Freeze-Thaw Cycles in Indiana Soils

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Introduction

The freezing and thawing of water in soils have both detrimental and beneficial effects. The development of potholes in streets and highways are familiar to everyone. Newman (1967) measured the heaving of cylindrical fence posts caused by freezing and thawing of soil water. Detrimental agricultural effects are the heaving of winter cover crops and increases in the soil erosion potential. Beneficial agricultural effects of soil freezing and thawing include decreasing soil compaction and breaking down limestone and aggregate fertilizer materials for faster availability for plant growth.

For these and other uses, soil temperature records for Indiana were used to determine the probabilities of various numbers of freeze-thaw cycles in northern, central and southern portions of the state.

Data and Procedures

Published daily soil temperature data (USDC, 1965-1980) for selected depths under a bare soil surface were used to compute the number of freeze-thaw cycles for three locations in Indiana: Purdue Agronomy Farm, West Lafayette 6 NW; Southern Indiana Purdue Agricultural Center, Dubois; and Pinney-Purdue Agricultural Center, Wanatah 2 WNW. Soil temperatures at 2.5 cm—the shallowest and most active freeze-thaw layer in which temperatures were measured—were used at all three locations. In addition, soil temperatures for the 10-, 20-, and 50-cm depths were also analyzed for West Lafayette 6 NW, the station with the longest record. All locations had slopes of 0°, but the soil types varied: Toronto silt loam (Udollic Ochraqualf, fine-silty, mixed, mesic) at West Lafayette 6NW; Zanesville silt loam (Typic Fragiudalf, fine silty, mixed mesic) at Dubois; and both Edwards muck (Limnic Medisaprist, marly, euic, mesic) and Tracy sandy loam (Ultic hapludalf, course-loamy, mixed, mesic) at Wanatah 2 WNW.

The time periods used to tabulate the number of freeze-thaw cycles were not identical for all locations, since some data were missing and some were suspect. A 15-year period (fall 1965 to spring 1980) was used for West Lafayette 6NW, excluding the 1966-1967 and 1967-1968 seasons for the 10-cm soil depth. A 13-year period (fall 1965 to spring 1978) was used for Dubois, and an 11-year period (fall 1967 to spring 1980) was used for Wanatah, deleting the 1974-1975 and 1976-1977 seasons.

Soil maximum and minimum temperatures were measured with a Palmer dial-type thermometer. The Palmer soil thermometers are calibrated twice a year (spring and fall) and have an accuracy of ± 0.5°C. An exposure time of about 10 minutes is required for accurate registration of a maximum or minimum temperature. Proper placement of the soil probe is essential for accurate readings. Errors occasionally are caused by soil erosion or heaving, which effectively change the depth of the thermometer, and soil cracking in dry weather, which may expose part of the sensor.

Freeze-thaw cycles were computed from temperature data in the following manner. A thaw, T, was defined as a temperature greater than OC and a freeze, F, was defined as a temperature less than or equal to OC. Each season initially began with a T. Each pass from T to F, or F to T was considered a half-cycle, with a full cycle being two half cycles. Since the observations were taken at 0800 EST, the soil temperature was assumed to progress from the maximum temperature of observational day 1 to the minimum temperature of observation day 1 to the maximum temperature of observational day 2 and to the minimum temperature of observational day 2.

F-T frequencies were compiled within climatological weeks, March 1-7 being week 1 and Feburary 21-27 as week 52. F-T cycles for February 28 and 29 were included with seasonal totals. The weekly mean numbers of F-T cycles were determined by summing the number of cycles within climatological weeks over all years. The number of F-T cycles expected at the 20, 50, and 80% probability levels were estimated by the relation, $\frac{m}{n+1}$ where m was the rank of the number of F-T cycles in ascending order, and n was the number of years of record.

Results and Discussion

The number of freeze-thaw cycles at the 2.5-cm soil depth for each winter for the four soil-locations—West Lafayette, Dubois, Wanatah-sand, and Wanatah-muck—is shown in FIGURE 1.

Generally, West Lafayette had the greatest number of freeze-thaw cycles at the 2.5-cm depth per season, $\overline{X}$ = 44.3 cycles/season and with a maximum of 80 in the 1974-75 season (FIGURE 1). Wanatah had an intermediate number of cycles, $\overline{X}$ sand = 31.1 and $\overline{X}$ muck = 21.6. Dubois had the lowest average number of cycles per season, $\overline{X}$ = 11.2, and there were no soil temperatures OC or below during the 1973-74 and 1974-75 seasons. The absence of freeze-thaw cycles at the

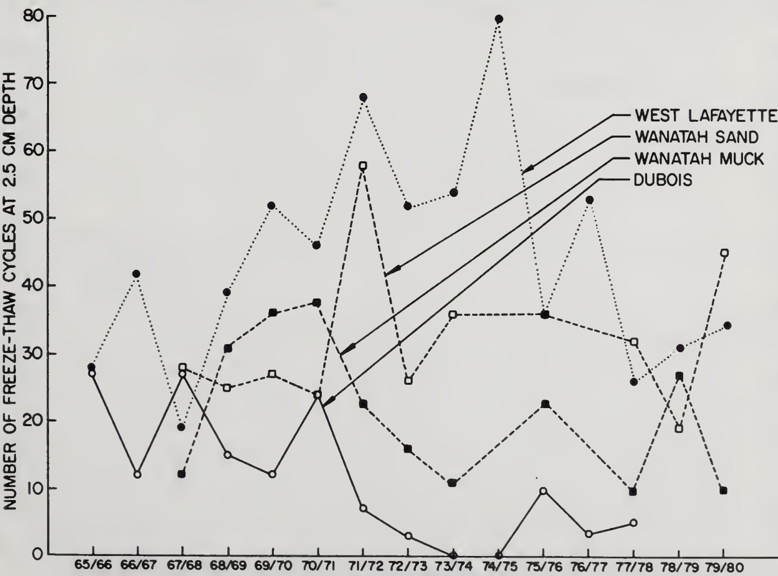

FIGURE 1. *Number of freeze-thaw cycles at 2.5-cm depth under bare soil surface for indicated season at Dubois and West Lafayette 6NW, and sand and muck soils at Wanatah 2WNW, Indiana.*

Dubois 2.5-cm soil depth in these two seasons was unusual. The records were checked to see if possibly the Palmer dial-type thermometers were out of calibration. The 2.5-cm temperatures appeared consistent with those at 5 and 10 cm. Apparently, the soil did not freeze at any depth in the several periods during which air temperatures were below OC in those seasons, because of high soil moisture, occasional snow cover, and upward soil heat flux. Central Indiana tends to have more freeze-thaw cycles at 2.5 cm than either northern or southern Indiana where soil temperatures tend to remain at or below OC and above OC, respectively.

The observed differences in average number of soil freeze-thaw cycles are caused not only by the geographic location of the station, but also by the natural drainage, physical, and chemical composition of the soil at each station, as shown by the frequencies for the two locations at Wanatah. The sandy soil had a greater mean number of freeze-thaw cycles than did the muck soil. Because muck retains more water than sand, the muck soil has a higher conductive capacity than the sandy soil, which decreases the soil temperature fluctuations as well as the number of freeze-thaw cycles.

The variation in the number of freeze-thaw cycles from year-to-year was caused by the different weather regimes. The number of freeze-thaw cycles usually decreased as the mean winter temperature decreased at West Lafayette. This was observed in the 77-78 winter which was unusually cold. The minimum number of F-T cycles at the 2.5-cm depth for West Lafayette occurred in the 67-68 season (19) and the maximum number occurred in the 74-75 season (80), a relatively mild winter.

At West Lafayette 6NW, the number of freeze-thaw cycles for each winter season are shown also for the 10-, 20-, and 50-cm depths in FIGURE 2. Every season

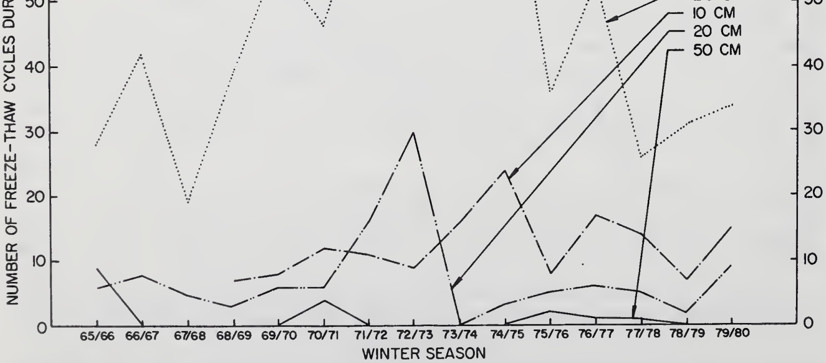

FIGURE 2. *Number of freeze-thaw cycles at the indicated depths under a bare soil surface for indicated season at West Lafayette 6NW, Indiana.*

the number of cycles was considerably greater for the 2.5-cm depth than for any of the other depths. For example, in the 1976-1977 season there were a total of 53 freeze-thaw cycles at the 2.5-cm depth, 17 at 10 cm, 6 at 20 cm, and only 1 cycle at the 50-cm depth. The maximum number of cycles at 20 cm (30 in the 1972-1973 season) was greater than that at 10 cm (24 in 1974-1975). This and the greater number of freeze-thaw cycles at 20 cm than at 10 cm in the 1971-1972 and 1972-1973 winter seasons indicate the OC isotherm was oscillating near the 20-cm depth. The mean seasonal number of freeze-thaw cycles at the 10-cm depth was 12.5, at 20 cm 7.3, and at 50 cm 1.1.

The total number of days with OC or lower for each season and depth are shown for West Lafayette 6NW in FIGURE 3. The shallower depths had more days with OC or below. The greatest number of freeze days (69) at the 50-cm depth occurred during the cold winter of 1976-1977, but in most winters the freezing level remained above the 50-cm depth, and in one season, 1973-1974, above the 20-cm depth. The fewer number of freezing days at greater depths results from the upward soil heat flux and the blanketing effect of the top soil layers and, occasionally, snow cover.

The first and last dates of soil freezing are shown for each season and depth at West Lafayette 6 NW in FIGURE 4. The earliest first freeze at the 2.5-cm depth was October 18, 1976, and the latest first freeze December 2, 1968. The earliest last freeze at the 2.5-cm depth was March 9, 1966, and the latest last freeze was April 14, 1973. The period of possible soil freezing decreases with greater soil depths.

The mean number and 80, 50, and 20 percent probabilities of having the indicated number or fewer freeze-thaw cycles in each week are shown in FIGURE 5 for the 2.5-, 10-, and 20-cm soil depths at West Lafayette 6NW. There is a distinct bimodal pattern with the first maximum occurring in the late fall and early winter

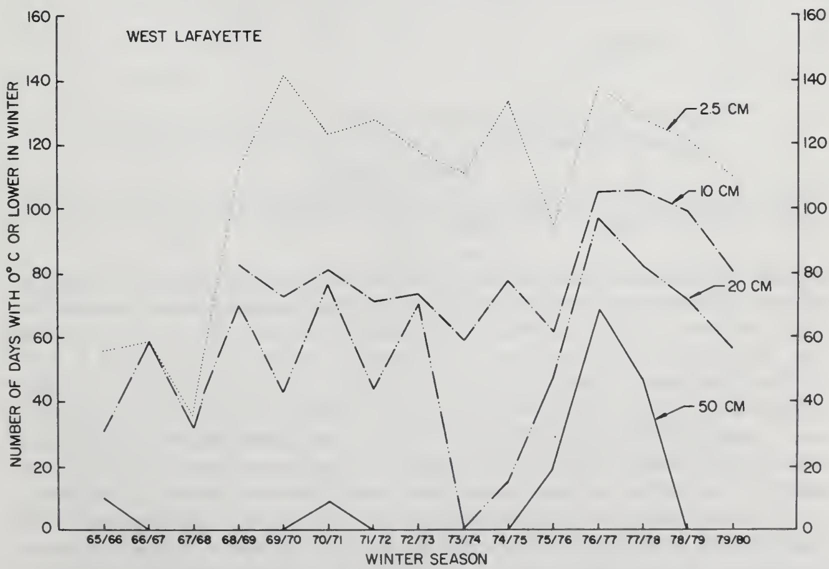

FIGURE 3. *Number of days with soil temperatures OC or lower at the indicated depth for each season at West Lafayette 6NW, Indiana.*

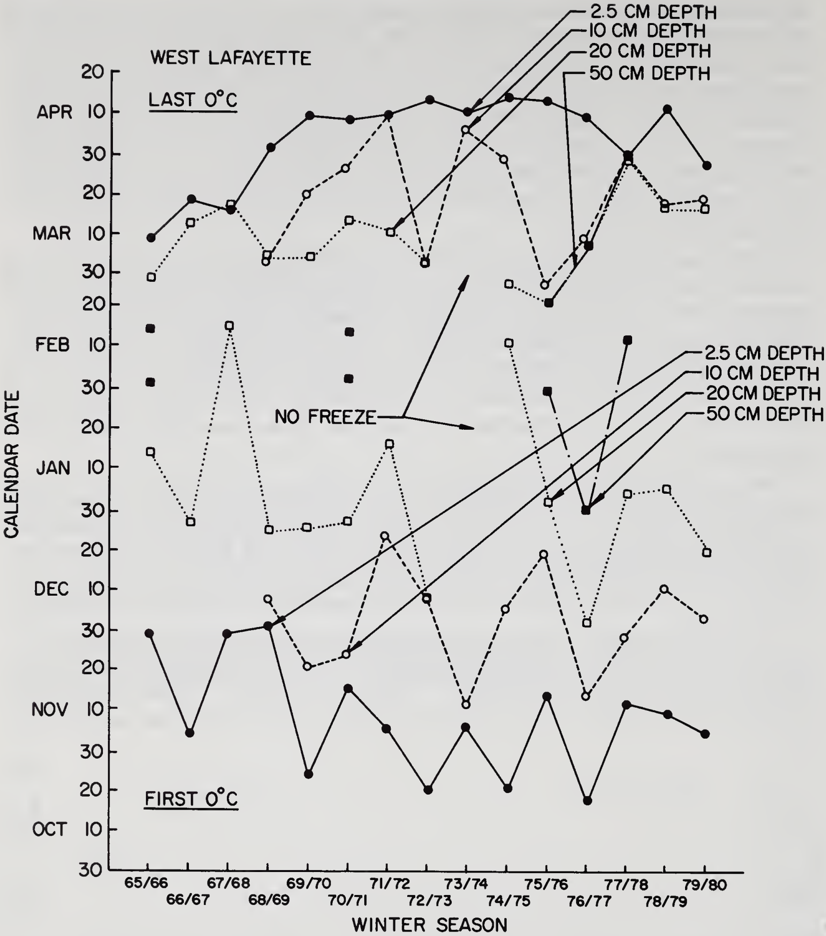

FIGURE 4. *First and last dates of soil freezing at the indicated depth for each season at West Lafayette 6NW, Indiana.*

and the second maximum in the late winter and early spring. For example, at the 2.5-cm depth there was an 80% probability of having 5 or fewer cycles within each of the weeks ending November 14 to Dec. 5, 3 or fewer cycles in each week ending Dec. 12 to Feb. 13, and 6 or fewer cycles during the weeks ending Feb. 27 to Apr. 14. The 2.5-cm weekly means peaked at 2.7 cycles in the week ending Dec. 5, and at 3.9 cycles in the week ending Feb. 27. The means were less than 1.5 cycles from the week ending Dec. 6 to that ending Feb. 13. Note that for the skewed distributions, bounded at 0 and 7 cycles in each week, the means were above the 50% probabilities for all but the week ending Nov. 28. The curves for the 10- and 20-cm depths in FIGURE 5 showed a lower number of F-T cycles with increasing depth. The highest 10-cm weekly mean occurred in the week ending Mar. 7 (1.7). Other means generally were less than 1.0 cycle per week. The 10-cm 80% probability showed 3 or less cycles occurred for the weeks ending Feb. 27 through Mar. 21, and also for the week ending Jan. 9. The frequency of freeze-thaw cycles decreases with in-

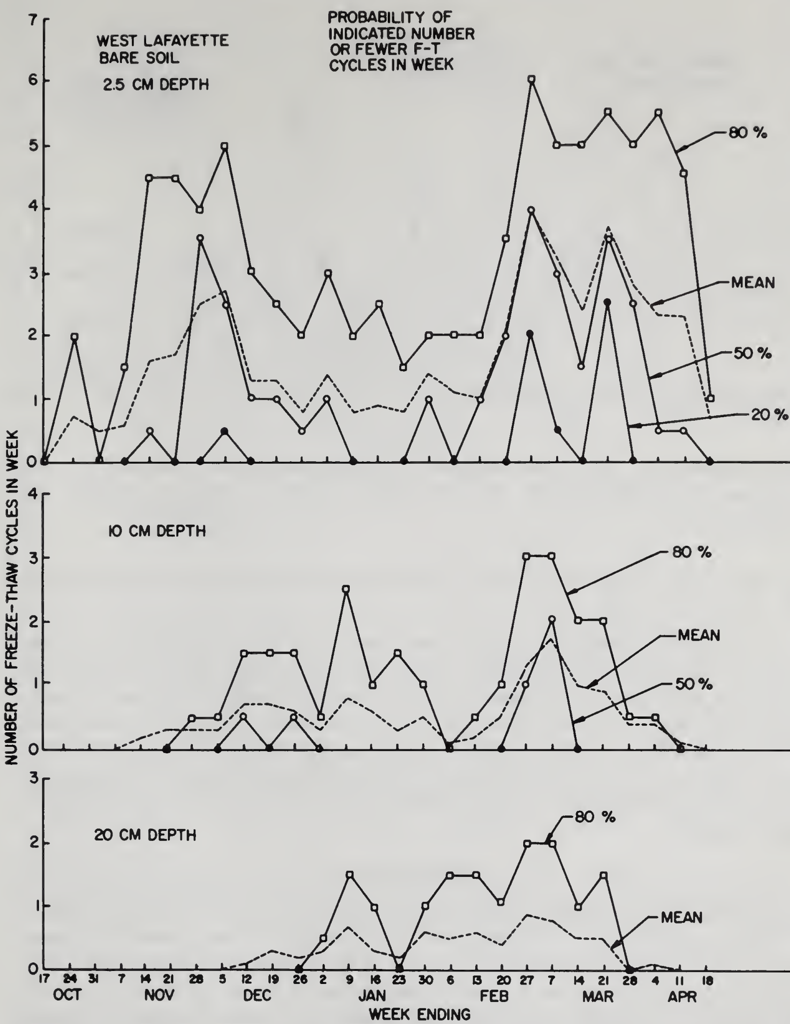

FIGURE 5. *Weekly mean and number of freeze-thaw cycles at 80-, 50-, and 20-percent probability levels at indicated depth for West Lafayette 6NW, Indiana, fall 1965-spring 1980, less 1966-67 and 1967-68 seasons.*

creasing depth. All 20-cm weekly means were less than 1 cycle per week, again a result of the insulating effect of top soil and, occasionally, snow cover.

The weekly mean and the probabilities of the number of freeze-thaw cycles for each week at the 2.5-cm soil depth are shown in FIGURE 6 for Dubois. Two sharp peaks are visible for the 80% probability, one for 5 or less cycles per week in the week ending Jan. 2, and the other for 4.5 cycles or less in the week ending Feb. 27. The mean number of weekly freeze-thaw cycles was less than 1.5 for all weeks at the 2.5 cm depth, with the exception of 2 cycles or less in the week ending Jan. 2. The minimum number of freeze-thaw cycles occurred the first week of February.

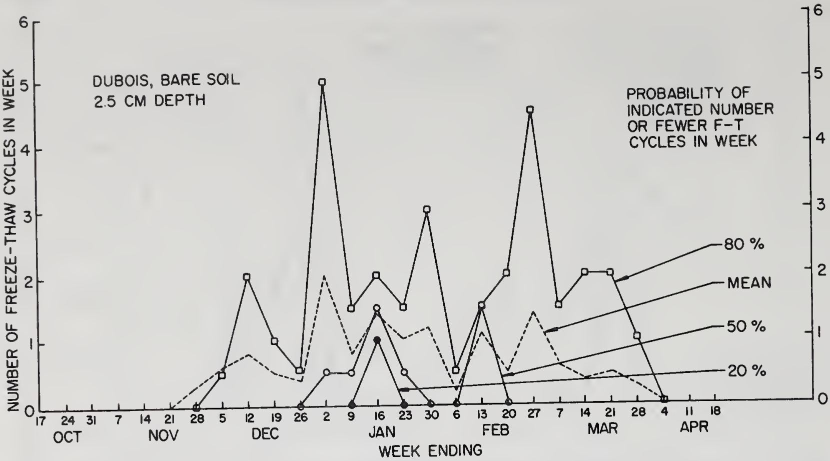

FIGURE 6. *Weekly mean and number of freeze-thaw cycles at 80-, 50-, and 20-percent probability levels for the 2.5-cm depth at Dubois, Indiana, fall 1965-spring 1978.*

This reflects the tendency for the 2.5-cm soil depth usually to be frozen by this date.

The weekly probabilities and F-T cycle means for Wanatah 2WNW are shown in FIGURE 7 for the sandy and muck soils at the 2.5-cm depth. Both the sandy and muck soils show distinct bimodal patterns, and the sandy soil generally had a higher probability of freeze-thaw cycles. At the muck site the weekly means were highest in the spring with 3.2 cycles or less for each of the weeks ending Feb. 27 to Apr. 11, and with 1.0 or less cycles in the remaining weeks. There were less freeze-thaw cycles per week in November and December than in the spring months at the muck soil site.

Summary

Freezing and thawing processes in the soil have both beneficial and detrimental effects in agriculture. To determine the probability of the number of freeze-thaw cycles at selected depths for bare soil, soil temperature records were summarized for the occurrences of OC at three locations in Indiana,—West Lafayette 6NW, Dubois Indiana Forage Farm, and Wanatah 2WNW—for the 2.5-cm soil depth at all three locations, also for and/the 10-, 20-, and 50-cm depths at West Lafayette 6NW. At Wanatah, freeze-thaw cycles were summed for both a muck and a sandy soil. West Lafayette, the most centrally located site, had the highest seasonal mean number of freeze-thaw cycles at the 2.5-cm soil depth, averaging 44.3 cycles/season with a maximum of 80 in the 1974-75 winter. Dubois, the southern-most site, had the lowest average, 11.2, and there were no occurrences in the 1973-74 and 74-75 seasons. At West Lafayette the average first freeze at 2.5 cm was Nov. 8 and the average last freeze Apr. 3. The mean number of freeze-thaw cycles and the 80, 50, and 20 percent probabilities of numbers of freeze-thaw cycles for each week were presented for all sites. The probabilities showed a strong bimodal pattern, with peaks in the fall and early spring. The mean and probability peaks for freeze-thaw cycles in the spring months (late Feb. Mar. and Apr.) are higher than the peaks in the fall (Nov. and Dec.).

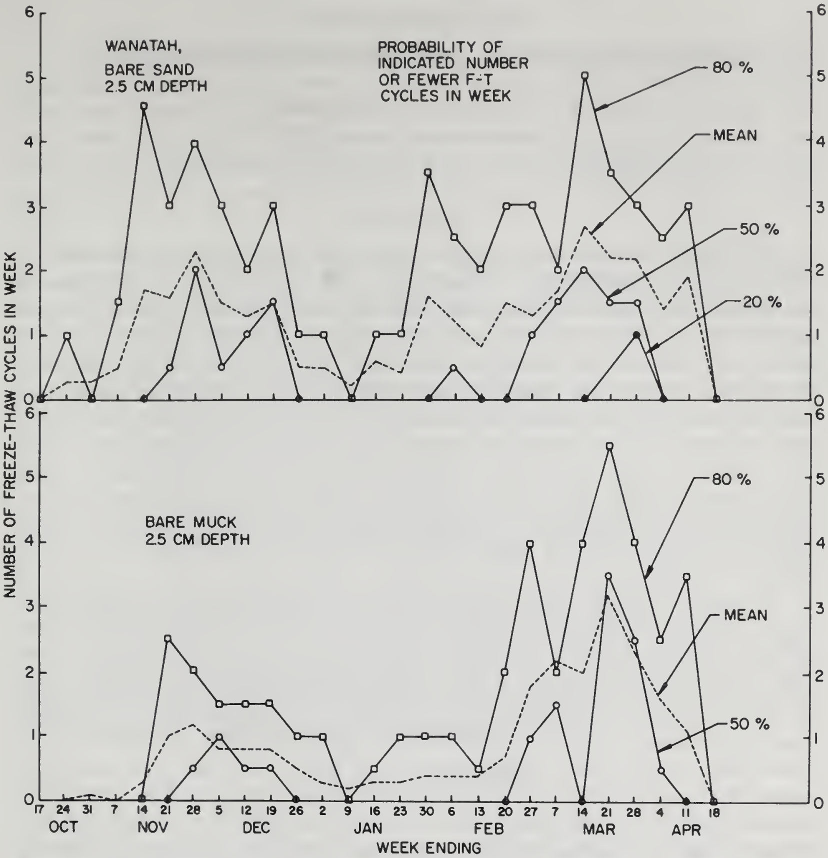

FIGURE 7. *Weekly mean and number of freeze-thaw cycles at 80-, 50-, and 20-percent probability levels for the 2.5-cm depth in sand and muck soils at Wanatah 2WNW, Indiana, fall 1967-spring 1980, less 1974-75 and 1976-77 seasons.*

The climatology of soil freeze-thaw cycles, shown here for three stations in Indiana, can be used for any number of applications in agriculture and engineering.

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