Reprinted from the *Soil Science Society of America Journal*
Volume 46, no. 4, July–August 1982
677 South Segoe Rd., Madison, WI 53711 USA

Surface Soil Physical Properties after 36 Years of Cropping to Winter Wheat

PAUL W. UNGER

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ABSTRACT

A dryland tillage and cropping system study for winter wheat (*Triticum aestivum* L.) was conducted on Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) from 1941 to 1977, a period much longer than most field studies. In 1977, soil samples were collected from the surface layer to evaluate effects of the long-term tillage and cropping practices on dry and water-stable aggregate distribution, organic matter (OM) concentration, modulus of rupture, penetrometer resistance, and bulk density of clods. Oneway disk tillage resulted in significantly fewer small dry aggregates than sweep tillage in the wheat–fallow system, but had no significant effect in the continuous wheat system. Mean weight diameters (MWD) were similar for all tillage methods. Oneway tillage resulted in more < 0.25-mm diameter water-stable aggregates than sweep tillage in both cropping systems, resulting in lower MWD for oneway than for sweep tillage. Organic matter concentration was lower for oneway than for sweep tillage in both systems, while continuous wheat resulted in higher OM concentration than wheat–fallow for comparable tillage methods. Slight changes from 1966 to 1977 indicated that soil OM concentration was at or nearly in equilibrium with prevailing management and climatic conditions. Modulus of rupture of briquettes and resistance of briquette fragments to fracture with a penetrometer were inversely related to OM concentration, but no tillage method or cropping system had an overriding influence on soil physical properties. Dry aggregate analyses indicated that the soil did not contain enough coarse aggregates to control wind erosion, indicating the need to maintain residues on the soil surface to aid wind erosion control.

Additional Index Words: **soil aggregates, organic matter, modulus of rupture, sweep tillage, oneway tillage, cropping systems, penetrometer resistance.**

Unger, P. W. 1982. Surface soil physical properties after 36 years of cropping to winter wheat. Soil Sci. Soc. Am. J. 46:796–801.

Soil surface properties affect, among other factors, a soil's susceptibility to wind and water erosion, water infiltration rate, and crusting. Susceptibility to wind and water erosion is influenced by the size, number, and stability of surface soil clods or aggregates. When about 75% of the surface soil clods or aggregates are stable and greater than about 0.84 mm in diameter, wind erosion is minimized, even if surface residues are absent (Woodruff and Siddoway, 1965). Likewise, water-stable aggregates resist or minimize soil dispersion, thereby maintaining higher infiltration rates and decreasing runoff and attendant erosion by water. Water-stable surface aggregates also decrease the potential of soil crusting that may hinder seedling emergence.

Many factors influence soil surface properties; included are crops grown, cropping systems, tillage methods, and surface residues. A dryland cropping system and tillage method study was initiated in 1941 for winter wheat (*Triticum aestivum* L.) on Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) and terminated in 1977. This report pertains to surface soil properties in 1977. The organic matter (OM) concentration in the upper 15 cm of soil averaged 2.44% when the study was initiated in 1941; by 1949, it had decreased an average of 13% in continuous-wheat and 18% in wheat–fallow plots. In both cropping systems, sweep (stubble mulch) tillage conserved more OM than oneway (one-directional disk) tillage; in 1949, the averages were 2.09 and 2.01%, respectively. Differences in bulk density were negligible in 1949, but sweep tillage resulted in greater water storage which slightly increased grain yields as compared with those in oneway plots (Johnson, 1950).

Twenty-four years after the study was initiated, Unger (1968, 1969) found that OM had further declined. By 1966, OM concentrations were 1.59 and 1.66% with oneway and sweep tillage, respectively, in wheat–fallow plots and 1.76 and 1.82% in oneway and sweep tillage plots, respectively, with continuous wheat (Unger, 1968). A delayed sweep tillage treatment, which allowed weeds and volunteer wheat to grow until the following spring and was used only in the wheat–fallow system, resulted in 2.03% OM in 1966. Other factors significantly affected by tillage method or cropping system were water stability of aggregates, surface crust strength as soil dried after rainfall, and distribution of dry aggregates in surface soil. The improved soil conditions generally were associated with cropping practices that maintained greater amounts of residue on the surface or that maintained OM at higher levels. Not significantly affected were bulk density, water retention, plant available water, water infiltration rate, and wind erodibility as determined by use of a wind tunnel under field conditions (Unger, 1969).

The tillage and cropping system study was terminated after 36 years, a much longer time than that used for most studies. The objective of the present study was to determine the effects of long-term practices on dry and water-stable aggregate distribution, OM concentration, modulus of rupture, penetrometer resistance, particle-size distribution, and bulk density of clods of the surface soil.

[1] Contribution from the USDA–ARS, in cooperation with The Texas Agric. Exp. Stn., Texas A&M University, College Station, TX 77843. Received 19 Oct. 1981. Approved 29 Jan. 1982.

[2] Soil Scientist, USDA Conservation and Production Research Laboratory, Bushland, TX 79012.

[3] Mention of a trade name does not constitute a recommendation for use by the USDA.

METHODS AND MATERIALS

The field study was conducted on Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) at Bushland, Tex., from 1941 to 1977. Oneway, sweep, and delayed sweep tillage were used on wheat–fallow plots, and oneway and sweep tillage were used on continuous wheat plots. The oneway implement was 1.2 m in width and had disks 0.56 m in diameter that were cupped 7.6 cm. The sweep implement was 3.6 m in width and had 0.76-m-wide sweeps with a 60° angle between the wings. Tillage depth was 7 to 10 cm. The field study had a randomized block design with two replications of each treatment with sufficient plots so that each phase of the wheat–fallow rotation could be evaluated each year. Plot size was 0.15 ha.

After the last winter wheat crop was harvested in June 1977, samples were collected at three locations per plot from the upper 2.5 cm of soil for determining dry aggregate size distribution. Then, after uniformly sweep tilling all plots 7 to 10 cm deep, samples were collected at three locations per plot from the tillage layer for determining OM concentration, water-stable aggregation, modulus of rupture, penetrometer resistance, particle-size distribution, and bulk density of clods.

The samples for dry aggregate size distribution were air-dried before determining the distribution with a rotary apparatus having five sieves, which had 0.42-, 0.84-, 2.0-, 6.4-, or 18.3-mm square openings (Chepil, 1962). The soil was sieved two times. After the second sieving, soil that passed through the different sieves was maintained separately and used for determining OM concentration, modulus of rupture, penetrometer resistance, and particle-size distribution. These measurements, except particle-size distribution, were also made on bulk soil from the tillage layer. Organic matter concentration was determined according to Jackson (1958) and modulus of rupture according to Richards (1954) using the Shell Mode Transverse accessory of a Model 405 Universal Sand Strength Machine (Harry W. Dietert Co., Detroit, Mich.)[3] to break the specimens. For modulus of rupture measurements, subsamples of soil from different fractions were ground to pass through 2.0- and 0.42-mm sieves. Specimens prepared from the 2.0-mm material were too fragile for analysis, but from 3 to 10 specimens of the 0.42-mm material were prepared and broken from each soil fraction. After determining the modulus of rupture, the resistance to crushing of briquette fragments was determined with a flat-surface penetrometer having a 4.76-mm-diameter piston needle (Model 719-5MRP, John Chatillon & Sons, Kew Garden, NY 11415) as the fragments lay flat on blotter paper. Resistance to crushing of the specimens of the 2.0-mm material was also determined. About 10 and 30 penetrometer determinations were made on specimens from the 2.0- and 0.42-mm material, respectively, for soil from each dry sieve fraction. Particle-size distribution was determined by Day's (1965) procedure.

Samples for water-stable aggregation were passed through a 12.7-mm sieve while moist, then air-dried. Water-stable aggregation was determined by a procedure similar to that of Kemper and Chepil (1965), but using sieve sizes of 0.25, 1.0, 2.0, and 4.0 mm. Mean weight diameters (MWD) were calculated for water-stable aggregates as well as for dry aggregates (Kemper and Chepil, 1965).

Bulk density of soil clods from the tillage layer was determined by displacing mercury in an apparatus similar to that described by Johnston (1945). The density was determined for 10 clods from the three locations in each plot. Clods were about 3 cm maximum diameter, but were irregularly shaped.

Data were analyzed by analysis of variance and by Duncan's Multiple Range Test (Le Clerg et al., 1962) to establish which differences were significant. Regression relationships among variables were calculated by methods of Ezekiel and Fox (1959).

Table 1—Size distribution of dry-sieved aggregates of Pullman clay loam as affected by cropping system and tillage method for dryland winter wheat.

Cropping system and tillage method	Size range, mm						MWD‡
	<0.42	0.42–0.84	0.84–2.0	2.0–6.4	6.4–18.3	>18.3	
	%						
Wheat-fallow—1st†							
Oneway	28.6	14.2	10.1	17.4	23.4	5.8	6.69a§
Sweep	31.4	15.2	10.6	14.8	20.7	7.8	7.17a
Delayed sweep	31.1	16.0	10.1	14.2	20.1	8.6	7.49a
Average	30.4a§	15.1c	10.3d	15.5c	21.4b	7.4e	
[Protected L.S.D. (0.05) for tillage × size = 1.5]¶							
Wheat-fallow—2nd							
Oneway	33.7	16.5	12.0	17.3	18.2	2.4	4.47a
Sweep	37.2	18.0	11.3	14.0	16.2	3.5	4.61a
Delayed sweep	36.0	18.9	11.3	13.7	16.3	4.0	4.86a
Average	35.6a	17.8b	11.5d	15.0c	16.9b	3.3e	
[Protected L.S.D. (0.05) for tillage × size = 2.1]							
Continuous wheat—1st							
Oneway	28.2	13.2	11.2	17.8	24.4	5.2	6.55a
Sweep	28.9	14.8	12.9	15.8	21.4	6.3	6.65a
Average	28.6a	14.0d	12.1d	16.8c	22.9b	5.8e	
Continuous wheat—2nd							
Oneway	34.0	15.6	12.3	17.3	18.8	1.9	4.30a
Sweep	33.8	16.8	13.7	16.7	16.5	2.6	4.35a
Average	33.9a	16.2bc	13.0c	17.0b	17.7b	2.3d	

† 1st and 2nd refer to first and second dry-sieving operations.
‡ Mean weight diameter.
§ Row or column values within a group for a given cropping system and sieving that are followed by the same letter or letters are not significantly different at the 5% level (Duncan's Multiple Range Test).
¶ Steel and Torrie (1980). L.S.D. values are shown only when the *F*-test indicated that the interaction was significant.

RESULTS AND DISCUSSION

Whether plots of the wheat–fallow system had been cropped to wheat or fallowed during the last wheat season before terminating the study usually had no significant effect on measured soil properties. Consequently, data in the tables are averages of those obtained for the wheat and fallow plots. Where data for wheat and fallow plots were significantly different, they are discussed in the text.

Dry Aggregate Size Distribution

The percentage of aggregates in most size ranges for both the first and second sievings was significantly affected by tillage methods for the wheat–fallow, but not for the continuous wheat system (Table 1). Oneway tillage usually resulted in fewer aggregates in the < 0.42-, 0.42- to 0.84-, and > 18.3-mm size ranges, and more in the 2.0- to 6.4- and 6.4- to 18.3-mm ranges than sweep or delayed sweep tillage. Mean weight diameters (MWD) were not significantly affected by tillage method, but tended to be lower for oneway tillage.

No tillage method resulted in 75% of the aggregates being > 0.84 mm, which is the approximate percentage of stable dry aggregates required to hold average annual soil losses due to wind erosion to less than the tolerable level of 11.2 metric tons/ha (5 tons/acre) on large, bare, smooth, unprotected fields (Woodruff and Siddoway, 1965). Consequently, the need for controlling wind erosion by means other than surface cloddiness as associated with normal tillage is apparent. Usually, residues retained on the surface by sweep or delayed sweep tillage are adequate to control erosion, even though these tillage methods result in less large surface aggregates than oneway tillage. Oneway tillage buries from 30 to 50% of the surface residues with each operation and, therefore, increases the potential for wind erosion. The potential for erosion is further increased by subsequent operations with oneway tillage, which reduces cloddiness more than does sweep tillage (Siddoway, 1963).

Organic Matter

Bulk soil samples from wheat–fallow plots had the highest OM concentration with delayed sweep tillage and lowest with oneway tillage (Table 2). Also, for continuous wheat, sweep tillage resulted in significantly higher OM than oneway tillage. The OM values obtained in 1977 (this study) were similar to those measured in 1966 for these same tillage treatments (Unger, 1968). The 1966 OM values for the 0- to 7.6-cm depth are included in Table 2. The slight differences between 1966 and 1977 in OM concentrations may have been random effects due to slight differences in sampling depth or residue distribution and decomposition. The similarity between values obtained in 1966 and 1977 for the different tillage methods suggests that OM concentration was probably in equilibrium with climatic conditions and prevailing cropping practices. The soil contained 2.44% OM in 1941. By 1977 about 33, 27, and 7% of the OM had been lost with oneway, sweep, and delayed sweep tillage, respectively, in the wheat–fallow system. In the continuous wheat system, about 30 and 14% of the OM had been lost with oneway and sweep tillage, respectively.

For the wheat–fallow system, OM concentration was significantly higher in the 0.84- to 2.0- and 2.0- to 6.4-mm fractions of the dry-sieved soil than in the remaining fractions; the < 0.42-mm fraction had the lowest concentration (Table 2). Low OM concentrations in the two smallest fractions differ from the results of Tabatabai and Hanway (1968) who showed that small fractions contain the most OM. A possible reason why the smallest fraction had the least OM was because this fraction contained more sand and less clay than the other fractions (Table 3). Percent OM (y) was related to percent sand (x) in the different fractions by the equation $y = 3.250 - 0.055x$, with $r = 0.575$ ($p = 0.10$). For percent clay (x), the equation was $y = 0.498 + 0.070x$, with $r = 0.469$ ($p = 0.20$). For silt, the relationship was not significant.

Differences among average OM concentrations in dry-sieved soil fractions from continuous wheat plots were not significant, but the average value for the tillage method was significantly higher for sweep than for oneway tillage.

Modulus of Rupture

Briquettes prepared from both the dry-sieved soil that passed through or which was subsequently ground to pass through a 2.0-mm sieve, and the bulk soil ground to pass through a 2.0-mm sieve, were too fragile to analyze and thus resulted in no modulus of rupture determinations. Moduli of rupture of briquettes prepared from sieved soil passing through or subsequently ground to pass through a 0.42-mm sieve were significantly different due to initial size of the soil fractions (Table 2). Briquettes prepared from soil initially passing through the 0.42-mm sieve had no measurable resistance to breaking, both for soil from wheat–fallow and continuous wheat plots. In both cases, however, briquettes prepared from soil initially in other size ranges had significantly greater resistances than the < 0.42-mm (initial) soil fraction. Differences among the moduli of rupture for briquettes from other initial fractions were significant for the continuous wheat, but not for the wheat–fallow system. Oneway tillage resulted in the highest moduli of rupture for sieved soil from both cropping systems. For bulk soil ground to pass through a 0.42-mm sieve, differences in moduli of rupture were not significantly affected by tillage in either cropping system.

Using average values for fractions for percent OM (x) and modulus of rupture (y) (dynes/cm^2 · 10^{-5}) in both cropping systems, the equation was $y = -9.399 + 6.865x$, with $r = 0.777$ ($p = 0.01$). These analyses indicate that increased OM concentration reduces soil crust strength and, therefore, should be beneficial for enhancing seedling emergence when soil drying after rainfall causes crusting.

Penetrometer Resistance

Although briquettes prepared for the < 2.0-mm fraction of dry-sieved soil and soil subsequently ground to pass through a 2-mm sieve were too fragile for determining the modulus of rupture, they had measurable penetrometer resistances. For the wheat–fallow system, delayed sweep tillage resulted in significantly lower average resistance than sweep or oneway tillage (Table 2). Also, the resistance was highest for briquettes made from the > 18.3-mm soil fraction and significantly decreased with decreases in size of the initial soil fractions. Penetrometer data for soil from continuous wheat plots were similar to those for soil from wheat–fallow plots, except that the difference due to tillage was not significant. Resistances for bulk soil were lower than the average for dry-sieved soil.

Penetrometer resistance of briquettes prepared from dry-sieved soil was not significantly related to percent OM for soil from the different fractions that passed through or was ground to pass through a 2-mm sieve.

For briquettes made from dry-sieved soil passing through or ground to pass through a 0.42-mm sieve, mean penetrometer resistances were significantly different due to tillage and initial size range for both cropping systems (Table 2), but differences for bulk soil were not significant. For sieved soil, delayed sweep tillage resulted in the lowest resistance in the wheat–fallow system, and sweep tillage resulted in lower resistances than oneway tillage in both systems. Penetrometer resistance (y) (dynes × 10^{-5}) was related to percent OM (x) by the equation $y = 15.99 + 12.35x$, with $r = 0.750$ ($p = 0.01$). Resistance values for the initial < 0.42-mm fraction were about one order of magnitude lower than resistances for the remaining fractions. The low resistances for the < 0.42-mm fraction were similar to the unmeasurably low breaking resistances of the briquettes made from this soil fraction. There was a positive relationship between penetrometer resistance (x) and modulus

Table 2—Organic matter content, modulus of rupture, and penetrometer resistances of soil from the various size fractions obtained by dry sieving. Organic matter concentrations of bulk soil for 1966 (from Unger, 1969) and 1977 are also given.

Cropping system and tillage method	Size of dry-sieved soil, mm: <0.42	0.42–0.84	0.84–2.0	2.0–6.4	6.4–18.3	>18.3	Average	Bulk soil: 1977	1966
				Organic matter, %					
Wheat–fallow									
Oneway	1.30	1.57	1.62	1.56	1.46	1.43	1.49c*	1.62c*	1.61
Sweep	1.45	1.82	2.06	2.03	1.76	1.76	1.81b	1.79b	1.72
Delayed sweep	1.83	2.24	2.44	2.56	2.21	2.14	2.24a	2.28a	2.26
Average	1.53c*	1.88b	2.04a	2.05a	1.81b	1.77b			
Continuous wheat									
Oneway	1.41	1.67	1.70	1.67	1.59	1.60	1.61b	1.71b	1.79
Sweep	1.63	1.97	2.04	2.10	1.90	2.50	2.02a	2.09a	1.93
Average	1.52a	1.82a	1.82a	1.84a	1.75a	2.05a			
				Modulus of rupture, dynes/cm² × 10^{-5} (<0.42-mm soil)					
Wheat–fallow									
Oneway	0	4.05	5.99	4.57	4.73	5.77	4.18a	2.98a	--
Sweep	0	3.73	4.73	3.66	3.14	4.73	3.34b	3.34a	--
Delayed sweep	0	2.53	3.27	2.85	3.08	2.69	2.40c	2.17a	--
Average	0b	3.44a	4.66a	3.69a	3.65a	4.40a			
Continuous wheat									
Oneway	0e	3.11	5.28	4.34	3.76	4.12	3.43a	4.41a	--
Sweep	0e	2.14	3.40	3.14	3.24	2.79	2.46b	2.11a	--
Average	0c	2.63b	4.34a	3.74a	3.40ab	3.46ab			
				Penetrometer resistance, dynes × 10^{-5} (<2.0-mm soil)					
Wheat–fallow									
Oneway	--	--	0.59	1.08	1.18	1.27	1.03a	0.72a	--
Sweep	--	--	0.69	0.88	1.08	1.08	0.93a	0.47b	--
Delayed sweep	--	--	0.39	0.69	0.78	1.08	0.74b	0.50b	--
Average	--	--	0.56c	0.88ab	1.01ab	1.14a			
Continuous wheat									
Oneway	--	--	0.59	0.88	0.69	1.27	0.86a	0.59a	--
Sweep	--	--	0.39	0.78	0.59	0.98	0.69a	0.42b	--
Average	--	--	0.49b	0.83ab	0.64ab	1.13a			
				Penetrometer resistance, dynes × 10^{-5} (<0.42-mm soil)					
Wheat–fallow									
Oneway	0.69	8.82	11.80	9.41	9.41	11.00	8.52a	5.66a	--
Sweep	0.69	7.75	9.32	7.65	6.77	9.12	6.88b	6.02a	--
Delayed sweep	0.59	5.49	6.77	5.88	6.37	6.67	5.30c	4.04a	--
Average	0.66b	7.35a	9.29a	7.65a	7.52a	8.92a			
Continuous wheat									
Oneway	0.88	6.86	10.50	8.83	7.65	6.96	6.94a	3.78a	--
Sweep	0.59	4.90	7.35	6.57	6.57	5.98	5.33b	4.21a	--
Average	0.74f	5.88e	8.92a	7.70b	7.11c	6.47d			

* Row or column mean values within a group for a given cropping system followed by the same letter or letters are not significantly different at the 5% level (Duncan Multiple Range Test).

Table 3—Sand, silt, and clay percentages of soil from the various size fractions obtained by dry sieving.

Cropping system and tillage method	Size of dry-sieved soil, mm <0.42	0.42–0.84	0.84–2.0	2.0–6.4	6.4–18.3	>18.3	Average
	Sand, %						
Wheat-fallow							
Oneway	28.4	22.8	24.0	26.1	25.2	27.0	25.6a*
Sweep	29.0	23.3	24.5	26.4	27.6	26.6	26.2a
Delayed sweep	29.0	24.0	24.7	25.4	26.3	27.1	26.1a
Average	28.8a*	23.4d	24.4cd	26.0bc	26.4b	26.9b	
Continuous wheat							
Oneway	27.7	24.1	25.4	23.5	25.8	26.9	25.6a
Sweep	29.0	23.0	24.1	25.6	25.5	26.8	25.7a
Average	28.9a	23.5c	24.8bc	24.6bc	25.7b	26.9ab	
	Silt, %						
Wheat-fallow							
Oneway	54.2	54.5	53.1	53.4	52.1	53.7	53.5a
Sweep	56.7	59.0	59.9	56.2	55.2	53.8	56.8a
Delayed sweep	55.6	57.7	59.8	55.3	55.0	52.7	56.0a
Average	55.5abc	57.1ab	57.6a	55.0bc	54.1c	53.4c	
Continuous wheat							
Oneway	52.8	57.2	53.3	56.1	52.0	53.4	56.1a
Sweep	54.3	59.2	58.1	54.9	57.1	53.4	56.2a
Average	53.6a	58.2a	55.7a	55.5a	54.6a	53.4a	
	Clay, %						
Wheat-fallow							
Oneway	17.4	22.7	22.9	20.5	22.7	19.3	20.9a
Sweep	14.3	17.7	15.6	17.4	17.2	19.6	17.0a
Delayed sweep	15.4	18.3	15.6	19.3	18.7	20.2	17.9a
Average	15.7b	19.6a	18.0ab	19.1a	19.5a	19.7a	
Continuous wheat							
Oneway	19.5	18.7	21.3	20.4	22.2	19.7	20.3a
Sweep	16.7	17.8	17.8	19.6	17.4	19.8	18.2a
Average	18.1a	18.3a	19.6a	20.0a	19.8a	19.8a	

* Row or column within a group for a given cropping system followed by the same letter or letters are not significantly different at the 5% level (Duncan Multiple Range Test).

Table 4—Size distribution of water-stable aggregates of Pullman clay loam as affected by cropping system and tillage method for dryland winter wheat.

Cropping system and tillage method	Size range, mm <0.25	0.25–1.0	1.0–2.0	2.0–4.0	4.0–12.7	MWD†
	%					
Wheat-fallow						
Oneway	48.7	41.2	4.9	2.9	2.4	0.68c*
Sweep	40.1	42.3	6.1	4.5	7.1	1.13b
Delayed sweep	34.7	39.2	7.0	6.7	12.6	1.64a
Average	41.2a*	40.9a	6.0bc	4.7c	7.3b	
[Protected L.S.D. (0.05) for tillage × size = 2.4]‡						
Continuous wheat						
Oneway	45.6	41.8	5.5	3.5	3.7	0.81b
Sweep	34.8	41.0	7.3	6.4	10.5	1.48a
Average	40.2b	41.4a	6.4d	5.0e	7.1c	
[Protected L.S.D. (0.05) for tillage × size = 3.8]						

* Row or column mean values within a cropping system followed by the same letter or letters are not significantly different at the 5% level (Duncan's Multiple Range Test).
† Mean weight diameter.
‡ Steel and Torrie (1980).

of rupture (y) as given by the equation $y = -0.367 \times 10^5 + 0.535x$, with $r = 0.997$ ($p = 0.001$). This significant relationship indicates that penetrometer resistance measurements are useful for evaluating the effect of crust strength on seedling emergence under field conditions.

Particle-size Distribution

The amount of sand, silt, and clay in the various fractions obtained by dry sieving the soil differed significantly for the wheat–fallow cropping system. For the continuous wheat system, the differences were significant only for sand. Tillage method had no significant effect on the amount of sand, silt, or clay in either system (Table 3).

The < 0.42-mm fraction contained more sand and less clay than other fractions and an intermediate amount of silt. The high sand content of the < 0.42-mm fraction resulted from breakdown of weak aggregates. The sand in Pullman clay loam is fine and therefore passed through the smallest sieve. The larger, more stable aggregates contained more clay and organic matter which were responsible for the greater stability of the larger aggregates.

Wet Aggregates

The size distribution of soil aggregates wetted under vacuum and sieved under water was significantly affected by tillage method in the wheat–fallow and continuous wheat cropping systems (Table 4). Oneway tillage resulted in the most small aggregates (< 0.25 mm) and the least large aggregates (4.0 to 12.7 mm) in both cropping systems. For the wheat–fallow system, delayed sweep tillage resulted in the least small and most large aggregates. These differences in aggregate distribution also resulted in significant MWD differences for both cropping systems. Oneway tillage resulted in the lowest MWD in both systems and delayed sweep tillage resulted in the highest MWD in the wheat–fallow system.

In addition to the tillage effects, the size distribution of aggregates was also significantly affected by crop sequence in the wheat–fallow system (data not shown). Plots in fallow had more small and fewer large aggregates than plots cropped to wheat during the season before sampling. Similar results were found by Unger (1972). Subsequent tillage during fallow causes breakdown of large aggregates present at the first tillage operation, but the above trends also reflect the ability of residues from recent crops to promote the formation of large water-stable aggregates (Smika and Greb, 1975). Soils with more large water-stable aggregates should have higher water infiltration rates than similar soils with numerous small aggregates because the small aggregates can move into and clog soil pores, thereby reducing infiltration. Infiltration differences under field conditions probably would have been small because the differences in aggregate size distribution, although statistically significant, were relatively small. Also, the samples for aggregate distribution determinations were wetted under vacuum, which minimized soil dispersion. In the field, raindrops striking bare soil enhance dispersion, thereby decreasing infiltration rates. Surface residues that intercept raindrops probably are of greater importance for influencing infiltration rates than the inherent distribution of water-stable aggregates in Pullman clay loam.

Bulk Density of Clods

The bulk density of soil clods from the tillage layer was not significantly affected by tillage method in either cropping system (data not shown). Densities averaged 1.64 and 1.67 g/cm^3 for tillage methods in the wheat-fallow and continuous wheat systems, respectively. These densities are much higher than those obtained for the tillage layer of this soil by core sampling (Unger, 1969, 1972; Unger et al., 1973). When measuring the density of soil cores, a greater percent of pores is included in the core volume than is involved when measuring the density of clods.

CONCLUSIONS

Although significant differences in soil physical properties or conditions were found due to 36 years of different tillage methods and cropping systems for winter wheat, the differences were relatively small and no tillage method or cropping system resulted in a condition that seemingly would adversely affect wheat production. In some cases, the differences were significantly related to soil organic matter concentration, which, after 36 years, was higher for sweep than for oneway disk tillage and higher for the continuous wheat than for the wheat–fallow system. No tillage method or cropping system resulted in sufficient large, stable dry aggregates to effectively control wind erosion, thus pointing to a need to maintain surface residues to aid in controlling erosion. The higher yields with sweep than with oneway tillage and for wheat–fallow than for continuous wheat (Johnson and Davis, 1972) apparently were related to greater water conservation than to any soil physical condition.

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