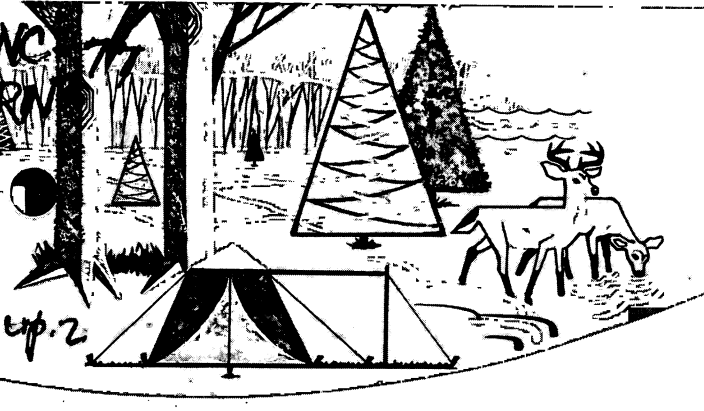

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NORTH CENTRAL FOREST EXPERIMENT STATION, FOREST SERVICE—U.S. DEPARTMENT OF AGRICULTURE
Folwell Avenue, St. Paul, Minnesota 55101

Interpreting Neutron Probe Readings In Frozen Soil

ABSTRACT. — Several factors associated with soil freezing complicate the interpretation of neutron probe readings in frozen soil. Temperature is unimportant, but the effect of vertical resolution must be considered. Because of the possibility of both gains and losses of water at the same depth during a period of measurement, interpreting changes in the water content of frozen soil is a subjective process.

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Soil freezing can affect the distribution of water in natural soil profiles in several ways: It may restrict or prevent infiltration and percolation, it may alter the direction of subsurface flow on sloping land, and it may cause upward movement to the freezing front. Rainfall or snowmelt on frozen soil may result in a water buildup in the upper few centimeters of the profile with no change at lower depths. The higher water content near the surface will affect neutron readings at lower depths if vertical resolution of the probe exceeds the sampling interval. The possibility of simultaneous gains from infiltration, losses from percolation, and upward migration further confuses the interpretation of neutron probe results in frozen soils.

Effect of Temperature and Frozen Soil

High temperatures can affect the shield count rate of some neutron probe instruments (van Bavel *et al.* 1963). However, I found no significant low-temperature effect on either shield or probe units of the one instrument tested (a Nuclear-Chicago Model P19 D/M gage with an 80 mc. Am-Be source)[1] and concluded that temperature *per se* would not affect neutron probe readings under the conditions that normally accompany soil freezing. The tests were run at temperatures ranging from 60° to –17° C. The abnormal condition created by the access tube must also be considered. By producing a horizontal temperature gradient, metal access tubes could cause water to move toward the tube from the surrounding soil. This possibility was investigated by Dickey *et al.* (1964) in a study of temperature and water gradients around steel access tubes, but they found no discernible temperature gradient and concluded that horizontal water movement does not occur.

Because the molecular density of water decreases when it changes to ice, I suspected that the change in state might affect neutron meter count. Readings taken in both water and ice (in a plastic container 52 cm. deep and 40 cm. in diameter) showed that freezing did indeed affect neutron meter count. The count in ice was 90 percent of the count in water.

[1] *Mention of trade name does not constitute endorsement of the product by the U.S.D.A. Forest Service.*

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To test the effect of soil freezing, I buried three plastic containers (52 by 40 cm.) so that just the top 2 cm. remained above the ground. I then filled each with a different soil: silt loam, sand, and a mixture of the two, which had water contents of 15, 32, and 35 percent by volume, respectively. I covered the containers to exclude rain and minimize evaporation, installed access tubes in each, and took readings before and after the soils froze. There was no significant change with freezing in any of the soils. The expected decrease in count was either too small to be measured, or was masked by an increase resulting from thermal movement.

Effect of Vertical Resolution

The layer of influence or vertical resolution of the probe — defined by van Bavel *et al.* (1954) as the thickness of the layer of soil that significantly determines the counting rate — should be considered when interpreting any neutron meter data. Vertical resolution determines the shallowest depth at which the observed count is unaffected by the soil surface. It also determines the minimum sampling distance that can be used without having overlap in the measurements. Vertical resolution varies only a little among different neutron source types (Ziemer *et al.* 1967), but it varies appreciably with water content of the soil (van Bavel *et al.* 1954). I found it to be 60 cm. in a dry soil (15 percent water) and 35 cm. in a wet soil (35 percent water). Thus, in the dry soil the shallowest reading would have to be taken at a depth of at least 30 cm. to be unaffected by the soil surface; and the depth interval would have to be at least 60 cm. for the readings to be unaffected by the water content at the next depth.

The effect of vertical resolution has special significance in frozen soil. This is because water can accumulate on or close to the ground surface — from snow or ice buildup, or from restricted percolation. For example, I found that 30 cm. of snow (water equivalent = 5 cm.) increased neutron count at the 15-cm. depth in a dry soil (17 Pv) by an amount equivalent to 1.0 percent water content. An ice layer at the ground surface could have a greater effect. A wet surface layer in an otherwise dry soil profile is common in winter. From gravimetric sampling in a frozen sandy soil, I found 33 percent water in the top 7.5 cm. and only 14 percent water in the next 7.5 cm. The wet surface layer would affect neutron readings at more than one depth in this situation if the depth sampling interval were too short.

Downward Versus Upward Movement

The possibility of both downward (from percolation) and upward (with a thermal gradient) movement of water further complicates the interpretation of neutron probe readings in frozen soil. In one study I tried to eliminate percolation to get a better picture of upward movement. Two access tubes 3 m. apart were installed in each of two soils, one a sandy soil, the other a silt loam. After the ground began to freeze, the soil surface around one tube at each site was covered with a sheet of clear polyethylene, 2.3 m. square, to prevent infiltration.

The procedure was only partly successful. Both covered and uncovered plots showed soil water increases in the upper 30 cm. (fig. 1). Increases at the covered plots resulted from water running under the plastic because the edges were not buried. This was observed several times during the frost period, particularly later on when the frost was harder, thus restricting infiltration more. However, the greater increases on the uncovered plots in the first 40 days coupled with no decreases at lower depths indicated that the changes resulted largely from infiltration rather than upward movement. Data from three other years suggested the same thing (Sartz 1969).

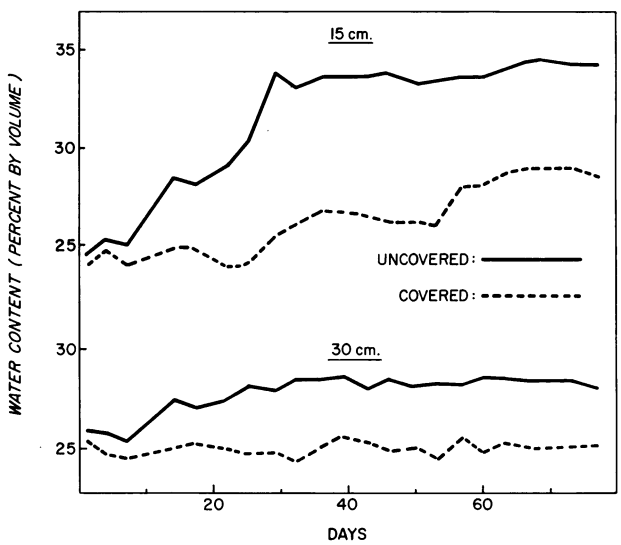

Figure 1. — Soil water changes at two depths on covered and uncovered plots in silt loam during soil freezing period, 1967-68.

However, in one instance I found what clearly appeared to be upward movement. Data from six tubes at two different sites indicated that water had moved from the 30-cm. zone to the 15-cm. zone. The change took place during a 2-week period in which frost penetrated from 2 cm. to 15 cm. (fig. 2). There was no rainfall or snowmelt during the period. The maximum change in soil water was 5 percent or 8 mm. in the 15-cm. layer. Some water may also have moved from the 45- to the 30-cm. zone, but this movement was less pronounced. The downward trend shown at the 45-cm. depth may have been simply a continuing percolation loss, and the upward trend at the 30-cm. depth may have been an infiltration gain, as indicated by the 15-cm. plotting (fig. 2). This example illustrates one of the difficulties in interpreting changes in the distribution of water in frozen soils.

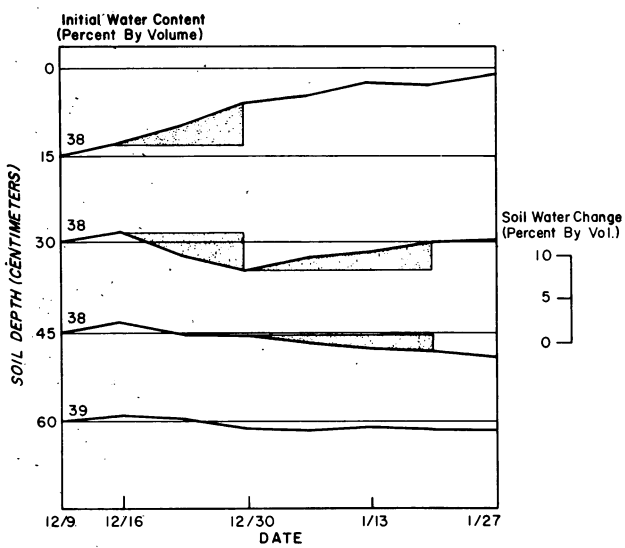

Figure 2. — Soil water changes at successive 15-cm. depths, silt loam, southeast slope — December 9, 1963, to January 27, 1964. Shading indicates probable translocation.

Even more puzzling are increases that cannot be explained by either infiltration or upward movement. Such increases occurred several times on both sloping and relatively level land. The most interesting example took place in a silt loam soil during a thaw in March 1964, when one of three plots on a southeast slope showed a 60-mm. gain in water during a 2-day period (fig. 3). The ground was bare of snow on March 2, and only 13 mm. of rain fell before the plots were remeasured on March 4. Although water content increased at all levels on one plot, only small

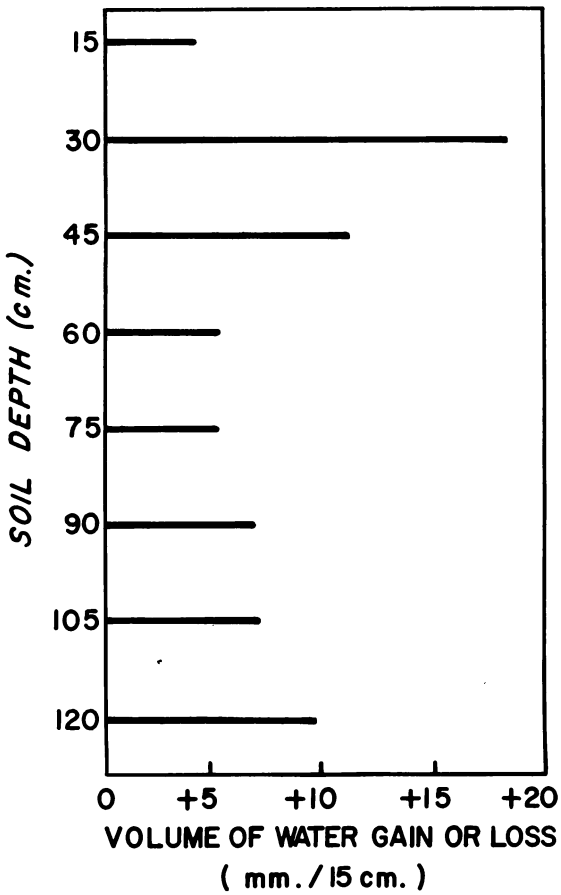

Figure 3. — Net change in soil water on silt loam Plot 3, southeast slope — March 2-4, 1964.

changes were found on the other two, and these could have resulted from instrument error. The differences are surprising because cover and slope were the same, and the access tubes were only 3 m. apart. Although penetrometer measurements showed bonded frost between depths of 8 and 30 cm. on the site, resistance blocks and thermistors installed near each access tube did indicate faster thaw on Plot 3. However, this could have been either a cause or an effect of the greater water movement on the plot. Whatever the reason, the example shows that large differences in water can occur over small distances in frozen soils.

Where the water came from is a good question. I ruled out translocation from a water table as suggested by Benz *et al.* (1968) because of depth to the water table (at least 5 m.) and the short time involved. Upward movement from unsaturated soil below the zone measured also seemed unlikely. That left interflow as the only reasonable explanation.

Conclusions

What actually takes place when natural soil profiles freeze and thaw is still something of a mystery. Because of the possibility of both gains and losses at the same depth from infiltration, percolation or thermal movement, interpreting changes in the water content of frozen soils is at best a subjective process. Low temperature and soil freezing *per se* had no apparent effect on neutron probe readings, but variation in the depth and density of frozen soil within a sampling unit increased the normal experimental error in measuring the distribution of soil water. A better understanding of how and why water moves in frozen soil is needed before we can interpret neutron probe readings with confidence.

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