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Soil Physical Properties as Influenced by Cropping and Residue Management

E. L. SKIDMORE, J. B. LAYTON, D. V. ARMBRUST, AND M. L. HOOKER

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ABSTRACT

Alternate methods of residue management for reduced tillage under irrigation and in double cropping systems are constantly being sought. One method that is becoming increasingly popular is residue burning. Knowing how to best manage crop residues to maintain desirable soil physical properties for decreasing erosion and increasing crop yields in these cropping systems is a problem. This study was conducted to determine the influence of several methods of residue management for winter wheat (*Triticum aestivum* L.) and grain sorghum [*Sorghum bicolor* (L.) Moench] on physical properties of Richfield silty clay loam (fine, montmorillonitic, mesic Aridic Argiustolls). Residue management treatments were: residue removed by burning, residue removed by baling and hauling, incorporation of the residue produced during the immediate past cropping season, and incorporation of twice the amount of residue produced by the crop. Most of the soil physical properties measured were not influenced by either grain sorghum or wheat residue management treatments; however, they differed between crops. The soil aggregates from the sorghum plots were smaller, more fragile, less dense, less stable dry, and more stable wet than the aggregates from the wheat plots. The pore size distribution of the soil from the Ap horizon of the sorghum plots was more conducive to water infiltration. The saturated hydraulic conductivity was several times greater in the soil cores obtained from the sorghum plots than those obtained from the wheat plots.

Additional Index Words: **Richfield, Argiustoll, wheat, grain sorghum, wind erosion, soil aggregates, bulk density, organic matter, pore size distribution, porosity, burning.**

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Intensive cropping of native grassland soils generally decreases organic matter content and causes an associated degradation of soil physical properties (Dormaar, 1979; Hobbs and Brown, 1957; Olmstead, 1946; Skidmore et al., 1975). The physical deterioration often associated with a decline in organic matter content is manifested by a decline in wet aggregate stability, an increase in bulk and clod densities, an increase in modulus of rupture, and a decline in large pore space. Harris et al. (1966) summarized their review of *Dynamics of Soil Aggregation* by stating that a soil's aggregate status usually deteriorates rapidly if the soil is repeatedly cropped with annuals that supply little organic matter to the soil, require extensive cultivation, and provide minimal vegetative cover. However, not all continuous row-cropping systems have deteriorated soil structure (Cary and Hayden, 1974).

Appropriate management of crop residues retards degradation of soil physical properties and sometimes improves the soil. Shipley and Regier (1977) found that after 12 yr (on irrigated plots) organic matter increased and the soil was less compact where wheat (*Triticum aestivium* L.) straw was incorporated than where straw was baled or burned. Organic matter increase from incorporating crop residue was also reported by Hooker et al. (1982). Black (1973) observed a progressive decrease in erodible soil fractions as residue levels increased. In a study comparing the effects of burning vs. incorporating wheat straw at two locations in Saskatchewan, Biederbeck et al. (1980) found that the hydraulic conductivity of the top 15 cm of the soil from burned plots at Melfort was significantly lower ($P < 0.10$) than that of the soil from chopped-straw plots (6.9 compared to 2.8 μm/s), but there was no difference between the two treatments at Indian Head where the average conductivity was 3.2 μm/s. On the other hand, bulk densities were no different between the two treatments at Melfort (avg 1.06 Mg/m^3) but were significantly greater ($P < 0.05$) in the burned plots at Indian Head (1.17 compared to 1.05 Mg/m^3).

After 36 yr of cropping to winter wheat, Unger (1982) found modulus of rupture inversely related to organic matter concentration, but no tillage method or cropping system had an overriding influence on soil physical properties. Delayed stubble-mulch tillage increased wet aggregate stability in a wheat-fallow system of another study (Unger, 1969).

The purpose of this study was to determine selected physical properties of Richfield silty clay loam (fine, montmorillonitic, mesic Aridic Agriustolls) as influenced by management of residues from winter wheat (*Triticum aestivum* L.) and grain sorghum [*Sorghum bicolor* (L.) Moench] crops.

MATERIALS AND METHODS

Experiments were established in 1969 at the Garden City Experiment Station in southwest Kansas on a relatively uniform Richfield silty clay loam (Hooker et al. 1982). Mean annual precipitation and temperature at Garden City are 477 mm and 12.4°C, respectively. Garden City Experiment Station is located in the southern portion of Central High Tableland within major land resource area (MLRA 72), where winter wheat (1700 kha), corn (*Zea mays* L.) (460 kha), and grain sorghum (205 kha) are major crops (Skidmore et al., 1979). Residue treatments on hard red winter wheat and grain sorghum plots were: (i) incorporation of the residue produced during the immediate past cropping season, (ii) incorporation of twice the amount of residue produced by the crop, (iii) residue removed by baling and hauling, and (iv) residue removed by burning. Residues were incorporated by tillage, which generally consisted of disking immediately after treatment application, plowing, then disking again, and harrowing. The four residue management treatments (incorporated, 2×-incorporated, removed, and burned residue) were assigned randomly and completely within each of four blocks planted to sorghum. This was repeated with four adjacent blocks planted to wheat. Residue treatments were applied annually, within 30 d (one month) after harvest, to plots 12.2 by 12.2 m. Winter wheat was planted in late September each year and grain sorghum was planted in

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[2] Soil Scientist, USDA-ARS; Research Assistant, Dep. of Agronomy, Kansas State Univ., Manhattan, KS 66506; Soil Scientist, USDA-ARS; and Assistant Professor, Kansas State Univ., Garden City Experiment Station.

early June. Both crops were irrigated two to four times during the growing season with a gravity flood/furrow system.

Soil samples were collected in the spring of 1983 for determination of physical properties. Wheat was emerging from winter dormancy, about 10-cm tall, and the sorghum plots were bare. Five 5-kg samples of soil were taken from the top 5 cm of the Ap horizon with a flat shovel from each treatment plot. These samples were used for determination of aggregate size distribution, dry and wet aggregate stabilities, and aggregate density.

A double cylinder, hammer-driven soil core sampler was used to obtain five soil-core samples (86 by 60 mm) from the Ap horizon of each treatment plot. The soil cores were trimmed flush with both ends of the retaining cylinder, thus removing any surface crust. These samples were used for low tension water release characteristics and saturated hydraulic conductivity determinations. Bulk and clod density values were determined by the methods of Blake (1965), except that kerosene was used as the known density liquid in the clod density measurements.

Dry aggregate stabilities were determined by repeated sieving using the method of Chepil (1962) and the improved rotary sieve (Lyles et al., 1970). The data from the first sieving were used to determine geometric mean diameter and log standard deviation for aggregate size distributions (Gardner, 1956; Kemper and Chepil, 1965) and wind erodibility index (Woodruff and Siddoway, 1965). Energy-based dry aggregate stabilities and rupture stress were determined by methods described by Skidmore and Powers (1982), with the apparatus of Boyd et al. (1983). Wet aggregate stabilities were determined by the method of Kemper (1965), except we used a 152-mm-diam sieve and a 30-g soil sample. Our mechanical sieving machine lowered and raised the sieve holder through a distance of 27 mm 25 times each min.

Soil water release curves were determined using hanging water column (Vomocil, 1965) and pressure cell (Klute, 1965b) techniques. Saturated hydraulic conductivities were measured using the falling-head method of Klute (1965a).

The data were analyzed using analysis of variance to test for crop, residue management, and crop management interaction effects. When *F*-tests (0.01 level) showed significant difference, least significant differences (LSD) were calculated at the 0.01 level for crop effects and 0.05 level for residue management effects.

RESULTS AND DISCUSSION

Most of the soil physical properties measured in this study were not influenced by either wheat or grain sorghum residue management treatments (Tables 1 and 2). Residue incorporation, removal, burning, or incorporation of added residues seemed to have very little influence on aggregate size distribution, dry aggregate stability, wet aggregate stability, bulk density, or aggregate density.

The dry aggregate size distribution as expressed by geometric mean diameter (GMD) did not differ significantly among treatments within a crop. However, the average GMD for the wheat residue treatments (2.86 mm) was more than twice as large as the average GMD for sorghum residue treatments (Table 3). It follows that a much larger fraction of the aggregates from the wheat plots were in the nonwind-erodible size range (>0.84 mm) than the aggregates from the sorghum plots (70.1 compared with 47.1%).

In a wheat-fallow rotation, Siddoway (1963) found that the proportion of nonwind-erodible aggregates was greater when the straw residue was returned to the soil than when it was burned or partially removed. The increase in aggregation attributed to the residue was higher when the residue was left on the surface than when it was plowed under. In this study, residues were incorporated into the soil soon after harvest.

Adding additional residue increased the soil organic matter content relative to the residue-removed plots in both grain sorghum and wheat during the 13-yr duration of this experiment. The organic matter concentration of the soil from wheat plots avg 19.6 and 17.9 g/kg in the 2X-incorporated plots and for the residue-removed and burned plots, respectively. Sim-

Table 1. Physical properties of Richfield silty clay loam as influenced by wheat residue management.

Residue management treatment	Soil property: Aggregates >0.84 mm	Wind erodibility index	Dry aggregate stability		Wet aggregate stability	Bulk density	Aggregate density	Rupture stress	Aggregate size distribution	Organic matter content	Saturated hydraulic conductivity
	%	Mg/(ha/yr)	J/m²	%	%	Mg/m³	Mg/m³	kPa	GMD, mm	g/kg	μm/s
Incorporated	69.5	27	22.8	89.7	36.1	1.19	1.65	383	2.82	18.9	6.9
2X-incorporated	71.3	25	17.1	89.2	45.6	1.25	1.65	299	2.86	19.6	6.6
Removed	69.5	27	17.1	88.9	37.7	1.29	1.64	298	2.82	17.5	6.8
Burned	70.0	27	15.0	87.8	39.1	1.18	1.62	266	2.93	18.2	6.3
LSD (0.05)	NS	NS	4.4	NS	NS	NS	NS	71	NS	1.3	NS

Table 2. Physical properties of Richfield silty clay loam as influenced by grain sorghum residue management.

Residue management treatment	Soil property: Aggregates >0.84 mm	Wind erodibility index	Dry aggregate stability		Wet aggregate stability	Bulk density	Rupture stress	Aggregate size distribution	Organic matter content	Saturated hydraulic conductivity
	%	Mg/(ha/yr)	J/m²	%	%	Mg/m³	kPa	GMD, mm	g/kg	μm/s
Incorporated	47.3	101	10.2	83.1	55.4	1.02	195	1.14	20.7	64
2X-incorporated	48.0	101	10.6	85.1	53.9	1.06	201	1.18	22.4	55
Removed	46.3	105	12.8	82.7	49.1	1.05	238	1.12	19.4	42
Burned	47.9	96	12.6	83.7	51.6	1.07	230	1.26	20.4	36
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	1.2	25

Table 3. Physical properties as influenced by growing grain sorghum or wheat on Richfield silty clay loam.

	Soil property									
Crop	Aggregates >0.84 mm	Wind erodibility index	Dry aggregate stability		Wet aggregate stability	Bulk† density	Rupture stress	Aggregate size distribution	Organic matter content	Saturated hydraulic conductivity
	%	Mg/(ha/yr)	J/m²	——— %	———	Mg/m³	kPa	GMD, mm	g/kg	μm/s
Wheat	70.1	27	18.0	88.9	39.6	1.23	312	2.86	18.6	6.7
Sorghum	47.1	101	11.6	83.7	52.5	1.05	216	1.18	20.7	49.4
LSD (0.01)	2.6	17	3.5	1.6	7.1	0.07	52	0.23	0.9	14.4

† At water content of field sampling, 0.24 and 0.28 m³/m³ for samples obtained from wheat and sorghum plots, respectively.

ilarly for the grain sorghum plots the organic matter concentration was 22.4 and 19.9 g/kg for 2×-incorporated and residue-removed and burned plots, respectively. Also, the organic matter concentration of the soil from the sorghum plots (20.7 g/kg) was significantly higher than the organic matter concentration (18.6 g/kg) of the soil from the wheat plots. With average grain yields of 7815 and 4153 kg/ha, for sorghum and wheat respectively (Hooker et al., 1982), the amount of residue produced by the grain sorghum crop was greater than the amount produced by wheat crop. Amounts of residue remaining after grain harvest of sorghum and winter wheat are approximately 1.0 and 1.7 times the amount of grain harvested, respectively (Larson et al., 1978). A higher organic matter concentration of soils when crop residues are incorporated compared with soils where residue is removed by burning or hauling away has been observed frequently (Dormaar et al., 1979; Rasmussen et al., 1980; Shipley and Regier, 1977; Unger et al., 1973).

Because of the strong influence of organic matter on soil physical conditions, one expects detectable differences of soil physical properties with differences of organic matter content. However, the small differences in organic matter content developed in the brief period of this study did not cause major difference in the physical properties among treatments within a crop. Also the concentration of organic matter being near 20 g/kg is approaching the range where Kemper and Koch (1966) found aggregate status less sensitive to organic matter concentration.

Although residue management treatments within a crop generally did not influence soil physical properties, soil physical properties differed in all categories between crops (Table 3). The soil aggregates from the sorghum plots that had higher organic matter content were smaller, more fragile, less dense, less stable (dry), and more stable (wet) than the aggregates from the wheat plots. Armbrust et al. (1982) also found that aggregates from winter wheat plots were less erodible, and more stable (dry) than were aggregates from sorghum plots.

The difference in soil organic matter concentration between wheat and sorghum plots does not adequately account for the differences in soil physical properties. The difference in soil organic matter concentration between wheat and sorghum plots was about the same as the difference in soil organic matter concentration between 2× and residue removed plots. Obviously, other mechanisms are operative: differences in activity of soil microorganisms, water and temperature regimes, and residue decomposition rates and products as influenced by modified cropping are all important.

The longer time interval between incorporating residues and soil sampling may account for some of the differences of soil physical properties between sorghum and wheat plots. Several researchers (Chepil, 1955; McCalla, 1945; Miller and Kemper, 1962; Siddoway, 1963) have observed that the influence of incorporating crop residues is of short duration and is not as effective as leaving the residue on the surface where it decomposes less rapidly and continues to replenish the cementing products for a much longer period. Additionally, a good stand of wheat in the fall provided over-winter protection of the surface soil against raindrop impact and freeze drying. Both of these actions reduce GMD of soil aggregates and increase wind erodibility index of the soil on the more unprotected sorghum plots (Table 3). Freeze drying can be especially destructive of soil aggregates (Skidmore, 1975).

The saturated hydraulic conductivity was seven times greater in the soil cores taken from the sorghum plots than in cores from the wheat plots. The comparison of water release characteristics shows a distinct difference in soil structure between the sorghum and wheat plots favorable to water infiltration in the soil of the sorghum plots (Fig. 1). No significant differences in the water release characteristics were found among residue management treatments within a crop.

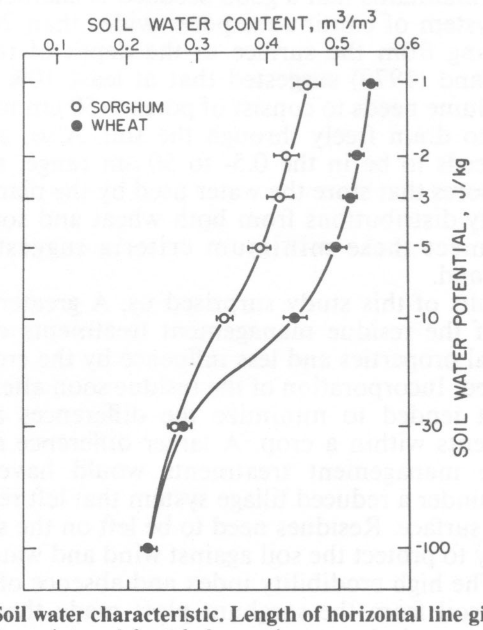

Fig. 1. Soil water characteristic. Length of horizontal line gives 95% confidence interval for 16 observations.

Table 4. Fractional soil volume of pores with equivalent diameters in the indicated ranges and corresponding soil water matric potentials.

	Equivalent pore diameter†, μm			
	<0.2	0.2 to 30	30 to 300	>300
	Soil water matric potential, J/kg			
Crop	−1500	−1500 to −10	−10 to −1	>1
Wheat	0.13	0.31	0.11	0.04
Sorghum	0.13	0.21	0.12	0.17

† The equivalent pore diameter (EPD) in micrometers of largest water-filled pore was calculated from EPD $= -4\gamma \cos \theta/\psi \varrho_w$ where ψ is matric potential of soil water (J/kg), γ is surface tension of water against air (N/m), ϱ_w is density of water (kg/m³), and θ is contact angle and assumed to be zero.

Average total porosities for the soils in the sorghum and wheat plots were 0.63 and 0.59 m^3/m^3, respectively, at −10-J/kg water potential. Volumetric water content at −1500-J/kg matric potential was 0.13 m^3/m^3 in both cases.

A large portion of the pores of the soil from the sorghum plots empty at high water potential and low soil-water suction, whereas a large portion of the pores in the soil from the wheat plots empty in the field capacity range of water potential between −10 and −30 J/kg.

At water potentials of −10 J/kg, corresponding equivalent pore diameter (EPD) was 30 μm, and air-filled pore space was 0.29 and 0.15 m^3/m^3 for the soil from the sorghum and wheat plots, respectively (Fig. 1, Table 4). Pores that are empty of water at those high potentials are usually referred to as macro or transmission pores (Greenland, 1977; Luxmoore, 1981; Brewer, 1964). The change in water content between −10 and −30 J/kg was larger in the soil from the wheat plots than that from the sorghum plots (0.16 compared with 0.07 m^3/m^3). A soil with the pore size distribution like the soil in the sorghum plots would be expected to readily admit water, have adequate O_2 diffusion, and allow rapid root development. Russell (1978) maintains that a good seedbed is characterized by a system of continuous pores wider than 200 μm stretching from the surface to the depth of rooting. Greenland (1979) suggested that at least 10% of the soil volume needs to consist of pores >50 μm to allow water to drain freely through the soil. Also, at least 10% needs to be in the 0.5- to 50-μm range, as it is these pores that store the water used by the plant. Soil porosity distributions from both wheat and sorghum plots meet these minimum criteria suggested by Greenland.

Results of this study surprised us. A greater influence of the residue management treatments on soil physical properties and less influence by the crop was expected. Incorporation of the residue soon after grain harvest tended to minimize the differences among treatments within a crop. A larger difference among residue management treatments would have been found under a reduced tillage system that left residues on the surface. Residues need to be left on the surface anyway to protect the soil against wind and water erosion. The high erodibility index and absence of cover of the soil from the sorghum plots made them susceptible to wind erosion.

Higher infiltration and more stable aggregates (wet) of the soil from the sorghum plots are generally associated with a more desirable tilth. The extent to which this effect would have on crop yields is uncertain. However, it is known that crop rotation often increases crop yields. To better understand the influence of crop and residue management on soil properties, samples must be collected temporally as well as spatially with present treatments and then rotate crops; growing sorghum where wheat is now, grow wheat where sorghum is grown, keep residue management treatments matched. We also need to know more about the decomposition rates of crop roots and residues as influenced by C/N ratios, specific surface area exposed to soil water potential, temperature, microorganisms, etc., and how organic matter decomposition products influence soil properties.

REFERENCES

Armbrust, D.V., J.D. Dickerson, E.L. Skidmore, and O.G. Russ. 1982. Dry soil aggregation as influenced by crop and tillage. Soil Sci. Soc. Am. J. 46:390–393.

Biederbeck, V.O., C.A. Campbell, K.E. Bowren, M. Schnitzer, and R.N. McIver. 1980. Effect of burning cereal straw on soil properties and grain yields in Saskatchewan. Soil Sci. Soc. Am. J. 44:103–111.

Black, A.L. 1973. Soil property changes and crop residue management in a wheat-fallow rotation. Soil Sci. Soc. Am. Proc. 37:943–946.

Blake, G.R. 1965. Bulk density. *In* C.A. Black et al. (ed.) Methods of Soil Analysis, Part 1. Agronomy 9:374–390.

Boyd, D.W., E.L. Skidmore, and J.G. Thompson. 1983. A soil-aggregate crushing-energy meter. Soil Sci. Soc. Am. J. 47:313–316.

Brewer, R. 1964. Fabric and mineral analysis of soils. John Wiley & Sons, Inc., New York.

Cary, J.W., and C.W. Hayden. 1974. Soil strength and porosities associated with cropping sequences. Soil Sci. Soc. Am. Proc. 38:840–843.

Chepil, W.S. 1955. Factors that influence clod structure and erodibility of soil by wind: V. Organic matter at various stages of decomposition. Soil Sci. 80:413–421.

Chepil, W.S. 1962. A compact rotary sieve and the importance of dry sieving in physical soil analysis. Soil Sci. Soc. Am. Proc. 26:4–6.

Dormaar, J.F. 1979. Organic matter characteristics of undisturbed and cultivated Chernozemic and Solonetzic A horizon. Can. J. Soil Sci. 59:349–456.

Dormaar, J.F., U.J. Pittman, and E.D. Spratt. 1979. Burning crop residues: Effect on selected soil characteristics and long-term wheat yields. Can. J. Soil Sci. 59:79–86.

Gardner, W.R. 1956. Representation of soil aggregate-size distribution by a logarithmic-normal distribution. Soil Sci. Soc. Am. Proc. 20:151–153.

Greenland, D.J. 1977. Soil damage by intensive arable cultivation: temporary or permanent? Phil. Trans. Roy Soc. (London) B. 281:193–208.

Greenland, D.J. 1979. Structural organization of soils and crop production. p. 47–56. *In* R. Lal and D.J. Greenland (ed.) Soil physical properties and crop production in the tropics. John Wiley & Sons, New York.

Harris, R.F., G. Chesters, and O.N. Allen. 1966. Dynamics of soil aggregation. Adv. Agron. 18:107–169.

Hobbs, J.A., and P.L. Brown. 1957. Nitrogen and organic carbon changes in cultivated western Kansas soils. Kans. Agric. Exp. Stn. Bull. 89.

Hooker, M.L., G.M. Herron, and P. Penas. 1982. Effects of residue burning, removal, and incorporation on irrigated cereal crop yields and soil chemical properties. Soil Sci. Soc. Am. J. 46:122–126.

Kemper, W.D. 1965. Aggregate stability. *In* C.A. Black et al. (ed.) Methods of Soil Analysis, Part 1. Agronomy 9:511–519.

Kemper, W.D., and W.S. Chepil. 1965. Size distribution of aggregates. *In* C.A. Black et al. (ed.) Methods of Soil Analysis, Part 1. Agronomy 9:499–510.

Kemper, W.D., and E.J. Koch. 1966. Aggregate stability of soils from western United States and Canada. Tech. Bull. no. 1355. USDA, U.S. Government Printing Office, Washington, DC.

Klute, A. 1965a. Laboratory measurements of hydraulic conductivity of saturated soil. *In* C.A. Black et al. (ed.) Methods of Soil Analysis, Part 1. Agronomy 9:210–221.

Klute, A. 1965b. Water capacity. *In* C.A. Black et al. (ed.) Methods of Soil Analysis, Part 1. Agronomy 9:273–278.

Luxmoore, R.J. 1981. Micro-, meso-, and macroporosity of soil. Soil Sci. Soc. Am. J. 45:671–672.

Larson, W.E., R.F. Holt, and C.W. Carlson. 1978. Residues for soil conservation. p. 1–15. *In* W.R. Oschwald (ed.) Crop residue management systems. Spec. Pub. 31. American Society of Agronomy, Madison, WI.

Lyles, L., J.D. Dickerson, and L.A. Disrud. 1970. Modified rotary sieve for improved accuracy. Soil Sci. 109:207–210.

McCalla, T.M. 1945. Influence of micro-organisms and some organic substances on soil structure. Soil Sci. 59:287–297.

Miller, D.E., and W.D. Kemper. 1962. Water stability of aggregates of two soils as influenced by incorporation of alfalfa. Agron. J. 54:494–496.

Olmstead, L.B. 1946. The effect of long-time cropping systems and tillage practices upon soil aggregation at Hays, Kansas. Soil Sci. Soc. Am. Proc. 11:89–92.

Rasmussen, P.E., R.R. Allmaras, C.R. Rohde, and N.C. Roager, Jr. 1980. Crop residue influence on soil carbon and nitrogen in a wheat-fallow system. Soil Sci. Soc. Am. J. 44:496–600.

Russell, E.W. 1978. Arable agriculture and soil deterioration. p. 216–227. *In* 11th Cong., International Society of Soil Science, Symposia Papers, Vol. 3. Edmonton, Canada. 19–27 July.

Shipley, J.L., and C. Regier. 1977. Effect of wheat straw disposal practices in the continuous production of irrigated winter wheat. Texas Agric. Exp. Stn. Misc. Rep. MP-1348C.

Siddoway, F.H. 1963. Effects of cropping and tillage methods on dry aggregate soil structure. Soil Sci. Soc. Am. Proc. 27:452–454.

Skidmore, E.L. 1975. Soil structure as influenced by freezing and thawing. Agron. Abstr. American Society of Agronomy, Madison, WI, p. 159.

Skidmore, E.L., W.A. Carstenson, and E.E. Banbury. 1975. Soil changes resulting from cropping. Soil Sci. Soc. Am. Proc. 39:964–967.

Skidmore, E.L., M. Kumar, and W.E. Larson. 1979. Crop residue management for wind erosion control in the Great Plains. J. Soil Water Conserv. 34:90–96.

Skidmore, E.L., and D.H. Powers. 1982. Dry soil-aggregate stability: Energy-based index. Soil Sci. Soc. Am. J. 46:1274–1279.

Unger, P.W. 1969. Physical properties of Pullman silty clay loam as affected by dryland wheat management practices. Texas Agric. Exp. Stn. Misc. Rep. MP-933.

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

Unger. P.W., R.R. Allen, and J.J. Parker. 1973. Cultural practices for irrigated wheat production. Soil Sci. Soc. Am. Proc. 37:437–442.

Vomocil, J.A. 1965. Porosity. *In* C.A. Black et al. (ed.) Methods of Soil Analysis, Part 1. Agronomy 9:299–314.

Woodruff, N.P., and F.H. Siddoway. 1965. A wind erosion equation. Soil Sci. Soc. Am. Proc. 29:602–608.