THE EFFECT OF LAND USE ON THE DEPTH AND DURATION OF SOIL FREEZING IN THE NORTHEAST

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R. S. PIERCE

NORTHEASTERN FOREST EXPERIMENT STATION, LACONIA, N.H.

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Northeastern Forest Experiment Station, Laconia, N.H.

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A study of concrete or impervious soil freezing was made over a two-winter period in the Northeast. Initial analysis has been made of the data to show the influence of vegetative cover on the depth and occurrence of this freezing. The greatest depth and the most frequent occurrence of frost in decreasing order was under the following cover conditions: cultivated fields, pasture, hayland, softwood reproduction, softwood sawtimber, hardwood reproduction and hardwood sawtimber.

INTRODUCTION

It has been pretty well proven that when precipitation enters and passes through the ground before it becomes streamflow, the aims of watershed management are better served than when this water flows over land on its way to the stream. Water that flows over the surface reaches the stream too quickly; it usually makes a major contribution to flood peaks. In addition, surface runoff is water lost to the area on which the precipitation falls; it serves no purpose, either as ground water for later streamflow or wells, nor to supply moisture for plant growth. Also, water flowing over the surface erodes the ground and carries sediment to the streams.

In northern climates, one condition which restricts rainfall or snow melt from entering the soil is impermeable soil freezing. It is important, for two reasons, to understand the nature and extent of this soil freezing: first, to aid in the development of a land use program designed to reduce surface runoff; and secondly, to more fully evaluate and predict the behaviour of streamflow during winter or spring thaws.

Most of the early investigations of soil freezing were concerned with measuring the depth of frost under widely contrasting types of vegetation, for example, open cultivated fields versus forest land. Not much effort was made to differentiate between cover conditions within these drastically different vegetation types.

Too, in the early studies, little attempt was made to differentiate the various degrees or types of soil freezing. Only within the past 20 years have detailed observations on soil freezing led to the development of morphological classifications. Today, most investigators working with frozen soil recognize four types of soil frost: granular, honeycomb, stalagmite, and concrete. Rather fragmentary field studies have, to date, indicated that of the four types, probably only concrete frost seriously impedes the infiltration of water into the soil.

In addition to the two primary requirements for soil freezing – that is, moisture in the soil and freezing air temperatures — soil frost is influenced by a multitude of other factors among which are: snow depth, aspect of the area, shade, soil texture and structure, soil organic matter content, and the presence or absence of litter and humus layers of various types and depths. The effects of some of these factors have been investigated in the field or laboratory or both. However, until recently, no designed studies under natural conditions had been undertaken in the Northeast to test on a broad scale the combinations of factors responsible for soil freezing.

This paper reports the initial results of a two-winter study, 1950-51 and 1951-52, made to obtain information on soil freezing in 21 different land-use conditions in the Northeast. The primary aim of this report is to show the effect of different cover conditions on average depth and average frequency of concrete frost. Further analysis of the results of this study as well as more field studies will be made to define in more detail the environmental-soil freezing relationships.

METHODS OF STUDY

The data given in this paper were based on soil frost and snow depth measurements made on 174 plots located in six study areas as follows: south central Maine, northeastern New York, east central New Hampshire, northwestern Massachusetts, south central New York, and northeastern Pennsylvania. The locations of the study areas are shown in Figure 1.

At each area, plots were laid out in 12 to 18 land-use conditions covering a range of 21 conditions in all. Two major categories of conditions were recognized: open land, or non-forest land, and forest land. The open land condition consisted of bare fields used for growing row crops, hayland, and pasture. Forest land conditions ran the gamut from young tree reproduction on abandoned farmland to mature sawtimber. Included in the forest land were young conifer plantations, immature and mature stands of both conifers and hardwoods with various degrees of stocking, and forest stands which had been disturbed and modified by logging and grazing.

In each land use condition, two 50 x 50 foot plots were laid out. On these, observations were made twice weekly during the frost season. These observations consisted of taking two measurements of each of the following: snow depth, snow water content (the second year only), litter and humus depths, frost type, and frost depth. This latter was further defined by recording which soil horizons were frozen. The depth of concrete frost was measured to a total depth of 10 inches. Where this depth was exceeded, total depth was recorded as 10 inches plus. Frost types other than concrete existed only in shallow depths, never approaching 10 inches. Approximately 35 visits were made to the plots during each of the two winters.

Daily precipitation and maximum and minimum temperatures were measured at a centrally-located weather station in each of the six areas.

METHODS OF ANALYSIS

Frost data were analyzed to determine for the period of record; average depth of concrete frost, frequency of its occurrence, and accumulated depth. This latter is an artificial value used to describe both depth and frequency. Average snow depths were also computed.

AVERAGE DEPTH OF CONCRETE FROST

The average depth of concrete frost was computed for each land use condition from the field data taken on the plots. This was done by adding up all the frost depth measurements, including the points of zero measurement, and dividing by the total number of days on which concrete soil freezing had been observed – even if it occurred at only one of the measuring points for the particular land use condition. If on any one day no frost was observed at any of the four points in the paired two plots in a cover type, then that day was not used in computing frost depth. These average frost depth figures, then, are based only on the days when frost was observed.

Similar land-use conditions and forest types were then grouped together for a series of 21 logical comparisons; e.g., open land versus forest, hayland versus pasture, hardwood versus conifer, etc. The differences in frost depth between these conditions were treated by statistical tests to determine their true significance.

PERCENTAGE OF FROST OCCURRENCE

To give a fuller comparison of the opportunities for soil freezing between land use and cover conditions, another parameter was computed — the frequency of frost occurrence. In this computation, the common base for all conditions in any one study area was the number of observations between the first and last recording of frost in that area. For instance, if in the Maine study area, the first concrete frost occurred as one observation in late October on a bare cultivated plot, then that date was the beginning of the computation period for the occurrence of frost under all conditions in that study area.

ACCUMULATED FROST DEPTH

Accumulated frost depth is the product of the average frost depth for a season and the number of days of frost. This term is descriptive of overall frost conditions on both a time and a depth basis. Since observations were taken only twice weekly – and not every day – it was necessary to do some estimating to account for the time between observations. This was done in the following manner: if frost occurred on two consecutive observations, days between were counted as frost days; and frost-free periods were considered to extend from the date of the last observation of frost to the date of its next observation if intermediate observations showed no frost.

AVERAGE SNOW DEPTH

Average snow depths were computed for each land use condition for each winter of record.

RESULTS

It should be emphasized again that this analysis is the initial one made from this study. It was not designed to determine the influence of all the variables of climate, soil, and topography involved in concrete soil freezing. Its only aim was to define for the Northeast the important overall effects of land use and cover on this type of freezing.

Table I shows the two-year average depths of concrete frost in six comparisons between major land use and cover conditions. These data are shown separately for the six study areas.

The first comparison between open land and forest land needs little explanation. Open land refers to bare cultivated fields, haylands, and pastures. Forest land includes both coniferous and hardwood pole and sawtimber. In all six areas the difference in frost depth was highly significant. This is in line with what might be expected.

In comparison number 2 (open land vs. forest reproduction) the difference is highly significant in all areas having these conditions. Forest reproduction refers to abandoned land which has seeded in naturally with tree species but has not reached a height of 10 feet. A small conifer plantation is also included in this category. Note the close similarity of frost depths in the forest land and forest reproduction.

The grass land in comparison number 3 includes both hayland and pasture. In three of the areas – Penobscot, Hopkins, and Pocono – the difference was highly significant. The remaining three areas exhibited differences in the same direction but these were not statistically significant.

In comparison, number 4 the conifer pole timber showed significantly less frost than hardwood pole timber in 3 out of 5 areas. While the other areas did not show statistically significant differences, the hardwood had less frost than the conifer.

A somewhat similar trend is shown in comparison number 5 of conifer sawtimber versus hardwood sawtimber. Here, in 4 out of 5 areas, the coniferous stands showed more frost than the hardwoods. No explanation for the inverse relationship at the Pocono area can be offered at this time.

In comparison between hardwood reproduction and hardwood sawtimber, in all cases the hardwood sawtimber had the least amount of frost.

The average frost depth, occurrence, accumulated depth and snow depth for all six areas is given in Table II. As might be expected, the bare cultivated areas had the greatest frost depths, the highest incidence of frost occurrence, and the greatest accumulated depth.

The pasture and hayland conditions had very similar depths, percentage of occurrence and accumulated depths. The non-forest conditions were conspicuously different from the forest.

Of forest conditions, the coniferous plantation had the greatest amount of frost and the highest frost occurrence.

With the exception of the grazed hardwood sawtimber stand, all other hardwood cover types whether reproduction or timber had less frost depth, percentage of occurrence and accumulated depth than any of the conifer stands.

The grazed hardwood sawtimber stand had slightly less frost depth than the conifer plantation; however, the accumulated depth was greater in the grazed hardwood.

The hardwood sawtimber stands had the least amount of frost of all conditions.

The logged sawtimber stands showed little difference in frost conditions from the unlogged sawtimber stands. This was true for both hardwoods and conifers.

The hardwood reproduction and brush conditions had greater frost depths than other hardwood stands but less than the conifer stands.

CONCLUSIONS

It was to be expected that the greatest frost depths and the highest rates of frost occurrence would be found under non-forest conditions. In large measure the factors responsible for the differences in frost between the various areas are difference in organic matter content, in compaction, in vegetative cover, and in snow depth.

Bare cultivated fields have the least organic matter, are the most compacted and have the least vegetation to act as a buffer against temperature extremes. And they have the most frost. Following them, in respect to these same factors and to frost, come hayland and pasture. Forests, with a blanket of organic matter covering the soil, with porous uncompacted soil, and with a high, heavy stand of vegetation to ameliorate extreme temperatures (forests are warmer than open land in the winter) have the least concrete freezing of all conditions.

Within the forest cover itself, the factor accounting for the most clearcut difference in frost conditions is the forest type or tree species. Thus we have significantly greater depths and higher occurrences of concrete soil freezing under conifers than under hardwoods. In this respect, the findings of this study are substantiated by isolated observations of other investigators. This situation calls for explanation as to the reasons. One reason for less frost under hardwoods than under conifers is quite obvious; the hardwoods have a deeper protective snow blanket; their crowns are less dense and intercept less of the snow that falls. A second reason for this difference is less obvious and more speculative; it lies with the differences in types of litter and humus found under the two kinds of stands. Hardwood litter is composed of layer after layer of matted leaves which typically cover a crumbly humus composed of a mixture of organic matter with mineral soil. The matted litter apparently provides good insulation against heat loss from the soil. In this litter, frost crystals may be present but in most cases they are not continuous within or between leaf layers. In the crumbly humus beneath, when frost is present, it rarely forms the concrete type. The litter of coniferous stands is composed chiefly of needles which do not form continuous layers and thus probably do not offer as much protection against heat loss as the hardwood leaf layers do. Too, the humus under the needle litter is not generally incorporated with the mineral soil but lies as a sharply defined layer above it. Often times, concrete frost forms in the underlying mineral soil before it does in the humus above.

Considerable reduction in frost penetration may be realized in abandoned farm lands which have been allowed to seed in with natural hardwood reproduction. Since the vegetative characteristics of hardwood brush in winter tend to be favorable for snow accumulation, the amount of frost under these conditions would be less than under grass or cultivated fields not having this deep insulating snow layer. Then too, the advent and growth of vegetation with its accompanying addition of humus to the soil mitigates still further against concrete freezing.

To the extent that logging and grazing reduce the depth of the humus layers, compact the soil, and reduce the insulating effect of the stand, they tend to favor the occurrence of concrete freezing. However, the picture is complicated by the fact that many stand disturbances, by reducing the crown canopy, favor greater snow accumulation. Thus, without careful study of the variables and adequate sampling of a number of stands it is not possible to define fully the relative effects of stand disturbances.

*Since the paper was presented, a further analysis of the data was made. The results are now being processed by the Northeastern Forest Experiment Station for publication.

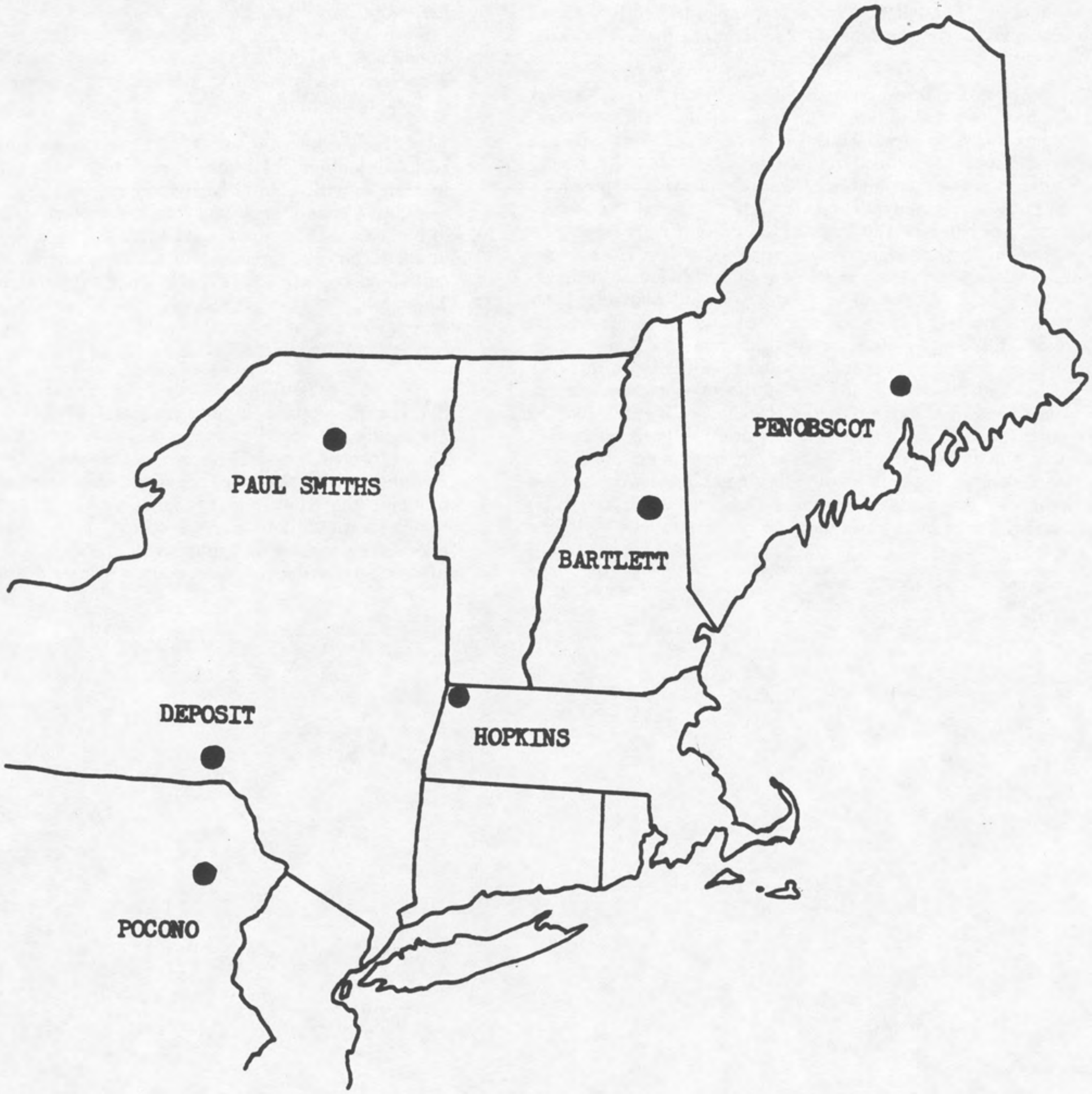

Figure 1.--Location of frost study areas in the Northeast.

TABLE I

Comparative Depths of Concrete Frost

Comparisons	Penobscot (S. Cent. Maine)	Paul Smiths (N.E. New York)	Bartlett (E. Cent. N.H.)	Hopkins (N.W. Mass.)	Deposit (S. Cent. N.Y.)	Pocono (N.E. Penna.)
	Concrete Frost Depth — Inches					
1. Open land	6.3**	6.4**	6.7**	3.5**	4.8**	4.2**
Forest land	3.8	3.3	1.4	2.7	3.2	2.1
2. Open land	6.3**	6.4**	6.8**	3.5**	4.8**	—
Forest reproduction	4.0	2.2	2.8	2.2	3.2	
3. Bare cultivated	7.2**	7.1	7.2	5.7**	5.1	4.8**
Grass land	6.0	6.2	6.4	2.7	4.7	4.0
4. Conifer pole timber		5.2**	1.4	2.9	4.6**	2.4**
Hardwood pole timber	—	1.8	1.2	2.2	1.8	1.6
5. Conifer sawtimber		2.7**	1.7**	3.3*	4.8*	1.7
Hardwood sawtimber	—	1.0	0.0	2.3	1.8	2.1
6. Hardwood reproduction	—	1.2	2.8**	2.4	3.0**	—
Hardwood sawtimber		1.0	0.0	2.3	1.8	

*Difference is significant
**Difference is highly significant

TABLE II

Average Frost Depth, Occurrence, Accumulated Depth and Snow Depth for All Areas

Land-use condition	Frost Depth Inches	Frost Percentage Occurrence Percent	Frost Accumulated Depth Inch-days	Snow Depth Inches
Non-forest				
1. Bare cultivated	6.2	86	624	5.6
2. Pasture	4.8	74	476	5.1
3. Hayland	4.9	77	456	6.6
Forest				
Disturbed				
4. Coniferous sawtimber **logged**	2.9	49	187	8.6
5. Hardwood sawtimber **grazed**	3.4	63	282	6.7
6. Hardwood sawtimber **logged**	1.6	32	66	10.0
7. Hardwood reproduction, brush	2.8	45	167	10.3
Undisturbed				
8. Coniferous plantation (12-18 yrs.)	3.5	68	264	4.9
9. Coniferous sawtimber	3.2	50	204	7.4
10. Hardwood sawtimber	1.4	27	55	10.5