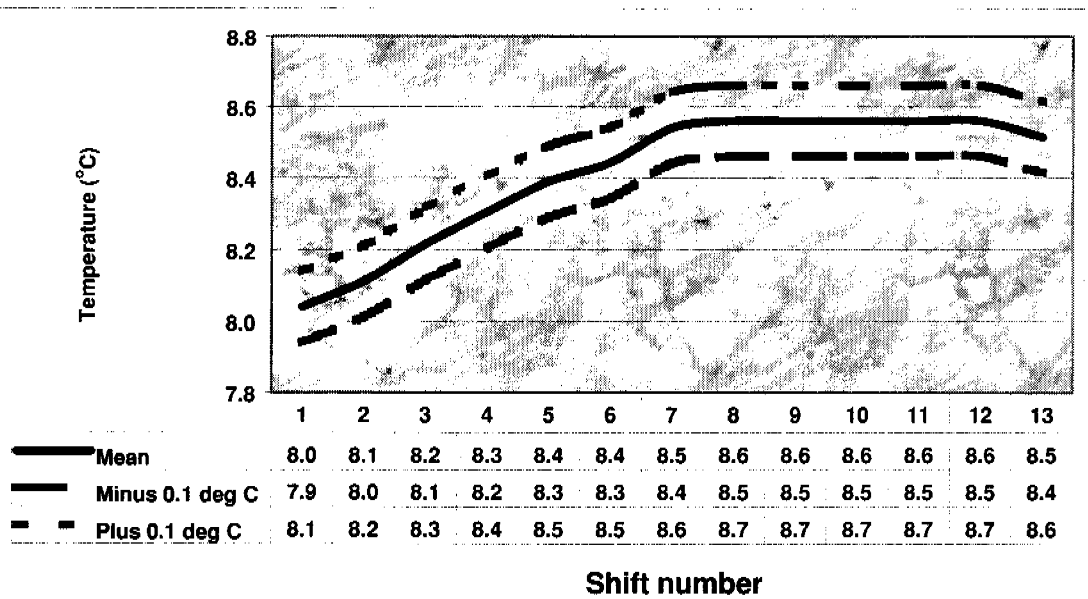


Figure 7.19.1.—Modeled shift of the MAST at 50 cm from July 1998 through July 1999 at site 1.

Site 2.—Data capture for the 50-cm soil depth at this site was 100 percent during the 1998-1999 period (table 7.19.3). With a MAST of 8.7 °C, the soil at this site was mesic. It is possible that in colder years it could be frigid. However, with the La Niña winter of 1998-1999, soil temperatures increased in Lewis County. The MAST at 50 cm was 8.2 °C during first year and 8.7 °C during the second year.

Table 7.19.3.—Temperatures (°C) for site 2.

Analysis	'97-'98 10-cm	'98-'99 10-cm	'97-'98 50-cm	'98-'99 50-cm	'97-'98 Air	'98-'99 Air
Jan	0.1	0.3	1.8	2.0	-0.4	-7.6
Feb	---	-0.1	1.7	1.5	---	-3.4
Mar	---	-1.0	1.4	0.8	---	-1.6
Apr	---	-0.1	5.5	2.2	---	7.9
May	---	---	10.6	9.5	---	17.1
Jun	17.7	---	12.8	13.0	22.0	21.2
Jul	17.8	20.0	14.9	15.9	19.6	23.3
Aug	17.5	19.4	15.4	17.9	18.0	18.6
Sep	14.4	16.5	14.3	16.4	13.6	15.9
Oct	9.0	11.0	10.9	12.6	7.7	8.9
Nov	4.2	5.1	6.6	7.6	0.1	2.5
Dec	0.6	2.9	3.1	4.8	-3.6	-1.1
Mean	---	---	8.2	8.7	---	8.5
MST	17.7	---	14.4	15.6	19.9	21.0
MWT	---	1.0	2.2	2.8	---	-4.0
Isotivity	---	---	12.2	12.8	---	25.0

Site 3.—Data capture at this site was 100 percent during this 2-year study (table 7.19.4). The data show the soil to be mesic. Between the first year and the second, the MAST increased by 0.2 °C at the 10-cm depth and by 0.3 °C at the 50-cm depth. The MAAT was identical during both years (7.8 °C). However, the period from June to December was warmer in the second year than in the first year.

Table 7.19.4.—Temperatures (°C) for site 3.

Analysis	'97-'98 10-cm	'98-'99 10-cm	'97-'98 50-cm	'98-'99 50-cm	'97-'98 Air	'98-'99 Air
Jan	0.2	0.4	1.5	2.1	-3.8	-7.6
Feb	0.1	0.3	1.3	1.5	-2.7	-3.8
Mar	0.3	0.1	0.9	1.1	0.4	-2.9
Apr	6.9	3.6	4.7	2.4	7.4	5.8
May	14.3	12.9	10.9	9.5	15.7	15.3
Jun	16.0	16.8	13.6	13.9	17.0	20.5
Jul	19.7	19.2	16.9	16.4	19.9	22.3
Aug	18.9	19.0	17.0	16.6	18.2	18.3
Sep	15.1	16.4	15.4	17.9	13.6	15.3
Oct	8.8	10.6	10.9	12.2	6.6	8.5
Nov	3.4	4.8	6.0	7.2	0.0	2.8
Dec	0.8	2.5	3.0	4.6	-3.1	-1.2
Mean	8.7	8.9	8.5	8.8	7.8	7.8
MST	18.2	18.3	15.8	15.6	19.9	20.4
MWT	0.3	1.1	1.9	2.7	-3.2	-4.2
Isotivity	17.8	17.2	13.9	12.9	23.1	24.6

4. Discussion

Between the first year and second year of the study, the MAST at 50 cm for the three sites in Lewis County increased, on average, by 0.4 °C. Soil temperature shifted with each 12-month segment of capture. Figure 7.19.1, displayed previously, showed the modeled shift of the MAST at 50 cm for site 1 from July 1998 through July 1999. Figure 7.19.2 shows the shift analyses for site 2. This analysis is based on measured data.

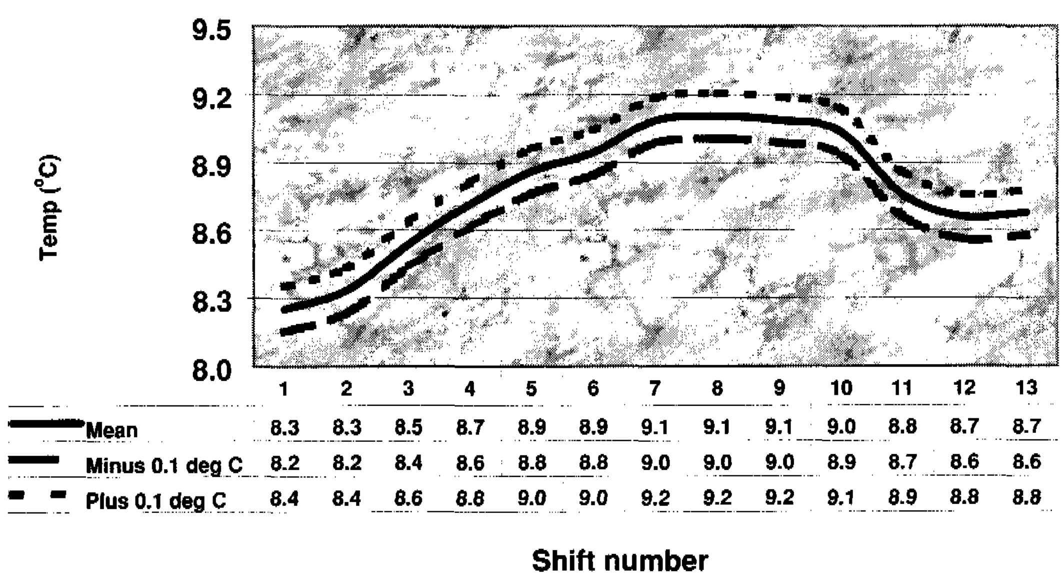


Figure 7.19.2.—Shift analysis of soil temperature at 50 cm for site 2.

Figure 7.19.2 indicates that the MAST was coldest at the first shift, then migrated to over 8.9 °C from shift 7 to shift 9.[†] Shifts 12 and 13 indicate that the MAST is shifting downward to near 8.7 °C.

It is presumed that air temperature increased as a result of the current global warming patterns and is the primary factor responsible for warming the soils in Lewis County, New York. As shown in this study, MAAT can be normal during a La Niña winter, but the summer and fall air temperatures of 1998 more than compensated for this normality. Therefore, an increase in soil temperature is not driven by how hot or how cold an individual year is during a soil temperature study. The warm summer, fall, and early winter air temperatures more than offset the cold winter and spring air temperatures. This phenomenon increased the second year means and clearly indicates a mesic soil temperature pattern for Lewis County.

[†] The - 0.1 °C and + 0.1 °C curves are shown to display the normal accuracy limits of the StowAway loggers.

Chapter 7.20

Current Findings From a Soil Temperature Study in the New York City Area*

ABSTRACT

A study was initiated during 1997 to measure air and soil temperatures in the greater New York City area. The mean annual soil temperature increased, on average, by 0.3 °C during the 1997-1999 study period. Most of this average increase was at a wooded site in Manhattan's Central Park. Shift analysis confirmed that the soil temperature shifted with each 12-month segment of capture. The first shift analysis was for the soil at the wooded site in Central Park, which increased 0.6 °C during the second year. The mean annual soil temperature for the 50-cm soil depth increased steadily through the seventh shift, then decreased somewhat before increasing again during the thirteenth and final shift. The second shift analysis was examined for the playground area in Central Park. The soil started out at the warm end of the mesic soil temperature regime (mean annual soil temperature of 14.4 °C) during its first shift, migrated to a thermic soil temperature regime during the seventh shift (mean annual soil temperature of 15.0 °C), then trended downward to a mesic soil temperature regime during the remainder of the period of record. Isotivity values (differences between mean summer and mean winter temperatures) were >6 °C, thus ruling out the presence of soils with isomesic temperature regimes in New York City.

1. Background

Efforts to publish soil temperature data as part of a progressive soil survey within the Natural Resources Conservation Service for the United States Department of Agriculture have generally been unsuccessful in the past 100 years (NRCS Soil Climate Team, 1995). With the advent of automated data collection technology, such as StowAway temperature loggers, the process of collecting and analyzing large amounts of data has been simplified.

The findings from the sites in the New York City area are an important addition to current soil temperature research. This study was funded by the NRCS Global Change Initiative. Data loggers were installed at three of the sites during late July of 1997 and collected data for 2 years. This report of the soil temperature sites in the New York City area reflects the current air and soil temperature increases resulting from warming continental weather patterns in the United States.

2. Study Area

The sites for this study are located in the greater New York City area. Two of the sites are in Manhattan, two are on Staten Island, one is in Brooklyn, and one is in Monmouth County, New Jersey (table 7.20.1).

* Luis Hernandez and Rob Tunstead, NRCS Soil Scientists, New York City Urban Soil Survey, Staten Island, New York, assisted in preparing this section.

Table 7.20.1.—Soil and site metadata for the study area.

Site ID	Latitude (north)	Longitude (west)	Elevation (m)	Slope (%)	Aspect (°)	Soil series name	Drainage class
NY 1	40°47'29"	73°57'18"	15	17	340	Chatfield	Well
NY 2	40°47'22"	73°57'32"	9	1	275	Greenbelt	Well
NY 3	40°34'14"	74°09'49"	9	15	280	Maplecrest	Well
NY 4	40°34'14"	74°10'01"	9	2	0	Greatkills	Well
NY 5	40°36'01"	73°53'42"	6	1	320	Bigapple	Well
NJ 1	40°25'36"	73°59'14"	8	1	340	Carollton	Excessive

The NY 1 site is in a forested area of Central Park. The vegetation consists of oak (*Quercus spp. L.*) and wild cherry (*Prunus spp. L.*) and a ground cover of grasses, forbs, and poison ivy (*Rhus radicans L.*). The soil at this site is of the Chatfield series, a coarse-loamy, mixed, superactive, mesic Typic Dystrudept (Hernandez and Galbraith, 1997). The soil has loamy till sediments over crystalline bedrock between 50 and 100 cm.

The NY 2 site is in the unvegetated playground area in the East Meadow portion of Central Park, across from Mount Sinai Hospital. The soil at this site is similar to Greenbelt soils, which are coarse-loamy, mixed, active, mesic Typic Udorthents. This soil has been created by human activities in Central Park.

The NY 3 site is in the Latourette Park section of Staten Island. The vegetation consists of red oak (*Quercus spp. L.*) and an understory of sassafras (*Sassafras albidum L.*) saplings. The soil at this site is of the Maplecrest series, a coarse-loamy, mixed, superactive, mesic Typic Dystrudept.

The NY 4 site is in a 60-year-old landfill section of western Latourette Park on Staten Island. The vegetation consists of phragmites (*Phragmites spp. L.*) and some ragwort (*Senecio spp. L.*) forbs. The soil at this site is of the Greatkills series, a loamy-skeletal, mixed, active, nonacid, hyperthermic Typic Udorthent (Hernandez and Galbraith, 1997).

The NY 5 site is near the edge of a circular bayberry thicket at Floyd Bennett Field, in the Jamaica Bay section of Brooklyn. The vegetation consists of bayberry (*Myrica pensylvanica L.*), sumac (*Rhus spp. L.*), milkweed (*Asclepias spp. L.*), switchgrass, mudwort (*Senecio spp. L.*), and blackberry (*Rubus spp. L.*). The soil at this site is of the Bigapple series, a mixed, mesic Typic Udipsamment.

The NJ site 1 is in Monmouth County, New Jersey, in the Sandy Hook Holly Forest. The vegetation consists of American holly (*Illex opaca L.*). This is one of the few holly forests in the Northeast. The ground surface is littered with dead holly tree leaves. The site also supports cactus (*Opuntia compressa L.*) and poison ivy (*Rhus radicans L*). The soil at this site is of the Hooksan series, a mesic, uncoated Typic Quartzipsamment.

3. Results

New York City site 1.—The soil temperature regime is mesic (table 7.20.2). Between the first year and the second, the MAST increased by 0.6 °C at both the 10- and 50-cm depths. This is the largest single-year increase of any site in the study area. Most of this increase results from the warmer monthly soil temperatures from the July to December period of 1998.

Table 7.20.2.—Temperatures (°C) for New York City site 1.

Analysis	'97-'98 10 cm	'98-'99 10 cm	'97-'98 50 cm	'98-'99 50 cm	'97-'98 Air	'98-'99 Air
Jan	4.1	2.0	5.2	4.3	---	0.9
Feb	3.8	2.6	4.5	4.2	---	3.3
Mar	5.4	4.1	5.3	4.6	---	6.0
Apr	9.7	9.2	9.0	8.3	---	12.0
May	14.0	13.6	12.1	11.7	---	16.6
Jun	16.7	18.7	14.8	15.8	---	22.1
Jul	19.3	20.9	17.1	18.7	24.4	24.4
Aug	19.4	21.3	18.1	19.6	23.9	24.1
Sep	17.7	19.7	17.4	19.1	---	20.7
Oct	13.9	14.9	14.9	15.9	---	13.9
Nov	8.4	9.7	10.4	11.7	---	8.8
Dec	4.5	7.0	6.4	9.2	---	6.1
Mean	11.4	12.0	11.3	11.9	---	13.2
MST	18.5	20.3	16.7	18.0	---	23.5
MWT	4.1	3.9	5.4	5.9	---	3.4
Isotivity	14.3	16.4	11.3	12.1	---	20.1

New York City site 2.—The soil at this site was mesic during both years (table 7.20.3). This soil is not so susceptible to swings in MAST as the forested soil at site 1. It is conjectured that the compacted playground surface acts as an inconsistent thermal transitive property. The water in the soil is suspected to buffer the thermal diffusivity at this site.

Table 7.20.3.—Temperatures (°C) for New York City site 2.

Analysis	'97-'98 20 cm	'98-'99 20 cm	'97-'98 38 cm	'98-'99 38 cm	'97-'98 50 cm	'98-'99 50 cm
Mean	14.4	14.4	14.4	---	---	14.3
MST	25.1	24.8	24.2	---	---	24.0
MWT	4.2	4.9	5.0	---	---	5.3
Isotivity	20.9	2.2	19.2	---	---	0.9

New York City site 3.—Between the first year and the second year of this study, the MAAT increased 0.3 °C and the MAST at 10 cm also increased 0.3 °C (table 7.20.4). The MAST at 10 cm is 0.7 °C warmer than the MAST at 50 cm. The MAST is less than the MAAT, a pattern that also occurred at site 1. One of the premises for soil temperature is that it will average 0.5 to 1.0 °C more than the MAAT (Soil Survey Staff, 1999). This holds true for studies in Cattaraugus, Fulton, and Lewis Counties, New York. However, along the Atlantic Ocean, air movements are conjectured to distribute heat across the soil. Therefore, heat does not transmit downward into the soil column so readily as in other areas of the United States.

Table 7.20.4.—Temperatures (°C) for New York City site 3.

Analysis	'97-'98 10 cm	'98-'99 10 cm	'98-'99 50 cm	'97-'98 Air	'98-'99 Air
Jan	5.6	3.4	4.7	4.5	0.9
Feb	5.2	4.2	5.0	4.5	3.1
Mar	6.7	5.2	5.1	7.1	5.8
Apr	10.7	9.8	8.3	11.7	11.2
May	14.2	13.4	11.3	16.4	15.6
Jun	16.8	17.7	14.8	18.9	21.3
Jul	19.6	20.7	17.7	22.9	23.8
Aug	19.5	20.9	18.3	21.1	22.9
Sep	17.9	19.4	18.1	18.1	19.8
Oct	13.8	14.8	15.2	12.7	13.3
Nov	9.1	10.2	11.4	6.5	8.4
Dec	5.5	7.7	9.3	3.2	5.2
Mean	12.0	12.3	11.6	12.3	12.6
MST	18.6	19.8	16.9	21.0	22.7
MWT	5.4	5.1	6.3	4.1	3.1
Isotivity	13.2	14.7	10.6	16.9	19.6

New York City site 4.—Soil temperature at site 4 suggests exothermic activity (Mount, Hernandez, et al., 1999). The soil at this site is hyperthermic at 50 cm (table 7.20.5). With a MAST of 16.1 °C, the 10-cm depth was 7.2 °C cooler than the 50-cm depth, a clear indication of increasing exothermic activity with depth. The MAAT at this site is 2.4 °C warmer than that of site 3 (14.7 vs. 12.3 °C). It indicates that exothermic heat from a landfill impacts the ground air layers.

Table 7.20.5.—Temperatures (°C) for New York City site 4.

Analysis	'97-'98 10 cm	'97-'98 50 cm	'97-'98 Air
Jan	4.6	13.0	9.6
Feb	8.7	21.8	9.8
Mar	13.5	24.8	9.4
Apr	14.9	24.6	11.8
May	17.9	26.7	19.3
Jun	30.9	28.4	20.3
Jul	30.6	30.6	25.0
Aug	25.2	29.1	21.8
Sep	20.8	26.4	18.3
Oct	14.3	23.0	14.8
Nov	7.6	16.9	10.2
Dec	4.1	13.7	5.7
Mean	16.1	23.3	14.7
MST	28.9	29.4	22.3
MWT	5.8	16.2	8.3
Isotivity	23.1	13.2	14.0

New York City site 5.—The MAST to MAAT trend continues with the soil at this site (table 7.20.6). The MAAT is 0.3 °C warmer than the MAST at 50 cm. The MAST at both the 10-cm and 50-cm depths is warmer than at New York City site 3. There is a rather large difference in MAST between these two depths. However, it is the inverse of New York City site 3; site 5 is warmer at 50 cm instead of cooler. Soils in New York City have historically been disturbed and modified (Mount, Hernandez, et al., 1999). This modification has lead to some interesting averages in this study.

Table 7.20.6.—Temperatures (°C) for New York City site 5.

Analysis	'98-'99 10 cm	'98-'99 50 cm	'98-'99 Air
Mean	11.9	12.4	12.7
MST	20.8	18.9	23.7
MWT	3.4	5.8	2.2
Isotivity	17.5	13.1	21.5

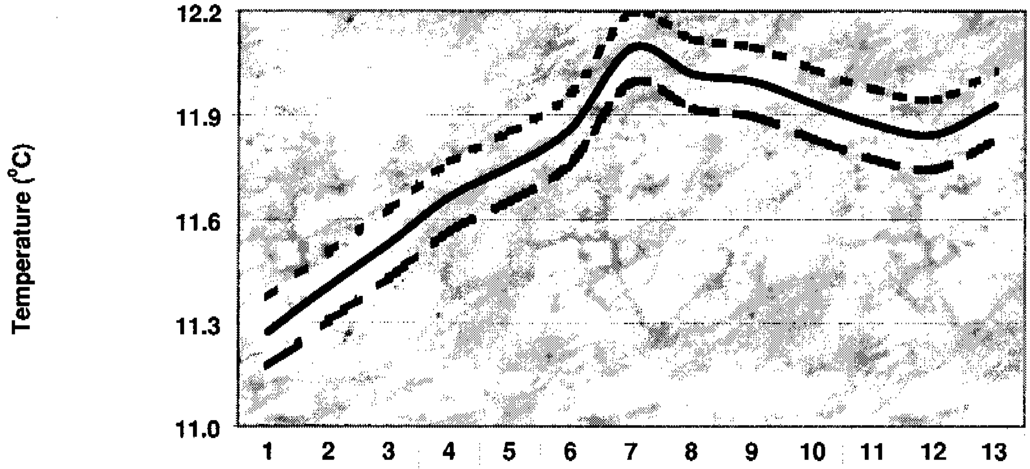
New Jersey site 1.—Table 7.20.7 compares the New Jersey site to New York City site 3 for the 1998-1999 period of record. The MAST is slightly warmer at the New Jersey site than at New York City site 3. In both cases the 10-cm depth is warmer than the 50-cm depth. The MAAT is warmer than the MAST at either depth. The isotivity value is lowest for the 50-cm depth at the New Jersey site. At 8.8 °C, it is the lowest value for the greater New York City study area. Waters of the Atlantic Ocean surround the New Jersey site. Nearby ocean air masses help to buffer soil temperature extremes, resulting in a low isotivity value.

Table 7.20.7.—Comparison of temperatures (°C) between New Jersey site 1 and New York City site 3.

Analysis	NJ '98'99 10 cm	NJ '98-'99 50 cm	NJ '98-'99 Air	NY3 '98-'99 10 cm	NY3 '98-'99 50 cm	NY3 '98-'99 Air
Jan	5.0	7.1	1.0	3.4	4.7	0.9
Feb	4.9	6.6	2.4	4.2	5.0	3.1
Mar	5.4	6.2	4.8	5.2	5.1	5.8
Apr	9.2	8.7	10.1	9.8	8.3	11.2
May	13.1	11.6	---	13.4	11.3	15.6
Jun	17.6	15.3	---	17.7	14.8	21.3
Jul	20.8	17.4	---	20.7	17.7	23.8
Aug	20.8	18.2	24.2	20.9	18.3	22.9
Sep	19.2	18.0	20.8	19.4	18.1	19.8
Oct	15.1	15.6	14.1	14.8	15.2	13.3
Nov	11.0	12.5	8.3	10.2	11.4	8.4
Dec	9.1	10.8	5.5	7.7	9.3	5.2
Mean	12.6	12.3	13.6	12.3	11.6	12.6
MST	19.7	16.9	24.2	19.8	16.9	22.7
MWT	6.3	8.2	3.0	5.1	6.3	3.1
Isotivity	13.4	8.8	21.2	14.7	10.6	19.6

4. Discussion

The MAST in the greater New York City area increased, on average, by 0.3 °C between the first and the second year of the study. Most of this average increase was at the wooded site in Manhattan's Central Park. Soil temperature shifts with each 12-month segment of capture. Figure 7.20.1 shows the shift analysis for this site between June 1998 and June 1999. The MAST at 50 cm increased 0.6 °C during this period. It increased steadily through shift 7, then decreased somewhat before increasing again during the thirteenth and final shift.

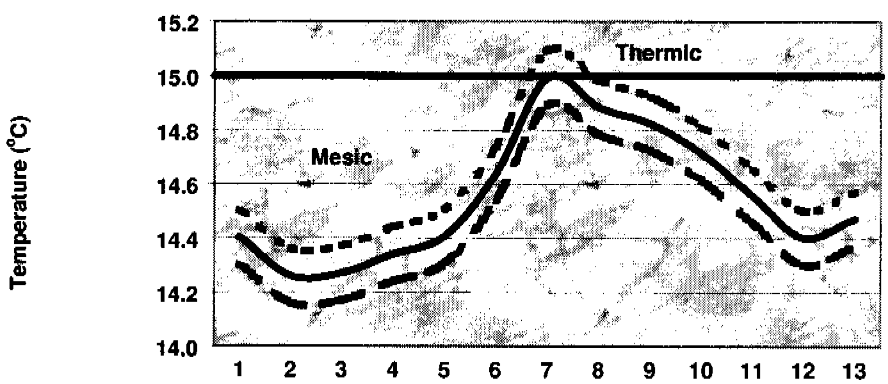


Shift number	1	2	3	4	5	6	7	8	9	10	11	12	13
Mean	11.3	11.4	11.5	11.7	11.8	11.9	12.1	12.0	12.0	11.9	11.9	11.8	11.9
Minus 0.1 deg C	11.2	11.3	11.4	11.6	11.7	11.8	12.0	11.9	11.9	11.8	11.8	11.7	11.8
Plus 0.1 deg C	11.4	11.5	11.6	11.8	11.9	12.0	12.2	12.1	12.1	12.0	12.0	11.9	12.0

Shift number

Figure 7.20.1.—Shift analysis for the 50-cm soil depth at New York City site 1.

Figure 7.20.2 shows the shift analysis the playground area at New York City site 2. The soil starts out at the warm end of the mesic soil temperature regime (14.4 °C), migrates to thermic during shift 7 (15.0 °C), then trends downward to a mesic temperature regime during the rest of the period of record.



Shift number	1	2	3	4	5	6	7	8	9	10	11	12	13
Mean	14.4	14.3	14.3	14.3	14.4	14.6	15.0	14.9	14.8	14.7	14.6	14.4	14.5
Minus 0.1 deg C	14.3	14.2	14.2	14.2	14.3	14.5	14.9	14.8	14.7	14.6	14.5	14.3	14.4
Plus 0.1 deg C	14.5	14.4	14.4	14.4	14.5	14.7	15.1	15.0	14.9	14.8	14.7	14.5	14.6

Shift number

Figure 7.20.2.—Shift analysis for the soil temperature at New York City site 2.

No matter how simple the technology, continuous data collection is difficult for long-term efforts. During this and most other short-term studies, there will be some difficulty in collecting all of the data.

Collecting 30-years of continuous soil temperature data would be expensive, impractical, and likely impossible.

Data from this study essentially rule out any "iso" soil temperature regimes along the East Coast. A prior study on Edisto Island in South Carolina showed that isotivity values for soils along the Atlantic Ocean are similar to those in New Jersey (Mount et al., 1998).

Acknowledgment

Steve Indrick, Assistant State Soil Scientist in Syracuse, New York, assisted in the installation of the data loggers in New York City.

Chapter 7.21

Effects of Wet Spring Seeps on Soil Temperature in North Carolina*

ABSTRACT

A study of the impact of wet spring seeps on soil temperature was initiated at four sites in North Carolina during 1998. Data for the 50-cm depth of a soil at an elevation of 975 m (site 2) exhibited unusual results. At 12.7 °C, the isotivity value (difference in mean summer and mean winter temperatures) is 2.3 °C greater than that of the adjacent well drained soil at nearly the same elevation. This finding implies that the spring water at site 2 is not buffered during the summer months. When seasonal and annual results for the 50-cm soil temperature at site 2 are examined with similar data for the 10-cm depth, interpretation becomes more difficult. The difference between the mean annual soil temperatures at 10 cm and 50 cm for site 2 is high. At 1.9 °C (12.8 vs. 10.9 °C), this difference cannot be explained. Generally, the mean annual soil temperatures at 10 cm and 50 cm are similar for soils in the Eastern United States. The June, July, and August temperature values between the 10- and 50-cm depths are also unusual. They are always more at the 50-cm depth than at the 10-cm depth. At site 4, the inverse is true. Another peculiarity at site 2 is that the mean monthly soil temperatures are warmer at 50 cm than at 10 cm in all months except for April. This unusual pattern might imply zones of hydrology in the soil with different temperature gradients. If the wet spring seep at site 2 is moving only across the upper layer, this pattern of movement might explain the lower mean annual soil temperature readings for the 10-cm depth. If a different water source is impacting the 50-cm depth, i.e., one that is discharged from warmer water sources, this impact might explain the warmer mean annual soil temperature at 50 cm. The temperature of spring water does not appear to be constant throughout the year.

1. Background and Purpose

Wet spring seeps occur throughout the Eastern United States. They usually are small in size (<1 ha) and generate hydrophytic vegetation and soils with a reduced matrix. Little is known about the influence of wet spring seeps on soil temperature. Consequently, a study was designed for two wet spring seeps in Watauga County, North Carolina. At each spring seep, data loggers collected air temperature readings and soil temperature readings at 10 cm and 50 cm.

We expected that the temperature of spring water would be reasonably constant throughout the year. The wet soils surrounding the springs should have smaller isotivity values than the surrounding better drained soils. This buffering of soil isotivity, or difference between summer and winter temperatures, in the spring seeps was suspected to approach the "iso" criteria defined in *Soil Taxonomy* (Soil Survey Staff, 1999)

2. Study Area

Watauga County is in northwestern North Carolina. Site 1 is at an elevation of 936 m. Its latitude is 36°16'08" north, and its longitude is 81°33'32" west. The slope is 7 percent. The soil is moderately well drained. It is a fine-loamy, mixed, active, mesic Aquic Humic Dystrudept (Soil Survey Staff, 1999). The parent material is colluvium derived from mica schist and gneiss. The vegetation consists of bluegrass (*Poa spp. L.*), blackberry (*Rubus spp. L.*), New England aster (*Aster spp. L.*), and hemlock (*Tsuga spp. L.*). In this study, site 1 is paired with site 3.

* Roy L. Mathis, Jr., NRCS Soil Survey Project Leader, Wilkesboro, North Carolina, assisted in preparing this section.

Site 2 is at an elevation of 975 m. Its latitude is 36°14'45" north, and its longitude is 81°38'56" west. The aspect at the site is neutral. The soil is very poorly drained. It is a coarse-loamy over sandy or sandy-skeletal, mixed, acid, mesic Cumulic Humaquept (Soil Survey Staff, 1999). The parent material is alluvium derived from mica schist and gneiss. The site is in a pasture, and the vegetation consists of rushes, sedges, and New England aster. For this study, site 2 is paired with site 4.

Site 3 is at an elevation of 934 m. Its latitude is 36°16'08" north, and its longitude is 81°33'32" west. The slope is 3 percent. The soil is very poorly drained. It is a coarse-loamy, mixed, acid, mesic Typic Humaquept (Soil Survey Staff, 1999). The parent material is colluvium derived from mica schist and gneiss. The site is in a wetland, and the vegetation consists of rushes, sedges, New England aster, and blackberry.

Site 4 is in a pasture and at an elevation of 977 m. Its latitude is 36°14'45" north, and its longitude is 81°38'56" west. The slope is 35 percent, and the aspect is west. The soil is well drained. It is a coarse-loamy, paramicaceous, mesic Typic Dystrudept (Soil Survey Staff, 1999). The parent material is residuum derived from mica gneiss. The vegetation consists of bluegrass and red maple (*Acer spp. L.*).

3. Results

Air temperature.—Table 7.21.1 shows that the MAAT at site 4, which is at an elevation of 977 m, is 1.4 °C warmer than the MAAT at site 1, which is at an elevation of 936 m (12.5 vs. 11.1 °C). Normally, the MAAT decreases with elevation in the same mountain valley in the Eastern United States (McMillen et al., 1998). However, since these sites are in different parts of Watauga County, it is suggested that other atmospheric variables, i.e., fog and air drainage, impacted the MAST at site 1.

Table 7.21.1.—Monthly, seasonal, and annual air temperatures (°C) at sites 1 and 4.

Analysis	Site 1	Site 4
Jan 99	2.2	2.4
Feb 99	2.7	3.6
Mar 99	4.2	5.3
Apr 99	12.7	13.6
May 99	14.9	17.6
Jun 99	18.4	20.3
Jul 99	21.0	23.4
Aug 99	19.9	22.7
Sep 99	15.9	18.2
Oct 99	10.7	11.8
Nov 98 & 99	6.4	6.9
Dec 98	3.7	4.4
Mean	11.1	12.5
MST	19.1	21.5
MWT	2.8	3.5
Isotivity	16.3	18.0

Soil temperature at 10 cm.—The MAST at 10 cm is similar among the sites (table 7.21.2). The MWT also is similar. However, the MST at sites 2 and 4 is warmer than the MST at site 1, probably because of warmer air temperatures at sites 2 and 4.

Table 7.21.2.—Monthly, seasonal, and annual soil temperatures (°C) at 10 cm.

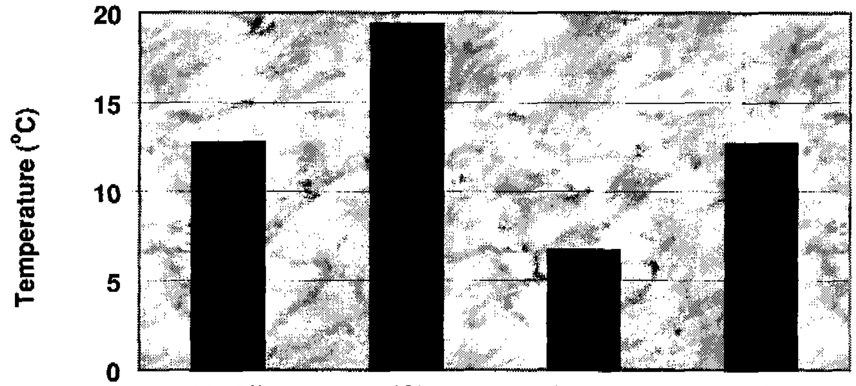
Analysis	Site 1	Site 2	Site 3	Site 4
Jan 99	3.6	3.5	3.6	2.9
Feb 99	4.4	4.1	4.3	3.4
Mar 99	4.1	3.8	4.1	3.2
Apr 99	10.2	10.6	9.8	10.7
May 99	12.0	14.2	12.2	14.3
Jun 99	15.4	17.2	---	17.9
Jul 99	18.6	19.6	---	20.9
Aug 99	18.7	19.0	---	20.3
Sep 99	16.2	14.6	---	16.3
Oct 99	12.5	10.8	---	11.7
Nov 98 & 99	9.2	7.5	7.4	7.6
Dec 98	6.5	5.5	5.8	5.2
Mean	11.0	10.9	---	11.2
MST	17.0	18.1	---	19.1
MWT	4.8	4.4	4.6	3.9
Isotivity	12.2	13.7	---	15.2

Soil temperature at 50 cm.—Unlike data for the 10-cm depth, data for the 50-cm depth are difficult to interpret (table 7.21.3). Site 2, in particular, exhibited unusual results. At 12.7 °C, the isotivity value for site 2 is 2.3 °C greater than that of the adjacent well drained soil at site 4. This finding implies that the spring water at site 2 is not buffered during the summer months.

Table 7.21.3.—Monthly, seasonal, and annual soil temperatures (°C) at 50 cm.

Analysis	Site 1	Site 2	Site 3	Site 4
Jan 99	5.0	5.6	5.2	5.4
Feb 99	5.7	6.2	5.8	6.6
Mar 99	4.5	5.5	4.9	5.5
Apr 99	8.8	10.4	7.6	10.2
May 99	11.0	14.5	---	12.9
Jun 99	13.8	18.1	---	15.6
Jul 99	16.8	20.8	---	18.0
Aug 99	17.8	20.7	---	18.8
Sep 99	16.1	18.0	---	17.0
Oct 99	13.6	14.9	---	14.3
Nov 98 & 99	10.7	10.3	8.9	10.6
Dec 98	8.5	8.2	7.4	8.3
Mean	11.0	12.8	---	11.9
MST	15.8	19.4	---	17.2
MWT	6.4	6.7	6.1	6.8
Isotivity	9.4	12.7	---	10.4

When seasonal and annual results for the 50-cm soil temperature at site 2 are examined along with similar data for the 10-cm depth, interpretation becomes more difficult (figure 7.21.1).

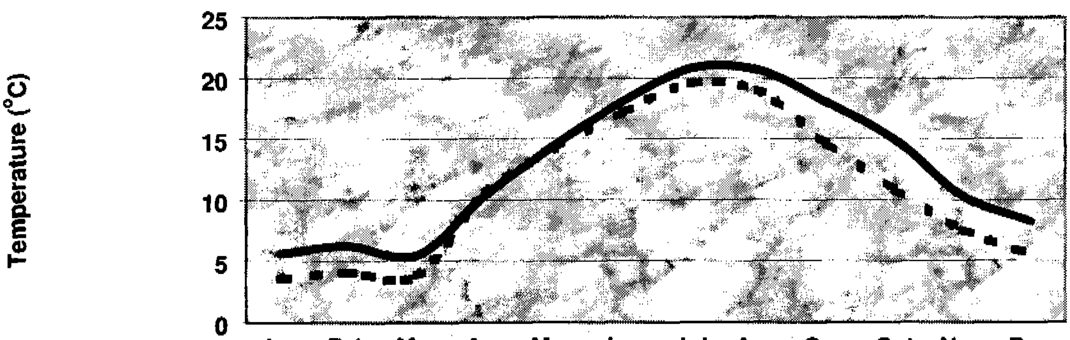


	MAST	MST	MWT	MS-MW
#2 50 Cm	12.8	19.4	6.7	12.7

Figure 7.21.1.—Summarized temperature data for the wet spring seep at site 2.

The difference between the MAST at 10 cm and the MAST at 50 cm for site 2 is quite expressed. At 1.9 °C (12.8 vs. 10.9° C), this difference cannot be explained. Generally, the MAST values at 10 cm and 50 cm are essentially the same for soils in the Eastern United States (Mount, 1999).

The June, July, and August temperature values also are unusual (figure 7.21.2). These values are always higher at the 50-cm depth than at the 10-cm depth. At site 4, the inverse is true. The reasons for this unusual pattern of soil temperatures are not known.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#2 10 cm	3.5	4.1	3.8	10.6	14.2	17.2	19.6	19.0	14.6	10.8	7.5	5.5
#2 50 Cm	5.6	6.2	5.5	10.4	14.4	18.1	20.8	20.7	18.0	14.9	10.3	8.2

Figure 7.21.2.—Relationship of soil temperature between 10 cm and 50 cm at site 2.

Another peculiarity at site 2 is that the mean monthly soil temperatures are warmer at 50 cm than at 10 cm in all months except for April. This unusual pattern might imply zones of hydrology in the soil with different temperature gradients. If the wet spring seep at site 2 is moving only across the upper layer, this pattern of movement might explain the lower MAST readings for the 10-cm depth. If a different water source is impacting the 50-cm depth, i.e., one that is discharged from warmer water sources, this impact might explain the warmer MAST at 50 cm.

4. Summary

This study resulted in temperature data that are not easily explained. The temperature of spring water is not constant throughout the year in the study area. This revelation compromised the basic assumption of what the data would show. Additional studies are needed in seep areas of the United States if we are to gain a clearer understanding of the effects of spring water on soil temperature.

Chapter 7.22

Findings From a 2-Year Soil Temperature Study in Warren County, Pennsylvania

ABSTRACT

Soils at four wooded sites in Warren County, Pennsylvania, were monitored for temperature from 1997 to 1999. The purpose of this study was to determine if the soils at the four sites have a mesic or a frigid soil temperature regime. The results of the study show that the four soils are at the cold end of the mesic temperature regime. The soil temperature increased, on average, by 0.4 °C during the second year of the study. This increase is similar to that indicated in a study in nearby Cattaraugus County, New York. Shift analysis of the Jake's Rocks site reveals that the soil at this site started out borderline mesic-frigid (8.2 °C), migrated to the cold end of mesic during the second and third shifts (8.3 and 8.4 °C, respectively), and continued to have a mesic soil temperature regime during the remainder of the period of record.

1. Background and Purpose

The soils in northwestern Pennsylvania have historically been correlated as having a mesic temperature regime. With the advent of data-logging technology, a study was designed to determine if the soils at the four sites had a mesic or a frigid temperature regime. Loggers were installed at the four sites during late July of 1997 and collected data for 2 years.

2. Study Area

Warren County is in northwestern Pennsylvania, in MLRA 127. The sites are south of the Allegheny River, in the Allegheny National Forest in southeastern Warren County. In this area predicting a change from mesic to frigid soil temperature regimes is difficult. There are no vegetative indicators of where soils with a frigid temperature regime occur.

Site 1 is in the Jake's Rocks area off Orest Highway 258. It is on the Cornplanter Bridge quad sheet. Its latitude is 41°38'32" north, and its longitude is 78°39'00" west. Elevation is 628 m. The slope is 3 percent, and the aspect is north. About 0.1 percent of the surface is covered with stones. The vegetation consists of beech (*Fagus spp. L.*), black cherry (*Prunus spp. L.*), and northern red oak (*Quercus spp. L.*) and an understory of ferns.

Site 2 is in the Fool's Creek area. It is on the Cherry Grove quad sheet. Its latitude is 41°38'26" north, and its longitude is 79°11'58" west. Elevation is 541 m. The slope is 3 percent, and the aspect is south. About 0.1 percent of the surface is covered with stones. The vegetation is beech, black cherry, and northern red oak.

Site 3 is in the Heart's Content area and is on the Cherry Grove quad sheet. Its latitude is 41°42'24" north, and its longitude is 79°15'23" west. Elevation is 571 m. The soil is moderately well drained. The slope is 1 percent, and the aspect is southeast. About 0.1 percent of the surface is covered with stones. The vegetation is black cherry, beech, and northern red oak and an understory of princess pine and fern.

Site 4 is in the North Branch area and is on the Cornplanter Bridge quad sheet. Its latitude is 41°47'00" north, and its longitude is 78°58'43" west. Elevation is 631 m. The soil is nearly level and has no surface stones. The vegetation is similar to that of site 3. About 70 percent of the canopy intercepts solar radiation.

3. Results

Jakes's Rocks site.—The soil at this site was at the cold end of mesic during the period of record (table 7.22.1). A mesic soil temperature regime has a mean annual soil temperature at 50 cm of more than 8 °C, and a frigid soil temperature regime has one of less than 8 °C (Soil Survey Staff, 1999). The MAST increased by 0.5 °C at 10 cm and 0.6 °C at 50 cm. The monthly means from July to December accounted for most of the annual increase. This pattern is similar to the increase in MAST at the 11 sites in Cattaraugus County, New York (Mount, 1999). The high MWT at 50 cm suggests that a carpet of snow insulated the soil during the winter months.

Table 7.22.1.—Soil and air temperatures (°C) for the Jake's Rocks site.

Analysis	'97-'98 10-cm	'98-'99 10-cm	'97-'98 50-cm	'98-'99 50-cm	'97-'98 Air
Jan	2.8	2.3	3.6	2.3	---
Feb	1.6	1.6	2.6	1.6	---
Mar	2.9	1.3	3.1	1.3	---
Apr	6.7	5.9	6.2	5.9	---
May	11.4	10.5	9.8	10.5	---
Jun	13.0	13.5	11.6	13.5	---
Jul	15.4	16.4	13.9	16.4	22.3
Aug	14.8	16.4	13.6	16.4	16.8
Sep	13.2	14.9	12.7	14.9	---
Oct	10.1	10.6	10.6	10.6	---
Nov	5.1	6.5	6.5	6.5	---
Dec	2.8	5.2	4.1	5.2	---
Mean	8.3	8.8	8.2	8.8	---
MST	14.4	15.4	13.1	15.4	---
MWT	2.4	3.0	3.4	3.0	---
Isotivity	12.0	12.4	9.6	12.4	---

Fool's Creek site.—Vermin activity compromised soil temperature comparisons for the second year of this study (table 7.22.2). The increase in monthly air temperature during the August to December period of 1998 indicates an increase in mean annual soil temperature similar to that of the Jake's Rocks site.

Table 7.22.2.—Soil and air temperatures (°C) for the Fool's Creek site.

Analysis	'97-'98 10-cm	'98-'99 10-cm	'97-'98 50-cm	'98-'99 50-cm	'97-'98 Air	'98-'99 Air
Jan	2.2	---	3.1	---	-0.1	-4.6
Feb	1.5	---	2.1	---	0.9	-1.7
Mar	2.9	---	2.8	---	3.0	-0.4
Apr	7.7	---	6.7	---	8.7	8.4
May	12.4	---	10.5	---	15.2	14.8
Jun	14.1	---	12.4	---	15.8	18.5
Jul	16.4	---	14.9	---	18.2	---
Aug	15.3	---	14.3	---	16.7	19.0
Sep	13.5	15.4	13.3	14.9	13.7	16.0
Oct	10.2	---	11.0	---	8.6	9.5
Nov	4.9	---	6.4	---	1.3	4.2
Dec	2.2	---	3.6	---	-1.6	0.6
Mean	8.6	---	8.4	---	8.4	---
MST	15.3	---	13.9	---	16.9	---
MWT	2.0	---	2.9	---	-0.2	-1.9
Isotivity	13.3	---	10.9	---	17.1	---

Heart's Content site.—The air temperature for January through March averaged 3.4 °C cooler during the second year than during the first year (table 7.22.3). However, the June through December period averaged 2.0 °C warmer. The summer, fall, and early winter increase in air temperature drove the MAST to increase by 0.6 °C at 10 cm and 0.4 °C at 50 cm. The soil at this site was mesic during the entire period of record.

Table 7.22.3.—Soil and air temperatures (°C) for the Heart's Content site.

Analysis	'97-'98 10-cm	'98-'99 10-cm	'97-'98 50-cm	'98-'99 50-cm	'97-'98 Air	'98-'99 Air	1999-1998 Air
Jan	3.1	3.2	3.8	3.6	-0.4	-4.9	-4.5
Feb	2.0	2.2	2.6	2.5	0.7	-1.8	-2.5
Mar	3.5	1.9	3.4	1.9	2.7	-0.6	-3.3
Apr	7.7	6.8	6.8	5.8	8.3	8.4	0.1
May	12.9	11.6	10.7	10.0	16.2	15.7	-0.5
Jun	14.4	14.3	12.6	12.7	16.5	18.1	1.6
Jul	16.6	17.3	14.9	15.6	19.2	21.2	2.0
Aug	15.5	17.1	14.4	16.0	16.9	19.2	2.3
Sep	13.8	15.6	13.4	14.9	13.9	16.5	2.6
Oct	10.6	11.8	11.0	11.9	8.8	9.3	0.5
Nov	5.1	7.5	6.4	7.9	1.2	3.9	2.7
Dec	2.8	6.1	4.0	6.4	-1.9	0.3	2.2
Mean	9.0	9.6	8.7	9.1	8.5	8.8	0.3
MST	15.5	16.2	13.9	14.8	17.5	19.5	2.0
MWT	2.6	3.8	3.5	4.2	-0.5	-2.2	-1.7
Isotivity	12.9	12.4	10.4	10.6	18.0	21.7	0.3

North Branch site.—Capture of the soil temperature data was 100 percent at this site (table 7.22.4). The MAST increased by 0.5° C at the 10- cm depth and 0.6° C at the 50-cm depth. This soil is mesic.

The trend is for the warmer summer, fall, and early winter soil temperatures to offset the cooler midwinter and spring soil temperatures for a net increase in MAST of 0.6 °C during the second year.

Table 7.22.4.—Soil and air temperatures (°C) for the North Branch site.

Analysis	'97-'98 10-cm	'98-'99 10-cm	'97-'98 50-cm	'98-'99 50-cm	'97-'98 Air
Jan	2.1	1.3	3.2	3.0	---
Feb	0.8	0.4	1.9	1.9	---
Mar	2.9	0.5	3.0	1.5	---
Apr	7.4	6.8	6.9	6.0	---
May	12.9	12.3	11.2	10.6	---
Jun	14.5	15.0	13.2	13.3	---
Jul	16.9	17.8	15.7	15.9	22.9
Aug	15.4	17.4	14.5	16.5	16.5
Sep	13.3	15.5	13.2	15.3	13.5
Oct	9.6	10.6	10.5	11.8	8.6
Nov	3.9	5.5	5.7	7.4	4.8
Dec	1.6	4.0	3.2	5.9	---
Mean	8.4	8.9	8.5	9.1	---
MST	15.6	16.7	14.5	15.2	---
MWT	1.5	1.9	2.8	3.6	---
Isotivity	14.1	14.8	11.7	11.6	---

4. Discussion

The MAST at the four sites increased, on average, by 0.4 °C during the second year. This increase is similar to that indicated in a study in nearby Cattaraugus County, New York.

Soil temperature is time-dependent and shifts either up or down with each 12-month segment of capture. Figure 7.22.1 shows, for the Jake's Rocks site, the shift in 12-month segments between July 1998 and July 1999 at the 50-cm soil depth. It indicates that the soil starts out borderline mesic-frigid (8.2 °C), migrates to the cold end of mesic during the second and third shifts, and continues to have a mesic soil temperature regime during the rest of the period of record.*

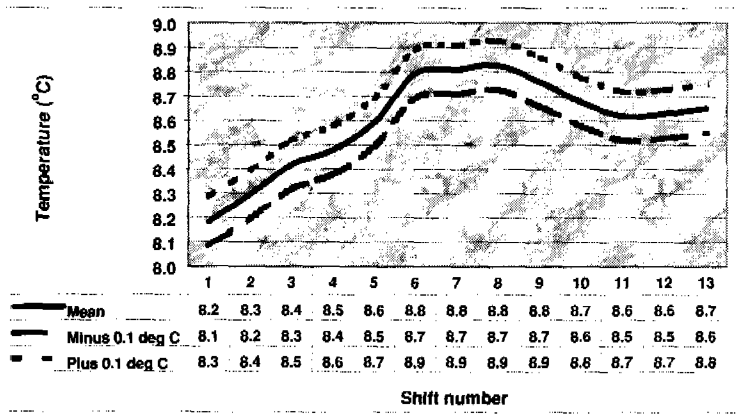


Figure 7.22.1.—Shift analysis for the 50-cm depth at the Jake's Rock site.

* The - 0.1 °C and + 0.1 °C curves are shown to display the normal accuracy limits of the StowAway loggers.

Summarized data in figure 7.22.2 clearly indicate that soil temperature regimes can shift with global climate warming, even during a short-term study. One way to handle short-term changes for correlation purposes is to determine a latitude-elevation regression based on measured data.

On March 22, 1999, a linear regression equation was generated using TableCurve software (figure 7.22.2). The measured data were derived from a site in the Great Smoky Mountains in Tennessee; a site in western Greenbrier County, West Virginia; and a northern site in Warren County, Pennsylvania. The elevation component, in meters, is where the mesic-frigid break has been measured from nearby data. With a r^2 of 0.999, this equation can be used to approximate the mesic-frigid soil temperature break on north-facing slopes for any given latitude between 35° and 43º north. The equation is as follows: Y (latitude in decimal degrees) = a + bx; where a = 46.204504; b = -0.0075558256; and x = elevation (m).

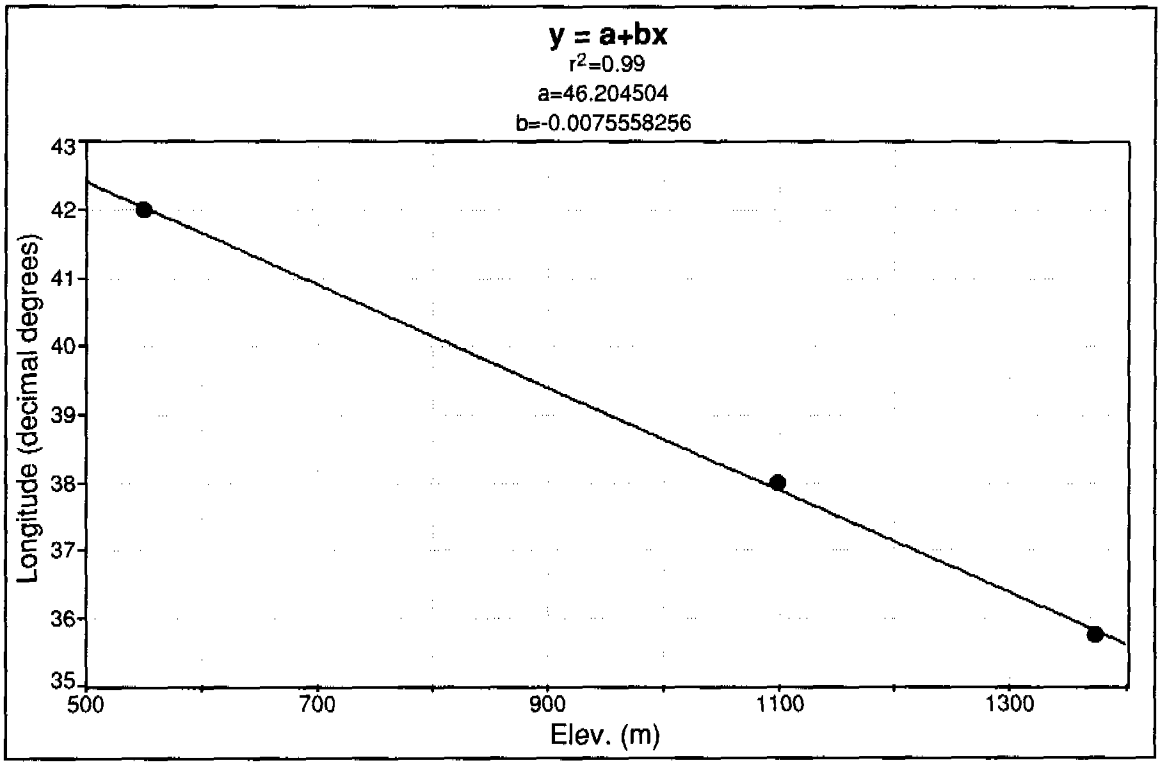


Figure 7.22.2.—Regression equation used to differentiate mesic and frigid soils in MO 13.

The regression equation expressed in figure 7.22.2 will continue to be used for correlation purposes in the Major Land Resource Area Office in Morgantown, West Virginia. It approximates conceptual temperature divisions as determined by short-term data in Warren County, Pennsylvania.

Acknowledgments

Alex Topalanchik and Roy Pyle, Soil Scientists at the MLRA Office in Morgantown, West Virginia, and Don Flegel, NRCS Soil Scientist at White Sulphur Springs, West Virginia, assisted in the installation of data loggers in this study area.

Chapter 7.23

Deep Soil Temperatures in Centre County, Pennsylvania*

ABSTRACT

The purpose of this study was to identify the variability of mean annual soil temperature among three sites in Centre County and to predict the depth of isostatic soil temperature at two of these sites. The results for all depths indicate a mesic temperature regime. The mean annual soil temperature at 25 cm increased during the second year for a forested soil at site 2 (10.2 to 10.7 °C). The annual average at 50 cm increased from 9.2 to 9.7 °C during the second year for a soil at Black Moshannon State Park (site 3). The mean winter soil temperature is the least for site 1 at Rock Spring (3.4 °C) and is indicative of a grass cover. The results for the 100-cm soil depth also showed an increase in annual temperature during the second year. The annual average increased at a forest site near Rock Spring (10.0 to 10.2 °C). This increase is attributed to an increase in summer soil temperature (5.7 to 6.0 °C). The winter soil temperature at the Rock Spring site is the lowest at 5.2 °C and is indicative of the grass cover. The mean annual soil temperature for the 160-, 165-, and 200-cm depths increased during the second year at the forested site (9.7 to 10.2 °C) and at the third site, in Black Moshannon State Park (9.0 to 9.5 °C). At 8.5 °C, the winter soil temperature at Rock Spring is the warmest of the three sites. The spring temperatures from March to May increased during the second year at the forested sites, especially during March. The soil at Black Moshannon State Park had the lowest mean annual temperature during the study (9.0 and 9.5 °C) and the lowest isotivity values (difference in mean summer and mean winter soil temperatures). The isotivity value for the forested soil at site 2 increased slightly during the second year of the study from 5.9 to 6.0 °C. There was a difference in mean annual soil temperature by depth and by site. The MAST of the soil at the Rock Spring site ranged from 11.1 to 11.6° C, for a variability of 0.5 °C. The forested soil at site 2 ranged from 10.2 to 10.7°C, for a variability of 0.5°C, and the soil in Black Moshannon State Park ranged from 9.7 to 9.5 °C. This variability of mean annual soil temperature within soil depths may be a function of several factors, i.e., a seasonal high water table and/or variations in particle size. The depth at which soil temperature remains constant throughout the year (isostatic temperature) was predicted using the straight-line formula $x = a+bx$. For the soil with a grass cover, the depth is 236 cm, and for the forested soil at site 2, the depth is 280 cm. All curvilinear formulas generated in TableCurve 2D v5 indicate the depth of isostatic soil temperature to be 6 meters.

1. Background and Purpose

Soil scientists in the United States normally collect soil temperature measurements at a depth of 50 cm. These measurements determine the temperature regime of a soil for classification purposes (Soil Survey Staff, 1999). Deeper measurements are needed for many other purposes. Some data from Mount, Schaefer, and Werner (1997) are from 21 sites in the Soil Moisture-Soil Temperature Network. Additional data are needed for Pennsylvania to complement the studies of Carter and Ciolkosz (1980) and Waltman et al. (1997). Therefore, a study was designed in Centre County, Pennsylvania, to collect soil temperature data at deep depths for 2 years.

The purpose of this study was to identify the variability of mean annual soil temperature (MAST) among three sites in Centre County, to provide deep soil temperature data, and to predict the depth of isostatic soil temperature.

* Dr. Ed Ciolkosz, Professor of Soil Genesis at Penn State University, and Alex Topalanchik, Roy Pyle, and Robert Dobos, Soil Scientists on the MO 13 staff in Morgantown, West Virginia, assisted in preparing this section.

2. Study Area

Pennsylvania State University is in Centre County, in central Pennsylvania. Information about the three sites in the study area is presented in table 7.23.1

Table 7.23.1.—Metadata for the three sites in Centre County.

Site number	Latitude (north)	Longitude (west)	Soil name	Elevation (m)	Slope (%)	Aspect (°)
1	40° 43'08"	77° 56'01"	Murrill	372	2	180
2	40° 49'06"	77° 52'29"	Morrison	341	2	89
3	40° 54'32"	77° 05'06"	Clymer	603	4	240

Site 1 is at the Rock Spring Agricultural Experiment Station, which is managed by Penn State University (figure 7.23.1). The vegetation is a mowed grass buffer strip. The Murrill soil at this site formed in colluvium over limestone residuum at about 105 cm. Murrill soils are fine, mixed, semiactive, mesic Typic Hapludalfs. They have less than 5 percent rock fragments.

Figure 7.23.1.—Numerous weather stations collect data at the Rock Spring site.

Site 2 is forested with white and red oaks (*Quercus spp. L.*), black cherry (*Prunus spp. L.*), and red maple (*Acer spp. L.*). The understory consists of black cherry and hickory (*Carya spp. L.*), and the ground cover consists of blackberry (*Rubus spp. L.*) and ferns. The mineral soil surface is covered with 1 cm of deciduous leaves. The Morrison soil at this site formed in sandstone residuum and has common hard sandstone rock fragments throughout. Morrison soils are fine-loamy, mixed, active, mesic Ultic Hapludalfs.

Site 3 is in an area forest land in Black Moshannon State Park. The vegetation consists of an overstory of black oak (*Quercus spp. L.*), red maple (*Acer spp. L.*), serviceberry (*Amelanchier spp. L.*), eastern white pine (*Pinus strobis L.*), mountain holly (*Ilex spp. L.*), and witch hazel and an understory of rattlesnake fern, huckleberry (*Vaccinium spp. L.*), mountain laurel (*Laurus spp. L.*), and blueberry (*Vaccinium spp L.*). The canopy cover is estimated to be 60 percent, and the understory cover is estimated to be 80 percent. The mineral soil surface is covered with about 5 cm of humus in varying states of decomposition. The Clymer soil at this site formed in sandstone residuum. Clymer soils are fine-loamy, mixed, active, mesic Typic Hapludults.

3. Results

Analysis of data for 25 cm.—Complete 2-year data were available only for site 2. Site 1 had partial data for the first year and complete data for the second year, while site 3 had complete data for the first year (table 7.23.2).

Table 7.23.2.—Temperatures (°C) for the 25-cm soil depth.

Analysis	Site 1	Site 2	Site 3	Analysis	Site 1	Site 2
Jan 99	-0.4	1.1	2.2	Jan 00	1.2	3.3
Feb 99	1.6	1.7	2.1	Feb 00	1.1	2.9
Mar 99	2.2	2.7	2.2	Mar 00	5.5	6.1
Apr 99	8.6	8.0	6.6	Apr 00	8.9	8.7
May 99	12.5	12.2	10.7	May 00	14.8	13.3
Jun 99	---	15.0	13.6	Jun 00	19.5	16.2
Jul 99	---	18.4	16.1	Jul 00	20.3	16.8
Aug 98	21.6	18.4	16.7	Aug 99	21.6	17.9
Sep 98	19.2	17.0	15.6	Sep 99	18.2	16.2
Oct 98	13.0	12.6	11.6	Oct 99	11.5	11.7
Nov 98	7.1	8.2	7.5	Nov 99	8.1	9.6
Dec 98	5.0	6.7	4.1	Dec 99	3.2	5.5
Mean	---	10.2	9.1	Mean	11.1	10.7
MST	---	17.3	15.4	MST	20.4	17.0
MWT	2.1	1.1	2.8	MWT	1.8	3.9
Isotivity	---	16.2	12.6	Isotivity	18.6	13.1

Results for the 25-cm soil depth are indicative of a mesic temperature regime. The MAST increased during the second year at site 2 (10.2 to 10.7 °C). This increase is attributed to an increase in MWT (1.1 to 3.9 °C). The MWT at site 1 actually decreased from 2.1 to 1.8 °C. However, the spring temperatures from March to May increased during the second year, especially during March (2.2 to 5.5 °C). Consequently, it is conjectured that the MAST increase is similar to that at site 2. Site 3 had the lowest MAST during the study and the lowest isotivity value (12.6 °C). However, the isotivity value at site 2 decreased during the second year of the study from 16.2 to 13.1 °C. Much of this reduction is attributed to an increase in MWT during the second year.

Analysis of data for 50 cm.—Complete 2-year data were available only for site 3. Site 1 had partial data for the first year and complete data for the second year, while site 2 had complete data for the second year (table 7.23.3). The results for the 50-cm soil depth are indicative of a mesic temperature regime. The MAST increased during the second year at site 3 (9.2 to 9.7 °C). This increase is attributed to an increase in MST (13.9 to 14.5 °C). The MWT is the least at site 1 (3.4 °C) and is indicative of a grass cover. The spring temperatures from March to May at site 3 increased during the second year, especially during March (2.9 to 5.0 °C). Site 3 had the lowest MAST during the study and the lowest isotivity values (9.4 °C and 9.7 °C).

Table 7.23.3.—Temperatures (°C) for the 50-cm soil depth.

Analysis	Site 1	Site 3	Analysis	Site 1	Site 2	Site 3
Jan 99	---	3.4	Jan 00	2.8	4.3	4.3
Feb 99	---	3.1	Feb 00	2.1	3.4	3.4
Mar 99	---	2.9	Mar 00	5.5	6.1	5.0
Apr 99	---	6.2	Apr 00	8.2	8.2	6.9
May 99	---	9.6	May 00	13.3	12.3	10.6
Jun 99	---	12.2	Jun 00	17.5	14.9	13.3
Jul 99	---	15.1	Jul 00	19.0	15.9	14.5
Aug 98	20.4	15.5	Aug 99	20.8	17.1	15.6
Sep 98	18.7	14.8	Sep 99	18.3	15.9	14.8
Oct 98	13.9	12.1	Oct 99	13.0	12.3	11.9
Nov 98	8.5	8.5	Nov 99	9.4	10.1	9.6
Dec 98	8.5	7.1	Dec 99	5.3	6.7	6.5
Mean	---	9.2	Mean	11.3	10.6	9.7
MST	---	13.9	MST	19.1	16.0	14.5
MWT	---	4.5	MWT	3.4	4.8	4.7
Isotivity	---	9.4	Isotivity	15.7	11.2	9.7

Analysis of data for 100 cm.—Complete 2-year data were available only for site 2. Site 1 had complete data for the second year, while site 3 was inoperative for the period of record (table 7.23.4). The results for the 100-cm soil depth showed an increase in MAST during the second year. The MAST increased at site 2 (10.0 to 10.2 °C). This increase is attributed to an increase in MST (5.7 to 6.0 °C). At 5.2 °C, the MWT at site 1 is the lowest in the study area and is indicative of a grass cover. The spring temperatures from March to May increased during the second year at site 2, especially during March (3.9 to 5.9 °C). Site 3 had the lowest MAST (10.0 and 10.4 °C) and the lowest isotivity value (8.7 and 8.5 °C). The isotivity value at site 2 decreased during the second year of the study. Much of this reduction is attributed to an increase in MWT during the second year.

Table 7.23.4.—Temperatures (°C) for the 100-cm soil depth.

Analysis	Site 2	Analysis	Site 1	Site 2
Jan 99	4.6	Jan 00	4.8	5.6
Feb 99	3.8	Feb 00	3.4	4.3
Mar 99	3.9	Mar 00	5.4	5.9
Apr 99	6.9	Apr 00	7.6	7.6
May 99	10.1	May 00	11.2	10.8
Jun 99	12.4	Jun 00	14.7	13.1
Jul 99	15.0	Jul 00	17.0	14.6
Aug 98	15.9	Aug 99	18.7	15.8
Sep 98	15.6	Sep 99	17.6	15.3
Oct 98	13.4	Oct 99	14.1	12.7
Nov 98	10.2	Nov 99	10.6	10.6
Dec 98	8.7	Dec 99	7.5	8.0
Mean	10.0	Mean	11.1	10.4
MST	14.4	MST	16.8	14.5
MWT	5.7	MWT	5.2	6.0
Isotivity	8.7	Isotivity	11.6	8.5

Analysis of data for deepest soil depth.—One objective of this study was to monitor soil temperature at 2 m. While site 1 was monitored at this depth, excavation difficulties limited the deepest depth to 167 cm at site 2 and 160 cm at site 3. Complete 2-year data were available only for sites 2 and 3. Site 1 had complete data for the second year (table 7.23.5). The results for the deepest soil depth are indicative of a mesic temperature regime. The MAST increased during the second year at site 2 (9.7 to 10.2 °C) and at site 3 (9.0 to 9.5 °C). This increase is attributed to an increase in both MST and MWT at these sites. At 8.5 °C, the MWT at site 1 is the warmest of the three sites. The spring temperatures from March to May increased during the second year at sites 2 and 3, especially during March. Site 3 had the lowest MAST during the study (9.0 and 9.5 °C) and the lowest isotivity values (5.0 and 5.1 °C). The isotivity value at site 2 increased slightly during the second year of the study from 5.9 to 6.0 °C.

Table 7.23.5.—Temperatures (°C) for the deepest soil depths.

Analysis	Site 2	Site 3	Analysis	Site 1	Site 2	Site 3
Jan 99	6.2	6.1	Jan 00	8.2	6.9	6.7
Feb 99	4.7	5.0	Feb 00	6.8	5.4	5.4
Mar 99	4.5	4.3	Mar 00	6.9	6.1	5.6
Apr 99	6.2	5.7	Apr 00	8.2	7.4	6.5
May 99	8.7	7.7	May 00	10.2	9.7	8.6
Jun 99	10.8	9.8	Jun 00	12.7	11.7	10.6
Jul 99	13.0	12.1	Jul 00	15.0	13.4	12.3
Aug 98	14.2	12.9	Aug 99	16.7	14.3	13.2
Sep 98	14.4	13.2	Sep 99	16.7	14.5	13.4
Oct 98	13.3	12.3	Oct 99	15.1	12.9	12.2
Nov 98	10.9	10.1	Nov 99	12.7	11.0	10.5
Dec 98	9.4	8.7	Dec 99	10.6	9.1	8.7
Mean	9.7	9.0	Mean	11.6	10.2	9.5
MST	12.7	11.6	MST	14.8	13.1	12.0
MWT	6.8	6.6	MWT	8.5	7.1	6.9
Isotivity	5.9	5.0	Isotivity	6.3	6.0	5.1

Figure 7.23.2 shows the relationship of the deepest depth among the three sites during the second year of the study.

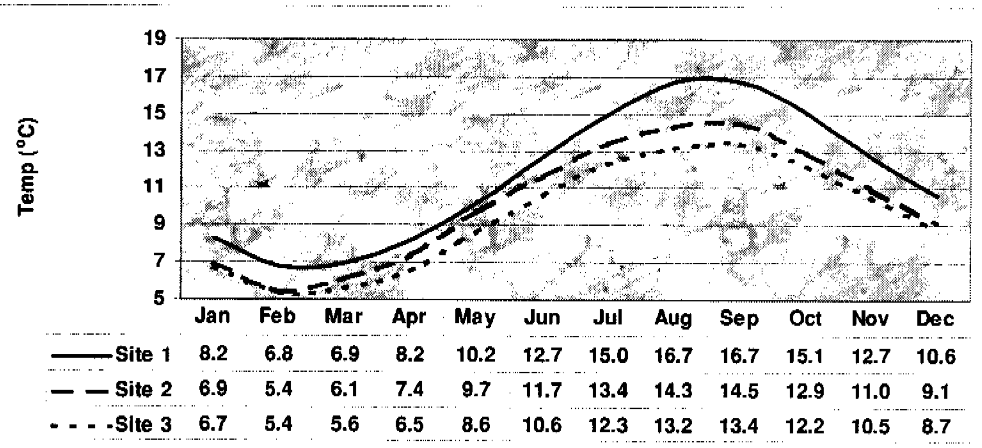


Figure 7.23.2.—Average monthly soil temperatures for the three sites during the second year.

Figure 7.23.2 shows that there are distinct signatures for soil temperatures at deep depths. It also shows that there is more isotivity than was suspected, i.e., the sine wave nature of soil temperature at deep depths is still apparent.

Variability of MAST.—The 50-cm depth for measuring MAST is arbitrary. Arguments can be made to define a shallower or deeper depth. At sites borderline to two different temperature regimes, it is possible to have a different regime at 10 cm than at 50 cm. For instance, unpublished data for a south aspect site in the Smoky Mountains of Tennessee showed a frigid regime at 10 cm and a regime at the cold end of mesic at 50 cm. Softwood trees at this site likely are more affected by the 10-cm soil depth than by the 50-cm depth. In the Centre County study, there was a difference in MAST by depth and by site. Table 7.23.6 shows these differences for the 1999 to 2000 period of record.

Table 7.23.6.—Variability of MAST by depth in Centre County.

Site no.	25 cm (°C)	50 cm (°C)	100 cm (°C)	Deepest depth (°C)	Variability (°C)
1	11.1	11.3	11.1	11.6	0.5
2	10.7	10.6	10.4	10.2	0.5
3	---	9.7	---	9.5	0.2

The MAST at site 1 ranged from 11.1 to 11.6 °C, for a variability of 0.5 °C. The MAST at site 2 ranged from 10.2 to 10.7 °C, for a variability of 0.5 °C, and the MAST at site 3 ranged from 9.7 to 9.5 °C. This variability of MAST within soil depths during the same period of record is noteworthy. It may be a function of several factors, e.g., a seasonal high water table. A study of in the Caribbean island of St. John in the Virgin Islands by Mount et al. (1995) showed the variability of MAST in soils of this tropical island to be within 0.1 °C.

Isostatic soil temperatures in central Pennsylvania.—One value of collecting soil temperature data at depths greater than 50 cm is assessment of deep isotivity values. Theoretically, with these data, it is possible to predict the depth at which soil temperature remains nearly constant throughout the year. The reduction in isotivity value by depth is shown in table 7.23.7 and in figures 7.23.3 and 7.23.4. The r^2 for the expression of reduced isotivity with depth is 99 for site 1 and 98 for site 2.

Predicting the depth of negligible isotivity (isostatic temperature) is achieved by solving for x in the formula $y = a+bx$, or $x = (y-a)/b$, where y is set to 0 °C. Extrapolation of a linear regression is normally not done and is shown only for discussion purposes. The depth is 236 cm for site 1 and 280 cm for site 2. This prediction is based on a straight-line function, which might be invalid. However, all curvilinear formulas examined in TableCurve 2D v5 indicate the depth of isostatic soil temperature to be somewhat less than 6 meters.

Table 7.23.7.—Decreasing isotivity values (°C) at sites 1 and 2.

Analysis	Site 1	Site 2
25 cm	18.6	13.1
50 cm	15.7	11.2
100 cm	11.6	8.5
165 cm	6.3	6.0

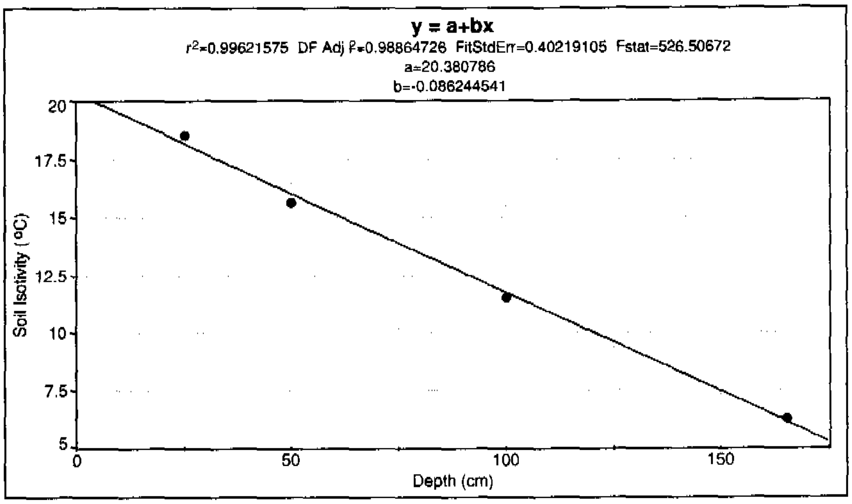


Figure 7.23.3.—The reduction in soil isotivity (°C) with depth at site 1.

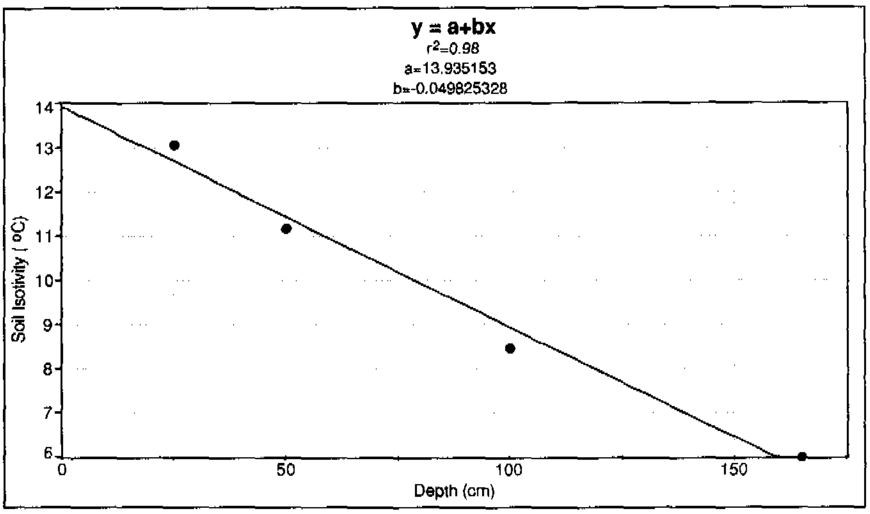


Figure 7.23.4.—The reduction in soil isotivity (°C) with depth at site 2.

4. Discussion

Soil temperature data at depths greater than 50 cm have value in the soil science community. Interpretation of these data can lead to a better understanding of the dynamics of soil temperature throughout a 2-meter column of soil. Perhaps the most valuable aspect of attaining temperature data at deep depths is assessment of the variability of MAST and prediction of the depth of isostatic temperature, as was done in the Centre County study.

The depth of measurement for determining the MAST of a soil is 50 cm (Soil Survey Staff, 1999). Though this depth provides a valuable common frame of reference for correlation activities in the Soil Survey Division, it shortcuts the knowledge about soil temperature throughout the soil column. It is this knowledge which will lead to a better understanding of the morphology and genesis of soils within a survey area.

Acknowledgment

Don Flegel, NRCS Soil Scientist at White Sulphur Springs, West Virginia, assisted in the installation of data loggers in this study area.

Chapter 7.24

Soil Temperature Study for a Hilltop on Vieques Island, Puerto Rico

ABSTRACT

Daily soil temperatures for depths of less than 10 cm had not been documented, summarized, and discussed within the Natural Resources Conservation Service before the design of this project in August 1997. The mean for the air temperature during the period of record was 28.0 °C. This was nearly identical to the mean August air temperature (28.1 °C). The minimum air temperature (23.9 °C) occurred on August 8 at 5:05 a.m. and then in three continuous readings on August 10 at 10:09 a.m., at 10:15 a.m., and at 10:22 a.m. The maximum air temperature (36.8 °C) occurred at 1:59 p.m. on August 12 and again at 2:38 p.m. the same day. The mean for the 2.5-cm soil depth during the period of record was 27.5 °C. The minimum 2.5-cm soil temperature (25.4 °C) occurred on August 10 at 10:23 a.m., following a rain shower. The maximum 2.5-cm soil temperature (31.3 °C) occurred at 2:45 p.m. on August 8. Soil temperature fluctuations (extreme maximum minus extreme minimum) were less at 5 cm than at 2.5 cm (3.3 vs. 5.9 °C). The mean for the 5-cm soil depth during the period of record was 27.3 °C. This was 0.2 °C cooler than that for the 2.5-cm depth. The minimum air temperature of 25.9 °C occurred on August 11 at 55 different times throughout the morning hours. The maximum air temperature of 29.2 °C occurred on August 7 at 7:02 p.m. and again on August 8 for 13 continuous readings starting at 2:22 p.m. and ending at 3:50 p.m. The air temperature fluctuated 12.9 °C during the period of record. This fluctuation was followed by the intermediate fluctuation of the 2.5-cm soil depth (5.9 °C) and the lower fluctuation of the 5-cm soil depth (3.3 °C). Temperature results for this study support the original hypotheses. At shallow soil depths, the diurnal fluctuations on Vieques Island are consistent with the air temperature inputs. The relationship of diurnal fluctuation for soil temperature and increasing depth is curvilinear for the soils on Vieques Island.

1. Background and Purpose

Current development of monitoring equipment has eased the challenge of collecting nearly continuous temperature data for short-term studies. Over 4,000 readings can now be recorded for a 6-day study, even in a remote area, such as Vieques Island, Puerto Rico. The Hobo XT1 Temperature Loggers from Onset Computer Corporation capture data at intervals ranging from every 15 seconds to every 4 hours and 48 minutes. These data are stored internally and can be off-loaded through software at the convenience of the designers of the study. Moreover, the advantage of being on the site while loggers collect data allows for verification and interpretation of the data.

The purpose of this study was to capture data to verify the notion that the diurnal fluctuation of air temperature would be greater than the soil temperature at either 2.5 or 5 cm. Another purpose was to quantify the differences in diurnal fluctuation among air temperature and soil temperatures at 2.5 cm and 5 cm.

2. Study Area

Vieques Island is between latitude 18°5' and 18°10' north and longitude 65°10' and 65°32' west. It is separated from the nearest point on the eastern coast of Puerto Rico by the 10-km-wide Vieques Passage.

Vieques is the largest of the numerous small islands adjacent to and politically attached to Puerto Rico. At the end of the Spanish-American War in 1898, Vieques along with Puerto Rico was ceded to the U.S. Their people became U.S. citizens in 1917. In 1952, the islands of Vieques, Culebra, and Mona and Puerto Rico were joined into the Commonwealth of Puerto Rico. Vieques got little attention in the twentieth century until 1948, when the U.S. Navy acted on a 1942 authorization of the U.S. Congress and took 70 percent of the island. This portion of Vieques Island has been placed under the jurisdiction of the Roosevelt Roads Naval Base, at the eastern end of Puerto Rico (Lugo-López et al., 1953).

The site for this 6-day study is in the northeastern part of Isabel Segunda, the capital of Vieques. It is on a private residence known as the Villa Vista Bella, near the height of land where waters flow to the north and south. Site information for the study area is given in table 7.24.1.

Table 7.24.1.—Site information for the 6-day temperature study on Vieques Island.

Site attribute	Property or value
Location	Villa Vista Bella Estate, Isabel Segunda, Vieques Island, Puerto Rico, about 3 m west of the northeast corner of the property, beside a flowering hibiscus hedge.
Latitude	18°10'05"
Longitude	65°25'10"
Elevation	About 150 m
Vegetation	Hibiscus (*Hibiscus spp. L.*) hedge with an understory of grasses
Slope	10 percent, on a convex backslope within 5 m of the ridgetop summit
Aspect of slope	10 degrees
Geology	Andesitic tuff (Lugo-López, et al., 1953).
Soil	Descalabrado clay, rolling phase. Surface color is 10YR 3/3. Descalabrado soils are clayey, mixed, superactive, isohyperthermic Lithic Haplustolls.
Soil burrows	Tarantula holes with a 2-cm diameter forming a repeating two-dimensional tetrahedral pattern.
Surface stone cover	None

3. Methods

Prior to installation, three Hobo XT1 data loggers were programmed to record air and soil temperature data every 6 minutes and 24 seconds. The period of record for this study is from August 7, 1997, at 7 p.m. Atlantic Standard Time, to August 13, 1997, at 7 p.m., or 6 days.

Soil temperature sensors were placed at 2.5 and 5 cm in a Descalabrado soil that is thinly covered by tropical grasses at the Villa Vista Bella Estate in Isabel Segunda. The sun does not shine directly onto the soil for more than 1 hour each day. The air temperature sensor was placed on a hibiscus hedge at a height of 1 m. The active part of the sensor was not exposed to the sun.

The data loggers were recovered on August 14, 1997, at 7 a.m., and data were off-loaded on August 15, 1997, in Lincoln, Nebraska. Though 1,463 temperature recordings were available from each sensor, only 1,350 data points (6 complete days) are used in this report (table 7.24.2).

Table 7.24.2.—Sensor type and period of record.

Sensor type	Beginning date	Ending date	Readings (number)
1	8/07/97 at 7:00 p.m.	8/13/97 at 6:54 p.m.	1,350
2	8/07/97 at 7:01 p.m.	8/13/97 at 6:55 p.m.	1,350
3	8/07/97 at 7:02 p.m.	8/13/97 at 6:55 p.m.	1,350

4. Diurnal Fluctuation of Temperature

Air temperature.—Air temperature drives the diurnal fluctuation of soil temperature. Therefore, for a complete understanding of the nature of soil temperature data at any depth, it is imperative that air temperature be collected within the same study area and preferably within a few meters of the soil temperature sensors. The air temperature data for the study area are shown in figure 7.24.1.

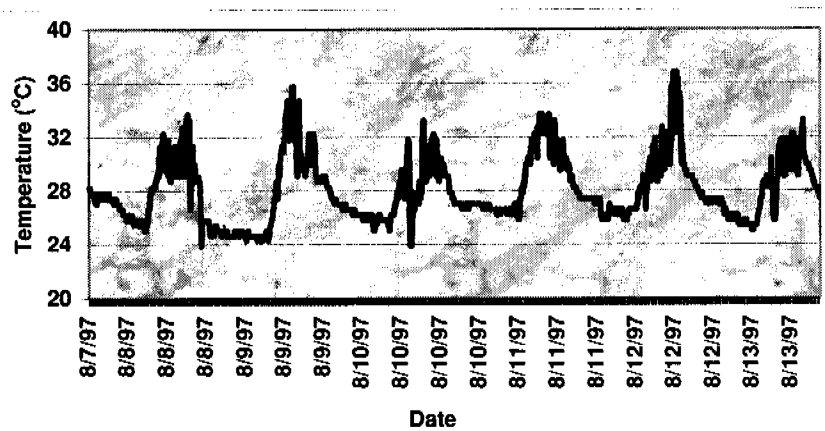


Figure 7.24.1.—Air temperature signature for the 6-day study on Vieques Island.

The mean air temperature during the period of record was 28.0 °C. This is nearly identical to the mean August air temperature (28.1 °C) indicated by Lugo-López et al. (1953). The minimum air temperature (23.9 °C) occurred on August 8 at 5:05 a.m. and again in three continuous readings on August 10 at 10:09 a.m., at 10:15 a.m., and at 10:22 a.m. The maximum air temperature (36.8 °C) occurred at 1:59 p.m. on August 12 and again at 2:38 p.m. the same day.

The air temperature fluctuation was greatest on August 10, when many passing showers briefly lowered the air temperature at the study site. Figure 7.24.2 graphs the air temperature for August 10, 1997, in the study area. This graph represents 225 measured readings.

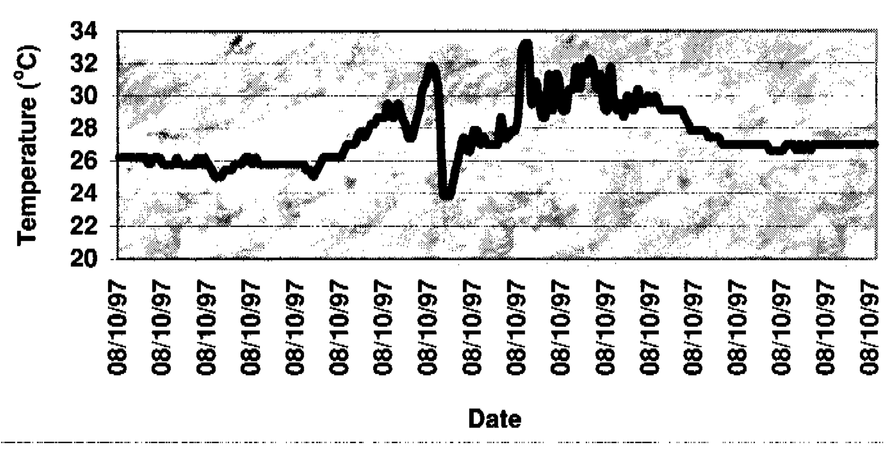


Figure 7.24.2.—The air temperature in the study area on August 10, 1997.

Soil temperature at 2.5 cm.—As shown by other researchers in the Caribbean (Mount et al., 1993 and 1995, and Mount, Paetzold, and Cortes-Colon, 1997), the soil temperature values deviated much less than the air temperature readings. Figure 7.24.3 graphs the 2.5-cm soil temperature in the study area.

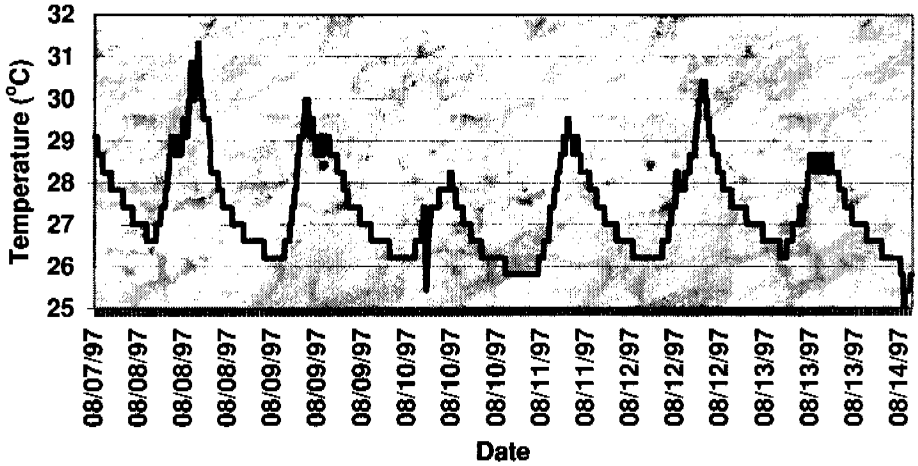


Figure 7.24.3.—Soil temperature signature at 2.5 cm for the 6-day study.

The mean for the 2.5-cm soil depth in the study area during the period of record was 27.5 °C. The minimum 2.5-cm soil temperature (25.4 °C) occurred on August 10 at 10:23 a.m., following a rain shower. The maximum 2.5-cm soil temperature (31.3 °C) occurred at 2:45 p.m. on August 8.

Soil temperature at 5 cm.—Figure 7.24.4 graphs the 5-cm soil temperature in the study area.

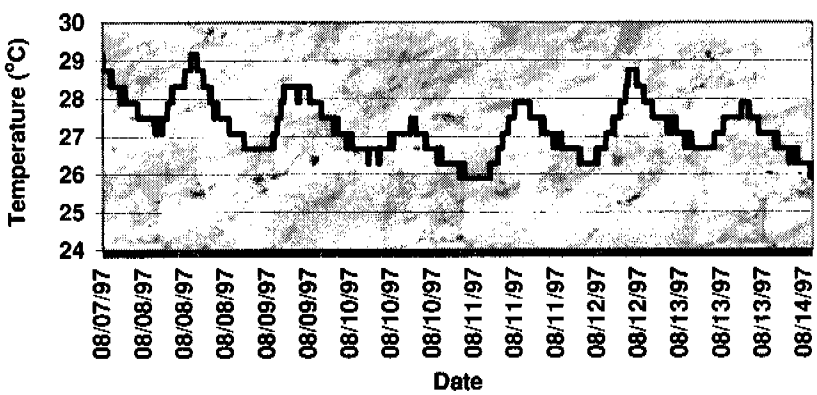


Figure 7.24.4.—Soil temperature signature at 5 cm.

Soil temperature at 5 cm fluctuated less than that at the 2.5-cm soil depth (3.3 vs. 5.9 °C). The mean for the 5-cm soil depth during the period of record was 27.3 °C. This is 0.2 °C cooler than the mean for the 2.5-cm depth. The minimum air temperature (25.9 °C) occurred on August 11 at 55 different times throughout the morning hours. The maximum air temperature (29.2 °C) occurred on August 7, 1997, at 7:02 p.m. and again on August 8, 1997, in 13 continuous readings starting at 2:22 p.m. and ending at 3:50 p.m.

Comparison of soil temperatures at 2.5 cm and 5 cm.—The relationship between the 2.5- and 5-cm soil temperature readings is graphed in figure 7.24.5. The 5-cm depth fluctuated less than the 2.5-cm depth, and its mean is slightly cooler for the period of record. The 5-cm depth is warmer during the evening hours and cooler during the afternoon. It also is less impacted by the brief showers that occurred during the period of record (Mount, H.R, 1997, "Vieques Journal, 8/7/97 to 8/14/97," unpublished data.).

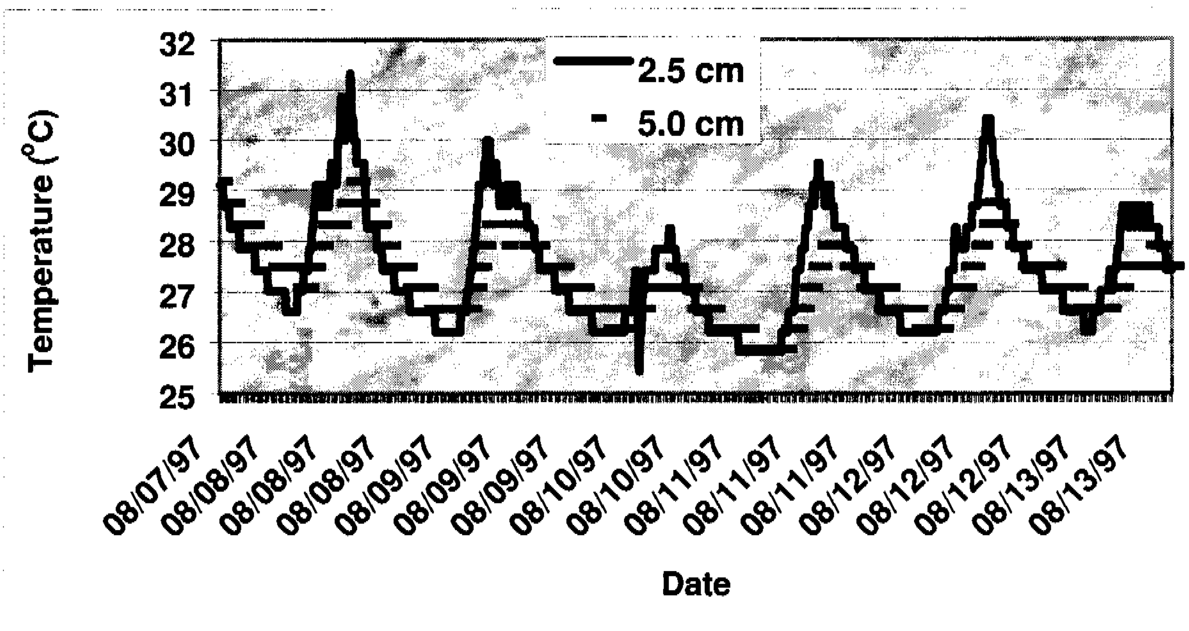


Figure 7.24.5.—Relationship of the soil temperature signatures at 2.5 cm and 5 cm.

5. Temperature Summaries

The relationship of all the air and soil temperature readings during the period of record is shown in figure 7.24.6 and in table 7.24.2.

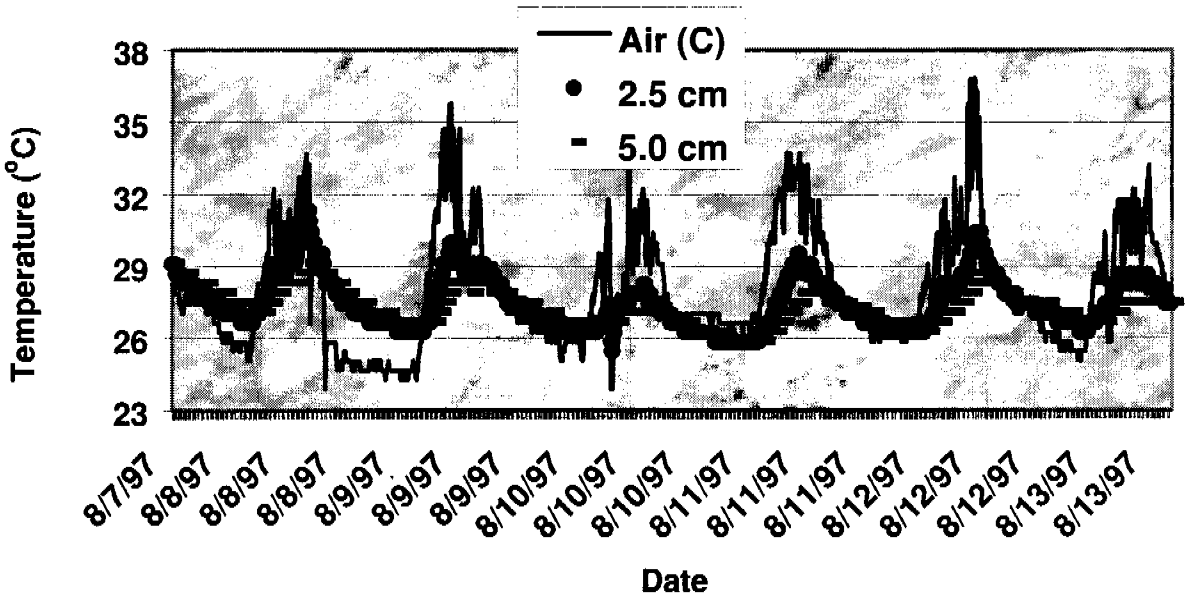


Figure 7.24.6.—Relationship between air temperature and soil temperature readings.

The air temperature fluctuated 12.9 °C during the period of record. This fluctuation was followed by an intermediate fluctuation at 2.5-cm and the lowest fluctuation at 5 cm (3.3 °C).

Table 7.24.2.—Summary of air and soil temperatures.

Sensor (kind)	Min. (°C)	Date and time	Max. (°C)	Date and time	Mean (°C)
Air	23.9	8/8 @ 5:05 a.m.	36.8	8/12 @ 1:59 p.m.	28.0
Air	23.9	8/10 @ 10:09 a.m.	36.8	8/12 @ 2:38 p.m.	28.0
Air	23.9	8/10 @ 10:15 a.m.	---	---	28.0
Air	23.9	8/10 @ 10:22 a.m.	---	---	28.0
2 cm	25.4	8/10 @ 10:23 a.m.	31.3	8/8 @ 2:45 p.m.	27.5
5 cm	25.9	55 times during 8/11	29.2	8/7 @ 7:02 p.m.	27.3
5 cm	---	---	29.2	13 times during 8/8	27.3

6. Discussion

Daily soil temperatures for depths of less than 10 cm had not been documented, summarized, and discussed within the NRCS before the design of this project. Temperature results for this study support studies in the Virgin Islands. At shallow soil depths, the diurnal fluctuations on Vieques Island are consistent with the air temperature inputs. The daily air temperature fluctuated 12.9 °C during the period of record. This fluctuation was followed by an intermediate fluctuation (5.9 °C) for the 2.5-cm soil depth and the lowest fluctuation (3.3 °C) for the 5-cm soil depth. Russian research has indicated that diurnal fluctuation ceases at the 30-cm soil depth for most soils (Shul'gin, 1965). Consequently, the relationship of diurnal fluctuation for soil temperature and increasing depth is curvilinear for soils on Vieques Island.

Chapter 7.25

Soil Temperature Regimes on Edisto Island, South Carolina*

ABSTRACT

Soils on Edisto Island have a thermic soil temperature regime. The mean annual soil temperatures at 10 cm and at 50 cm are not identical in this study area. The 50-cm soil depth is 0.3°C warmer than the 10-cm soil depth (19.5 vs. 19.2 °C). Based on vegetative cover, the two soils on coastal sand dunes within 30 meters of the Atlantic Ocean have a larger difference in mean annual soil temperature at 50 cm than was originally expected. In addition, the difference between their mean summer and mean winter soil temperatures at 50 cm was greater than was originally conjectured. The soil at the partially vegetated coastal sand dune site has an isotivity value of 12.6 °C, while the soil at the vegetated coastal sand dune site has an isotivity value of 9.6 °C. *Soil Taxonomy* requires that isotivity values be less than or equal to 6 °C for the temperature regime to be "iso." With a value of 7.0 °C, the soil at site 4 came the closest to meeting the "iso" definition. This study rules out the possibility of isothermic temperature regimes along the Atlantic Seaboard, at least from Maine to Edisto Island. While it is possible that an isothermic or isohyperthermic soil temperature regime might occur near Savannah, Georgia, or in areas to the south, the question of where "iso" temperature regimes start remains unanswered.

1. Background and Purpose

The National Soil Survey Center's Remote Soil Temperature Network was initiated in 1996 to acquire a soil temperature database for all of the United States. Hobo/StowAway temperature loggers were selected to capture air and soil temperature data from remote sites. The South Carolina Sea Island Global Change Project on Edisto Island, approved in 1996, provides temperature data that will supplement currently approved Global Change Projects in the Caribbean area, Idaho, Illinois, Iowa, Nebraska, New Hampshire, New York, North Carolina, Tennessee, Virginia, West Virginia, and Wyoming.

Following approval, eight sites were selected on Edisto Island for the installation of loggers to capture annual air and soil temperature data. Seven of these sites included the primary vegetative zones of the island. Site 5 was is on a partially vegetated coastal sand dune adjacent to the Atlantic Ocean. A total of 24 StowAway temperature loggers with 1.8-m temperature sensor leads were installed at the eight sites on November 18 and 19, 1996.

The primary purpose of this study is threefold: 1) to verify the thermic soil temperature regime on Edisto Island, 2) to identify the presence of a hypothesized isothermic soil temperature regime on coastal sand dunes adjacent to the Atlantic Ocean, and 3) to determine if any of the sites attain biological zero (5 °C) during the period of record.

2. Study Area

Edisto Island is a sea island in southeastern South Carolina. The latitude ranges from 32°29'51" to 32°34'59" north, and the longitude ranges from 80°13'58" to 80°19'13" west. All sites are within 8 km of each other. Their elevation is less than 8 meters above sea level. Each site is fully vegetated, except for site 5, which is a partially vegetated coastal sand dune. Sites 5, 6, 7, and 8 are either within 30 meters of

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* Ben Stuckey, NRCS State Soil Scientist, Columbia, South Carolina, and Bob Eppinette, NRCS Resource Soil Scientist, Walterboro, South Carolina, assisted in preparing this section.

the Atlantic Ocean or in a tidal marsh environment. The coastal sand dunes at sites 5 and 6 are less than 400 meters apart. Table 7.25.1 gives differentiating site characteristics.

Table 7.25.1.—Differentiating characteristics of the eight sites on Edisto Island.

Site number	Soil name	Slope (%)	Aspect (°)	Vegetation
1	Echaw	0	Neutral	Cabbage palmetto, cherry, and honeysuckle
2	Foxworth	0	Neutral	Mature live oak glade and muscadine grape vines
3	Foxworth	0	Neutral	Loblolly pine and cedar
4	Coosaw	0	Neutral	Magnolia, sweetgum, and loblolly pine
5	Newhan	7	300	Palmetto, yucca, sweetgrass, and seaoxeye
6	Fripp	12	2	Live oak and palms
7	Foxworth	25	270	Mature live oak, palmetto, and youpon holly
8	Chipley	0	Neutral	Mature live oak, loblolly seedlings, and honeysuckle

The soils at the sites are in the sandy particle-size-class, except for the soil site 4, which is in a loamy particle-size class. The soils are Quartzipsamments or Alorthods, except for the Coosaw soil at site 4, which is an Arenic Hapludult (Soil Survey Staff, 1999). The soils at sites 1 and 8 have a seasonal high water table above 1 meter, while the other soils are either excessively drained or well drained.

3. Average Readings From Eight Sites on Edisto Island

Averages of 1,800 annual temperature readings were calculated for mean annual air temperature (MAAT), mean annual soil temperature (MAST) at 10 cm, and MAST at 50 cm. The MST for June, July, and August and the MWT for December, January, and February were also derived. From those averages, the isotivity values (difference between MST and MWT) were calculated. In addition, the minimum air and soil temperature readings were identified. These average readings are shown in table 7.25.2.

Table 7.25.2.—Average air and soil temperatures (°C) at eight sites on Edisto Island.

Sensor	Annual	Min.	Max.	MST	MWT	Isotivity
10 cm	19.2	7.0	27.9	24.4	12.9	11.9
50 cm	19.5	11.6	25.3	23.5	14.4	9.1
Air	18.7	-4.3	35.0	---	---	---

Air temperature.—The average of MAAT for the eight sites was 18.7 °C. The highest MAAT was 19.7 °C at site 5, and the lowest MAAT was 18.1 °C at site 4. The lowest single low reading was -6.8 °C at site 2, and the highest single low reading was -2.9 °C at site 6. The highest single high reading was 43.9 °C at site 5, and the lowest single high reading was 31.3 °C at site 6. The partially vegetated coastal sand dune at site 5 had the highest recorded air temperature reading (43.9 °C). The vegetated coastal sand dune at site 6 had the highest low air temperature reading and the lowest high air temperature reading.

MAST at 10 cm.—The average MAST at 10 cm for the eight sites was 19.2 °C. The highest MAST was 20.4 °C at site 5, and the lowest MAST was 18.1 °C at site 4. The lowest single reading was 0.4 °C at site 5, and the highest single low reading for the period of record was 8.9 °C at site 4. The highest single high reading was 35.7 °C at site 5, and the lowest single high reading was 25.8 °C at site 4.

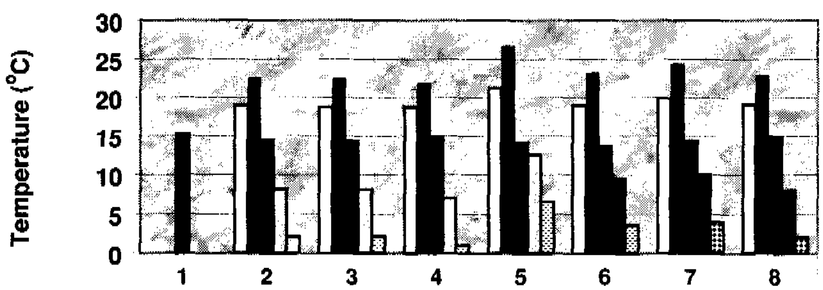
MAST at 50 cm.—The average MAST at 50 cm for the eight sites was 19.5 °C. The highest MAST was 21.2 °C at site 5, and the lowest MAST was 18.7 °C at site 4. The lowest single reading was 10.1 °C at site 5, and the highest single low reading was 12.8 °C at site 4. The highest single high reading was 29.2 °C at site 5, and the lowest single high reading was 23.6 °C at site 4. The partially vegetated coastal sand dune at site 5 had the highest MAST at both the 10- and 50-cm soil depths. Site 5 had the lowest single low value and the highest single high value for these depths. The partially vegetated coastal sand dune also was the only site to have soil temperatures below biological zero (5 °C). This occurred at the 10-cm soil depth during brief periods in December of 1996 and January of 1997. The MAST at 50 cm is warmer than the MAAT. This difference is 0.8 °C and compares favorably to the Tidewater Global Change Site in North Carolina, which had a difference of 0.7 °C during 1995 (Mount, Schaefer, and Werner, 1997).

MST and MWT at 10 cm.—The average MST at 10 cm for the eight sites was 24.4 °C. The highest MST was 27.8 °C at site 5, and the lowest MST was 23.1 °C at site 4. The average MWT at 10 cm for the eight sites was 12.9 °C. The highest MWT was 13.8 °C at site 1, and the lowest MWT was 11.4 °C at site 5. The average isotivity value at 10 cm for the eight sites was 11.5 °C. The highest isotivity value was 16.4 °C at site 5, and the lowest isotivity value was 9.7 °C at site 4.

MST and MWT at 50 cm.—The average MST at 50 cm for the eight sites was 23.5 °C. The highest MST was 26.7 °C at site 5, and the lowest MST was 21.9 °C at site 4. The average MWT at 50 cm for the eight sites was 14.4 °C. The highest MWT was 14.9 °C at site 8, and the lowest MWT was 13.7 °C at site 6. The average isotivity value at 50 cm for the eight sites was 9.1 °C. The highest isotivity value was 12.6 °C at site 5, and the lowest isotivity value was 7.1 °C at site 4. These analyses rule out the presence of an isothermic soil temperature regime on Edisto Island during the period of record.

4. Coastal Sand Dune Results

The soil temperature signature of the partially vegetated coastal sand dune is clearly different from that of the other sites in the study area. The 50-cm soil temperature signatures at all the sites, including MAST, MST, MWT, and isotivity values (MS-MW), are displayed in figure 7.25.1.

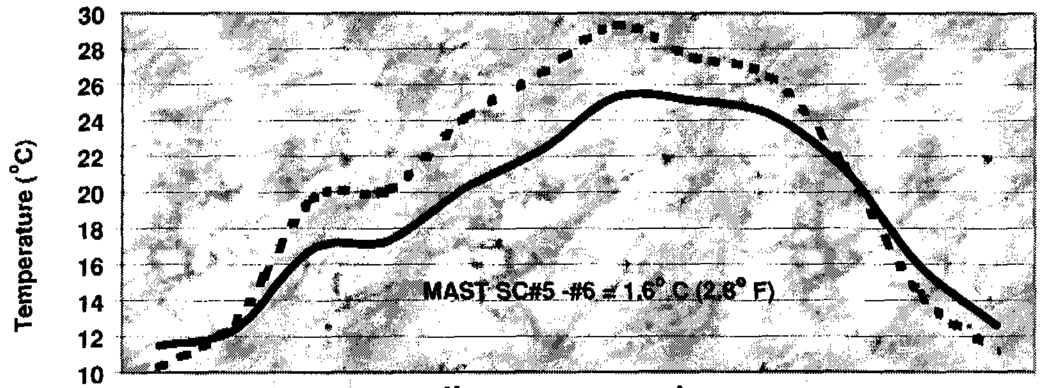


	1	2	3	4	5	6	7	8
MAST		19.0	18.8	18.7	21.2	19.0	19.9	19.1
MST		22.6	22.5	21.9	26.7	23.3	24.5	23.0
MWT	15.2	14.5	14.3	14.9	14.1	13.7	14.4	14.9
MS-MW		8.1	8.2	7.0	12.6	9.6	10.0	8.0
(MS-MW-6)		2.1	2.2	1.0	6.6	3.6	4.0	2.0

Site number

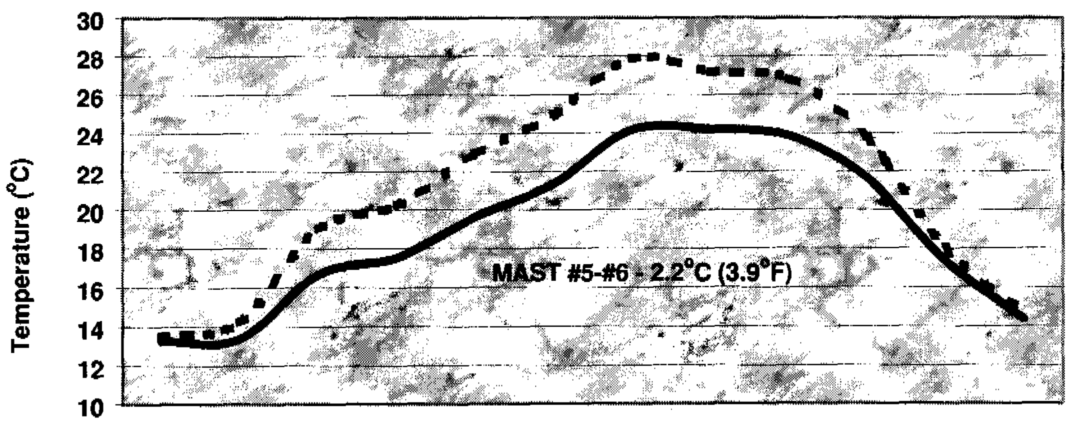
Figure 7.25.1.—Average seasonal and annual soil temperatures at 50-cm for sites in the study area.

The increase in MAST at site 5 is shown in figure 7.25.2. In addition, the MST and isotivity value at 50 cm are noticeable when graphed. The MWT is essentially the same at all of the sites and deviates only 1.2 °C. The soil temperature signature at site 5 is unusual at both the 10- and 50-cm depths. Figure 7.25.2 displays the monthly soil temperatures at 10 cm for sites 5 and 6, and figure 7.25.3 displays the monthly soil temperatures at 50 cm for the same sites.



	Jan 97	Feb 97	Mar 97	Apr 97	May 97	Jun 97	Jul 97	Aug 97	Sep 97	Oct 97	Nov 96	Dec 96
Site #5	10.3	12.8	19.6	20.1	24.1	26.6	29.3	27.5	26.4	21.4	14.3	11.2
Site #6	11.5	12.4	16.8	17.3	20.2	22.3	25.3	25.1	24.3	21.2	15.9	12.6

Figure 7.25.2.—Average monthly soil temperatures at 10 cm for sites 5 and 6.



	Jan 97	Feb 97	Mar 97	Apr 97	May 97	Jun 97	Jul 97	Aug 97	Sep 97	Oct 97	Nov 96	Dec 96
Site #5	13.5	14.2	19.0	20.2	22.9	24.9	27.9	27.2	26.8	23.8	18.0	14.6
Site #6	13.3	13.4	16.7	17.5	19.6	21.3	24.2	24.2	23.8	21.7	17.4	14.4

Figure 7.25.3.—Mean monthly soil temperatures at 50 cm for sites 5 and 6.

The soil temperature at 10 cm crosses over after February and before November at sites 5 and 6. At the 10-cm soil depth, site 5 is warmer than site 6 for most of the year. This difference is most pronounced from March to September. Other than February, site 5 is warmer than site 6 throughout the period of record. Site 5 is more than 2.8 °C warmer than site 6 during May and from July through October.

The 50-cm average monthly temperature difference between site 5 and site 6 is 2.2 °C (21.1 vs. 18.9 °C). It has been documented in other studies that cropland ecosystems are as much as 1 °C warmer than adjacent forested ecosystems (Mount, 1999). This study supports the notion that there is a major difference in the mean annual soil temperature based on earth cover as a result of human manipulations.

Table 7.25.3 shows how the soil and air temperatures at sites 5 and 6 depart from the means of the eight sites. The biggest departure is the MST at site 5 for the 10- and 50-cm soil depths (3.4 °C and 3.2 °C, respectively). While the averages for site 6 are near the mean of the eight sites for nearly all the categories listed, the averages for site 5 are either much higher or much lower than the mean of the eight sites. The minimum soil temperature value at 10 cm is about 6.7 °C lower than the mean lowest temperature, while the maximum soil temperature value at 10 cm is about 7.8 °C warmer than the mean highest temperature.

Table 7.25.3.—Departures from average soil and air temperatures on coastal sand dune sites.

Site number	Sensor (kind)	Average (°C)	Min. (°C)	Max. (°C)	MST (°C)	MWT (°C)
5	10 cm	+1.3	-6.6	+7.8	+3.4	-1.6
5	50 cm	+1.7	-1.4	+3.9	+3.2	-0.3
5	Air	+1.0	+0.4	+8.9	---	---
6	10 cm	-0.3	-0.7	-1.2	-0.1	-0.8
6	50 cm	-0.5	-0.9	-0.3	-0.2	-0.7
6	Air	+0.1	+1.4	-3.7	---	---

5. Discussion

The soils at all eight sites on Edisto Island are thermic. With a MAST of 21.2 °C, the partially vegetated coastal sand dune at site 5 comes closest to being hyperthermic. A hyperthermic soil temperature regime requires a MAST at 50 cm of 22.0 °C and an isotivity value of more than 6 °C (Soil Survey Staff, 1999).

Based on vegetative cover, the two soils on coastal sand dunes within 30 meters of the Atlantic Ocean have a larger difference in MAST at 50 cm than was originally suspected. In addition, their isotivity values at 50 cm are greater than was expected. The partially vegetated coastal sand dune has an isotivity value at 50 cm of 12.6 °C, while the vegetated coastal sand dune has an isotivity value of 9.6 °C. This difference must be less than or equal to 6 °C for the temperature regime to be "iso." At 7.0 °C, the soil at site 4, which is not on a coastal dune, came the closest to meeting the "iso" definition.

This study suggests there are no "iso" temperature regimes along the Atlantic Seaboard, at least from Maine to Edisto Island in South Carolina. While it is possible that an isothermic or isohyperthermic soil temperature regime might occur near Savannah, Georgia, or in areas to the south, the question of where "iso" temperature regimes start remains unanswered.

The average difference between the MAST at 10 cm and the MAST at 50 cm proved to be more than was expected. The difference is 0.3 °C (19.5 °C at 50 cm and 19.2 °C at 10 cm). StowAway temperature studies in West Virginia and Tennessee showed these differences to be within 0.1 °C, and a recent study on St. John Island showed these differences to be negligible (Mount et al., 1993 and 1995).

Acknowledgment

Mr. Raymond Tumbleston, landowner on Edisto Island, provided support for this study.

Chapter 7.26

Analysis of a Soil With an Isomesic Temperature Regime on a North Aspect in the Great Smoky Mountains of Tennessee*

ABSTRACT

The study area is in the northeast part of the Great Smoky Mountains National Park and within the State of Tennessee. The soil with an isomesic temperature regime is at an elevation of 1,158 m and has a slope of 69 percent. The three methods of determining soil isotivity values (difference in mean summer and mean winter soil temperatures at 50 cm) resulted in temperatures of less than 6.0 °C. The three coldest months at this site did not line up well for data from December, January, and February. Instead, the three coldest months were shifted two months to February, March, and April. Even after this shift, this soil still meets the current criteria for "iso" by having an isotivity value of less than 6.0 °C. Each method of examination showed that the soil is isomesic. This is the first soil east of the Mississippi River documented to have an isomesic temperature regime. It occupies a rather narrow elevation zone on north aspects. Though a scientific curiosity, this regime is thought to occur in other remote areas in the Appalachian Mountains of the Eastern United States.

1. Background and Purpose

Planning for the Great Smoky Mountains Global Change Project started in Memphis, Tennessee, in September 1995. Seven to nine climate stations were targeted to be installed along an elevation transect in Tennessee. These stations would collect data for soil temperature and moisture, air temperature, and relative humidity. This proposal specified using onsite cell phones that would transmit data to a database in Portland, Oregon. The exact location was not identified, but two areas of Tennessee were considered, either within the Great Smoky Mountains National Park or on Roan Mountain.

During late-1995, scientists in the National Soil Survey Center proposed micrologging technology as an alternative to the Tennessee climate station proposal. This technology is less expensive and does not require sophisticated programming to make it operational. Thus, StowAway temperature data loggers were selected for this project. Funding for the project was provided by the NRCS Global Change Initiative.

On August 28, 1996, 24 StowAway temperature data loggers with 1.8-meter sensor leads were installed at eight sites in the Great Smoky Mountains National Park. The field phase of the project covered 17 km of hiking and involved 10 scientists.

The purpose of the study was to quantify the relationship between decreasing mean annual soil temperatures with increasing elevation in the Great Smoky Mountains National Park. Other objectives were to evaluate the performance of new data-logging technology installed during the study and to verify the mesic-frigid soil temperature regime separation in the Great Smoky Mountains. At the start of the study, it was not hypothesized that an isomesic soil temperature regime would occur in the study area

2. Study Area

The study area is in the northeast part of the Great Smoky Mountains National Park and within the State of Tennessee. Of the eight sites selected, detailed soil and site information is given only for site 4, which has an isomesic temperature regime. Site 4 is in Cocke County, on Snake Den Trail in the Great

* Darwin L. Newton, NRCS State Soil Scientist, Nashville, Tennessee, assisted in preparing this section.

Smoky Mountains National Park. Its latitude is 35°45'36" north, and its longitude is 83°14'24" west. Its elevation is 1,158 m. The vegetation consists of mountain laurel (*Laurus spp. L.*), rhododendron (*Rhododendron spp. L.*), cucumber magnolia (*Magnolia spp. L.*), table mountain pine (*Pinus spp. L.*), and dogwood (*Cornus spp. L.*). The slope is 69 percent. The soil at this site is on a backslope, and the aspect is slightly east of north. The soil has an Oe horizon that is 0 to 25 cm thick with 5YR 3/3 partially decomposed rhododendron leaves. The Oa horizon consists of 25 to 50 cm of black (N /) muck. The soil is a loamy-skeletal isotic, isomesic Andic Dystrudept (Soil Survey Staff, 1999). The geology in this area is Anequista phyllite and/or thunderhead sandstone fragments.

3. Results

Data were off-loaded on September 11, 1996, in Knoxville, Tennessee. A visual review of the data from the sites in this study area showed that the signature of the data at site 4 was unique. Figure 7.26.1 displays the soil temperature at 50 cm for sites 1, 4, and 7.

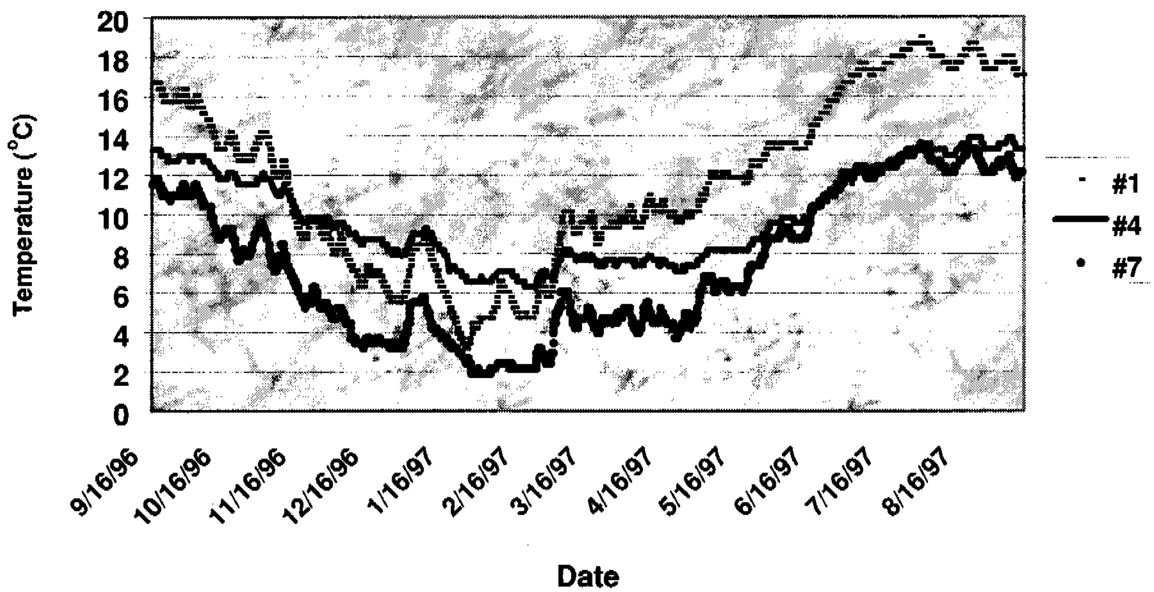


Figure 7.26.1.—Soil temperature signatures for the 50-cm soil depth at sites 1, 4, and 7.

Figure 7.26.1 shows that the winter soil temperatures at site 4 are warmer than those on sites at elevations both above and below. The question of its isotivity value, or the difference between mean summer temperature (MST) and mean winter temperature MWT), was of immediate interest.

Method 1.—Three methods of analysis were used to determine the isotivity value for the 50-cm depth at site 4. In method 1, the monthly averages were first determined. Figure 7.26.2 graphs the average monthly soil temperatures at site 4. The MAST was calculated from the monthly averages, and the isotivity value was then calculated. The MAST is 9.9 °C; hence, this soil was initially thought to be mesic. However, the isotivity value is only 4.5 °C. Since the isotivity value is less than 6 °C, the soil fits into an "iso" category. Consequently, this method indicates that the soil at site 4 has an isomesic temperature regime.[†] Table 7.26.1 shows the results of method 1.

[†] Method 1 is the preferred method of determining a soil temperature regime (Soil Survey Staff, 1999).

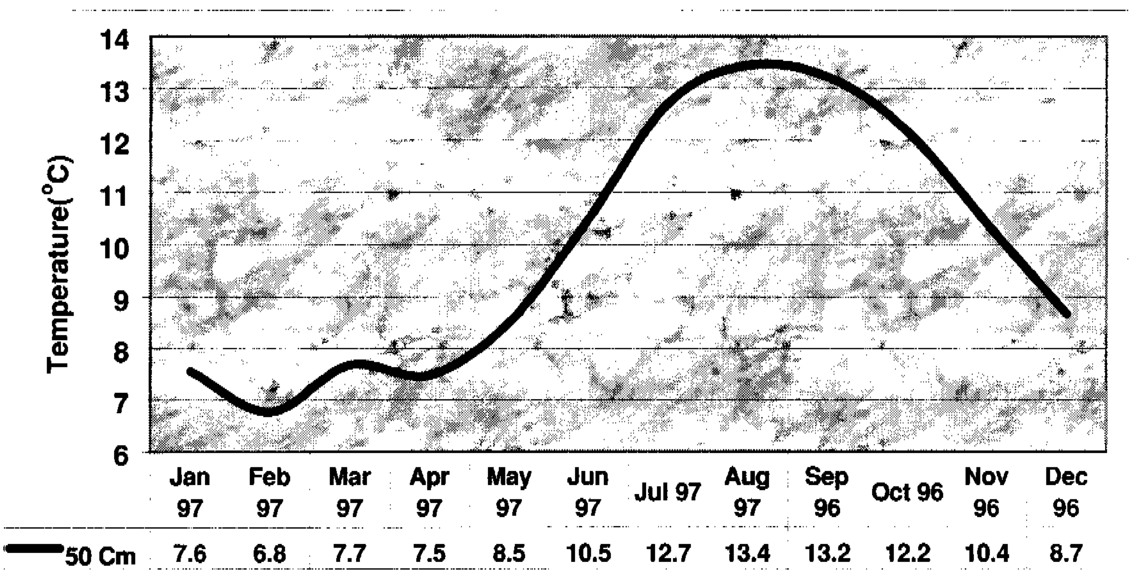


Figure 7.26.2.—Average monthly soil temperatures for the isomesic soil at site 4.

Table 7.26.1.—Soil temperature analysis for site 4 using monthly means.

Analysis	50 cm (°C)
Jan 97	7.6
Feb 97	6.8
Mar 97	7.7
Apr 97	7.5
May 97	8.5
Jun 97	10.5
Jul 97	12.7
Aug 97	13.4
Sep 96	13.2
Oct 96	12.2
Nov 96	10.4
Dec 96	8.7
Mean	9.9
MST	12.2
MWT	7.7
Isotivity	4.5

Method 2.—The second method was initiated to examine the difference between the three warmest months and the three coldest months for the period of record. Table 7.26.1 indicates that July, August, and September are the three warmest months while February, March, and April are the three coldest months. This shifting of the warmest and coldest months does make a difference in the results. When examined this way, the difference between the three warmest and the three coldest months is 5.8 °C, or about 1.3 °C more than the results of method 1 (table 7.26.2). Method 2 indicates that soil has an isotivity value of 5.8 °C and is isomesic.

Table 7.26.2.—Soil temperature analysis using the three warmest and three coldest months.

Analysis	Temp. (°C)
3 warmest	13.1
3 coldest	7.3
3 W − 3 C	5.8

Method 3.—In method 3, the true summer and winter temperature averages were first calculated, then subtracted from each other (table 7.26.3). The soil temperature readings at 50 cm are averaged between June 20 and September 20, resulting in a mean summer temperature of 12.9 °C. The mean soil temperature at 50 cm between December 20 and March 20 during the period of record was 7.5 °C. The isotivity value at 50 cm is 5.4 °C. This is 0.9 °C more than the results of method 1, although the soil remains isomesic.

Table 7.26.3.—Soil temperature data based on true summer and true winter readings.

Analysis	Temp. (°C)
6/20–9/20	12.9
12/20–3/20	7.5
Sum − Win	5.4

4. Summary

Defining dates for summer and winter is very important when isotivity values are determined. The biggest difference among the three methods involves whether soil scientists should determine isotivity on the basis of any current definition of summer and winter or by using the three warmest and the three coldest months. The results of the difference in isotivity values are summarized in table 7.26.4.

Table 7.26.4.—Isomesic determination based on three different methods.

Method number	Isotivity (°C)
1	4.5
2	5.8
3	5.4
Mean	5.2

The three methods of determining isotivity values resulted in values of less than 6.0 °C. The coldest three months do not line up well at this site with December, January, and February. Instead, the coldest three months are shifted two months to February, March, and April. Even with this wider difference, method 2 shows that the soil still meets the current criteria for "iso" by having an isotivity value of less than 6.0 °C (Soil Survey Staff, 1999). This is the first soil east of the Mississippi River documented to have an isomesic temperature regime. It occupies a rather narrow elevation zone on north aspects in the park. This regime is thought to also occur in other remote areas in the Appalachian Mountains of the Eastern United States.

Acknowledgments

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Chapter 7.27

The Relationship of Altitude to Soil Temperature on South Aspects in the Great Smoky Mountains of Tennessee*

ABSTRACT

The study area is in the northeast part of the Great Smoky Mountains National Park and within the State of Tennessee. Seven forested sites with southerly aspects were monitored for air and soil temperatures at altitudes ranging from 1,188 to 1,946 m and at about 150-m intervals. The soil temperature at site 1 (1,946 m) was the coldest in the study area, while the soil temperature at site 7 (1,188 m) was the warmest. Site 7 had the warmest mean annual soil temperature at both 10 cm and 50 cm. At 9.1°C, its mean annual air temperature was the same as that of site 6. However, its isotivity value (difference between mean summer and mean winter soil temperatures) was higher (11.2 vs. 9.0 °C), suggesting that cold air drainage was not so pronounced at this site as at site 6. Though site 4 was lower in altitude than site 3 (1,562 vs. 1,734 m), its mean annual soil temperature was colder and it had a frigid temperature regime during the period of record. Its mean annual soil temperature was identical at 10 cm and 50 cm (7.6 °C) and nearly the same as the mean annual air temperature (7.5 °C). At 7.4°C, its isotivity value was the least of any site in the study area and suggests that a mid-mountain inversion suppressed the difference between mean summer and mean winter soil temperatures. Site 4 has a nonconforming relationship to its descending altitude. This relationship impacts regression analysis. There is a trend of increasing mean annual soil temperature with descending altitude, but this relationship is not perfect. With an r^2 of 0.86, this relationship and its mathematical assumptions can only approximate mean annual temperature for soils on south aspects.

1. Background and Purpose

Data loggers were installed at seven sites along an elevation transect in Tennessee in September of 1998. The purpose of this study was to quantify the inverse relationship between mean annual soil temperature and elevation on soils with south aspects in the Great Smoky Mountains National Park. Another purpose was to verify the mesic-frigid soil temperature regime separation in the Great Smoky Mountains. To facilitate a common altitude stratification, the sites were monitored at about 150-m (500-ft) intervals. A frigid soil temperature regime has a mean annual soil temperature of less than 8 °C and an isotivity value (difference in mean summer and mean winter soil temperatures) of more than 6 °C. Its mean summer temperature is more than 8 °C for soils with humus layers. A mesic soil temperature regime has a mean annual soil temperature of 8 to 15 °C and an isotivity value of more than 6 °C (Soil Survey Staff, 1999).

2. Study Area

The study area is in the northeast part of the Great Smoky Mountains National Park and within the State of Tennessee. The sites are in Sevier County, on Alum Cave Bluff Trail. The soils in the study area are well drained and formed in material weathered from the Anakeeste geologic formation, which typically consists of slate, phyllite, and schist rocks. The soil at site 1 is a loamy-skeletal, mixed, superactive, frigid Humic Dystrudept (Soil Survey Staff, 1999). It supports red spruce (*Picea spp. L.*), Fraser fir (*Abies spp. L.*), and mountain ash. The soil at site 2 is a loamy-skeletal, mixed, superactive, frigid Humic Dystrudept. It supports red spruce and Fraser fir. The soil at site 3 is a loamy-skeletal,

* Darwin L. Newton, NRCS State Soil Scientist, Nashville, Tennessee, assisted in preparing this section.

mixed, superactive, frigid Humic Dystrudept. It supports red spruce and yellow birch (*Betula spp. L.*). The soil at site 4 is a loamy-skeletal, mixed, superactive, frigid Humic Dystrudept. It supports red spruce and yellow birch. The soil at site 5 is a fine-loamy, mixed, superactive, mesic Typic Dystrudept. It supports red spruce, hemlock (*Tsuga spp. L.*), and yellow birch. The soil at site 6 is a fine-loamy, mixed, superactive, mesic Typic Dystrudept. It supports yellow and gray birch (*Betula spp. L.*), hemlock, and red spruce. The soil at site 7 is a fine-loamy, mixed, superactive, mesic Typic Dystrudept. It supports red spruce, Fraser fir, and mountain ash and a ground cover of briars. At site 7, the soil temperature is thought to be influenced by cold air drainage. Table 7.27 gives additional site metadata.

Table 7.27.1.—Site information for the study area.

Site no.	Latitude (north)	Longitude (west)	Elevation (m)	Slope (%)	Aspect (°)
1	39°39'21"	83°26'37"	1,946	25	270
2	39°39'08"	83°26'19"	1,830	90	170
3	39°35'52"	83°25'17"	1,734	72	230
4	39°38'26"	83°26'44"	1,562	68	130
5	39°38'16"	83°26'35"	1,448	72	220
6	39°38'27"	83°26'21"	1,352	45	180
7	39°37'47"	83°26'31"	1,188	4	270

3. Results

Site 1.—This soil at this site has the coldest MAST at 50 cm in the study area and is frigid (table 7.27.2). The MAST is 6.2 °C at 10 cm and 6.3 °C at 50 cm. The MAAT is 6.1 °C. The MWT and MST averages are the lowest in the study area. At 9.1 °C, however, the isotivity value at 50 cm is too high for a cryic temperature regime. It is thought that none of the soils at high altitudes in Tennessee are cryic. However, it is possible that some portions of grass balds might have cryic temperature regimes because the MST requirement for soils without an O horizon can range to 15 °C (Soil Survey Staff, 1999).

Table 7.27.2.—Air and soil temperatures (°C) for site 1.

Analysis	10 cm	50 cm	Air
Jan 98	1.1	2.2	-0.8
Feb 98	0.6	1.8	-1.5
Mar 98	1.1	1.6	-0.7
Apr 98	4.1	3.9	4.4
May 98	8.6	7.0	11.3
Jun 98	11.9	10.3	14.1
Jul 98	13.0	11.7	14.7
Aug 98	12.7	11.7	14.4
Sep 97 & 98	11.4	10.6	13.0
Oct 97	7.6	8.6	6.7
Nov 97	2.0	4.2	-0.8
Dec 97	0.6	2.3	-1.8
Mean	6.2	6.3	6.1
MST	12.5	11.2	14.4
MWT	0.8	2.1	-1.4
Isotivity	11.7	9.1	15.8

Site 2.—The soil at site 2 is frigid because the MST is greater than 8 °C (table 7.27.3). The MAST is 7.5 °C at 10 cm and 7.6 °C at 50 cm. The MAAT is 7.3 °C. The isotivity value at 50 cm is slightly more than that at site 1 (10.4 vs. 9.1°C).

Table 7.27.3.—Air and soil temperatures (°C) for site 2.

Analysis	10 cm	50 cm	Air
Jan 98	1.9	3.2	0.6
Feb 98	0.6	1.7	-0.1
Mar 98	2.2	2.4	1.0
Apr 98	5.5	5.4	5.7
May 98	10.8	8.7	12.6
Jun 98	13.9	12.1	15.0
Jul 98	14.8	13.6	15.3
Aug 98	14.6	13.5	15.3
Sep 97 & 98	13.0	12.9	13.1
Oct 97	9.0	9.9	8.0
Nov 97	2.3	4.3	0.7
Dec 97	1.8	3.2	0.3
Mean	7.5	7.6	7.3
MST	14.4	13.0	15.2
MWT	1.4	2.7	0.3
Isotivity	13.0	10.4	14.9

Site 3.—The soil at this site is mesic. Curiously, had this soil been terminated by bedrock at 10 cm, it would have had a frigid temperature regime because its MAST is 7.5 °C (table 7.27.4). The air temperature sensor at this site was inoperative.

Table 7.27.4.—Soil temperatures (°C) for site 3.

Analysis	10 cm	50 cm
Jan 98	2.6	4.6
Feb 98	1.1	3.1
Mar 98	1.8	2.7
Apr 98	4.8	4.9
May 98	9.3	7.7
Jun 98	12.5	11.3
Jul 98	14.1	13.2
Aug 98	14.4	13.9
Sep 97 & 98	12.8	13.1
Oct 97	9.8	11.5
Nov 97	4.4	7.5
Dec 97	3.0	5.4
Mean	7.5	8.2
MST	13.6	12.8
MWT	2.2	4.4
Isotivity	11.4	8.4

Site 4.—Though site 4 is lower in altitude than site 3 (1,562 vs. 1,734 m), its MAST is colder and its soil is frigid. The MAST is 7.6 °C at 10 cm and 50 cm, and the MAAT is 7.5 °C (table 7.27.5). At 7.4

°C, the isotivity value is the least of any site in the study area and suggests that a mid-mountain inversion suppressed the difference between mean summer and mean winter soil temperatures.

Table 7.27.5.—Air and soil temperatures (°C) for site 4.

Analysis	10 cm	50 cm	Air
Jan 98	3.0	4.6	0.2
Feb 98	1.6	3.3	-0.5
Mar 98	2.1	2.9	0.7
Apr 98	5.6	5.3	6.2
May 98	10.0	7.8	13.5
Jun 98	12.8	10.5	15.7
Jul 98	14.1	11.9	16.5
Aug 98	14.0	12.3	16.4
Sep 97 & 98	12.3	11.4	13.5
Oct 97	8.9	9.7	8.0
Nov 97	3.6	6.1	0.7
Dec 97	2.7	4.8	-0.6
Mean	7.6	7.6	7.5
MST	13.7	11.6	16.2
MWT	2.4	4.2	-0.3
Isotivity	11.2	7.4	16.4

Site 5.—The soil at site 5 is mesic. The MAST is 9.6 °C at 10 cm and 8.7 °C at 50 cm (table 7.27.6). At 8.8 °C, the MAAT approximates the MAST at 50 cm. The isotivity value at 50 cm is doubled that at site 4 (14.9 vs. 7.4°C).

Table 7.27.6.—Air and soil temperatures (°C) for site 5.

Analysis	10 cm	50 cm	Air
Jan 98	3.7	5.4	1.9
Feb 98	2.0	3.9	1.0
Mar 98	4.6	4.5	2.1
Apr 98	8.2	6.8	7.4
May 98	13.8	9.5	14.5
Jun 98	16.4	12.1	16.8
Jul 98	17.6	13.5	17.4
Aug 98	17.6	13.7	17.5
Sep 97 & 98	14.8	12.8	14.6
Oct 97	10.2	10.4	9.4
Nov 97	3.5	6.3	2.1
Dec 97	3.1	5.4	0.6
Mean	9.6	8.7	8.8
MST	17.2	13.1	17.2
MWT	2.9	4.9	1.2
Isotivity	25.7	14.9	28.9

Site 6.—The soil at site 6 is mesic. Its MAST at 50 cm is slightly warmer than the MAAT (9.4 vs. 9.1 °C). (See table 7.27.7). Because of possible cold air drainage, the isotivity value is lower than that of site 5 (9.0 vs. 14.9 °C).

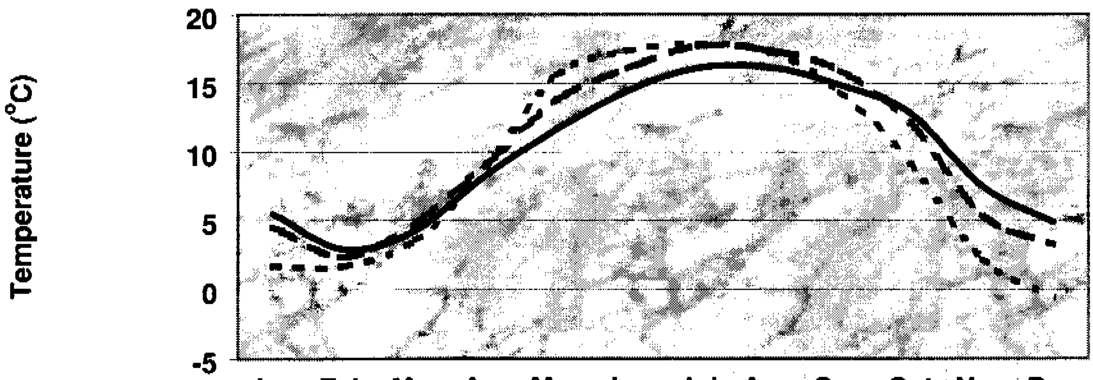
Table 7.27.7.—Air and soil temperatures (°C) for site 6.

Analysis	10 cm	50 cm	Air
Jan 98	4.6	5.6	1.9
Feb 98	3.2	3.8	1.5
Mar 98	5.1	4.4	2.9
Apr 98	8.5	7.0	8.3
May 98	12.8	9.8	14.4
Jun 98	15.5	12.8	17.0
Jul 98	17.0	14.7	17.5
Aug 98	16.9	15.0	17.6
Sep 97 & 98	14.9	14.2	15.8
Oct 97	11.3	12.1	9.4
Nov 97	5.7	7.8	2.3
Dec 97	4.5	6.0	0.2
Mean	10.0	9.4	9.1
MST	16.5	14.2	17.4
MWT	4.1	5.2	1.2
Isotivity	12.4	9.0	16.1

Site 7.—The results for site 7 are consistent with its altitude of 1,188 m (table 7.27.8). The soil at this site is mesic. It had the warmest MAST at both the 10-cm and 50-cm soil depths in the study area. At 9.1 °C, its MAAT was the same as that of site 6. However, its isotivity is higher (11.2 vs. 9.0 °C), suggesting that cold air drainage was not so pronounced as at site 6. Figure 7.27.1 graphs these monthly data.

Table 7.27.8.—Air and soil temperatures (°C) for site 7.

Analysis	10 cm	50 cm	Air
Jan 98	4.5	5.4	1.7
Feb 98	2.4	2.9	1.7
Mar 98	4.8	4.3	3.6
Apr 98	9.1	8.3	8.9
May 98	13.8	11.6	15.6
Jun 98	16.1	14.4	17.4
Jul 98	17.7	16.1	17.9
Aug 98	17.4	16.2	17.3
Sep 97 & 98	15.9	14.9	14.4
Oct 97	12.1	12.8	9.1
Nov 97	5.4	7.5	2.2
Dec 97	3.2	4.9	-0.6
Mean	10.2	9.9	9.1
MST	17.1	15.6	17.5
MWT	3.4	4.4	0.9
Isotivity	13.7	11.2	16.6



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10 cm	4.5	2.4	4.8	9.1	13.8	16.1	17.7	17.4	15.9	12.1	5.4	3.2
50 cm	5.4	2.9	4.3	8.3	11.6	14.4	16.1	16.2	14.9	12.8	7.5	4.9
Air	1.7	1.7	3.6	8.9	15.6	17.4	17.9	17.3	14.4	9.1	2.2	-0.6

Figure 7.27.1.—Comparison of monthly air and soil temperatures at site 7.

4. Summary

The MAST for the study area averaged 8.3 °C at 50 cm. This is similar to the MAST at 10 cm, which averaged 8.4 °C. This similarity suggests that, on average, the MAST will likely be the same at any depth for any sites in the Great Smoky Mountains. The mid-mountain blip in MAST at site 4 suggests that there is an inversion phenomenon on both north- and south-facing slopes. The altitudinal relationship of MAST, MST, MWT, and isotivity values for the soils is shown in table 7.27.9. This table also shows similarities of the site averages at both the 10- and 50-cm soil depths.

Table 7.27.9.—Seasonal and annual soil temperatures (°C) in the study area.

Analysis	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	50-cm ave.	10-cm ave.
Mean	6.3	7.6	8.2	7.6	8.7	9.4	9.9	8.3	8.4
MST	11.2	13.0	12.8	11.6	13.1	14.2	15.6	13.1	15.0
MWT	2.1	2.7	4.4	4.2	4.9	5.2	4.4	4.0	2.5
Isotivity	9.1	10.4	8.4	7.4	8.3	9.0	11.2	9.1	12.5

Site 4 shows a nonconforming relationship to its descending altitude. This relationship impacts regression analysis (figure 7.27.2). There is a trend of increasing MAST with descending altitude, but this relationship is not perfect. With an r^2 of 0.86, this relationship and its mathematical assumptions can only approximate MAST on south aspects in the Great Smoky Mountains.

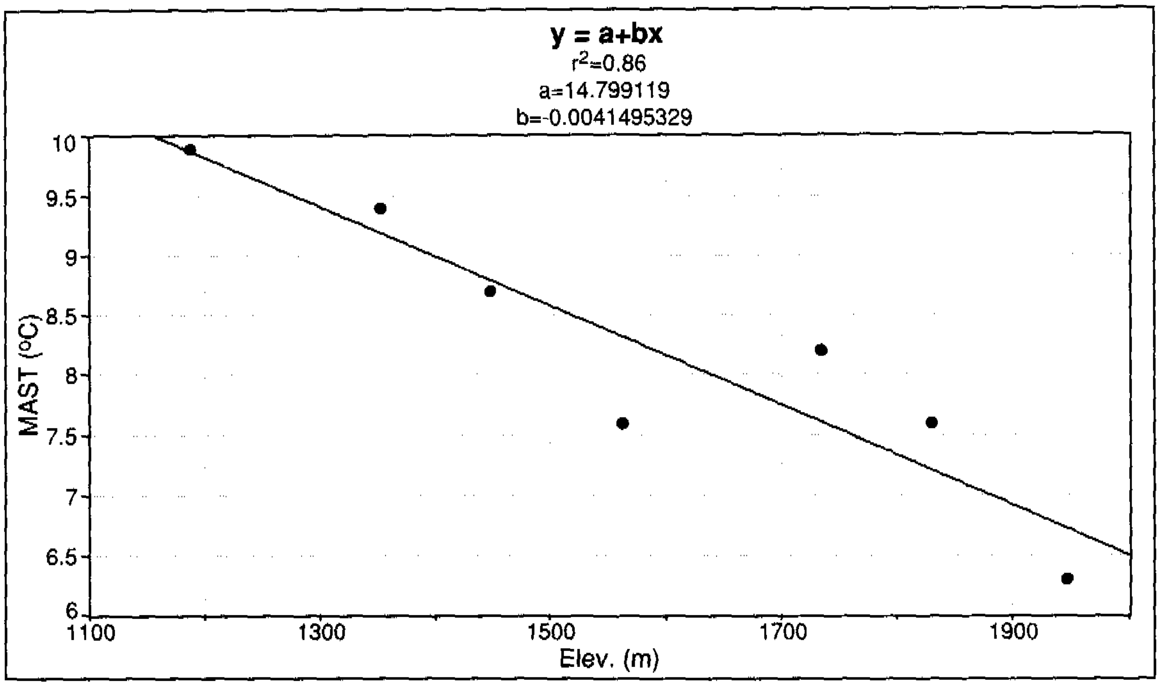


Figure 7.27.2.—Trend of MAST at 50 cm to elevation in the Great Smoky Mountains of Tennessee.

The formula y (MAST) = a+bx should be used only for altitudes between 1,188 and 1,946 m in the Great Smoky Mountains of Tennessee and adjacent North Carolina. In a calculation of a theoretical MAST for an altitude (x) of 1,400 m, y = 14.799119 + -0.0041495329 * 1,400. The calculated result is 8.99 °C. Figure 7.27.2 shows the same result.

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Chapter 7.28

Soil Temperature Signatures for Two Zones on St. John Island, Virgin Islands*

ABSTRACT

Several studies were designed during the 1990s to determine the differences in soil and air temperatures between the north and south sides of St. John Island. The soils at sites with similar solar radiation interruption in Lameshur Bay (south side) and on Caneel Hill (north side) have the most similar mean annual soil temperatures at 20 cm (26.8 °C and 25.7 °C, respectively). The results of this study did not quantify the interrelationship among vegetative canopy cover, slope aspect, mean annual soil temperature, and the isotivity values (difference in mean summer and mean winter soil temperatures). Lam site 1, on a west aspect in Lameshur Bay, has the highest mean annual soil temperature (28.6 °C) and the highest isotivity value at 20 cm (5.3 °C) in the study area. Conversely, the Caneel Hill site has the lowest mean annual soil temperature (25.7 °C) but also has a high isotivity value at 20 cm (5.1 °C). The south-facing soils at Lam sites 2 and 3 in Lameshur Bay have intermediate mean annual soil temperatures (26.8 °C and 27.7 °C, respectively) and have the lowest isotivity values at 20 cm (3.9 °C and 2.5 °C, respectively). The reasons for high isotivity values at the Caneel Hill site in the northern zone are related to the air temperature signature of the site. At 18° north of the Equator, the Caneel Hill site is close enough to the Equator for sunlight to create a microclimate environment during the summer and winter months. Though the incoming solar radiation is intercepted by the canopy cover, the thermodynamics of air-soil heat exchange are maximized throughout the summer. In winter, mountain peaks shade the Caneel Hill site from the sun, resulting in a cooler environment. Data from this study show that the mean annual soil temperature in the northern zone of St. John Island is less than the mean annual soil temperature in the southern zone and suggest that the temperature signatures of soils in the Tropics are site-specific. The St. John Island study shows that these signatures must be measured and then analyzed for precise differences. Soil temperature modeling cannot approach real distinctions for any useful application basis.

1. Background

Soil temperature regimes, as defined in *Soil Taxonomy*, have precise criteria for seasonal and annual fluctuations (Soil Survey Staff, 1999). Knowledge of the soil temperature regimes in the Tropics is important for three primary reasons: first, to understand the development and formation of specific soils; second, to consistently classify and accurately map soils; and third, to apply that knowledge to the use and management of soil-plant-water systems. Measured soil temperature data greatly enhance the understanding and management of soils and land use planning (Mount, Bauer, et al., 1992).

The soil temperature monitoring in the Lameshur Bay Watershed and on Caneel Hill on St. John Island has been a cooperative effort between the Natural Resources Conservation Service (NRCS) and the National Biological Survey (NBS) since December 1990. Major funding for this study was provided by the NRCS Global Change Initiative and the National Biological Survey on St. John Island.

The purpose of this study is to quantify the difference in air and soil temperature signatures between sites on the south side of St. John Island (Lameshur Bay zone) and a site on the north side of the island (Caneel Hill zone). Observations during many visits to St. John Island had indicated that the biomass is more enhanced in the northern zones than in the southern zones. It was hypothesized that the air and soil temperatures in the northern zone affect this difference in biomass enhancement.

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* Carmen Santiago, Staff Soil Scientist for the NRCS Caribbean Area, Hato Rey, Puerto Rico, assisted in preparing this section.

2. Study Area

St. John Island is part of the United States Virgin Islands, which also include St. Croix and St. Thomas Islands and about 50 smaller islands that range in size from a cluster of small rocks to about 240 hectares (ha) (Rivera, et al., 1970). St. John Island has a land area of 4,920.9 ha. It is about 1,770 kilometers (km) southeast of Miami, Florida. It is in the Tropics and has a latitude of 18° north and a longitude of 64° west. It is 3.2 km east of St. Thomas Island and about 65 km north of St. Croix Island..

The Lameshur Bay zone is on the south side of the island, in the Virgin Islands National Park. Three sites in Lameshur Bay were chosen for comparison of air and soil temperatures with those on Caneel Hill. The latitude of the three sites is 18°19'16" to 18°19'36" north, and the longitude is 64°43'22" to 64°43'25" west. The slope, aspect, elevation, and canopy cover are shown in table 7.28.1.

Table 7.28.1.—Slope, aspect, elevation, and canopy cover for the Lameshur Bay sites.

Station name	Slope (%)	Aspect (°)	Elevation (m)	Canopy cover (%)
LAM 1	70	270	43	50
LAM 2	3	180	2	95
LAM 3	25	120	104	50

The Caneel Hill site is on the north side of the island, has a north aspect, and is at an elevation of 107 m. It has a latitude of 18°21'0" north and a longitude of 64°47'24" west. It has a 45 percent slope to the north (downhill) and a 36 percent slope to the south (uphill). Stones cover an estimated 25 percent of the surface. *Maytenus* is the dominant tree genus, and guavaberry shrubs are evident. The canopy cover shades the soil surface throughout the day, making the site most similar to Lam site 2 in Lameshur Bay for soil temperature comparison purposes. The distance between the Lameshur Bay zone and the Caneel Hill zone is about 15 km.

Weather data recorded on the Lameshur Bay Watershed from 1972 to 1989 indicate that the total mean annual precipitation is about 1,140 mm with two seasonal peaks. Minor peaks in precipitation occur in April and May. The most significant peak in precipitation occurs from September through November. The highest mean monthly precipitation is 189 mm in November, and the lowest is 50 mm in March. Evaporative demand is high on St. John Island and exceeds the precipitation in every month of the year. The lack of rainfall, coupled with a mean annual relative humidity of 85 percent, makes for a semiarid island (Rivera et al., 1970). This semiarid condition is most pronounced on the small eastern and southern peninsulas of St. John Island, where abundant cacti flourish.

All the woody vegetation on St. John Island is in a secondary forest, which has been classified as a dominantly Subtropical Moist Forest with Dry Evergreen Woodland and Semi-Evergreen Seasonal Forest (Weaver and Chinea-Rivera, 1987). About 70 tree species have been documented in the Cinnamon Bay Watershed on the north side of St. John Island, which receives about 114 cm of annual rainfall. The dominant trees on the Lameshur Bay Watershed include species of the *Pimenta, Rondia, Lantana, Rauvolfia, Leuceama, Capparis, Ginoria, Bucida, Acacia,* and *Genip* genera.

The soils at the sites are tropical Inceptisols and Mollisols. Cramer clay loam (S91VI-020-003), a clayey, mixed, active, isohyperthermic, shallow Typic Haplustoll, is the dominant soil on St. John Island and on Caneel Hill (Rivera et al., 1970, and Davis and Vick, 1995). This soil is 6 m upslope (NW) from the long-term vegetative plots being monitored by the NBS. Cobbles and stones cover about 1 percent of the surface. The soil horizon sequence is Oi, A, Bt1, Bt2, and Crt. A large amount of wormcasts and tubular pores in the soil suggests a high infiltration rate and little accelerated soil erosion (Mount, Hudson, et al., 1992).

3. Methods

Soil temperature sensors were installed at 10 cm and 20 cm on all of the sites in Lameshur Bay during 1991. Soil temperature sensors also were installed at 50 cm on Lam sites 1 and 2 but not on Lam site 3, where the soil is shallow to bedrock (Mount, Hudson, et al., 1992). The soil on Caneel Hill is also shallow to bedrock, and soil temperature sensors were installed at 10 cm and 20 cm in this soil during November 1996. A steel rebar was driven into the ground and then extracted before the soil temperature sensors were installed at 10 cm and 20 cm on all of the sites in Lameshur Bay. A sharpshooter spade was used to excavate the Cramer soil before the soil temperature sensors were installed on the Caneel Hill site.

The mean annual soil temperature on St. John Island has nearly the same average value no matter the depth at which it is measured (Mount et al., 1995). A depth of 50 cm was chosen as a point of measurement in *Soil Taxonomy* simply because the diurnal fluctuation is nil and the seasonal fluctuation is much less at 50 cm than that at 10 cm or 20 cm. Since two of the sites in this study are less than 50 cm deep to bedrock, the 20-cm soil depth is used as a point of comparison among the sites for this report.

The period of record is calendar year 1994 for the Lameshur Bay data and November 1996 to November 1997 for the Caneel Hill data. Over 42,000 hourly temperature readings are available for Lameshur Bay, and 3,600 readings (5 times per day) are available for Caneel Hill. The Virgin Islands have the most equable climate in the world, and comparisons of temperature data from one year to the next are not a concern in temperature summaries (Mount, Hudson, et al., 1992). Monthly air and soil temperature data from Lameshur Bay were published in 1993 and 1995 (Mount et al., 1993 and 1995).

Air and soil temperature data from the Caneel Hill site were off-loaded onto Excel software on St. John Island in November 1997 and then were graphed (figure 7.28.1). Monthly and annual means for air temperature (MAAT) and soil temperature (MAST) were calculated. Also, calculations of mean summer temperature (MST) and mean winter temperature (MWT) were made. The calculations of MST and MWT show the extreme seasonal variation at each of the sites. The MST is the average soil temperature for June, July, and August, and the MWT is the average soil temperature for December, January, and February (Soil Survey Staff, 1999). An isotivity value, or the difference between MST and MWT, was determined at each of the sites. This value indicates the extreme seasonal variation at the sites.

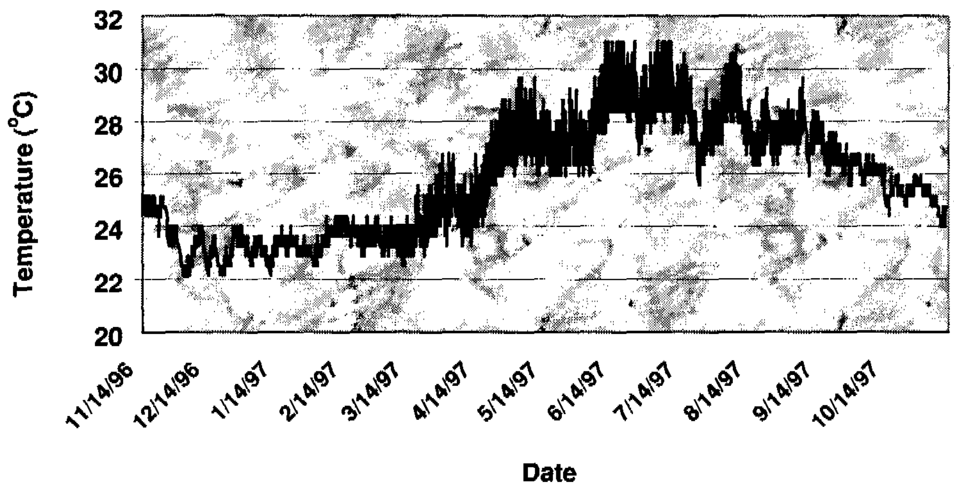


Figure 7.28.1.—Soil temperature signature for the 20-cm soil depth at Caneel Hill.

4. Results

Air Temperature.—Monthly and annual air temperatures are shown in table 7.28.2 and graphed in figure 7.28.2. The MAAT was highest at Lam site 3 (26.6 °C) and coolest at the Caneel Hill site (25.7 °C). The MAAT at Caneel Hill is 0.7 °C cooler than the average for the three sites in Lameshur Bay. On average, the Caneel Hill site is warmer from May through August but much cooler during the rest of the year. The difference in air temperature between the Caneel Hill site and the Lameshur Bay sites is greatest (2.7 °C) in December (22.7 °C at Caneel Hill vs. an average of 25.4 °C at Lameshur Bay). The air temperature in December is much cooler on the Caneel Hill site, which has a north aspect, than on any of the sites in Lameshur Bay.

Table 7.28.2.—Monthly air temperatures (°C) for Lameshur Bay and Caneel Hill.

Analysis	LAM 1	LAM 2	LAM 3	LAM ave.	Caneel Hill
Jan	22.1	24.2	24.8	23.7	22.4
Feb	23.9	24.8	25.0	24.6	22.7
Mar	25.4	25.1	25.4	25.3	23.7
Apr	26.1	26.0	25.7	25.9	25.9
May	27.6	27.6	27.0	27.4	27.7
Jun	27.9	28.0	27.3	27.8	29.2
Jul	28.1	28.2	27.6	28.0	28.8
Aug	28.4	28.5	28.1	28.3	28.6
Sep	26.9	27.7	27.6	27.4	27.4
Oct	27.0	26.9	27.6	27.2	25.8
Nov	25.3	26.0	26.6	25.9	24.0
Dec	24.5	25.1	26.6	25.4	22.7
Mean	26.1	26.5	26.6	26.4	25.7

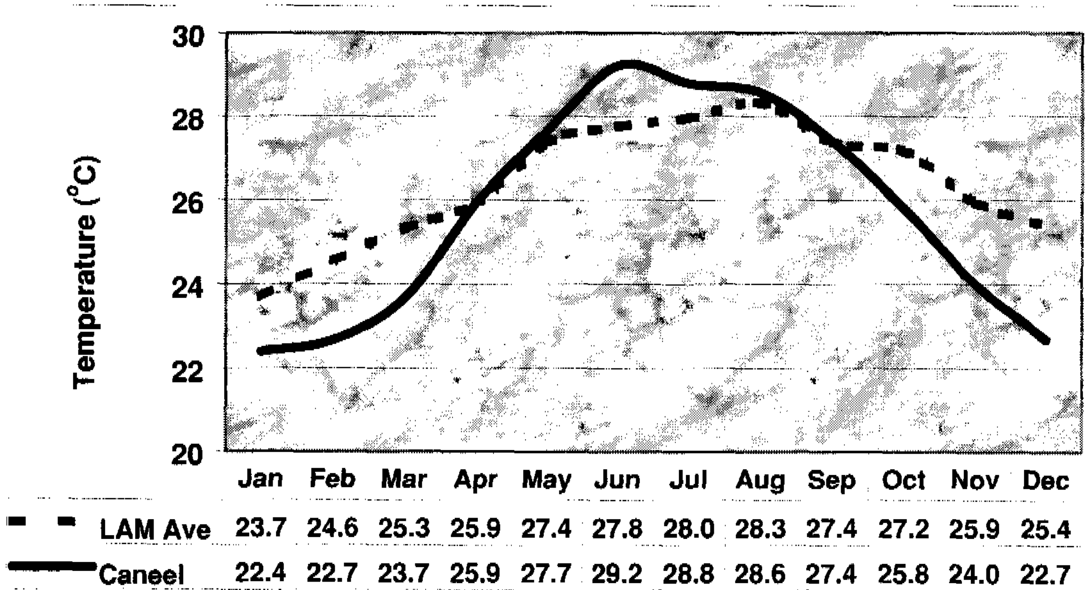


Figure 7.28.2.—Monthly air temperature values for the average of the Lameshur Bay sites and for the Caneel Hill site.

Soil temperature at 20 cm.—Monthly, seasonal, and annual temperatures are shown in table 7.28.3. Figure 7.28.3 graphs the monthly soil temperature averages for the three Lameshur Bay sites and the monthly soil temperatures at the Caneel Hill site.

Table 7.28.3.—Monthly and annual soil temperatures (°C) at 20 cm for Lameshur Bay and Caneel Hill.

Analysis	LAM 1	LAM 2	LAM 3	LAM ave.	Caneel Hill
Jan	26.1	24.3	25.7	25.3	23.1
Feb	25.7	24.5	26.0	25.4	23.7
Mar	27.4	25.6	27.2	26.7	23.9
Apr	28.2	26.1	27.3	27.2	25.8
May	30.6	27.6	28.1	28.7	27.2
Jun	31.3	28.5	28.4	29.4	28.7
Jul	31.0	28.5	28.5	29.3	28.3
Aug	31.5	28.9	29.1	29.8	27.9
Sep	29.8	28.4	28.7	28.9	27.0
Oct	28.7	27.3	29.1	28.4	25.6
Nov	27.3	26.2	27.8	27.1	24.4
Dec	26.1	25.6	26.9	26.2	23.0
Mean	28.6	26.8	27.7	27.7	25.7
MST	31.3	28.6	28.7	29.5	28.3
MWT	25.9	24.8	26.2	25.6	23.3
Isotivity	5.3	3.9	2.5	3.9	5.1

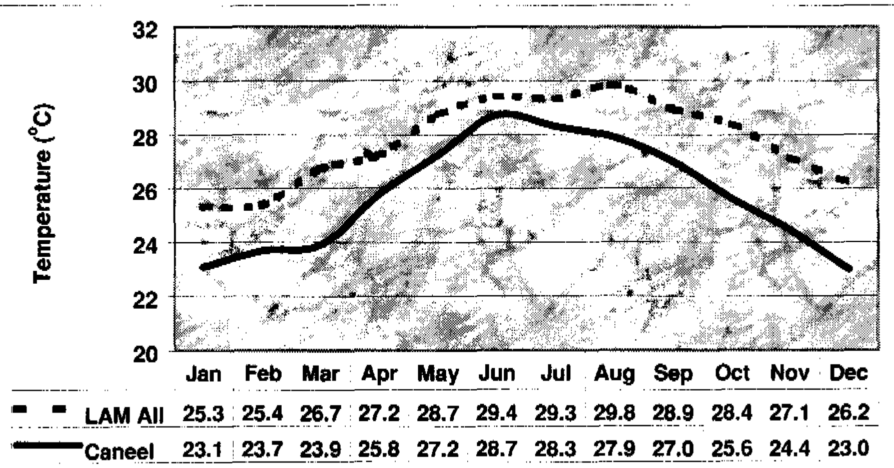
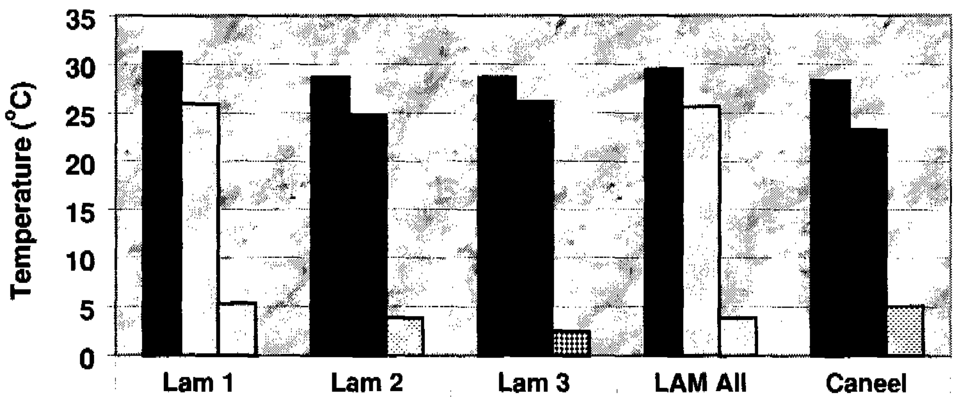


Figure 7.28.3.—Average monthly soil temperatures at 20 cm for Lameshur Bay and Caneel Hill.

The MAST at 20 cm was highest at Lam site 1 and was coolest on the Caneel Hill site. The difference between the highest and the coolest is 2.9 °C. The difference between Lam site 2 and the Caneel Hill site, which has similar enclosed canopy cover, is much smaller (1.1 °C). The MAST at 20 cm on the Caneel Hill site is 2.0 °C cooler than the MAST at 20 cm on the three sites in Lameshur Bay. Moreover, the soil temperature at 20 cm is cooler on the Caneel Hill site than on the sites in Lameshur Bay for every month of the year. The soil temperature differences at 20 cm are the most pronounced (3.2 °C) in December (23.0 °C at Caneel Hill vs. an average of 26.2 °C in Lameshur Bay). During December, the 20-cm soil temperature on the north aspect site at Caneel Hill is much cooler than the 20-cm soil temperature at any of the sites in Lameshur Bay.

Soils in the Tropics have higher isotivity values at 20 cm and 50 cm than had been originally thought (Mount, Hudson, et al., 1992). This maximum difference has historically been set at 5 °C (Soil Survey Staff, 1975). A change in *Soil Taxonomy* now allows a soil to have isotivity value of as much as 6 °C and still be "iso" (Soil Survey Staff, 1999). This change is the result of recent temperature findings in the Hawaiian Islands. Studies on the island of Maui show isotivity values of more than 5 °C on savanna soils (Nullet et al., 1990). Figure 7.28.4 shows seasonal changes in soil temperature at 20 cm for the study area.



	Lam 1	Lam 2	Lam 3	LAM All	Caneel
MST	31.3	28.6	28.7	29.5	28.3
MWT	25.9	24.8	26.2	25.6	23.3
MS-MW	5.3	3.9	2.5	3.9	5.1

Figure 7.28.4.—MST, MWT, and isotivity values at Lameshur Bay and Caneel Hill.

The isotivity value of 5.1 °C in the Caneel Hill zone is larger than the average in the Lameshur Bay zone (3.9 °C) but less than the maximum difference, which occurred at Lam site 1 (5.3 °C). The 50-cm soil depth at Lam site 1 has an isotivity value of 4.8 °C, which substantiates the depth paradigm of decreasing seasonal fluctuation with depth.

5. Discussion

Data from this study show that the MAST is cooler in the northern zone of St. John Island than in the southern zone. The soils at the sites where solar radiation is interrupted because of the canopy cover (Lam site 2 and the Caneel Hill site) have the most similar annual temperatures at 20 cm (26.8 °C and 25.7 °C, respectively).

The interrelationships among vegetative canopy cover, slope aspect, MAST, and isotivity value are complicated. Lam site 1 is on a west aspect and has the highest MAST (28.6 °C) and the highest isotivity value (5.3 °C). Conversely, the Caneel Hill site has the lowest MAST (25.7 °C) but also has a high isotivity value (5.1 °C). The south-facing soils at Lam sites 2 and 3 have an intermediate MAST (26.8 °C and 27.7 °C, respectively) and have the lowest isotivity values (3.9 °C and 2.5 °C, respectively).

The reasons for the high isotivity values at the Caneel Hill site are closely tied to the air temperature signature for the site. At 18° north of the Equator, the Caneel Hill site is close enough to the Equator for sunlight to create a microclimate environment during the summer and winter months. Though the incoming solar radiation is intercepted by the canopy cover, the air-soil heat exchange is maximized throughout the summer. In winter, mountain peaks shade the Caneel Hill site from the sun, resulting in a cooler soil climate.

This study confirms that the temperature signatures of soils are site-specific. It shows that these signatures must be measured and then analyzed for precise differences. Soil temperature modeling cannot approach real distinctions for any useful application basis.

Acknowledgments

Milton Cortes, NRCS Assistant State Soil Scientist, Raleigh, North Carolina, and Dr. Caroline Rogers, Research Director of the National Biological Survey on St. John Island, provided assistance for this project.

Chapter 7.29

Impact of Sandy Textures on Mean Annual Soil Temperatures at the Camden Farms in Caroline County, Virginia*

ABSTRACT

A study in 1997 and 1998 at six sites in Caroline County, Virginia, helped to quantify the impact of soil texture on mean annual soil temperature at 25 cm and 50 cm. Prior soil temperature studies in the NRCS have not examined spatial differences of mean annual soil temperature based on soil texture. The variation of mean annual soil temperature in the study area was related more closely to soil properties than to cropping systems. The three soils with sandy particle-size control sections are about 1.2 °C warmer at both 25 cm and 50 cm than the three soils with coarse-loamy particle-size control sections. A linear regression equation between sand content and the mean annual soil temperature was derived. At 0.97, the r^2 indicates a good fit of the data. Increasing sand content in the soils of the study resulted in increasing mean annual soil temperature.

1. Background

Few scientists in the Natural Resources Conservation Service suspected that sandy textures can impact the mean annual temperature of a soil. Though early researchers in Russia revealed the varying thermodynamics of soil texture, they presented no data specifically showing that sandy soils have a warmer mean annual soil temperature than loamy soils (Shul'gin, 1965).

Soil temperature data for cropland are relatively uncommon in the United States. Traditionally, soil temperature has been measured under grass vegetation or beneath tree canopies. Historically, the data for cropland are rare because of the difficulty of monitoring the soil during tillage operations.

Consequently, a study was designed on the Camden Farms in Caroline County to measure the soil temperature in a highly managed area used to monitor precision farming activities. The principal purpose was to gather baseline data. Part of this study involved sampling and characterizing the soils at six sites in the Camden Farms. Funding for this study was provided by the NRCS Global Change Initiative.

2. Study Area

The sites are in Caroline County, Virginia. The field consists of 21 strips with 7 treatments and 3 reps. All treatments consist of crop rotations ranging from wheat-beans-corn in treatment 1 to barley-sorghum-wheat-beans in treatment 7. The sites were equally divided in soil properties. Three of the sites have soils with a loamy particle-size control section, and three have soils with a sandy particle-size control section. Table 7.29.1 gives information about each of sites.

Table 7.29.1.—Strip information for the six soil temperature sites.

Site no.	Strip no.	Treatment (crop)	Rep. (no.)	Clay (%)	Sand (%)	Particle-size class
1	1	Beans	1	12	58	Coarse-loamy
2	7	Sorghum	1	16	61	Coarse-loamy
3	13	Corn	2	38	19	Coarse-loamy
4	2	Corn	1	3	95	Sandy
5	21	Barley	3	7	83	Sandy
6	17	Beans	3	5	88	Sandy

* Marc Crouch, Soil Data Quality Specialist from Richmond, Virginia, helped prepare this section.

3. Results

Soil temperature at 25 cm.—Table 7.29.2 shows temperatures for the 25-cm depth. The "Crs-loamy" and "Sandy" columns show the averages of the three coarse-loamy sites (1 to 3) and the three sandy sites (4 to 6). The MAST of the sandy sites averages 1.2 °C warmer than the MAST of the coarse-loamy sites (15.9 vs. 14.7 °C). Sites 1 to 3 are mesic, and sites 4 to 6 are thermic.

Table 7.29.2.—Soil temperatures (°C) for the 25-cm soil depth.

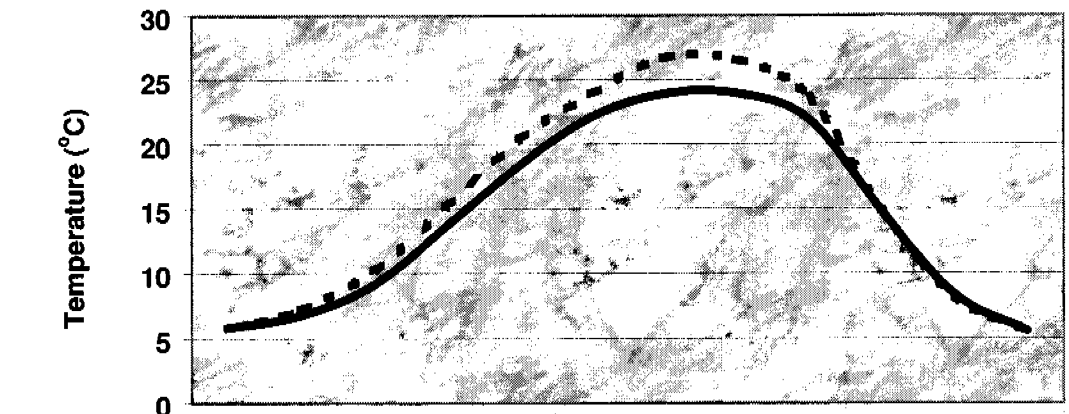
Analysis	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Crs-loamy (average)	Sandy (average)
Jan 98	4.8	4.8	4.7	4.9	4.7	4.8	4.8	4.8
Feb 98	7.2	7.0	6.5	7.3	7.1	7.2	6.9	7.2
Mar 98	9.7	9.8	9.5	11.1	10.5	10.5	9.6	10.7
Apr 98	14.0	14.7	15.5	17.4	15.5	15.4	14.7	16.1
May 98	18.7	19.6	21.5	23.9	21.2	21.0	19.9	22.1
Jun 98	23.7	24.1	23.5	25.4	25.3	25.2	23.7	25.3
Jul 98	25.3	26.0	24.2	28.4	27.8	28.2	25.2	28.1
Aug 98	24.2	25.3	25.0	27.8	26.7	27.4	24.8	27.3
Sep 97 & 98	21.4	22.1	22.5	23.7	23.2	23.6	22.0	23.5
Oct 97	13.3	13.6	13.4	13.8	13.4	13.8	13.4	13.6
Nov 97	6.5	6.7	6.7	6.9	6.5	6.8	6.6	6.7
Dec 97	4.8	4.8	4.5	5.2	4.6	4.8	4.7	4.8
MAST	14.5	14.9	14.8	16.3	15.5	15.7	14.7	15.9
MST	24.4	25.1	24.2	27.2	26.6	26.9	24.6	26.9
MWT	5.6	5.5	5.2	5.8	5.4	5.6	5.5	5.6
Isotivity	18.8	19.6	19.0	21.4	21.2	21.3	19.1	21.3

Soil temperature at 50 cm.—Table 7.29.3 shows the same trend at 50 cm, where the MAST also differs by 1.2°C between the sandy and coarse-loamy soils (15.7 vs. 14.5 °C). The MWT is 0.6 °C warmer and the MST is more than 1.1 °C cooler than for the 25-cm depths.

Table 7.29.3 – Soil temperatures (°C) for the 50-cm soil depth.

Analysis	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Crs-loamy (average)	Sandy (average)
Jan 98	6.1	5.8	5.6	6.1	5.5	5.8	5.8	5.8
Feb 98	7.1	6.9	6.2	7.2	7.0	7.3	6.7	7.2
Mar 98	9.2	9.3	8.7	10.3	10.0	10.3	9.1	10.2
Apr 98	13.0	13.8	14.0	16.1	14.7	14.7	13.6	15.1
May 98	17.1	18.1	19.7	21.8	19.8	19.6	18.3	20.4
Jun 98	21.5	22.4	22.3	24.0	23.9	23.7	22.1	23.9
Jul 98	23.7	24.7	23.2	26.6	26.6	26.9	23.9	26.7
Aug 98	23.3	24.5	24.0	26.9	26.1	26.7	23.9	26.5
Sep 97 & 98	21.3	22.0	22.4	24.1	23.2	23.7	21.9	23.7
Oct 97	14.9	14.7	14.9	15.1	14.4	15.1	14.8	14.9
Nov 97	8.4	8.2	8.4	8.4	7.7	8.3	8.4	8.1
Dec 97	5.8	5.6	5.4	6.0	5.1	5.6	5.6	5.6
MAST	14.3	14.7	14.6	16.1	15.3	15.6	14.5	15.7
MST	22.8	23.9	23.2	25.8	25.5	25.8	23.3	25.7
MWT	6.3	6.1	5.7	6.4	5.9	6.2	6.1	6.2
Isotivity	16.5	17.8	17.4	19.4	19.6	19.6	17.2	19.5

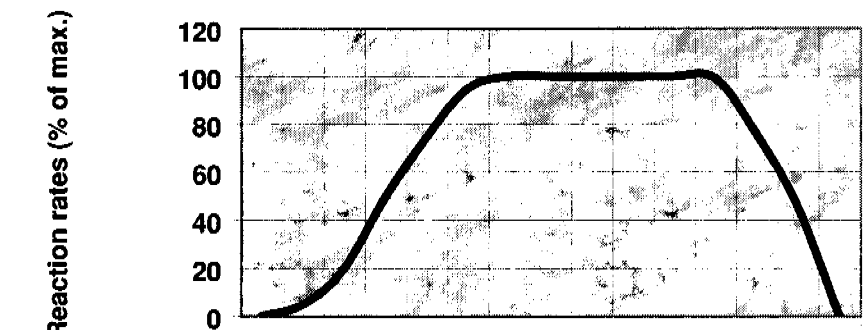
Figure 7.29.1 shows the monthly temperature signature at 50 cm for the coarse-loamy and sandy soils.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Crs-Lmy	5.8	6.7	9.1	13.6	18.3	22.1	23.9	23.9	21.9	14.8	8.4	5.6
Sandy	5.8	7.2	10.2	15.1	20.4	23.9	26.7	26.5	23.7	14.9	8.1	5.6

Figure 7.29.1.—Monthly temperature signature at 50 cm showing warmer averages for the sandy sites.

Biological activity.—Paul and Clark (1989) described biological activity rates as a function of soil temperature. Biological activity becomes less expressed as the soil cools during the winter months. At 5º C, the rate of biological activity is reduced to the 95 percent level (figure 7.29.2).



Soil temperature (°C)	0	5	15	20	24	30	33	35	36	40	62
Bio Rate (%)	0	5	50	75	95	100	100	100	99	75	0

Figure 7.29.2.—Conceptual model for biological activity rates (Paul and Clark, 1989).

Figure 7.293 shows the biological activity signature for site 1. The line at 5 °C shows the zone between activity and inactivity.

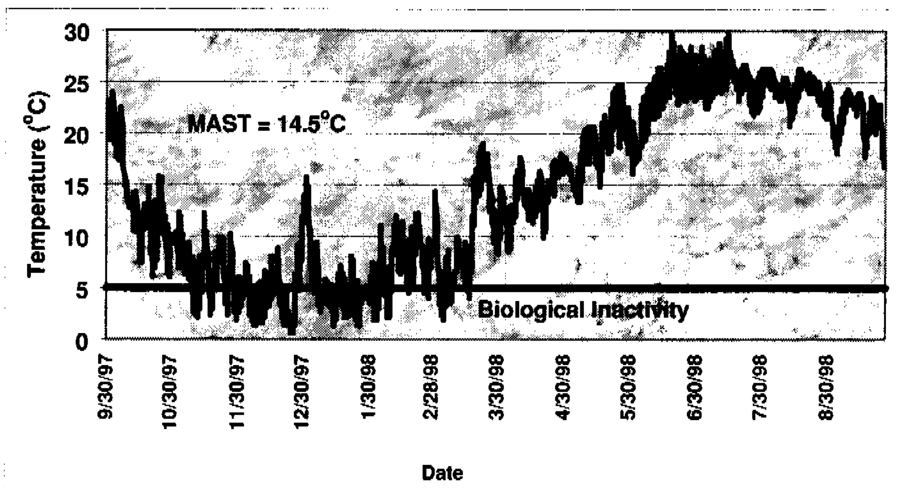


Figure 7.29.3.—Biological activity for the 25-cm depth at site 1.

Figure 7.29.3 suggests that there were about 4 months of reduced biological activity on the Camden Farms. The soil temperature signature shows wide fluctuations during this period with some days above 5 °C, some below 5 °C, and some partly above and partly below 5 °C. The first occurrence of less than 5 °C was at 1:37 a.m. on November 9, 1997, and the last was at 11:13 a.m. on March 17, 1998. The sandy soils at sites 4 to 6 showed the same relationship to reduced biological activity as the coarse-loamy soil at site 1.

4. Summary

The variation of mean annual soil temperature in the study area was related more closely to soil properties than to cropping systems. The sandy soils are about 1.2 °C warmer at both the 25-cm and 50-cm depths than the coarse-loamy soils. Prior to this study, soil temperature studies in the NRCS had not examined spatial differences based on soil texture. Regardless of the crop yield relationships to soil temperature on the Camden Farms, the real value of this temperature study was a quantification of the impact of soil texture on mean annual soil temperature at 50 cm. Figure 7.29.4 shows a linear regression equation of sand content and the mean annual soil temperature.

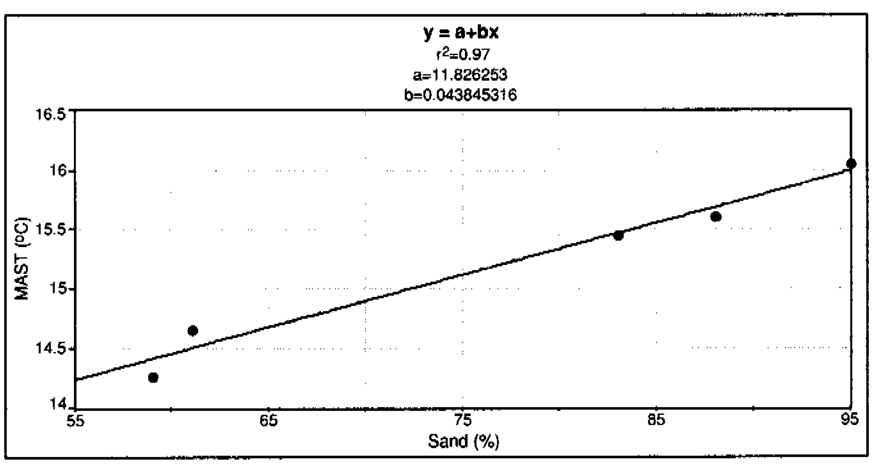


Figure 7.29.4.—Regression of sand content to the MAST at 50 cm.

At 0.97, the r^2 indicates a good fit of the data. Increasing sand content in the soils of the study is correlated with increasing MAST. It is emphasized that the equation expressed in figure 7.29.4 is a model that applies only to the field in the study area.

Acknowledgment

John Nicholson, NRCS Soil Scientist in Virginia, assisted in the installation and retrieval of data loggers for this study.

Chapter 7.30

Effects of Water Tables on Soil Temperature in Virginia and North Carolina*

ABSTRACT

Sixteen sites were monitored in Virginia and North Carolina for air and soil temperature during 1998 and 1999. All of the sites are in areas of woodland. Paired sites are generally within 100 m of each other. All but three of the well drained sites are flat and have no aspect. The amount of incoming solar radiation is approximately the same at each site. Had the wet-dry study been restricted to North Carolina, interpreting the results would have been much easier. Except for site 1 in Rockingham County, the poorly drained soils in North Carolina were warmer than their companion well drained sites. The poorly drained sites in North Carolina had a mean annual soil temperature that averaged 0.4 °C warmer than that of their paired well drained sites. This difference is within one standard deviation of the accuracy of the measurement technology used to capture data. The trend for the poorly drained soils in North Carolina to have a warmer mean annual soil temperature is only marginally significant. In Virginia, the poorly drained soils at three of the four paired sites tend to have a cooler mean annual soil temperature than the adjacent well drained soils. However, more data are needed before one can categorically state that soil drainage class is a factor that drives the mean annual soil temperature.

1. Background

There are many unknown factors that affect the mean annual soil temperature (MAST) of a soil. Scientists in the soil climate community have conjectured that the presence of soil water can impact the MAST. Some scientists suggest that soil water will buffer the soil temperature, resulting in warmer MAST values in poorly drained soils than in nearby well drained soils. Others have conjectured that soil water would result in a colder MAST, and some scientists have presumed that there would be no significant difference in MAST between well drained and poorly drained soils in close proximity. In this study, eight paired sites in North Carolina and Virginia were monitored for soil temperature during a 2-year period from September 1997 to September 1999. The purpose of the study was to investigate the effect of soil drainage class on mean annual soil temperature.

2. Study Area

The study area is in the Piedmont and Coastal Plains of North Carolina and Virginia. It includes four paired sites in North Carolina and four paired sites in Virginia. The latitude ranges from 35°04'08" to 36°24'30" north in North Carolina and from 36°44'14" to 38°24'17" north in Virginia. The longitude ranges form 79°12'54" to 80°18'44" west in North Carolina and from 75°59'40" to 78°50'02" west in Virginia. All of the sites are in areas of woodland. The paired sites are generally within 100 meters of each other. Except for NC 2, VA 1, and VA 8, the well drained sites are flat and have no aspect. The amount of incoming solar radiation is approximately the same at each site. Additional metadata for each site are shown in table 7.30.1.

* Marc Crouch, Soil Data Quality Specialist in Richmond, Virginia, helped prepare this section.

Table 7.30.1.—Drainage class, slope, aspect, and soil series at the sites in the study area.

Site ID	County name	Drainage class	Slope (%)	Aspect (°)	Soil name
VA 1	Culpepper	Well	10	60	Herndon
VA 2	Culpepper	Poor	0	Neutral	Kindora
VA 3	Sussex	Poor	0	Neutral	Roanoke
VA 4	Sussex	Well	0	Neutral	Emporia
VA 5	Virginia Beach	Poor	0	Neutral	Tomotley
VA 6	Virginia Beach	Well	1	240	Bojack
VA 7	Halifax	Poor	0	Neutral	Roanoke
VA 8	Halifax	Well	8	60	Mayodan
NC 1	Rockingham	Poor	1	60	Hatboro
NC 2	Rockingham	Well	10	80	Pacolet
NC 3	Chatham	Poor	0.5	90	Peawick
NC 4	Chatham	Well	0	Neutral	Mattaponi
NC 5	Montgomery	Poor	0	Neutral	Armenia
NC 6	Montgomery	Well	0	Neutral	Georgeville
NC 7	Forsyth	Poor	0	Neutral	Hatboro
NC 8	Forsyth	Well	0	Neutral	Mecklenburg

3. Results

Virginia sites 1 and 2.—During both years of the study, the MAST at 50 cm was colder in the poorly drained soil at site 2 than in the well drained soil at site 1 (table 7.30.2). At a depth of 50 cm, the poorly drained soil was 0.4 °C colder than the well drained soil during the first year (12.5 vs. 12.9 °C) and 0.3 °C colder during the second year (18.6 vs. 18.9 °C). The 10-cm depth increased an of average 0.2 °C between the first and second year at both sites, while the 50-cm depth increased an average of 0.3 °C. MST values were similar during both years, while MWT values increased. Both soils are mesic.

Table 7.30.2.—Comparison of temperature data (°C) between VA 1 and VA 2.

Analysis	'98 VA 1	'99 VA 1	'98 VA 2	'99 VA 2
Mean (10 cm)	13.1	13.3	12.6	12.9
Mean (50 cm)	12.9	13.1	12.5	12.9
MST (50 cm)	18.8	18.9	19.0	18.6
MWT (50 cm)	6.9	7.7	6.3	7.4
STR	Mesic	Mesic	Mesic	Mesic

Virginia sites 3 and 4.—The MAST at 50 cm was colder in the poorly drained soil at site 3 than in the well drained soil at site 4 during the first year of the study (14.9 vs. 15.1 °C). This relationship changed during the second year, when the well drained soil was 0.5 °C colder (table 7.30.3). Consequently, there is no clear indication of which site is warmer or colder. The MAST at 10 cm was similar at both sites and increased slightly during the second year. The MST decreased during the second year, while the MWT increased. The soil at site 3 was mesic during the first year (14.9 °C) and thermic during the second year (15.1 °C). Conversely, the soil at site 4 was thermic during the first year (15.1 °C) and mesic during the second year (14.6 °C).

Table 7.30.3.—Comparison of temperature data (°C) between VA 3 and VA 4.

Analysis	'98 VA 3	'99 VA 3	'98 VA 4	'99 VA 4
Mean (10 cm)	15.1	15.5	14.9	15.4
Mean (50 cm)	14.9	15.1	15.1	14.6
MST (50 cm)	20.5	19.8	19.8	24.2
MWT (50 cm)	9.5	10.6	10.1	6.4
STR	Mesic	Thermic	Thermic	Mesic

Virginia sites 5 and 6.—The MAST at 50-cm was colder in the poorly soil at site 5 than in the well drained soil at site 6 during the first year of the study (15.2 vs. 17.7 °C) but was warmer in the poorly drained soil during the second year (16.3 vs. 16.1°C). The 10-cm depth increased an average of 0.8 °C during second year at both sites, while the 50-cm depth displayed mixed results (table 7.30.4). Because of the proximity of the sites to a fire-fighting station, the MST and MWT are difficult to interpret. The soils at both sites are thermic.

Table 7.30.4.—Comparison of temperature data (°C) between VA 5 and VA 6.

Analysis	'98 VA 5	'99 VA 5	'98 VA 6	'99 VA 6
Mean (10 cm)	15.3	16.1	16.5	---
Mean (50 cm)	15.2	16.3	17.7	16.1
MST (50 cm)	20.0	20.4	21.4	19.8
MWT (50 cm)	10.8	12.5	14.4	12.4
STR	Thermic	Thermic	Thermic	Thermic

Virginia sites 7 and 8.—The MAST at 50 cm was colder in the poorly drained soil at site 7 than in the well drained soil at site 8 during the second year of the study (13.9 vs. 14.4 °C). The 10-cm depth was warmer in the poorly drained soil than in the well drained soil during the first year (14.0 vs. 13.8 °C). The 50-cm depth at site 8 increased an average of 0.8 °C between the first year and the second (13.6 to 14.4 °C). At site 8, MST and MWT values increased during the second year (table 7.30.5). The soils at both sites are mesic.

Table 7.30.5.—Comparison of temperature data (°C) between VA 7 and VA 8.

Analysis	'98 VA 7	'99 VA 7	'98 VA 8	'99 VA 8
Mean (10 cm)	14.0	---	13.8	---
Mean (50 cm)	---	13.9	13.6	14.4
MST (50 cm)	---	19.0	19.3	19.7
MWT (50 cm)	---	8.9	7.7	8.9
STR	Mesic	Mesic	Mesic	Mesic

North Carolina sites 1 and 2.—The MAST at 50 cm was slightly warmer in the poorly drained soil at site 1 than in the well drained soil at site 2 during the first year (13.6 vs. 13.5 °C) but was slightly cooler in the poorly drained soil during the second year (14.0 vs. 14.1 °C). During the second year, the MAST at 10 cm was warmer in the poorly drained soil than in the well drained soil (14.3 vs. 13.9 °C). The MAST at both sites increased about 0.5 °C between the first year and the second year (table 7.30.6). At both sites, the MST decreased and the MWT increased during the second year. The soil at each site is mesic.

Table 7.30.6.—Comparison of temperature data (°C) between NC 1 and NC 2.

Analysis	'98 NC 1	'99 NC 1	'98 NC 2	'99 NC 2
Mean (10 cm)	---	14.3	13.5	13.9
Mean (50 cm)	13.6	14.0	13.5	14.1
MST (50 cm)	19.3	18.6	20.2	19.9
MWT (50 cm)	7.3	8.8	6.7	8.4
STR	Mesic	Mesic	Mesic	Mesic

North Carolina sites 3 and 4.—The MAST at 50 cm was warmer in the poorly drained soil at site 3 than in the well drained soil at site 4 during the second year of the study (16.3 vs. 14.9 °C). The MAST at 10 cm was warmer in the poorly drained soil than in the well drained soil during both years (table 7.30.7). The 10-cm depth increased an average of 0.4 °C between the first year and the second year. The MST decreased during the second year, while the MWT increased. The soil at each site is thermic.

Table 7.30.7.—Comparison of temperature data (°C) between NC 3 and NC 4.

Analysis	'98 NC 3	'99 NC 3	'98 NC 4	'99 NC 4
Mean (10 cm)	15.6	16.1	15.1	15.5
Mean (50 cm)	15.7	16.3	15.6	14.9
MST (50 cm)	21.5	20.7	19.8	24.9
MWT (50 cm)	9.7	11.8	11.3	5.8
STR	Thermic	Thermic	Thermic	Thermic

North Carolina sites 5 and 6.—The MAST at 50 cm was warmer in the poorly drained soil at site 5 than in the well drained soil at site 6 during the first year of the study (15.3 vs. 15.1 °C). During both years of the study, the MAST at 10 cm was similar to the MAST at 50 cm on both sites (table 7.30.8). During the second year, the 10-cm mean temperature increased 0. 6 °C at the site 5 and 0.8 °C at site 6. The MST decreased during the second year, while the MWT increased. The soil at each site is thermic.

Table 7.30.8.—Comparison of temperature data (°C) between NC 5 and NC 6.

Analysis	'98 NC 5	'99 NC 5	'98 NC 6	'99 NC 6
Mean (10 cm)	15.2	15.8	15.2	16.0
Mean (50 cm)	15.3	--	15.1	15.8
MST (50 cm)	21.5	--	20.9	20.1
MWT (50 cm)	9.2	7.1	9.6	11.5
STR	Thermic	Thermic	Thermic	Thermic

North Carolina sites 7 and 8.—The MAST at 50 cm was 0.7 °C warmer in the poorly drained soil at site 7 than in the well drained soil at site 8 during the first year of the study (14.2 vs. 13.5 °C). It was 0.5 °C warmer in the poorly drained soil than in the well drained soil during the second year (14.8 vs. 14.3 °C). The 10-cm depth increased an average of 0.3 °C between the first year and the second year at both sites, while the 50-cm depth increased an average of 0.7 °C (table 7.30.9). The MST decreased during the second year, while the MWT increased. The soil at each site is mesic.

Table 7.30.9.—Comparison of temperature data (°C) between NC 7 and NC 8.

Analysis	'98 NC 7	'99 NC 7	'98 NC 8	'99 NC 8
Mean (10 cm)	14.5	14.7	13.6	14.1
Mean (50 cm)	14.2	14.8	13.5	14.3
MST (50 cm)	19.8	19.3	19.7	19.1
MWT (50 cm)	8.4	10.2	7.5	9.5
STR	Mesic	Mesic	Mesic	Mesic

4. Summary

Had the wet-dry study in Major Land Resource Area Office 14 been restricted to North Carolina, interpreting the results would have been much easier (figure 7.30.1).

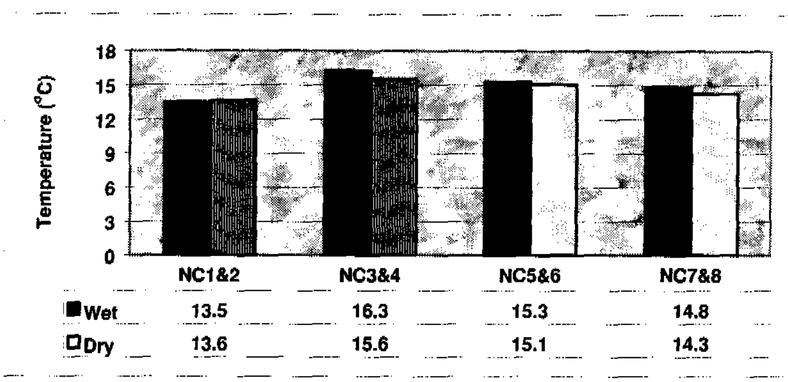


Figure 7.30.1.—Relationship of MAST for the poorly drained (wet) and well drained (dry) soils in North Carolina.

Except for site 1, the poorly drained soils in North Carolina were warmer than their companion well drained soils. Their MAST averaged 0.4 °C warmer than the MAST of their companion well drained soils. This difference is within one standard deviation of the accuracy of the measurement technology used to capture data. The trend for the poorly drained soils in North Carolina to have a warmer MAST is only marginally significant.

Soil temperature data from Virginia show a different trend on the sole basis of drainage class (figure 7.30.2).

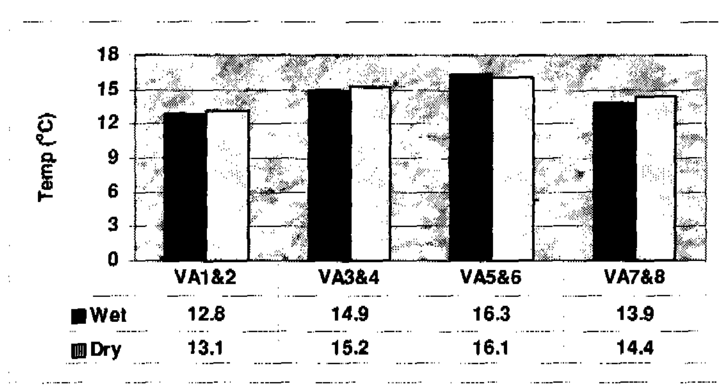


Figure 7.30.2.—Relationship of MAST for the poorly drained (wet) and well drained (dry) soils in Virginia.

In Virginia, the poorly drained soils at three of the four paired sites have a cooler MAST than the well drained soils. Though the poorly drained soil at site 5 has a warmer MAST than its companion well drained soil at site 6, it is conjectured that the adjacent fire-fighter's school has impacted the MAST. At the other sites, poorly drained soils have a colder MAST than their companion soils. Consequently, it can be stated that for those sites in Virginia, there is a trend for poorly drained soils to have a cooler MAST than the adjacent well drained soils. However, more data are needed before one can categorically state that soil drainage class is a factor that drives the MAST in Virginia.

In this study, the wet soils in Virginia tended to have a colder MAST than the dry soils. In North Carolina, the wet soils tended to have a warmer MAST than the dry soils. This trend is supported by a wet spring study in North Carolina that showed the MAST of a wet spring soil to be 0.9 °C warmer than that of an adjacent dry soil (12.8 vs. 11.9 °C).

Acknowledgments

The field soil scientists at Virginia Beach, in Culpepper, Sussex, and Halifax Counties, Virginia, and in Rockingham, Chatham, Montgomery, and Forsyth Counties, North Carolina, assisted in the installation and retrieval phases of this study.

Chapter 7.31

Interpretation of Soil Temperature Data, Butte DEMO Unit 4 Research Area, Gifford Pinchot National Forest

ABSTRACT

This study was conducted to measure the effects of clearcutting on soil temperature in the Gifford Pinchot National Forest of Washington. A soil at a control site (site 4) has the coldest mean annual soil temperature (9.1 °C), followed by a soil at a wooded site (site 1 at 11.2 °C), and then a soil at a clearcut edge (site 2 at 12.3 °C). Though data were available for only two complete months (July and August 1998) for site 3, they suggest that the soil at this clearcut site is 2.5 to 6.6 °C warmer during July than the other three sites. In August, this difference is tempered and site 3 ranges from 0.8 to 5.7 °C warmer than the other three sites. Site 2 was the only location to freeze at 10 cm. Data capture was 100 percent for the 50-cm depth. The mean annual soil temperature at site 4 is 1.4 °C colder than that at site 3, 1.4 °C cooler than that at site 2, and 0.8 °C colder than that at the center of the aggregate retention cell at site 1. The soil temperature regime is frigid for sites 1, 2, and 3. Since the difference between the mean summer soil temperature and the mean winter soil temperature is only 5.9 °C, site 4 is isofrigid. The soil at site 4 (at an elevation of 1,160 m) is also close to having a cryic temperature regime, which requires a mean summer soil temperature of less than 8 °C. The impact of clearcutting on soil temperature was similar between sites 2 and 3. Though the cutover area at site 3 has a warmer mean annual soil temperature than site 2 (7.0 vs. 6.3 °C), the MST is actually warmer at the clearcut edge site than at site 3 (12.6 vs. 12.3 °C). Thus, the soil temperature increases at the edge of a clearcut and not some distance away. The MWT is coldest at the border of the clearcut in this study. However, it is suggested that this edge warming in the study area results, in part, from lower snowfall amounts than at the other sites. The air temperature signature for the clearcut edge site indicates marginal impact from snow cover. The sensors captured diurnal fluctuation throughout the winter months. This is contrasted with the flat-lining of data capture that occurred at the control site in winter because of a snow cover.

1. Background

The temperature regimes for soils in eastern Washington are driven by elevation and aspect dependency. Currently, the division between the frigid and cryic temperature regimes is about 1,066 m. For areas with large amounts of snowfall in Washington, there was previously little or no information about soil temperature during winter months. With the advent of data-logging technology, a study was designed for the Butte DEMO Unit 4 Research Area in the Gifford Pinchot National Forest. The effects of clearcutting on soil temperature have not been well understood. This study assesses these impacts.

2. Butte DEMO Unit 4 Research Area Sites

On June 18, 1998, data loggers were installed to measure air and soil temperatures at four sites in the study area. These sites are in the northern part of the Gifford Pinchot National Forest (GPNF) and are in Skamania County, Washington, which is in the southwest part of the State. Table 7.31.1 gives information about the sites.

Table 7.31.1.—Site information for the study area.

Site number	Latitude (north)	Longitude (west)	Elevation (m)	Slope (%)	Aspect (°)	Canopy cover (%)
1	46°22'53"	121°34'37"	1,097	55	120	60
2	46°22'51"	121°34'37"	1,088	52	110	60
3	46°22'49"	121°34'43"	1,113	45	140	0
4	46°22'54"	121°34'43"	1,158	72	130	60

Site 1 is 3.5 m at an azimuth of 250° from grid point B8. It is 56 m from the edge of a clearcut timber area. The vegetation consists of a western hemlock (*Tsuga spp. L.*) overstory and an understory and ground cover of Oregongrape (*Mahonia aquifolium L.*) and Solomons seal. The soil at this site is a medial-skeletal, amorphic, frigid Vitric Hapludand (Soil Survey Staff, 1999).

Site 2 is 4.5 m at an azimuth of 37° from a red flag labeled 5B8306 and about 10 to 15 m from the edge of a clearcut timber area. The vegetation consists of a western hemlock overstory and an understory and ground cover of Oregongrape and Solomons seal. The soil at this site is a medial-skeletal, amorphic, frigid Vitric Hapludand.

Site 3 is 2.77 m at an azimuth of 30° from tree tag #2 and is in the middle of a clearcut timber area. Western hemlock trees have been harvested on this site. Bracken ferns cover 5 to 10 percent of the surface. The soil at this site is a medial-skeletal, amorphic, frigid Vitric Hapludand.

Site 4 is near the Lewis County line. It is 160 m at an azimuth of 20° from grid point A9. It is 7.6 m upslope from a vertical cliff that is difficult to navigate. The vegetation consists of a Douglas-fir (*Pseudotsuga spp. L.*), Pacific silver fir (*Abies spp. L.*), and western redcedar (*Juniperus spp. L.*) overstory and an understory and ground cover of vine maple and Solomons seal. The soil at this site is a medial-skeletal, amorphic, frigid Vitric Haplocryand.

3. Results

Soil temperature at 10 cm.—Table 7.31.2 shows that control site 4 has the coldest MAST (9.1 °C), followed by the wooded site 1 (11.2 °C), and then the clearcut edge site 2 (12.3 °C). Though data were available for only two complete months (July and August 1998) for site 3, they suggest that this clearcut site is 2.5 to 6.6 °C warmer during July than the other three sites. In August, this difference is tempered and site 3 ranges from 0.8 to 5.7 °C warmer than the other three sites. Site 2 was the only location to freeze at 10 cm.

Table 7.31.2.—Monthly and annual temperatures (°C) for the 10-cm depth.

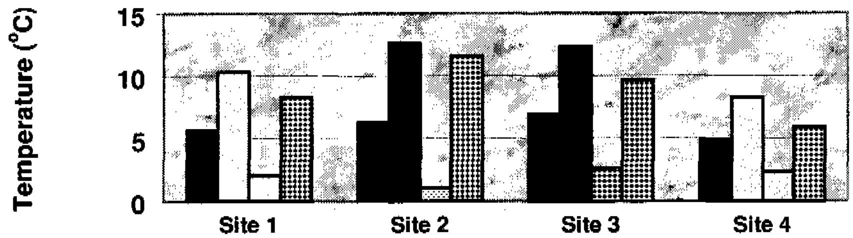
Analysis	Site 1	Site 2	Site 3	Site 4
Jan 99	0.5	0.3	---	0.7
Feb 99	0.6	0.3	---	0.8
Mar 99	0.5	0.0	---	0.5
Apr 99	0.5	1.1	---	0.4
May 99	2.3	4.9	---	0.8
Jun 98 & 99	8.0	8.4	---	6.0
Jul 98	14.7	15.5	18.8	12.2
Aug 98	15.2	16.9	18.1	12.4
Sep 98	13.9	15.3	---	11.6
Oct 98	7.3	8.3	---	6.1
Nov 98	3.1	2.8	---	2.4
Dec 98	0.7	-0.3	---	0.7
MAST	11.2	12.3	---	9.1
MST	27.2	27.2	35.6	20.4
MWT	1.3	0.2	---	1.5
Isotivity	26.0	27.0	---	18.9

Soil temperature at 50 cm.—Data capture was 100 percent for the 50-cm depth. The MAST for the control location (site 4) is 1.4 °C colder than that of the clearcut location (site 3), 1.4°C cooler than that of the edge location (site 2), and 0.8°C colder than that of the center of the aggregate retention cell at site 1 (table 7.31.3). The soil temperature regime is frigid at sites 1, 2, and 3. Since the isotivity value is only 5.9 °C, site 4 is isofrigid (Soil Survey Staff, 1999). This site is at an elevation of 1,158 m and is close to having a cryic temperature regime, which requires a MST of less than 8 °C.

Table 7.31.3.—Monthly and annual temperatures (°C) for the 50-cm depth.

Analysis	Site 1	Site 2	Site 3	Site 4
Jan 99	1.7	0.9	2.4	2.3
Feb 99	1.8	1.1	2.7	2.1
Mar 99	1.5	0.8	2.6	1.7
Apr 99	1.4	1.2	2.1	1.5
May 99	2.0	4.7	2.6	1.6
Jun 98 & 99	6.5	8.3	9.0	5.0
Jul 98	11.2	14.1	13.3	9.3
Aug 98	13.1	15.4	14.7	10.6
Sep 98	12.7	14.4	14.1	10.4
Oct 98	8.6	9.2	10.7	7.2
Nov 98	5.1	4.3	6.4	4.4
Dec 98	2.5	1.1	2.9	2.8
MAST	5.7	6.3	7.0	4.9
MST	10.3	12.6	12.3	8.3
MWT	2.0	1.0	2.7	2.4
Isotivity	8.3	11.6	9.6	5.9

The differences in seasonal and annual changes among the four sites are shown in figure 7.31.1.



	Site 1	Site 2	Site 3	Site 4
Mean	5.7	6.3	7.0	4.9
MST	10.3	12.6	12.3	8.3
MWT	2.0	1.0	2.7	2.4
MS-MW	8.3	11.6	9.6	5.9

Figure 7.31.1.—Seasonal and annual comparisons at 50 cm among the four sites in the study area.

The impact of clearcutting was similar between sites 2 and 3 (figure 7.31.1). Though the cutover area at site 3 has a warmer MAST than the edge area at site 2 (7.0 vs. 6.3 °C), the MST is actually warmer at site 2 than at site 3 (12.6 vs. 12.3 °C). Thus, the soil temperature increases at the edge of a clearcut, especially during the summer months, and not some distance away. Winter soil temperatures are also coldest at the border of the clearcut in this study area.

Air temperature.—It is suspected that the edge warming in the study area results, in part, from conjectured lower snowfall amounts than at the other sites. The air temperature at site 2 indicates marginal impact from snow cover, and soil temperature sensors captured diurnal fluctuation throughout the winter months. The air temperature sensors were placed 1 m above the ground at all of the sites in this study area. Data capture was 100 percent at sites 1, 2, and 4. The air temperature data are shown in table 7.31.4.

Table 7.31.4.—Monthly, seasonal, and annual air temperatures (°C) in the study area.

Analysis	Site 1	Site 2	Site 3	Site 4
Jan 99	-0.4	0.2	---	-0.9
Feb 99	-0.9	-1.0	---	-1.1
Mar 99	-0.3	0.7	---	-0.2
Apr 99	1.6	3.2	---	0.0
May 99	4.4	5.7	---	2.9
Jun 98 & 99	8.9	9.5	---	7.8
Jul 98	16.6	17.5	18.8	15.6
Aug 98	16.2	17.4	18.6	15.7
Sep 98	14.5	16.1	16.3	13.5
Oct 98	6.5	8.0	7.4	5.8
Nov 98	1.6	2.0	1.7	0.8
Dec 98	-2.4	-1.8	-2.1	-3.0
MAAT	5.5	6.5	---	4.8
MST	13.9	14.8	17.0	13.0
MWT	-1.2	---	-0.8	-1.7
Isotivity	15.1	---	17.9	14.7

Data from site 2 are contrasted by the flat-lining of data capture that occurred at site 4 during the winter months (figure 7.31.2).

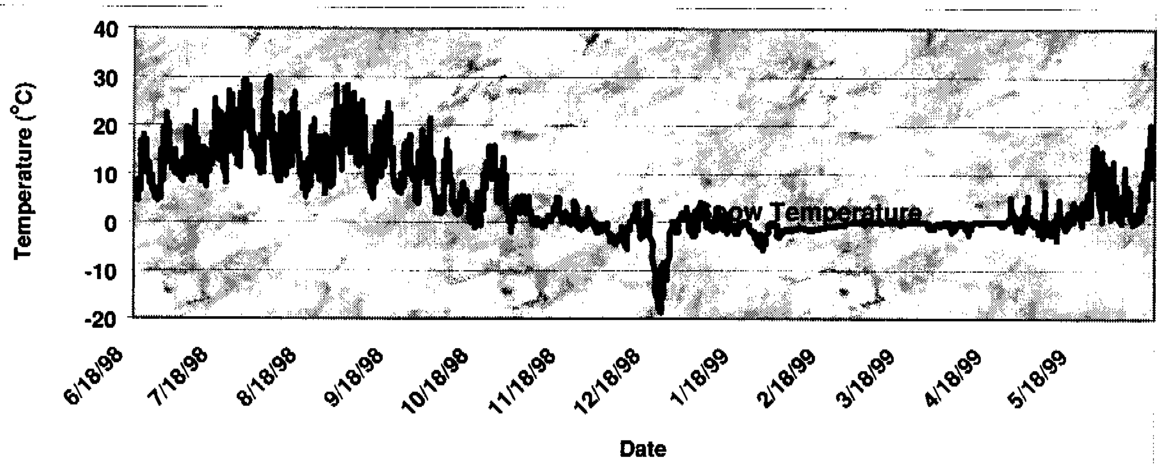


Figure 7.31.2.—Impact of snowfall on air temperature at site 4.

Data for air temperature are mitigated by snow cover during the winter months. Consequently, the MWT and MAAT are expected to be somewhat colder than is indicated by the data captured by the loggers. Snowfall, which covered the sensor at site 4, flat-lined to near 0 °C during the winter. It was not until April 24, 1999, that air temperature readings above freezing were recorded. Since the air temperature sensor at site 4 was still 1 m above the forest floor when it was removed, it can be assumed that more than 1 m of snow was covering the soil temperature sensor until April 24, 1999.

4. Discussion

The northern part of the Gifford Pinchot National Forest offers scientists the opportunity to assess soil temperature under controlled conditions. Since control site 4 was located with precise care and represents an ecosystem beyond the impacts of adjacent clearcutting, it can be inferred that there are measurable impacts of clearcutting on air and soil temperature. Soil temperature averages at 10 cm during July are 6.6 °C warmer at clearcut site 3 than at control site 4. The 10-cm soil temperature for the clearcut location at site 3 reached a maximum of 25.9 °C on July 27 and 28, 1998. This is contrasted to the control location at site 4, where the 10-cm soil temperature peaked at 16.1 °C on July 27 and 28, 1998. Therefore, the 10-cm soil temperature at the cutover site is nearly 10 °C warmer at its maximum than the 10-cm soil temperature at the control site.

This study also suggests that a small (<2 ha) cell of uncut trees will be impacted by a change in the air and soil temperature environment. The soil at site 1, in the middle of the aggregate retention cell, has warmer average temperatures than the soil at control site 4.

Acknowledgments

Cara Nelson, Ph.D. candidate from the University of Washington at Seattle, assisted in site selection, in the collection of metadata, and in the installation and retrieval of data loggers. Don Fallon, SSPL for the Gifford Pinchot National Forest (now Montana) and Dr. Stefan Miara, Soil Scientist from Westfalen, Germany, provided assistance during the installation phase of this study.

Chapter 7.32

Interpretation of Soil Temperature Data From Spokane County, Washington*

ABSTRACT

Air and soil temperatures were measured at six sites in Spokane County, Washington, in 1999 and 2000. The soils range in altitude from 512 to 1,448 m. At the 50-cm depth, the soil at site 6, at an elevation of 1,448 m, has the coldest mean annual soil temperature (4.8 °C), followed by the soil at site 5, at 1,219 m (5.3 °C), the soils at sites 3 and 4, at 579 m (8.4 and 8.8 °C), and the soils at sites 1 and 2, near the city of Spokane (9.1 °C). Sites 5 and 6, in Mt. Spokane State Park, averaged between 4 and 5 °C colder than the other sites during the summer compared to about 2 °C colder during the winter. At the 10-cm depth, site 5 had the lowest mean annual soil temperature (6.1 °C). The warmest mean annual soil temperature at 10 cm was at site 3, which had an annual average of 10.4 °C. Site 6 had the lowest isotivity value (difference in mean summer and mean winter soil temperatures) at 6.7 °C, followed by the soil at site 5, which had an isotivity value of 8.7 °C. The soils at open sites 1 and 4 had the highest isotivity values at the 10-cm depth (19.4 and 19.0 °C). The soil did not freeze at 10 cm or 50 cm at any site. The 10-cm soil temperature signature for site 1 was the most expressed in its diurnal fluctuation. The mean annual soil temperature at 50 cm shows the soil at site 1 be to mesic and is identical to the mean annual soil temperature at 10 cm (10.0 °C). The soil at sites 4 (9.4 °C) and 5 (10.6 °C) are mesic. The soil at site 5 is isofrigid. With a MAST of 5.8 °C and a mean summer temperature of 8.4 °C, the soil at this site is too warm to be cryic. However, at 4.6 °C, the isotivity value is too low for frigid and the soil fits into an "iso" category. The soil at site 6 is cryic. At 3.3 °C, its isotivity value is the lowest in the study area. The results of this study are anticipated to contribute positively to the correlation of soils in the Spokane County soil survey area.

1. Background

Though partial temperature data are available for Spokane County, Washington, the mean annual soil temperatures can only be approximated for soil survey activities. Frequently, soil scientists have to infer the soil temperature from a change in vegetation at a specified altitude. Consequently, a study was designed to assess and quantify soil temperatures at six sites in the county. This study was funded by the NRCS Global Change Initiative.

2. Study Area and Site Hypotheses

Data loggers were installed to measure air and soil temperatures at six sites in the county on July 27-28, 1999.

Site 1 is south of the Spokane River, in Riverside State Park. Its vegetation consists of ponderosa pine (*Pinus spp. L.*), Idaho fescue, arrowleaf balsamroot, and cheatgrass. The soil at this site is of the Springdale series. It is a sandy-skeletal, isotic, mesic Vitrandic Haploxerept. It is covered with 1 mm of ponderosa pine needle litter. The soil temperature regime is expected to be mesic.

Site 2 is in an area of woodland west of the Spokane River, in Riverside State Park. Its vegetation consists of Douglas-fir (*Pseudotsuga spp. L.*), ponderosa pine, and ninebark pinegrass. The soil at this site is of the Scoap series. It is a loamy-skeletal, mixed, superactive, frigid Vitrandic Haploxeroll. It is covered with 7.5 cm of humus. The soil temperature regime is expected to be frigid but borderline to mesic.

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* Eva Muller, Soil Survey Project Leader for Spokane County, assisted in preparing this section.

Site 3 is paired with site 4. It is in an area of woodland, and its vegetation consists of an overstory of Douglas-fir and larch (*Larix spp.* L.) and an understory of oceanspray, Oregongrape, and spirea. The soil at this site is of the Clayton series. It is a coarse-loamy, mixed, superactive, mesic Vitrandic Haploxerept. It is covered with 7.5 cm of humus. This site is expected to be frigid.

Site 4 is paired with site 3. It is in CRP (Idle Acres), and its vegetation consists of orchardgrass and equisetum (horsetail) and a single ponderosa pine seedling. The soil at this site is of the Clayton series. It is a coarse-loamy, mixed, superactive, mesic Vitrandic Haploxerept. It was thought that this soil would have a mesic temperature regime and would have a MAST 1 °C warmer than that of site 3.

Site 5 is in Mt. Spokane State Park. It is in an area of woodland, and its vegetation consists of an overstory of western hemlock (*Tsuga spp. L.*), grand fir (*Abies spp. L.*), and cedar (*Juniperus spp. L.*) and a ground cover of disporum. The soil at this site is of the Boulderjud series. It is an ashy over loamy-skeletal, amorphic over mixed, superactive, frigid Typic Udivitrand. It is covered with 7.5 cm of humus.

Site 6 is along Lodgepole Trail 220, in Mt. Spokane State Park, in northeast Spokane County. It is in an area of woodland, and its vegetation consists of mountain hemlock, subalpine fir (*Abies spp. L.*), and Engelmann spruce (*Picea engelmannii L.*) and an understory and ground cover of false huckleberry and beargrass (*Xerophyllum tenax L.*). The soil at this site is of the Vay series. It is a medial over loamy-skeletal, mixed, superactive Typic Haplocryand. It is covered with 7.5 cm of humus. The mean annual precipitation is about 1,000 mm, the highest in the study area. The soil is expected to be cryic.

Table 7.32.1 gives additional information about the sites.

Table 7.32.1.—Site information for the study area.

Site number	Latitude (north)	Longitude (west)	Elevation (m)	Slope (%)	Aspect (°)	Canopy cover (%)
1	47°45'18"	117°32'03"	512	2	180	5
2	47°46'17"	117°33'49"	594	45	30	30
3	47°50'34"	117°18'14"	579	1	180	40
4	47°50'35"	117°18'28"	579	1	180	0
5	47°54'30"	117°07'10"	1,219	42	120	95
6	47°53'27"	117°05'26"	1,448	30	0	60

3. Results

Air temperature.—Site 6 has the coldest MAAT (4.8 °C), followed by site 5 (5.3 °C), the paired sites 3 and 4 (8.4 and 8.8°C), and sites 1 and 2, near the city of Spokane (9.1 °C). (See table 7.32.2.) There was not so much difference between the winter air temperatures as between the summer air temperatures among the sites in the study area. The MST at sites 5 and 6 averaged between 4 and 5 °C colder than that at the other sites, and the MWT averaged about 2 °C colder during the winter period of the study.

Table 7.32.2.—Air temperatures (°C) for the sites in Spokane County.

Analysis	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Jan 00	-1.3	-1.3	-1.6	-1.4	-4.0	-2.6
Feb 00	1.0	1.0	0.6	0.8	-1.5	-0.4
Mar 00	4.0	4.0	4.0	4.1	-0.3	0.2
Apr 00	9.3	9.8	8.8	9.6	3.1	0.6
May 00	12.5	11.7	11.3	12.1	6.3	5.0
Jun 00	16.8	16.0	15.4	16.5	11.8	11.5
Jul 00	19.8	18.5	17.5	19.3	14.8	14.5
Aug 99	21.5	21.4	19.7	20.9	16.5	15.8
Sep 99	13.1	14.1	12.3	12.5	11.2	10.5
Oct 99	7.3	8.2	7.2	7.2	5.8	4.6
Nov 99	4.2	5.2	4.5	4.1	3.0	1.8
Dec 99	0.6	0.8	0.6	0.2	-2.9	-3.3
MAST	9.1	9.1	8.4	8.8	5.3	4.8
MST	19.4	18.6	17.5	18.9	14.3	13.9
MWT	0.1	0.2	-0.1	-0.1	-2.8	-2.1
Isotivity	19.3	18.5	17.7	19.0	17.1	16.0

Soil temperature at 10 cm.—Monthly, seasonal, and annual temperatures for the 10-cm depth are given in table 7.32.3. Curiously, site 5 has the lowest MAST (6.1 °C). The warmest MAST is at site 3 (10.4 °C). Site 6 has the lowest isotivity value (6.7 °C), followed by site 5 (8.7 °C). The soils in open ecosystems (sites 1 and 4) have the highest isotivity values at the 10-cm depth (19.4 and 19.0 °C). Since these soils are exposed to winter conditions, they also have the lowest MWT (0.9 °C). For the soils at sites 3, 5, and 6, which have thick layers of humus, the MWT is 3.4 °C, 2.6 °C, and 4.9 °C, respectively. The soils did not freeze at any of the sites during the period of record. The temperature signature for site 1 has the most expressed diurnal fluctuation (figure 7.32.1).

Table 7.32.3.—Monthly and annual soil temperatures (°C) for the 10-cm depth.

Analysis	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Jan 00	0.5	0.5	2.9	0.3	2.6	4.8
Feb 00	0.5	0.5	2.3	0.9	2.5	5.9
Mar 00	4.1	3.8	4.8	4.7	2.2	6.0
Apr 00	9.3	7.6	8.4	10.3	2.3	5.6
May 00	13.8	10.1	12.0	14.0	5.9	5.8
Jun 00	17.7	13.5	18.1	17.4	9.5	10.3
Jul 00	21.3	15.4	21.7	20.5	11.7	12.3
Aug 99	22.0	16.9	16.9	21.6	12.7	12.0
Sep 99	15.3	12.6	13.6	15.4	9.4	8.1
Oct 99	8.9	8.5	10.3	8.7	6.2	4.2
Nov 99	5.3	5.9	8.2	5.1	5.6	4.1
Dec 99	1.8	2.4	4.9	1.4	2.8	3.9
MAST	10.0	8.1	10.4	10.0	6.1	6.9
MST	20.3	15.3	18.9	19.8	11.3	11.6
MWT	0.9	1.1	3.4	0.9	2.6	4.9
Isotivity	19.4	14.1	15.5	19.0	8.7	6.7

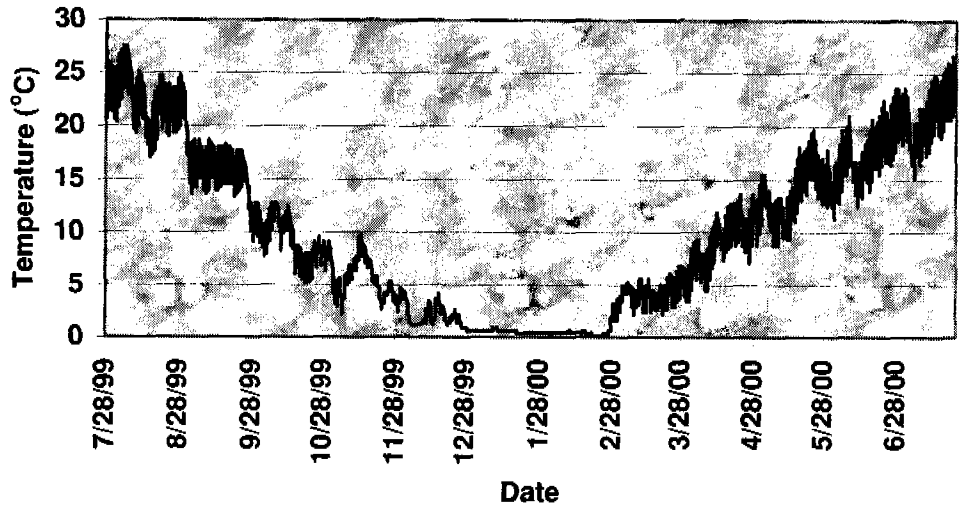

Figure 7.32.1.—Soil temperature signature for the 10-cm depth at site 1.

The soil temperature signature for the 10-cm depth at site 1 reflects an open ecosystem. The soil temperature approached freezing during the period from December through February. During the summer, soil temperature values were more than 25 °C.

Soil temperature at 50 cm.—Monthly, seasonal, and annual temperatures for the 50-cm depth are given in table 7.32.4. The soil temperature regime (STR) also is indicated.

Table 7.32.4.—Monthly and annual soil temperatures (°C) for the 50-cm depth.

Analysis	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Jan 00	1.6	4.0	6.5	1.6	3.6	3.5
Feb 00	1.2	3.6	5.4	1.3	3.4	3.1
Mar 00	4.0	6.2	6.4	3.8	3.2	2.8
Apr 00	8.3	10.3	8.4	7.8	2.9	2.4
May 00	12.7	14.7	10.9	11.5	4.4	2.3
Jun 00	16.1	19.0	13.8	14.5	6.7	5.2
Jul 00	19.4	20.8	15.8	16.9	9.0	7.4
Aug 99	20.6	14.0	14.9	18.6	9.5	7.8
Sep 99	16.1	12.9	14.2	15.4	9.2	8.1
Oct 99	10.5	10.5	12.5	10.5	7.6	6.5
Nov 99	6.8	8.5	10.6	7.2	6.4	5.3
Dec 99	3.1	6.0	8.1	3.4	4.3	3.9
MAST	10.0	10.9	10.6	9.4	5.8	4.9
MST	18.7	17.9	14.8	16.6	8.4	6.8
MWT	2.0	4.6	6.7	2.1	3.8	3.5
Isotivity	16.7	13.4	8.1	14.6	4.6	3.3
STR	Mesic	Mesic	Mesic	Mesic	Isofrigid	Cryic

The MAST at 50 cm shows that the soil at site 1 is mesic. It is identical to the MAST at 10 cm (10.0 °C). The soil at site 2 also is mesic. Its MAST at 50 cm is 10.9 °C, which is much warmer than the MAST at 10 cm. Only two reasons can explain this difference: 1) underlying geothermal activity in the area or 2) miscalibration of the temperature sensor. The soil at site 4, in an open field, and has a lower

MAST at 50 cm than the soil at site 3, under woodland vegetation (9.4 vs. 10.6 °C). When sites are paired, a soil at an open site generally will have a warmer MAST than a soil at a forested site (Mount, 1999, and Mount, Pyle, et al., 1999). The soil at site 5 is isofrigid. With a MAST of 5.8 °C and a MST of 8.4°C, this soil is too warm to be cryic. At 4.6 °C, its isotivity value is too low for frigid, and the soil fits into an "iso" category. The soil at site 6 is cryic. At 3.3 °C, its isotivity value is the lowest in the study area.

It is anticipated that the results of this temperature study will contribute positively to the correlation of soils in Spokane County and to understanding the nuances of soil temperature.

Acknowledgments

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Chapter 7.33

Soil Temperature in the Central Appalachians of West Virginia*

ABSTRACT

In 1997 and 1998, forested soils at sites in the central Appalachians of West Virginia were paired so that differences in mean annual soil temperature based on aspect could be determined. Aspect dependency for mean annual soil temperature at 50 cm was shown for all the sites. At every location, the mean annual soil temperature on the south aspect was warmer than that on its paired north aspect. The least difference was 0.3 °C for the soils at an elevation of 914 m (sites 4 and 5). The largest difference was 1.6 °C for the soils at an elevation of 853 m (sites 1 and 2). The trend of mean annual soil temperature versus elevation was low (r^2 of <0.1), and there was an increase in mean annual soil temperature with elevation until 975 m, at which point the mean annual soil temperature began to decrease. The mean winter soil temperatures were generally lower on north aspects than on south aspects Except for the soil at 914 m (site 4), the mean summer soil temperatures were lower on north aspects. The mean annual soil temperature increased at the seven sites an average of 0.5 °C during the second year. The mean annual soil temperature increased equally on north and south aspects. The soils in this study area have a mesic temperature regime. Shift analysis for a soil in an area of suspected cold air drainage shows that the soil started as mesic (>8 °C) during the first shift, decreased to frigid during the third shift, and continued to have a frigid soil temperature regime through the ninth shift. It returned to a mesic soil temperature regime during the tenth shift and increased in mean annual soil temperature until the thirteenth and final shift. Summarized data suggest that a soil temperature regime will shift with warming weather patterns, even during a short-term study. A latitude-elevation linear regression was generated. This regression was based on measured data at a southern site from the Great Smoky Mountains in Tennessee; a site in western Greenbrier County, West Virginia; and a northern site in Cattaraugus County, New York. With an r^2 of 0.99, this equation can be used to approximate the mesic-frigid soil temperature break on north aspects for any given latitude between 35° and 43° north. The equation is as follows: Y (latitude in decimal degrees) = a + bx, where a = 46.204504, b = -0.0075558256, and x = elevation (m).

1. Background and Purpose

Temperature data from sites in Pocahontas and Greenbrier Counties, West Virginia, are an important addition to current soil temperature research. Data loggers were installed at these sites in late July of 1997 and collected data for 2 years.

Before this study was initiated, scientists from the study area identified the purpose of the study. The soil temperature regime for the study area was in question. Thus, data loggers were installed at seven sites to gather information indicating if the soils have a mesic or a frigid soil temperature regime. A mesic temperature regime has a mean annual soil temperature (MAST) of 8 to 15 °C and an isotivity value, or difference between mean summer soil temperature (MST) and mean winter soil temperature (MWT), of more than 6 °C. A frigid temperature regime has a MAST of less than 8 °C and an isotivity value of more than 8 °C. Also, a frigid temperature regime is required to have a MST of less than 8° C for soils with an O horizon (Soil Survey Staff, 1999). It was thought that the results of this study would establish a break between the mesic and frigid soil temperature regimes in the central Appalachians.

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2. Study Area

The study area is in Pocahontas and Greenbrier Counties. These counties are in the southeastern part of West Virginia and border the State of Virginia. Latitude, longitude, soil series, slope, aspect, elevation, and ecosystem type were documented at each site (table 7.33.1).

Table 7.33.1.—Site metadata for the study area.

Site number	County name	Latitude (north)	Longitude (west)	Soil series	Slope (%)	Aspect (°)	Elevation (m)
1	Pocahontas	38°11'15"	80°3'01"	Calvin	25	180	853
2	Pocahontas	38°11'01"	80°3'01"	Calvin	40	0	853
3	Greenbrier	38°00'00"	84°2'24"	Berks	25	180	853
4	Greenbrier	38°01'12"	80°1'48"	Berks	25	0	914
5	Greenbrier	38°01'12"	80°0'00"	Berks	28	180	914
6	Greenbrier	38°01'12"	80°0'36"	Berks	45	0	853
7	Greenbrier	38°00'36"	80°4'48"	Potomac	10	0	783

Sites 1 to 6 are in a mixed hardwood and softwood forest, and site 7 is in a thicket of rhododendron (*Rhododendron spp. L.*). Calvin and Berks soils are loamy-skeletal, mixed, active, mesic Typic Dystrudepts, and Potomac soils are sandy-skeletal, mixed, mesic Typic Udifluvents (Soil Survey Staff, 1999).

3. Results

Site 1.—Data capture was 100 percent at site 1 during both years of the study. Consequently, nearly 11,000 temperature readings were available for analysis. Site 1 is paired with site 2. The MAST of the soil on the south aspect is 1.6 °C warmer than that of the adjacent soil on the north aspect (table 7.33.2). The MAST at 10 cm increased 0.3 °C during the second year. The MAST at 50 cm also increased 0.3 °C, and the MAAT increased 0.9 °C. The soil at site 1 is mesic.

Table 7.33.2.—Average air and soil temperatures (°C) for site 1.

Analysis	'96-'97 10 cm	'97-'98 10 cm	'96-'97 50 cm	'97-'98 50 cm	'96-'97 Air	'97-'98 Air
Jan	3.4	4.0	4.8	5.2	-2.2	0.7
Feb	4.0	3.3	4.3	4.2	1.8	1.6
Mar	7.0	4.9	6.9	5.3	5.2	3.9
Apr	8.5	9.8	8.4	9.5	7.5	10.4
May	11.5	13.5	10.8	12.6	11.7	15.6
Jun	15.0	15.7	13.8	14.8	16.5	17.4
Jul	17.9	17.8	16.6	16.9	19.5	19.3
Aug	17.1	17.9	16.4	17.1	17.4	19.0
Sep	14.8	15.0	15.0	15.0	13.1	13.8
Oct	11.7	12.1	12.2	12.8	9.7	9.5
Nov	6.4	6.3	8.2	7.8	0.7	2.2
Dec	4.6	4.2	5.7	5.7	1.2	-0.7
Mean	10.1	10.4	10.3	10.6	8.5	9.4
MST	16.7	17.1	15.6	16.3	17.8	18.6
MWT	4.0	3.8	4.9	5.1	0.3	0.5
Isotivity	12.7	13.3	10.7	11.2	17.6	18.1

Site 2.—Soil scientists paired this site with site 1 to determine the aspect dependency of soil temperature. The MAST of the soil on the north aspect is 1.6 °C cooler than that of the adjacent soil on the south aspect (table 7.33.3). The MAST at 10 cm for the north aspect at site 2 increased 0.6 °C during the second year of the study. It is presumed that the increase at the 50-cm soil depth is similar. The 0.3 °C increase in MAST at 50 cm is suspected to reflect the increase in MAST during the second year. The air temperature thermistor at site 2 was inoperative during both years of the study. The soil at site 2 is mesic.

Table 7.33.3.—Average soil temperatures (°C) for site 2.

Analysis	'96-'97 10 cm	'97-'98 10 cm	'96-'97 50 cm	'97-'98 50 cm
Mean	8.5	9.1	8.7	9.0
MST	15.2	16.2	13.5	14.2
MWT	2.6	2.9	4.2	4.2
Isotivity	12.6	13.3	9.4	10.0

Site 3.—The MAST at 50 cm in the soil on this south aspect site (9.7 °C) was 0.6 °C warmer than that of an adjacent soil on a north aspect (site 6) during the first year (table 7.33.4). The MWT at 50 cm on site 3 decreased from 4.7 to 3.9 °C during the second year of the study. However, the monthly temperature averages for April of 1998 increased 1.8 °C at 10 cm, 0.9 °C at 50 cm, and 2.5 °C for air. These data suggest that the MAST and MAAT increased during the second year. The soil at site 3 is mesic.

Table 7.33.4.— Average air and soil temperatures (°C) for site 3.

Analysis	'96-'97 10 cm	'97-'98 10 cm	'96-'97 50 cm	'97-'98 50 cm	'96-'97 Air	'97-'98 Air
Jan	3.3	4.1	4.6	4.2	-1.6	1.5
Feb	3.5	2.6	3.8	2.6	2.5	1.9
Mar	6.3	4.6	6.2	3.9	6.0	4.1
Apr	7.7	9.5	7.5	8.4	7.8	10.3
May	10.7	10.7	9.8	11.6	12.3	15.5
Jun	14.3	---	12.9	14.1	16.4	17.4
Jul	17.3	---	15.9	16.1	19.3	19.5
Aug	16.6	---	15.8	---	---	---
Sep	14.2	14.7	14.4	14.3	---	14.6
Oct	11.3	11.7	11.7	11.9	10.4	10.1
Nov	6.7	6.3	8.2	7.0	1.3	2.8
Dec	4.7	4.3	5.5	4.8	2.4	0.0
Mean	9.7	---	9.7	---	---	---
MST	16.1	---	14.9	---	---	---
MWT	3.8	3.7	4.7	3.9	1.1	1.1
Isotivity	12.3	---	10.2	---	---	---

Site 4.—This site was paired with site 5. The MAST at 50 cm in the soil on the north aspect (10.1 °C) is 0.3 °C cooler than that of the adjacent soil on the south aspect (site 5). (See table 7.33.5.) The monthly soil temperature at 50 cm was 1.4 °C higher in April 1998 than in April 1997 (9.4 vs. 8.0 °C).

Table 7.33.5.—Average air and soil temperatures (°C) for site 4.

Analysis	'96-'97 10 cm	'97-'98 10 cm	'96-'97 50 cm	'97-'98 50 cm	'96-'97 Air	'97-'98 Air
Jan	3.7	3.3	4.3	4.7	-1.6	2.1
Feb	3.9	2.3	3.5	3.6	2.3	2.9
Mar	6.9	5.0	6.2	5.2	5.9	4.9
Apr	8.7	10.5	8.0	9.4	7.7	10.4
May	11.3	14.6	10.9	---	11.9	---
Jun	14.1	15.8	14.1	---	17.0	---
Jul	18.1	---	17.3	---	19.8	---
Aug	17.6	---	17.0	---	18.5	---
Sep	14.7	15.4	15.1	15.5	14.1	15.0
Oct	11.6	11.9	12.0	12.8	10.8	10.6
Nov	7.0	5.4	7.9	7.1	1.5	3.2
Dec	5.1	3.2	5.2	4.8	2.4	-0.1
Mean	10.2	---	10.1	---	9.2	---
MST	16.6	---	16.1	---	18.5	---
MWT	4.2	2.9	4.3	4.4	1.0	1.6
Isotivity	12.4	---	11.8	---	17.4	---

Site 5.—The MAST at 50 cm for this south aspect site is 0.3 °C warmer than that of the adjacent north aspect site 4 (table 7.33.6). The MAAT increased from 9.4 to 10.0 °C in the second year (like the MAAT at site 1, which increased 0.9 °C in the second year). At 10.4 °C, the MAST for site 5 was warmer than that of the south aspect sites 1 and 3. These averages are contrary to most regression equations of MAST and elevation, in which MAST decreases with increasing elevation (Mount, 1998).

Table 7.33.6.—Average air and soil temperatures (°C) for site 5.

Analysis	'96-'97 10 cm	'97-'98 10 cm	'96-'97 50 cm	'97-'98 50 cm	'96-'97 Air	'97-'98 Air
Mean	10.3	--	10.4	--	9.4	10.0
MST	16.9	--	15.1	--	18.4	19.2
MWT	4.2	4.9	5.7	5.1	1.5	1.2
Isotivity	12.6	--	9.5	--	16.8	18.0

Site 6.—This site was paired with site 3. The MAST of the soil on this north aspect site (9.1 °C) was 0.6 °C cooler than that of the adjacent soil on the south aspect (site 3) in the first year (table 7.33.7). The MAST at 10 cm increased 0.8 °C during the second year (9.7 vs. 8.9 °C). This large increase suggests that the general warming trend during this study does not discriminate on the basis of slope or aspect.

Table 7.33.7.—Average air and soil temperatures (°C) for site 6.

Analysis	'96-'97 10 cm	'97-'98 10 cm	'96-'97 50 cm	'97-'98 50 cm	'96-'97 Air	'97-'98 Air
Mean	8.9	9.7	9.1	---	---	---
MST	16.4	17.2	14.8	---	---	---
MWT	2.1	2.7	3.5	3.5	---	0.4
Isotivity	14.3	14.6	11.3	---	---	---

Site 7.—The soil at site 7 was monitored for soil temperature in an area of suspected cold air drainage in Greenbrier County. The MAST at 10 cm increased 0.5 °C during the second year (table 7.33.8). The 10-cm depth froze during each of the five readings on March 13, 1998. Though the soil is mesic, it is the only soil that froze in the study area.

Table 7.33.8.—Average air and soil temperatures (°C) for site 7.

Analysis	'96-'97 10 cm	'97-'98 10 cm	'96-'97 50 cm	'97-'98 50 cm	'96-'97 Air	'97-'98 Air
Jan	2.7	1.7	3.6	3.2	2.6	2.3
Feb	1.9	1.5	2.8	3.1	4.7	2.1
Mar	4.6	3.2	5.0	3.8	8.5	3.4
Apr	5.6	7.9	6.0	7.4	8.9	7.6
May	8.3	12.7	8.2	10.7	11.8	11.8
Jun	12.5	15.6	11.9	12.7	15.2	14.6
Jul	15.7	17.6	15.0	---	18.0	16.7
Aug	15.4	17.3	15.0	---	16.5	16.5
Sep	13.3	13.1	13.5	13.3	12.1	12.9
Oct	9.8	9.1	10.2	10.6	8.6	8.8
Nov	5.7	3.7	6.9	5.7	0.9	3.2
Dec	3.1	1.5	4.3	3.2	5.5	1.3
Mean	8.2	8.7	8.5	---	9.4	8.4
MST	14.5	16.8	14.0	---	16.6	15.9
MWT	2.6	1.6	3.6	3.2	4.3	1.9
Isotivity	12.0	15.2	10.4	---	12.3	14.1

The MAAT at site 7 decreased during the second year (9.4 to 8.4 °C). The air temperature signature at this site seems abnormal (figure 7.33.1). It is suspected that there was some mitigation of normal airflow around the sensor, most likely snow.

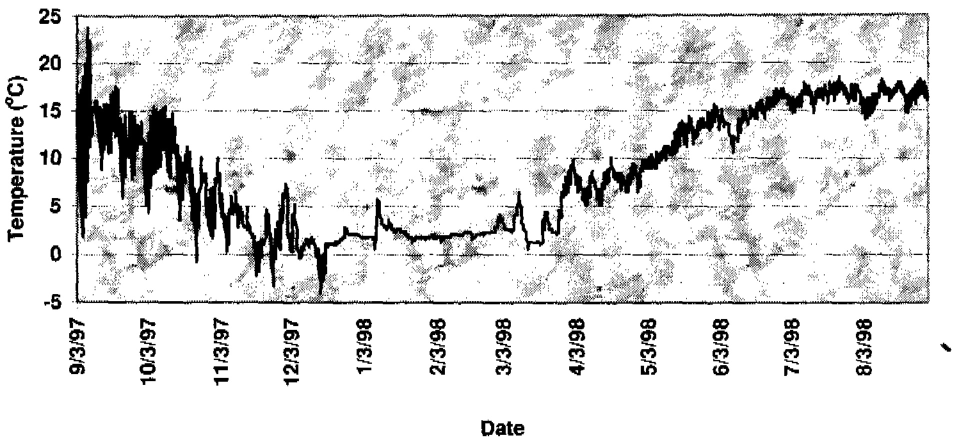


Figure 7.33.1.—Air temperature signature at site 7.

4. Aspect Dependency

Soil scientists paired eight sites to determine differences in MAST based on aspect. Site 1 was paired with site 2, site 3 with site 6, and site 4 with site 5 during the first year. During the second year, another pair of sites was added (Buf N and Buf S).[†] Table 7.33.9 shows the aspect dependency for soil temperature at 50 cm on all the sites. At every location, the MAST on the south aspect was warmer than that on its paired north aspect. The least difference was 0.3 °C at sites 4 and 5. The largest difference was 1.6 °C at sites 1 and 2. The trend of MAST versus elevation was low (r^2 of <0.1). In fact, there was an increase in MAST with elevation until 975 m, at which point the MAST began to decrease. The MWT was generally lower on north aspects than on south aspects. Except for site 4, the MST also was lower on north aspects.

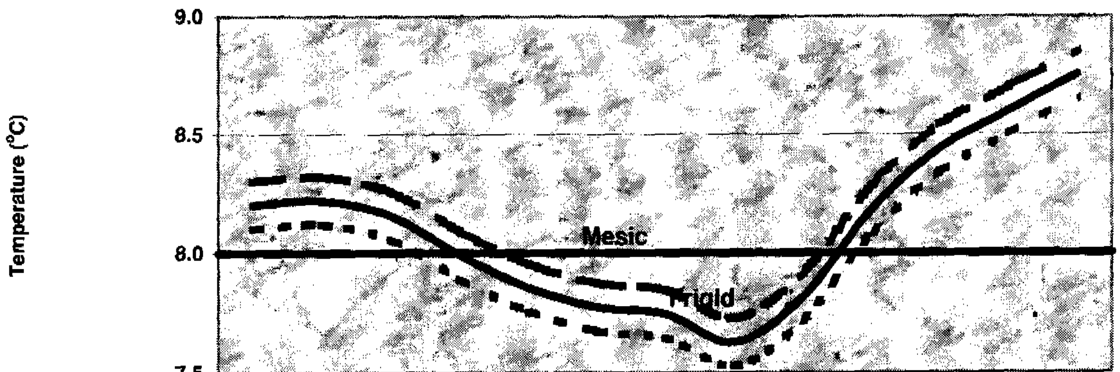
Table 7.33.9.—Relationship of seasonal and annual soil temperatures (°C) to elevation and aspect.

Analysis	1 south (853 m)	2 north (853 m)	3 south (853 m)	6 north (853 m)	5 south (914 m)	4 north (914 m)	Buf S (975 m)	Buf N (975 m)
MAST	10.3	8.7	9.7	9.1	10.4	10.1	9.8	8.8
MST	15.6	13.5	14.9	14.8	15.1	16.1	15.0	13.4
MWT	4.9	4.2	4.7	3.5	5.7	4.3	3.9	3.4
Isotivity	10.7	9.3	10.2	11.3	9.4	11.8	11.1	10.0

[†] Other than elevation, metadata are not available for these sites.

5. Discussion

The MAST at 50 cm in the study area increased, on average, by 0.5 °C during the second year of the study. The MAST increased equally on north and south aspects. Soil temperature is time-dependent and shifts either up or down with each 12-month segment of capture. Figure 7.33.2 shows the shift in 12-month segments between August 1997 and August 1998 at site 7. The graph shows that the soil starts out mesic (>8 °C), decreases to frigid during the third shift, and continues to be frigid through the ninth shift. It returns to mesic during the tenth shift and increases until the thirteenth and final shift. Summarized data in figure 7.33.2 clearly indicate that a soil temperature regime will shift with warming weather patterns—even during a short-term study.



	1	2	3	4	5	6	7	8	9	10	11	12	13
Mean	8.2	8.2	8.2	8.0	7.9	7.8	7.7	7.6	7.8	8.2	8.4	8.6	8.8
Minus 0.1 deg C	8.1	8.1	8.1	7.9	7.8	7.7	7.6	7.5	7.7	8.1	8.3	8.5	8.7
Plus 0.1 deg C	8.3	8.3	8.3	8.1	8.0	7.9	7.8	7.7	7.9	8.3	8.5	8.7	8.9

Shift No.

Figure 7.33.2.—Shift analysis of the 10-cm soil temperature at site 7.

To address short-term changes in soil temperature for correlation purposes, we calculated a latitude-elevation regression based on measured data. This linear regression equation was generated using TableCurve software (figure 7.33.3).

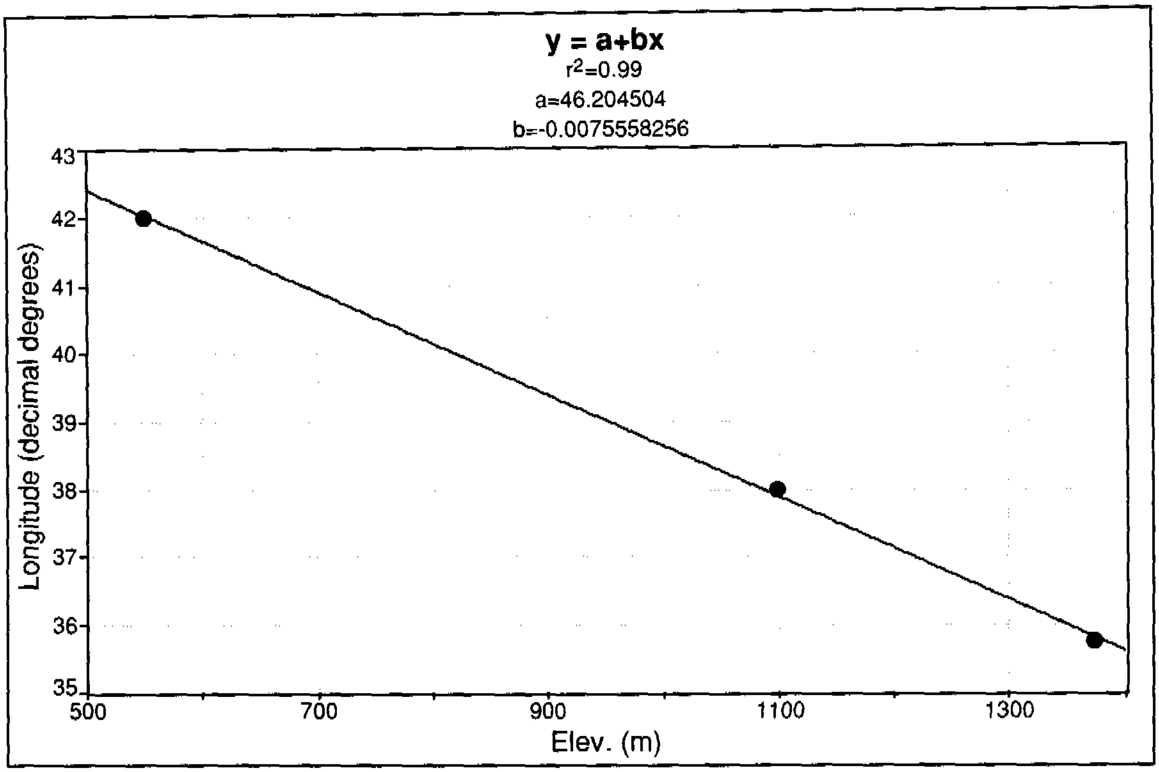


Figure 7.33.3.—Regression equation used to differentiate mesic and frigid soils in MLRA Region 13.

This regression was based on a site in the Great Smoky Mountains in Tennessee; a site in western Greenbrier County, West Virginia; and a northern site in Cattaraugus County, New York. The elevation component is where the mesic-frigid break has been measured from nearby data. With an r^2 of 0.99, this equation can be used to approximate the mesic-frigid soil temperature break on north-facing slopes for any given latitude between 35° and 43º north. The equation is as follows: Y (latitude in decimal degrees) = a + bx, where a = 46.204504, b = -0.0075558256, and x = elevation (m). This regression equation will continue to be used for correlation purposes in MLRA Region 13. It approximates conceptual temperature divisions as determined by short-term data in Pocahontas and Greenbrier Counties, West Virginia.

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Chapter 8

Climate Maps

By

M.M. Striker*

Some time ago, I received a copy of *Myths and Science of Soils in the Tropics*, Soil Science Society of America (SSSA) Special Publication No. 29, 1992, 2nd printing. This 185-page book has nine chapters, each with two or more authors, and a long list of references cited. The basic purpose or goal of this book on tropical soils was two-fold:

a) In a cooperative group effort, to present and discuss data and ideas on soil science views and research that are important to tropical agriculture, land use and management, productivity, etc., and
b) To clarify and discuss some doubtful, misleading, earlier notions, views, and beliefs, that is, "myths" of contemporary scientists about lands in the tropics.

Commonly, the lands and waters between the Tropics of Cancer and Capricorn, centered on the Equator, that is, some 23 degrees latitude on each side, have been called the tropics, the Equatorial Zone, Torrid Lands, etc. Early Greek scholars noted that the sun's turnaround was at the same place and time each year in this zone. Contemporary geographers and others recognized a mid-world belt with much green vegetation the year around, small changes in annual or monthly temperature, and no or rare frost or freeze. Currently this belt, some 46 degrees of latitude and some 5,500 km in width, comprises half of the world's lands, excluding the ice lands of Antarctica and Greenland, and has half of the world's people and one-quarter of the world's deserts. Some 75 percent of the people in this belt have relatively low, subsistence livelihood and live in the rural areas, and both city and country living are alike in many instances. Commonly, poverty, overpopulation, and political instability are the mode.

Since the early 1900s, scientists and others have seen fit to select the 65 °F (18.3 °C) air temperature mean of the coolest 3-month season and lowlands below 600 meters as the cool-side limit for both north and south tropics. This 65 °F mean is commonly near the two tropic belts, at a latitude of 23°27' (Cancer and Capricorn).

Recently, most agriculturists, geographers, and others have used the term "subtropics" for lands next to the tropics which also have long growing seasons and temperatures much like those in the tropics (especially in the 3 to 5 summer months) and for a 7- to 9-month growing season in most years. Many crops, grasses, etc. here are similar to those in the tropics. Winter months in the subtropics have some frost and light freezing weather. The limit for this zone seems to be around 50 to 55 °F (coolest 3 months) mean temperature and for altitudes below 600 meters. Commonly, night lows are around 40 °F at the subtropics limit in the coolest 3 months. Most any night can have a frost or freeze, or for several nights there can be light snowfall from a cold front in winter. This 52 °F isotherm commonly is near to the 30-degree latitude for both the lowlands north or south of the Equator.

Also, there are large land areas in these latitudes of less than 23 degrees or 30 degrees that are highlands and mountains, often filled with people, livestock, and large cities that are to be considered as part of the tropics and subtropics. These large land areas have such characteristics as narrow annual temperature limits, long growing seasons, cooler temperatures, and slow weathering of the soil mantle.

* After writing this chapter, Mr. Striker passed away in November 2000. He spent many years between the 1940s and 1970s working on various mapping projects in the Caribbean and Central and South America.

Myths and Science of Soils in the Tropics (page 2) has adopted a "two-pronged" definition for tropic limits and tropic soils; the first is the latitudes between the Tropics of Capricorn and Cancer, and the second, selected for soil taxonomy purposes, is a regime: "We consider tropical soils to be those that have an *iso* soil temperature regime." Such regimes denote a difference between the mean summer soil temperature and the mean winter soil temperature of 9 °F (5 °C) or less. That is, soil temperature is not (for soil classification) a constraint for most of the common year-round agricultural uses. Perhaps, it would be more exact to use the term "mean warmest 3-month" rather than "summer" and the term "mean coolest 3-month" rather than "winter." Soil science recognizes that the common air temperature will serve well for a common soil research on agricultural uses.

Early soil scientists, geographers, biologists, agriculturists, and people in general noted soil and land similarities and differences in the temperate lands as well as the tropics and subtropics. These scientists include Dukochaev, Glinka, Marbut, Baldwin, Pendleton, Mohr, Whitney, Skutch, Humbolt, Ableiter, Alexander, Bennett, Allison, Roberts, Mannifold, Veatch, Thorp, and others. They dealt with such terms as "Latisols," "Laterite," "Planosols," "plinthite," and "highly weathered." Charles Kellogg and Roy Simonson searched the early literature for soil survey and land classification activities, some of which date back to 1880. Guy Smith, starting in the 1950s, led the group interested in national and international soil taxonomy classification. The Soil Survey Division (Bureau of Plant Industry) had a group working on using air photos as a base map for soil map lines and symbols. Orvedal led a group making a soil world map inventory, printed by FAO in 1971, using Smith's latest approximation of taxonomic groups for the legend. The first Soil Survey Division joined up with the soil survey, farm mapping, and land-use capability surveys group of the Soil Conservation Service in the early 1960s. In the 1980s, Russian soil scientists also published a world soil map. Many of the foreign soil scientists received training and some assistance from United States agricultural colleges. Now, soil scientists everywhere travel easily and exchange views on research on the tropics and elsewhere, if accessible.

Perhaps a brief on my travels, work, etc. in the tropic belts would be in order. My first tropical assignment was the soil survey in Puerto Rico in 1935 and 1936, and my last was in Colombia from 1964 to 1968. I retired from the USDA at age 59. Altogether, I had some 20 years in middle America and northwest South America to the Upper Amazon, and some short periods with FAO foreign agricultural groups and private consultant work in the tropics. My professional work included training, inspecting, and printing general soil and land classification surveys and detailed soil surveys in some 20 countries and islands.

While I was unemployed for a short period in the early 1960s, our family returned to our 160-acre farm in Florida (rented). There, I had spare time to accumulate reference materials to work on studying climate data for classification for climate maps. In the early 1840s, I knew Thornthwaite, who lamented that climate classification and mapping were thought to be of small importance. At that time, evapotranspiration (ET) received a lot of attention with indices for humidity conditions. Koeppen, a renowned climate geographer and mapmaker since the 1920s, was a leader in climatography. Even as late as 1995, Koeppen's climate map, with some changes, was used in the atlas of the National Geographic Society. My review and study of climate data, plus lots of trial and error, indicated that temperature belts were needed for one part of the map legend and monthly and season precipitation types for a second legend on climate maps.

Nomenclature requires temperature and humidity names that are well defined in common climate terms. That is, borrowing the word "regime" from soil taxonomists, climate regimes need definition and limits in figures, and the nomenclature had to be climatic all the way. The climate conditions during the growing season period would give the necessary utility for agriculture interpretation, just as in soil taxonomy for soil mapping. Other matters, such as altitude and frost period, would be blended into the classification scheme. The scheme was used for my earlier climate maps dating back to 1967 and for the 5,000 copies of the World Land Climate Map published in Bogota, Colombia, in 1971.

For temperature belts at both north and south latitudes, I decided on four major regime types—tropic, subtropic, temperate, and frigid. These are all based on the coolest 3-month season. The four major regimes were then further divided. The tropic regime was divided into cool-tropical, 65 to 70 °F (for coolest 3-month season); warm tropical, 70 to 77 °F; and hot-tropical, 77 to 84 °F. The subtropic regime was divided into warm-subtropical, 58 to 65 °F, and cool-subtropical, 52 to 58 °F. The temperate regime was divided into warm-temperate, 42 to 52 °F; moderate-temperate; 20 to 42 °F; cool-temperate, 10 to 20 °F; and cold-temperate below 10 °F. The frigid regime was divided into warm-frigid, under 55 °F in summer but above 10 °F in winter; cool-frigid, 42 to 55 °F in summer; and cold-frigid, below 42 °F in summer. These 12 temperature divisions are based on observations of plant growth and agriculture. For instance, the cold-temperate belt (below 10 °F in winter) has a cool, 4-month growing season with a frost-freeze hazard in summer but with long days of 14 to 17 hours in the 3 summer months. The warm-temperate belt commonly has 32 °F night lows at the 42° F isotherm and has day highs of around 32 °F at the cooler 20 °F isotherm. Some winter pasturing is possible in the warm-temperate belt and all winter in the subtropic belts. Winter grain is common in the middle of the cool-temperate belt (about the 15 °F winter isotherm).

Four major moisture "regimes" were selected—arid, subhumid, humid, and superhumid (or perhumid). Temperatures from 40 to 85 °F were integrated at 5-°F intervals. Each moisture type was "rationed"in inches for each 5 °F. For instance, for a month with a 75 °F air temperature mean, the moisture type is arid if precipitation is less than 1.6 inches, subhumid if precipitation is 1.6 to less than 3.3 inches, humid if precipitation is 3.3 to less than 7.0 inches, and superhumid if precipitation is more than 7.0 inches. A humid climate would require 4 successive humid months and a 17-week growing season as a minimum, and the area might be humid, cool-temperate; humid, warm-temperate; or humid, warm-subtropical, etc. This would result in an H symbol delineation area on the World Land Climate Map. This scheme is positive and objective and permits the comparative values for places on an equal-area base map, at a scale of 1:35,000,000. This basic scheme could be made more detailed for larger scale maps. On the World Land Climate Map, there is an elevational climate belt table with six elevations for 0° to 12° and 12° to 20° latitudes and named units with the temperature range cited. It was possible to delineate most but not all of the 600-, 1,500-, and 2,400-meter elevation contours (2,000, 5,000, and 7,500 feet) on the World Land Climate Map. Some of the contour lines on the U.S. Armed Forces World Topo Maps were used to delineate boundaries for humidity and temperature separations.

Chapter 6 (and other chapters too) of *Myths and Science of Soils in the Tropics* use arid, semiarid, and humid moisture types for the growing season period for the tropics, probably above 65 °F mean (coldest month), and for lowlands, below 600 meters. Temperature and precipitation guidelines, in figures, are not detailed for the three types. Average monthly rainfall for four places are shown in figure 6-3 (page 100). These graphs depict the Lower Niger Valley with the Sahara Desert on the north and the humid coast (delta) on the south.

The NIAMEY graph is on the World Land Climate Map, on the Niger River and at some 13° north latitude, and has a seasonal rain distribution of 0-1-15-4 inches, beginning with the climatic season months of December to February. Some 7 months are arid, and none are superhumid, that is 7-3-2-0. The rainy season is subhumid with 2 humid and 3 subhumid months and 5 months in all with some or appreciable rain. The growing season is commonly short on moisture and only some 4 months in length. Niamey is in the subhumid moisture type (5) on the World Land Climate Map, and it is semiarid for the chapter 6 classification. The 2 or 3 months ahead of the rainy season, south of the Sahara, can have means go to 95 °F or higher, just as in some India Lowlands with the Himalayas to the north. Natives in Niamey, and India in places, realize that if the rainy season starts 2 or 3 weeks late, the rainfall will likely be below average and the growing season will be shorter. Of course, if river irrigation provides supplemental water, this moisture could help to provide sufficient supplemental moisture for a humid crop season.

The OUACADOUGOU graph, capital of Brutania, is some 125 km south and 340 km west of Niamey. It has a seasonal rain distribution of 0-5-21-7 inches and 6-2-3-1 months, arid to superhumid. Commonly, this rainy season is humid for some 4 or 5 months with some 25 inches of precipitation. It is designated as an HC classification on the World Land Climate Map. The C (in HC) is for 6 to 7 arid months. HC is a climate symbol for a common tropical land moisture regime. This is identified as a monomodal rain distribution type in chapter 6 (page 94).

The HYPERABAD graph has a seasonal rain distribution of 0-1-16-18 inches, 7-2-3-0 humidity months, and a subhumid growing season of 4 or 5 months (SM on the World Land Climate Map). Like the previous three examples, Ibadan, on the Niger Delta at 7° north latitude, is in the humid, tropic-hot country. It has an average seasonal rain distribution of 3-15-14-14 inches and 3-3-6-0 humidity months. Its notation on the World Land Climatic Map is HA (0 to 3 months, arid). This short dry season is probably much appreciated by most of the people. The mean monthly temperatures at Ibadan are around 80 °F for the entire year. *Myths and Science of Soils in the Tropics* calls this a bimodal type of tropic climate. Commonly, the growing season is some 8 to 10 months, even though August is often a subhumid month. Thus, it seems that three of the four graphs are semiarid monomodal in *Myths and Science of Soils in the Tropics*, chapter 6 (page 100), but with important climatic agricultural use differences.

Thus, for west-central Africa along the southerly route of the Niger River Valley from 16° to 5° north latitude, a distance of 1,400 km, the World Land Climate Map shows many climate types in a predominantly tropic-hot climate belt. That is, from arid Sahara to a 10- to 20-inch semiarid moisture type and to three subhumid types and three humid types—to the delta coast. To the east of the delta is a superhumid moisture type, and to the west a mixture of subhumid and humid types on the coastal lands. Some lands even have two short rainy periods and two drier periods in a 12-month span. This two-season, wet and dry type of annual rain distribution is common only near the Equator and commonly is referred to as the "climatic equator."

Figure 6-2 (page 95) of *Myths and Science of Soils in the Tropics* shows an uneven moisture distribution from one rainstorm on some 2.5 km^2 land area (250 hectares). As most country folks know, the next rainstorm will not have the same amount or distribution of rainfall. For a simple, rough, easy check on soil moisture, push a $^{3}/_{16}$-inch rod downward to the "not so easy to penetrate" dry subsoil. Depth of thawing or frozen ground under deep snow also can be checked.

As we all realize, rain is usually best contained and used where it falls, but depth penetration or storage in soil is often a large variable and often within short distances, as figure 6-4 (page 101) in *Myths and Science of Soils in the Tropics* illustrates. Runoff could be to lower slopes or concave areas or streams. It can be beneficial in some lower areas and can increase the aridity of the areas where the runoff originates.

The four rain graphs show that the mean monthly temperatures are around 75 to 85 °F in the rainy season in the Niger Valley (page 100 of *Myths and Science of Soils in the Tropics*). The graphs also show the evaporation-transpiration (ET) values in inches, by months. The ET values in the rainy season are some 5 or 6 inches per month for those four places, and only IRADAN has "sufficient" moisture for 6 months. The other three places have 9 to 11 semiarid and arid months, that is, below the ET values for humid. The table for humidity types as related to temperature for the World Land Climate Map has a 4- to 7-inch range for a humid condition. It seems that land use and management interpretation would benefit from a climate type classification scheme, having both subhumid and superhumid types for both months and seasonal conditions.

Rainfall distribution graphs, some 137, were used to fill the many open spaces on the World Land Climate Map and were selected to show the common conditions in the more populated places and also to fit well in small open map spaces. Each graph lists altitude and latitude, annual and seasonal precipitation in inches, and humidity type (symbol) for the "growing" months. The colored months indicate periods above 50 to 55 °F, according to the humidity type for each month in the growing season.

The graphs give the average summer and winter mean temperature, the 3-month average of the lowest and highest summertime temperatures, and finally the absolute low and high on record. Graph "selection" was a time-consuming task but was invaluable for more ample presentation of accurate, relative climate data and was unique as a first for such climate graphs with four seasons, colors, and data summary.

Temperature and precipitation data were quite abundant for this map scale for only the United States and Europe. A good source of worldwide data were climate pamphlets of the London Meteorological Society, 1957-58. Another good source was the more recent monthly data pamphlets of the climate data international center at Asheville, North Carolina. *Climate and Man*, 1942, also has some climate data and world maps. For Africa, there were only some 500 stations. For Europe, one station on the north coast of Norway has 150-year records. Army posts on the north and northeast borders of China, next to Russia, sent data to the Asheville National Climatic Data Center. One station in the Arctic Circle in northwest Siberia shows an absolute high of 98 °F, a low of –90 °F, a value of 54 °F for the 3-month summer average, and a total of 7 inches of precipitation. Frigid lands are without map color on the World Land Climate Map, and ice-snow lands are colored blue.

Having often worked in agricultural assistance in highlands in the tropics and subtropics, I find it worthwhile to discuss the current agricultural uses of these lands. Perhaps about 20 percent of these highlands are not hilly and mountainous and have terrain suitable for mechanized crop production with or without fertilizer. The population is dense in places, as people like the cooler temperatures, and the highlands have many capitals and large cities. Brasilia, the "new" capital of Brazil, at 15° south latitude is at an elevation of 1,000 m and has a mean of about 65 to 70° F for its cooler and warmer seasons. In central Africa the frost-freeze hazard starts at 15° south latitude on the highland plains and extends southward to the Kalahari Desert. The population increase is expected to be high (see population map, '94 atlas) for the tropical and subtropical land, and currently some or most of this land is significantly over-populated. Perhaps one-third of the tropics consists of areas that have highlands above 600 meters.

The continent maps of the National Geographic Society served well as map bases for the World Land Climate Map. These maps were reduced to 1:35,000,000 and were used for locating rivers, cities, etc. The continents in the Northern Hemisphere were placed on the 40° north latitude line, and the continents below the Equator were placed below the upper continents. The oceans were left out. The Antarctic was reduced four times for the map, and the Pacific islands were reduced two times (1:70,000,000). By "squeezing" everywhere, we had an equal-area projection in a map space of about 24 by 32 inches, a good map size. There was lots of "trial and error" during a 5-year work period starting in 1985. We had made climate maps of three continents and had very small sales, and so we tried again with a world map. Sr. Rodrigues, my cartographic Bogota friend since 1964, and his three mapmaking daughters were sold on the idea of a world climate map, and without their enthusiasm, interest, and ideas, the World Land Climate Map, a monumental, tedious task, would not have been completed. In Bogota, the facilities for making and printing maps were about equal to those in the United States and the costs for work and materials were about 50 percent less.

I made regular annual trips to Colombia after 1979. The Geodetic Branch, U.S. Corps of Engineers in Bogota, helped to get the printed maps to Florida. We were unable to get financing assistance from any society or professional group and no help for expenses or reductions from the Internal Revenue Service. Fortunately, the University of Florida libraries and their map library are near our town and our country residence. We hand-colored early draft copies and sent copies to places for review and suggestions. Kallman of the University of Florida Bookstore at Gainesville, Professor V.A. Kovda of the Academy of Sciences of the USSR, and some other geographers and climatologists were sent copies. My hobby, not counting my time and travels for the final map (5,000 copies), cost some $30,000, of which over one-half was for cartographic work. Anyhow, this map monograph and several other climate maps are documented in our National Archives, copyright division. The National Geographic Society sent me a bound, free copy of their '94 atlas. To my surprise, their climate maps were somewhat like my climate map. Sales have been small, a ratio of 25 or so maps given away for every sale. Many copies are sparingly scattered over the United States and in foreign countries.

Even though its future as a scheme for climate classification and maps is still doubtful, my 30-year hobby and its costs have caused me no regrets. Climatography will have its day in the future and will have a chance for scheme comparison with current climate classifications in use by soil science and other folks. I was reared on a homestead in southwest North Dakota, at an elevation of 2,500 feet, in a subhumid, dry climate with a 4-month growing season. Niamey is at a low elevation along the Niger River and, at 33 degree latitude, is closer to the Equator, but it has similar plant vigor and growing conditions. The two places have rainfall scarcity, growing time, and drought hazards in common, resulting in common comparative values on the World Land Climate Map.

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