SOIL TEMPERATURE GRADIENTS IN A NORTHERN HARDWOOD FOREST

1994

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ABSTRACT

A study was initiated in January 1993 to continuously monitor soil temperature at several depths in a northern hardwood forest stand located at the Proctor Maple Research Center in Underhill, VT. In 1993 and 1994 treatments applied to these plots were designed to examine the effects of snow cover on soil temperature within a hardwood forest. Overall seasonal trends were similar in both years with soil temperatures increasing with increasing soil depth during fall and winter and decreasing with increasing depth in spring and summer. During winter, soil temperatures in snow-free plot were generally more responsive to ambient air temperature than those in snow-covered plots, and were consistently 1 to 5° C (1993) and 3 to 9° C (1994) lower than those measured at corresponding depths in snow-covered plots. In 1994, soil temperature at all subsurface depths (-30, -15, and -5 cm) on snow-covered plots remained above freezing throughout winter, while in 1993, only at -30 cm was soil temperature consistently above freezing. On snow-free plots average daily soil temperature reached lows of -2, -4.5, and -9° C at depths of -30, -15, and -5 cm, respectively. When a continuous snow pack develops in December, it appears that soil temperatures tend to stay above freezing even at depths as shallow as -5 cm. When averaged over the two years, below freezing temperatures (1 February-15 April) occurred only 0.5% of the time at -30 cm when snow cover was present, but 92% of the time when snow was absent.

INTRODUCTION

In January 1993 a study was initiated to continuously monitor soil temperatures at several depths within a northern hardwood forest. This monitoring will provide basic data on soil temperature gradients within the forest and address questions about the frequency of freezing in the forest soil rooting zone. Soil thermocouples were installed within the upper rooting zone in two sets of paired, m^2 plots located near the VMC canopy research tower at the Proctor Maple Research Center in Underhill, VT. The paired-plot approach allows treatment of one plot in each pair while maintaining the second plot as a control. Over time, this instrumentation will allow us to add soil temperature information under a variety of environmental conditions to the ever-increasing database being generated at the tower site.

In 1994 treatments of snow-covered vs. snow-free plots were continued to again look at the effects of snow cover on soil temperatures during winter and early spring. Snow was allowed to accumulate naturally on one plot in each pair while the other plot was kept free of snow throughout winter.

Objectives

The overall goals of this project are to increase our understanding of soil temperature dynamics within the upper rooting zone of a northern hardwood forest and to examine the effects of snow cover on forest soil temperatures. Specific goals are to:

1. continuously monitor soil temperature at several depths within the upper rooting zone of a northern hardwood forest,

2. examine the effects of snow cover on soil temperature at various depths within the upper rooting zone of a northern hardwood forest, and

3. relate meteorological variables such as ambient temperature, total irradiance, and wind speed to soil temperature.

METHODS

On 15 January 1993 four-point, averaging thermocouples were installed 2 cm above and 5, 15 and 30 cm below the soil surface (2, -5, -15, and -30 cm) in each of the four plots (two sets of paired plots). Subsurface thermocouples were installed by excavating a small pit with a smooth vertical face and inserting the four ends of each thermocouple set horizontally into the face of the soil approximately 10 cm apart at each depth and 7 cm deep into the soil face. Thermocouples were patterned after commercially available ones sold by Campbell Scientific Inc. (CSI), but were made by us from bulk teflon-coated 22 gauge copper-constantan thermocouple wire. The actual thermocouple junctions were waterproofed by applying clear heat shrink tubing over which several coats of clear commercial plasti-dip were applied. Thermocouples were calibrated and referenced to

National Institute of Standards and Technology (NIST) traceable thermometers prior to installation, with individual temperature corrections developed for each thermocouple. Plots were randomly designated as snow-covered (snow) or snow-free treatments. Data from one set of plots were recorded as 15 min averages to the CSI 21X datalogger located at the VMC research tower. Because of a shortage of available channels on the datalogger, data from the second set of plots were recorded directly to a computer, also as 15 min averages, by means of an analog to digital converter (ADC "blue box") and a Turbo Pascal program.

The first snowfall of the 1993-94 season occurred on 1 November 1993, but 4 cm of snow on 30 November marked the beginning of a continuous snow pack which lasted into late April 1994. Average snow depths on all plots were measured and recorded and snow was cleared from snow-free plots after each snowfall, as was done in 1993. In keeping with the yearly format of the VMC annual reports, data presented here will begin on 1 January 1994.

RESULTS

In 1994 overall seasonal trends in soil temperature were similar to those found in 1993. Soil temperature generally increased with depth during fall and winter and decreased with depth in spring and summer (Fig. 1). Soil temperatures at all three subsurface depths came into equilibrium with air temperature near the soil surface in mid March and again in early September, with both points being slightly earlier than in 1993. These times represent the transition from soil temperatures warmer than ambient air in fall and winter to those cooler than ambient air in spring and summer and back to warmer than ambient air. Seasonal soil temperatures increased sharply from April to June, then continued to increase at a slower rate until mid July. Soil temperatures then began to decrease gradually in response to the decrease in ambient air temperatures from mid August through early November and then more rapidly through the end of December. Average monthly soil temperatures fluctuated by 12 °C from February until July at -30 cm and 16° C at -5 cm, again very close to 1993 values. Significant differences in temperature related to soil depth were found during all seasons of the year.

During the period of continuous snow cover (late November to late April) soil temperatures in snow-free plots were generally more responsive to ambient air temperature than those in snow plots (Fig. 2). Soil temperature at all subsurface depths on snow-free plots, including -30 cm, were below freezing from mid January until late March. Average daily temperatures at -30, -15, and -5 cm on snow-free plots reached lows of -2, -4.5, and -9° C, respectively. Hourly average temperature at -5 cm on snow-free plots reached a low of -12° C in late January. Average daily temperatures of soil on snow-covered plots, on the other hand, remained above freezing at all depths, although only slightly above at -5 cm, throughout the entire snow-covered period. Average daily soil temperatures at -30, and -15 cm on snow-covered plots did not drop below 0.4° C, but soil temperature at -5 cm did approach freezing and some hourly averages did reach 0° C between mid February and early March.

Figure 1. Average monthly soil temperature measured 2 cm above and 5, 15, and 30 cm below the soil surface in a northern hardwood forest stand at the Proctor Maple Research Center in Underhill, VT.

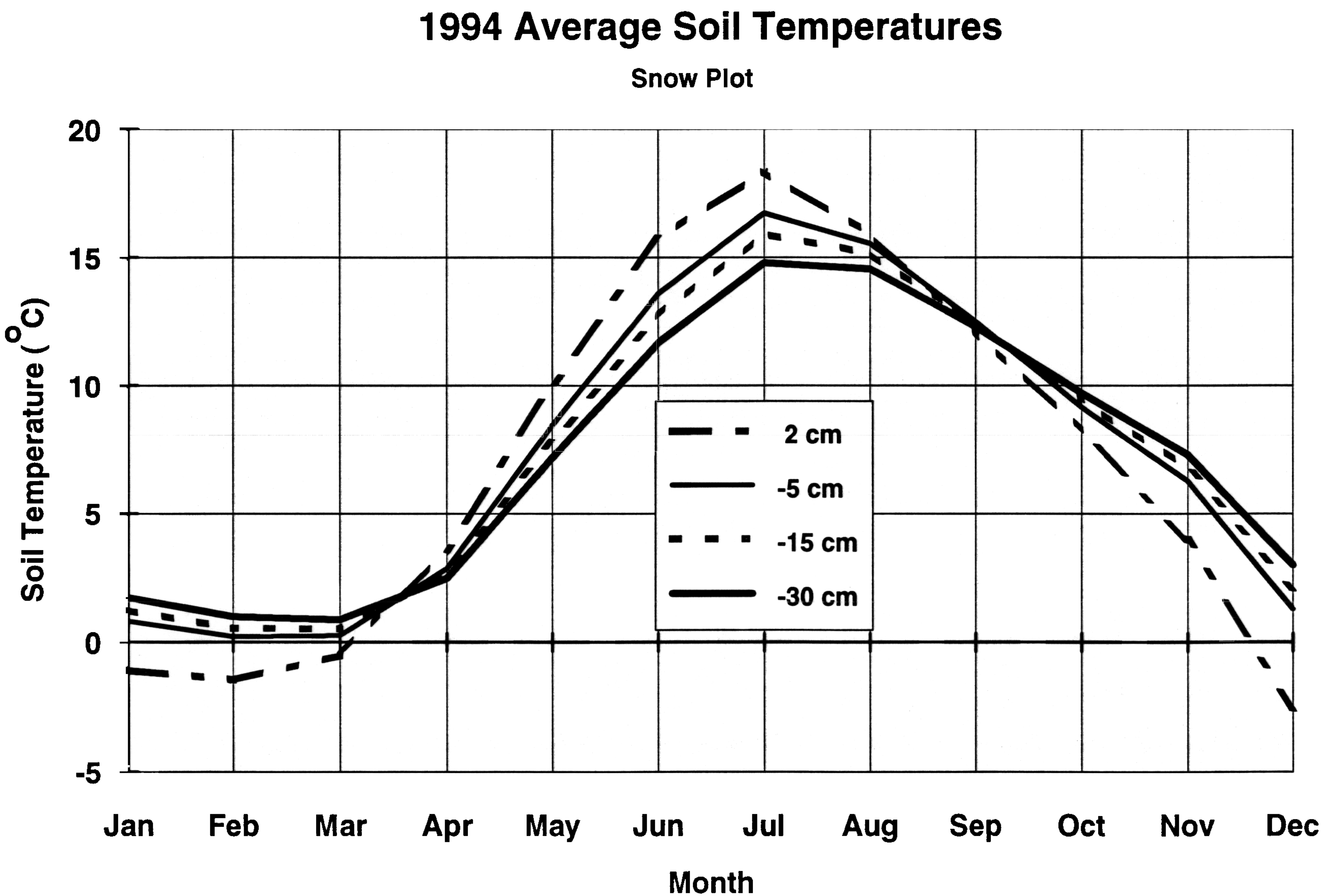
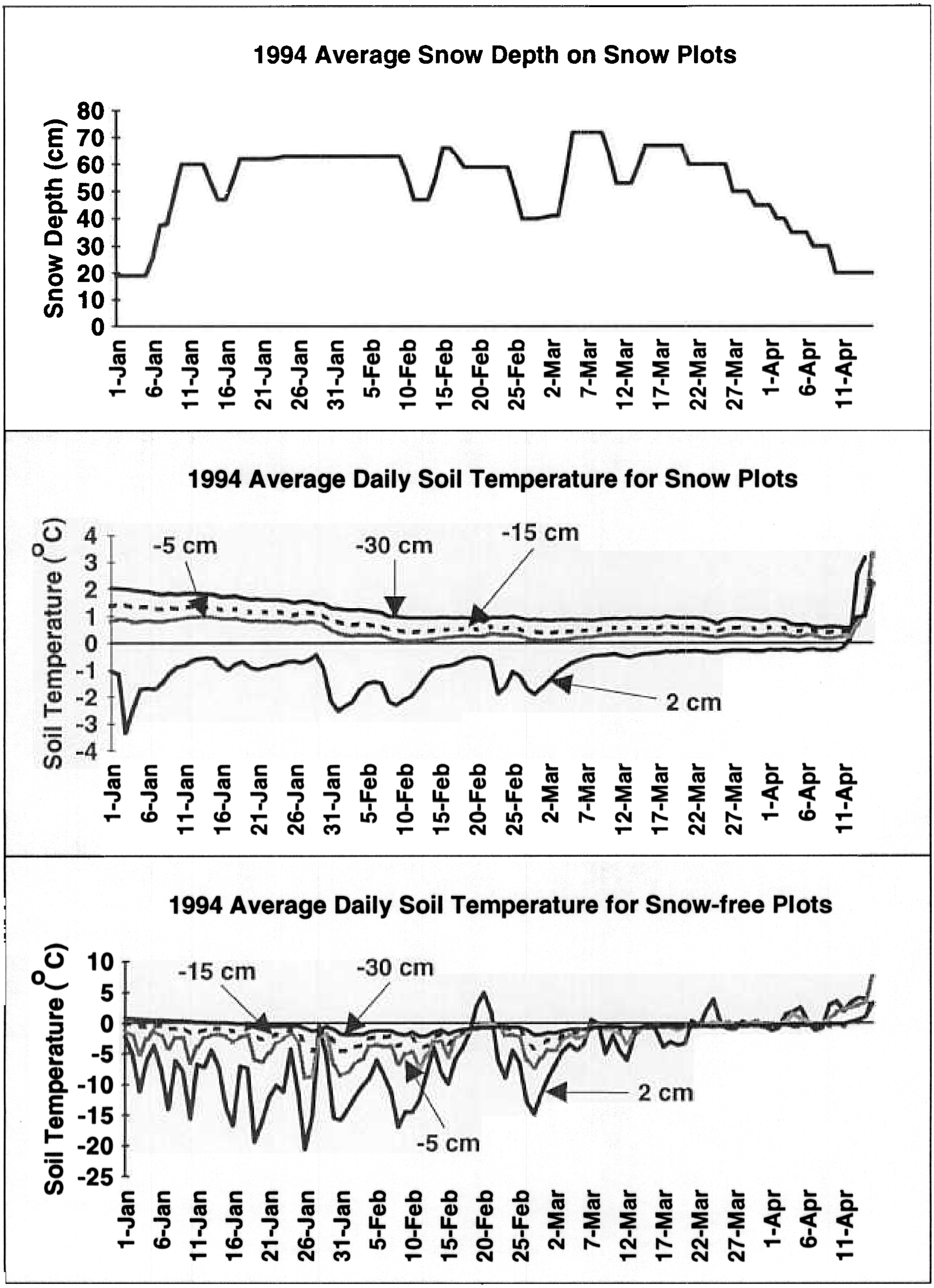


Figure 2. Average snow depth and average daily soil temperature for snow-covered (snow) and snow-free plots from 1 January to 15 April 1994 measured in a northern hardwood forest stand at the Proctor Maple Research Center in Underhill, VT.



Specific results show that soil temperatures at -30 cm were 1 to 2° C above freezing in the snow-covered plots and ranged from 1° C above to 2° C below freezing (1 to -2° C) in snow-free plots (Fig. 3). At -15 cm soil temperatures in snow plots were 0.5 to 1.5° C above freezing throughout the entire period (1 January to 14 April). In contrast, soil temperatures in snow-free plots at -15 cm were consistently below freezing (-0.25 to -4.5° C) before increasing rapidly in early to mid April. Daily average soil temperatures at -5 cm remained above freezing in snow-covered plots, although only slightly at times, and hourly averages did reach 0° C. In contrast, temperatures at -5 cm in snow-free plots tended to vary with ambient temperatures (2 cm), although not to the same magnitude, and remained consistently below freezing until late March to early April. Temperatures in snow-free plots at -5 cm fluctuated between -1 and -9° C until early to mid April when temperatures in both snow and snow-free plots began to rise rapidly in response to warming ambient air temperatures.

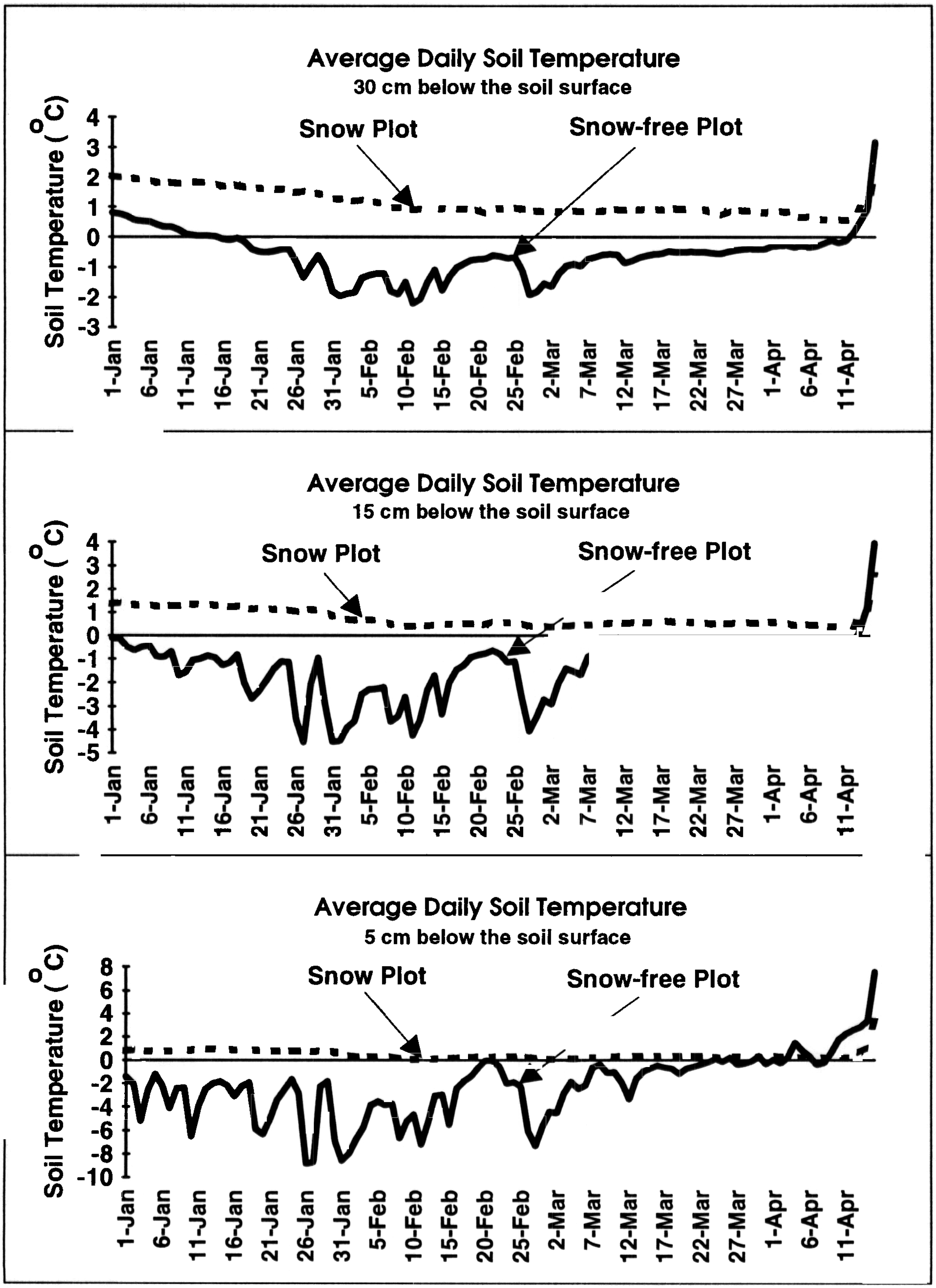
Although, trends for snow-free plots were quite similar in 1993 and 1994, some major differences were noted in the performance of snow-covered plots. In 1993 soil temperatures at all depths except -30 cm remained below freezing throughout most of the winter. In that year temperatures at -30 cm went above-freezing only after a snow pack of about 30 cm had accumulated and never reached 1° C throughout the entire snow-covered period. In contrast, 1994 soil temperatures on snow-coverd plots remained above freezing at all subsurface depths throughout the entire period (1 January to 15 April), although daily average temperatures at -5 cm did approach freezing. Soil temperatures in 1994 at -30 cm remained 1 to 2° C above freezing throughout winter.

The number of hours (1 February to 15 April) in 1993 and 1994 that temperatures remained below freezing, at the various depths, in snow and snow-free plots is summarized in Table 1.

Table 1. Number of hours and % of time that subfreezing soil temperatures occurred, at various depths, between 1 February and 15 April 1993 and 1994, in snow-covered and snow-free plots.

Soil Depth	Snow-covered				Snow-free			
	1993		1994		1993		1994	
cm	hrs	(%)	hrs	(%)	hrs	(%)	hrs	(%)
2	1572	(89)	1693	(95)	1331	(75)	1277	(72)
-5	.473	(83)	3	(0.2)	1448	(82)	1496	(84)
-15	1100	(62)	0	(0)	1579	(89)	1712	(96)
-30	23	(01)	0	(0)	1581	(89)	1691	(95)

Figure 3. Average daily soil temperature from 1 January to 15 April 1994 measured at 30, 15, and 5 cm below the soil surface on snow-covered and snow-free plots within a northern hardwood stand at the Proctor Maple Research Center in Underhill, VT.



In both years the number of hours of subfreezing temperatures decreased with soil depth in snow-covered plots and generally increased with depth in snow-free plots. The most striking difference between the two years is the significant reduction in hours of subfreezing temperatures (1994) in snow-covered plots at -5,-15, and -30 cm. This reduction in hours of subfreezing temperatures is apparently due to the much earlier snowfall and development of a continuous snow pack in 1994, although maximum snow depths were similar (about 70 cm) in both years. The insulating layer of snow (snow plots) increased the number of hours of subfreezing temperatures near the soil surface (2 cm) in both years, compared to snow-free plots. When averaged over both years, below freezing temperatures occurred only 0.5% of the time at -30 cm when snow cover was present, but 92% of the time when snow was absent.

DISCUSSION

Soil temperature is an important factor affecting establishment, growth and productivity, and survival of forest trees. In winter, soil temperature influences the degree of cold hardiness in roots of woody plants, regulates the supply of available moisture, and affects insect populations (i.e., pear thrips) and other soil-dwelling organisms. Winter desiccation, a particular problem in some conifer species, results when plants are deprived of moisture due to frozen soils and possibly frozen roots at the same time water is being lost through transpiration. In winter, length and frequency of soil freeze-thaw cycles, as well as depth of freezing, influence the severity of physiological and physical perturbation to trees and other biota. Extremes in high as well as low soil temperatures can also have detrimental effects on many forest organisms. In mature sugar maple (*Acer saccharum* Marsh.) it has been shown that when roots were exposed to freezing temperatures (-6° C) to a depth of 20 cm, that a significant reduction in sap flow rates, total sap volumes, and total sugar per tree occurred (Robitaille et al. 1995). These perturbations persisted for at least two years after treatment and were accompanied by increased canopy transparency (dieback).

We now have temperature data at differnt depths for two winters in soils beneath a northern hardwood forest. The two winters were quite different in the timing of snowfall and duration of a continuous snow pack. In 1994, snowfall and the associated snow pack began in late November and persisted until mid to late April. No significant snowfall occurred until mid January in 1993 and a continuous snow pack did not develop until early February. Despite the difference in timing of snow events, similar maximum depths of snow were recorded in both years (about 70 cm). Data from both winters show that in the absence of snow cover, soil temperatures can be below freezing to a depth of -30 cm for a significant part of the winter. At lesser depths of -5 and -15 cm, soil temperature in the absence of snow cover can be as low as -12 and -6° C (based on hourly averages), respectively. These depths encompass the major rooting zone for many tree species, subjecting roots (and other soil biota) to significant freezing events. These conditions usually occur during winters with extended periods of little or no snow cover. With snow present in December, soil temperatures remained above freezing for the entire winter even at depths as shallow as -5 cm. In 1993 when significant snowfall occurred late, we found that soil temperatures dropped below freezing even to depths of -30 cm. When snow-cover did occur in 1993, soil temperatures began to rise very gradually over the winter, but still remained below freezing at all depths except -30 cm.

Soil temperatures well below freezing are certain to cause freezing of soil water, but it is unclear if temperatures slightly below freezing also cause soil water to freeze. It seems probable that matric and solute forces in soil water may prevent freezing at temperatures -1 or -2° C. Once winter acclimated, most tree tissues are protected to temperatures well below freezing, but root tissues may not be so well protected (A. Auclair, pers. comm.). There is a need for more information about the effects of freezing degree and frequency on root physiology, as well as about the occurrence of freezing and high temperature events in soils. There are limited continuous multi-depth data on soil temperatures available, so these data provide valuable information about this fundamental property of soils and its important effects on plant roots and soil biota.

FUTURE PLANS

We plan to continue the experiment over several winters in an attempt to characterize soil temperature patterns under a variety of winter climatic conditions. Additional analyses will be done to examine number and timing of freeze-thaw cycles and extremes in high soil temperature.

FUNDING SOURCES

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LITERATURE CITED:

Robitaille, G., Boutin, R., and Lachance, D. 1995. Effects of soil freezing stress on sap flow and sugar content of mature sugar maples (Acer saccharum). Can. J. For. Res. 25: 577-587.