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EFFECT OF NO-TILL FARMING ON SOIL WATER INTAKE

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Rainfall simulation and ponded infiltrometer methods were used to investigate the infiltration characteristics of no-till vs. conventional tillage farms. Seven pairs of no-till and conventional till farms under a corn-soybean rotation were selected on soils ranging from sandy loam to silty clay loams. The relative importance of surface residue and macroporosity (number of earthworms and middens) in both tillage systems was evaluated through the use of three different infiltration measurement techniques, and by the removal or addition of surface residue. The results of the ponded infiltration tests indicate that on the silt loam and silty clay loam soils, no-till farms had higher infiltration rates than those of conventional farms when earthworm activity and/or residue amount were higher in the no-till farms. On sandy loam soil, when earthworm activities were similar for both no-till and conventional farms, conventional farms had higher infiltration rates than the no-till farms. Under simulated rainfall, placing residue cover on the conventional plots generally increased final infiltration rates for silt loam and silty clay loam soils. Furthermore, in the absence of plant residues, the no-till farms had equal and/or significantly higher infiltration rates than the corresponding conventional farms on the sites with silt loam and silty clay loam soils. As was the case with ponding infiltration, the terminal infiltration rate for the no-till farm was less with the rainfall simulator than for the conventional farm, at the site with sandy loam soil.

INTRODUCTION

Knowledge of water infiltration under different farming systems is important, because water infiltration greatly influences root zone soil water content, runoff, and erosion. Reduced soil erosion from tillage systems which leave crop residue on the soil surface has been demonstrated by several researchers (Laflen and Colvin, 1981). However, literature on the effect of no-till systems on soil water intake rate and runoff show inconclusive results. Baker and Laflen (1983) reported that the observed effectiveness of no-till for conserving soil and water varies significantly. Runoff from no-till plots was reported to be as great as runoff from conventional tillage plots (Siemens and Oschwald, 1978; Laflen and Colvin, 1981). Lindstrom et al. (1981) reported that infiltration rates for no-till systems are less than those for tilled systems. The influence of different tillage systems on soil physical parameters and infiltration planting was studied by Lindstrom and Onstad (1984) on a site with Barnes loam soil. They reported that the no-till system forms a surface condition characterized by high bulk density, high penetrometer resistance, low saturated hydraulic conductivity, and low volume of macropores. Lindstrom and Onstad (1984) concluded that although much research has shown reduction of runoff (increased infiltration) and erosion due to no-till farming, no-till cannot be expected to be effective at all locations.

Several researchers have reported increases in infiltration and reduction in runoff due to no-till practices. Edwards et al. (1990) studied long-term runoff records of different watersheds at Coshocton, Ohio. They reported that infiltration could increase by more than 100 mm/yr in a watershed farmed with no-till practices as compared to similar fields that were conventionally tilled. They concluded that soil physical properties, possibly macropores due to earthworm activities, caused the increase in infiltration. Meek et al. (1990) reported that structural changes and the development of continuous channels due to no-tillage have been shown to be an important factor in increasing infiltration rates.

Increased earthworm activity has been found by several researchers to be the main reason for increases in infiltration in no-till systems. Conservation tillage practices are reported to be the main reason for increases in earthworm populations in cropland (De St. Remy and Daynard, 1982; Derpsch et al., 1986). Earthworm activity in conservation tillage row crop farms with higher volumes of crop residues should be greater than under more conventional tillage systems. This is because residue cover provides: 1) a food resource for earthworms; 2) insulation during winter; and 3) a more conducive surface habitat (Mackay and Kladivko, 1985). Ehlers (1975) reported that the residue cover left on soil in no-till systems serves as a food source for surface feeding large earthworms such as *Lumbricus terrestris.* These large worms typically make vertical burrows to a depth of 2 m, with a burrow diameter of 3-10 mm (Edwards et al., 1990). Macroporous infiltration and soil water redistribution as affected by earthworms, tillage, and residue were studied by Zachmann et al. (1987). They reported that burrows produced by two species of earthworms (*Aporrectodea tuberculata* and *Lumbricus rubellus)* over a 46-day period increased average infiltration rate by 30 mm of water, relative to control plots. They concluded that surface residues more than doubled the number of burrows open to the surface relative to incorporated residues. Ehlers (1975) reported a six-fold increase in infiltration rate due to worm holes in a no-till loess soil as compared to a plowed soil. A two- to three-fold increase in infiltration rates was reported by Kladivko et al. (1986) who studied the effect of earthworms on soil crusting and infiltration in the laboratory, and reported that earthworms increased the size and stability of soil aggregates. On the effect of crop residues on infiltration rate, they concluded that steady-state infiltration rate in soil to which crop residues had been added were increased eight- and fifteen-fold by activity of 15 and 30 earthworms per 16 L plots, respectively. They further concluded that surface soil crusting from simulated rainfall was greatly reduced in soils where earthworms had been active.

To date, no experiments with rainfall and ponding have been carried out to study the effect of no-tillage systems on infiltration rates in farm fields with different soil textures. The objectives of this study are: (a) to evaluate the infiltration characteristics of no-till vs. conventional tillage systems in different farms in Indiana and Illinois, and (b) to study the relative importance of surface residues and subsurface macroporosity on infiltration rates for both tillage systems using simulated rainfall and a ponding infiltrometer method.

METHOD AND MATERIALS

Study sites

Six pairs of no-till and conventional farms in Indiana and one conventional and two no-till farms in Illinois were selected for this study (Figure 1). The criteria for selecting the paired sites were: 1) all the sites should be under a corn-soybean rotation with present crop to be corn; 2) the two fields within each paired site should have the same soil (texture and series); and 3) different paired sites should be located on different soils (texture and series). Table 1 contains soil information from each of the sites studied. Figure 2 shows various kinds of settings for the experimentation.

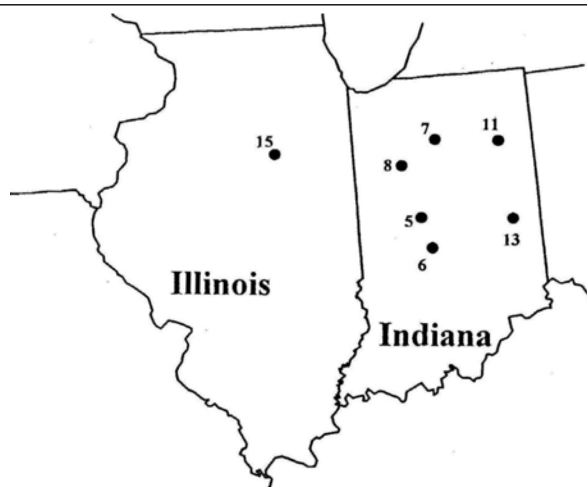

Figure 1. Infiltration measurement sites in Illinois and Indiana, USA.

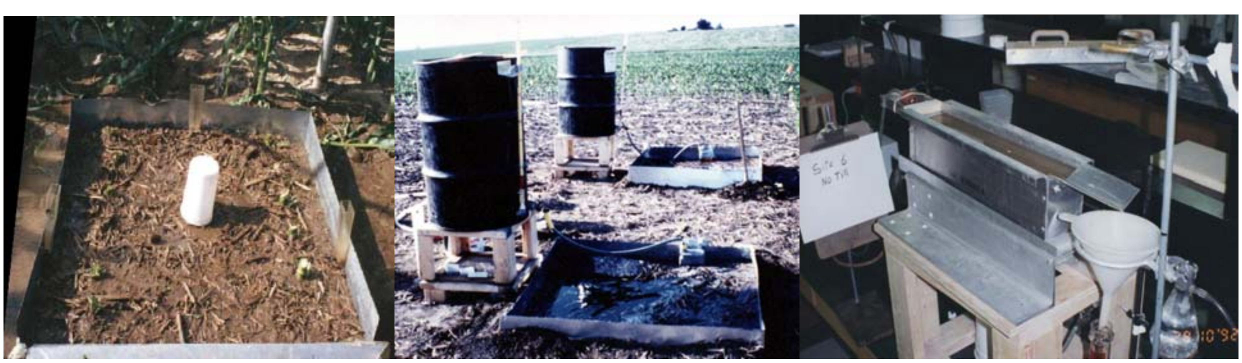

Figure 2. Infiltration plots under the rainfall simulator in Indiana corn farm (left); Ponding infiltration test on a farm in Illinois (middle). Measuring infiltration rate using the laboratory flume method (right).

Table 1. Infiltration sites selected for this study.

Site	Soil Series	Soil texture	Years under no-till
15	Saybrook	Silt loam	17
13	Treaty	Silty clay loam	8
11	Pewano	Silty clay loam	6
8	Martin	Silt loam	2
7	Owoasso	Sandy loam	6
6	Fincastle	Silt loam	7
5	Crosby	Silty clay loam	10

Infiltration measurements

Sprinkler rainfall simulation, ponded infiltrometer, and laboratory flume methods were used to measure infiltration characteristics of different paired sites during June-August of 1992. These methods are discussed in the following section.

Sprinkler rainfall simulation

The sprinkler rainfall simulator used in this study was designed after Shelton et al. (1985), Miller (1987) and Tossell et al. (1987) (Figure 3). The simulator utilizes the Spraying System, full circle spray 25 SS nozzles. The nozzles are threaded into a solenoid valve, which opens when electrically energized. The simulated rain intensity was controlled by varying the duration of valve opening. The opening period of the valves was controlled by a programmable control timer. Calibration results indicated that a rainfall intensity of 100 mm/hr could be simulated with a nozzle opening time of 1/2 sec, closing time of 1 sec, and the water pressure at the nozzle set to 15 PSI. The relative erosivity of the simulator is about 70 percent of natural rainfall.

On each field, four small plots (1.22 m^2 each) were contained by plot borders and a runoff collection trough (Figure 2, left). The corn plants were clipped before the rainfall simulation test. On each paired site, the surface residues of two of the plots on the no-till farm were collected, weighed and placed on two of the plots in the conventional field. The crust on the conventional plots

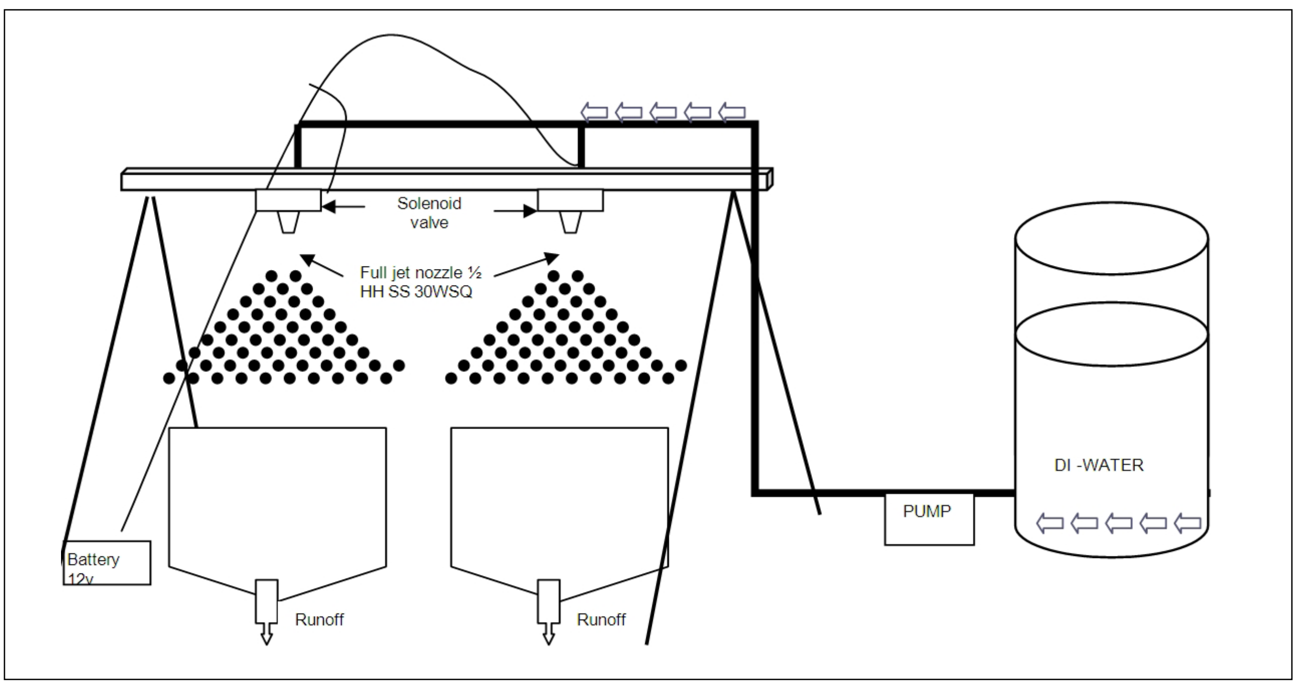

Figure 3. Rainfall simulator setup.

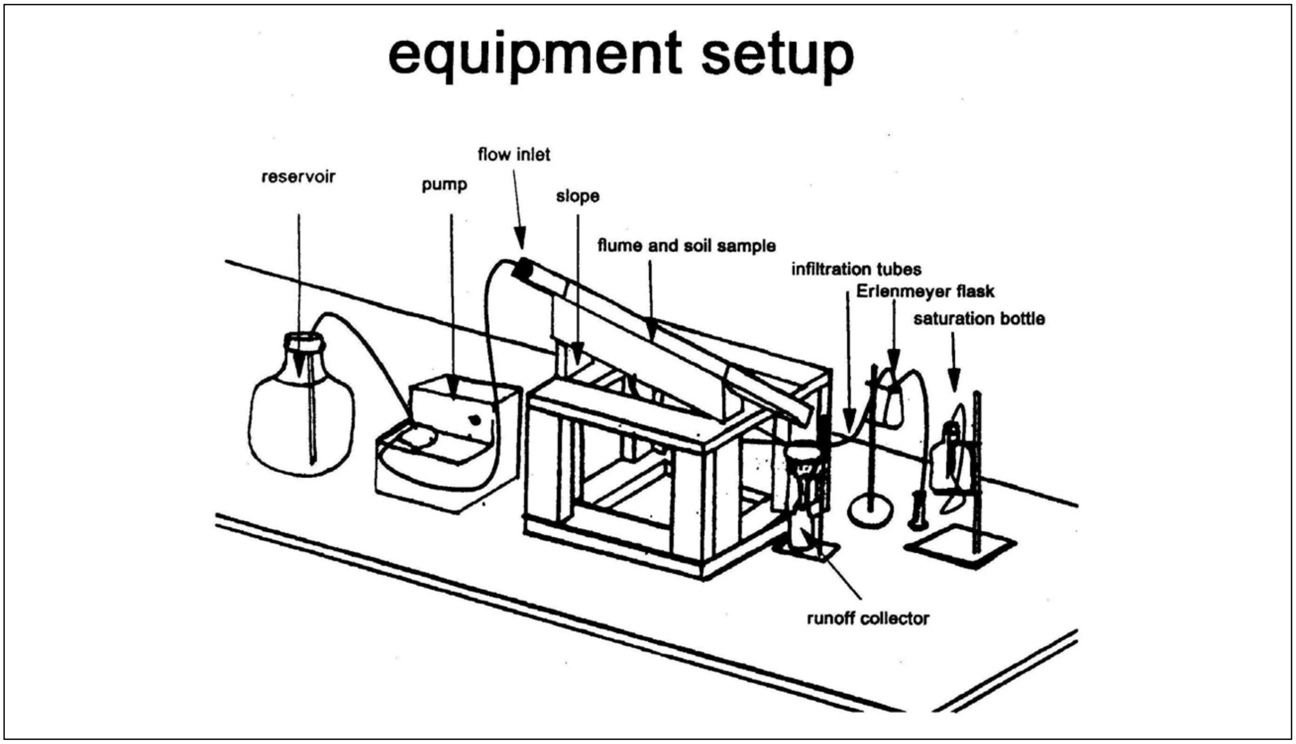

Figure 4. Laboratory flume setup

was broken by a garden rake before placing the residue. Rainfall simulation of about 100 mm/hr was conducted on paired sites 7, 11, and 15. The plots were pre-wetted by simulating a rainfall of 100 mm/hr for 1 hr one day prior to the infiltration test. Rainfall and runoff were monitored during the rainfall simulations. On all the sites, deionized water was used to prevent possible chemical reaction between simulated rain water and the soil surface due to using water with different qualities. Infiltration rates were obtained by subtracting runoff rate from the simulated rainfall rate. Infiltration rates at the end of 1 hr of the simulated rainfall will be referred to as terminal infiltration rate (f_s), reflecting the rate of infiltration into the soil matrix and flow into macropores. Comparisons of f_s indicate the effects of residue cover and/or crusting.

In addition to the infiltration measurements, soil bulk density, soil organic matter, soil water content before rainfall simulation, mass of residue on the soil surface, percent residue cover on the soil surface, and number of earthworms and middens (Kladivko et al., 1986) within a 25 cm depth of soil were measured on each site.

Ponding Infiltrometer

Ponding infiltration tests were conducted by adding enough water to a 1.22 m^2 plot to initiate a ponding depth of about 3 inches (Figure 2, middle). A float valve connected to a 55 gallon water reservoir was used to maintain a constant head of water in the plot. A graduated tube was mounted along the side of the water reservoir to measure the amount of water added for a given time, and was converted to mm/hr as the infiltration rate. The duration of each ponding infiltration test was about 3 hr. Three ponding tests were conducted on each of the no-till and conventional farms. The infiltration rate measured using the ponding method will be referred to as $f_{mm,}$ reflecting the infiltration into the soil matrix and flow into macropores.

Laboratory flume method

Surface soils (0-10 cm) from each farm (no-till and conventional tillage) were collected and

Table 2. Soil properties, ponding infiltration rates (f_{mm}), and soil matrix infiltration (f_m) of no-till and conventional tillage farms in IN and IL.

Site	Man. 1/	Sand %	Clay %	OM2/ %	BD3/ g/cm3	fmm4/ (pond.) mm/hr	fm5/ mm/hr	Worms #/m2 6/	Middens 7/
5	N	14.5	24.7	3.1	1.37	20.7	2.9	159	yes
5	C	10.2	36.5	1.6	1.26	5.5	3.4	103	no
6	N	16.9	12.5	2.1	1.45	5.2	1.5	58	yes
6	C	16.0	20.6	2.5	1.38	5.0	1.4	29	yes
7	N	60.3	8.0	1.4	1.45	18.7	9.1	41	no
7	C	68.5	6.0	1.4	1.44	25.8	16.5	39	no
8	N	32.9	12.3	2	1.43	5.7	5.5	2	no
8	C	37.6	13.1	1.3	1.22	5.4	6.2	16	no
11	N	18.6	27.4	2.5	1.37	8.9	2.0	168	yes
11	C	12.8	27.6	3.5	1.23	10.6	1.8	107	no
13	N	17.1	25.3	4.3	1.29	7.2	3.0	343	yes
13	C	11.3	27.0	4.5	1.27	6.0	1.5	35	no
15	Nc	4.5	25.6		1.22		2.5	---	---
15	Nb	5	23.4	4.0	1.23	46.8	2.4	259	yes
15	C	5.7	21.1	4.2	1.12	18.0	5.8	119	no

Note: 1/ N = no-till farm, C = conventional farm (for site 15, Nc is a no-till farm cropped with corn in the previous year, and Nb is a no-till farm cropped with beans in the previous year); 2/ OM = organic matter in the top 10 cm of soil; 3/ BD = bulk density of the top 10 cm of soil; 4/ f_{mm} = final ponding infiltration rates (average of at least 2 plots); 5/ f_{mm} = final infiltration rate of soil matrix; 6/ number of red worms; 7/ were middens present or not in the field. Ponding infiltration and earthworm measurements were not conducted on at site 15, a no-till farm cropped with corn in the previous year.

air-dried in the laboratory. The soil was later ground (<2 mm) and placed on a 5.5 cm x 55 cm flume (Figures 2, right, and 4). The soil was packed to obtain the bulk density which was measured from the field samples. The soil was saturated from below for 4 hr and then a known rate of water was added to the flume inlet. Runoff and drained water were measured every 3 min for 1 hr. The experiment was repeated three times for each farm soil. The results of these tests indicate the infiltration rate of the soil matrix (fm) in the absence of management effects (i.e. residue cover, crusting, and macroporosity).

RESULTS AND DISCUSSION

The results of soil textural analysis, soil bulk density, organic matter, ponding infiltration rate (f_{mm}), earthworm activities and matrix infiltration rate (f_m) are given in Table 2. The bulk density of the top 10 cm of the soil is slightly higher for the no-till farms than for the conventional tillage farms. The ponding infiltration rates (f_{mm}) of the no-till farms were higher than for the conventional farms on sites 5 and 15 which had silty clay loam and silt loam soils, respectively. For sites 5 and 15, organic matter content and/or earthworm activities were higher on the no-till farms than on the conventional farms, both of which may contribute to increased infiltration rate. The infiltration rate of the no-till farm was significantly less than that of the conventional farm on site 7 which had a sandy loam soil and had similar organic matter content, bulk density, and earthworm activities for both the no-till and conventional farms. The conventional field for site 7 had slightly greater sand content than the no-till field (68 vs. 60%) but it is doubtful that this small difference is enough to cause large infiltration differences.

The difference between f_m and f_{mm} is a good indication of the effect of macroporosity on infiltration, assuming validity of the ponding method to determine infiltration of water into the soil matrix and macroporosity. It should be noted that rock fragments on all sites were negligible. At site 15, the ponding infiltration rate (f_{mm}) is about 20 times greater than f_m on the no-till farm (46.8 vs. 2.4 mm/hr). However, on the conventional farm, the ponding infiltration rate (f_{mm}) is only about 3 times greater than the matrix infiltration f_m (18.0 vs. 5.8 mm/hr, Table 1). The earthworm activity was significantly higher on the no-till farm than on the conventional farm at site 15. On the other site that had significantly higher ponding infiltration rates on no-till than conventional (site 5), there was also a much greater rate of f_{mm} to f_m with no-till (20.7 vs. 2.9 mm/hr) than with conventional till (5.5 vs. 3.4 mm/hr), again suggesting a large increase in macroporosity with no-till practices. In contrast, the one site that had significantly lower ponded infiltration rates on no-till than on conventional farms (site 7), showed no real difference in f_{mm} to f_m ratios with the tillage system, suggesting that macroporosity either had not developed or was not important for infiltration on this sandy soil. This is consistent with other observations (Rawls et al., 1989) and modeling approaches (WEPP, Lane and Nearing, 1989), which assume that macropores are less important on sandy soils.

Three of the sites had large differences in the soil matrix infiltration rate (f_{mm}) between the soils from the no-till and conventional farms. In the absence of plant residues (on the soil surface or

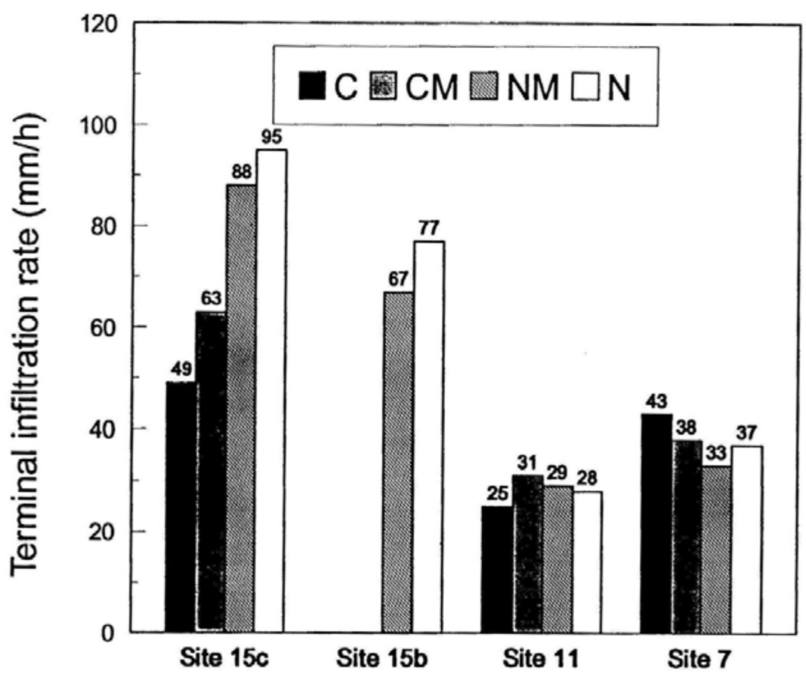

Figure 5. Average terminal infiltration rate under rainfall simulation of about 100 mm/hr, at different sites. C=conventional, CM=conventional plots with residue from the no-till plots, NM= no till plots with residue removed, N=no till plots with residue. The mass of residue was 1.1, 0.4, 0.1, and 0.2, kg/m2 on sites 15c, 15b, 11, and 7, respectively. The values represent the average of two plots.

incorporated), plant roots, macropores, and structure as found in the field, infiltration rate (f_m) was directly related to sand content and indirectly related to bulk density (BD)(Table 2). Site 7 had similar BD and organic matter (OM) values for no-till and conventional, but had lower sand content and matrix infiltration rate in the no-till. Site 13 also had similar BD and OM values for no-till and conventional, but had higher sand content and matrix infiltration with no-till. Site 15 had similar OM and sand contents under both tillage system, however no-till had higher BD and lower matrix infiltration. The limited number of comparisons do not permit broader generalizations, but the findings are within the expectations for texture and density effects on the infiltration process.

Infiltration measurements with the rainfall simulator reflect infiltration of water into the soil matrix, flow into macropores and the effects of residue cover and/or crusting on infiltration. However, infiltration rates under simulated rainfall exhibit the same pattern as the ponding infiltration tests (Figure 5). At site 15c, no-till plots with residues of 1.1 kg/m^2 had the highest terminal infiltration rates, followed by the no-till plot without residue, and conventional plots with 1.1 kg/m^2 residues from the no-till plots. The conventional farm, with a negligible amount of crop residues, had the lowest infiltration rates. Removal of the 1.1 kg/m^2 and 0.4 kg/m^2 residue mass from the no-till plots at sites 15c and 15b, respectively, resulted in formation of surface crust from the impact of raindrops, which reduced the terminal infiltration rate of the plots (95 vs. 88 mm/hr for site 15c and 77 vs. 67 mm/hr for site 15b). In contrast, placing surface residues on plots on the conventional farm at site 15c protected the soil from raindrop and crust formation, resulting in increased terminal infiltration on the conventional farm plots (49 vs. 63 mm/hr).

Regardless of the presence and/or absence of residues on the soil surface, plots on the no-till farms all had higher terminal infiltration rates than plots on the conventional farms (site 15c). At site 11, the average terminal infiltration rate on the no-till farm was slightly higher than for the conventional farm (28 vs. 25 mm/hr, Figure 5). Removal of the residues from no-till plots and placing them on the conventional plots had very little effect on the terminal infiltration rate. This may be due to the fact that the amount of residues on the no-till farm at site 11 was very little compared with site 15c (0.1 vs. 1.1 kg/m^2). In contrast, the one site that had lower average terminal infiltration rates on no-till farm than on conventional farm (site 7) showed a slight reduction of the terminal infiltration with placing of residue on the plots (Figure 5), suggesting that macroporosity either had not developed or was not important, and the 0.2 kg/m^2 residue had a slightly negative effect on terminal infiltration on this sandy soil (Figure 5). Average infiltration rate during the wet run is shown in Figure 6. No-till plots show slightly higher infiltration than conventional tillage plots.

SUMMARY AND CONCLUSIONS

Rainfall simulation and ponded infiltrometer methods were used to investigate the infiltration characteristics of no-till vs. conventional tillage farms. Seven pairs of no-till and conventional till farms under a corn-soybean rotation were selected on soils ranging from sandy loam to silty clay loams. The relative importance of surface residue and macroporosity (number of earthworms and middens) in both tillage systems was evaluated through the use of three different infiltration measurement techniques, and by the removal or addition of surface residue. The results of the ponded infiltration tests indicate that on the silt loam and silty clay loam soils, no-till farms had higher infiltration rates than those of conventional farms when earthworm activity and/or residue amounts were higher in the no-till farms. On the sandy loam soil, when earthworm activities were the same for the no-till and the conventional farms, conventional farms had higher infiltration rates

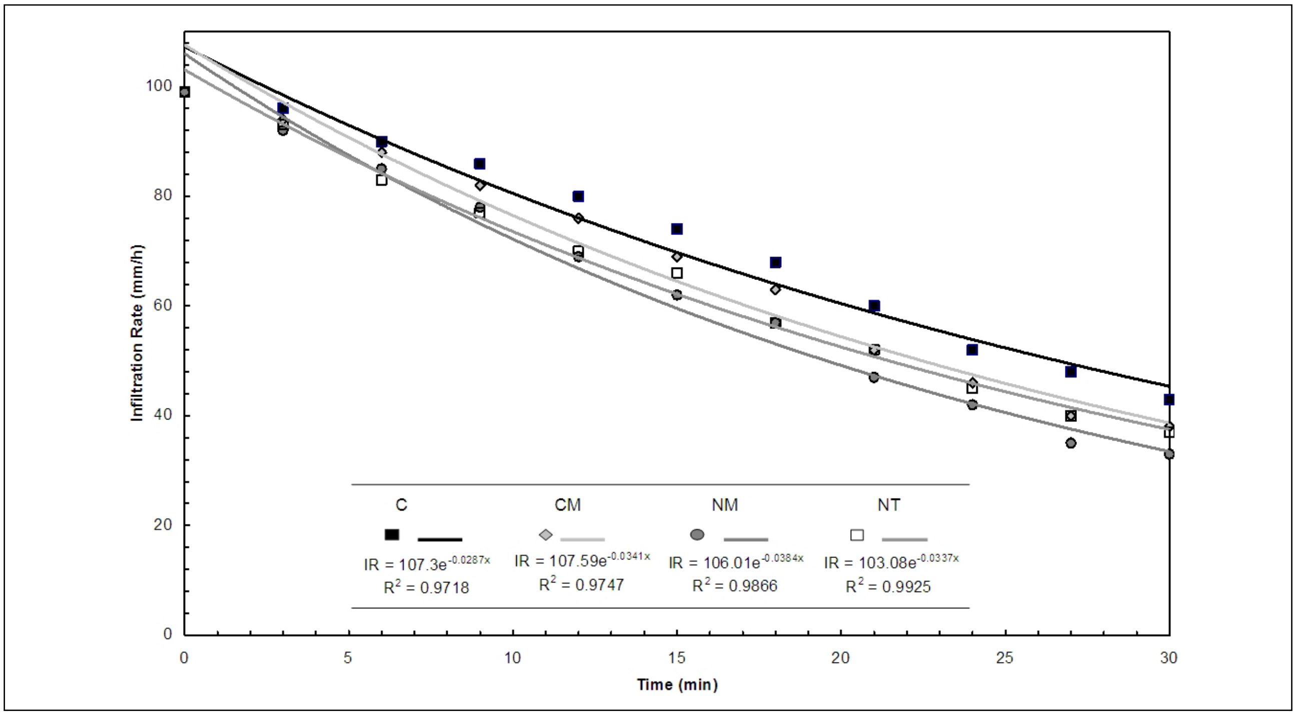

Figure 6. Average infiltration rate (IR) under rainfall simulation of about 100 mm/hr, at different sites. C=conventional, CM=conventional plots with residue from the no-till plots, NM= no till plots with residue removed, N=no till plots with residue.

than the no-till farms. Under simulated rainfall, placing residue cover on the conventional plots increased the final infiltration rate of the silt loam and silty clay loam soils. Furthermore, in the absence of plant residue, the no-till farms had equal and/or significantly higher infiltration rates than the corresponding conventional farms on the sites with silt loam and silty clay loam soils. As was the case with ponding infiltration, the terminal infiltration rate under the rainfall simulator for the no-till farm was less than for the conventional farm at the site with sandy loam soil. Based on our results the following conclusions can be drawn: 1) the effect of no-till farming practices on improving soil water intake rate depends on the soil texture, our results indicate that no-till farming enhances soil water intake of farms with silt loam and silty clay loam soils, while the soil water intake of farms with sandy loam soil was not affected; and 2) on the sites tested in this study, improvement of infiltration rate due to a no-till farming practice is directly related to earthworm activity and the amount of plant residues on the no-till farms.

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