Frost Tillage for Soil Management in the Northeastern USA[†]

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Abstract

Tillage during the winter is typically considered impossible, despite its desirability in some cases. Soil freezing results in net upward movement of water to the freezing zone which facilitates primary tillage or incorporation of amendments. These can be performed during a time window when the frost layer is sufficiently thin to be ripped and the underlying soil is tillable. We evaluated the feasibility of frost tillage and performed an agronomic comparison with spring-tilled soil. Soil conditions conducive to frost tillage occurred during three time windows in the 1991/1992 and two in the 1992/1993 winter at Ithaca, NY. Frost tillage resulted in a rough soil surface, even after thawing, thereby presumably facilitating water infiltration. Soil drying was improved in the spring of 1992, but not in 1993 after a very wet period had caused soil settling. Residue cover was greater with frost tillage in 1993 compared to spring tillage. Yields were similar in both 1992 and 1993. Frost tillage may be an attractive management option to shift fall and spring field work (primary tillage or manure application/injection) to the winter. In addition, winter manure incorporation may reduce spring runoff losses.

Introduction

In the Northern U.S. and Canada, tillage during the winter seldom occurs due to frozen or excessively wet soil conditions. Tillage may nevertheless be desirable to minimize the workload in fall or spring, improve water infiltration (1), improve the beneficial effects of freeze-thaw cycles (2), and to incorporate animal manures or other amendments.

Several winter thaw and freeze periods may occur in areas of the Northern U.S., depending on location and weather conditions (temperature, snow depth, etc.). The early work of Bouyoucos and McCool (3) suggested that soil freezing causes upward movement of water to the freezing zone. In unsaturated soils, this process is referred to as freezing-induced water redistribution (4). This process is generated by changes in the water potential gradient resulting from a lowering of the pore water pressure in the freezing zone, which in turn is correlated with unstable air-ice interfaces when pore water freezes (5). The accumulation of ice in the frozen zone occurs concurrently with water extraction from the unfrozen layer below. Much of the research effort related to soil freezing has focused on the conditions in the freezing zone (e.g. 6, 7), especially as it relates to the formation of ice lenses. However, the freezing process may also significantly alter soil conditions below the frozen zone in that the soil may become sufficiently dry to be worked.

Frost tillage (the term is introduced here for lack of a previous reference) is a primary tillage practice which is performed when a frozen layer exists at the surface and the underlying soil is tillable. The frozen layer needs to be sufficiently thick to support field equipment, but still be thin enough to be readily ripped by a tillage tool. This is generally the case when this layer is between 50 and 100 mm thick. This study aimed at 1. determining the feasibility of tilling soil when frozen and the soil conditions that allow the soil to be tilled, 2. observing the soil surface and soil water characteristics after frost tillage, and 3. evaluating the response of maize (*Zea mays* L.) to frost-tilled soil. Although not discussed here, soil conditions that facilitate frost tillage also allow for other practices, such as injection of chemicals, manures, and wastes.

Materials and Methods

This study was conducted at the Caldwell Field Research Farm at Cornell University in Ithaca, NY (42°25'N, 76°30'W) on a Williamson silt loam soil (Typic Fragiochrept, coarse-silty, mixed, mesic). Prior to this study, the site had been used for corn silage production. During the 1991/1992 and 1992/1993 winters, the field was monitored for the occurrence of soil conditions that are conducive to frost tillage by determining whether the frost layer was between 50 and 100 mm thick, the underlying layer was tillable, surface snow accumulation was negligible, and surface soil conditions provided for adequate traction.

Frost tillage to a depth of approximately 0.2 m was performed on 4 March, 1992 and 2 January, 1993 using a two-rank chisel implement with twisted (1992) and straight (1993) points at 0.3 m spacing. Treatments were assigned to plots in a spatially-balanced complete block design (7) using six replicates. The plots were harrowed (1992) and disked (1993) in the spring prior to corn planting. As a comparison treatment, adjacent plots were spring chisel tilled with identical secondary tillage and planting as the frost-tilled plots.

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During the 1991/1992 winter, soil water content was determined gravimetrically from the 0 to 50, 100 to 150, and 200 to 250-mm depths. Soil samples were obtained during the period 6 January through 4 March at times when the frost depth was shallow enough to allow for sampling. After frost tillage in 1992, soil water pressure was measured at the 0.10- and 0.30-m depths using tensiometers. This was continued until the soil had dried sufficiently for secondary tillage and planting. Precipitation, snow depth, and maximal and minimal temperatures were measured at a nearby (1 km) weather station. Corn grain yields were determined in 1992 and 1993. Crop residue cover was determined on 6 July, 1993 by determining the fraction of 0.1-m spaced points overlying residue material on ten 6-m transects per plot ("point and line" method).

Results and Discussion

Occurrence of Frost Tillage Condition

Since the initiation of soil monitoring on 5 January 1992, frost tillage conditions occurred on 4-5 January, 29-30 January and 3-4 March, 1992. Frost tillage was only performed at the latter time. During the next winter, frost tillage conditions occurred on 24-26 December, 1992 and 26-27 January, 1993 with tillage being done during the latter time window. Typically, frost tillage conditions persisted for only 2 days, and always occurred when a thaw period was followed by 2 to 3 days of freezing without significant snowfall. The frost tillage window was typically terminated by extension of the frozen zone beyond 100 mm. In one instance, it was terminated by above-zero daytime temperatures causing supersaturated and slippery surface conditions.

Frost tillage conditions appeared predictable for the short term. If soil was unfrozen, these conditions could be anticipated based on three-day weather forecasts. In January 1993, soil freezing was initiated immediately after significant rain in near-saturated soil, but still provided for tillable conditions after two days of frost. Frost tillable conditions were easily verified by digging through the frozen layer and evaluating the consistence of the underlying layer. It appears from this study that these conditions may occur several times per winter under the Ithaca, NY climate. It is presumed that frost tillage windows are less opportune in colder climates (less number of thaw and freeze periods) and areas with greater snow accumulation, but may occur more frequently in regions with slightly warmer climate. In addition, the occurrence of frost tillage conditions at any location may vary among years. During the 1993/94 winter, these conditions occurred only once in Ithaca, NY (17 and 18 December).

Soil Water Redistribution

In 1992, freezing-induced water redistribution resulted in wide fluctuations in soil water content, especially near the soil surface (Fig. 1). Frost tillage conditions existed on Day of Year (DOY) 4 when measurements were initiated. Soil water contents (as water or ice) in the 0 to 50-mm surface layer were at least 0.10 g g^{-1} greater than in the underlying layers. This relationship reversed during the subsequent thaw period (DOY 15) to be followed again by increased water content during the subsequent 12-day period of below-freezing temperatures and little snow depth. The soil was tillable on DOY 29 and 30, followed by a 17-day period in which the frost layer and/or snow accumulation were too deep. The soil thawed again after DOY 48, resulting in a decrease in water content of the surface layer. Several cold nights after DOY 59 resulted in upward water movement and frost-tillable soil conditions on DOY 62 and 63. It is noted that soil water fluctuations in Fig. 1 are not solely the result of freezing-induced potential gradients, but may at times also have been caused by snowmelt infiltration.

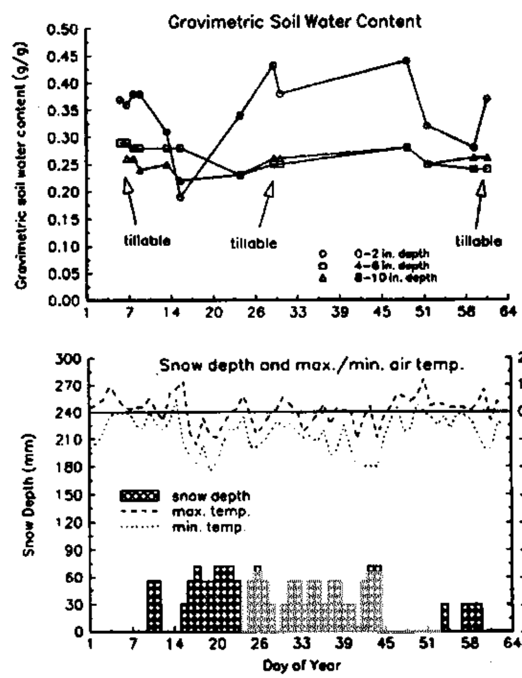

Fig. 1. Soil water content at three depths, min/max air temperatures, and snow depth during early 1992, before frost tillage.

Soil Surface Conditions

Frost tillage resulted in a rough soil surface consisting of randomly cast plates of frozen soil of up to 0.4 m length and 0.1 m thickness which typically showed distinguishable accumulations of ice (Fig. 2). The underlying unfrozen soil was disturbed in a manner similar to conventional tillage. The extremely rough soil surface was maintained until a thaw period occurred. In 1992, this occurred soon after frost tillage and resulted in the collapse of the frozen plates, leaving a loose, but still rough surface. In 1993, the tops of frozen plates became freeze-dried during the weeks after tillage, but collapsed when melt occurred after record snowfall. In both years, the soil surface after thaw was adequately rough to provide for an estimated 20 to 30- mm surface water storage capacity, resulting is visibly less runoff compared to untilled plots (no measurements were made). Based on observations from another site, it is presumed that soil surface roughness after melt remains greater on soils with greater structural stability, thereby more effectively reducing spring runoff.

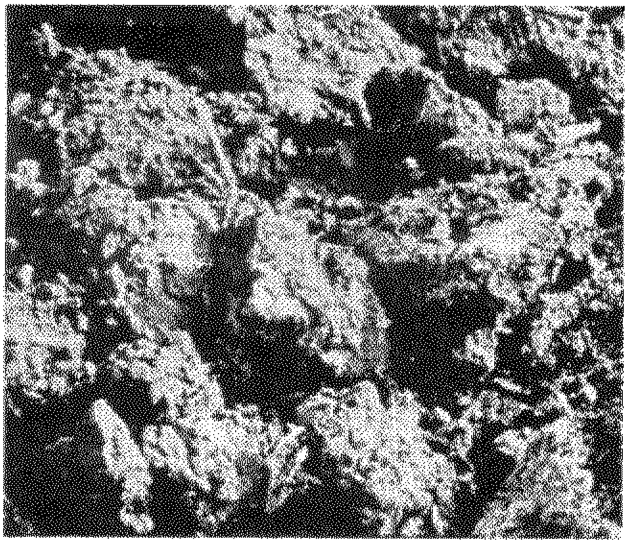

Fig. 2. Frost-tilled soil (frozen plates are 0.2 to 0.4-m wide).

Residue cover in July, 1993 was greater for the frost tillage (31.3%) than for the spring tillage treatment (25.5%; $p < 0.05$). This is attributed to less residue burial during primary tillage. Frost tillage may facilitate compliance to federal soil conservation programs, although the actual benefits of frost tillage for erosion control are unknown. Compared to spring tillage, the frost tilled soil surface may aid surface storage and infiltration during critical early-spring periods, but looser (more detachable) soil may aggravate erosion once runoff is initiated, depending on soil erodibility. Frost tillage may be an attractive alternative to fall tillage which generally results in high erosion rates.

Maize grain yields were not different among the tillage treatments in 1992 and 1993 (7.93 and 7.57 Mg ha^{-1}, respectively for frost tillage and 7.79 and 7.18 Mg ha^{-1}, respectively for spring tillage; $p > 0.1$). This indicates no adverse effect of frost tillage on crop yields.

Conclusions

Freezing-induced water redistribution generates soil conditions which may allow for tillage during the late-fall, winter and early-spring, depending on weather conditions. Results show that frost tillage is feasible and may be an attractive management option for the following reasons. 1. It shifts spring or fall workloads to the winter. This may be especially advantageous for early season crops when a wet fall or spring delays tillage. In addition, frost-tilled land may often dry faster in the spring than untilled soil. 2. Frost tillage allows for incorporation of winter-applied manure which reduces runoff losses during snowmelt and rain on frozen or saturated soil. It also provides for a time window to apply and incorporate/inject stored manure or organic wastes. This reduces spring field work delays as well as odor nuisance due to decreased volatilization potential and less outdoor activity of neighbors during low air temperatures.

Potential disadvantages of frost tillage are increased power requirements (estimated at 20%) and lack of seasonal predictability of the occurrence of frost tillage conditions. The effects of frost tillage on erosion are unknown and will likely vary by soil type. It is presumed that increased surface roughness and residue cover offset increased soil detachability during critical early spring periods. In this study, frost tillage was performed using a chisel tillage tool. Although no comparisons were made with other implements, shank-type tillage tools appear most effective for this practice.

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