TILLAGE AND RESIDUE EFFECTS ON INFILTRATION AND SEDIMENT LOSSES ON VERTISOLS

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ABSTRACT. *Management effects on water infiltration in vertisols is not well understood. Rainfall simulators and ponded and tension infiltrometers were used to characterize water infiltration rates as affected by traffic, crop residue, and tillage. Management was characterized by controlled traffic, with wide beds with either no-till or annual chisel-tillage on a Houston Black Clay soil (fine montmorillonitic, thermic Udic Pellusterts), a self-mulching vertisol. Traffic greatly reduced water infiltration rates compared to nontracked areas. Soil disturbance resulting from tillage in nontraffic areas was not a significant variable in determining water infiltration rates. Rather, tillage effects on surface residue cover were more important in determining water infiltration rates. Surface residue was effective in controlling erosion from the wide bed management practices used in these studies. Erosion losses were greater than 4 t ha^{-1} for the wet runs from both the no-till and tilled beds without adequate residue cover. Surface residue reduced erosion losses to less than one-tenth that of an unprotected surface.* ***Keywords.*** *Tillage, Vertisols, Water infiltration.*

Conservation tillage has been slow to be adopted for vertisols in the Blackland region of Central Texas. These are high clay content soils with a large shrink/swell potential and associated deep cracking upon drying. The surface 0.1 m of soil is self-mulching, i.e., the surface layer crumbles and becomes strongly granular upon drying. Producer concerns about soil compaction, crop establishment, timeliness of operations, and water management remain unanswered. A soil conservation management system developed for the vertisols in the Central Texas Blacklands has been tested for more than 10 years (Morrison et al., 1990). However, management effects on soil properties have only recently been examined (Potter and Chichester, 1993) and effects on water infiltration and soil erosion have not been tested rigorously.

The conservation management system developed for the Blacklands uses 1.5-m-wide beds with 0.5-m-wide furrows between beds (Morrison et al., 1990). The wide bed system allows controlled traffic practices to be followed with the furrows acting as traffic lanes as well as providing surface drainage for the beds. The beds may be chisel-tilled and reconstructed every year or no-till practices may be adopted.

Intensive agricultural cultivation of vertisols has often resulted in degradation of soil properties which results in lower productivity (Seiny-Boukar et al., 1992; Oleschko et al., 1993). Vertisol degradation has been related to loss of aggregate stability resulting from organic carbon decreases or increased sodicity (Cook et al., 1992), soil smearing when tilled too wet which reduces gas permeability (Hodgson and MacLeod, 1989), and reductions in water infiltration rates (Seiny-Boukar et al., 1992). Hydraulic properties of vertisols are especially important in the long-term sustainability of management practices. Degraded vertisols have been abandoned in some cases primarily because of restricted water infiltration (Seiny-Boukar et al., 1992). Some researchers have suggested no-till practices may be beneficial in vertisols because soil cracks would not be disturbed by tillage (Seiny-Boukar et al., 1992; Loch and Coughlan, 1984). Ritchie et al. (1972) confirmed that soil cracks provide routes for water movement under ponded surface water conditions.

However, hydraulic properties can be very difficult to measure in vertisols. Ritchie et al. (1972) found that measurements using disturbed soil cores resulted in hydraulic conductivity estimates which were much smaller than undisturbed cores and that the undisturbed core values were much smaller than field estimates for a Houston Black clay soil. The discrepancies between methods were attributed to structural unit boundaries or soil cracks which are propagated in this vertisol. Disturbed samples and small cores disrupted pore continuity which resulted in reduced hydraulic conductivity. This suggests that soil hydraulic properties should be determined *in situ* for vertisols for the results to be meaningful (Ritchie et al., 1972).

Tension infiltrometers have been used to determine infiltration rates and routes of infiltration in swelling clay soils (Jarvis et al., 1987). However, most tension infiltrometers are restricted to relatively small sample sizes which may exclude widely spaced cracks from being sampled. Rainfall simulators have been shown to be useful tools for determining water infiltration rates. Rainfall simulators enable the use of larger sample areas and

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include the effects of raindrop impact and seal development effects on water infiltration.

OBJECTIVE

The objectives of this study were to determine the effects of no-till and annual chisel-till wide bed management systems on water infiltration and sediment losses in a Houston Black clay vertisol.

MATERIALS AND METHODS

A rainfall simulator and ponded and tension infiltrometers were used to determine water infiltration characteristics of a Houston Black clay, a self-mulching vertisol which contains 48 g kg^{-1} sand, 390 g kg^{-1} silt, and 562 g kg^{-1} clay.

RAINFALL SIMULATOR STUDY

SITE HISTORY

Rainfall simulator studies were conducted on a Houston Black clay soil which had been under continuous management for four years using the wide bed system described by Morrison et al. (1990). Briefly, this system consisted of raised beds 1.5 m wide, 0.15 m high, separated by 0.5-m-wide furrows which served as traffic lanes and surface drainage ways. The site was in a wheat-corn-grain sorghum (*Triticum aestivum* L.-*Zea mays* L.-*Sorghum bicolor* L.) crop rotation with the rainfall simulations occurring after the wheat harvest.

EXPERIMENTAL PROCEDURES

Simulated rainfall was imposed on four tillage/residue combinations. Two tillage regimes were studied, no-till except for reshaping the bed shoulders every three years, and annual chisel-till with complete bed reformation (Morrison et al., 1990). Both management systems were tested with low and high amounts of surface residue cover. Residue was removed from the no-till/low residue treatments and used to supplement the chisel-till/high residue treatments. Percentage surface residue cover was determined by the number of residue hits by a 2-mm-diameter rod at 100 points. Rod drop points were located randomly within 50 consecutive 0.025-m segments across two diagonal transects of the plot. This method is similar to the point-intercept methods of residue determination discussed by Morrison et al. (1993). The percentage residue cover was over 90% in the no-till/high residue and chisel-till/high residue treatments (table 1). In the no-till/low residue and chisel-till/low residue plots, percentage residue cover was higher than expected, approaching the 30% cover usually used to define conservation tillage systems. However, the residue on the low residue plots consisted of small particles, mostly chaff, which adhered to the soil surface. Simulated rain decreased the percentage residue cover slightly in the low residue plots, but had little effect in the high residue plots.

Table 1. Percentage residue cover

	T/LR* (%)	T/HR* (%)	NT/LR* (%)	NT/HR* (%)
Dry run	39.5 (8.3)†	97.3 (3.1)	28.3 (5.3)	99.8 (0.5)
Wet run	30.0 (8.6)	95.5 (5.9)	24.7 (2.2)	99.3 (1.5)

* Till/low residue, till/high residue, no-till/low residue, no-till/high residue.

† Mean (n = 4) and standard deviation.

A rainfall simulator similar to that described by Miller (1987) was used to determine water infiltration and runoff rates from 1 × 1 m^2 plots located on the bed. Each plot was surrounded by a metal frame driven 0.1 m into the soil to define the study area. Rainfall was simulated over an area of 10 m^2 surrounding the study plots. Water was applied with a Spraying Systems wide square spray 30 WSQ nozzle at a nominal rate of 125 mm h^{-1} with a mean drop size diameter of 2.5 mm and kinetic energy of 23 J m^{-2} mm^{-1}. This rainfall rate is about that of a 10-year 30-min rain. The actual rate of water application was measured for each individual plot by measuring all water applied to the plot for 4 min. Water was captured in a metal pan which fit tightly into the plot frame. Runoff was captured at the downslope edge of the plot and transferred to tanks by peristaltic pumps. Water height was measured and runoff volume calculated every 5 s and recorded on a Campbell Scientific 21X datalogger. The rate of water application was measured after the rainfall simulator had been adjusted over the plot to account for minor differences due to the simulator placement. The measured rainfall rate was used for all calculations. Infiltration during the simulation was calculated as the difference between the amount of water applied and runoff.

Two initial soil water contents were studied, dry and wet, on the same areas. The dry condition was provided by the ambient water content after wheat harvest. After a dry run was completed, the sites were covered and allowed to drain for two days before the wet runs were conducted on the same site. No rain occurred during the four weeks required for the simulation studies.

Rains were continued until there were 30 min of runoff for each plot. Total sediment losses were determined by summing the amount settling in a still portion of the collection flume and the concentration of sediment in suspension in the runoff water.

Surface soil gravimetric water content and bulk density was sampled to a 0.1 m depth in 0.02 m increments prior to each run.

The experimental design was a split plot with four replications, where the main plots were two tillage systems and the subplots were residue amounts. Analysis of variance (ANOVA) tests were conducted to determine differences among tillage and residue treatments. All treatment combinations were grouped near each other and tested within a one-week period. Grouping treatment combinations in this manner reduced the potential effect of soil water content differences which may have occurred.

TENSION INFILTROMETER STUDY

Tension infiltrometers measure infiltration rates at water pressures which are negative with respect to atmospheric pressure. Ponded infiltrometers by definition require a positive water pressure. Since capillary pressure can be related to an equivalent pore diameter, the pressure potential of water at the soil surface can be used to estimate the range of pore sizes contributing to measured infiltration rates. Increasing tension results in lower amounts of infiltration as larger soil pores are excluded from transporting water.

Site History

For this study, we used both ponded and tension infiltrometers to determine soil hydraulic properties on two adjacent fields, each about 1.2 ha in size. One field had been in continuous controlled-traffic no-till management with the wide bed system for eight years. The other field was tilled intensively with annual chisel plow, tandem-disk, and field cultivation before wide bed reconstruction in the fall. Other management practices were documented in Morrison et al. (1990). Both fields had been in a wheat-grain sorghum-corn rotation for eight years. Infiltration measurements were made in the fall of 1992, after a wheat crop and in the spring of 1993 in the same area as before but after grain sorghum planting. For the 1992 sampling, the soil was still fairly dry after the wheat crop. The 1993 infiltrometer measurements occurred about six months after fall tillage, after 600 mm of rain had fallen on the plots. Infiltration was measured in both the crop beds and traffic furrows in 1992. Only the crop beds were sampled in 1993.

Experimental Procedures

Ponded infiltration rates were determined using an automated infiltrometer similar to that described by Prieksat et al. (1992). A 10.2-cm-diameter steel ring was inserted 10 mm into the soil surface. Two layers of cheese cloth were placed over the soil surface to prevent slaking of soil particles. Water was ponded on the surface to a height of 5 mm inside the ring for at least 15 min or until bubble rate indicated infiltration was approaching a steady rate. After prewetting, infiltration was monitored for 1000 s. The amount of water infiltrating was determined from the pressure difference between two pressure transducers mounted at the top and bottom of the mariotte water supply reservoir. Analog output from the pressure transducers were recorded every 5 s on a Campbell 21x datalogger.

After ponded infiltration measurements were completed, the infiltrometer was removed and fine sand was placed inside the ring and struck level with the ring surface. A tension infiltrometer similar to that described by Ankeny et al. (1988) was preset at 20-mm tension and the base placed in contact with the sand. Unsaturated infiltration was measured after bubble formation indicated the desired surface tension had been obtained. Unsaturated infiltration was recorded every 5 s in the same manner as in the ponded infiltrometer. Unsaturated infiltration was also measured for 30- and 60-mm tension. Using the assumptions of the capillary rise equation, the largest pore conducting water has a diameter of 1.4, 1.0, and 0.5 mm for tension values of 20-, 30-, and 60-mm water tension, respectively (Jarvis, 1987).

Soil water content samples were collected near each infiltration site in depth increments of 0 to 50, 50 to 150, and 150 to 250 mm. The soil samples were weighed, oven dried at 105° C for 24 h, and reweighed to determine dry weight.

Soil infiltration rate was calculated using the Flowdata software system developed by Ankeny et al. (1993). The 1992 data were statistically analyzed using a split-split plot design with tillage as the main plot and wheel traffic the first split and tension as the second split. There were eight replications of infiltration measurements on the beds and four replications on the furrows. Analysis of the 1993 crop bed data compared the effect of tillage on water infiltration without the confounding effect of having had a crop. The statistical design was similar to that in 1992, with tillage the main plot and tension as the split plot, with eight replications. Infiltration rate and tension were log transformed prior to statistical analysis. Log-log transformations have been used by Ankeny et al. (1990) and Schuh et al. (1984) for tensions greater than the air-entry value.

Results

Rainfall Simulator Study

Water infiltration data during the dry run had a general pattern in all tillage/residue combinations of very large initial infiltration rate, followed by a rapid decline in infiltration rate. In most cases, a lower, nearly constant rate, was eventually established (fig. 1). Similar results were reported for vertisols in Australia with small (1 m^2) plots, and large (18 m^2) plots with rainfall simulators, and 1-ha watersheds with natural rainfall (Freebairn et al., 1984). A large portion of the water infiltration occurred before any runoff was measured (table 2). Several authors have noted the importance of this "initial infiltration" in recharging the soil profile with water in vertisols (Bouma and Loveday, 1988; Freebairn et al., 1984; Coughlan et al., 1989). In the dry condition, initial infiltration accounted for 100% of the cumulative infiltration during the initial 30 min of rain in both chisel-till and no-till with large amounts of surface residue. With low amounts of residue, initial infiltration accounted for 65 and 89% of cumulative infiltration during the initial 30 min in both the chisel-till and no-till sites, respectively.

During the wet runs residue amount significantly affected the amount of initial infiltration (table 3). With low amounts of residue, initial infiltration amounts were very small, accounting for 5% of cumulative infiltration during the initial 30 min in both tillage treatments. With large amounts of surface residue, initial infiltration accounted for 53 and 29% of cumulative infiltration during the initial 30 min for till and no-till plots, respectively.

Surface residue cover also had a large effect on final water infiltration rates in both the dry and the wet runs. As

Table 2. Summary of rainfall simulator infiltration data

	T/LR	T/HR	NT/LR	NT/HR
	Initial Infiltration (mm)			
Dry run	32.4 (13)*	129 (41)	54 (26)	75 (45)
Wet run	1.1 (0.9)	31 (21)	1.4 (0.9)	12 (2)
	Final Infiltration Rate (mm h^{-1})			
Dry run	28 (9)	—	58 (20)	78 (3)
Wet run	20 (8)	56 (3)	28 (8)	45 (24)
	30-min Cumulative Infiltration (mm)			
Dry run	50 (6)	62 (9)	61 (5)	66 (7)
Wet run	21 (10)	58 (9)	28 (5)	42 (6)

* Mean (n = 4) and standard deviation.

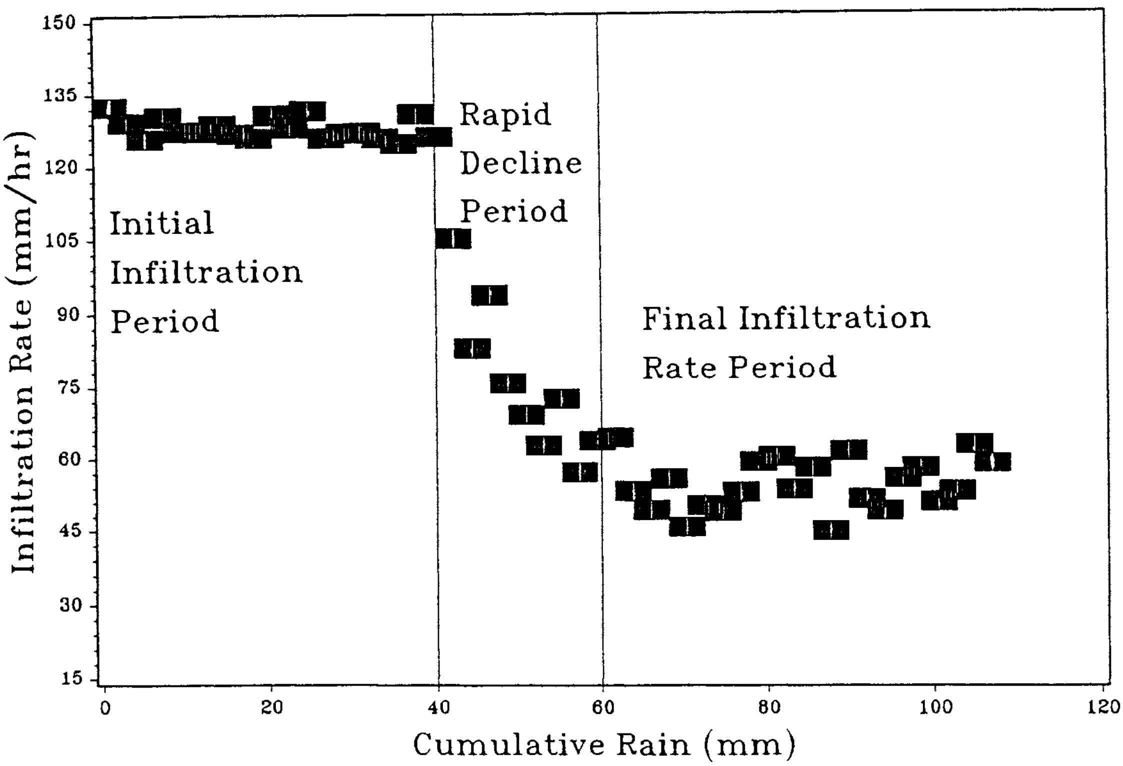

Figure 1–Infiltration rate vs. cumulative rain measured for tilled wet soil with high amounts of residue. The initial infiltration, rapid decline in infiltration rate, and "final" rate periods are illustrated.

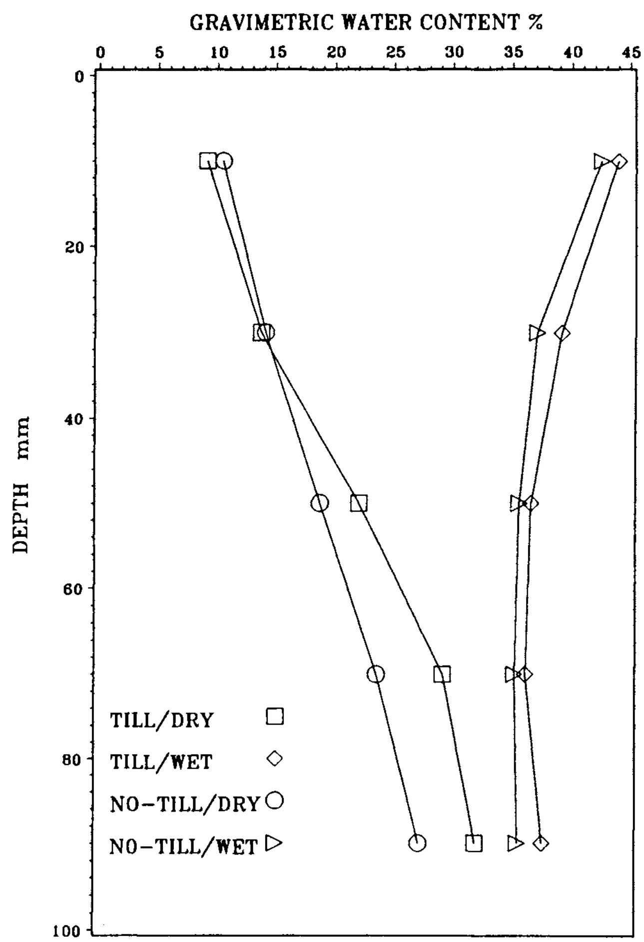

Figure 2–Surface soil water contents before and two days after the first rainfall simulation treatment (n = 8).

expected, final infiltration rates were greater during the dry runs than in the wet runs (table 2). The chisel-tilled sites with residue never obtained a constant rate during the dry runs. In contrast, the chisel-tilled plots with low residue had the lowest final rates of all treatments. High amounts of surface residue cover resulted in significantly higher final infiltration rates during the wet runs in both chisel-tilled and no-till plots (table 3). Final infiltration rates averaging 56 for the chisel-till and 45 mm h^{-1} for the no-till plots with high rates of surface residue compared to 20 and 28 mm h^{-1} for the respective low residue plots. Soil disturbance from tillage was not a significant factor in determining final rates during the wet run rainfall simulations (table 3). Rather, it appears that the effect of

Table 3. Analysis of variance of rainfall simulator study data

	Probability of > F			
Source	Initial Infiltration Amount	Final Infiltration Rate	Cumulative Infiltration in 30 Min	Total Sediment Losses
		Dry Run		
Tillage	0.1978	—*	0.0719	0.1286
Residue	0.0124†	—	0.0400†	0.0002‡
T×R	0.0741	—	0.4401	0.1475
		Wet Run		
Tillage	0.0641	0.8341	0.3108	0.9982
Residue	0.0044‡	0.0184†	0.0001‡	0.0001‡
T×R	0.1123	0.3249	0.0162†	0.8314

* Missing parameters prevented meaningful ANOVA.
† Significant at 5% probability level.
‡ Significant at 1% probability level.

tillage on surface residue cover is important in determining the final infiltration rate.

Infiltration rates varied between dry and wet runs due to differences in surface water content (fig. 2), soil swelling, and the effect of raindrop impact. With low residue levels, soil cracks visible at the start of the dry runs were swollen shut after about 12 min of rainfall. Runoff began soon after the cracks had swollen shut. No cracks were visible at the onset of the wet runs.

Raindrop impact induced soil slaking which quickly filled most macropores with soil in both the no-till and chisel till treatments with low residue covers. Despite the development of a surface seal, bulk densities were not increased in the surface 20 mm.

Prior to rainfall simulation, the chisel-till soil had a lower surface bulk density than the no-till soil (fig. 3a). Bulk density did not change between the wet and dry rainfall simulations on the chisel-till soil with or without large percentage surface residue cover. In contrast, the no-till plots had lower surface bulk density after the first rainfall simulation (fig. 3b). Near surface bulk density was much lower in the no-till with residue retained, probably due to soil swelling with the increase in soil water content (fig. 2). Below 60 mm, the no-till soil still had a greater bulk density than the chisel-till soil.

Surface residue cover was highly effective in controlling sediment losses from the raised beds. Mean sediment losses were 9 to 15 times greater from the low residue plots than from the high residue plots (table 4). It is interesting to note that, although not statistically different (table 3), the no-till low residue plots tended to have lower sediment losses than the tilled low residue plots in the dry runs (table 4). Losses were similar between the low residue treatments in the wet runs. Most of the sediment losses appeared to originate from the shoulder of the bed, with sediment slaking into the furrow. The high residue plots did not appear to slake into the furrow. From visual observations, it appeared that weathered beds in tilled plots exhibited similar characteristics, with year-old beds often eroded by natural rainfall to the first row of wheat stubble in the bed. Sediment which eroded into the furrows between beds was assumed to be lost from the field because of rapid surface drainage from the fields. This was corroborated by the fact that little sediment was observed in the furrows, but sediment was apparent in the grassed waterway at the edge of the field.

Tension Infiltrometer Study

Mean water infiltration rates for crop beds and furrows are illustrated in figure 4. Infiltration rates were lower in

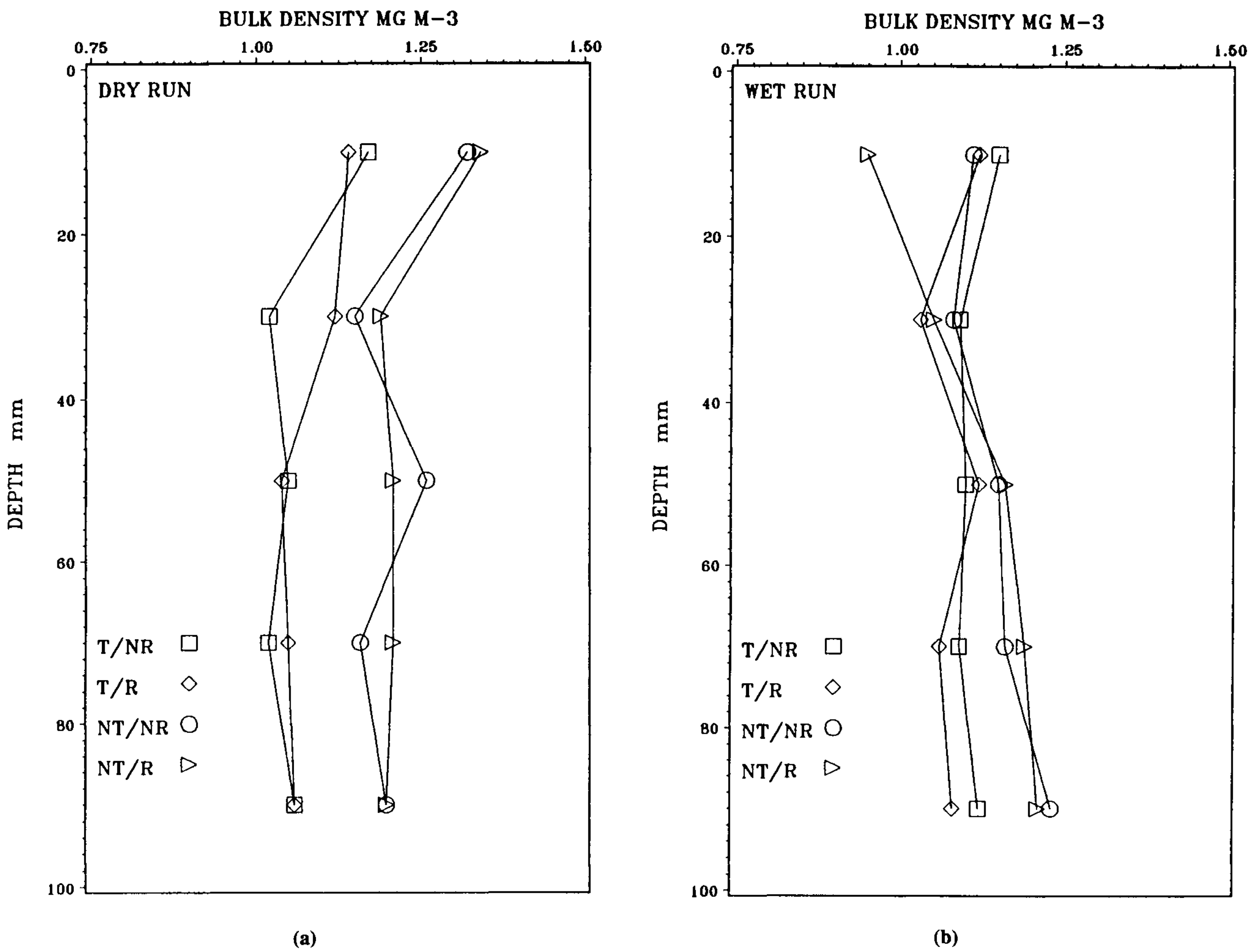

Figure 3–Surface bulk density (a) before and (b) two days after the first rainfall simulation treatments (n = 4).

Table 4. Total sediment losses with 30-min runoff

	T/LR	T/HR	NT/LR	NT/HR
	Total Sediment Losses (g m^{-2})			
Dry	461 (205)†	30 (27)	264 (134)	25 (24)
Wet	422 (195)	34 (24)	411 (48)	45 (30)

* Mean (n = 4) and standard deviation.

the all-traffic furrows than in the crop beds. Although reduced to a greater extent in the no-till site which had been trafficked for eight years without deep tillage, infiltration rates within furrows were not statistically different between management systems probably because of the traffic which occurred during the cropping season (table 5). Low infiltration rates in the furrow helps drain excess surface water rapidly from the field. Surface drainage is especially desirable in the spring when the soil is usually saturated. Also, the lower water infiltration may aid in earlier trafficability, which is an important consideration with this type of soil.

Water infiltration rates were not significantly different (P = 0.05) between tilled and no-till crop beds in 1992 (table 5 and fig. 4). This implies that similar pore size distributions and pore continuity were present with both management systems. Infiltration measurements were made about one year after tillage and after a wheat crop had been grown on this site. The soil had been desiccated by evapotranspiration by the previous wheat crop. Soil self-mulching and deep cracking had occurred during the growing season. However, at the time of the tension infiltrometer measurements, the soil had rewet so that large deep cracks were not open in the soil surface (table 6). The crop canopy and surface residue also prevented the development of a substantial surface seal.

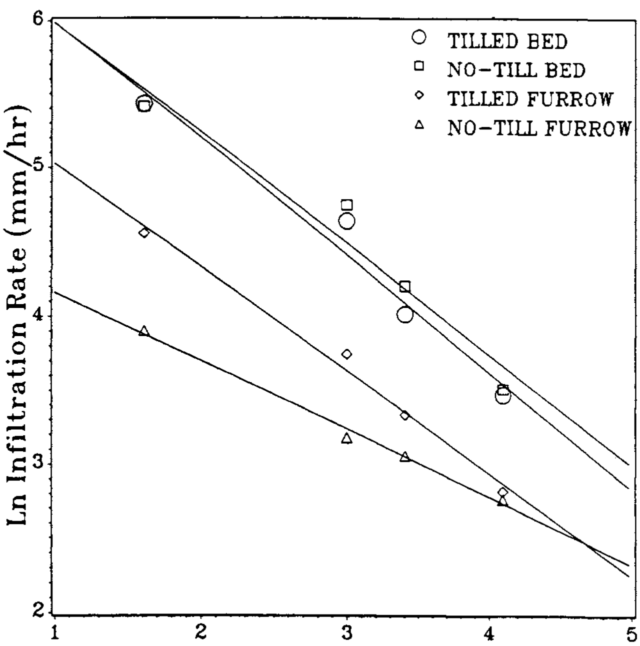

Figure 4–Plot of the natural log of the unconfined infiltration rate means (n = 8) vs. the natural log of tension for trafficked furrow and untrafficked cropbeds in 1992.

Table 5. Analysis of variance results of effects of tillage, traffic, and tension level on water infiltration rates with the tension infiltrometer

Source	Probability of > F	
	After Harvest	Six Months after Tillage
Tillage (Ti)	0.2009	0.0258*
Traffic (Tr)	0.0113*	NA†
Ti × Tr	0.3392	NA
Tension (Te)	0.0001‡	0.0001‡
Ti × Te	0.0572	0.5167
Tr × Te	0.0022‡	NA
Tr × Ti × Te	0.2957	NA

* Significant at 5% probability level.
† Not applicable.
‡ Significant at 1% probability level.

In contrast to the 1992 measurements, infiltration rates were significantly different (P = 0.05, table 5) between tillage systems in the 1993 measurements (fig. 5). Six months after tillage, water infiltration rates were larger in the no-till soil than in the tilled soil. This suggests that soil macropores and pore continuity were retained to a greater extent in the no-till management system compared to the fall tillage management system. Over 600 mm of rain had fallen since tillage, which consolidated the soil surface of the tilled beds. The no-till soil beds, which had nearly 100% residue cover, were more protected from raindrop impact than the tilled soils. Also, soil cracking and self-mulching had not occurred at the time of the 1993 infiltration measurements. These results are consistent with those of Messing and Jarvis (1990), who reported that infiltration varied with crop history and initial soil water contents.

Summary

Water infiltration rates on a Houston Black clay soil were determined in two studies. The first study used a rainfall simulator and the second study used ponded and tension infiltrometers. Soil in no-till and annually chisel-tilled wide bed management systems was examined in both studies. While both studies examined management effects on water infiltration, different mechanisms controlling the rate of water infiltration were examined. The ponded and tension infiltrometers determined the infiltration rate dependent upon soil pore size and continuity. The rainfall simulator study addressed raindrop impact and surface residue effects on water infiltration. The following conclusions may be drawn from these two studies:

- Water infiltration rates can be large soon after tillage. After rainfall and settling, however, infiltration is reduced in a tilled vertisol compared to a long-term no-till vertisol, probably because of reduced macropore continuity after tillage.

Table 6. Soil water content for three depths at the time of the tension infiltrometer measurements

Year	Depth (mm)	Tilled Bed (kg/kg)	Tilled Furrow (kg/kg)	No-till Bed (kg/kg)	No-till Furrow (kg/kg)
1992	0 - 50	0.18* (0.04)	0.20† (0.02)	0.18 (0.05)	0.19 (0.04)
	50 - 150	0.28 (0.02)	0.26 (0.02)	0.26 (0.02)	0.24 (0.02)
	150 - 250	0.27 (0.02)	0.25 (0.04)	0.26 (0.02)	0.24 (0.01)
1993	0 - 50	0.24 (0.04)	—†	0.24 (0.08)	—†
	50 - 150	0.31 (0.03)	—	0.27 (0.03)	—
	150 - 250	0.29 (0.03)	—	0.28 (0.03)	—

* Mean and standard deviation, n = 8 in beds; n = 4 in furrows.
† Not sampled.

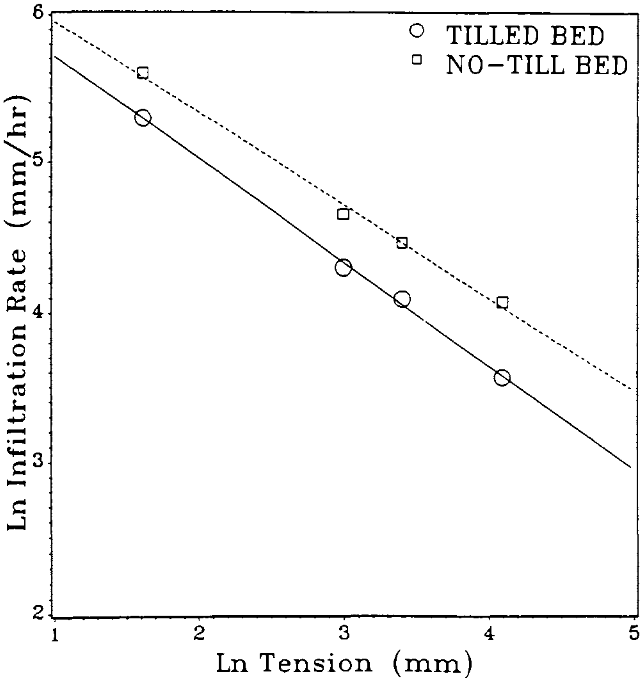

Figure 5–Plot of the natural log of the unconfined infiltration rate means (n = 8) vs. natural log of tension for untrafficked crop beds in 1993.

Macropores and pore continuity appear to be restored during one cropping season in this vertisol, either by self-mulching or deep cracking after desiccation.

- Wheel traffic greatly reduces the rate of water infiltration. With the wide bed system, the wheel traffic is confined to furrows which also serve as conduits for surface drainage. However, random wheel traffic could be detrimental with no-till management systems.
- Surface sealing from raindrop impact can have large effects on water infiltration rates. Surface residue was effective in reducing raindrop impact and resulted in increased water infiltration rates with both till and no-till practices.
- Surface residue was effective in controlling erosion from the wide bed management practices used in these studies. Erosion losses approached 4 t ha^{-1} for the wet runs from both the no-till and tilled beds without adequate residue cover.

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