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Soil organic matter and water stable aggregate effects on water infiltration

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ABSTRACT

Soil water conservation is important for dryland farming. Soil organic matter (OM) and aggregate mean weight diameter (MWD) effects on simulated rainfall infiltration were evaluated in this study. Samples were from the 0- to 5-cm depth where no- (NT), sweep (ST), or sweep plus disk (ST+DT) tillage treatments were used on Sherm loam (Torrertic Paleustoll), and NT, lister (LT), or lister tillage plus planting (LT+P) treatments were used on Olton loam (Aridic Paleustoll). Water was applied at 25 or 49 mm h^{-1}. OM was greatest with NT, whereas MWD was greatest with ST on Sherm and with LT on Olton loam. Infiltration for both loams and at both intensities generally was greater with NT than with other soils. Final infiltration (I_f) rates were greatest for NT soil, but lower with application at 49- than at 25-mm h^{-1}. Differences in infiltration were attributed mainly to OM differences. Although MWD for NT soil was lower than for ST and LT soil, NT soil aggregates possibly were more stable and, hence, contributed to greater infiltration. Re-

yields, but expense and water supply limitations curtail its use for supplementing marginal rainfall in some semiarid regions. Hence, soil water conservation is strongly emphasized in such regions, especially where dryland (non-irrigated) farming is practiced.

Soil water conservation depends on water infiltration into a soil and soil water evaporation, storage capacity, and retention. Infiltration is influenced by numerous factors, including soil surface conditions such as organic matter concentration, aggregate size distribution and stability, and crop residues on the surface. Tillage practices employed influence these soil surface conditions and, hence, water infiltration and conservation. Control of soil erosion by water is closely related to infiltration because water that infiltrates does not transport soil particles from the land in runoff water.

A better understanding of tillage-induced effects of surface soil organic matter concentration and aggregate size distribution on rainwater infiltration could lead to a better understanding of factors that control water and soil conservation. This knowledge consequently could lead also by soil type and soil water content at the time of tillage (7). The physical and hydraulic properties of aggregated soil surfaces are changed by rainstorms, with changes being related to aggregate stability (8,9), rainfall amount (10,11), and raindrop kinetic energy (12). Disintegration of aggregates and reorientation of soil particles result in surface sealing, which is a major factor causing infiltration decreases under natural rainfall (13,14).

The objective of this study was to evaluate the effects of tillage-induced differences in surface soil organic matter concentration and water stable aggregate size distribution on simulated rainfall infiltration. A better understanding of these effects should foster the development of practices for improved soil water conservation, which is highly essential for improved and sustained dryland crop production in semiarid regions.

MATERIALS AND METHODS

The study was conducted under laboratory conditions at the USDA Conservation and Production Research Laboratory at Bushland, Texas, involving Sherm soil from near Etter, Texas, and Olton soil from near Lubbock, Texas. Etter is about 100 km north and Lubbock is about 200 km south of Bushland. Sherm is classified as a silty clay loam and Olton as a clay loam. However, particle size distribution determinations showed that both soils had a loam texture. Mean sand, silt, and clay concentrations were 29, 47, and 24%, respectively, for the Sherm loam, and 30, 47, and 23%, respectively, for the Olton loam.

Bulk soil samples for this study were obtained from field areas where no-tillage (NT), sweep tillage (ST), and sweep plus disk tillage (ST+DT) treatments had been imposed on Sherm loam, and where NT, lister (ridge- and furrow-forming) tillage (LT), and lister tillage plus planting (LT+P) treatments had been imposed on Olton loam. The treatments had been in place for 5 yr on Sherm loam and 3 yr on Olton loam at the time of sampling. The Sherm loam was used for a winter wheat (*Triticum aestivum* L.)-grain sorghum [*Sorghum bicolor* (L.) Moench] rotation, and was in fallow after wheat when it was sampled on 8 May 1988 (wheat was harvested the previous July). The Olton soil was used for grain sorghum and was sampled on 28 April 1988. Samples from the different locations with different past management and tillage treatments were obtained to provide soils having a range in OM concentration and MWD of water-stable aggregates. Both field studies had a randomized block design and the treatments were replicated four times.

The soils were relatively dry (near the wilting point) when they were sampled at the 0- to 5-cm depth. The field plots on Sherm loam were managed flat (no ridges and furrows) and samples were obtained without regard to surface position. Plots on Olton loam had ridges and furrows (1-meter spacing), and samples were obtained from the ridge tops. Samples were air-dried and crushed to pass through a 6.4-mm opening of the crusher. Subsamples of the bulk soil were analyzed for organic matter (OM) concentration (15) and mean weight diameter (MWD) of water stable aggregates (16).

For infiltration determinations, soil was packed into metal boxes over a layer of 3- to 5-mm diam. gravel covered with cheesecloth. Relatively uniform packing was achieved by repeatedly tapping the sides of the boxes until no further soil settling was observed. The boxes containing the soil were placed on a turntable that made one revolution each 250 s beneath a rotating disk type rainfall simulator (17). Rain from the simulator falls from a height of 2 m and it has kinetic energies similar to those of natural rainfall when intensities are up to 50 mm h^{-1} (17). The boxes were 300 mm wide, 500 mm long, and 120 mm high on the inside, except on one end where the height was 100 mm. This box design permitted runoff across the soil surface that sloped 1.0% toward the lower end when placed on the turntable. Gravel depth was 50 mm and soil depth was 50 mm, leaving a free-board of 20 mm. The boxes were designed so that runoff across the surface and percolation through the soil could be determined independently. To minimize the possible delay in water percolating from the boxes, the gravel was saturated with water shortly before packing soil in the boxes. Some drainage, however, occurred before the simulations were started, usually within 4 h after packing soil in the boxes.

Water was applied simultaneously to four boxes prepared for randomly selected treatments from a given soil. Water application rate was determined using a fifth box covered with wire mesh. For simulations, rainwater having an electrical conductivity of 0.0039 S m^{-1} and a sodium concentration of 0.196 mg kg^{-1} was applied at rates of 25 or 49 mm h^{-1} (calibrated rates).

For a given run, water was applied until runoff and percolation rates from all boxes became constant, generally in 2 to 3 h. Runoff and infiltration were determined for hourly intervals, and final infiltration rates were calculated from the volume of water that percolated from the soil.

Data were analyzed by the analysis of variance technique, with the analyses being based on the field plot layout. Separate analyses were used for the two soils and rates of water application. Duncan's multiple range test or the protected least significant difference were used to separate means when differences were significant at the $P = 0.05$ level. A paired *t* test was used to determine whether differences due to water application rates were significant (18,19).

RESULTS AND DISCUSSION

Organic matter (OM) concentration and aggregate mean weight diameter (MWD)

The OMC concentration and MWDs resulting from the different tillage methods are presented in Table 1. Because tillage on the loams differed, except for NT, data for each are discussed separately.

Sherm loam

The OM concentration was greatest for soil from NT, intermediate from ST, and least from ST + DT treatment plots. No-tillage retains crop residues (organic materials) on the surface while they are incorporated to some extent with soil to the depth of operation when tillage is performed. Thus, the greater OM with NT. Residue incorporation was to about a 15-cm depth with ST + DT and about a 10-cm depth with ST. As a result, OM dispersion' was greater with the ST + DT treatment and OM

Table 1. Tillage effect on organic matter (OC) concentration and water stable aggregates (MWD) of Sherm and Olton loams.

Loam	Tillage treatment soil[a]	Soil parameter	
		OM (g kg^{-1})	MWD[b] (mm)
Sherm	NT	27.1a[c]	1.71b
	ST	21.4b	2.10a
	ST + DT	17.6c	0.87c
Olton	NT	12.4a	0.93b
	LT	13.1a	1.61a
	LT + P	9.1b	1.09b

[a] Tillage treatments: NT--no-tillage, ST--sweep, ST + DT--sweep + disk, LT--lister, LT + P--lister + planting.

[b] MWD = mean weight diameter.

[c] Column values for a given loam and soil parameter followed by the same letter are not significantly different at the 5% level (Duncan multiple range test).

concentration was lower near the surface where the samples were obtained. Similar results were obtained for Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll), which is similar to the Sherm loam. For Pullman clay loam, OM was greater near the surface in no-tillage areas than in adjacent tillage areas (6).

The MWD was greatest for soil from ST, intermediate from NT, and least from ST + DT treatment plots. Soil OM positively influences water stable aggregation (20), and it was expected that the MWD would be greater for the NT soil. The NT soil probably had a lower MWD than ST soil because the OM of NT soil was concentrated at the surface and, hence, did not improve the stability of aggregates to the depth of sampling (to 5 cm). In contrast, residues with the ST treatment were incorporated with soil to some degree, thus tending to stabilize aggregates to a greater degree. Another possible reason for lower MWD of NT soil is that the greater OM with NT stabilizes the aggregates, but most of them are relatively small, thus resulting in the lower MWD. Even lower MWD of the ST + DT treatment soil aggregates resulted from residue incorporation to an even greater depth, thus diffusing the effectiveness of residues for stabilizing soil aggregates.

Olton loam

The OM concentration of Olton loam was lower for LT + P soil than for NT and LT soils (Table 1). For the LT + P treatment, the planting operation apparently moved soil with greater OM away from the ridge tops, thus resulting in the lower OM in samples that were obtained from the ridge tops. The LT treatment (ridge-forming tillage) apparently concentrated OM-rich surface soil on the lister ridges, thus resulting in similar OM for soil from NT and LT treatment plots. Positional (ridge vs. furrow) differences in OM due to different tillage methods were as large as 10.4 g kg^{-1} before planting grain sorghum on ridge-tilled Pullman clay loam (21). Subsequent planting and ridge rebuilding operations also resulted in positional differences in OM.

The overall lower OM for Olton than for Sherm loam is attributed to past cropping practices. Olton loam often is used for cotton (*Gossypium hirsutum* L.), which produces relatively few residues. Sherm loam primarily is used for grain crops (wheat or sorghum). Natural differences also may have been in-

Table 2. Final infiltration rates (mm h^{-1}) for Sherm and Olton loams under laboratory conditions as affected by tillage treatment and simulated rainfall rate.

Loam	Tillage treatment soil[a]	Water application rate (mm h^{-1}) 25	49	Prob. t[b]
Sherm	NT	10.0a[c]	6.4a	0.0004
	ST	4.0b	3.7b	0.0208
	ST + DT	5.2b	2.7c	0.0032
Olton	NT	9.5a	7.6a	0.0384
	LT	4.4b	3.1b	0.0245
	LT + P	5.6b	3.8b	0.0980

[a] Tillage treatments: NT--no-tillage, ST--sweep, ST + DT--sweep + disk, LT--lister, LT + P--lister + planting.

[b] Probability of *t* for significance of difference due to water application rate.

[c] Column values for a given loam or water application rate followed by the same letter are not significantly different at the 5% level (Duncan multiple range test).

volved.

The MWD was greater for LT than for NT and LT + P treatment soils, for which it was similar. As on Sherm loam, lower MWD with NT on Olton loam resulted from OM being concentrated at the surface whereas residues were incorporated with the LT treatment, which stabilized the aggregates throughout the tillage layer that was sampled. For the LT + P treatment, planting moved the more-stable soil away from ridge tops, thus resulting in less-stable soil being sampled. In addition, as for Sherm loam, aggregates with NT possibly were as stable, but smaller, than with other treatments.

Table 3. Cumulative water runoff and infiltration of simulated rainfall on Sherm loam as affected by rate of water application, time of water application, and soil from tillage treatment plots.

Water application			Tillage treatment soil[b]			
Rate (mm h^{-1})	Time (h)	KE[a] (J m^{-2})	NT	ST	ST+DT	Mean
			Runoff (mm)			
25	1	550	0.0B[c]	0.4B	0.3B	0.3
	2	1100	3.0B	10.4B	8.1B	7.2
	3	1650	10.8	25.7	20.8	19.1
		Prot. LSD[d] (0.05): Time = 0.5, Treatment x Time = 1.3				
49	1	1078	9.3A	14.4A	10.7A	11.5
	2	2156	33.3A	42.6A	36.0A	37.3
		Prot. LSD (0.05): Time = 1.2, Treatment x Time = NS[e]				
			Infiltration (mm)			
25	1	550	25.0A	24.6A	24.7A	24.8
	2	1100	37.1A	30.2A	30.9A	32.7
	3	1650	49.2	35.6	37.5	40.8
		Prot. LSD (0.05): Time = 0.9, Treatment x Time = 3.1				
49	1	1078	25.8A	25.0A	25.2A	25.3
	2	2156	34.1A	25.5B	30.7A	30.1
		Prot. LSD (0.05): Time = 1.2, Treatment x Time = 2.9				

[a] Kinetic energy of applied rainfall.
[b] Tillage treatments: NT -- no-tillage, ST -- sweep, ST + DT -- sweep + disk.
[c] Values for a given treatment and time of water application for runoff or infiltration at the two rates of water application that are followed by the same letter are not significantly different according to the *t* test.
[d] Protected least significant difference.
[e] Not significant.

Infiltration and runoff

On Sherm loam, I_f (final infiltration) rate was greatest for soil from NT and similar for soil from ST and ST+DT treatment plots at the 25-mm h^{-1} application rate (Table 2). At the 49-mm h^{-1} application rate, I_f was greatest with NT and least with the ST+DT soil. These results indicate a generally close relationship between soil OM and I_f (Tables 1 and 2) for Sherm loam. Generally, lower I_f values with the 49- than with the 25-mm h^{-1} application rate are logical because more energy is provided by the 49-mm h^{-1} rainfall, which results in greater dispersion of aggregates and surface sealing.

Table 4. Cumulative water runoff and infiltration of simulated rainfall on Olton loam as affected by rate of water application, time of water application, and soils from tillage treatment plots.

Water application			Tillage treatment soil[b]			
Rate (mm h^{-1})	Time (h)	KE[a] (J m^{-2})	NT	LT	LT+P	Mean
			Runoff (mm)			
25	1	550	0.0B[c]	0.0B	0.2B	0.1
	2	1100	4.4B	8.9B	8.6B	7.3
	3	1650	12.5	24.1	22.1	19.6
		Prot. LSD[d] (0.05): Time = 1.1, Treatment x Time = 2.0				
49	1	1078	6.8A	13.4A	11.2A	10.5
	2	2156	27.2A	41.2A	37.6A	35.3
		Prot. LSD (0.05): Time = 1.8, Treatment x Time = NS[e]				
			Infiltration (mm)			
25	1	550	25.0A	25.0A	25.0A	25.0
	2	1100	33.3B	30.4A	29.7A	31.1
	3	1650	45.9	36.6	37.7	40.1
		Prot. LSD (0.05): Time = 0.9, Treatment x Time = 2.5				
49	1	1078	26.4A	25.3A	25.0A	25.6
	2	2156	39.1A	28.0A	28.1A	31.7
		Prot. LSD (0.05): Time = 0.3, Treatment x Time = 2.5				

[a] Kinetic energy of applied rainfall.
[b] Tillage treatments: NT -- no-tillage, LT -- lister, LT+P -- lister + planting.
[c] Values for a given treatment and time of water application for runoff or infiltration at the two rates of water application that are followed by the same letter are not significantly different according to the *t* test.
[d] Protected least significant difference.
[e] Not significant.

Cumulative runoff from Sherm loam was or tended to be less with NT soil than with ST and ST + DT soil at both rates and at all times of water application (Table 3). Runoff was much greater during identical periods with the 49- than with the 25-mm h^{-1} rate. At 1 h, infiltration amounts were similar for soils from all plots at both application rates. At later times, cumulative infiltration remained greater with NT than for other soils at both application rates, but infiltration at 2 h was greater with the 25- than with the 49-mm h^{-1} application rate only for the ST soil. Water application at 49 mm h^{-1} resulted in greater aggregate dispersion and surface sealing than application at 25-mm h^{-1}. Consequently, runoff losses were greater and infiltration was lower with the 49-mm h^{-1} rate at 2 h.

At both water application rates on Olton loam, I_f rate was greatest for NT and similarly low for LT and LT+P soils (Table 2). The I_f was significantly lower with water application at 49 than at 25 mm h^{-1} for NT and LT soils.

Cumulative runoff differences from the Olton loam at 1 h were not significant, but were or tended to be lower for NT than for other soils at both rates at other times of water application (Table 4). For identical times, runoff was greater with the 49- than with the 25-mm h^{-1} application rate. Cumulative infiltration was similar at 1 h for all soils at both application rates. At subsequent times, infiltration was greater for NT than for LT and LT+P soils. Infiltration at 2 h for NT soil was greater at the 49- than at the 25-mm h^{-1} application rate. For LT and LT+P soils, cumulative infiltration was similar with both application rates.

Greater I_f rates and infiltration amounts at different times for NT soil than for the other soils, both for the Sherm and Olton loams, are attributed to the greater OM of the NT soil (Table 1). Greater OM may provide more surface protection and results in a soil surface more resistant to aggregate dispersion and surface sealing than soil having lower OM and less-stable aggregates. Although MWD values did not exhibit the same trends as those for OM and infiltration, aggregates of NT soil may have been as or more stable, but smaller, than those of other soils. Hence, greater water stable aggregation possibly contributed to the greater infiltration for the NT soil.

The I_f rates and infiltration amounts at different times for both loams were or tended to be greater for NT than for other soils. This indicates that surface soil conditions in the field could be more favorable for infiltration with NT than with other tillage methods. Although the NT soil was disturbed during sampling and processing before making the determinations, the results still are considered applicable to the zone of NT soil in the field that is disturbed at crop planting. As a result, water infiltration in the field with NT may be as great as or greater than with other tillage methods, provided subsoil conditions do not differ greatly from those for other tillage methods. More surface residues with NT would further enhance infiltration, as would large biopores, if present (22).

Besides infiltration differences, this study suggests that surface sealing and subsequent surface crusting would be less intense with NT than with other tillage methods. For example, crust strength with time after rainfall on Pullman clay loam increased less on NT plots than on sweep, disk, rotary, or moldboard tillage plots (23), thus providing for more favorable conditions for seedling emergence with NT. Pullman clay loam is similar in many respects to the Sherm and Olton loams.

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REFERENCES

1. Chan, K.Y., Heenan, D.P. & Ashley, R. 1994. *Soil Tillage Res. 28*:301-314.
2. Dick, W.A. 1983. *Soil Sci. Soc. Am. J. 47*:102-107.
3. Haas, H.J., Evans, C.E. & Miles, E.F. 1957. *USDA Tech. Bull. 1164*. U.S. Gov. Print. Off., Washington, DC.
4. Hobbs, J.A. & Brown, P.L. 1965. *Tech. Bull. 144*. Kansas Agric. Exp. Stn., Manhattan, KS.
5. Sparling, G.P., Shepherd, T.G. & Kettles,

H.A. 1992. *Soil Tillage Res. 24*:225-241.
6. Unger, P.W. 1991. *Agron. J. 83*:186-189.
7. Armbrust, D.V., Dickerson, J.D., Skidmore, E.L. & Russ, O.G. 1982. *Soil Sci. Soc. Am. J. 46*:390-393.
8. DeBoodt, M.L., De Leenheer, L. & Kirkham, D. 1961. *Soil Sci. 91*:138-146.
9. Rawitz, E. & Hazan, A. 1978. *Soil Sci. Soc. Am. J. 42*:787-793.
10. Dexter, A.R., Radke, J.K. & Hewitt, J.S. 1983. *Soil Sci. Soc. Am. J. 47*:570-575.
11. Morin, J. & Benyamini, Y. 1977. *Water Resour. Res. 13*:813-817.
12. Wustamidin & Douglas, L.A. 1985. *Soil Sci. 139*:239-242.
13. Moore, I.D. 1981. *Trans. Am. Soc. Agric. Eng.* 24:1546-1561.
14. Morin, J., Benyamini, Y. & Michaeli, A. 1981. *J. Hydrology 52*:321-335.
15. Jackson, M.L. 1958. In Soil Chemical Analysis. Prentice-Hall, Englewood Cliffs, NJ, pp 205-226.
16. Kemper, W.D. & Rosenau, R.C. 1986. In Arnold Klute (Ed.) Methods of Soil Analysis, Part I. 2nd ed. Am. Soc. Agron., Madison, WI, pp 425-442.
17. Morin, J., Goldberg, S. & Seginer, I. 1967. *Trans. Am. Soc. Agric. Eng. 10*:74-79.
18. LeClerg, E.L., Leonard, W.H. & Clark, A.G. 1962. Field Plot Technique, 2nd ed. Burgess Publ. Co., Minneapolis, MN.
19. SAS Institute, Inc. 1985. SAS User's Gui de: Statistics. 1985 Edition. SAS Inst., Inc., Cary, NC.
20. Kemper, W.D. & Koch, E.J. 1966. *USDA Tech. Bull. 1355*. U.S. Gov. Print. Office, Washington, DC.
21. Unger, P.W. 199x. *Soil Sci. Soc. Am. J.* (submitted).
22. Edwards, W.M., Norton, L.D. & Redmond, C.E. 1988. *Soil Sci. Soc. Am. J. 52*:483-487.
23. Unger, P.W. 1984. *Soil Sci. Soc. Am. J. 48*:1423-1432.