Can Cover Crop and Manure Maintain Soil Properties After Stover Removal from Irrigated No-Till Corn?

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Addition of cover crops and animal manure following corn (*Zea mays* L.) stover removal for expanded uses may mitigate negative soil property effects of stover removal. We studied the short-term (3 yr) cumulative impacts of stover removal with and without winter rye (*Secale cereale* L.) cover crop or animal manure application on near-surface (0- to 5-cm depth) soil properties under irrigated no-till continuous corn on a Hastings silt loam (fine, smectitic, mesic Udic Argiustolls) (<3% slope) near Clay Center, NE. Treatments were irrigation levels (full and deficit), amelioration practices (none, cover crop, or animal manure), stover removal (no removal or maximum removal), and N fertilization (125 or 200 kg N ha^{-1}). Data collected after 3 yr indicate that stover removal (63%) reduced geometric mean diameter of dry aggregates 93%, increased erodible fraction sixfold, and reduced aggregate stability 32% compared with plots without stover removal. Stover removal from plots with cover crop or manure reduced dry aggregate size and stability and increased erodible fraction compared with plots without removal and amelioration practices, indicating that amelioration practices did not offset stover removal effects. Stover removal reduced wet aggregate stability and soil organic C (SOC) concentration in the 0- to 2.5-cm depth, but cover crop or manure mitigated these small reductions. Stover removal did not change water infiltration rates and had small effects on particulate organic matter (POM). Overall, in the short term, cover crop or manure may not provide sufficient protection from raindrop impact and wetting and drying cycles to maintain soil structure, resulting in increased susceptibility to wind erosion. Use of these amelioration practices, however, may offset changes in surface layer wet aggregate stability and SOC after high rates of stover removal in this region.

Abbreviations: POM, particulate organic matter; SOC, soil organic C.

Corn stover is currently facing many competing uses such as soil and water conservation, water and wind erosion control, soil fertility maintenance, SOC storage, feed for livestock, industrial uses (i.e., fiber), and as a potential candidate for cellulosic ethanol production. Stover removal for expanded uses is expected to increase in the future as demands for livestock feed and other uses increase. Corn stover is being grazed or baled for livestock, particularly during dry years (such as in 2012) when forage supplies are low. Stover is often mixed with distillers grains and used as livestock feed.

Several questions still remain, however, about the effects of corn stover removal on soil physical quality, water and wind erosion, crop yields, and storage of soil water, C, and nutrients. Literature indicates that stover removal impacts on soil properties can be highly site-specific, depending on soil type, slope, management duration, initial soil fertility, and the amount of stover removed. For example, crop residue removal may or may not reduce SOC concentration (Moebius-Clune et

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al., 2008; Blanco-Canqui and Lal, 2009; Stetson et al., 2012; Wienhold et al., 2013). We hypothesize, however, that high rates of stover removal may rapidly affect near-surface (<5-cm depth) soil physical properties and processes including aggregation, surface sealing, water infiltration, and SOC dynamics. These near-surface changes in soil processes may increase soil's susceptibility to water and wind erosion and affect soil productivity in the long term. In the central Great Plains, wind erosion is more of a concern than water erosion due to the relatively flat topography, high average wind speed, and moderately low precipitation. Thus, in this region, a better understanding of changes in near-surface soil physical properties after stover removal is needed. This information could be useful to establish regional permissible levels of stover removal.

If corn stover is removed, particularly at high rates, ameliorative practices may need to be established following stover removal to counteract any negative effects of the stover removal on near-surface soil properties and long-term soil productivity. Potential amelioration practices include the use of cover crops and animal manure application (Fronning et al., 2008). Cover crops provide surface cover and may replace the protective cover lost with stover removal. The benefits of cover crops for protecting soil from water (Kaspar et al., 2001) and wind (Blanco-Canqui et al., 2013a) erosion are well recognized. Cover crops may also maintain or improve soil properties such as aggregate stability, SOC concentration, water infiltration, and biological activity due to the addition of above and belowground biomass. For instance, addition of cover crops to no-till systems may enhance no-till performance to improve soil properties relative to no-till without cover crops (Blanco-Canqui et al., 2011).

Similarly, animal manure contains C and nutrients that can replace those lost with stover removal. It also improves soil fertility and enhances soil microbial processes (Eivazi et al., 2003). It can more rapidly increase soil C pool compared with cover crops (Fronning et al., 2008). Its impacts on soil aggregate properties affecting wind erosion, however, are unclear (Mbagwu and Piccolo, 1990; Miller et al., 2012). Some studies in the northern Great Plains report that long-term manure application (>30 Mg ha^{-1}) may not significantly increase dry aggregate size and stability because manure-induced increase in SOC could increase friability of dry aggregates (Whalen and Chang, 2002; Miller et al., 2012). In Kansas, Woodruff et al. (1974), using a field wind tunnel, found that 15 Mg ha^{-1} of surface-applied manure reduced erosion by about 90%. The reduction in wind erosion with surface applied manure could be the result of the consolidated manure increasing roughness and providing stable cover of the erodible surface (J. Tatarko, personal communication, 2013).

The potential use of cover crops and animal manure to offset any possible adverse effects of stover removal on soil properties has not been widely documented. Yet, the combined effects of stover removal, cover crops, and other practices deserve consideration in a time when there is increased interest in harvesting corn stover and establishing single species and mixtures of cover crops. Most previous studies have focused on the independent effects of stover removal and cover crops and not on the combined effects of both management practices (Karlen et al., 1994; Moebius-Clune et al., 2008; Blanco-Canqui and Lal., 2009). The few studies assessing stover removal in conjunction with the use of amelioration practices have reported mixed results. Fronning et al. (2008) studied the effects of three C amendments: dairy compost, beef feedlot manure, and winter cereal rye cover crop on soil C after corn stover harvest from corn–soybean [*Glycine max* (L.) Merr.] rotation and found that winter rye cover crop had no effect, but compost and manure increased soil C concentration after 3 yr of management in Michigan. A similar study by Stetson et al. (2012) reported that soil organic matter concentration decreased significantly with high stover removal rates, but it did not decrease when slender wheatgrass [*Elymus trachycaulus* (Link) Gould ex Shinners] cover crop was planted after stover harvest; and lentil (*Lens culinaris* Medik. 'Morton') cover crop was planted after soybean during the last 3 yr of an 8-yr stover removal study under corn–soybean rotation in eastern South Dakota. The same study found that stover removal from plots with cover crops did not reduce wet soil aggregate stability relative to plots without cover crops. Using the DAYCENT model, Gao et al. (2013) estimated that winter cover crops may supplant about 21 to 36% of SOC loss due to whole-corn plant removal at both immature and mature stages.

More experimental data are needed to better understand the extent to which cover crops and animal manure can offset effects of stover removal. Synergies between stover removal and use of cover crops for irrigated no-till continuous corn systems are not well understood. This information can be important to develop improved and multi-purpose cropping systems for sustainable management of corn stover for expanded uses. Cover crops may be particularly useful as potential companion practices in irrigated no-till corn production systems after stover removal. Cover crops could be an integral component of improved management strategies to manage crop residues. Our hypothesis was that the use of cover crop and animal manure could offset any potential negative effects of stover removal on soil properties and, thus, allow stover removal from irrigated no-till continuous corn in a sustainable manner. The objective of this study was to assess the short-term (3 yr) cumulative impacts of stover removal with and without winter rye cover crop or animal manure application on soil properties under irrigated no-till continuous corn. This study investigated whether cover crops or animal manure could ameliorate potential stover removal impacts on near-surface soil physical properties affecting soil erosion, SOC and POM concentrations on a silt loam in south central Nebraska.

MATERIALS AND METHODS

Experiment Description

We conducted this study in spring 2013 on an ongoing corn stover removal experiment, which was established in 2010, at the University of Nebraska-Lincoln (UNL)'s South Central Agricultural Laboratory near Clay Center, NE (40.582° N lat; 98.144° W long; 552 m asl). The soil is a Hastings silt loam with

<3% slope. The soils in the Hastings series are very deep, well drained, and formed in loess in the Central Loess Plains. Additional information on the soil characteristics for the Hastings series is provided by NCSS (2014). The experiment occupies an area of 5 ha and is within a 13-ha field managed under no-till continuous corn using a variable rate linear-move irrigation system. Corn cultivars Pioneer 1173HR in 2010, Pioneer 541 in 2011, and Pioneer 876 CHR in 2012, were planted at a rate of 72,897 seeds ha^{-1} on 21 Apr. 2010 and 29 Apr. 2011 and 84,017 seeds ha^{-1} on 24 Apr. 2012. Weeds in this experiment were controlled using glyphosate [N-(phosphonomethyl) glycine].

The experimental design is a completely randomized split–split–split block with four replications. The study includes four factors, that is, two irrigation levels using groundwater, three amelioration practices, two corn stover removal approaches, and two N fertilization rates. This resulted in a total of 96 experimental units ($2 \times 3 \times 2 \times 2 \times 4$ reps = 96).

Main Plot: The experiment included eight 24-m-wide by 155-m-long main plots for each irrigation level. Full irrigation treatments were managed to maintain 45 to 90% of total available water holding capacity within the 1.2-m soil profile. A supplemental irrigation event occurred whenever total available water holding capacity reached 45% in the full irrigation treatments. The deficit irrigation treatment is 60% of total applied water compared with the fully irrigated treatments. A total of four or five irrigation events occurred between July and August for an annual total of 14.2 cm in 2010, 13.5 cm in 2011, and 18.5 cm in 2012. Deficit irrigation events were applied at the same time as full irrigation events. Irrigation timing was based on soil matric potential sensor (Irrometer Co. Inc., Riverside, CA) measurements in the full irrigation plots and supplementary neutron soil moisture gauge measurements from an adjacent study within this field (Troxler Electronic Labs., Research Triangle Park, NC; Djaman and Irmak, 2012). Soil matric potential sensors were installed every 0.3 m to a 1.2-m soil depth within the crop row.

Split Plot: Each irrigation-level main plot was split into three 24-m by 52-m amelioration plots and treated with either winter rye cover crop, animal manure, or control (no manure or cover crop). Manure was surface applied in the fall after stover removal using a mechanical manure spreader. Manure was applied at a P-rate approximating crop P removal by irrigated corn (28–33 kg P ha^{-1} yr^{-1}; Stewart and Gordon, 2008), which resulted in manure applications every 2 yr. Sheep manure was applied in the fall of 2010 and beef cattle manure in 2012 at dry weight rates of 17.3 and 19.0 Mg ha^{-1}, respectively. Sheep manure was applied in 2010 due to the unavailability of beef cattle manure. First-year available nutrients from sheep manure were 4.2 Mg of C, 75 kg N, 58 kg P, and 308 kg K, while those from beef cattle manure were 2.4 Mg of C, 76 kg N, 97 kg P, and 213 kg K. These inputs were calculated as 100% of total organic C, 25% of total organic N, 70% of total P, and 90% of total K in manures (Barbarick, 1996; Wortmann and Shapiro, 2008; Leubbe et al., 2011). For each growing season following manure application, first-year mineralizable manure N was credited to the amount of commercial N applied at side-dress to meet experimental N treatment levels. Winter rye cover crop was planted at a rate of 67 kg ha^{-1} in 2010 and 112 kg ha^{-1} in 2011 and 2012. Winter rye was planted in fall after corn stover harvest using a no-till drill and chemically terminated using glyphosate in spring of each year before corn planting.

Spit–Split Plot: Each amelioration plot was further subdivided into two 12-m by 52-m stover management plots, where stover was either removed or retained. Maximum removal rates were 53% in 2010, 71% in 2011, and 66% in 2012. The mean, 63%, removal rate reflects the annual variation in stover removal as a result of inherent or random variability of the stover removal process under field conditions, even when the same equipment and method were used. The mean (63%) removal rate is used hereafter for discussion purposes. A stalk cutting height of 5 cm followed by shredding–round baling was used in all years. The 5-cm cutting height is representative of the maximum amount of stover that can be removed mechanically under field conditions. Corn stover harvest was done with a flail shredder, high-capacity hay rake, and round baler in 2010 and 2011 and with a self-propelled disk mower-conditioner and round baler in 2012.

Stover harvest was done in late October following grain harvest. Stover removed was measured by cutting, raking, and baling the split–split plot. Split–split–split plot (described below) stover yields were hand collected from an area 0.76 m by 3.04 m at physiological maturity. Ears were removed, dried, and weighed. Stalks were cut at ground level, chopped, weighed, and a subsample was dried at 60°C until constant mass was reached for calculation of stover dry matter production. After shelling, cob weights were added to the calculated stover weight to obtain total nongrain dry matter (stover) production. Nongrain biomass from hand collection was used to calculate the amount removed by baling. Mean stover removal rate from 2010 to 2012 was 6.5 dry Mg ha^{-1} yr^{-1}, equivalent to 63% of total nongrain aboveground biomass.

Split–Split–Split Plot: Finally, the stover management plots were divided into two 12-m by 26-m N fertilizer plots, which received either 125 or 200 kg N ha^{-1}. Urea ammonium nitrate was applied post-emergence between corn rows using a coulter injection application system. As indicated earlier, manure treatment plots were credited for N mineralization from applied manure based on 25% organic N mineralization the first year after application (Koelsch and Shapiro, 2006).

Rye aboveground biomass was sampled in the spring of 2012 and 2013 before herbicide termination using two (0.25-m^2 quadrat) frames per plot. Biomass samples were oven-dried until a constant dry weight was reached. Mean rye aboveground biomass production across all treatments before termination was 0.8 dry Mg ha^{-1}.

Soil Sampling and Analysis

We conducted field measurements and collected three sets of soil samples in spring 2013. Sample Sets 1 and 2 were used to determine dry aggregate size distribution and dry aggregate stability, respectively, which provided a measure of the soil's susceptibility to wind erosion. This was done in early spring because the potential for wind erosion is greatest in spring, due to strong and frequent winds and short vegetation (Schmeisser et al., 2010). The third set of soil samples was collected for the determination of water-stable aggregates, SOC, POM fractions, pH, and particle-size distribution

Measuring Susceptibility to Wind Erosion

Soil samples for the assessment of wind erosion potential were collected only from plots with treatments that were representative of producer practices in this region; thus, deficit irrigated and high-N fertilization experimental units were excluded. Only one soil sample was collected from each of the sampled experimental plots, giving a total of 24.

Dry Aggregate Size Distribution and Wind Erodible Fraction

Approximately 2 kg of soil was collected from the 0- to 5-cm depth between corn rows with a flat-bottom shovel. These samples were gently placed in trays to minimize disturbance or aggregate breakdown before analysis. The soil samples were oven-dried at 60°C for 48 h for the determination of dry aggregate size distribution using the modified rotary sieve (Lyles et al., 1970). Different aggregate-size fractions were obtained from the rotary sieve test as follows: <0.42, 0.42 to 0.84, 0.84 to 2, 2 to 6.35, 6.35 to 14.05, 14.05 to 44.45, and >44.45 mm in diameter. These aggregate-size fractions were used to compute geometric mean diameter of dry aggregates by using the mesh size of each sieve and the amount of aggregates within each fraction (Nimmo and Perkins, 2002). Wind erodible fraction, which is the most common parameter used to evaluate soil susceptibility to wind erosion, was computed from the dry aggregate size distribution as a percentage of aggregates with <0.84 mm diameter (Hagen et al., 1999).

Dry Aggregate Stability

Samples were collected from the 0- to 5-cm soil depth and passed through a 19.0-mm diam. sieve. The sieved samples were then air-dried and 30 aggregates were selected from each air-dry sample and crushed using an aggregate crushing-meter apparatus, which consists of two parallel plates supported by a load cell and connected to a computer to measure the energy to crush each aggregate (Boyd et al., 1983). Dry aggregate stability was expressed as the natural log of the crushing energy per unit mass (Skidmore and Powers, 1982) and is related to the resistance of soil aggregate to abrasion by saltating particles (Hagen et al., 1992).

Measuring Infiltration, Wet Aggregate Stability, Soil Organic Carbon, Particulate Organic Matter, and pH

For the determination of water-stable aggregates, SOC, POM fractions, pH, and particle-size distribution, intact soil cores (7.5 cm in diameter by 2.5 cm tall) were collected from the 0- to 2.5-cm and 2.5- to 5.0-cm soil depth from each experimental unit (96 plots). Two intact soil samples were collected from each plot between corn rows and composited before analysis. The soil sample was air-dried for 72 h. A portion of the sample was passed through 4.75- and 8-mm sieves to obtain aggregates for the analysis of wet aggregate stability by the wet-sieving method (Nimmo and Perkins, 2002). This method employs a set of six nested sieves with 4.75-, 2-, 1-, 0.5-, and 0.25-mm openings. Fifty grams of 4.75- to 8-mm aggregates were placed on the top sieve with the 4.75-mm openings, saturated by capillarity for 10 min, then mechanically sieved in a column of water for 10 min at 30 cycles per min. Next, aggregates from each sieve were transferred to preweighed beakers, oven-dried at 105°C, weighed, and corrected for sand content before computing proportion of water-stable aggregates and mean weight diameter of aggregates (Nimmo and Perkins, 2002).

A fraction of the initial air-dry soil sample was crushed, ground, and passed through a 250-mm sieve to determine the SOC concentration by the dry combustion method (Nelson and Sommers, 1996). Particulate soil organic matter was measured by weight loss on ignition as outlined by Cambardella et al. (2001). Air-dry soil samples were gently broken apart by hand and passed through a 2-mm sieve. The sieved sample was dispersed in Na hexametaphosphate for 24 h, mechanically stirred in a multi-mixer, wet sieved through sieves with 0.5- and 0.053-mm openings. The sample retained in each sieve was transferred to preweighed Al pans and ignited in a muffle furnace at 450°C for 4 h to determine POM by loss on ignition. The POM retained on the 0.5-mm sieve was considered as coarse POM while that retained on the 0.053-mm sieve was considered as fine POM. Soil pH was determined with a pH meter on a 1:2 suspension (10 g of soil to 20 mL of water; Thomas, 1996). Particle-size analysis was performed by the hydrometer method (Gee and Or, 2002). There were no significant differences in particle-size fractions among plots. Mean content, averaged across all plots, was 200 g kg^{-1} for sand, 573 g kg^{-1} for silt, and 227 g kg^{-1} for clay.

Water infiltration rate was determined in the field by the single-ring infiltrometer method for 2 h (Reynolds et al., 2002). A ring infiltrometer with a diameter of 25 cm was placed between the rows and inserted into the soil to a 10-cm depth. Water infiltration was determined in the 24 plots that were used for the determination of wind erosion potential. One measurement was done within each plot.

Data Analysis

Differences in dry aggregate size distribution, dry aggregate stability, wind erodible fraction, and water infiltration among the three amelioration practices (cover crop, manure, and control) and two stover removal rates were tested using PROC MIXED in SAS (SAS Institute, 2013). For the statistical analysis of the four soil properties, the three amelioration practices were considered as main plot and the stover removal treatments as split plot. The fixed factors were amelioration practice and stover removal rates while the random factors were replicate and its interactions with amelioration practice and stover removal. Data on mean weight diameter of water-stable aggregates, SOC, coarse

POM, fine POM, and pH were analyzed as split–split–split design using PROC MIXED in SAS. The fixed factors were irrigation level, amelioration practice, stover removal, and N application level while the random factors were replicate and its interactions with irrigation level, amelioration practice, stover removal, and N rate. Means among treatments were compared using LSMEANS in PROC MIXED. The PROC REG procedure in SAS was used to study relationships among the soil properties. Treatment differences were discussed at the 0.05 probability level.

Table 1. Statistical analysis of soil properties related to wind erosion potential after 3 yr of stover management under an irrigated no-till continuous corn in south central Nebraska. Means followed by different lowercase letters within a column are significantly different.

Treatments and their interactions	Geometric mean diameter of dry aggregates	Erodible fraction	Dry aggregate stability
	mm	%	ln Jkg^{-1}
Amelioration effect			
Cover crop	44.40	14.07	3.53
Manure	28.26	17.54	3.52
None	18.92	21.12	3.42
Stover removal effect			
No removal	56.97a	4.71b	4.16a
63% removal	4.09b	30.44a	2.82b
	Statistical significance (*P* > *F*)		
Amelioration	ns†	ns	ns
Removal	***	***	***
Amelioration × removal	ns	ns	ns
	Contrasts of interest and significance level (*P* > *F*)		
(0% Removal + no amendment) vs. (63% removal + Cover Crop)	*	***	***
(0% Removal + no amendment) vs. (63% removal + manure)	*	***	***

* Significant at the 0.05 probability level.

*** Significant at the 0.001 probability level.

† ns, No significant differences.

RESULTS AND DISCUSSION

Wind Erosion Potential

Results after 3 yr of stover removal and use of amelioration practices under irrigated no-till continuous corn in south central Nebraska indicated that amelioration practices (cover crop and animal manure) did not have a significant effect on wind erosion potential, but stover removal had large effects compared with no removal (Table 1). Interaction of amelioration × stover removal was not significant (Table 1). Maximum stover removal (63%) increased wind erosion potential. It resulted in a large reduction in dry aggregate size and stability and an increase in wind erodible fraction across all treatments (Table 1). Averaged across all amelioration treatments, stover removal reduced geometric mean diameter of dry aggregates 93%, increased erodible fraction sixfold, and reduced aggregate stability 32% compared with plots without stover removal (Table 1).

Contrasts between no stover removal and stover removal followed with either cover crops or animal manure was significant (Table 1). Stover removal from plots with either cover crop or manure reduced geometric mean diameter of dry aggregates 85% (5.5 vs. 36.5 mm), increased wind erodible fraction fivefold (27.0 vs. 5.0%), and reduced dry aggregate stability 34% (2.9 vs. 4.4 ln J kg^{-1}) compared with plots without stover removal. This finding thus indicates that the addition of cover crop or manure after stover removal did not offset the adverse effects of removal on soil aggregate properties affecting wind erosion. Our study hypothesis stating that cover crop or animal manure could offset the negative effects of stover removal on soil properties was not supported for soil physical properties affecting wind erosion. Use of cover crop and manure for 3 yr after stover removal was insufficient to offset the soil's susceptibility to wind erosion after stover removal (Table 1).

It is important, however, that although amelioration practices did not significantly offset the stover removal effects, they tended to reduce wind erosion potential. Table 1 shows that mean values of geometric mean diameter of dry aggregates were in the order: Cover crops > Manure > None, while mean values of erodible fraction were in the order: None > Manure > Cover crops (Table 1). These results suggest that amelioration practices tended to reduce the magnitude of adverse effects compared with plots without amelioration practices (Table 1). Results also appear to suggest that winter rye cover crop may be more effective than animal manure at reducing wind erosion potential.

The large stover removal-induced reduction in dry aggregate size and stability and increase in wind erodible fraction indicate that stover removal degraded near-surface physical properties and increased the soil's susceptibility to wind erosion (Table 1). Soil aggregates became smaller and weaker after stover was removed for 3 yr. The small aggregates can be more easily transported by wind, while the weak aggregates can break more easily into small aggregate sizes compared with large and stable aggregates (Kohake et al., 2010). The near-surface degradation of soil aggregate processes and properties may be partly attributed to (i) the decrease in SOC due to stover removal as discussed later, (ii) physical disruption due to raindrop and irrigation drop impact, (iii) possible effects of freezing-thawing cycles and wetting-drying cycles due to soil exposure to the atmosphere after stover removal (Layton et al., 1993), and (iv) some possible mechanical breakdown of aggregates during baling operations. Data from this short-term study appear to suggest that stover removal at high rates (63%) should probably be avoided in the region to reduce wind erosion potential.

Infiltration, Water-Stable Aggregates, Soil Organic Carbon, Particulate Organic Matter, and pH

Stover removal and amelioration practices did not change water infiltration rates. Mean cumulative water infiltration across

Table 2. Statistical analysis of soil properties in the 0- to 2.5-cm depth after 3 yr of stover management under an irrigated no-till continuous corn in south central Nebraska. Different lowercase letters in a column within the same treatment group indicate significant differences.

Treatments and their interactions	Mean weight diameter of water-stable aggregates	Soil organic C	Coarse particulate organic matter	Fine particulate organic matter	pH
	mm	g kg^{-1}	mg g^{-1}	mg g^{-1}	
Amelioration effect					
Cover crop	1.49a	20.6b	4.64ab	11.71b	6.53ab
Manure	1.27ab	22.7a	5.47a	14.64a	6.85a
None	1.03b	19.5b	3.86b	11.09b	6.32b
Stover removal effect					
No removal	1.47a	21.9a	4.67	13.05a	6.59
63% Removal	1.05b	20.0b	4.64	11.9b	6.53
Inorganic fertilizer effect					
125 kg N ha^{-1}	1.44a	21.0	4.91	10.81	6.78a
200 kg N ha^{-1}	1.09b	20.8	4.40	12.15	6.35b
		Statistical significance (*P* > *F*)			
Irrigation	ns†	ns	ns	ns	ns
Amelioration	**	***	**	***	**
Irrigation × amelioration	ns	ns	ns	ns	ns
Removal	***	***	ns	*	ns
Irrigation × removal	ns	ns	ns	ns	ns
Amelioration × removal	ns	ns	ns	ns	ns
Irrigation × amelioration × removal	ns	ns	ns	ns	ns
N rate	***	ns	ns	ns	***
Irrigation × N rate	ns	ns	ns	ns	ns
Amelioration × N rate	ns	ns	ns	ns	ns
Removal × N rate	ns	ns	ns	ns	ns
Irrigation × amelioration × N rate	ns	ns	ns	ns	ns
Irrigation × removal × N rate	ns	ns	ns	ns	ns
Amelioration × removal × N rate	ns	ns	ns	ns	ns
Irrigation × amelioration × removal × N rate	ns	ns	ns	ns	ns
		Contrasts of interest and significance level (*P* > *F*)			
(0% Removal + no Amendment) vs. (63% removal + cover crop)	ns	ns	ns	ns	ns
(0% Removal + no amendment) vs. (63% removal + manure)	ns	ns	ns	ns	ns

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† ns, No significant differences.

all treatments was 20.4 ± 18.5 mm (mean ± SD) in 2 h. This result suggests that stover removal even at a high rate (63%) would not significantly reduce precipitation or irrigation water infiltration within the soil profile. Water infiltration did not decrease in spite of a significant reduction in near-surface aggregate size and stability due to stover removal. The lack of significant changes in water infiltration due to stover removal is encouraging as this hydraulic property is often the result of an integrated effect of all soil properties and processes related to soil structure including macroporosity, compaction, surface sealing, and aggregation within the root zone. Further monitoring of water infiltration characteristics with time is needed to ascertain long-term effects of stover removal on soil hydraulic properties.

Irrigation level had no significant effects on soil properties (Tables 2 and 3). Amelioration practices affected wet aggregate stability, SOC, and POM fractions only in the 0- to 2.5-cm depth (Tables 2 and 3). Stover removal affected SOC and fine POM only in the 0- to 2.5-cm depth, but it affected wet aggregate stability at both soil depth intervals: 0 to 2.5 cm (Table 2) and 2.5 to 5 cm (Table 3). Nitrogen fertilization also affected wet aggregate stability at both soil depths. Interactions among all study factors were not significant (Table 2 and 3).

Table 3. Statistical analysis of soil properties in the 2.5- to 5.0-cm depth after 3 yr of stover management under an irrigated no-till continuous corn in south central Nebraska. Different lowercase letters in a column within the same treatment group indicate significant differences.

Treatments and their interactions	Mean weight diameter of water-stable aggregates	Soil organic carbon	Coarse particulate organic matter	Fine particulate organic matter	pH
	mm	g kg^{-1}	mg g^{-1}	mg g^{-1}	
Amelioration effect					
Cover crop	1.86	19.3	3.22	9.71	6.65
Manure	1.69	18.8	3.25	10.73	6.76
None	1.66	18.8	3.14	10.29	6.55
Stover removal effect					
No removal	1.90a	19.0	3.04	10.14	6.63
63% Removal	1.58b	18.9	3.36	10.34	6.67
Inorganic fertilizer effect					
125 kg N ha^{-1}	1.87a	19.1	3.17	11.50	6.88a
200 kg N ha^{-1}	1.61b	18.9	3.23	8.99	6.43b
	Statistical significance (*P* > *F*)				
Irrigation	ns†	ns	ns	ns	ns
Amelioration	ns	ns	ns	ns	ns
Irrigation × amelioration	ns	ns	ns	ns	ns
Removal	**	ns	ns	ns	ns
Irrigation × removal	ns	ns	ns	ns	ns
Amelioration × removal	ns	ns	ns	ns	ns
Irrigation × amelioration × removal	ns	ns	ns	ns	ns
N rate	**	ns	ns	ns	***
Irrigation × N rate	ns	ns	ns	ns	ns
Amelioration × N rate	ns	ns	ns	ns	ns
Removal × N rate	ns	ns	ns	ns	ns
Irrigation × amelioration × N rate	ns	ns	ns	ns	ns
Irrigation × removal × N rate	ns	ns	ns	ns	ns
Amelioration × removal × N rate	ns	ns	ns	ns	ns
Irrigation × amelioration × removal × N rate	ns	ns	ns	ns	ns
	Contrasts of interest and significance level (*P* > *F*)				
(0% Removal + no amendment) vs. (63% removal + cover crop)	ns	ns	ns	ns	ns
(0% Removal + no amendment) vs. (63% removal + manure)	ns	ns	ns	ns	ns

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† ns, No significant differences.

Cover crop increased wet aggregate stability by 1.4 times in the 0- to 2.5-cm depth, but manure had no effect compared with plots without amelioration practices (Table 2). At the same depth, compared with control, manure application increased SOC by about 1.2 times, coarse POM by 1.4 times, and fine POM by 1.3 times, but cover crop had no effects (Table 2). The benefits of manure application for increasing SOC and POM concentration were expected. Results suggest that cover crop may not rapidly increase SOC and POM concentration, unlike manure application.

Stover removal reduced wet aggregate stability by 29% and SOC and fine POM concentration by 9% in the 0- to 2.5-cm depth relative to retained stover, but it did not affect coarse POM (Table 2). Stover removal also reduced wet aggregate stability by 17% in the 2.5- to 5.0-cm depth compared to retained stover (Table 3). These results suggest that maximum stover removal (63%) can have adverse effects on soil structural properties near the surface.

Stover removal and cover crop did not affect soil pH, but manure application resulted in slightly higher pH (6.8) than plots without manure (6.3) in the 0- to 2.5-cm depth (Table 2). Increasing N fertilizer application from 125 to 200 kg N ha^{-1}, however, reduced soil pH by 6% in the 0- to 2.5-cm and 2.5- to 5.0-cm depths. The decrease in soil pH in near-surface layers with inorganic fertilization has been well documented in literature (Biederbeck et al., 1996; Blanco-Canqui et al., 2014). Results suggest that animal manure may be used to increase pH of acidic

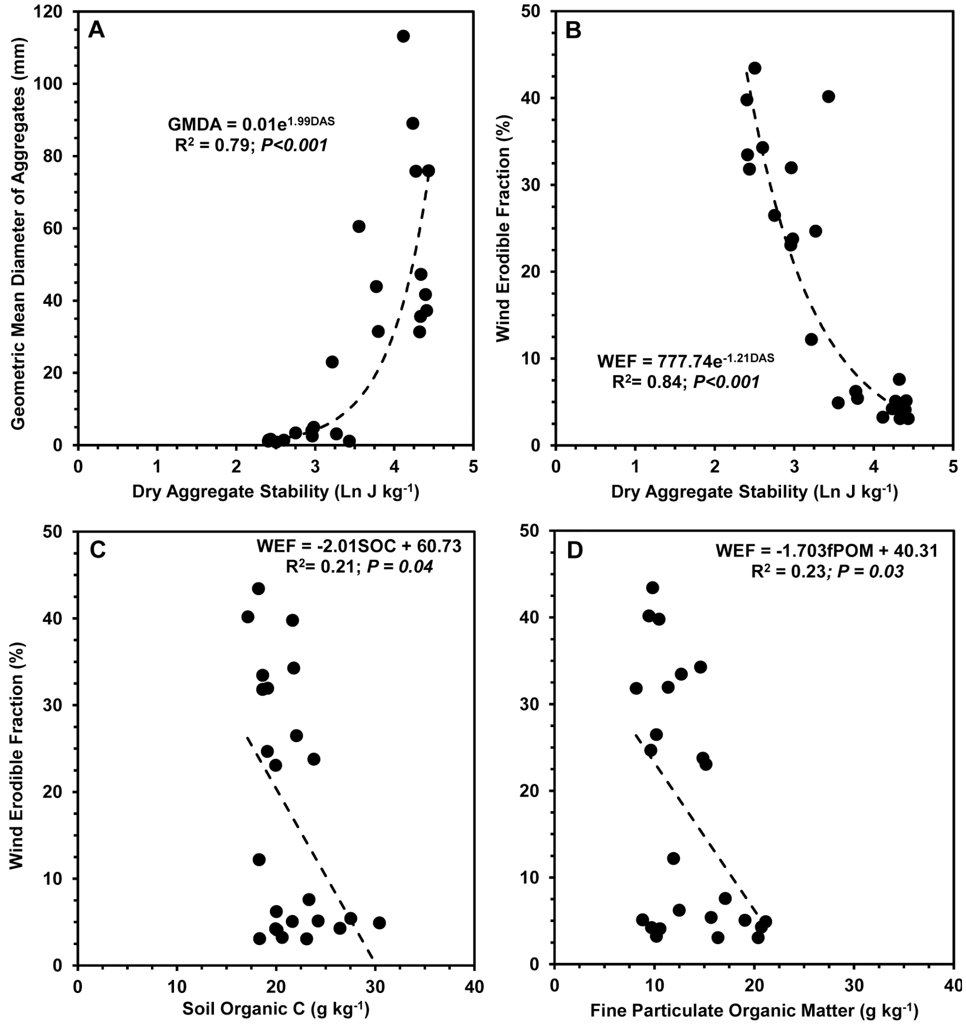

Fig. 1. Relationships among geometric mean diameter of aggregates (GMDA), dry aggregate stability (DAS), wind erodible fraction (WEF), soil organic C (SOC), and fine particulate organic matter (POM) near the soil surface after 3 yr of stover removal from an irrigated no-till continuous corn with and without winter rye cover crop and manure in south central Nebraska.

soils. The liming benefits of cattle manure has been discussed in previous studies (Eghball, 1999).

Contrasts between no stover removal and stover removal followed with either cover crop or animal manure was not significant (Table 2 and 3). Thus, differences in wet aggregate stability and concentrations of SOC, POM, and pH between plots without stover removal and plots with removal followed by cover crop or manure were not significant. This finding suggests that unlike results for aggregate properties related to wind erosion, inclusion of cover crop or application of manure after stover removal did ameliorate the negative effects of stover removal on wet aggregate stability, concentrations of SOC, fine POM, and pH. The decrease in SOC, fine POM, and pH due to stover removal was small, and this decrease was offset with the addition of cover crop or animal manure.

The greater decrease in wet aggregate stability and SOC and fine POM concentration in the 0- to 2.5-cm depth than in the 2.5- to 5.0-cm depth indicates that stover removal effects on soil properties were stratified and confined to the shallow surface in the short term. Results suggest that high rates of stover removal can have limited adverse effects on water-stable aggregates, SOC, and POM in the short term. The small decrease in wet aggregate stability due to stover removal near the surface may not greatly affect crop production but may increase risks of water erosion if amelioration practices are not used. Results also indicate that stover removal had more consistent effects on soil aggregation than on POM fractions in the 0- to 5-cm depth (Table 2 and 3).

An increase in inorganic N application rate from 125 to 200 kg ha^{-1} reduced wet aggregate stability by 1.3 times in the 0- to 2.5-cm depth (Table 2) and by 1.2 times in the 2.5- to 5.0-cm depth (Table 3). Although differences were numerically small, this finding suggests that high rates of inorganic N application may tend to deteriorate soil structure. Further monitoring is warranted to better understand inorganic N application effects on wet aggregate stability. Some previous studies have suggested that inorganic N may have soil aggregate dispersing agents (Haynes and Naidu, 1998; Fonte et al., 2009).

Correlations Among Near-Surface Soil Properties

Across all treatments, the near-surface changes in soil aggregate properties and SOC concentration were interrelated. Geometric mean diameter of dry aggregates was exponentially and strongly correlated with dry aggregate stability (Fig. 1a), indicating that dry aggregate size decreased as aggregates became weaker. As a result, wind erodible fraction (<0.84-mm aggregates) decreased exponentially with an increase in aggregate stability (Fig. 1b). Erodible fraction was moderately correlated with SOC (Fig. 1c) and fine POM (Fig. 1d), indicating that the amount of small aggregates increased as SOC and fine POM concentration decreased due to stover removal. Wet aggregate stability was weakly but positively correlated with SOC concentration (Fig. 2a), but it was not significantly correlated with coarse POM (Fig. 2b) or fine POM (Fig. 2c). An increase in SOC concentration improved soil aggregation. We expected that wet aggregate stability could be more strongly correlated with POM fractions than with SOC, but this relationship was not significant in this study (Fig. 2b and 2c).

The near-surface decrease in wet and dry aggregate stability is partly attributed to the decrease in SOC concentration due to sto-

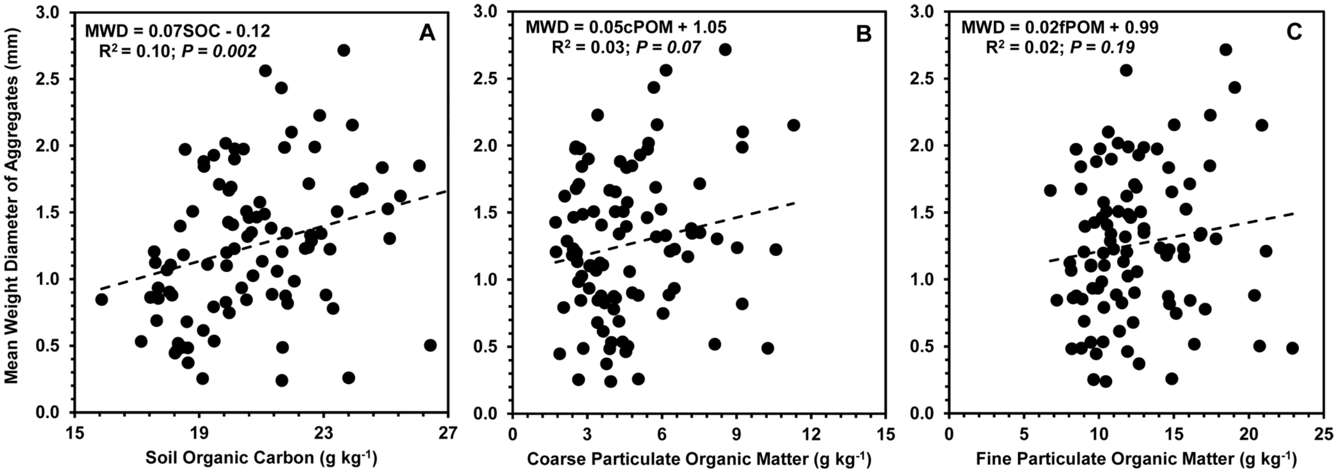

Fig. 2. Interrelationships of mean weight diameter (MWD) of water-stable aggregates with soil organic carbon (SOC), coarse particulate organic matter (cPOM), and fine particulate organic matter (fPOM) concentrations in the 0- to 2.5-cm depth after 3 yr of stover removal from an irrigated no-till continuous corn with and without winter rye cover crop and manure in south central Nebraska.

ver removal. Although the regression coefficients between SOC and soil physical properties were low (Fig. 1c and 1d and Fig. 2a and 2b), they were statistically significant, indicating that changes in SOC concentration had small and significant impacts on determining wind erodible fraction and water-stable aggregation. Stover-derived organic materials possess substances that bind soil particles together to form stable aggregates (Blanco-Canqui et al., 2013b). The reduced SOC concentration in combination with the reduced stover cover most probably contributed to the degradation of soil structural properties near the surface.

SUMMARY AND CONCLUSIONS

Results from this short-term study (3 yr) in south central Nebraska indicate that stover removal at a high rate (63%) from irrigated no-till continuous corn can rapidly increase the soil's susceptibility to wind erosion, but it may have small or no effects on other soil properties. Stover removal reduced dry aggregate size and stability and increased wind erodible fraction regardless of the use of winter rye cover crop or animal manure, indicating that the amelioration practices may have limited benefits for offsetting the adverse effects of stover removal on wind erosion potential in the short term. Soil aggregates were smaller and less stable when stover was removed than when it was retained. Stover removal did not, however, adversely affect water infiltration capacity in this soil, which suggests that stover removal may not affect precipitation or irrigation capture in the short term. Wet aggregate stability, and SOC and POM concentrations decreased near the soil surface due to stover removal, but this decrease was offset with the use of cover crop or animal manure. Thus, results from this study suggest that, in this region, increased wind erosion potential may be the most limiting factors for high rates of stover removal. The establishment of threshold levels of stover removal in this region should probably be based more on the stover cover requirements to control wind erosion than other soil and crop production parameters. Maintaining appropriate levels of stover cover is, thus, critical for erosion control and maintenance of soil physical quality. Because this study reports results from one-time sampling after 3 yr, multi-year measurements are warranted to further clarify the findings from this study. Overall, in the short term, addition of cover crop or animal manure may not offset stover removal effects on wind erosion potential, but it may offset changes in other near-surface soil properties after stover removal from irrigated no-till continuous corn.

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