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Infiltration and Soil Properties as Affected by Annual Cropping in the Northern Great Plains

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ABSTRACT

Fallow–wheat (*Triticum aestivum* L.) cropping systems may be responsible for declines in soil organic matter and degradation of soil physical properties. A change to annual cropping may improve or at least maintain soil properties. Tillage and crop sequence effects on soil properties and water infiltration were tested after 9 yr of cropping on a Dooley sandy loam (fine-loamy, mixed Typic Argiborolls) derived in glacial till. Annual cropping tillage of fall sweep and spring disk (AWFST), and no tillage (AWNT) were compared with conventional tillage in wheat-fallow (FWCT) as the control. Statistical design was a randomized complete block with four replications. Soil samples were taken at 0.03-m increments to a depth of 0.3 m and were used to measure organic carbon (OC), pH, bulk density (BD), and particle size. Point resistance was measured in 0.02-m increments. Water infiltration into dry and wet soil was measured using a rainfall simulator. Maximum soil BD was 1.61 Mg m^{-3} on FWCT and 1.56 Mg m^{-3} on AWNT. Soil BD was not changed by one winter of freezing and thawing. Maximum point resistance was 2.2 MPa on FWCT and 1.7 MPa on AWNT. Cumulative 3-h infiltration into dry soil was 52 mm for FWCT and 69 mm for AWNT. Final infiltration rate into wet soil was 5 mm h^{-1} for FWCT and 6 mm h^{-1} for AWNT. There was a significant difference in the depth distribution of OC between annual crop and FWCT treatments. Mass of OC in the top 0.09 m of soil was 1.65 kg m^{-2} on annual crop treatments and 1.45 kg m^{-2} on FWCT. Greater amounts of OC on the annual crop treatments compared with the FWCT attest to the beneficial aspect of annual cropping in maintaining a level of soil quality that is greater than FWCT. From a soil conservation perspective, no-tillage has an additional advantage because surface cover is maintained throughout the year, thereby reducing the potential for soil erosion.

FALLOW–CROP ROTATIONS are used throughout the semiarid wheat producing regions of the United States and Canada. Considerable research has been conducted on relationships among cropping sequence, soil organic matter, and various biological and physical soil properties. It is generally accepted that crop production alone has caused a decline in soil organic matter on the northern prairies (Campbell and Souster, 1982; Monreal and Janzen, 1993). As the common practice, the fallow–wheat crop sequence has been implicated as the cause of serious declines in organic matter (Rasmussen and Parton, 1994; Monreal and Janzen, 1993; Biederbeck et al., 1984).

Organic matter is linked to fertility and desirable soil tilth. Boyle et al. (1989) provided a review of the influence of organic matter on soil aggregation and water infiltration. They indicate that organic matter is related to important biological and chemical soil properties and has a disproportionate effect on soil physical behavior. Hudson (1994) reported that soils high in organic matter have greater available water-holding capacity than soils of similar texture with less organic matter. Bauer and Black (1992) found that a decline in soil organic matter did not change the available water-holding capacity of moderately coarse-textured soils, but increased the available water-holding capacity in medium- and fine-textured soils because of an increase in soil bulk density. Soane (1990) reported that soil compaction is sensitive to small changes in organic matter and, generally, decreases with increasing organic matter.

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Abbreviations: AWFST, annual wheat with fall sweep and spring disk tillage; AWNT, annual wheat with no tillage; BD, bulk density; FWCT, fallow–wheat with conventional tillage; OC, organic carbon; SSE, error sum of squares; TPR, total penetration resistance.

The relationship of soil organic matter to soil physical behavior is not always clearly defined. Organic C accounted for about 70 to 90% of the variability in soil aggregate stability of a clay loam soil (Mbagwu and Bazzoffi, 1989). Bruce et al. (1992) determined that increased phytomass input to a loamy sand increased aggregate stability and water infiltration. On a silt loam, Pikul et al. (1993) found a significant correlation of bulk density and organic C with cone index (a measure of penetrometer resistance) within the tillage layer. Long-term tillage, residue management, and N-fertility had significant effects on soil organic matter content near the surface. Pikul and Zuzel (1994) reported that soil organic matter had a significant effect on porosity of surface crusts. Mulla et al. (1992) attempted to quantify differences in aggregate stability between conventional and alternative farms. They were not able to establish a relation between soil organic matter and physical behavior of a Naff silt loam (65% silt; Ultic Argixerolls), although surface crusting was observed on the conventional but not on the alternative farm.

A clear statement cannot always be made concerning the effect of no-tillage on runoff and infiltration. Seta et al. (1993) found that reduced tillage reduced runoff and sediment loss from 0.01-ha runoff plots subjected to simulated rainfall. At the watershed scale, Edwards et al. (1993) could not confidently evaluate the erosion-controlling benefits of no-tillage in a corn–soybean rotation because of great year-to-year variability in measured erosion. Increased water transmission in no-till soil has been attributed to surface connected macropore channels (Ehlers, 1975).

Variable relations between tillage and soil bulk density have been observed. Investigators have reported that greater bulk densities can be expected with no-tillage as compared with conventional tillage practices (Rhoton et al., 1993; Vyn and Raimbault, 1993; Bruce et al., 1990). There are reports that tillage has had an insignificant effect on bulk density (Blevins et al., 1983; Chang and Lindwall, 1990). Mielke et al. (1984) found that fallow tillage did not affect bulk density in a silt loam soil; however, reduced tillage reduced soil bulk density in a loam soil.

There is not a standard method for characterizing soil bulk density, and interpretation of research findings can be difficult because large sampling increments may overlap layers of compacted and noncompacted soil and dilute or mask treatment effects. Investigators using thin sampling increments of 0.02 m have successfully identified unique profiles of C and bulk density in long-term tillage and residue management experiments (Allmaras et al., 1988; Pikul and Allmaras, 1986; Pikul et al., 1993).

Our experiment was part of a larger cropping and tillage management study that was designed to test the suitability of annual cropping in the hard red spring wheat production area of the northern Great Plains. We selected three treatments from the larger study for detailed soil investigation. Annual wheat with no tillage and fallow-wheat with conventional tillage represent management extremes, while annual wheat with fall and spring tillage was intermediate. As part of this larger study, Aase and Schaefer (1996) have shown that annually cropped no-tillage wheat was the most profitable cropping practice. Soil organic matter levels in the top 0.08 m of the FWCT treatment of this study have decreased at about 0.4 g kg^{-1} yr^{-1} during the last 10 yr. In contrast, there has been a negligible decrease of organic C on the annually cropped treatments (see the companion paper, Aase and Pikul, 1995). Our objectives were to determine the effects of tillage and crop sequence on soil properties and water infiltration after 9 yr of cropping in the northern Great Plains.

MATERIALS AND METHODS

Experimental Site

Soil at the research site, located 11 km north of Culbertson, MT, is a Dooley sandy loam (fine-loamy, mixed Typic Argiborolls) on about a 2% slope. Average annual precipitation is 360 mm, with about 290 mm (80%) occurring during the growing season, April through September.

Prior to 1975, the experimental area was in grass. Between 1975 and the start of the experiment in 1983, small grains were grown annually and seedbeds were prepared using tandem disk tillage in the spring. Experimental design was a randomized complete block with four replications. Plots were 30 m long by 12 m wide. Two treatments were annually cropped spring wheat with sweep tillage in the fall and tandem disk tillage for seedbed preparation in the spring (AWFST) or no tillage, cropped annually with spring wheat (AWNT); a third treatment was fallow–spring wheat rotation using tandem disk tillage in the spring for seedbed preparation (FWCT). The fallow–wheat rotation is the control, because most wheat farming in the area has fallow in the rotation. Sweep tillage was with 0.45-m-wide medium-crown sweeps. Tillage during summer of the fallow year on the FWCT treatment was conducted with sweeps as necessary to control weeds. Additional details of the cultural operations on this experiment have been reported by Aase and Reitz (1989).

Bulk Density, pH, and Organic Carbon

Soil bulk density samples were taken with a tube sampler as described by Allmaras et al. (1988). The sampler has a cutting tip of 19.6 mm. Samples were randomly collected from each replicate in the fall of 1992. Trafficked areas were avoided. Soil conditions for bulk density measurement were ideal, because the soil was firmly settled following the wheat crop and a late season rain had uniformly wetted the soil. Soil cores that compacted during sampling were discarded, as were cores damaged by rocks. The small-diameter cutting tip provided a degree of quality control because large stones were excluded. The last soil disturbance on all treatments was at planting in the spring of 1992. On each replicate, six intact 0.27-m cores were cut into 0.03-m increments, resulting in 24 measurements of soil bulk density for each 0.03-m increment on each treatment.

To evaluate the effect of soil freezing on bulk density, measurements were repeated on the AWNT and FWCT treatments in the spring of 1993. Analysis of variance showed that there were no differences of soil bulk density at each soil depth between years, therefore we combined the measurements from the 2 yr. The combined data provided 48 soil bulk density measurements for each depth in both AWNT and FWCT treatments.

Soil pH and organic C were determined on the same samples that were collected for bulk density. Samples were air dried. For soil pH and soil C determinations, samples were ground and sieved through a 2.0-mm sieve. For soil C determinations, visible plant residues were removed and the soil was further sieved through a 0.5-mm sieve. Soil C was determined by combustion using an automatic C–N analyzer (Model 1500, Carlo

Erba Manufacturing, Milan, Italy[1]). There are significant amounts of $CaCO_3$ in the soil, starting at about the 0.20-m depth; therefore, soil samples starting at about 0.15 m in depth were treated with a dilute solution of HCl to remove inorganic C prior to combustion. Soil pH was measured in a 1:1 soil water paste.

Point Resistance and Particle Size

In the fall of 1992, total penetration resistance (TPR) was measured with a Soiltest CL-700 (Soiltest, Evanston, IL) pocket penetrometer with a 6.35 mm diameter blunt tip. Results of measurements with the penetrometer are referred to as point resistance in the figures. The unconfined compressive strength scale on the barrel of the instrument was converted to read in units of total penetration resistance (kPa) by calibrating the penetrometer using a load cell (Bradford, 1980). Our calibration was linear with $r^2 = 0.999$.

A trench was dug close to where we obtained the soil cores for bulk density to obtain a depth profile of TPR. The trench face was carefully prepared for TPR measurements by scraping off several centimeters of soil. Three transects were laid out in 0.02-m increments to a depth of 0.28 m on the trench face. On each replicate, there were three measurements of TPR for each 0.02-m depth increment, resulting in 12 measurements of TPR for each 0.02-m increment on each treatment. Measurements of TPR were obtained by pushing the penetrometer horizontally into the profile. Immediately after the TPR measurements, soil samples for gravimetric water content were taken at 0.04-m increments to a depth of 0.28 m. Gravimetric water content was converted to volumetric water using soil bulk density. This method of soil exploration on a glacial till soil worked well because we were able to avoid rocks.

The hydrometer method (Gee and Bauder, 1986) was used to determine soil texture on the same samples that were taken for soil bulk density. Individual samples for each depth within a replicate were bulked together prior to analysis. Sand fractions were separated by sieving the sediment and suspension from 1-L sedimentation cylinders. Sieve sizes were 2.0 to 1.0 mm, 1.0 to 0.5 mm, 0.5 to 0.25 mm, 0.25 to 0.105 mm, and 0.105 to 0.053 mm. These sieve sizes generally follow the USDA classification for very coarse sand, coarse sand, medium sand, fine sand, and very fine sand, respectively.

Water Infiltration

A Palouse rainfall simulator (Bubenzer et al., 1985) was used to apply water at a rate of about 40 mm h^{-1} to 1.16- by 1.16-m infiltration frames. Electrical conductivity of water (Culbertson, MT, municipal water supply drawn from the Missouri River) used for the infiltration tests was 0.7 dS m^{-1} and concentration of cations was 0.157 g L^{-1}. The simulator has two rainfall heads that are used to run duplicate infiltration tests for each setup. Simulated rainfall mimics low-intensity storms of the inland Pacific Northwest. Typical summer rainstorms in the northern Great Plains are of high intensity and short duration. The Palouse simulator produces drop sizes about 1.3 to 1.8 mm diameter. By comparison, natural rainfalls with intensities of about 50 mm h^{-1} have drop sizes that are about 1 to 5 mm in diameter (Wischmeier and Smith, 1958). Therefore, the test soil was not exposed to rainfall energy that exceeded that of naturally occurring storms.

Infiltration tests were conducted on three of the four replicates of the AWNT and FWCT treatments, resulting in six infiltration tests on each of the two treatments. These treatments were selected for infiltration tests because they represent management extremes. Measurements were made during spring and summer of 1993. Customary fallow tillage on FWCT was postponed, to avoid disturbance of the standing wheat residue from the 1992 crop. Herbicides were used to kill plant growth within the designated infiltration test areas on both treatments. Therefore, surface conditions and soil water content on both treatments were similar, even though we compared a wheat-fallow treatment with an annual crop treatment.

Infiltration frames were constructed of heavy-gauge steel. To install the frame to a depth of 0.25 m, we carefully dug a shallow and narrow trench around the outside of the frame. As layers of soil were removed, the infiltration frame was forced downward to enclose an undisturbed soil monolith. Soil was then backfilled and compacted around the outside of the frame. Inside edges of the infiltration frames were sealed with bentonite clay to prevent any water leakage along the metal-soil interface.

Water application by the rainfall simulator was measured at the start and finish of each infiltration test. Application rate was determined by collecting the runoff from a 1.35-m^2 calibration pan placed over the infiltration frame. Infiltration was calculated as the difference between application rate and runoff rate. Excess water was removed from within the infiltration frame by vacuum. Water was applied in a cycle of 3 h on Day 1, 20 h off, and 3 h on Day 2. This cycle is often described as a dry and wet run and is conducted to reduce the confounding effects of variable soil water content in the infiltration tests.

Values of OC, pH, BD, and TPR among treatments were tested for significance at each sampling depth using analysis of variance and least significant differences (LSD) at $P = 0.05$. Standard error of the mean was used to show variability in water infiltration rate as a function of time for AWNT and FWCT. Multiple linear regression analysis was used to identify relations of TPR with BD and OC at $P = 0.05$.

A linear regression model (Neter et al., 1990) was used to test whether the distributions of OC with depth on the AWNT, AWFST, and FWCT treatments were significantly different (Table 1). Briefly, a test statistic F^* was calculated using error sum of squares for the full and the reduced models (SSE_f and SSE_r, respectively) as

$$F^* = [(SSE_r - SSE_f)/2] \div [SSE_f / (n_1 + n_2 - 4)] \quad [1]$$

where $SSE_f = SSE_{FWCT} + SSE_{AWNT,AWFST}$ and SSE_r is the error sum of squares of the pooled data for AWNT, AWFST, and FWCT (reduced model). The error sum of squares for the full model, SSE_f, contains the error sum of squares for the FWCT treatment, SSE_{FWCT}, and the error sum of squares of the pooled data for the AWNT and AWFST treatments, $SSE_{AWNT,AWFST}$. The

Table 1. Regressions and analysis of variance for organic carbon predicted with soil depth.

Regression coefficients		Analysis of variance			
Slope	Intercept	Source	df	Sum of squares	P
FWCT†					
−31.85	13.30	Regression	1	25.56	0.001
		Error	5	0.22‡	
AWNT and AWFST, pooled					
−42.71	15.37	Regression	1	91.93	0.001
		Error	12	4.86‡	
AWNT, AWFST, and FWCT pooled§					
−39.09	14.68	Regression	1	115.51	0.001
		Error	19	11.11‡	

† FWCT, fallow-wheat with conventional tillage; AWNT, annual wheat with no tillage; AWFST, annual wheat with fall and spring tillage.
‡ Error sum of squares: used in Eq. [1] to calculate F-test statistics.
§ Reduced model.

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[1] Mention of a specific proprietary product does not constitute a recommendation by the USDA and does not imply approval to the exclusion of other suitable products.

greater the difference between F^* and tabulated F-values (F_{tab}), the more the data support a hypothesis that the two regression lines represent two different populations.

RESULTS AND DISCUSSION

Physical Properties

Soil organic C profiles (Fig. 1) show that on the annual wheat treatments (AWFST and AWNT) there was a greater concentration of organic C near the surface as compared with FWCT. Organic C profiles reflect cumulative long-term differences between annual wheat and fallow–wheat rotations. On an annual basis, there has been about 40% less crop residues returned to the soil on the FWCT treatment compared with the annual crop treatments, and the depth distribution of organic C (Fig. 1) reflects this difference.

A linear regression model was used to test whether the distributions of OC with depth (Fig. 1) on the AWNT, AWFST, and FWCT treatments were significantly different. There was a significant ($P = 0.001$) correlation between OC and soil depth for each of the three treatments (regression lines are not shown in Fig. 1). Correlation coefficients for AWNT, AWFST, and FWCT were 0.99, 0.96, and 0.99; respectively. Linear regression lines for the AWNT and AWFST treatments were not significantly different; therefore, OC values for the AWNT and AWFST treatments were pooled and the regression line for the annual crop treatments was compared with the FWCT treatment (Table 1). Statistical comparison of the regression lines for OC distribution on annual cropped and FWCT treatments shows that there are two populations: $F_{tab}(0.95, 2,17) = 3.59$ and $F^* = 10.08$ (Eq. [1]).

Nine years of annual cropping had a slight but significant ($P = 0.05$) effect on organic C near the surface. Mass of soil OC in the top 0.09 m was 1.65 kg m^{-2} on annual crop treatments and 1.45 kg m^{-2} on FWCT. Mass of soil organic C (kg m^{-2}) was calculated as the product of organic C concentration (g kg^{-1}), soil bulk density (Mg m^{-3}), and sample increment (m) summed across depth. Mass of organic C in the top 0.21 m was not significantly different between annual cropped and FWCT treatments, even though there was 8% more organic C on the annual cropped treatments compared with FWCT treatment.

There was little difference in soil pH among the three treatments (Fig. 2). In the top 0.05 m of the AWFST and FWCT treatments, there was a trend toward uniformity of soil pH that probably reflects shallow tillage on both of these treatments. Tillage on AWFST and FWCT was never deeper than 0.10 m and often only 0.05 m deep. We cannot explain why significant differences in pH appear only near the bottom of the test profile. All treatments except fallow received 56 kg N ha^{-1} as NH_4NO_3 (34-0-0 N-P-K) broadcast at the time of seeding in 1983, 1984, and 1985. In 1986, the rate was changed to 34 kg N ha^{-1}. Fallow plots received 34 kg N ha^{-1} in every crop year. In the top 0.08 m of soil on all treatments, pH declined about 0.6 units during the life of the larger study.

The test soil is a glacial till and there is large spatial variability in soil texture. For example, on field plots within a 79- by 137-m area adjacent to this study we measured sand, silt, and clay contents in the top 2 m at seven depths and 54 locations. At the 0.38- to 0.53-m depth, average sand content was 57%, with a minimum of 34% and a maximum of 73%. Similarly, clay content varied from 13% to 40%. Fortunately, the extreme variability in soil texture found in the subsoil was not present in the upper 0.3 m of soil. Soil particle size analysis of individual sampling depths on each replication and treatment revealed no statistical difference among treatments. Results for individ-

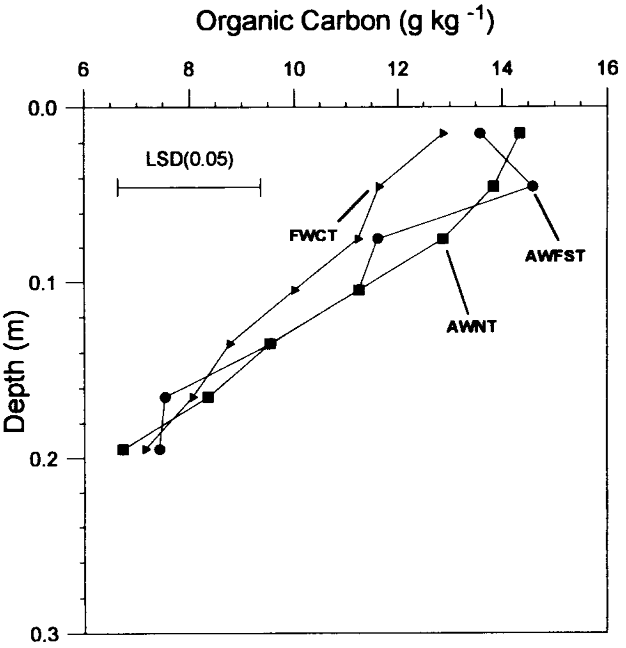

Fig. 1. Soil organic C on annual wheat treatments with fall and spring tillage (AWFST), and no tillage (AWNT), and fallow–wheat with conventional tillage (FWCT). For those depths where significant differences exist among treatments, bars indicate LSD (0.05).

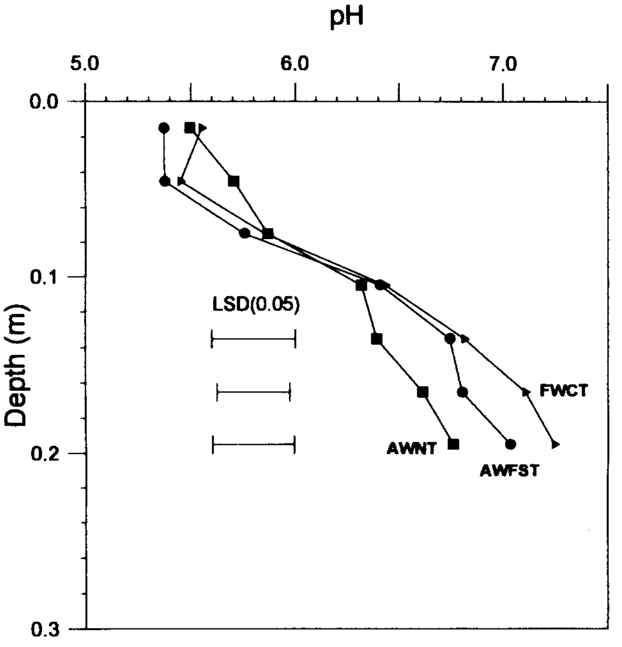

Fig. 2. Soil pH on annual wheat treatments with fall and spring tillage (AWFST), and no tillage (AWNT), and fallow–wheat with conventional tillage (FWCT). For those depths where significant differences exist among treatments, bars indicate LSD (0.05).

ual analysis at each depth were averaged and are shown in Fig. 3.

Soil bulk density in the top 0.12 m reflects a significant difference between annually cropped treatments and fallow-wheat rotation (Fig. 4). Maximum bulk density was 1.61 Mg m^{-3} on FWCT at a depth of 0.075 m. On the AWNT, bulk density at this same depth was 1.55 Mg m^{-3}. The zone of maximum soil bulk density roughly corresponds to the depth of tillage on FWCT. Abrupt changes in soil texture are not the cause of this distinct bulge in bulk density (Fig. 3).

One winter of soil freezing and thawing had no effect on reducing soil bulk density. During the winter of 1992-1993, the soil froze to a depth that exceeded one meter. Soil water content of the top 0.20 m was about 0.20 m^3 m^{-3} at onset of freezing. We measured soil bulk density in the fall and spring, to test a concept that compacted layers are quickly ameliorated by freeze-thaw effect. There was no soil disturbance between fall and spring sampling. Voorhees and Benoit (1990) have reported that even seven annual freezing and thawing cycles were not sufficient to ameliorate subsoil compaction.

Point resistance values generally show the same trends as soil bulk density (Fig. 5). Maximum point resistance was 2160 kPa on FWCT at a depth of 0.12 m. On AWNT at this same depth, point resistance was 1650 kPa. Point resistance profiles also revealed that the AWFST had a maximum point resistance of 2210 kPa at a depth of 0.10 m, which is contrary to what one would expect based on bulk density profiles (Fig. 4). Soil water content on the AWFST treatment was generally less than AWNT and FWCT (Fig. 5), and this may account for the apparent discrepancy. However, water content in the upper 0.12 m was not statistically different among treatments and was not significantly correlated with point resistance.

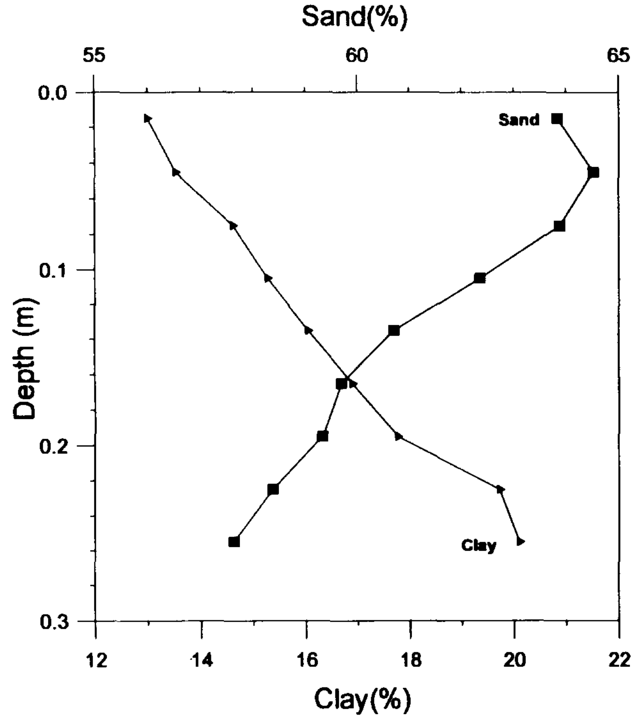

Fig. 3. Percent sand and clay for Dooley sandy loam.

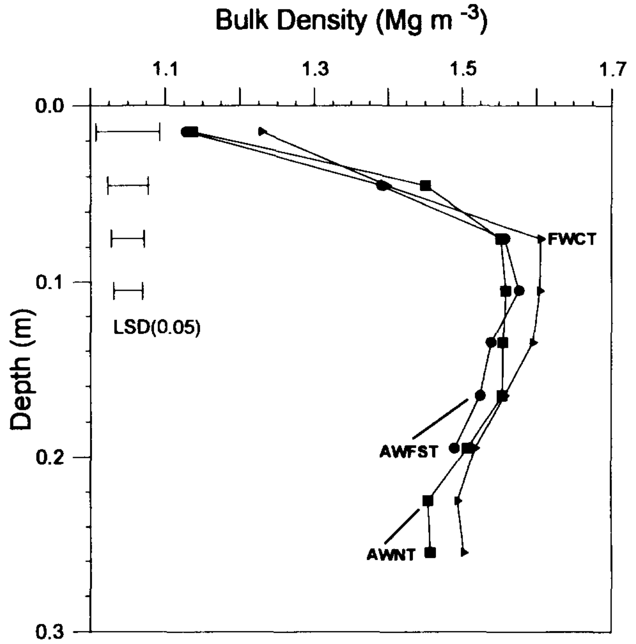

Fig. 4. Soil bulk density on annual wheat treatments with fall and spring tillage (AWFST), and no tillage (AWNT), and fallow-wheat with conventional tillage (FWCT). For those depths where significant differences exist among treatments, bars indicate LSD (0.05).

Multiple linear regression was used to identify relations among point resistance, bulk density, and soil organic C in the upper 0.15 m of soil. This depth was selected to include all of the maximum values of point resistance, bulk density, and soil organic C. Point resistance is also

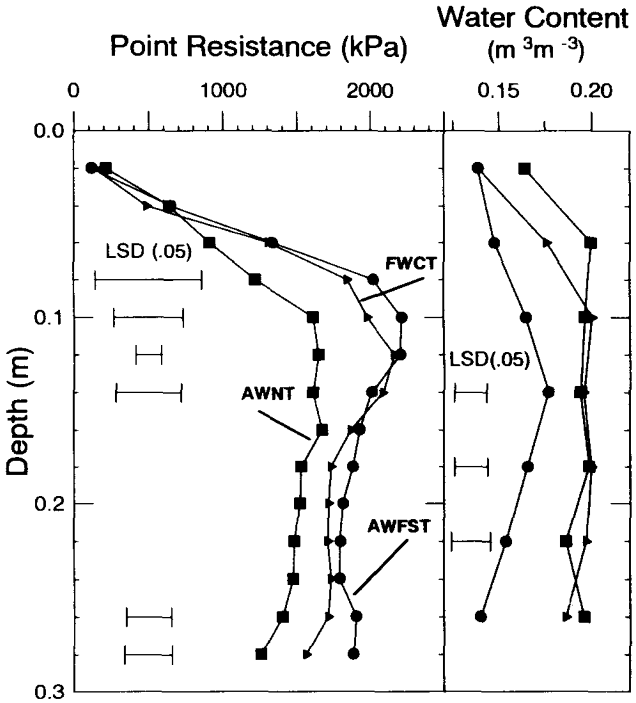

Fig. 5. Total point resistance and volumetric water on annual wheat treatments with fall and spring tillage (AWFST), and no tillage (AWNT), and fallow-wheat with conventional tillage (FWCT). For those depths where significant differences exist among treatments, bars indicate LSD (0.05).

related to soil texture. However, no significant soil textural differences existed among treatments, and therefore soil texture was not used as a predictor in the regression analysis.

Within the upper 0.15 m, soil bulk density was the only significant predictor of point resistance (Table 2). Bulk density as a single predictor (data not shown) accounted for 80, 64, and 83% of the variation in point resistance on AWFST, AWNT, and FWCT, respectively.

The small R^2 (square of the multiple correlation coefficient) value on the AWNT as compared with AWFST and FWCT suggests a unique soil structure on the AWNT treatment, which may be best quantified using a small probe such as the pocket penetrometer. Total point resistance measurements with the pocket penetrometer, which had a tip diameter of 6.35 mm, may have been sensitive to small cracks and voids that were not detectable at the relatively large soil sampling scale that was used for bulk density. Small-scale variation in soil structure as detected with the pocket penetrometer did not have a one-to-one relation with the bulk density measurements obtained at another scale. Continuous no tillage has preserved vertical and horizontal root paths, whereas annual tillage on AWFST and FWCT destroyed continuity of root channels. Both the bulk density and penetrometer measurements show that the soil on AWNT is more mellow than on AWFST or FWCT.

Water Infiltration

There was a weak relationship between infiltration rate and cropping system. Infiltration rate was significantly greater on AWNT than on FWCT during the first hour of the first day (Fig. 6). This difference disappeared over the course of the infiltration run. The final infiltration rate was 16 mm h^{-1} on AWNT and 13.1 mm h^{-1} on FWCT. On the second day, there was virtually no difference in water infiltration between AWNT and FWCT, with a final infiltration rate of 6.3 mm h^{-1} on AWNT and 5.1 mm h^{-1} on FWCT. We expected larger differences in infiltration rates between treatments because of significant differences in profile properties of soil bulk density and point resistance.

Measured infiltration rates support local observations. Early in the growing season runoff is rarely seen; by midsummer, however, runoff can be severe after high-intensity thunderstorms. Runoff problems coincide in time with a perception by field workers that the soil becomes very hard and difficult to work. Sweep tillage implements penetrate the soil only with difficulty and appear to ride on the layer of high point resistance at about 0.10 m.

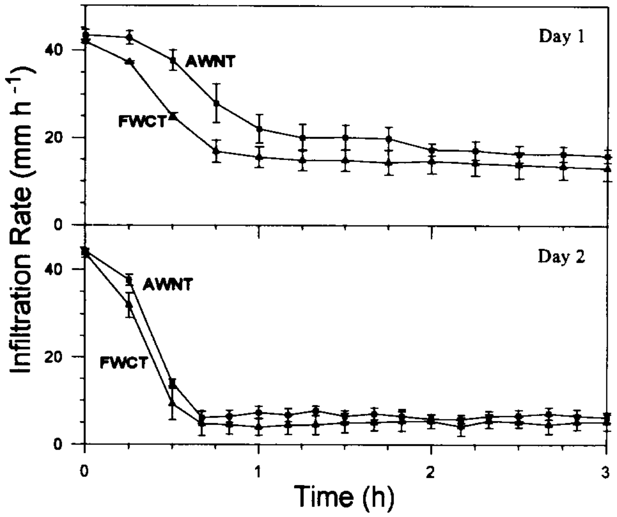

Fig. 6. Water infiltration for Day 1 (dry run) and Day 2 (wet run) on annual wheat treatment with no tillage (AWNT) and fallow–wheat treatment with conventional tillage (FWCT). Error bars indicate ±1 standard error of the mean.

Table 2. Linear regression coefficients for predicting total point resistance from bulk density and organic carbon on annual wheat with fall and spring tillage (AWFST), annual wheat with no tillage (AWNT), and fallow–wheat with conventional tillage (FWCT).

Cropping system	Predictor	Coefficient	*P*-value
AWFST	Constant	−3254	0.015
	Bulk density	3988	0.001
	Carbon	−892	0.057
	R^2 = 0.85*		
AWNT	Constant	−1758	0.207
	Bulk density	2449	0.001
	Carbon	−595	0.241
	R^2 = 0.69*		
FWCT	Constant	−5452	0.001
	Bulk density	4817	0.001
	Carbon	−369	0.332
	R^2 = 0.85*		

* Significant at the 0.05 probability level. N = 20.

This sandy loam soil settles very firmly following rainfall, possibly due to the low organic matter levels and gradation of sand, silt, and clay. The 0- to 0.03-m layer averaged 1.5% very coarse sand, 3% coarse sand, 13% medium sand, 33% fine sand, 14% very fine sand, 20% silt, and 12% clay. This textural makeup has the size components to effectively fill the available void space with solids. We believe the decline in water infiltration was caused by rearrangement of soil particles, or filtration of finer particles into soil pores, as water moved into the profile. Such surface sealing processes have been described by Gupta et al. (1992).

SUMMARY

Water infiltration measurements identified a very difficult soil management problem. This soil has little structure and was very susceptible to surface crusting, even with artificial rainfall that was less intense than naturally occurring storms. Soil bulk density and point resistance measurements indicate the presence of a compact layer at about 0.1 m and this compact layer was more pronounced on the fallow–wheat rotation. We think that this compact layer is the result of repeated shallow tillage operations using sweeps. The AWNT treatment had lower bulk density and greater organic C, compared with FWCT, suggesting that infiltration should be greater on the AWNT; however, the AWNT treatment did not have appreciably greater water infiltration rates compared with the FWCT treatment. We speculate that surface crusting on both the AWNT and FWCT treatments inhibits water infiltration as opposed to profile controls such as high density tillage pans. From a soil erosion viewpoint, the annual wheat no-tillage system has an advantage over AWFST and FWCT because surface cover is maintained throughout the year. Soil organic C was significantly greater near the surface of the annual crop treatments compared with the wheat–fallow treatment. Greater amounts of organic C on the annual crop treatments compared with the FWCT treatment attest to the beneficial aspect of annual cropping in maintaining a level of soil quality that is greater than the fallow system.

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