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FOREST SERVICE, U. S. DEPT. OF AGRICULTURE, 6816 MARKET STREET, UPPER DARBY, PA.

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A DEVICE FOR MEASURING SOIL FROST

Abstract.—A water-filled plastic tube buried vertically in the soil in a copper casing permitted repeated observation of frost depth without damaging the sampling site. The device is simple and inexpensive and provides data on soil freezing at least as accurate as direct observation by digging through frozen soil.

Recent research reports about frost penetration in forest soils have relied on some admittedly unsatisfactory measurement techniques. Patric *(1967)* used direct observation: holes dug through frozen to unfrozen soil, a method recognized as accurate but laborious and destructive to the sampling site. Sartz *(1967)* tested three indirect measurement methods: electrical resistance blocks, a penetrometer, and a stack of buried water bottles. The older literature records yet other devices for indirect frost measurement, the most successful of which employed water-filled capillary tubes buried in the soil *(Gailleux and Thellier 1947)*.

A method was needed to combine the ease of indirect measurement and the accuracy of direct measurement with the capability for a statistically adequate sampling frequency.

A device was envisioned in which ice present in a buried water column would accurately reflect the advance and retreat of freezing temperature in the soil. Its ability to reflect advance of freezing temperature would rely on water's property of maximum density at 39°F. Water cooler than 39°F. would rise to the top of the column, then freeze when the temperature falls to 32°F. Warming of soil around the buried column would convert the ice back to water. A device was needed that would:

- React to soil freezing and thawing with reasonable speed and accuracy.
- Withstand expansion pressures during change from water to ice.
- Cause minimum alteration or damage to the sampling site.
- Be economical in construction and operation to permit frequent and replicated observation.

The Instrument

The frost tube finally developed consists of two basic parts: a 1/2-inch copper tube to serve as a well casing; and a transparent plastic 3/8-inch tube containing colored water (fig. 1). The copper casing was made water-tight by capping the bottom end to preclude ice formation inside, which would prevent withdrawing the plastic tube for taking readings from it.

To install a frost tube, we forced a length of rigid copper tubing into unfrozen soil, then pushed the frost tube into the pilot hole. In stony soils a slender soil auger or a steel drive pin may be needed to make snug-fitting pilot holes.

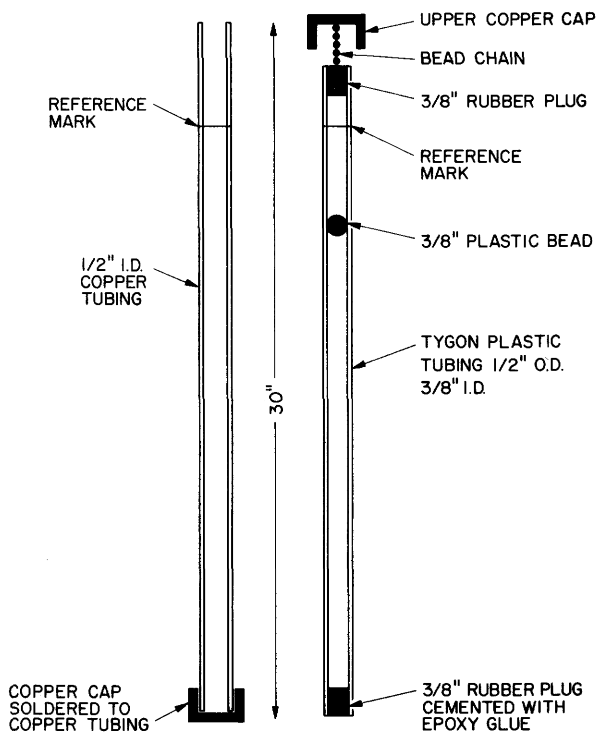

Figure 1.—Diagram of a frost tube. Not to exact scale.

For taking frost observations, the plastic tube is withdrawn by the chain connecting it to the upper cap. For proper reinsertion, this chain needs sufficient slack to permit reseating the plastic tube firmly against the bottom of the copper tube, before replacing the cap. The space partially occupied by the slack chain was intended to provide for expansion during freezing. However, the plastic tube was not observed to expand in any direction throughout the winter. We did dust all of the plastic tubes with graphite to make them easier to withdraw and reinsert.

It was necessary to insert in the tube a bead, of plastic or some other water-insoluble material, to prevent water overturn at the onset of freezing weather. At this time, even though surface soil froze, ice did not form within frost tubes without beads when subsoil temperature exceeded 39°F. Failure to freeze stemmed from water's unique property of maximum density at 7° above its freezing temperature. Placing the bead about 6 inches below the reference lines prevented this early-winter water overturn and provided more certain results on shallow freezing. The bead must of course be moved down as frost moves more deeply into the soil.

Reference marks can be inked or painted on both the copper and the plastic tubes. The frost tubes are inserted to the depth of the exterior reference mark, usually about 6 inches below the upper copper cap for easy relocation in snow and to forestall ice formation on the cover cap. Though exact placement of the exterior reference mark is unimportant, it and the interior reference mark must be at the same level. When the exterior reference mark is at the soil surface, frost measurements are made from the interior reference mark to the lowest ice dendrite visible inside the plastic tube.

Supercooling occasionally delayed ice formation when the frost tubes were being developed. A small quantity of finely dispersed silver iodide was mixed into the water to provide nucleating surfaces for ice-crystal formation. Although nearly insoluble, silver iodide was chosen for this purpose because its crystalline structure resembles that of ice.

Kool-Aid at 50 percent above drinking strength (3/4 package of Kool-Aid per quart of water) also was used in the frost tubes.[1] It contains a dye which tends to move away from ice and to concentrate in water (fig. 2). The contrasting pale ice and darker colored water greatly helps to determine the lowermost ice formation on dark winter days.

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[1] The authors are indebted to Dr. Charles Stroh of the Chemistry Department, West Virginia University, for providing silver iodide and for pointing out the contrasting colors of frozen and liquid solutions of Kool-Aid. Mention of a commercial product should not be taken as an endorsement by the Forest Service.

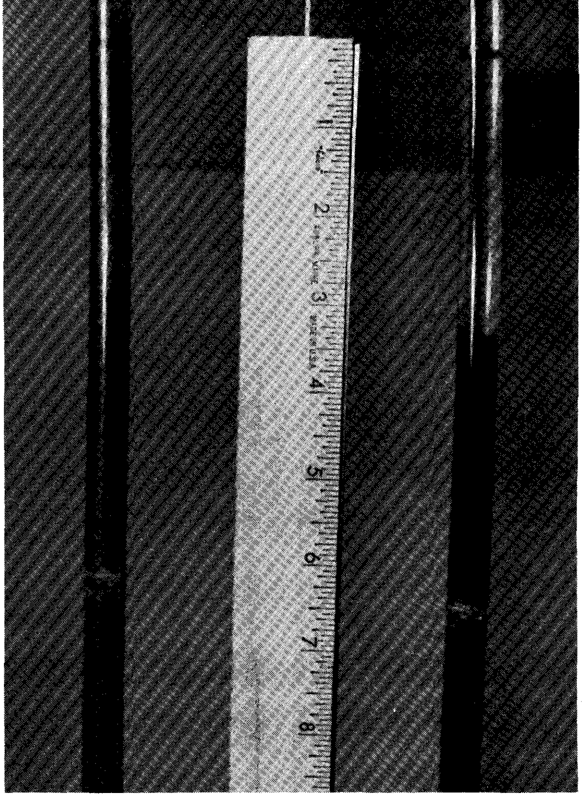

Figure 2. — The plastic tubes in course of development. Note the reference marks at top, and the plastic beads at 6½ inches. In the tube at right, coloring material in the water helps to mark the depth of freezing 3 inches below the reference line.

Test Results

The frost tubes were checked for ice whenever air temperatures fell below freezing. Ice never was observed in tubes when soil was unfrozen, regardless of air temperature. The soil froze first as a disc about 1 inch in radius and 1/2 inch deep around the tubes. This preliminary formation of frozen soil around the tubes suggests that the copper tubing initially conducts some heat from soil to atmosphere. At this stage of soil freezing, some but not all of the tubes contained ice in the uppermost portions. After continuous freezing more than 1 inch deep, ice will form in all properly constructed frost tubes .

During the period 17 January to 14 March 1968 we obtained 78 comparisons of frozen soil depths with the lengths of ice columns in frost tubes. These data, measured to the nearest 1/4 inch, are plotted in figure 3. The regression line expresses virtually a 1:1 relationship between ice-column length and frozen soil depth.

Late in the morning of 29 January, the soil thawed rapidly after being frozen about 8 inches deep. The following tabulation compares depths of freshly thawed soil to meltwater in frost tubes and depth of yet-frozen soil to ice remaining in frost tubes. These data suggest that water and ice in frost tubes reflect thawed and frozen soil fairly accurately, but with some time lag. Unfortunately no other observations were obtained under thaw conditions.

Tube No.	Newly thawed Soil (inches)	Newly thawed Water in tube (inches)	Still frozen Soil (inches)	Still frozen Ice in tube (inches)
3	4.0	2.50	4.5	6.50
6	3.5	2.75	4.0	2.25
11	4.0	2.75	.5	1.50
12	4.0	3.75	2.0	2.50

Five frost tubes were excavated on 28 February and the ice-frozen soil comparisons tabulated below illustrate the consistency of these data. Only the last comparison differed by more than 1/2 inch. Although differences as large as 2 inches were rare, they did occur. Errors even of this magnitude will decrease in consequence as frost depth increases.

Length of ice column (inches)	Depth of frozen soil (inches)
8.0	8.0
8.0	8.5
8.5	8.5
10.0	9.5
10.0	8.0

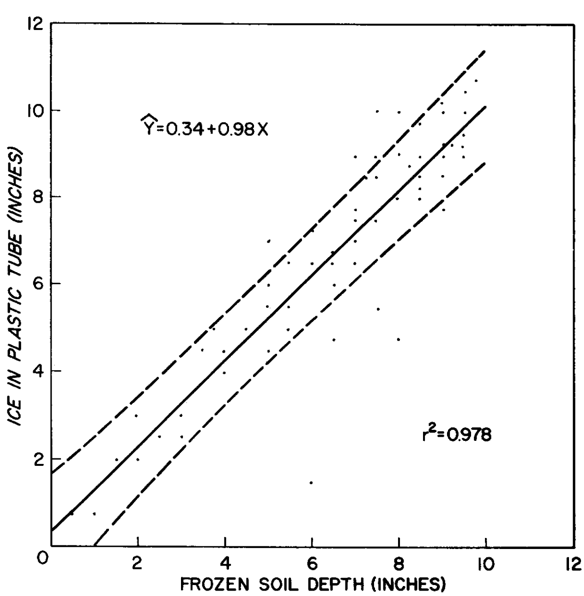

Figure 3. — The relationship of frozen soil to ice-column length on the frost tubes.

Discussion

Our study suggests that frost tubes provide strong evidence of depth of freezing temperature in the soil. However, Sartz's *(1967)* literature review, corroborated by results from his study in Wisconsin, led him to conclude that soil temperature is not a good indicator of soil freezing. This inexact relation of soil freezing to temperature may explain much of the point scatter around the regression line in figure 3 and the wild reading in the last text tabulation.

Possibly frost tubes can provide more accurate measurement of frozen soil depth than does excavation. The frost tube was held at eye-level in good light, assuring accurate measurement from the interior reference mark to the lowest ice dendrite in the plastic tube. To obtain a frozen soil measurement, frost tubes were excavated with a pick, crowbar, shovel or any other usable tool. The soil surface was not uniform and the exterior reference mark sometimes was 1/2 inch over or under the general soil level. Sometimes invisible, the probable bottom of the frozen layer was located by probing with a pocket knife, usually near the bottom of a very rough, small hole through the frozen soil. Soil easily penetrated by the knife blade was assumed to be unfrozen; yet sometimes small ice crystals were found in soft soil.

Thus, though frost tubes probably provide accurate indices of soil temperature, measurement of frozen soil combines personal judgment, imprecise boundaries, and awkward conditions for obtaining measurements. These error sources in direct measurement of frozen soil probably increase with increasing frost depth.

Although the available evidence suggests that frost tubes provide reasonably accurate estimates of frozen soil depth, further testing may be needed. For example, frost depths greater than 10 inches rarely occur in our relatively mild winters. Only one observation of thawing was obtained. Measurements both of deeper freezing and of thawing are being made in the severer climates of Wisconsin and Alaska. On the other hand, for frost depths of less than 2 inches, it is more accurate, less expensive, and easier to measure the frozen soil directly.

Frost tubes are simple, completely safe devices that permit us to estimate depth of soil freezing inexpensively, accurately, and in replicated installations. Most important, the frost tubes are non-destructive to the sampling site. They seem to provide a better method for measuring both freezing and thawing than any of the methods listed by Sartz *(1967)*. They should prove particularly useful for measuring the depths of active layers in permafrost regions.

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—JAMES H. PATRIC and BURLEY D. FRIDLEY

Timber and Watershed Laboratory
Northeastern Forest Experiment Station
Forest Service, U.S. Dep. Agriculture
Parsons, W. Va.

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