Influence of Long-Term No-Tillage on the Physical Properties of an Ultisol

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Introduction

No-tillage cultivation offers significant advantages over conventional tillage in terms of water, energy, and particularly soil conservation (Francis et al., 1987). However, continuous no-tillage farming on sandy Ultisols may lead to high bulk density that has a pronounced effect on soil strength due to traffic compaction and lack of plowing (NeSmith et al., 1987). This increase in soil strength under no-till cultivation might have a significant effect on root distribution. On sandy loam soils with good soil structure, greater root density has been reported in no-till as compared to conventional systems (Francis et al., 1987). In contrast, on structurally unstable soils, the presence of a high-strength, root-impeding layer can lead to proliferation of roots above this layer resulting in a greater root density in the top soil of plowed than in no-till soils (Francis et al., 1987).

Infiltration of rainfall into the soil is important, both in supplying water to the root zone and in preventing excessive erosion due to high runoff volumes. In the southeastern United States, infiltration rates on bare soils are typically low, due to crusting of the highly weathered, poorly structured soils (Miller and Bahruddin, 1986). However, infiltration of water into these soils is usually higher under no-tillage than in conventional tillage (Hargrove, 1985).

The objective of this paper is to examine the effect of long-term continuous no-tillage on physical properties, with emphasis on the effect of no-tillage on infiltrability of these soils.

Methods and Materials

The long-term tillage experiment was established in the fall of 1974 on a Cecil sandy loam (clayey, kaolinitic, thermic Typic Hapludult) in Georgia, and consisted of three tillage treatments, replicated four times in a winter wheat-soybean doublecropping system. The fall/spring tillage treatments were as follows: moldboard plow and disk/moldboard plow and disk (CT, conventional tillage); moldboard plow and disk/no-tillage (MT, minimum tillage); and no-tillagelno-tillage (NT, no-tillage). Details of the experimental design and management may be found in Hargrove et al. (1982).

On July 18 and 19, 1985, cone index was measured using a tractor-mounted, hydraulically driven cone penetrometer (Clark and Reid, 1984). The instrument measured mean cone index in one-inch depth increments to 24 inches below the soil surface. Five measurements were made along a transect in each treatment at 15-inch intervals starting where the tractor wheel passed during planting in the spring of 1985. Soil water content was measured gravimetrically by sampling randomly from inter-row and in-row positions, in 6-inch depth increments to 30 inches below the surface.

Sprinkler infiltration measurements (Peterson and Bubenzer, 1986) were conducted during the summer of 1987. A square metal enclosure with dimensions the same as row width (30 inches) was used. Water was applied for one hour and any runoff that accumulated at the downslope end of the enclosure was pumped off and the amount recorded during alternate minutes. Two measurements were made in each CT and NT plot; one with a straw cover and one without. Before these measurements, the surface of the plowed soil was raked to destroy any crust that might have been present. In the NT plots, for the uncovered measurements, the straw was removed by hand, the surface was raked and the top 0.8 inch of soil and fine organic litter was removed so that the mineral soil was exposed. The surface was then raked. In the CT plots, the bare soil measurements were made after raking the surface. For the covered run, the surface was raked and straw (4,635 Ib/acre) was added. A sprinkling rate of 2.8 inches per hour was used to rain on the enclosure.

Single-ring infiltration measurements (Bouwer, 1986) were conducted during April and May of 1988. Thirty-eight-inch diameter cylinders were pressed into the soil to successive depths of 2, 4, and 8 inches in NT and 4, 8, and 12 inches in CT. At each depth, infiltration rate was measured over a 2-hour period, which was sufficient to attain a constant rate. Care was taken not to disturb the surface in NT so that any macropores that were present would not be plugged. The surface of the CT plots was raked before making the measurements to remove any crust that was present. Two sets of measurements were made in each plot.

Results

Soil Strength

Soil water content measured at the same time cone index was measured was not significantly different between tillage

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treatments (data not shown). Statistical analysis indicated that cone index was significantly affected bytillage and row position (in-row, non-traffic between row, or traffic between row). Tillage had a significant effect on cone index in the row and non-traffic between row positions, but not in the traffic position. In the row position (Figure l), cone index was low in CT and MT above 10 inches, but in NT there was a high strength zone at 10 inches. Cone index exceeded 40 bars at the center of the high strength zone in NT, well above the 20 to 30-bar range that is reported to prevent root growth (Taylor and Gardner, 1963; Taylor and Burnett, 1964). The compacted zone in NT may have been due to traffic or it may have been an old tillage pan. The low organic matter content and expanding clay minerals in these soils, combined with a shallow depth of freezing during winter may have allowed a compacted layer, once formed, to presist for many years (Elkins et al., 1983).

Sprinkler Infiltration

The first set of sprinkler infiltration measurements conducted in July, 1987, showed that infiltration was higher in NT (Figure 2). Using a sprinkling rate of 1.6 inches per hour, runoff occurred in only one of four replicated NT plots, producing a mean final infiltration rate (infiltration rate after 60 minutes of sprinkling) of 1.45 inches per hour for NT compared to 0.63 inch per hour for CT. At this point, it was not clear whether the difference in infiltration was due to the presence of large macropores in NT or a surface crust in CCT. To determine if surface crusting was responsible for the low infiltration rate in CT, the second set of infiltration measurements was made in August 1987.

Infiltration was sharply reduced in NT when the mineral soil was exposed to raindrop impact (Figure 3). The final infiltration rate of NT without cover (0.03 inch per hour) was

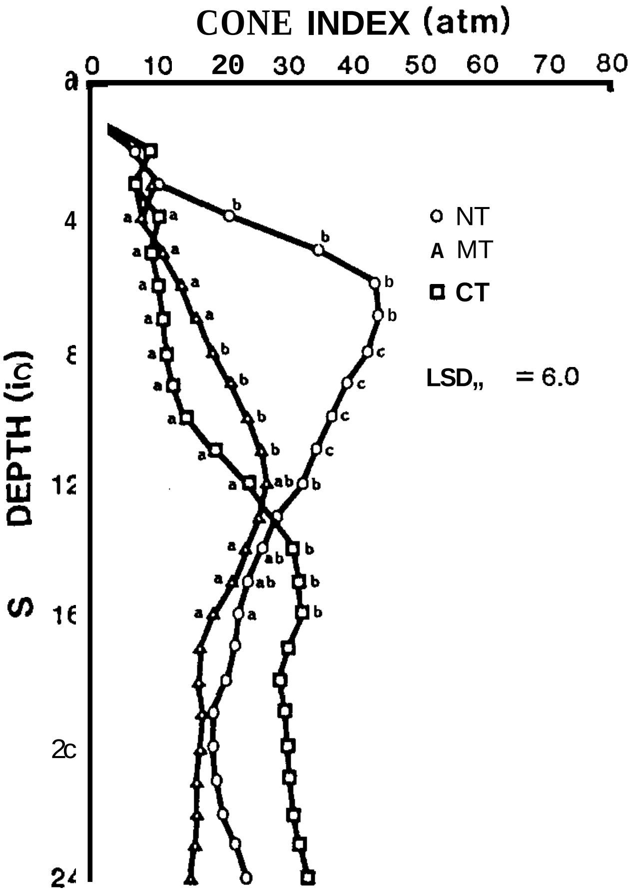

Figure 1. Cone index with soil depth for three tillage treatments measured on July 18 and 19, 1985 (NT = no-till; MT = minimum till; C T = conventional till).

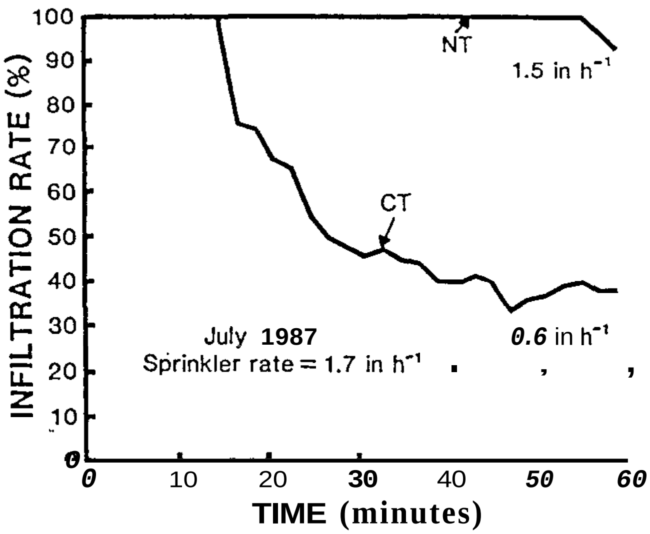

Figure 2. Infiltration measured by sprinkler infiltrometer for the no-till (NT) and conventional till (CT) treatments.

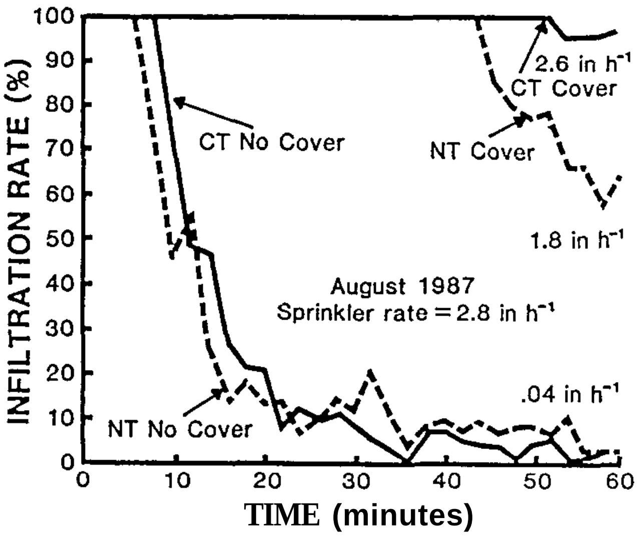

Figure 3. Infiltration measured by sprinkler infiltrometer for no-till (NT) and conventional till (CT) treatments with and without surface mulch.

identical to that of CT without cover. Statistical analysis showed that cover was significant factor in controlling the rate of infiltration. Adding a surface mulch to CT increased infiltration to the point that runoff was minimal after one hour with a sprinkling rate of 2.75 inches per hour. These results indicate that a surface crust rapidly developed when the mineral soil was exposed to raindrop impact. The final infiltration rate (0.03 inch per hour) in CT without cover was lower that observed in the earlier measurements (0.63 inch per hour). This was because the higher sprinkling rate was more effective in producing a crust.

The surfaces of all the treatments in the later measurements were raked before starting the sprinkler, so we were not measuring the effect of a crust that was already in place in this study. A straw mulch at a rate of 4,462 pounds per acre was sufficient to prevent the formation of a crust, as shown in the CT with cover treatment. The surface layer of fine organic litter may also be sufficient to prevent crusting from raindrop impact. In preliminary measurements, we did not see a drop in infiltration in NT if we removed the straw mulch, but did not remove the top 0.8 inch of organic litter and soil. The decrease in infiltration in NT with cover after about 45 minutes may indicate that sufficient water had been applied at this point (about 2.08 inches) for the compacted zone in NT to impede infiltration.

Single-Ring Infiltration

Rooting measurements in this experiment had shown that vigorous subsoil root growth occurred in NT, in spite of the hardpan at 4-10 inches (Hargrove et al., these proceedings). To determine if macropores had developed in NT that allowed roots to grow through the hardpan, we measured infiltration rate with cylinder infiltrometers.

It was apparent from our measurements that a cylinder infiltrometer overestimated infiltration unless the ring is driven to the depth of the least permeable horizon. In NT, the final infiltration rate (infiltration rate after approximately 2 hours) was much higher at a depth of 2 inches compared to 4 and 8 inches (Table 1). With the ring driven into the soil to a depth of 2 inches, most of the water entering the soil moved laterally when it encountered the hardpan starting at about 4 inches (Figure 1). The fact that there was little difference in infiltration rate between 4 and 8 inches in NT, indicated that lateral movement of water ceased once the cylinder extended to 4 inches. In CT where the hardpan occurred at a deeper depth (Figure 1), driving the rings into the soil to 8 inches was not sufficient to eliminate lateral movement as indicated by the drop in infiltration rate when the rings were lowered to 12 inches (Table 1).

The measurements also indicated that macropores had developed through the hardpan in NT. Infiltration rates at the 8-inch depth were not significantly different between tillage treatments (Table 1) in spite of the higher cone index at this depth in NT (Figure 1). The coefficient of variation in CT was remarkably constant with depth, but in NT, there was a sharp increase in variation once the rings extended to the hardpan. The higher coefficient of variation at the depth of the hardpan in NT is evidenced that macropores provide a low impedance pathway through the pan for water movement and root growth.

Not only were the final infiltration rates variable in NT, but infiltration rates during the 2-hour measurement period were less steady. In about one-third of the subplot comparisons between NT and CT, the infiltration rate at 4 or 8 inches in NT increased sharply for short intervals (Figure 4a). This did not occur in CT (Figure 4b). We believe that this was caused by macropores in NT that were not continuous to the surface. These pores could not fill until matric potential at the depth where the pore began, rose to a level where water could enter the pore. When this happened, infiltration rate increased sharply. The higher infiltration rate drained the soil so that matric potential fell below the critical value for the pore to fill and the infiltration rate decreased again.

Table 1. Single-ring final infiltration rates and coefficients of variation as a function of depth and tillage.

Ring installation depth (inches)	Infiltration rate (inches/hr)		Coefficient of variation (%)	
	NT	CT	NT	CT
2	5.47		41.7	
4	1.73	6.49**	119.8	52.7
8	1.78	1.02	87.6	56.3
12		0.35		58.6

****Significant difference between tillage treatments at 0.01 level of probability.**

Conclusions

It has been suggested that the full beneficial effect of NT may not be evident until several years after establishment in the Southeast (Hargrove et al., 1982). Our results show that the higher infiltration rate in NT is largely an effect of a surface mulch. Therefore, one would not expect to see the full extent of improved infiltration until surface residue cover approaches 100 percent on a continuous basis, a process that may take several years in this region. Macropore development may also be a process that enhances productivity of NT in the long term.

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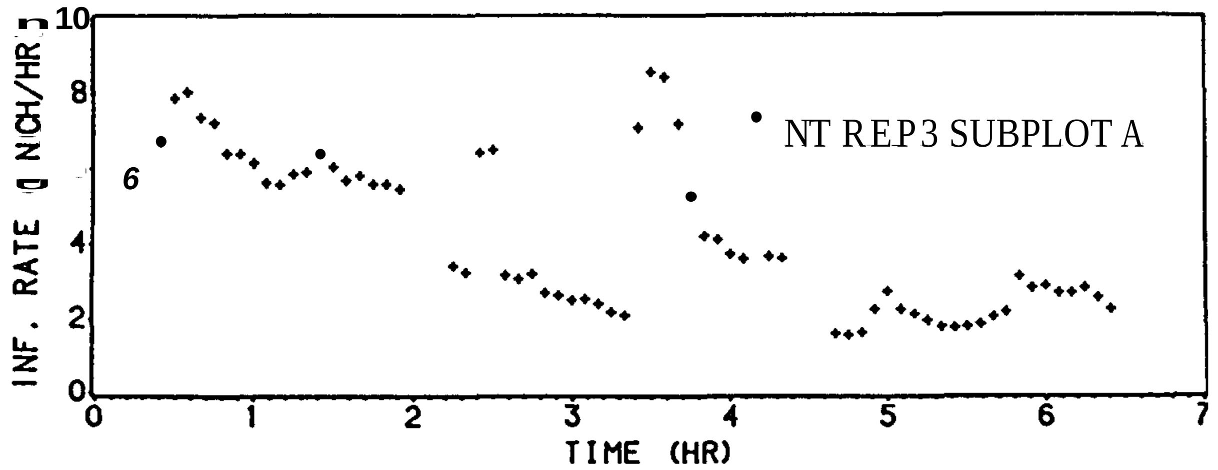

Figure 4a. Cylinder infiltration rate during 2-hour periods at successive ring depths of 2, 4, and 8 inches in NT rep 3, subplot A.

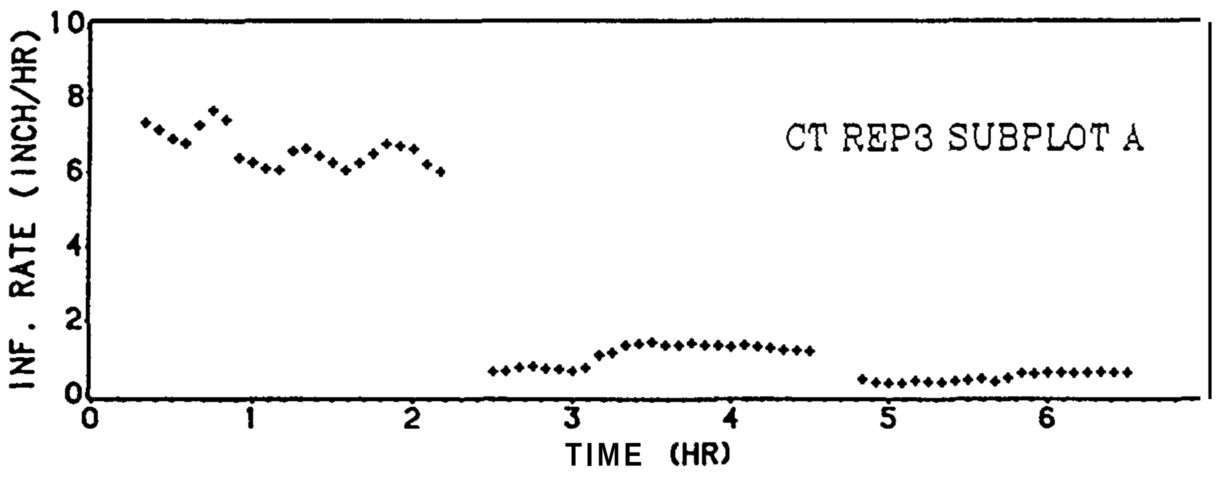

Figure 4b. Cylinder infiltration rate during 2-hour periods at successive ring depths of 4, 8, and I2 inches in CT, rep 3, subplot A.