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Temperature and Soil Moisture Regimes In and Adjacent to the Fernow Experimental Forest

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Abstract

The effects of elevation, aspect, ambient air temperature, and soil moisture on soil temperature were examined in and adjacent to the Fernow Experimental Forest in West Virginia to determine the extent of frigid soils. The mean annual temperature of frigid soils ranges from 1° to 7°C at a depth of 50 cm; the difference between mean winter and mean summer temperatures exceeds 5°C. Soil temperature and moisture were measured and data on air temperature were collected at study sites on or near the Fernow from December l994 to December l997. Readings were taken 6 times during the year (January, February, June, July, August, and December) and the mean annual and seasonal soil temperatures were calculated. The winter (December-February) and summer (June-August) mean soil temperatures at each site were used to determine the extent of frigid soils. One soil was classified as frigid for 2 consecutive years.

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Introduction

On certain landscapes at higher elevations, average annual soil temperatures may be within the range of frigid soil-temperature regimes. In Pennsylvania, Carter and Ciolkosz (1980) found many soils at elevations of 460 m and higher that could be classified as frigid. They also proposed that at lower latitudes and elevations that exceed 914 m, soils might fit the frigid classification on central Appalachian mountain ridges as far south as Pocahontas County, West Virginia.

The mean annual soil temperature (MAST) of frigid soils ranges from 1° to 7°C. At 50 cm below ground, the difference between summer and winter temperatures exceeds 5°C. The variety of plant communities is greater on frigid than on mesic soils. The latter support the eastern and deciduous Appalachian forest types. Predominant species in these forests are northern red oak and yellow-poplar. Frigid soils are associated with northern hardwood and northeastern conifer forest types. Species that characterize these forests include sugar maple, black cherry, gray birch, American beech, and eastern hemlock.

Soil temperature is an important variable in forest management because it affects plant growth, species diversity, nutrient cycling, rates of soil formation, and other biotic activity (Flucker 1958; Munn et al. 1978; Tajchman et al. 1986). Frigid soils dramatically reduce the site index for most oak species (Kricher and Morrison 1988), and alter the relationship between certain plants and wildlife (Tajchman et al. 1983; Werling et al. 1984).

The objective of this study was to determine the frigid-mesic soil temperature zonal boundary in the Fernow Experimental Forest and an adjacent study site in West Virginia by measuring MAST at various elevations and aspects.

Materials and Methods

The areas selected for study included Fork Mountain and McGowan Mountain on the Fernow and Bearden Knob near Davis, West Virginia. At these sites, MAST was measured on the northeast (NE), northwest (NW), east-southeast (E/SE), and southwest (SW) aspects, and at the summit (SU) where possible. The study sites had the following elevations: Bearden Knob, 1,174 m (SU); Fork Mountain, 768 (SU) and 762 m (NW, SW, E/SE); McGowan Mountain, 908 m (SW) and 896 m (NW). The site index for oak and soil series, respectively, were 60 and Mandy for Bearden, 70 and Dekalb (three aspects) or Calvin (one aspect) for Fork Mountain, and 80 and Cateache for McGowan Mountain. The landtype association was M221Ba08 for Bearden and M221Ba10 for the Fork and McGowan Mountain sites.

Soils at the lower elevation sites were classified as Typic Hapludults and those at higher elevations were classified as Typic Dystrochrepts (Soil Survey Staff 1967). The soil organic layer (Oi and Oa horizons) of the deciduous forest was 3 to 5 cm thick.

Each year from December 1994 through December 1997, soil temperatures were measured six times (January, February, June, July, August, December). All but one Fork Mountain site and one McGown Mountain site were established in 1996. The time of measurement ranged from 0800 to 2000 hours on the 15th to the 25th day of the month. At each study site, three temperature-moisture cells (model MC 301, Soiltest, Lake Bluff, IL)[1] were installed 50 cm below the ground. The cells were positioned within 5 m of each other. The reference junction of the thermocouple protruded from the soil surface and was covered with a plactic bag. Soil temperatures were measured with a Soiltest soil moisture temperature meter (MC-300B). Accuracy of the sensors during readings was 1°C at 22°C.

The mean winter soil temperature was derived from readings taken in December, January, and February. The mean summer temperature was derived from readings in June, July, and August. MAST was calculated from the mean seasonal soil temperatures (MSST) to determine the soil-temperature regime at each study site. Because some of our resistance data were invalid, the readings are used only to indicate relative soil moisture (Table 1).

Results

The Bearden Knob summit was the only site classified as having frigid soils for 2 consecutive years based on MAST and MSST (Table 2, Figs. 1-2). Aspect influenced ambient temperatures, which, in turn, influenced soil temperatures (Table 3, Fig. 3). For example, the McGowan Mountain SW site had the highest MSST for 2 consecutive years. As expected, both SW sites (McGowan and Fork) had the highest ambient air temperature in 1996 and 1997 (Table 3). In northern latitudes, soils on NW sites are cooler and the MAST should be cooler. Although the soil on the Fork Mountain NW site was mesic by definition, it was the coldest of the Fernow sites. The likely reason for this apparent anomaly was a “frost pocket” or cold air that was trapped in a valley below the site. This cold air probably influenced both the mean seasonal air temperature at the site and the MSST in both summer and winter. The

[1]The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

McGowan NW site, with no frost pocket and at a higher elevation, maintained a mesic soil-temperature regime.

The Bearden Knob summit had higher mean seasonal soil electrical resistance than the mesic study sites (Table 1). Higher resistance readings indicate drier soils, which are influenced more by ambient air temperatures than wetter soils because of the higher specific heat of soil moisture. Lower seasonal ambient air temperatures at this drier site probably were responsible for the frigid soils at Bearden Knob.

Seasonal ambient temperatures varied widely with elevation (Table 3). The soil at Bearden Knob was frigid but soils were mesic at the next lower elevation (McGowan Mountain SW site). Both sites were higher than the Fork Mountain NW site, which has a cooler MAST than the McGowan NW site.

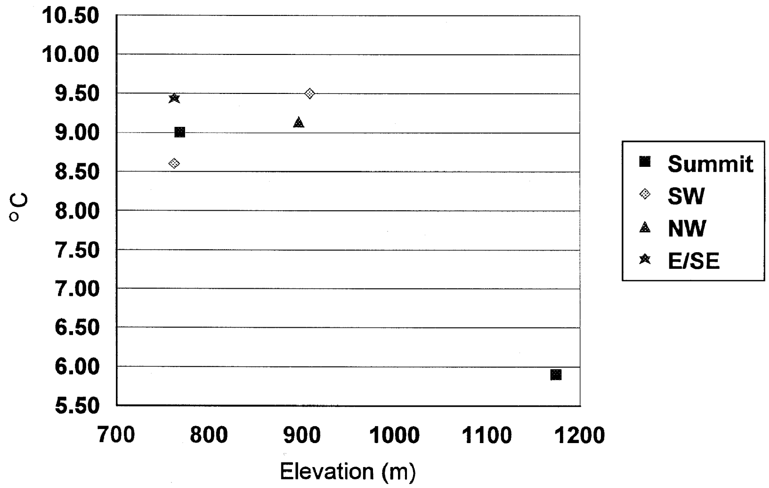

Figure 1.—Effect of elevation on mean annual soil temperatures, 1996.

Discussion

Soil moisture, ambient air temperature, and aspect influence soil temperature and largely determine the soil-temperature classification. However, when evaluated individually, none of these factors determined the MAST nor the extent of frigid soils. Anomalies such as frost pockets can influence soil temperatures. A multivariate equation that includes ambient air temperature, aspect, elevation, and moisture could provide predictive information.

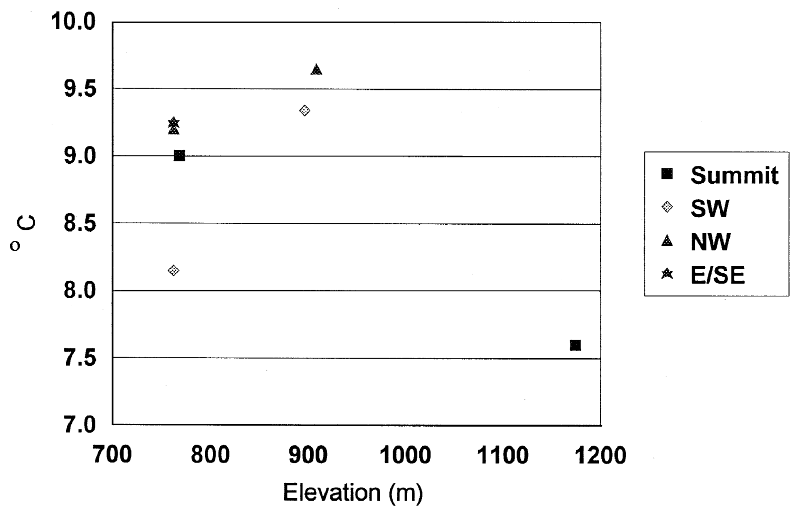

Figure 2.—Effect of elevation on mean annual soil temperatures, 1997.

Soil temperature influences mineral and organic matter content and microbial activity of the soil. Warmer mesic soils contain less organic matter and more iron and aluminum oxides than cooler and frigid soils. Mesic soils promote seed germination and rapid plant growth, but the increased toxicity of harmful ions such as Fe^{+++} and Al^{+++} in these soils may slow or retard tree development. Leaf fall and to a lesser extent decay and death of roots increase the organic matter content of forest soils. The accumulation of organic matter in cooler soils leads to increased sequestration of carbon as well as increased retention of beneficial nutrients (e.g., phosphorus, nitrogen) available to plants.

Increased chelation by soil organic matter reactive groups (e.g., carboxyl, phenolic hydroxyl, amine) not only promotes the retention of beneficial nutrients but also reduces the toxicity of harmful ions by lowering their concentrations in soil solution. However, seed germination and plant growth are slower in frigid soils.

We did not address the possible influence of forest canopy on soil temperatures. The warmer temperatures at the Fork and McGowan Mountain SW sites likely were influenced by little or no forest canopy in addition to aspect. A companion study on sites farther south and eastward on the Monongahela and George Washington National Forests will extend the scope of this investigation by providing additional data on the effect of ambient air temperature, soil moisture, aspect, and canopy on soil temperatures at higher elevations.

Table 1.—Electrical resistance of soil at study sites, in ohms[a]

	Bearden (SU)		Fork (SU)		Fork (NW)		Fork (E/SE)		Fork (SW)		McGowan (SW)		McGowan (NW)	
Year	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
1995	4.4	5.3			3.7	5.4					5.6	5.0		
1996	4.1	4.5	4.0	2.5	3.8	4.1	4.0	2.5	6.4	1.5	3.2	4.0	4.7	3.4
1997	4.1	4.3	1.2	2.4	3.4	3.8	1.2	2.4	1.0	4.2	0.9	2.9	1.9	2.5

[a]All measurements taken at a depth of 50 cm.

Table 2.—Mean annual (A) soil temperature and mean annual winter (W) and summer (S) temperatures (°C) at depth of 50 cm derived from mean winter (December, January, February) and mean summer (June, July, August) measurements

	Bearden (SU)			Fork (SU)			Fork (NW)			Fork (E/SE)			Fork (SW)			McGowan (SW)			McGowan (NW)		
Year	W	S	A	W	S	A	W	S	A	W	S	A	W	S	A	W	S	A	W	S	A
1995	3.7	12.5	8.1				3.8	15.2	9.5												
1996	3.0	8.8	5.9	4.3	13.8	9.0	4.0	13.1	8.6	4.5	14.3	9.4	3.9	14.2	9.0	4.7	14.2	9.5	4.4	13.8	9.1
1997	4.8	10.4	7.6	5.0	13.0	9.0	4.7	11.6	8.2	5.0	13.6	9.3	4.9	13.5	9.2	5.3	13.8	9.7	5.3	13.3	9.3

Table 3.—Mean seasonal ambient air temperatures (°C) at study sites

	Bearden (SU)		Fork (SU)		Fork (NW)		Fork (E/SE)		Fork (SW)		McGowan (SW)		McGowan (NW)	
Year	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
1995	0.0	22.5			2.9	24.6								
1996	-3.0	16.3	3.3	22.7	3.3	23.6	3.3	22.7	6.1	23.2	5.2	22.7	3.5	20.7
1997	-2.2	16.2	4.4	22.6	5.0	22.9	5.0	22.9	6.4	24.7	6.1	24.3	5.3	21.1

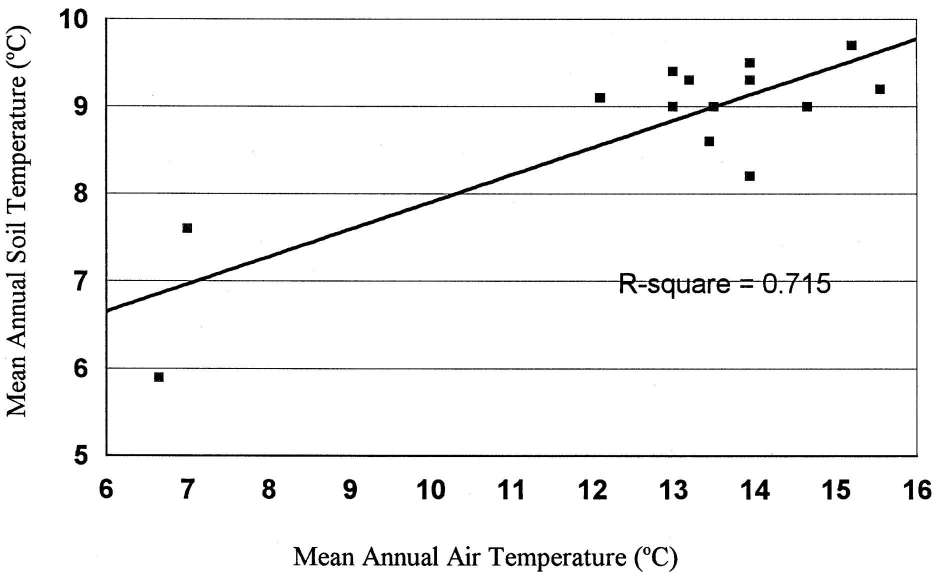

Figure 3.—Mean annual soil temperature vs. mean annual air temperature, 1996-97.

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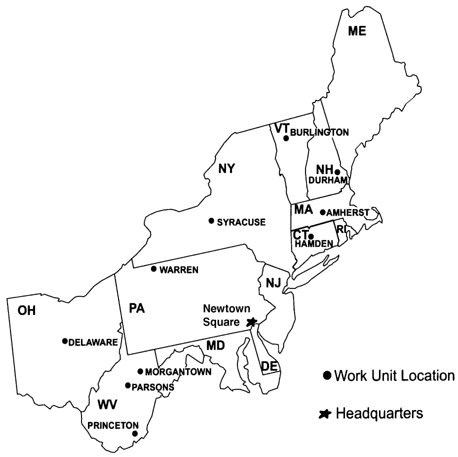
Keywords: Forest soils; mesic soils; aspect; elevation



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