2019

Cover Crops and Corn Residue Removal: Impacts on Soil Hydraulic Properties and Their Relationships with Carbon

Michael Sindelar
University of Nebraska-Lincoln, msindelar2@unl.edu

Humberto Blanco-Canqui
University of Nebraska-Lincoln, hblanco2@unl.edu

Virginia L. Jin
USDA, Agricultural Research Service

Richard B. Ferguson
University of Nebraska-Lincoln, rferguson1@unl.edu

Published February 1, 2019

Cover Crops and Corn Residue Removal: Impacts on Soil Hydraulic Properties and Their Relationships with Carbon

Michael Sindelar*
Humberto Blanco-Canqui
Dep. of Agronomy & Horticulture
Univ. of Nebraska-Lincoln
Lincoln, NE 68583

Virginia L. Jin
USDA-Agricultural Research Service
Lincoln, NE 68583

Richard Ferguson
Dep. of Agronomy & Horticulture
Univ. of Nebraska-Lincoln
Lincoln, NE 68583

Large-scale crop residue removal may negatively affect soil water dynamics. Integrating cover crop (CC) with crop residue management can be a strategy to offset potential adverse effects of residue removal. We studied: (i) the impact of corn (*Zea mays* L.) residue removal (56%) with and without the use of winter rye (*Secale cereale* L.) CC on soil hydraulic properties, (ii) whether CC would ameliorate residue removal effects on hydraulic properties, and (iii) relationships of hydraulic properties with soil organic C (SOC) and other properties under irrigated no-till continuous corn on a silt loam in south central Nebraska after 5 and 6 yr of management. Cover crops did not affect soil hydraulic properties. However, residue removal reduced cumulative water infiltration by about 45% in one year. Across years, residue removal reduced plant available water (PAW) by 32% and mean weight diameter of water-stable aggregates (MWD) by 23% for the upper 5-cm soil depth. Under no CC, residue removal reduced SOC concentration by 25% in the 0- to 5-cm and by 11% in the 5- to 10-cm depths. Under residue removal, CC increased SOC concentration by 18% in the 0- to 5-cm and by 8% in the 5 to 10-cm depths. Cover crop did not completely offset the residue removal-induced decrease in SOC concentration in the upper 5-cm depth. Plant available water decreased as SOC concentration and MWD decreased. After 6 yr, corn residue removal adversely affected soil hydraulic properties and SOC concentration, but CC was unable to fully offset such adverse impacts.

Abbreviations: CC, cover crop; MWD, mean weight diameter of water-stable aggregates, PAW, plant available water, SOC, soil organic C.

Core Ideas

- **Cover crop generally had no effect on water infiltration, water retention, and available water after 5 and 6 yr.**
- **Corn residue removal reduced water infiltration, water retention, and available water after 5 and 6 yr.**
- **Cover crop partially mitigated the negative impacts of corn residue removal on soil hydraulic properties.**
- **Reductions in soil micropores and soil C concentration due to corn residue removal partly explained the reduction in plant-available water.**

Proper management of soil and water resources is critical to sustain agricultural production under fluctuating climatic conditions, which include changes in precipitation patterns, heat waves, droughts, and others. In the central Great Plains, management of soil water resources is of special interest because precipitation is often supplemented with irrigation to meet crop production goals (USDA, 2013). Improved agronomic management strategies are needed to address the above concerns (Wienhold et al., 2018). Practices such as CC and crop residue management that maintain or increase surface residue cover can increase precipitation capture, reduce evaporation, and increase water retention capacity.

Cover crops can impact soil water management decisions (Unger and Vigil, 1998; Daigh et al., 2014; Basche et al., 2016a). In water-limited regions, CC could reduce PAW needed for main crop production (Nielsen et al., 2016; Alvarez et al., 2017). However, CC may be able to also contribute to water storage by increasing water infiltration, retention, and PAW in the long term. Improved management of CC may ameliorate the negative impacts of precipitation fluctuations (Daigh et al., 2014; Steele et al., 2012; Basche et al., 2016a, 2016b).

Many have studied CC effects on wind and water erosion, SOC pools, and soil chemical and biological properties (Villamil et al., 2006; Dinesh et al., 2009; Blanco-Canqui et al., 2011; Premrov et al., 2012; Hubbard et al., 2013; Abdollahi

Soil Sci. Soc. Am. J. 83:221–231
doi:10.2136/sssaj2018.06.0225
Received 12 June 2018.
Accepted 25 Oct. 2018.
*Corresponding author (msindelar2@unl.edu).

et al., 2014). However, few have studied impacts of CC on properties that affect soil water dynamics such as water infiltration, retention, and PAW. The few published studies have reported conflicting results. For example, in Maryland after 13 yr across three rainfed sites, winter rye CC had inconsistent effects on water infiltration rate (Steele et al., 2012). However, a 15-yr study in Kansas found that summer CCs [hairy vetch (*Vicia villosa* Roth) and sunn hemp (*Crotalaria juncea* L.)] planted after winter wheat (*Triticum aestivum* L.) harvest increased cumulative water infiltration by three times compared with no CC (Blanco-Canqui et al., 2011).

Likewise, the few studies on soil water retention and PAW have reported some mixed effects of CC. In Iowa after 13 yr, rye CC increased PAW by 21% (Basche et al., 2016b). Similarly, in Illinois after 5 yr, cereal rye or hairy vetch CCs increased PAW by 4 to 8% (Villamil et al., 2006). However, a 15-yr study in Kansas found no summer CC effects on PAW (Blanco-Canqui et al., 2011). Additionally, a 4-yr study in Indiana reported that cereal rye had no effect on PAW (Rorick and Kladivko, 2017). These conflicting reports warrant additional research on CC effects on soil hydraulic properties. Moreover, previous studies have focused on rainfed systems. Data are lacking from irrigated cropping systems.

Crop residue management can also affect soil water dynamics. The retention of plant residues on the soil surface helps conserve soil water, maintain soil fertility, and provide other ecosystem services (Graham et al., 2007; Fronning et al., 2008; Blanco-Canqui et al., 2014), but as the demand for livestock feed and biofuel feedstock increases, the pressure to remove crop residues could increase in the future. Short-term (<3 yr) studies have indicated that corn residue removal at high rates can have positive effects on early season N mineralization, soil temperature, seed germination, and early root growth in regions with high residue production such as under irrigated conditions (Kenney et al., 2015; Wortmann et al., 2016). At the same time, however, high rates of residue removal can have negative effects on long-term soil productivity by increasing water and wind erosion and evaporation, which can reduce soil water storage and recharge (Kenney et al., 2015). Similar to CC, few studies have specifically measured changes in soil hydraulic properties after residue removal, to better understand water capture, retention, and losses. Some have suggested that corn residue removal at high rates (>50%) could negatively affect soil water storage and recharge by reducing water infiltration and PAW (Blanco-Canqui et al., 2007; Johnson et al., 2016; Tormena et al., 2017), but measured data on the latter hydraulic properties are limited. In Minnesota, a 7-yr study found that corn residue removal at about 70% reduced hydraulic conductivity by 20% compared with plots without removal (Johnson et al., 2016). In Ohio, high rates of residue removal (≥50%) reduced water retention at low matric potentials within the first year following residue removal although the magnitude differed with soil textural class (Blanco-Canqui et al., 2007)

These few studies suggest that corn residue removal at high rates can negatively affect soil hydraulic properties. Adding CC after residue removal could be a strategy to reduce such negative effects. Short-term (<3 yr) studies in Michigan and Nebraska, however, have found limited or no effects of CC on offsetting the negative impacts of residue removal on SOC and wet-aggregate soil aggregate stability (Fronning et al., 2008; Blanco-Canqui et al., 2014). Even in the medium term, CC may have limited effects on ameliorating residue removal- induced impacts on hydraulic properties in some soils. For example, in South Dakota, CC were unable to offset the negative impact of 98% crop residue removal on water content at any matric potential (Wegner et al., 2015). In the longer term, however, pairing residue removal with CC could enhance soil properties and agricultural production more than managing crop residues or using CC alone, and information on this combination is needed.

It is also imperative to understand how CC and crop residue removal can affect soil properties that are indicators of changes in soil hydraulic properties such as SOC concentration. Some of the questions include: (i) Does crop residue removal reduce water retention capacity by reducing SOC concentration? (ii) Can CC offset any effects of residue removal by replacing the SOC lost with residue removal? It is well recognized that a decrease in SOC can result in a corresponding decrease in PAW (Hudson, 1994; Rawls et al., 2004; Saxton and Rawls, 2006). However, such relationship can vary among soils because of differences in the amount of residue removed, CC management, and initial SOC concentration, among others. The relationships between changes in soil hydraulic properties and SOC have not been much discussed based on field data.

The objectives of this study were to assess: (i) the impact of corn residue removal (56%) with and without the use of winter rye CC on soil hydraulic properties including water infiltration, water retention, pore-size distribution, and PAW, (ii) whether CC would ameliorate residue removal effects on hydraulic properties, and (iii) relationships of hydraulic properties with SOC and other properties. The first hypothesis was that corn residue removal would reduce cumulative water infiltration, water retention, and PAW. The second hypothesis was that CC would ameliorate residue removal effects on soil hydraulic properties. The third hypothesis was that CC and residue removal would affect water retention and PAW by altering SOC concentration.

MATERIALS AND METHODS

Study Site

This study was conducted on an ongoing experiment 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 classified as Hastings silt loam (fine, smectitic, mesic Udic Argiustolls) with an average slope of <3% (Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture, 2017). The experiment is under irrigated no-till continuous corn. The experimental design is a completely randomized split-split-split block in quadruplicate with four study factors. The factors are: (i) two irrigation levels (full, deficit), (ii) three amelioration practices(none, cereal rye CC, surface broadcast animal manure), (iii) two corn residue removal rates (none, removal), and (iv) two inorganic N fertilizer rates (125, 200 kg N ha^{-1} yr^{-1}). This results in a total of 96 experimental units (2 × 3×2 × 2 × 4 reps = 96). Agronomic operations for 2015 to 2017 are shown in Table 1, which are representative of the management for the previous years.

Experiment Design

Main Plot

The experiment has eight 24-m by 155-m main plots for each irrigation treatment. Full irrigation treatments have 45 to 90% of total available water holding capacity within 1.2-m soil profile. An irrigation event is set to occur when PAW is at 45% in the full irrigation treatment. The deficit irrigation treatment applies 60% of the water inputs of the fully irrigated treatment. Deficit irrigation events are applied at the same time as full irrigation events. Irrigation timings are based on the average soil matric potential value from watermark sensors (Irrometer Co. Inc.) measurements in both irrigation level treatments (full and deficit). The sensors were installed in the high N treatment only for control and CC subplots with and without residue removal in all replications. Additionally, supplementary neutron soil moisture gauge measurements from an adjacent study within this field were included in the average soil matric potential average (Troxler Electronic Labs.). Irrigation was applied when the average soil matric potential was between –0.09 to –0.11 MPa. Soil matric potential sensors are installed every 0.3 m to a 1.2-m soil depth within the crop row.

Split Plot

Each irrigation level main plot is split into three 24-m by 52-m amelioration plots to compare winter rye CC, animal manure, or control (no manure or CC). Beef (*Bos taurus*) or sheep (*Ovis aries*) manure was used depending on availability. Manure was surface applied in the fall after residue removal using a mechanical manure spreader. Manure is applied at a P rate using approximate crop P removal as described by Blanco-Canqui et al. (2014), which results in manure applications every 2 yr. Winter rye is planted in fall after corn residue harvest using a no-till drill and terminated using glyphosate ($C_3H_8NO_5P$) in spring of each year before corn planting. The winter rye was seeded at an average rate of 112 kg ha^{-1} at a depth of 3 cm with 15-cm row width.

Table 1. Information of the experiment management.

Year	Date	Field operation
2015	27 Jan	P fertilizer surface broadcasted (11–52–0; 112 kg ha^{-1}) to the whole field
	17 Apr	Herbicide applied to whole field (Roundup Power Max [$C_3H_8NO_5P$; Bayer] 2.34 L ha^{-1}); termination of winter rye (*Secale cereal* L.)
	1 May	Corn (*Zea mays* L.) planted (Dekalb 60–67; 84,000 seeds ha^{-1}); Starter fertilizer (10–34–0; 65.5 kg ha^{-1})
	22 Jun	N fertilizer injected (urea and ammonium nitrate, UAN 32–0–0; 125 or 200 kg N ha^{-1}; banded at the 12-cm depth)
	20, 27 Jul; 3, 17, 26, 31 Aug	Irrigation water applied (3.4 and 2 cm water for full and deficit irrigation, respectively)
	16 Oct	Corn grain harvested
	27 Oct	Corn residue removed
	3 Nov	Winter rye cover crop planted (112 kg ha^{-1}) with no-till drill
2016	27 Jan	Broadcasted P fertilizer (11–52–0; 112 kg ha^{-1}) to whole field.
	22 Apr	Herbicide applied to whole field (Power Max 2.34 L ha^{-1}, Bayer); termination of winter rye
	13 May	Corn planted (Dekalb 60–67; 84,000 seeds ha^{-1}) with starter fertilizer (10–34–0; 65.5 kg ha^{-1})
	18 May	Herbicide applied to whole field (5.84 L ha^{-1} Lumax [Syngenta] + 2.34 L ha^{-1} Round up)
	16 Jun	N fertilizer injected (UAN 32–0–0; 125 or 200 kg N ha^{-1}; banded at the 12-cm depth)
	17 Jun	Herbicide applied to whole field (Roundup at 2.92 L ha^{-1})
	20 Jun; 1, 8, 19, 27 Jul; 2, 17 Aug	Irrigation water applied (3.4 and 2 cm water for full and deficit irrigation, respectively)
	14 Oct	Corn grain harvested
	27 Oct	Corn residue removed
	31 Oct	Winter rye cover crop planted (112 kg ha^{-1}) with no-till drill
	6 Nov	Beef (*Bos taurus*) feedlot manure surface broadcasted to amelioration treatment plots (~25 fresh Mg ha^{-1})
	Dec	Surface broadcasted P fertilizer (11–52–0; 112 kg ha^{-1}) to whole field
2017	11 Apr	Herbicide applied to whole field (Power Max 3.50 L ha^{-1}); termination of winter rye
	6 May	Corn planted (Dekalb 60–67; 84,000 seeds ha^{-1}) with starter fertilizer (10–34–0; 65.5 kg ha^{-1})
	9 May	Herbicide applied to whole field (7.01 L ha^{-1} Lumax + 3.51 L ha^{-1} Round up PowerMax)
	13 Jun	Nitrogen fertilizer injected (UAN 32–0–0; 125 or 200 kg N ha^{-1}; banded at the 12-cm depth)
	27 Jun; 5, 11, 26 Jul; 15 Aug	Irrigation water applied (3.4 and 2 cm water for full and deficit irrigation, respectively)
	19 Oct	Corn grain harvested
	2 Nov	Corn residue removed
	3 Nov	Winter rye cover crop planted (112 kg ha^{-1}) with no-till drill
2018	Jan	Surface broadcasted P fertilizer (11–52–0; 168 kg ha^{-1}) to whole field

Spit–Split Plot

Each split plot was subdivided into two 12-m by 52-m plots for corn residue management, where corn residue is either removed or retained. Residue removal occurred in late October of each year following grain harvest. Residue was removed with a three-pass system (mow, rake into windrows, round bale) in 2010, and with a two-pass system (mow-windrow, round bale) from 2011 to 2016. The corn residue was mowed at a 5-cm cutting height to allow the maximum amount of mechanically removable residue under field conditions. The mean residue removal rate was 56 ± 3% (5.6 ± 0.5 Mg dry matter ha^{-1}) from 2010 to 2015. The standard error reflects the variation in percentage of removal over time. The actual dry mass associated with the percentage of removal will vary with the year, depending on total residue production. Corn residue amount was determined by hand-harvesting corn from a 0.76 m by 3.04 m area at physiological maturity and prior to combine harvest. Ears were removed, and then stalks were cut at ground level, chopped, and weighed, and a subsample was dried at 60°C until constant mass. Ears were dried, weighed, and shelled to calculate grain yields. Cob weights were added to the residue yield to calculate total residue production.

Split–Split–Split Plot

The residue management plots are additionally divided into two 12-m by 26-m N fertilizer treatment plots to compare 125 vs. 200 kg N ha^{-1}. Nitrogen source is solution of urea and ammonium nitrate (UAN) applied at post-emergence between corn rows using a coulter injection application system. Manure treatment plots are credited for first, second, and third-year mineralizable N from applied manure, as per University of Nebraska recommendations (Shapiro et al., 2006).

In the present study, residue removal and CC effects on soil hydraulic properties were evaluated for a subset of treatments that best represented producer practices for irrigation (full) and N management (200 kg N ha^{-1} yr^{-1}). Manure-treated soils were not evaluated.

Measurement of Soil Organic Carbon and Water-Stable Aggregates

In spring of 2015 and 2016, six hand-probe samples (3.1-cm diam.) were collected from each plot from 0- to 15-cm depth and split into 5-cm depth increments and composited by depth. The composite samples were gently broken up along natural planes of weakness and allowed to air dry. These samples were used to measure wet-aggregate stability and SOC concentration.

A fraction of the initial air-dry sample was crushed and passed through a 2-mm sieve for the analysis of SOC concentration. The sieved sample was cleaned to remove visible residues, placed in a glass vial, and ground on a roller mill for 24 h. About 90 mg of the ground sample were used to determine SOC concentration by the dry combustion method using an EA Flash 2000 Analyzer equipped with a MAS auto sampler (CE Elantech; Nelson and Sommers, 1996).

Wet-aggregate stability was determined by the wet sieving method (Nimmo and Perkins, 2002). A portion of the air-dry sample was passed through 4.75- to 8-mm sieves to collect about 50 g of aggregates ranging from 4.75- to 8-mm diameter. The collected aggregates were then placed on the top of sieves with 4.75-, 2.00-, 1.00-, 0.50-, and 0.25-mm openings and saturated by capillarity for 10 min. The samples were then mechanically sieved in a column of water at 30 cycles per min for 10 min. The aggregates from each sieve were transferred to pre-weighed beakers and oven-dried at 105°C and weighed. Samples were then treated with sodium hexametaphosphate dispersing agent and passed through a 0.053-mm sieve for sand correction. The sand particles on the sieves were recovered and oven dried at 105°C. Mean MWD of water-stable aggregates was then computed as described by Nimmo and Perkins (2002).

Measurement of Water Retention

For the laboratory measurements of soil water retention, 5 × 5 cm intact soil cores were collected in spring of 2015 and 2016 from representative non-trafficked row shoulders in each plot. Two soil cores were collected from the 0- to 10-cm soil depth from each plot. The cores were carefully inserted into the soil by hand until soil occupied the full volume of the core to avoid compacting the soil. The cores were transported and stored in the cold room at 2.2°C until further processing.

The intact soil cores were carefully trimmed flush with the top and bottom of the metal core. The soil cores were saturated slowly by capillary action over the course of about 3 d. Water retention was determined at 0, −0.001, −0.003, −0.01, −0.033, −0.1, −0.3, and −1.5 MPa. For the 0, −0.001, and −0.003 MPa points, a tension table was used to equilibrate the soil cores at each pressure head. Soil cores were weighed at each step to determine change in volumetric water content. To determine volumetric water content at −0.01, −0.033, −0.1, −0.3 MPa, the intact soil cores were transferred from the tension table to a low suction pressure extractor, corresponding air pressure applied, and soil cores weighed at each pressure step (Klute, 1986). Afterward, a subsample of soil was collected from each intact core, dried in an oven at 105°C for 24 h, and used to calculate bulk density by the core method (Grossman and Reinsch, 2002). Then, the intact soil cores were air dried, ground, and passed through a 5-mm sieve. The sieved sample was packed in 1 cm by 5 cm plastic rings on top of a −1.5 MPa ceramic plate and allowed to saturate for 24 h. The ceramic plate along with the samples were then placed in a high-pressure extractor to determine water content at −1.5 MPa (Dane and Hopmans, 2002).

Plant available water was calculated by subtracting the volumetric water content at permanent wilting point (−1.5 MPa) from field capacity (−0.033 MPa). Pore-size distribution was computed from the water retention data using the capillary equation (Dane and Hopmans, 2002). Pore-size classes were divided into macropores (>300-µm diam.), mesopores (10–300 µm diam.), and micropores based on pore diameter (<10-µm diam.; Luxmoore, 1981).

Water Infiltration

Water infiltration was measured in situ during spring, summer, and fall 2016 using a double ring infiltrometer under a constant head (Reynolds et al., 2002). Water infiltration in spring was measured after corn emergence, while infiltration in summer was measured approximately 7 d after an irrigation event. Infiltration in fall was conducted after harvest, but prior to the residue removal and planting of the winter rye CC. One infiltration measurement was done per plot. The double rings (75-cm outer ring and 25-cm inner ring) were placed on the shoulder of the corn row and inserted to a 10-cm depth in non-trafficked rows. The row shoulder was selected to avoid soil disturbance left from an application of N fertilizer that was knifed into the center of the interrow.

A constant head for the infiltrometer was established and maintained by a custom Mariotte bottle fabricated out of polyvinyl chloride (PVC) pipe with an inner diameter of 15.25 cm. At times of 1, 2, 3, 5, 10, 30, 60, 90, 120, 150, and 180 min, the height of the water in the Mariotte bottle. The infiltration rate was measured for 3 h until steady-state condition was reached (Reynolds et al., 2002). The infiltration rate for each time interval was calculated along with the cumulative water infiltration. Soil samples for antecedent water content were collected with a hand probe (diameter of 3.1 cm) for depths of 0- to 5-cm and 5- to 10-cm near the infiltration sites prior to the start of each measurement. The samples were weighed, and a subsample collected and dried at 105°C for 24 h to determine gravimetric water content and then multiplied by the corresponding bulk density to determine volumetric water content.

Statistical Analysis

All collected data were tested for normality using PROC UNIVARIATE in SAS (SAS Institute Inc., 2017) and data were found to be normally distributed. Data were analyzed using a randomized complete block design with a split plot. The main plot was the CC treatment and the split plot was the corn residue removal treatment. Analysis of water retention, PAW, pore-size distribution, MWD, SOC concentration, and bulk density data was conducted by depth and date. Water infiltration data were analyzed by each measurement time (1, 2, 3, 5, 10, 30, 60, 90, 120, 150, and 180 min) and date. All data were analyzed using PROC MIXED to determine main effects and interactions. All differences in main effects and interactions (multiple comparisons) were studied using LSMEANS utilizing the pdiff statement in SAS and declared significant at the 0.05 probability level unless otherwise noted. To assess whether the CC could fully offset or partially offset the potential negative impacts of residue removal on SOC concentration, MWD, water retention, pore-size distribution, PAW, and cumulative infiltration, the differences of LSMEANS (multiple comparisons) in SAS were used.

Relationships among volumetric water content at −0.033 and −1.5 MPa, pore-size distribution, SOC concentration, MWD, and PAW content were studied using PROC CORR. Next, simple predictive equations for estimating PAW from other soil properties were developed using PROC STEPWISE in SAS. The parameters used for the PROC STEPWISE regression analysis included PAW, total porosity (volumetric water content at saturation), SOC concentration, and MWD. After initial analysis, data were pooled across dates for water retention, PAW, pore-size distribution, MWD, SOC concentration, and bulk density as neither the main nor interactive effects of date were significant.

RESULTS AND DISSCUSION

Soil Organic Carbon and Water-Stable Aggregates

Cover crop significantly affected SOC concentration at the 0.10 probability level for the 0- to 5-cm soil depth (p = 0.09; Table 2) but had no effect at deeper soil depths. However, corn residue removal at 56% significantly affected SOC concentration at all soil depth intervals (0 to 5, 5 to 10, and 10 to 15 cm; Table 2). Cover crop × residue removal interaction was significant for SOC concentration for the 0- to 5-cm and 5- to 10-cm soil depths. Specifically, CC did not affect SOC concentration when residue was retained but increased it by 18% in the 0- to 5-cm and by 11% in the 5- to 10-cm depth when residue was removed. When no CC was used, residue removal reduced SOC concentration by 25% in the 0- to 5-cm depth and 11% in the 5- to 10-cm depth compared with no removal (Table 2). Cover crop had no effect on MWD at any soil depth, but residue removal affected at the 0- to 5-cm and 5- to 10-cm depths (Fig. 1). Residue removal × CC interaction was not significant

Table 2. Mean soil organic C concentration averaged across 2015 and 2016 as affected by cover crop (CC) and corn residue removal (RR) treatments for three soil depth intervals. Different uppercase letters within a column indicate significant differences between cover crop treatments, while different lowercase letters within a column and depth interval indicate significant differences between corn residue removal treatments.

Treatments		Soil depth	Soil Organic C
		cm	g kg^{-1}
No CC	No RR	0–5	24.1a
	56% RR	0–5	18.0Bb
CC	No RR	0–5	23.2a
	56% RR	0–5	21.9Ab
No CC	No RR	5–10	16.8a
	56% RR	5–10	15.0Bb
CC	No RR	5–10	16.5
	56% RR	5–10	16.3A
No CC		10–15	14.0
CC		10–15	14.2
No RR		10–15	14.4a
56% RR		10–15	13.8b
		Statistical significance ($P > F$)	
CC		0–5	0.095
RR		0–5	< 0.0001
CC × RR		0–5	0.0001
CC		5–10	0.28
RR		5–10	0.002
CC × RR		5–10	0.009
CC		10–15	0.48
RR		10–15	0.009
CC × RR		10–15	0.48

for MWD. Residue removal reduced MWD by about 23% in the 0 to 5 cm and by 24% in the 5- to 10-cm depth (Fig. 1).

Difference of LSMEANS between control (no CC and no residue removal) and residue removal followed by CC was significant for both SOC concentration in the 0- to 5-cm depth (Table 2). Similarly, the difference of LSMEANS between control (no CC and no residue removal) and residue removal followed by CC was significant for MWD in the 0- to 5-cm depth (data not shown). These results suggest that CC did not offset the residue removal-induced decrease in SOC concentration and MWD near the soil surface after 5 and 6 yr. The increase in SOC concentration by 18% with CC suggests, however, that CC partly offset the residue removal effect on SOC in the 0- to 5-cm depth. However, in the 5- to 10-cm depth, CC was able to offset the lesser negative effect of residue removal on SOC concentration relative to no CC. The decrease in MWD with 56% corn residue removal suggests that high rates of removal can increase risks of water erosion. Because CC did not increase MWD, it did not offset residue removal-induced decreases in MWD at any soil depth. Studies in the region have also found that CC had limited or no effect on offsetting the negative effects of high rates of residue removal on SOC and aggregate stability (Wegner et al., 2015; Ruis et al., 2017). The limited effects of CC can be because of low amount of CC biomass input. On average, 5.6 Mg ha^{-1} yr^{-1} of corn residue were removed from the residue removal plots. This removal rate was seven times greater than the amount of CC aboveground biomass produced (0.8 Mg ha^{-1} yr^{-1}), which can explain the larger effect of residue removal on SOC and MWD than CC.

Comparison of our results with those by Blanco-Canqui et al. (2014) for the same experiment after 3 yr provides valuable insights into CC and residue removal effects on soil properties on a temporal scale. In the present study, after 5 and 6 yr, CC plots had greater SOC concentrations near the soil surface compared with no CC plots unlike after 3 yr when SOC concentration did not differ between CC and no CC plots (Blanco-Canqui et al., 2014). This suggests that CC effects on SOC concentration can develop with time. In other words, CC may change SOC concentration in the long term but not in the short term (<3 yr).

Additionally, the same study by Blanco-Canqui et al. (2014) found that residue removal reduced SOC concentration only in the 2.5 cm of the soil profile after 3 yr, but in the present study after 5 and 6 yr, residue removal reduced SOC concentration for the 0- to 15-cm depth. This suggests that residue removal can reduce SOC concentration at deeper depths in the long term. It is clear that the cumulative residue removal effect on SOC became more pronounced and measurable at deeper soil depths after 5 and 6 yr (Table 2). Our results thus suggest that to fully understand CC and residue removal interactive effects on soil properties, longer-term (>3 yr) experiments of CC and crop residue removal are needed (Table 2).

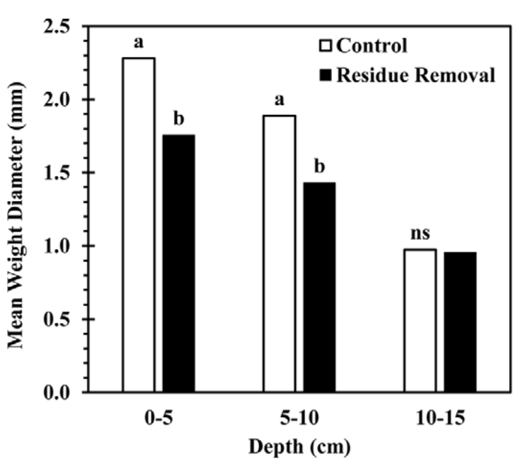

Fig. 1. Mean weight diameter of water-stable aggregates for three soil depths, averaged across cover crop treatments and 2 yr as affected by 56% residue removal under no-till irrigated continuous corn in south central Nebraska. Different lowercase letters at each depth interval indicate significant differences between control and residue removal. ns denotes no significant difference between treatments.

Water Retention, Pore-Size Distribution, and Available Water

There was no CC effect on water retention ($p > 0.10$), pore-size distribution ($p > 0.10$), or PAW ($p > 0.10$) at any of the measured depths. However, corn residue removal significantly affected water retention, pore-size distribution, and PAW in the 0- to 10-cm depth. Residue removal × CC interaction was not significant. Cover crop and residue removal treatments had no effect on soil bulk density at any depth (data not shown). These results support our first hypothesis that corn residue removal would decrease water retention and PAW. Previous studies have found inconsistent CC effects on water retention (Villamil et al., 2006; Basche et al., 2016b; Blanco-Canqui et al., 2011; Rorick and Kladivko, 2017).

Corn residue removal at 56% significantly affected soil volumetric water content at the −0.010, −0.033, and −0.100 MPa matric potentials. In the 0- to 5-cm depth, residue removal reduced volumetric water content by 18 to 23% at the above matric potentials compared with no residue removal (Fig. 2A). In the 5- to 10-cm depth, residue removal reduced volumetric water content at the −0.033- and −0.100-MPa matric potentials by about 10% (Fig. 2B). In the 10- to 15-cm depth, residue removal reduced volumetric water content at the 0.10 probability level for the −0.033- and −0.100-MPa matric potentials by 5 to 9% (Fig. 2C). The significant decrease in water retention with residue removal is similar to that reported by Blanco-Canqui et al. (2007) and Wegner et al. (2015).

Residue removal did not affect the volume of macropores (>300 μm in diameter) at any depth (Fig. 3A). However, it increased the volume of mesopores (10 to 300 μm in diameter) by 30% in the 0- to 5-cm depth and by 24% in the 5- to 10-cm depth (Fig. 3B). There was no treatment effect on the volume of mesopores in the 10- to 15-cm depth. The volume of micropores (<10 μm) under no residue removal was 19% greater in the 0- to 5-cm depth and 9% greater in the 5- to 10-cm depth compared with removal (Fig. 3C). In the 10- to 15-cm depth, the treatment effect on mesopores was not significant. Residue removal significantly reduced PAW in the 0- to 5-cm and 5- to

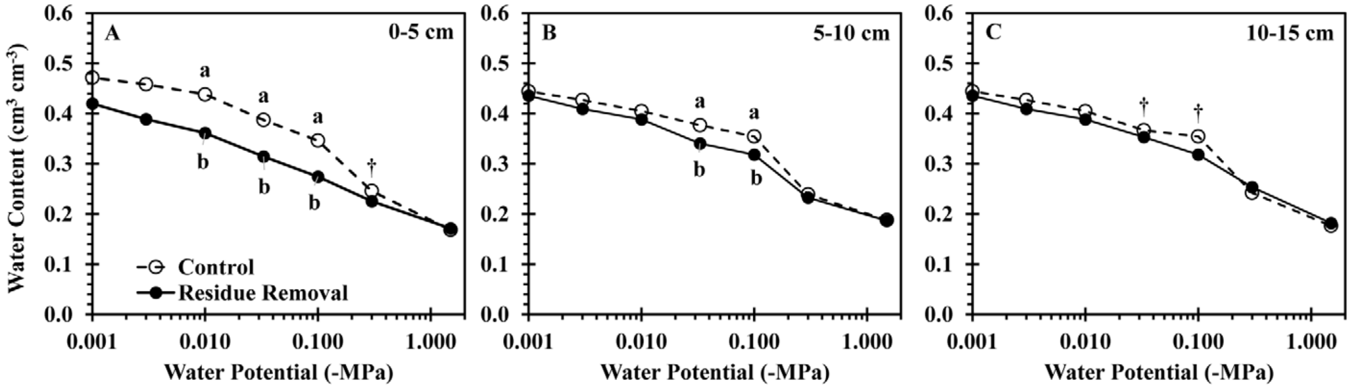

Fig. 2. Laboratory measured water retention curves for (A) 0- to 5-cm, (B) 5- to 10-cm, and (C) 10- to 15-cm depth, averaged across cover crop treatments as affected by 56% corn residue removal under irrigated no-till continuous corn on a silt loam in south central Nebraska. Different lowercase letters at each pressure head indicate significant differences between control and residue removal. † denotes differences at $p = 0.10$. Note that data for water retention at 0 kPa are not reported because of log scale use. However, corn residue removal effect on water content at 0-kPa matric potential was not significant at any soil depth interval.

10-cm depths (Fig. 4). Plant available water decreased by 32% in the 0- to 5-cm and by 21% in the 5- to 10-cm depth. Residue removal did not affect PAW below 10-cm depth. The difference of LSMEANS between control (no CC and no residue removal) and residue removal with CC was significant for volumetric water content at all matric potentials, mesopores, micropores, and PAW at the measured soil depths (0- to 15-cm; data not shown). This significant difference suggests that CC was unable to offset the negative effects of residue removal on water retention, pore-size distribution, and PAW. This rejects our second hypothesis, which stated that CC would ameliorate residue removal effect on water retention, pore-size distribution, and PAW. Studies on the potential of CC to offset crop residue removal are very few. In eastern South Dakota, Wegner et al. (2015) found that CC did not offset the negative impact of high rates of corn residue removal on water retention.

Water Infiltration

Antecedent soil water content measured prior to water infiltration measurements did not differ among treatments. Across treatments, mean antecedent water content for spring was 0.32 ± 0.06 $cm^3\ cm^{-3}$, summer was 0.30 ± 0.08 $cm^3\ cm^{-3}$, and fall was 0.23 ± 0.05 $cm^3\ cm^{-3}$. Cover crop effect on cumulative water infiltration was not significant in spring and summer measurements, but residue removal reduced cumulative water infiltration at all (spring, summer, and fall) measurement dates. The CC × residue removal interaction for cumulative infiltration was not significant in spring (Fig. 5A) and summer (Fig. 5A), but it was significant in fall (Fig. 6). These results did partly support our first hypothesis stating that residue removal can reduce water infiltration. In spring, residue removal reduced total cumulative water infiltration by 33% compared with no residue removal (Fig. 5A). Differences between residue removal and no removal were significant after 60 min. In summer, residue removal reduced total cumulative water infiltration by 56% (Fig. 5B). At this measurement date, cumulative water infiltration between removal and no removal significantly differed after 10 min.

The interactive effect between residue removal and CC use on cumulative infiltration in fall suggested that the magnitude at which residue removal decreased infiltration depended on CC treatment. In fall, when residue was retained, CC had no effect on cumulative water infiltration, but when residue was removed, CC

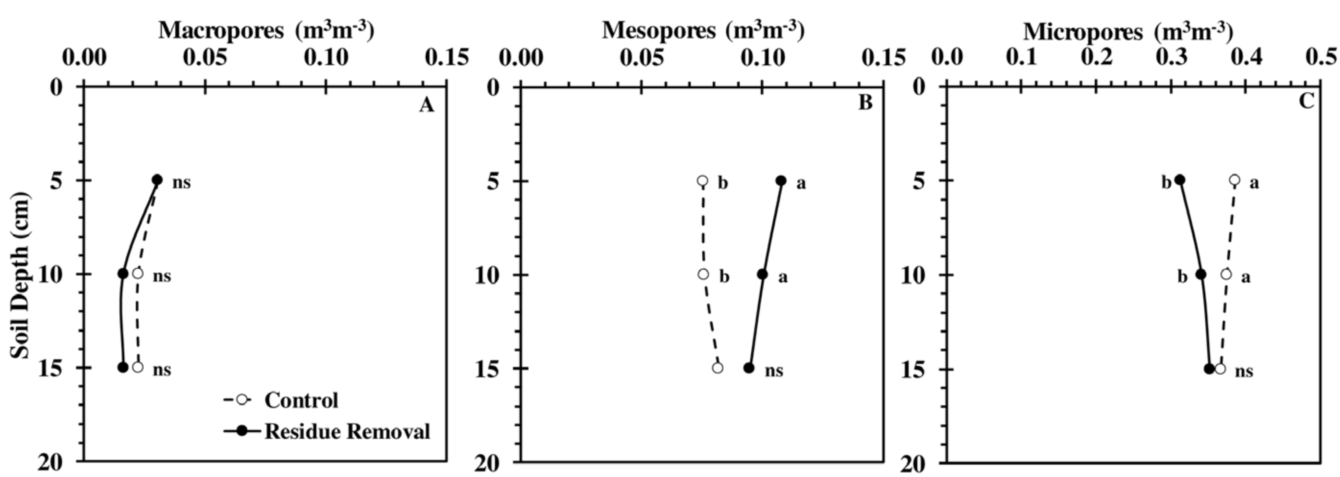

Fig. 3. Laboratory measured volume of (A) macropores, (B) mesopores, and (C) micropores by depth, averaged across cover crop treatments as affected by 56% corn residue removal under irrigated no-till continuous corn on a silt loam in south central Nebraska. Different lowercase letters at each depth interval indicate significant differences between control and residue removal. ns denote no significant difference between treatments.

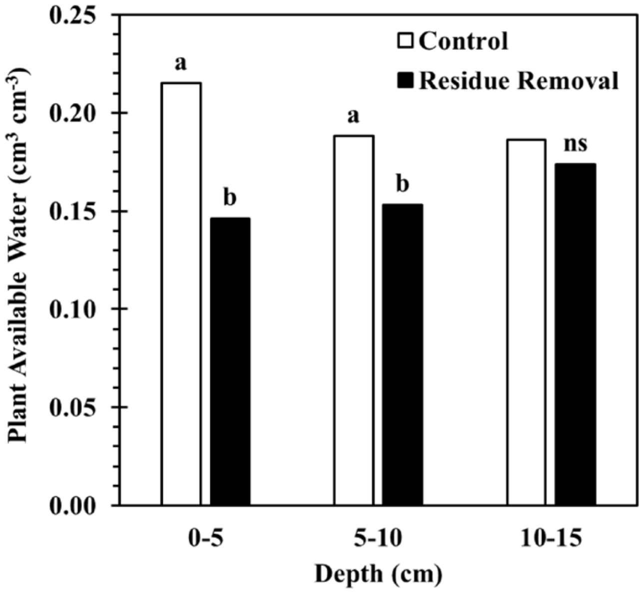

Fig. 4. Laboratory measured plant available water content by depth, averaged across cover crop treatments as affected by 56% corn residue removal under irrigated no-till continuous corn on a silt loam in south central Nebraska. Different lowercase letters at each depth interval indicate significant differences between control and residue removal. ns denote no significant difference between treatments.

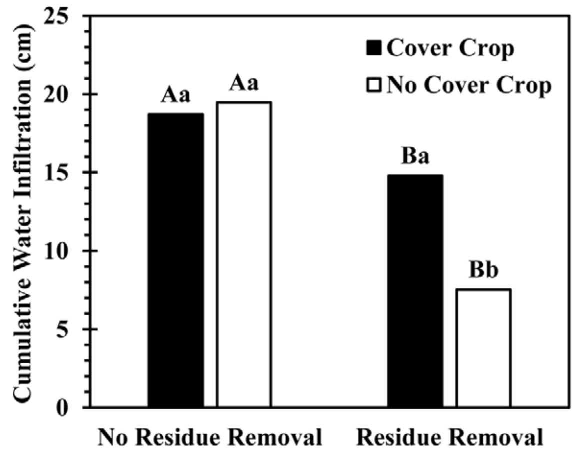

Fig. 6. Cumulative water infiltration in fall of 2016 as affected by 56% corn residue removal under and cover crop use under irrigated no-till continuous corn on a silt loam in south central Nebraska. Uppercase letters denote significant differences residue removal and no removal. Lowercase letters denote significant differences between cover crop treatments. Because of significant cover crop × residue removal interaction for cumulative water infiltration in fall 2016, residue removal effects on water infiltration was reported by cover crop treatment unlike in spring and summer 2016 where the interaction was not significant.

increased cumulative water infiltration by 49% compared with no CC (Fig. 6). Under plots without CC, residue removal reduced cumulative water infiltration by 61% (Fig. 6). The difference in LSMEANS between control (no CC and no residue removal) and residue removal with CC was significant for cumulative water infiltration in all dates. This suggests that CC did not fully offset the residue removal-induced decrease in cumulative infiltration after 6 yr. The results of this study indicate that CC was unable to increase water infiltration compared with the control after 6 yr of use. We expect that changes in water infiltration and other soil properties under CC can be measurable in the long term. For example, the few previous CC studies found that CC increased water infiltration after 12 to 13 yr (Blanco-Canqui et al., 2011; Steele et al., 2012).

A comparison of water infiltration results after 6 yr (this study) with those reported after 3 yr for the same experiment (Blanco-Canqui et al., 2014) highlights how corn residue removal effects develop with time. Blanco-Canqui et al. (2014) did not find corn residue removal effects on cumulative water infiltration after 3 yr, but, in the present study, cumulative water infiltration decreased with residue removal. This comparison clearly suggests that crop residue removal can affect water infiltration with time after several consecutive years of residue removal. Similarly, the decrease in aggregate stability and SOC with residue removal was larger after 5 and 6 yr compared with that after 3 yr. Such large decrease most likely explains the reduction in water infiltration after 6 yr.

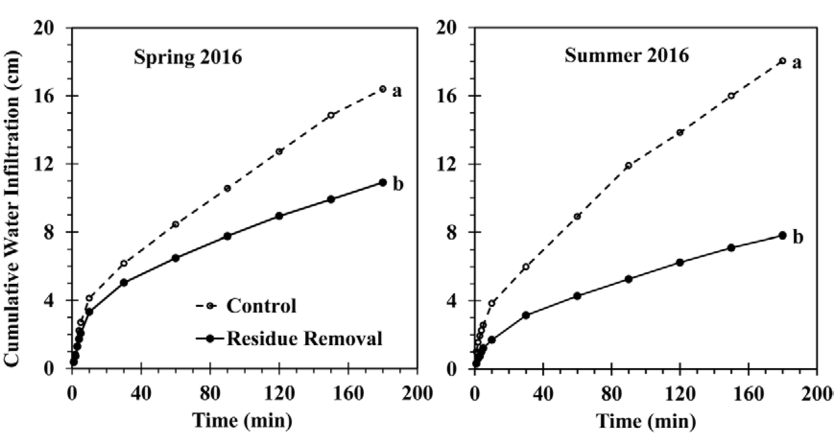

Fig. 5. Cumulative water infiltration in (A) spring 2016 and (B) summer 2016 across cover crop treatments as affected by 56% corn residue removal under irritated no-till continuous corn on a silt loam in south central Nebraska. Different lowercase letters indicate significant differences between control and residue removal.

Relationships of Hydraulic Properties with Soil Organic Carbon and Other Properties

To understand interrelationships of PAW with other soil properties as affected by CC and residue removal, correlations were studied. The correlation of most interest was that between PAW and SOC (Hudson, 1994; Rawls et al., 2004; Saxton and Rawls, 2006; Minasny and McBratney, 2018). Plant available water was correlated with SOC concentration, MWD, and the volume of micropores for the 0- to 10-cm depth (Table 3). In the 0- to 5-cm depth, PAW was correlated most strongly with the volume of micropores, followed by SOC concentration, and then MWD (Table 3). However, in the 5- to 10-cm depth, PAW was most correlated with MWD followed by SOC concentration, and the volume of micropores (Table 3). In the 10- to 15-cm depth, PAW was correlated only with the volume of micropores (Table 3). The relatively strong correlation between PAW and volume of micropores at all depths was expected as the

Table 3. Correlations among soil organic C concentrations (SOC), bulk density (BD), mean weight diameter of water-stable aggregates (MWD), volumetric water content (θ_v) at –0.033 MPa matric potential, volumetric water content at –1.5 MPa matric potential, plant available water (PAW), and volume of macropores, mesopores, and micropores across both cover crop and residue removal treatments and years (2015 and 2016) by depth in an irrigated no-till continuous corn on a silt loam soil in south central Nebraska.

	BD	MWD	θ_v at –0.033 MPa	θ_v at –1.5 MPa	PAW	Macropores	Mesopores	Micropores
				0- to 5-cm depth				
SOC, g kg^{-1}	–0.015	0.44**	0.59***	–0.17	0.60***	0.07	0.31	0.51**
BD, g cm^{-3}		0.12	–0.29	0.06	–0.29	0.04	0.15	–0.29
MWD, mm			0.53**	0.03	0.50**	–0.05	–0.06	0.53**
θ_v at –0.033, cm^3 cm^{-3}				0.23	0.83***	–0.12	–0.40*	1
θ_v at –1.5, cm^3 cm^{-3}					–0.34†	–0.29	–0.13	0.23
PAW, cm^3 cm^{-3}						0.05	–0.33†	0.83***
Macropores, cm^3 cm^{-3}							0.14	–0.12
Mesopores, cm^3 cm^{-3}								–0.39*
				5- to 10-cm depth				
SOC, g kg^{-1}	0.21	0.54**	0.09	–0.47	0.60***	0.21	–0.005	0.09
BD, g cm^{-3}		–0.04	–0.03	0.09	–0.09	–0.05	–0.27	–0.03
MWD, mm			0.44**	–0.29	0.68***	0.44*	0.28	0.44**
θ_v at –0.033, cm^3 cm^{-3}				–0.57**	0.44**	0.27	–0.68***	1
θ_v at –1.5, cm^3 cm^{-3}					–0.57***	–0.19	–0.47**	0.47**
PAW, cm^3 cm^{-3}						0.38*	–0.15	0.44*
Macropores, cm^3 cm^{-3}							0.01	0.27
Mesopores, cm^3 cm^{-3}								–0.68***
				10- to 15-cm depth				
SOC, g kg^{-1}	0.13	–0.11	–0.15	–0.03	–0.12	0.23	–0.023	–0.15
BD, g cm^{-3}		–0.02	0.01	0.32	–0.32	–0.08	–0.18	0.01
MWD, mm			0.15	–0.04	0.20	0.13	0.30	0.15
θ_v at –0.033, cm^3 cm^{-3}				0.57***	0.60***	0.05	–0.69	1
θ_v at –1.5, cm^3 cm^{-3}					–0.29	–0.14	–0.46**	0.59*
PAW, cm^3 cm^{-3}						0.16	–0.32†	0.60***
Macropores, cm^3 cm^{-3}							0.20	0.05
Mesopores, cm^3 cm^{-3}								–0.69***

*, **, and ***, significant at 0.05, 0.01, and 0.001 probability levels.
† Significant at 0.10 probability level.

proportion of micropores directly affect the soil's ability to retain water. Available water was also highly correlated with volumetric water content at –0.033 MPa at all depths (Table 3).

Based on the correlations (Table 3), a predictive equation of PAW was developed through stepwise linear regression analysis for each depth interval. The potential equations to predict PAW were:

Depth: 0- to 5-cm depth

$$\text{PAW} = -0.16 + 0.75\times\text{Micropores} + 0.004\times\text{SOC} \quad (r^2 = 0.73; p < 0.001). \qquad [1]$$

Depth: 5- to 10-cm depth

$$\text{PAW} = -0.14 + 0.036\times\text{MWD} + 0.009\times\text{SOC} \quad (r^2 = 0.54; p < 0.05). \qquad [2]$$

Depth: 10- to 15-cm depth

$$\text{PAW} = 0.18 - 0.13\times\text{Bulk Density} + 0.53\times \text{Micropores} \quad (r^2 = 0.47; p < 0.05). \qquad [3]$$

The stepwise linear regression analysis in Eq. [1], [2], and [3] showed that SOC concentration was a common predictor of PAW in the 0- to 5- and 5- to 10-cm depths, while volume of micropores was a common predictor of PAW in the 0- to 5-cm and 10- to 15-cm depths. For the 0- to 5-cm depth, volume of micropores accounted for 69% ($p < 0.0001$) of the variability in PAW, while SOC concentration accounted for only 4% ($p = 0.048$) of the variability in PAW data. For the 5- to 10-cm depth, MWD accounted for 47% ($p < 0.0001$) of the variability in PAW and SOC concentration accounted for only 7% ($p = 0.041$) of the variability in PAW data. For the 10- to 15-cm depth, volume of micropores explained 36% ($p = 0.0003$) of variability in PAW while bulk density explained only 11% ($p = 0.022$) of the variability. As expected, the r^2 values were the largest near the soil surface where changes in volume of micropores and SOC explained about 73% of the variability. Our study corroborates that volume of micropores can be an essential property affecting retention of PAW. It is well recognized that water at high matric potentials is commonly retained by small pores (micropores; Danielson and Sutherland, 1986). Our results also support our third hypothesis, which stated that CC and residue removal can alter PAW by changing SOC concentration and other soil properties. However, the effects of changes in SOC concentration on PAW were smaller compared with the effect of micropores. The modest PAW predictive ability of SOC appears to agree with Minasny and McBratney (2018) who recently, after conducting a meta-analysis from 60 published studies, concluded that the increase in SOC concentration has small effects on soil water content. They also discussed that the increase in SOC can increase PAW more in coarse-textured than in fine-textured soils. Our soil was silt loam, which may be less sensitive to changes in SOC concentration than sandy soils. While some studies (Rawls et al., 2004; Saxton and Rawls, 2006) have indicated that SOC is a sensitive predictor of PAW, based on our results and the study by Minasny and McBratney (2018), we conclude that changes in SOC concentration because of corn residue removal and CC addition may have only modest effects on PAW in this silt loam soil.

CONCLUSIONS

Results from this 6-yr study on irrigated no-till continuous corn in south central Nebraska indicated that winter rye CC generally had no effect on soil properties except SOC concentration, which increased marginally with CC. However, corn residue removal at 56% reduced water infiltration, PAW, wet-aggregate stability, and SOC concentration. Cover crop was unable to offset such negative impacts of residue removal on soil physical properties. However, CC was able to partially mitigate the decrease in SOC concentration in the 0- to 10-cm soil depth. A comparison of our results after 5 and 6 yr with those by Blanco-Canqui et al. (2014) after 3 yr for the same experiment indicates that, unlike after 3 yr, CC plots had greater near-surface SOC concentration after 5 and 6 yr compared with no CC plots. Similarly, corn residue removal had no effect on water infiltration after 3 yr (Blanco-Canqui et al., 2014), but, after 6 yr (this study), it had lower infiltration compared with no removal. This suggests that effects of CC and crop residue removal are more evident in the long than in the short term. This study also found that volume of micropores was a strong predictor of PAW while changes in SOC concentration had only modest effects on PAW.

The significant adverse effects of corn residue removal on soil properties suggest that annual removal at high rates (56%) may not be sustainable. We suggest that threshold levels of corn residue removal should be established for this region to reduce degradation of soil hydraulic properties and SOC levels. For example, the reduction in water infiltration could lead to increased risks of water erosion and runoff and reduced water storage. We hypothesize that performing residue harvest in alternate years could be a strategy to reduce negative effects of removal, but this needs further research. Additionally, CC management strategies (planting date, planting method, and termination date) should be developed to increase CC biomass production and improve soil properties for offsetting residue removal effects. As discussed earlier, in this study, rye CC produced only 0.8 Mg ha^{-1} yr^{-1}, which does not appear to be sufficient to change soil properties and offset the negative effects of the high rates (5.6 Mg ha^{-1} yr^{-1} or 56%) of corn residue removal. Overall, corn residue removal adversely affected soil hydraulic properties and SOC concentration after 6 yr, but CC was unable to completely offset the effects of residue removal on soil properties in this irrigated silt loam soil.

REFERENCES

Abdollahi, L., L.J. Munkholm, and A. Garbout. 2014. Tillage system and cover crop effects on soil quality: II. Pore characteristics. Soil Sci. Soc. Am. J. 78:271–279. doi:10.2136/sssaj2013.07.0302

Alvarez, R., H.S. Steinbach, and J.L. De Paepe. 2017. Cover crop effects on soils and subsequent crops in the pampas: A meta-analysis. Soil Tillage Res. 170:53–65. doi:10.1016/j.still.2017.03.005

Basche, A.D., S.V. Archontoulis, T.C. Kaspar, D.B. Jaynes, T.B. Parkin, and F.E. Miguez. 2016b. Simulating long-term impacts of cover crops and climate change on crop production and environmental outcomes in the Midwestern United States. Agric. Ecosyst. Environ. 218:95–106. doi:10.1016/j.agee.2015.11.011

Basche, A.D., T.C. Kaspar, S.V. Archontoulis, D.B. Jaynes, T.J. Sauer, T.B. Parkin, and F.E. Miguez. 2016a. Soil water improvements with the long-term use of a winter rye cover crop. Agric. Water Manage. 172:40–50. doi:10.1016/j.agwat.2016.04.006

Blanco-Canqui, H., R. Lal, W.M. Post, R.C. Izaurralde, and M.J. Shipitalo. 2007. Soil hydraulic properties influenced by corn stover removal from no-till corn in Ohio. Soil Tillage Res. 92:144–155. doi:10.1016/j.still.2006.02.002

Blanco-Canqui, H., M.M. Mikha, D.R. Presley, and M.M. Claassen. 2011. Addition of cover crops enhances no-till potential for improving soil physical properties. Soil Sci. Soc. Am. J. 75:1471–1482. doi:10.2136/sssaj2010.0430

Blanco-Canqui, H., R.B. Ferguson, V.L. Jin, M.R. Schmer, B.J. Wienhold, and J. Tatarko. 2014. Can cover crop and manure maintain soil properties after stover removal from irrigated no-till corn? Soil Sci. Soc. Am. J. 78:1368–1377. doi:10.2136/sssaj2013.12.0550

Daigh, A.L., M.J. Helmers, E. Kladivko, X. Zhou, R. Goeken, J. Cavdini, D. Barker, and J. Sawyer. 2014. Soil water during the drought of 2012 as affected by rye cover crops in fields in Iowa and Indiana. J. Soil Water Conserv. 69:564–573. doi:10.2489/jswc.69.6.564

Dane, J.H., and J.W. Hopmans. 2002. Laboratory. In: J.H. Dane and G.C. Topp, editors, Methods of soil analysis. Part 4. SSSA Book Ser. No. 5. Soil Sci. Soc. Am., Madison, WI. p. 675–719.

Dinesh, R., S. Ghoshal Chaudhuri, T.E. Sheeja, and K.N. Shiva. 2009. Soil microbial activity and biomass is stimulated by leguminous cover crops. J. Plant Nutr. 172:288–296. doi:10.1002/jpln.200700300

Danielson, R.E., and P.L. Sutherland. 1986. Porosity. Laboratory methods. In: A. Klute, editor, Methods of soil analysis. Part 1. SSSA Book Ser. 5. SSSA, Madison, WI. p. 443-460.

Fronning, B.E., K.D. Thelen, and D.H. Min. 2008. Use of manure, compost, and cover crops to supplant crop residue carbon in corn stover removed cropping systems. Agron. J. 100:1703–1710. doi:10.2134/agronj2008.0052

Graham, R.L., R. Nelson, J. Sheehan, R.D. Perlack, and L.L. Wright. 2007. Current and potential US corn stover supplies. Agron. J. 99:1–11. doi:10.2134/agronj2005.0222

Grossman, R.B., and T.G. Reinsch. 2002. Bulk density and linear extensibility. In: J.H. Dane and G.C. Topp, editors, Methods of soil analysis. Part 4. SSSA Book Ser. 5. SSSA, Madison, WI. p. 201–225.

Hubbard, R.K., T.C. Strickland, and S. Phatak. 2013. Effects of cover crop systems on soil physical properties and carbon/nitrogen relationships in the coastal plain of southeastern USA. Soil Tillage Res. 126:276–283. doi:10.1016/j.still.2012.07.009

Hudson, B.D. 1994. Soil organic matter and available water capacity. J. Soil Water Conserv. 49:189–194.

Johnson, J.M., J.S. Strock, J.E. Tallaksen, and M. Reese. 2016. Corn stover harvest changes soil hydrology and soil aggregation. Soil Tillage Res. 161:106–115. doi:10.1016/j.still.2016.04.004

Kenney, I., H. Blanco-Canqui, D.R. Presley, C.W. Rice, K. Janssen, and B. Olson. 2015. Soil and crop response to stover removal from rainfed and irrigated corn. Glob. Change Biol. Bioenergy 7:219–230. doi:10.1111/gcbb.12128

Klute, A. 1986. Water retention. In: J.H. Dane and G.C. Topp, editors, Methods of soil analysis. Part 4. SSSA Book Ser. 5. SSSA, Madison, WI. p. 635–662.

Luxmoore, R.J. 1981. Micro-, meso-, and macroporosity of soil. Soil Sci. Soc. Am. J. 45:671–672. doi:10.2136/sssaj1981.03615995004500030051x

Minasny, B., and A.B. McBratney. 2018. Limited effect of organic matter on soil available water capacity. Eur. J. Soil Sci. 69:39–47. doi:10.1111/ejss.12475

Nelson, D.W., and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter: Laboratory methods. In: D.L. Sparks, editor, Methods of

soil analysis. Part 3. SSSA Book Ser. 5. SSSA, Madison, WI. p. 961–1010.
Nielsen, D.C., M.F. Vigil, D.J. Lyon, R.K. Higgins, G.W. Hergert, and J.D. Holman. 2016. Cover crops can affect subsequent wheat yield in the central great plains. Crops Soils. 49:51–53. doi:10.2134/cs2016.49.0315
Nimmo, J.R., and K.S. Perkins. 2002. Aggregate stability and size distribution. In: J.H. Dane and G.C. Topp, editors, Methods of soil analysis. Part 4. SSSA Book Ser. 5. SSSA, Madison, WI. p. 317–327.
Premrov, A., C.E. Coxon, R. Hackett, L. Kirwan, and K.G. Richards. 2012. Effects of over-winter green cover on groundwater nitrate and dissolved organic carbon concentrations beneath tillage land. Sci. Total Environ. 438:144–153. doi:10.1016/j.scitotenv.2012.08.043
Rawls, W.J., A. Nemes, and Y.A. Pachepsky. 2004. Effect of soil organic carbon on soil hydraulic properties. Develop. Soil Sci. 30:95–114. doi:10.1016/S0166-2481(04)30006-1
Reynolds, W.D., D.E. Elrick, E.G. Youngs, A. Amoozegar, H.W.G. Booltink, and J. Bouma. 2002. Saturated and field-saturated water flow parameters. In: J.H. Dane and G.C. Topp, editors, Methods of soil analysis. Part 4. SSSA Book Ser. 5. SSSA, Madison, WI. p. 797–801.
Rorick, J.D., and E.J. Kladivko. 2017. Cereal rye cover crop effects on soil carbon and physical properties in southeastern Indiana. J. Soil Water Conserv. 72:260–265. doi:10.2489/jswc.72.3.260
Ruis, S.J., H. Blanco-Canqui, P.J. Jasa, R.B. Ferguson, and G. Slater. 2017. Can cover crop use allow increased levels of corn residue removal for biofuel in irrigated and rainfed systems? BioEnergy Res. 10:992–1004. doi:10.1007/s12155-017-9858-z
SAS Institute Inc. 2017. SAS 9.1.3 Documentation. Available online at: http://support.sas.com/documentation/onlinedoc/91pdf/index_913.html (accessed 1 Mar. 2017).
Saxton, K.E., and W.J. Rawls. 2006. Soil water characteristic estimates by texture and organic matter for hydrologic solutions. Soil Sci. Soc. Am. J. 70:1569–1578. doi:10.2136/sssaj2005.0117
Shapiro, C.S., L. Johnson, A.M. Schmidt, and R.K. Koelsch. 2006. Determining crop available nutrients from manure. NebGuide G1335. University of Nebraska-Lincoln Extension. Available online at http://extensionpublications.unl.edu/assets/pdf/g1335.pdf (accessed 8 Feb. 2016).
Soil Survey Staff, Natural Resources Consservation Service, United States Department of Agriculture. 2017. Web soil survey. Available online https://websoilsurvey.sc.egov.usda.gov/
Steele, M.K., F.J. Coale, and R.L. Hill. 2012. Winter annual cover crop impacts on no-till soil physical properties and organic matter. Soil Sci. Soc. Am. J. 76:2164–2173. doi:10.2136/sssaj2012.0008
Tormena, C.A., D.L. Karlen, S. Logsdon, and M.R. Cherubin. 2017. Corn stover harvest and tillage impacts on near-surface soil physical quality. Soil Tillage Res. 166:122–130. doi:10.1016/j.still.2016.09.015
Unger, P.W., and M.F. Vigil. 1998. Cover crop effects on soil water relationships. J. Soil Water Conserv. 53:200–207.
USDA. 2013. Farm and ranch irrigation survey (2013) Washington, DC. Available at: www.agcensus.usda.gov/Publications/2012/Online_Resources/Ag_Census_Web_Maps/Overview/(Accessed: 2 June 2018).
Villamil, M.B., G.A. Bollero, R.G. Darmody, F.W. Simmons, and D.G. Bullock. 2006. No-till corn/soybean systems including winter cover crops. Soil Sci. Soc. Am. J. 70:1936–1944. doi:10.2136/sssaj2005.0350
Wegner, B.R., S. Kumar, S.L. Osborne, T.E. Schumacher, I.E. Vahyala, and A. Eynarde. 2015. Soil response to corn residue removal and cover crops in eastern South Dakota. Soil Sci. Soc. Am. J. 79:1179–1187. doi:10.2136/sssaj2014.10.0399
Wienhold, B.J., M.F. Vigil, J.R. Hendrickson, and J.D. Derner. 2018. Vulnerability of crops and croplands in the US Northern Plains to predicted climate change. Clim. Change 146:219–230. doi:10.1007/s10584-017-1989-x
Wortmann, C.S., C.A. Shapiro, and M.R. Schmer. 2016. Residue harvest effects on irrigated, no-till corn yield and nitrogen response. Agron. J. 108:384–390. doi:10.2134/agronj2015.0361