Organic Carbon Effects on Soil Physical and Hydraulic Properties in a Semiarid Climate

Joseph G. Benjamin*
Maysoon M. Mikha
Merle F. Vigil
USDA-ARS
Central Great Plains Research Station
Akron, CO 80720

Increasing cropping intensity in the central Great Plains of the United States has the potential to increase organic carbon (OC) stored in the soil and lead to improved soil physical properties. A cropping systems study was started in 1990 at the Central Great Plains Research Station near Akron, CO. In 2005 soil samples were taken in six 95-mm increments to a depth of 370 mm to measure OC, water stable macroaggregates (water stable aggregates > 250 μm), bulk density (ρ_b), total porosity (φ_{total}), water storage porosity (φ_{ws}), and saturated hydraulic conductivity (k_{sat}). Samples were collected from permanent grass plots {45% smooth brome [*Bromus inermis* (Leyss.)], 40% pubescent wheat grass [*Agropyrons trichophorum* (Link) Richt.], and 15% alfalfa [*Medicago sativa* (L.)]}, plots in a wheat {[*Triticum aestivum* (L.)]–corn [*Zea mays* (L.)]–millet [*Panicum miliaceum* (L.)]} rotation, and plots in a wheat–fallow rotation. Increased cropping intensity significantly increased OC, water stable macroaggregates, and k_{sat}, but had no significant effect on ρ_b, φ_{total}, or φ_{ws}. Permanent grass increased OC compared with the annually cropped rotations, particularly deeper in the soil. Plots in permanent grass had greater k_{sat} and this may indicate greater pore continuity and stability under saturated conditions. Organic carbon and water stable macroaggregates were poorly correlated. Water stable macroaggregates was negatively correlated with ρ_b and positively correlated with k_{sat}. Increasing soil OC may not immediately lead to changes in soil aggregation in a semiarid climate. Increased time and biological activity may be needed to convert the crop residues into organic compounds that stabilize aggregates and soil pore systems.

Abbreviations: CI, cropping intensity; k_{sat}, saturated hydraulic conductivity; OC, organic carbon; WCM, wheat–corn–millet; WF, wheat–fallow; θ_{g33}, gravimetric water content; θ_{v1500}, wilting point water content; ρ_b, bulk density; φ_{total}, total porosity; φ_{ws}, water storage porosity

Soil organic matter plays an important role in stabilizing soil aggregates. Tisdall and Oades (1982) noted that transient and temporary organic bonding agents were the main binding agent for aggregates > 250 μm in diameter (macroaggregates). Persistent binding agents, such as resistant aromatic compounds associated with polyvalent metal cations, and strongly sorbed polymers, were the main binding agent for aggregates < 250 μm in diameter (microaggregates). In the opinion of Tisdall and Oades, macroaggregation was controlled by soil management in that management influences the growth of plant roots and the oxidation of OC.

Aggregate stability may influence soil aggregation, hydraulic conductivity, and soil water retention. Lado et al. (2004) showed that more stable soil macroaggregates decreased swelling and slaking of the soil aggregates under saturated conditions and so maintained greater saturated hydraulic conductivity. Bowman et al. (1990) measured lower water content at field capacity (–33 kPa) and lower cation exchange capacity associated with the loss of organic matter. On the other hand, Bauer and Black (1981) measured no significant soil bulk density differences between cropped and grassland soils at depths to 450 mm.

Significant loss of OC has occurred in soil where native grasslands have been converted to crop land. Bauer and Black (1981) showed that cultivated soils lost 28 to 38% of the original OC, compared with virgin grassland, after 25 yr of cultivation. Bowman et al. (1990) showed that, after 60 yr of tillage, approximately 60% of the original OC was lost in the surface 150 mm of a sandy soil in eastern Colorado. Most of the carbon loss occurred in the first 3 yr after the onset of cultivation.

Benjamin et al. (2003) showed that the soil physical environment can influence crop productivity in a semiarid environment by improving or degrading water holding capacity, soil strength, or soil aeration. In the range of bulk densities of their study, a lower bulk density was correlated to a greater least limiting water range and improved winter wheat production. Stepniewski et al. (1994) cite evidence that improved soil structure can lead to better macroporosity and improved aeration. Increasing organic matter in soil has the potential to improve soil hydraulic properties by increasing macroporosity, improving water holding capacity, and increasing saturated hydraulic conductivity. Pikul and Allmaras (1986) reported lower bulk density, increased volume of soil pores > 50 μm, and greater saturated hydraulic conductivity in wheat–fallow cropping systems when manure was added to the soil compared with only returning the straw to the system.

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*Corresponding author (Joseph.Benjamin@ars.usda.gov).

Increasing cropping intensity and decreasing fallow in no-till cropping systems in the central Great Plains has the potential to increase OC in the soil profile both by increasing carbon additions to the system and decreasing oxidation caused by tillage. Greater cropping intensity may increase organic matter near the soil surface and may lead to better soil physical and chemical properties for crop production (Bowman et al., 1999; Mikha et al., 2006; McVay et al., 2006). Ball et al. (2005) showed that changes in crop species and soil management may influence soil structure. It is conceivable that different crop species may affect soil properties because of different rooting characteristics and rooting depths.

Most changes in soil organic matter caused by a change in cropping system have been limited to the surface 50 to75 mm (Bowman et al., 1999; Mikha et al., 2006; McVay et al., 2006). However, changes of other soil physical properties can extend to significant depths. Plant roots exert forces on the soil and can be used to change soil physical conditions, particularly by changing pore size distribution and pore continuity (Elkins, 1985). Many of the effects of plant roots may be found in the subsoil. "Biological drilling" is a term used for the improvement of compacted subsoil by selecting plant species in a rotation that will loosen the soil for subsequent crops (Cresswell and Kirkegaard, 1995). Certain plant species have been selected specifically for their ability to penetrate compacted subsoil (Cresswell and Kirkegaard, 1995).

The objective of this study was to quantify the change of soil water characteristics as soil organic matter increases because of greater intensity of cropping systems in the central Great Plains.

MATERIALS AND METHODS

The study was conducted on the Alternative Crops Rotation study plots at the USDA-ARS Central Great Plains Research Station near Akron, CO. The station lies at 40.15° N lat and 103.15° W long. The elevation of the station is 1384 m above mean sea level. The research station location is within a semiarid climate with approximately 400 mm annual precipitation. The soil is a Weld silt loam (fine, smectitic, mesic Aridic Paleustolls). This soil has a silt loam (approximately 22% clay) Ap horizon from about 0 to 120 mm with fine granular structure. A silty clay loam (approximately 32% clay) Bt1 horizon with fine to medium subangular blocky structure extends from about 120 to 240 mm with a smooth boundary to a silty clay loam (approximately 28% clay) Bt2 horizon, also with fine to medium subangular blocky structure to about 410 mm. A silty clay loam (approximately 28% clay) Btk horizon with fine to medium subangular blocky structure extends to about 640 mm.

The cropping systems experiment started in 1990. The experiment is organized as a randomized complete block design with three replications. Rotations of crops suited for dryland crop production in the central Great Plains are the experimental units. Each phase of each rotation occurs each year. The wheat–fallow, wheat–corn–millet, and perennial grass plots were selected for study. The wheat–fallow (WF) rotation harvests one crop every 2 yr, so the cropping intensity (CI) is 0.5. The wheat–corn–millet (WCM) rotation harvests a crop every year, so it has a CI of 1.0. The perennial grass plots were originally seeded to a mixture of 45% smooth brome, 40% pubescent wheat grass, and 15% alfalfa at the start of the experiment. The alfalfa quickly died, however, so by the time the samples were taken the plots were almost exclusively grass.

No tillage is conducted on any of the plots. Plot size and machinery working widths are such that the wheel tracks for field operations follow a controlled wheel traffic pattern. The only soil disturbance in nontracked areas is by planter or drill operations to plant the seed. Chemical weed control is used during the fallow and cropped seasons. A typical herbicide application scheme for each rotation consists of a residual herbicide application of atrazine (2-chloro-4-ethylamino-6-isopropylamino-*s*-triazine) after wheat harvest. A burn-down application of glyphosate [isopropylamine salt of *N*-(phosphonomethyl) glycine] is applied shortly before planting the next crop. Several glyphosate applications are made, as needed, during the fallow period for weed control. Wheat planting occurred in mid to late September for each year of the study. Corn planting occurred in mid to late May. Millet planting occurred in late May or early June. Wheat and millet were planted in 0.19-m rows. Corn was planted in 0.75-m rows.

Soil cores to determine soil physical properties were taken from each plot in each rotation in 2005, 15 yr after the start of experiment. Samples were collected before planting in May for the corn and millet. Samples were collected in June for all of the fallow plots and the grass plots, and immediately after wheat harvest in July for the wheat plots. Wheel-trafficked areas were purposely avoided during sampling. Previous work on these plots indicated little in-season variation of infiltration or bulk density for no-till cropping systems at this location (Pikul et al., 2006). Sampling was conducted with a Giddings[1] hydraulic probe (Giddings Machine Co., Windsor, CO) that used aluminum sleeves to contain the undisturbed soil sample. One soil core 75 mm diam. by 75 mm long was taken to a depth of 0.5 m from each plot. Two 10-mm spacer rings were inserted between each core to facilitate trimming. The surface 20 mm of soil was discarded to ensure a smooth surface on the confined ring. Samples represented depth increments of 20 to 95 mm (Depth 1), 115 to 180 mm (Depth 2), 200 to 275 mm (Depth 3), and 295 to 370 mm (Depth 4). The cores were trimmed to the size of the ring and transported to the lab.

Separate soil cores for determining soil OC and aggregate stability were taken at comparable depths with the Giddings hydraulic probe. For these samples a 50-mm unconfined probe was used. Two probe samples were taken within about 1 m of the cores sampled for hydraulic properties and the soil for each depth was combined for a composite sample.

Saturated Hydraulic Conductivity and Porosity

Saturated hydraulic conductivity (k_{sat}) was determined for each core with the constant head method (Reynolds and Elrick, 2002). Each core was then placed in an individual pressure chamber and the water desorption was measured at 33-kPa air pressure (Flint and Flint, 2002). Water outflow was measured daily until no more water was expelled from the core. The cores were then removed from the chamber and the gravimetric water content (θ_{g33}) was determined. The bulk density (ρ_b) of each core was determined and the volumetric water content at −33 kPa (θ_{v33}) was calculated from θ_{g33} and ρ_b by

$$\theta_{v33} = \theta_{g33}\ \rho_b \qquad [1]$$

[1]Mention of specific brand names are for informational purposes only and do not denote an endorsement of that brand over other, similar brands.

An estimate of the wilting point water content (θ_{v1500}) was determined by placing disturbed soil samples from each sampling depth on a high-pressure desorption apparatus and determining the water content at 1500 kPa pressure. The gravimetric water content was multiplied by ρ_b of the individual core to determine θ_{v1500}.

Pore sizes that emptied of water at each pressure step were determined by the capillary rise equation (Flint and Flint, 2002)

$$d = 2(-2 \sigma \cos \alpha)/P \qquad [2]$$

where d is the pore diameter (m), σ is the surface tension of water (0.0728 J m^{-2}), α is the contact angle of the water–soil interface (assumed to be 0), and P is the pressure in the chamber (Pa). Water storage pores, or plant available water, were the volume of pores with diameters between 8.8 μm and 0.2 μm (φ_{ws}) determined between θ_{v33} and θ_{v1500}. Total porosity (φ_{total}) was calculated from the measured ρ_b by

$$\varphi_{total} = 1 - \rho_b/2.65 \qquad [3]$$

Aggregate Size Distributions

Water stable aggregates were separated using an instrument similar in principle to the Yoder wet-sieving apparatus (Yoder, 1936) and modified by Mikha et al. (2005). The apparatus was modified and designed to handle stacked sieves (12.7 cm diam.) and to allow for complete recovery of all particle fractions from individual samples. Aggregate size classes were collected from each treatment (n = 4), >1000-, 500- to 1000-, 250- to 500-, 53- to 250-, and 20- to 53-μm diam. Macroaggregates were operationally defined as the sum of the >1000, 500- to 1000-, and 250- to 500-μm size fractions; microaggregates were defined as the sum of the 53- to 250- and 20- to 53-μm size fractions. The amount of soil used was < 0.4 g of air-dried soil cm^{-2} of sieve area. Soils were air dried for 24 h and evenly distributed over the nested sieve surfaces (>1000, 500- to 1000-, and 250- to 500-μm diam.). The nest was set at the highest point of the oscillation cycle. The cylinders were filled with distilled water to the point at which the bottom sieve (250-μm diam.) was completely covered with water without reaching the top screen (1000-μm diam.). Four 50-g subsamples of air-dried soil were placed on the top sieve of each nest. To slake the air-dried soil, 1 L of distilled water was rapidly added to each cylinder until the soil sample and top screen were covered with water. The soils were submerged in water for 10 min before the start of the wet-sieving action. The apparatus specifications of oscillation time (10 min), stroke length (4 cm), and frequency (30-cycle min^{-1}) were held constant.

Following wet sieving, soil plus water remaining in the oscillation cylinder was poured onto the finer sieves (53 and 20 μm in diam.). Each sieve was shaken horizontally for 1 min to allow water and particle fractions smaller than the sieve size to pass through. Material remaining on each sieve was backwashed into a round aluminum pan (11-cm top diam., volume of 200 mL) and dried at 50 °C for 24 h. The dried aggregate from each size class was weighed and stored in crush-resistant containers at room temperature. Floating organic matter (density < 1 g cm^{-3}) was removed from the >1000-μm aggregate size class since it was mostly plant debris. However, organic matter from other aggregate size classes was considered organic matter associated with the size class and not removed. Aggregates < 20 μm diam. were discarded and soil recovery calculated. Subsamples (0.2–2.0 g) of water stable aggregates from each size class were dried at 105 °C for 24 h to allow correction for oven-dry weight.

Sand-free water stable aggregation was measured using a subsample of intact aggregates (2–5 g) and combined with fivefold volume (10–25 mL) of 5 g L^{-1} sodium hexametaphosphate, left overnight and shaken on an orbital shaker at 350 rpm for 4 h. The dispersed organic matter and sand was collected on a 53 μm mesh sieve, washed with deionized water, and dried at 105 °C for 24 h, and the aggregate weights were recorded for estimating the sand-free correction (Six et al., 1998).

Soil Organic Carbon

Soil OC was determined by subtraction of soil inorganic C from the total C. Soil total C was measured by direct combustion (950 °C) using a Leco CHN-2000 analyzer (Leco Co., St Joseph, MI). Air-dry soils were ground to a fine powder using a roller mill and about 0.2 g of grounded soil was used for C analysis. Soil inorganic C was evaluated using a modified pressure-calcimeter method reported by Sherrod et al. (2002). In a 20-mL Wheaton serum bottle, (Wheaton Science Products, Millville, NJ), 2 mL of HCl acid was added to 0.5 g of ground soil. Each serum bottle were sealed with a rubber stopper and crimped closed with an aluminum seal. The reaction between the soil and the acid was started by vigorously shaking the serum bottle for less than a minute. After a 6-h reaction time, the CO_2 evolved (representing soil $CaCO_3$ concentration after applying the calibration curve) was measured using the apparatus proposed by Sherrod et al. (2002).

Statistical Analysis

Statistical analysis of crop rotation effects on OC, water stable macroaggregates, ρ_b, φ_{total}, φ_{ws}, and k_{sat} was conducted using Proc GLM of SAS ver. 8 (SAS Institute, Inc., 1999). For statistical analysis on k_{sat}, a natural log transformation was used to normalize the data. The data were then re-transformed for presentation in the accompanying tables and figures. Statistical analysis of the crop phase within each year and depth showed no significant effect of the particular crop growing that year on any of the physical properties measured. Therefore, data were pooled across crop species to determine crop rotation effects on physical property variables. The level for significant treatment effects was chosen at P = 0.05. Means separation was determined with Duncan's multiple range test on soil physical properties averaged over all depths and for each depth if the F statistic was significant for that variable.

Nonlinear regression was used to determine the relationship between soil OC and macroaggregates, macroaggregates and ρ_b, and macroaggregates and k_{sat}. An exponential equation was used with the form of

$$f = y0 + a\exp(-bx) \qquad [4]$$

where f represents the dependent variable, x represents the independent variable and a and b are regression coefficients.

RESULTS AND DISCUSSION

Cropping Intensity Effects on Organic Carbon, Macroaggregation, ρ_b, k_{sat}, and Soil Porosity

Cropping intensity had a significant effect on soil OC, water stable macroaggregates, and k_{sat} (Table 1). Cropping intensity had no significant effect on ρ_b, φ_{total}, or φ_{ws}. Depth had a significant effect on OC, water stable macroaggregates, ρ_b, φ_{total}, and φ_{ws}. Only k_{sat} did not vary with depth. There were no cropping intensity by depth interactions detected at P = 0.05.

Soil OC values from the grass plots and the WCM plots were similar (Table 2) when averaged over the surface 370 mm

Table 1. Crop rotation, depth, and crop rotation by depth interaction effects on organic carbon (OC), macroaggregates (A_{macro}), bulk density (ρ_b), total porosity (φ_{total}), water storage porosity (φ_{ws}), and saturated hydraulic conductivity (k_{sat}).

Rotation	OC	A_{macro}	ρ_b	φ_{total}	φ_{ws}	k_{sat}
	$P > F$					
Crop Intensity	0.0051	0.014	0.373	0.373	0.225	<0.0001
Depth	<0.0001	<0.0001	0.0009	0.0009	0.048	0.284
Intensity by Depth	0.111	0.071	0.341	0.341	0.942	0.978

Table 2. Mean values† for organic carbon (OC), macroaggregates (A_{macro}), bulk density (ρ_b), total porosity (φ_{total}), water storage porosity (φ_{ws}) and saturated hydraulic conductivity (k_{sat}) in the surface 370 mm of soil.

Contrast by Plot Type‡	OC	A_{macro}	r_b	j_{total}	j_{ws}	k_{sat}
	g kg^{-1}		mg m^{-3}	m^3 m^{-3}		mm h^{-1}
Grass	7.9 a	94.6 a	1.29 a	0.51 a	0.28 a	10.8 a
WCM	7.8 a	85.9 a	1.32 a	0.50 a	0.28 a	3.2 b
WF	6.1 b	60.3 b	1.32 a	0.50 a	0.26 a	3.0 b

†Mean values followed by the same letter are not significant at P = 0.05 determined by Duncan's multiple range test.

‡WCM indicates the wheat–corn–millet rotation plots, WF indicates the wheat–fallow rotation plots, and Grass indicates permanent grass plots.

of soil. Both the grass plots and the WCM plots had greater OC than the WF plots. Soil OC concentration was greatest at Depth 1 (20–95 mm) and decreased in samples taken from deeper depths (Fig. 1). In depth 1 there was no difference in OC between grass and WCM plots. Both treatments had greater OC than the WF plots. At Depth 2 (115–180 mm) the grass plots had significantly greater OC than the cropped plots, although there was no difference between WCM and WF. At Depth 3 (200–275 mm) grass had the greatest OC, followed by WCM and WF with the least OC. At Depth 4 (295–370 mm) there was no difference among the cropping systems. Other studies in the region (Bowman et al., 1999; Mikha et al., 2006; McVay et al., 2006), have measured greater OC near the surface but found no significant treatment effects on OC when averaged over a large volume of soil.

The relative difference in OC between the WCM and WF cropping systems widened during the years between 1999 and 2005. Bowman et al. (1999) reported approximately 13% greater OC in the 0 to 150-mm layer of soil with a CI of 1.0 compared with the cropping system with a CI of 0.5. We found a 30% increase of OC for the WCM rotation over the WF rotation when averaged over 370 mm of soil. Bowman et al. (1999) found no OC differences among cropping intensities below 150 mm of soil. In this study, there were OC differences between the 1.0 CI and the 0.5 CI at the 20- to 95-mm soil depth as well as OC differences at the 200- to 275-mm soil depth. Changes in OC over time indicate that a CI of 1.0 continues to add OC to the soil system and that the OC is accumulating deeper in the soil. Permanent grass caused an increase in OC compared with the annually cropped rotations, particularly deeper in the soil.

The proportion of water stable macroaggregates increased with cropping intensity (Table 2). The grass plots had the greatest water stable macroaggregates and the WF had the least. The greatest proportion of water stable macroaggregates occurred in Depths 3 and 4 (Fig. 1). These depths correspond to the Bt2 horizon of the Weld silt loam. The increase in clay from the Ap to the Bt2 horizon increased the effects of cropping system on aggregate stability. At Depths 1 and 2 there was no cropping intensity effect on water stable macroaggregates. At Depth 3 the grass plots had greater aggregate stability than either WCM plots or WF plots. At Depth 4 the grass and WCM plots had similar aggregate stability and both were greater than the WF plots.

There were no differences among cropping systems for ρ_b, φ_{total}, or φ_{ws} at any depth (Table 2). The grass plots had greater k_{sat} than the cropped systems, but there was no difference between WCM and WF. The grass plots had consistently greater k_{sat} at all depths compared with either of the annually cropped plots (Fig. 1).

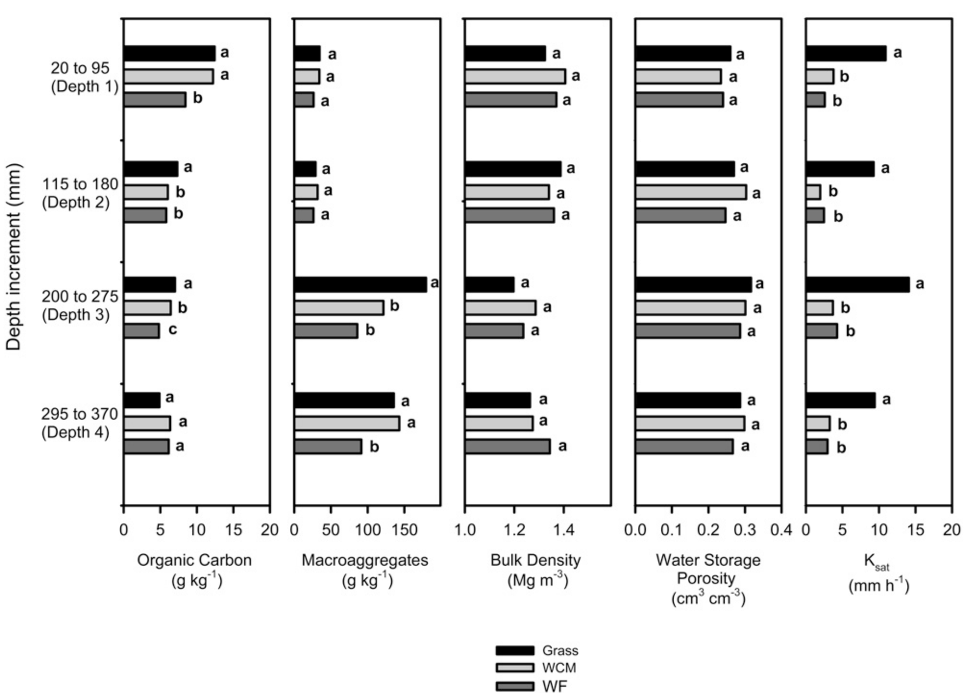

Fig. 1. Cropping intensity effects on soil organic C, macroaggregates, bulk density, water storage porosity, and saturated hydraulic conductivity (k_{sat}) for a Weld silt loam. Means followed by the same letter are not significant at P = 0.05 determined by Duncan's multiple range test. WCM indicates the wheat–corn–millet rotation plots, WF indicates the wheat–fallow rotation plots, and Grass indicates permanent grass plots.

Soil Organic Carbon Effects on Macroaggregates and Soil Hydraulic Properties

The correlation between OC and water stable macroaggregates was generally low (Fig. 2). In Depths 1 and 2 there was essentially no change in proportion of water stable macroaggregates across the observed range of OC. There was also no difference in correla-

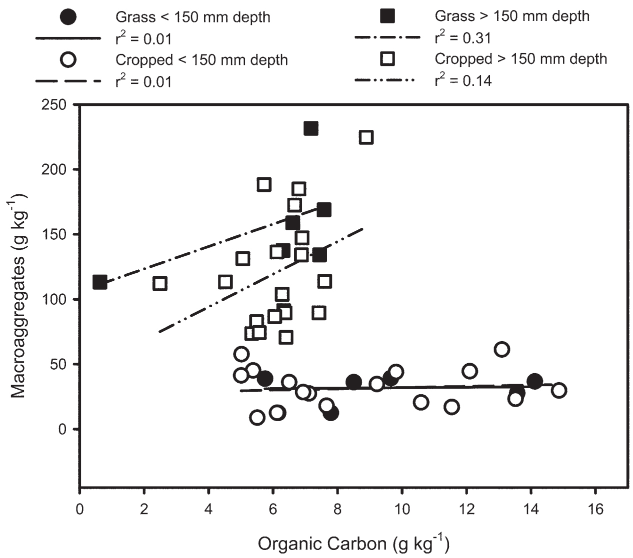

Fig. 2. Correlation between organic C and macroaggregates for grass plots and cropped plots. Data for grass plots were separated into Depths 1 and 2 (●, solid circle) and Depths 3 and 4 (■, solid square). Data for wheat–corn–millet and wheat–fallow rotations were combined (cropped) and separated into Depths 1 and 2 (○, open circle) and Depths 3 and 4 (□, open square).

tion of OC and water stable macroaggregates between plots in the cropped systems and the permanent grass plots. In Depths 3 and 4 there was a positive slope in the regression between OC and water stable macroaggregates, but the correlation was weak (r^2 = 0.31 for the grass plots and r^2 = 0.14 for the cropped plots). A relatively narrow range of OC was found in these soils (approximately 4–14 g kg^{-1}). Chaney and Swift (1984) showed a greater positive correlation between OC and water stable aggregates, but their study was from a number of soils and spanned an OC range of 5 to 95 g kg^{-1}. Correlations between OC and the other soil physical properties measured in this study were also generally low.

Treatment differences in soil OC were a poor indicator of changes in other soil physical and hydraulic properties. For instance, at the first sampling depth the OC content was similar between the grass plots and the WCM plots, yet k_{sat} for the grass plots was over 250% greater than the WCM plots. At the 295- to 370-mm depth there was no OC difference among any of the cropping intensity treatments, yet k_{sat} for the grass plots was 300% greater than the cropped plots.

Macroaggregate Effects on ρ_b and k_{sat}

Aggregate stability was a better indicator of changes in other physical and hydraulic properties than was OC. There appeared to be a curvilinear negative correlation between water stable macroaggregates and ρ_b (Fig. 3). With low quantities of water stable macroaggregates, the ρ_b values of the grass plots and the cropped plots were similar. As aggregation increased, ρ_b of the grass plots decreased more quickly than the cropped plots. At the highest level of water stable macroaggregates measured in this study, ρ_b of the grass plots and cropped plots became similar again.

There appeared to be curvilinear correlation between water stable macroaggregates and k_{sat} in the cropped plots, but a nearly linear correlation between water stable macroaggregates

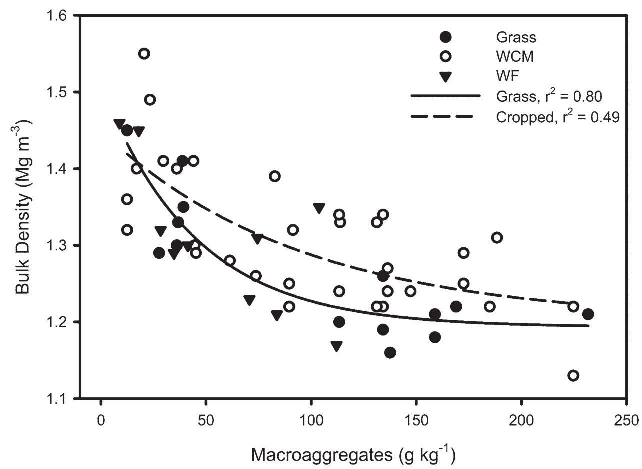

Fig. 3. Correlation between stable macroaggregates and bulk density for grass plots and cropped plots. WCM indicates the wheat–corn–millet rotation plots, WF indicates the wheat–fallow rotation plots, Grass indicates permanent grass plots, and Cropped indicates combined WCM and WF plots.

and k_{sat} in the grass plots (Fig. 4). At low levels of water stable macroaggregates, k_{sat} of the grass plots was approximately double that of the cropped plots. For a relatively wide range of aggregate stability, k_{sat} of the cropped plots remained constantly low. As water stable macroaggregates increased above the 150-g kg^{-1} range, k_{sat} in the cropped plots increased to nearly the level observed in the grass plots. Lado et al. (2004) found greater k_{sat} in columns of aggregates and attributed the increased k_{sat} to less slaking under saturated conditions. In their study, greater aggregate stability was attributed to higher OC levels. In this study, OC level had little effect on aggregate stability and aggregate stability was better correlated to crop species and cropping intensity. It is possible that the additional OC from the cropping system has not been incorporated into binding agents that promote aggregate stability and that more time is needed to show an improvement of aggregate stability based on cropping intensity and rotation. Elkins (1985) noted that soils with permanent vegetation create a more continuous pore network due to more root activity and persistence when

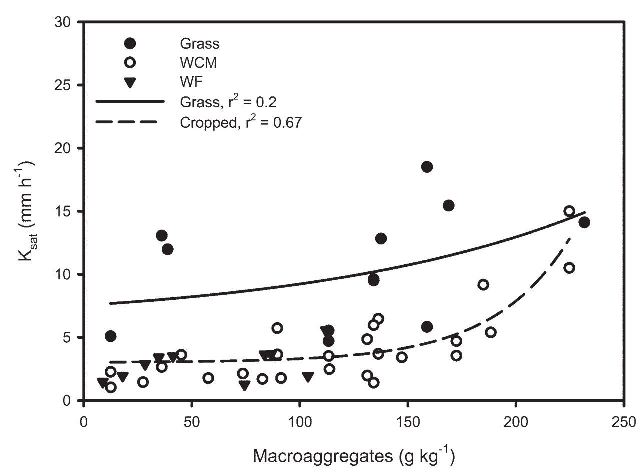

Fig. 4. Correlation between stable macroaggregates and saturated hydraulic conductivity (k_{sat}) for grass plots and cropped plots. WCM indicates the wheat–corn–millet rotation plots, WF indicates the wheat–fallow rotation plots, Grass indicates permanent grass plots, and Cropped indicates combined WCM and WF plots.

compared with annually cropped systems. Acosta-Martinez et al. (2007) showed both greater microbial biomass C and a different microbial community in the grass plots compared with the cropped plots. The combination of greater pore continuity and greater pore integrity under saturated conditions would cause greater k_{sat} in the grass vs. cropped plots.

CONCLUSIONS

Increasing soil OC content with no-till systems in the central Great Plains may not immediately lead to beneficial changes in other soil physical and hydraulic properties. There may be delayed incorporation of carbon from plant residues into aggregate-stabilizing compounds because of a lack of mixing with no tillage. Another factor that may delay beneficial effects of increasing OC on physical and hydraulic properties is the dry soil-surface conditions that occur for extended periods of time in this climate. Dry conditions minimize the microbial activity necessary for the oxidation of organic compounds into agents needed for soil aggregation. It may be helpful to concentrate efforts on identifying the constituents of soil OC that improve water stable macroaggregates and other soil physical properties to help design rotations that will improve soil productivity for long-term sustainable agricultural use.

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