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CONTROLLED TRAFFIC EFFECTS ON SOIL DENSITY, PENETRATION RESISTANCE, AND HYDRAULIC CONDUCTIVITY

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ABSTRACT

Winter wheat (Triticum aestivum L.) and grain sorghum [Sorghum bicolor (L.) Moench] were grown in rotation with limited irrigation at Bushland, Texas, from 1986 to 1992 on leveled plots. All equipment traffic was controlled. Tillage treatments were no-tillage with residues left standing (TRT-1) or shredded (TRT-2), and no-tillage after wheat and conventional tillage after sorghum (TRT-3). Soil penetration resistance (PR), bulk density (BD), and water content (WC) were determined at traffic furrow, non-traffic furrow, and row positions after the 1992 sorghum crop. In addition, hydraulic conductivity (HC), BD, and PR were determined on cores from those positions in the laboratory. Under field conditions, mean BD and PR were greatest in the traffic furrow; tillage had no effect on BD or PR. For laboratory cores, mean BD and PR were greatest for the traffic furrow and least for the non-traffic furrow. Tillage did not affect PR. Differences in HC due to tillage, sampling position, and sampling depth were not significant at the P = 0.05 level. These results show the importance of controlling traffic when no-tillage crop production systems are used.

INTRODUCTION

Conservation tillage is widely promoted because of the erosion control benefits that result from retaining crop residues on the soil surface. Surface residues, however, also enhance soil water conservation (1,2,3), which is highly important for successful crop production under non-irrigated conditions in semiarid regions. No-tillage results in greatest retention of residues, but concern often is expressed regarding the potential for the development of unfavorable soil physical conditions when it is used because the soil is not loosened by tillage. No-tillage had no consistent beneficial or detrimental effects on physical conditions of Pullman clay loam (Torrertic Paleustoll) under non-irrigated conditions (4). However, the potential for development of localized zones of unfavorable conditions seemed likely when the soil is irrigated and when all cultural operations are restricted to specified areas (controlled traffic). The objectives of this study were to compare the effects of controlled traffic in no-tillage and reduced-tillage plots on bulk density, penetration resistance, and hydraulic conductivity of soil used for winter wheat and grain sorghum production under limited irrigation conditions. Soil organic matter concentration was determined also.

METHODS AND MATERIALS

The study was conducted at the USDA Conservation and Production Research Laboratory, Bushland, Texas (USA), on Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) on which winter wheat and grain sorghum were grown in rotation from 1986 to 1992. Plots were leveled before starting the study, but plowed to form ridges at 1.0-m intervals for the study. Wheat drill row spacing was 0.25 m and sorghum row spacing was 1 m (one row per ridge). Crops were irrigated by flooding the plots when major plant water stress developed. Treatments, replicated three times, were no-tillage with residues left standing (TRT-1), no-tillage with residues shredded (TRT-2), and no-tillage after wheat and conventional tillage after sorghum (residues incorporated) (TRT-3). Complete details of the rotation study are given in Unger (5).

All equipment traffic on plots was restricted to specified furrows throughout the 6-year study. After sorghum harvest in 1992, various determinations were made under field and laboratory conditions. Sampling was done at traffic furrow, non-traffic furrow, and row positions. Bulk density (BD) was determined from 5.4-cm-diam. cores taken to a 50-cm depth at five locations for each position. Cores were separated into 10-cm-long segments, weighed, oven-dried at 105°C, and weighed again to determine water content. Penetration resistance (PR) was determined to a 50-cm depth at 10 locations at each position using a 12.8-mm diam. cone on a recording penetrometer (Bush Soil Penetrometer SP1000, Findlay Irvine Ltd., Penicuik, Midlothian EH26 9BU, Scotland)[1]. Values at 5-, 15-, 25-, 35-, and 45-cm depths were used to analyze the PR data statistically.

For laboratory determinations, cores were obtained from each furrow position at the surface and at a 10-cm depth. For row position cores, surface soil was removed so that the sampling level was the same as for furrow positions. The cores, 5.4 cm diam. and 3.5 cm long, were kept in plastic bags and refrigerated until determining hydraulic conductivity (HC) on eight cores from each position by the procedure of Klute (6). Conductivities were determined for 0- to 1-, 1- to 3-, and 3- to 6-hour periods. The data were scaled by the procedure of Warrick et al. (7) before statistical analysis. After determining HC, 10 measurements with a penetrometer (4.76-mm diam. flat point, Model 719-5MRP, John Chatillon & Sons, Kew Garden, NY 11415) were made on each core. Cores were dried at 60°C and weighed before calculating bulk density. The cores were then ground before determining organic matter concentration (OMC) by the modified Walkley-Black procedure (8).

Data were analyzed by the analysis of variance technique (9) and, when the F-test showed statistical significance at the 5% level (P = 0.05), the protected least significant difference (Prot. LSD) procedure was used to separate means.

RESULTS AND DISCUSSION

Significance levels of F values, as determined by the analysis of variance technique, are given in Table 1. No variable [sampling depth (D), sampling position (P), or tillage method (T)] had a significant effect on soil HC. Except for OM concentration that was affected only by the D variable, all remaining factors were significantly affected by the D and P variables and the D x P interaction. No P x T x D interaction was significant and the values are not shown. Because tillage methods did not significantly affect any of the measured factors, except BD of laboratory cores, data given in Table 2 are for position and depth averaged across tillage methods. Effects of tillage on BD of laboratory cores are given in the text.

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[1] Names are necessary to report factually on available data: however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

Table 1. Significance levels of F values for soil variables as influenced by sampling depth (D), sampling position (P), and tillage treatment (T).

Soil variable	Significance level of F value for					
	D	P	P x D	T	T x D	P x T
Field determinations						
Bulk density	.0005	.0025	.0002	.1682	.4751	.7085
Penetration resistance	.0001	.0001	.0001	.1494	.8813	.2721
Water content	.0002	.0012	.0006	.5593	.9875	.4303
Lab determinations						
Hydraulic conductivity						
0 - 1 hour	.1889	.1638	.2977	.3243	.2008	.4661
1 - 3 hour	.1358	.1295	.4131	.2291	.1969	.2328
3 - 6 hour	.1778	.1691	.6170	.2711	.2230	.2725
Penetration resistance	.0016	.0079	.3272	.2011	.0767	.3056
Organic matter conc.	.0425	.2672	.5024	.2067	.1529	.6149
Bulk density	.0059	.0012	.0016	.0203	.0378	.5437

Large core or field determinations

Mean soil BD was greatest at the traffic furrow and similar at the non-traffic furrow and row positions for all tillage methods. Although significant, mean differences were not large because differences among positions at individual depths were significant only for the 0- to 10-cm depth increment. At this depth, BD was greatest in the traffic furrow because of repeated traffic and least in the non-traffic furrow because of no traffic. Greater BD at the row position than at the non-traffic furrow position at the 0- to 10-cm depth is attributed to some soil compression during crop planting, especially sorghum that was planted on ridges where the row sampling occurred. At other depths, differences among positions were not significant. Except for the same BDs at 10 to 20 and 20 to 30 cm, BD increased with depth, which is typical for Pullman soil (10).

Mean water contents (WCs) were similar for both furrow positions, but both were greater than for the row position. Differences occurred mainly in the two upper increments where WC for the row position was lowest. Lower WC in the row possibly resulted from greater water use by sorghum. Decreasing WCs with depth suggest that late growing-season or post-harvest rainfall may have partially replenished the soil water supply near the surface.

Penetration resistance at 5 cm was greatest in the traffic furrow and least in the non-traffic furrow. At 15 cm, PR was greater in the traffic furrow than at other positions and, at 25 cm, it was greater at both furrow positions than at the row position. Differences at 35 cm were not significant, but PR was less at the row position than in the non-traffic furrow at 45 cm. Greater PRs at 5, 15, and 25 cm and the mean for the traffic furrow resulted from traffic being confined to that position during the 6-year study. Greater PR at 5 cm for the row than for the non-traffic furrow is attributed to greater soil compression during crop planting, as mentioned previously. Reason for the difference at 45 cm is not apparent. Mean PR was greatest for the traffic furrow position because of repeated traffic. It was least for the row position because no traffic occurred there and possibly because of greater root activity. Mean PR increases with depth, in a general way, followed mean BD increases and water content (WC) decreases with depth. Based on multiple regression analysis, PR was related to BD and WC as given by:

Table 2. Sampling position and depth effects on soil conditions in a controlled-traffic study for wheat and grain sorghum production, Bushland, Texas (U.S.A.)

	Position			
Depth	Traffic	Non-Traffic	Row	Mean
cm	Bulk density — g/cm³ (field)			
0 - 10	1.52	1.40	1.45	1.46
10 - 20	1.51	1.52	1.50	1.51
20 - 30	1.51	1.50	1.51	1.51
30 - 40	1.54	1.55	1.53	1.54
40 - 50	1.57	1.55	1.57	1.56
Mean	1.53	1.50	1.51	
LSD (0.05): Depth (D) — 0.031, Position (P) — 0.014, P x D — 0.035				
	Water content — % by volume (field)			
0 - 10	40.5	41.2	38.2	40.0
10 - 20	38.9	40.1	38.3	39.1
20 - 30	37.3	37.3	37.4	37.3
30 - 40	36.5	36.9	36.7	36.7
40 - 50	35.8	35.4	36.0	35.7
Mean	37.8	38.2	37.3	
LSD (0.05): Depth (D) — 1.2, Position (P) — 0.43, D x P — 1.06				
	Penetration resistance — MPa (field)			
5	0.62	0.30	0.47	0.46
15	0.88	0.56	0.64	0.69
25	1.30	1.23	1.04	1.19
35	1.58	1.65	1.63	1.53
45	1.79	1.89	1.69	1.79
Mean	1.23	1.13	1.04	
LSD (0.05): Depth (D) — 0.07, Position (P) — 0.07, D x P — 0.16				
	Bulk density — g/cm³ (laboratory)			
0 - 3.5	1.53	1.33	1.45	1.44
10.0 - 13.5	1.60	1.59	1.56	1.58
Mean	1.57	1.46	1.51	
LSD (0.05): Depth (D) — 0.05, Position (P) — 0.04, D x P — 0.06				
	Organic matter concentration — g/kg (laboratory)			
0 - 3.5	18.3	17.2	17.1	17.6
10.0 - 13.5	14.3	13.8	14.2	14.1
Mean	16.3	15.5	15.7	
LSD (0.05): Depth (D) — 3.2, Position (P) — NS, D x P — NS				
	Penetration resistance — MPa (laboratory)			
0 - 3.5	0.37	0.17	0.28	0.27
10.0 - 13.5	0.43	0.33	0.46	0.41
Mean	0.40	0.25	0.37	
LSD (0.05): Depth (D) — 0.02, Position (P) — 0.08, D x P — 0.12				

$$PR = 3.125 + 3.960\ BD - 0.211\ WC\ (R^2 = 0.886)$$

The significance level of the F value was 0.037 for the BD effect and 0.0003 for the WC effect, suggesting that the relatively slight decreases in WC with depth had a greater effect on PR increases with depth than the increases in BD with depth.

Laboratory determinations

Differences in HC due to tillage methods, sampling positions, and sampling depths were not significant at the 0.05 level, but were significant at levels between 0.13 and 0.19 for depths and positions and between 0.22 and 0.33 for tillage (Table 1). For all periods (0 to 1, 1 to 3, and 3 to 6 hours), HCs were greater for TRT-3 than for TRT-1 and TRT-2, for which they were similar; greatest for the row position and least for the traffic furrow position; and greater for the 0- to 3.5-cm (upper) and than for the 10.0- to 13.5-cm (lower) depth (data not shown). These trends were, in a general way, inversely related to trends in PR and BD of the cores, as discussed in following paragraphs and shown in Table 2.

Soil BD was lower for the 0- to 3.5-cm depth than for the 10.0- to 13.5-cm depth at all positions, which resulted in a lower mean for the 0- to 3.5-cm depth. For that depth, BD was greatest for the traffic furrow and least for the non-traffic furrow. For the lower depth, BDs were similar for all positions. Mean BD was greatest for the traffic furrow and least for the non-traffic furrow because of differences for the upper depth, with these results reflecting the influence of traffic control during the 6-year study period. Mean BDs were 1.51, 1.55, and 1.48 g/cm^3 for TRT-1, TRT-2, and TRT-3, respectively, with a difference of 0.043 needed for statistical significance. The lower BD for TRT-3 resulted from soil loosening by tillage after sorghum harvest in previous years of the study. For TRT-1 and TRT-2, the soil was not loosened during the 6-year study period. Soil loosening also contributed to the significant tillage x depth interaction effect (Table 1). Because of soil loosening at previous times during the rotation study, mean BD for the upper depth of TRT-3 was lower than for the other treatments, especially for non-traffic furrow and row positions (data not shown). Means were similar for all treatments for the lower depth.

Soil OMC was significantly greater for the upper than for the lower sampling depth. A sharp decline in OMC with depth is typical for Pullman clay loam (10), and especially under no-tillage conditions (11). Differences in OMC due to tillage methods and sampling positions were not significant, but OMC tended to be greater on TRT-1 and TRT-2 (only no-tillage) plots than in TRT-3 plots (data not shown) and greater for the traffic furrow than for the other positions. The trend due to positions probably resulted from the greater density of the traffic furrow soil that may have slowed microbiological activity and, hence, breakdown of surface residues and incorporation of residual organic materials with soil.

Soil PRs were similar for both depths at the traffic furrow position. In the non-traffic furrow and row positions, the lower depth had a greater PR, resulting in mean PR across all positions being greatest for the lower depth. For the upper depth, PR was greater in the traffic furrow due to repeated traffic than in the non-traffic furrow that received no traffic during the 6-year study. Although not significant at the 0.05 level, traffic contributed to the trend toward the greater PR in the traffic furrow as compared with that in the non-traffic furrow for the lower depth. However, at that depth, PRs for traffic furrow and row positions were similar, indicating that traffic alone does not influence differences in PR. This is indicated also by the means for non-traffic furrow and row positions, which differed significantly. Greater PR for the row position, which occurred also under field conditions, is attributed to soil compression at crop planting that was previously mentioned. Soil PR was significantly related to BD, but not to soil OMC, as determined by regression analysis. The relationship is given by:

$$PR = -1.020 + 0.901\ BD\ (R^2 = 0.774)$$

Soil WCs were uniformly high when PRs were measured and, hence, were not considered to be a factor that affected PR of the cores.

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