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ABSTRACT

Residue management with cover crops (CC) can conserve soil moisture and thus has a potential to increase crop yield, but its effectiveness varies significantly by region and cropping system management. A study was conducted at Brookings, SD, on fine-silty, mixed, superactive, frigid, Calcic/Pachic Hapludolls soils to understand the impact of CC and crop residue on soil properties and soil-water dynamics for soybean (*Glycine max* L.) crop grown after corn (*Zea mays* L.). The site had two crop residue treatments (residue returned [RR] and residue not returned [RNR]) under a no-till corn–soybean rotation. Each residue returned treatment was later subdivided to include CC and no CC (NCC) treatments. Results from this 3 yr (2014, 2015, and 2016) study showed that RR (1.30 Mg m⁻³) had 7% lower bulk density (BD) compared to the RNR (1.40 Mg m⁻³). Soil organic carbon (SOC) was 22% higher under RR (26.2 g kg⁻¹) compared to RNR (21.5 g kg⁻¹). Soil water infiltration was 66% higher under RR (108 mm h⁻¹) compared to RNR (64.8 mm h⁻¹). Similarly, soil water infiltration in CC treatment (111 mm h⁻¹) was 80% higher compared to NCC (61.7 mm h⁻¹). The RR with CC treatment increased soil volumetric water content and soil water storage. Overall, the CC increased soybean yield by 14% compared to NCC. Data from this study suggest that the use of CC with RR are beneficial for improving soil properties, conserving soil moisture and enhancing crop yield.

Core Ideas

- Residue returned increased organic carbon and reduced bulk density compared to residue not returned.
- Residue returned increased water retention and infiltration compared to residue not returned.
- Residue returned and cover crop increased soil volumetric water content and water storage.
- Cover crop reduced bulk density and increased water infiltration compared with no cover crop.
- Cover crop increased the soybean yield by 14% compared with no cover crop.

CROP RESIDUE removal has been increasing in recent years due to its demand for biofuel production and for short-term economic benefits to farmers (Muth and Bryden, 2013). It is estimated that over 207 million metric tons of corn (*Zea mays* L.) biomass will be removed for biofuel production by 2030 (Muth et al., 2013). However, the increasing rate of residue removal is estimated to create a threat to soil productivity (Mann et al., 2002; Muth and Bryden, 2013). Therefore, there was increased interest of retaining crop residue and use of cover crops (CC) for enhancing soil water dynamics (Blanco-Canqui and Lal, 2009b; Blanco-Canqui et al., 2015; Johnson et al., 2016). Removal of crop residue reduces soil organic carbon (SOC), and impacts soil productivity. However, the impacts of residue removal rates on soils depend on certain factors such as soil texture, soil topography, initial contents of SOC, tillage, and cropping system (Blanco-Canqui et al., 2013).

Water is the most limiting factor for crop production in regions where either irrigation is not available or precipitation is limited (Das et al., 2017). Water stored in the soil profile helps to fulfill the water requirement for following crop in the rotation. Corn residue left behind after corn harvest helps to conserve water in soil (Iqbal et al., 2013) and plays an important role in water conservation and hence increase grain yields where irrigation or precipitation is a limiting factor in crop production (Van Donk et al., 2010; VanLoocke et al., 2012).

The long-term adoption of CC could negate the adverse effects of residue removal and increase SOC and improve soil water dynamics, eventually improving crop production and soil productivity (Basche et al., 2016a; Basche et al., 2016b; Kahimba et al., 2008). A study by Chahal and Van Eerd (2018) showed that cover crop increased SOC concentrations by 8.4 to 9.3% and crop yield by 7.9 to 22% compared with no cover crop treatment. Basche and DeLonge (2017) showed that adoption of CC for more than 10 yr improved soil hydrological properties

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Abbreviations: BD, bulk density; CC, cover crop; NCC, no cover crop; RNR, residue not returned; RR, residue returned; SOC, soil organic carbon; SPR, soil penetration resistance; SWR, soil water retention; SWS, soil water storage; TC, total carbon; TN, total nitrogen; VWC, volumetric water content.

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such as total porosity and water retained at field capacity. Chu et al. (2017) also observed that CC increased soybean yield and gravimetric soil water content after 3 yr of CC practice. Improved soil water management practices can reduce evaporation and runoff, which has positive impact on crop production (Jägermeyr et al., 2016). In some cases, cover crops have been shown to reduce water availability for the following cash crop reducing crop yield (Nielsen et al., 2016; Unger and Vigil, 1998). Conversely, many researchers have shown that the residue left after termination of cover crops helps to store more water in the soil profile (Alliaume et al., 2014; Basche et al., 2016b).

There are many unanswered questions on the significance of adopting CC and the rate of crop residue removal and their subsequent impacts on soils and crop yield in the upper US Great Plains. Therefore, this study was conducted to better understand the impact of crop residue and cover crops on soil water dynamics and soil properties. Specific objectives were to analyze the impacts of corn crop residue and cover crops on soil organic carbon and hydrological properties, and to assess the interaction between corn crop residue removal and CC on soil moisture, soil water storage, and soybean yield.

MATERIALS AND METHODS

Experimental Design and Field Management

The study was conducted at the USDA–ARS North Central Agricultural Research Laboratory, located in Brookings, SD (46°19' N, 96°46' W). Soil types of the study area were Kranzburg–Brookings silty loam complex; Kranzburg (fine-silty, mixed, superactive, frigid, Calcic Hapludolls) and Brookings (fine-silty, mixed, superactive, frigid Pachic Hapludolls). The experiment site was initiated in spring of 2000 under a no-till corn and soybean (*Glycine max* L.) rotation. Before establishing this experiment, the study area was continuously cropped with alfalfa (*Medicago sativa* L.) from 1995 to 1999. Initial bulk density, SOC and pH at 0–5 cm depth were 1.35 Mg m⁻³, 27.8 g kg⁻¹, and 6.7, respectively with 47% sand, 6% clay and 47% silt. Two residue removal treatments that include residue returned (RR) and residue not returned (RNR) were established with three replicates in a randomized complete block design in the year 2000. In RR treatment, after grain harvesting all the remaining plant material was left in the surface. However, in RNR treatment, corn stalks of 0.15 m above the ground were left and all other corn biomass were removed. The average amount of C returned was 6.87 and 0.21 Mg C ha⁻¹ for the RR and RNR treatments, respectively (Hammerbeck et al., 2012). In fall 2005, two cover crop (CC) treatments; CC and no CC (NCC) were integrated into the overall design, adjusting the experimental design from a randomized complete block design to a split-plot design with three replications. Residue removal treatments were applied to the main plots and cover crops to the subplots. In RR treatment, only the grain was harvested and all the crop residue was left on the soil surface. However, in RNR treatment, all crop residue above 0.15 m from the ground was removed. The CC treatments consisted of a mixture of winter rye (*Secale cereale* L.) and hairy vetch (*Vicia villosa* L.) were planted after the corn harvest, and only hairy vetch was planted after the soybean harvest. Individual plot dimensions were 30 × 30 m. Additional details about the experimental site can be found in previous publications (e.g., Hammerbeck et

al., 2012; Olson et al., 2010; Stetson et al., 2012). Data for this study was collected from 2014 through 2016.

Corn hybrid Viking 087–80N and soybean variety Hefty H01R4 were seeded at the rate of 81,628 seeds ha⁻¹ and 350,554 seeds ha⁻¹, respectively, using a Kinze 3400, with 50.8 cm row spacing. The mixture of CC (winter rye and hairy vetch) was seeded at the rate of 31.75–34.20 kg ha⁻¹. Before crop emergence, herbicides Sharpen (saflufenacil 29.74% a.i. 219 mL ha⁻¹), Clarity (diglycolamine salt of 3, 6-dichloro-o-anisic acid 41.9% a.i. 1.16 L ha⁻¹), Roundup Weathermax (glyphosate 48.8% a.i. 1.625 L ha⁻¹) and Dual II Magnum (s-metolachlor 82.4% a.i. [1.16 L ha⁻¹]) were applied. After the crop emergence herbicides Cadet (fluthiacet-methyl 10.3% a.i. 1.23 L ha⁻¹) and Select Max (clethodim 12.6% a.i. 1.18 L ha⁻¹) were applied.

Soil Sampling and Analysis

Two intact soil cores (5 cm diameter × 5 cm length) per plot were collected on 22 Aug. 2014 and 23 July 2015 from 0–5 and 5–15 cm depths to measure total carbon (TC) and total nitrogen (TN). In the laboratory, soils from each core were air-dried, and dry samples were sieved through a 2-mm screen and processed for TC and TN. The TC and TN were analyzed using TruSpec CHN analyzer (LECO Corporation, St. Joseph, MI). In this study, soil inorganic carbon was found below detection levels, therefore, TC was considered as SOC for analyses purposes. Soil penetration resistance (SPR) was measured for 0–5 cm and 5–15 cm depths using Eijelkamp-type hand penetrometer (Herrick and Jones, 2002). Five SPR readings in each plot were taken and the average value was used to represent SPR of each plot. Soil sample was also collected from the same depths at the time of SPR measurements for measuring the moisture content, and this moisture data was used to adjust the SPR using the relationship developed by Busscher and Bauer (2003).

In addition, intact core samples from 0–5 and 5–15 cm were also collected to determine bulk density (BD) and soil water retention (SWR). Two soil cores from each plot in every replication were collected, labeled and sealed in plastic bags, and the extra soil from the intact cores was trimmed and removed from the core. The BD was calculated by dividing the oven-dried soil sample with the volume of soil core (Grossman and Reinsch, 2002). The SWR was measured for the 0–5 and 5–15 cm depths. A cheese cloth was fixed at the bottom of intact soil cores, and these cores were prewetted by capillarity with water for 24 to 48 h. The SWR was determined at seven matric potentials (Ψ_m): a tension table method was used for five soil water potentials (0, -0.4, -1.0, -2.5, and -5.0 kPa) (Amoozegar and Wilson, 1999), but the pressure plate methods was used for the two soil water potentials (-10.0 and -30.0 kPa) (Klute, 1986). Soil water content (g g⁻¹) was determined gravimetrically by oven-drying the soil samples at 105°C for 48 h. The conversion of gravimetric water content methods to volumetric water content (θ , m³ m⁻³) was based on the bulk density of the soil samples.

Soil infiltration rate (q_s) was measured in August 2014 and late June 2015 using a double-ring infiltrometer (ring of 30-cm outer × 20-cm inner diameter × 20 cm height) using a constant-head method (Reynolds et al., 2002). Two Infiltration measurements per plot were conducted for all the plots, until a steady state was achieved. Soil samples were collected for the analysis of

Table 1. Soil organic carbon (SOC), total nitrogen (TN), and soil penetration resistance (SPR) as influenced by residue returned and residue not returned, and cover crops for the 0–5 and 5–15 cm depths under soybean phase of corn–soybean rotation.

Treatment	Depths (cm)							
	0–5		5–15		0–5		5–15	
	SOC		TN		SPR			
	g kg ⁻¹		g kg ⁻¹		MPa			
Residue								
RR†	26.2a‡	21.0a	2.14a	1.75a	2.23b	2.37b		
RNR	21.5b	19.8a	1.83b	1.68a	2.77a	3.01a		
Cover crop								
CC	24.0a	20.6a	2.00a	1.73a	2.24b	2.46b		
NCC	23.8a	20.2a	1.98a	1.71a	2.76a	2.92a		
	Analysis of variance (<i>P</i> > <i>F</i>)							
Residue (R)	<0.01	0.184	<0.01	0.18	0.009	0.001		
Crop (C)	0.84	0.689	0.82	0.68	0.01	0.01		
R × C	0.06	0.326	0.054	0.32	0.07	0.03		

† RR, residue returned; RNR, residue not returned; CC, cover crop; NCC, no cover crop.

‡ Means values followed by different letters within a column for different treatments are significantly different at *P* < 0.05.

initial gravimetric soil moisture content next to the place where infiltration measurements were conducted.

Soil samples were collected routinely to analyze for soil moisture content throughout the growing season from May through October 2016. Two soil samples per plot were collected with a standard hand held sampling auger from 0–5, 5–15, 15–30, and 30–45 cm depths. Soil water storage was determined for upper 0–45 cm depth as more than 90% of active roots were located at this depth (Steduto, 2012). Soil samples were immediately weighed and placed in an oven to dry at 105°C for 48 h to measure gravimetric soil water content. Soil water storage was calculated using the equation as shown below:

$$W = \sum_{i=1}^n \left(d_i \times \frac{\rho_i}{\rho_w} \times w_i \right) \times 10$$

where, d_i = depth interval for soil samples (cm), ρ = soil bulk density (g cm⁻³), ρ_w = density of water (g cm⁻³), w_i = gravimetric water content (g g⁻¹), i refers to soil layers, and n to the number of soil layers. The units for water storage (W) was mm.

Grain yields were measured by harvesting 15 m two central rows of each plot with a Massey Ferguson MF 8–XP research plot combine (Kincaid Equipment Manufacturing, Haven, KS). The grain yield was adjusted to 13% seed moisture content.

Statistical Analysis

Statistical analysis of crop residue returned (RR) and cover crop (CC) effects on the selected soil properties for each depth and year, and soybean yield in 2016 were obtained using pairwise differences method to compare least-squares means estimated by mixed models using the GLIMMIX procedure in SAS9.4 (SAS, 2013), where RR, CC, RR×CC were considered as fixed effects and replication as the random effect. The analysis of variance (ANOVA) was used to test the fixed effects of RR and CC on soil properties based on the mixed models. If the effect of RR×CC on a parameter was significant, the data were separately analyzed for each RR and CC. Data were

Table 2. Interaction effects of residue and cover crops on soil penetration resistance (SPR) for 5–15 cm depth.†

Treatment	SPR	
	CC	NCC
	MPa	
RR	2.33aA‡	2.41bA
RNR	2.57aB	3.43aA

† RR, residue returned; RNR, residue not returned; CC, cover crop; NCC, no cover crop.

‡ Average value followed by same lowercase letter within a column and by capital letter within each row are not significantly different at *P* < 0.05.

transformed when necessary, and the transformation was determined using the Box-Cox method (Box and Cox, 1964, 1981). Statistical differences were declared significant at $\alpha = 0.05$ level.

RESULTS AND DISCUSSION

Soil Organic Carbon, Total Nitrogen, and Soil Penetration Resistance

The SOC under RR (26.2 g kg⁻¹) was 21.8% higher as compared to that under RNR (21.5 g kg⁻¹) for the 0–5 cm. Cover crop did not impact SOC and TN at both the soil depths (Table 1). The TN under RR treatment (2.14 g kg⁻¹) was 17% higher as compared to that under RNR (1.83 g kg⁻¹). The interactions of residue by cover crop on SOC and TN were not significant at any depth. A study that was conducted in Ohio on silt loam and clay loam soils with 0, 25, 50, 75, and 100% of residue removal treatments found higher SOC with a higher residue retention rate in silt loam soil under long-term no-till continuous corn (Blanco-Canqui and Lal, 2007). Another study conducted in Brookings, SD, with similar soil type showed that increase in SOC was due to the retaining crop residue in the soil surface, as microbes break down the residue and store C in the soil surface (Stetson et al., 2012). In addition to SOC, the crop residue removal rate also impacted the TN. Blanco-Canqui and Lal (2009a) reported that complete removal of residue under continuous no-till corn reduced the TN pool by 0.82 Mg ha⁻¹ in silt loam soils. Similarly, a multi-location study conducted at 28 locations in the corn belt region of the United States showed that with high removal of corn stover (7.2 Mg ha⁻¹), 47 kg ha⁻¹ N was removed while moderate removal of corn stover (3.9 Mg ha⁻¹) removed 24 kg ha⁻¹ N (Karlen et al., 2014). Removal of residue directly reduces the amount of N added to the soil. In the present study, CC did not impact the SOC at any depth. Similar results were observed in previous studies on a similar site (e.g., Wegner et al., 2015). Similarly, another study showed that CC did not increase SOC, however, they minimized the SOC loss (e.g., Olson et al., 2010). In some situations, it takes a few years before cover crops started showing beneficial impacts on SOC and other soil properties, hence long-term assessment is needed (Blanco-Canqui et al., 2014).

Residue removal and CC treatments reduced the SPR at 0–5 and 5–15 cm depths (Table 1). At the 0–5 cm depth, the mean SPR for the RR treatment (2.23 MPa) was 24% lower as compared to the RNR (2.77 MPa). Similarly, mean SPR for CC (2.24 MPa) was 23% lower compared with the NCC (2.76 MPa). No significant interactions were observed between residue removal and CC on SPR at 0–5 cm depth. However, for the 5–15 cm depth, interactions of the residue by CC treatments were significant (*P* < 0.03; Tables 1 and 2). Data showed that RR with

Table 3. Soil bulk density (BD) as influenced by residue returned and residue not returned and cover crops for the 0–5 and 5–15 cm depths under soybean phase of corn–soybean rotation for 2014, 2015, and 2016.

Treatment†	2014		2015		2016	
	Depth (cm)					
	0–5	5–15	0–5	5–15	0–5	5–15
	BD (Mg m ⁻³)					
Residue						
RR	1.41a‡	1.42a	1.30b	1.37a	1.29b	1.34b
RNR	1.42a	1.44a	1.40a	1.37a	1.38a	1.39a
Cover Crop						
CC	1.40a	1.43a	1.30b	1.36a	1.32a	1.33b
NCC	1.43a	1.43a	1.39a	1.38a	1.35a	1.40a
	Analysis of variance (<i>P</i> > <i>F</i>)					
Residue (R)	0.68	0.62	0.001	0.83	0.001	0.006
Crop (C)	0.30	0.92	0.005	0.13	0.11	0.002
R × C	0.04	0.40	0.08	0.25	0.08	0.23

† RR, residue returned; RNR, residue not returned; CC, cover crop; NCC, no cover crop.

‡ Means values followed by different letters within a column for different treatments are significantly different at *P* < 0.05.

NCC treatment (2.41 MPa) had significantly lower SPR (by 42%) compared with RNR with NCC treatment (3.43 MPa). Similarly, RNR with CC treatment (2.57 MPa) had significantly lower SPR (by 33%) compared with RNR with NCC treatment (3.43 MPa). Our results showed that RR reduced the SPR value in the 0–5 cm depth. Similar results were observed in a study conducted at Ames, IA, where high stover harvest increased the SPR value by 39% compared with no stover removal (Tormena et al., 2017). Similar results were also observed in a long-term study conducted in Ohio on silt loam soil in which the SPR value increased by 17 to 24% when >50% of residues were removed compared to no residue removal (Blanco-Canqui and Lal, 2007). However, these results did not support the study conducted in Chazy, NY, where residue harvest did not impact the SPR compared to no harvest of residue (Moebius-Clune et al., 2008). Our results showed that CC reduced SPR value by 23% compared with that under NCC treatment. Similar results were observed in a study conducted in Illinois on silty clay loam (Acuña and Villamil, 2014). The RR with CC increase the accumulation of SOC and hence decrease the SPR.

Soil Bulk Density

In 2014, the BD under RR and RNR was not significantly different for the 0–5 cm depth (Table 3). However, the interactions between cover crops and crop residue were significant at 0–5 cm depth (Table 4). In 2015, the BD was impacted by the residue removal as well as by cover crops for 0–5 cm depth. The RR treatment (1.30 Mg m⁻³) had 7.6% lower BD compared to RNR (1.40 Mg m⁻³). Similarly, CC (1.30 Mg m⁻³) had 7% lower BD compared to NCC treatment (1.39 Mg m⁻³). However, no significant impact of residue removal and CC was observed for the 5–15 cm depth. In addition, no interactions were observed between the residue removal and CC treatments at both soil depths. A similar trend was observed in 2016. The RR treatment (1.29 Mg m⁻³) had a 7% lower BD compared to the RNR treatment (1.38 Mg m⁻³). However, significant impacts of CC and NCC treatments were not observed. For the 5–15 cm depth, residue removal, as well as cover crops significantly impacted

Table 4. Interaction effects of residue and cover crops on bulk density (BD) for 0–5 cm depth in 2014.†

Treatment	BD	
	CC	NCC
	Mg m ⁻³	
RR	1.35aB‡	1.46aA
RNR	1.44aA	1.40aA

† RR, residue returned; RNR, residue not returned; CC, cover crop; NCC, no cover crop.

‡ Average value followed by same lowercase letter within a column and by capital letter within a row are not significantly different at *P* < 0.05.

the BD. The BD for the RR treatment (1.34 Mg m⁻³) was 3.7% lower compared with the RNR (1.39 Mg m⁻³). The BD for the CC treatment (1.33 Mg m⁻³) was 5% lower compared to the NCC (1.40 Mg m⁻³). However, no interactions between the residue removal and cover crops treatments were observed in 2016. Data from a study conducted in Rosemont, MN, and Ames, IA, showed 7% higher BD with high residue removal rate compared to no harvest of residue (Dolan et al., 2006; Tormena et al., 2017). The present study showed that CC reduced BD for the 0–5 cm depth. Cover crops protect the soil from compaction, as well as increase SOC, which result in lower BD under cover crops compared with no cover crops (Dolan et al., 2006; Tormena et al., 2017). In the year 2016, we observed lower BD at both soil depths, which was probably due to root contributions. In 2016, it was observed that RR reduced BD by 7% and 3.7% for depth 0–5 and 5–15 cm, respectively, compared with BD under RNR treatment. Similar results were observed in another study conducted at Chazy, NY, with silt loam soil under corn production which showed that stover-returned had 5% lower BD compared to stover-harvested (Moebius-Clune et al., 2008).

Soil Water Retention

For 2014, the RR treatment had a significantly higher soil water retention (SWR) compared with that under RNR at all seven pressures for the 0–5 cm depth (Fig. 1A). For 5–15 cm depth, the RR treatment had significantly higher SWR compared with RNR at 0 and –0.4 kPa (Fig. 1B). For the CC treatments, the CC had significantly higher SWR as compared to that under NCC at 0 kPa for 0–5 cm depth (Fig. 1C). However, no significant differences were observed for CC treatments at any pressure for the 5–15 cm depth (Fig. 1D). For 2015, SWR for RR treatment was significantly higher at –2.5 kPa, –5.0 kPa, –10.0 kPa, and –30.0 kPa for the 0–5 cm depth compared with the RNR treatment (Fig. 1E). For 5–15 cm depth, RR treatment had a higher SWR than that under RNR only at 0 and –0.4 kPa (Fig. 1F). However, no significant differences were observed on SWR between the CC treatments at the 0–5 cm (Fig. 1G) and 5–15 cm depth (Fig. 1H).

Data showed that SWR was higher with RR due to higher SOC and lower BD in this treatment compared to that under RNR. A similar finding was observed in a study conducted in Ohio, where RR had 20–50% more water retained compared to that under RNR treatment (Blanco-Canqui and Lal, 2007). A positive relationship between SOC and SWR was reported by Rawls et al. (2003). Cover crop treatments did not affect SWR at all pressures except at 0 kPa in 2014. The previous study conducted on the same experimental plots showed that there was no impact of cover crops on SWR (Wegner et al., 2015). In

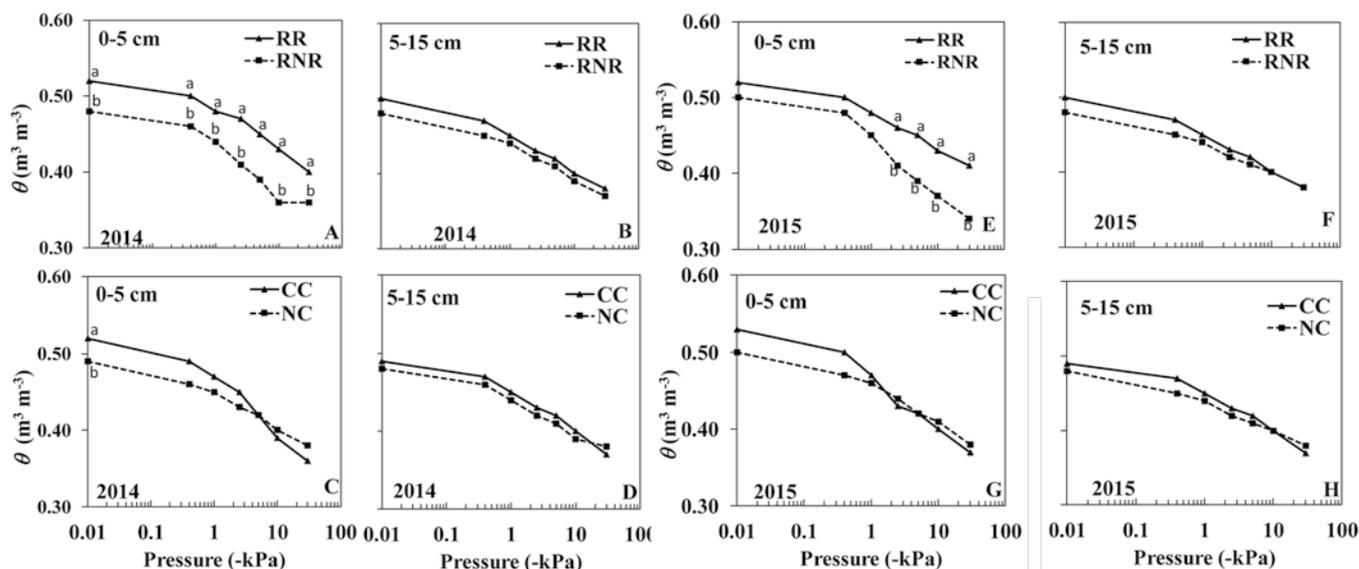


Fig. 1. Soil water retention as influenced by residue returned (RR) and residue not returned (RNR), and cover crops for the 0–5 and 5–15 cm depths under soybean (9 mo. following residue removal) phase of corn–soybean rotation for 2014 (A–D) and 2015 (E–H). The small different letters shown in the figures represent the significant differences in soil water content at different soil water pressures between RR and RNR (A and E), and cover crops and no cover crops (C). No letters represent the non-significant differences.

that case, the nonsignificant impact of CC could have been due to low CC biomass. Present and previous studies (e.g., Wegner et al., 2015) on the same experimental plot showed that cover crops did not impact SOC.

Infiltration Rate

In 2014, the residue removal significantly impacted the q_s (Fig. 2). The RR had 67% higher q_s as compared to that under the RNR treatment. Similarly, the CC treatment significantly impacted the q_s . The CC treatment (111 mm h⁻¹) had 80% higher q_s compared with NCC treatment (61.7 mm h⁻¹). Similar results were observed in 2015 (Fig. 2). The RR (87 mm h⁻¹) had 22.5% higher q_s compared with that under RNR treatment (71 mm h⁻¹). Similarly, the q_s under CC (88.5 mm h⁻¹) was 27% higher than the NCC treatment (69.6 mm h⁻¹). Data from the present study showed that the q_s under RR was 1.6 and 1.2 times greater compared with RNR for 2014 and 2015, respectively. Similar results were observed in a study conducted at Swan Lake research farm near Morris, MN, where full return of residue (>7 Mg ha⁻¹) significantly increased q_s by two times as compared with that under less return of residue (<2 Mg ha⁻¹) (Johnson et al., 2016). Similarly, another study conducted at Ohio showed that when the residue cover was 100%, the q_s was four times greater than when the residue cover was none (0%) (Blanco-Canqui and Lal, 2007). Crop residue increases SOC concentration in soil, which stabilizes soil aggregates, reduces soil bulk density, and improves soil porosity which further enhances soil hydrological properties (Blanco-Canqui and Benjamin, 2013; Hammerbeck et al., 2012; Johnson et al., 2016). Data from the present study showed that q_s with CC were 1.8 and 1.3 times greater compared with the NCC for 2014 and 2015, respectively. The possible reason for the higher q_s with CC was due to improved soil structure with more and continuous macro and micro pores, root channels, and less compaction. The previous study on the same experimental plots showed greater stability of soil aggregates and smaller erodible fraction for the CC

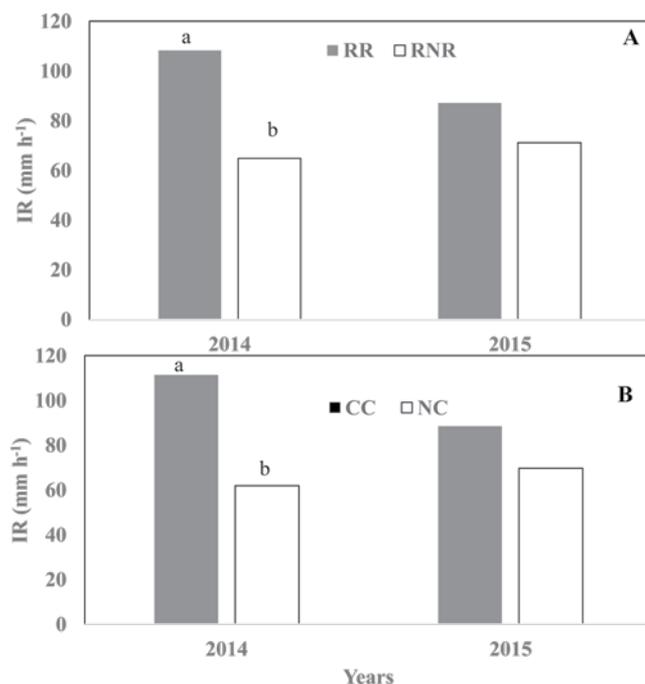


Fig. 2. Soil water infiltration rate (IR) as influenced by residue returned (RR) and residue not returned (RNR), and cover crops under soybean (9 months following residue removal) phase of corn–soybean rotation for 2014 and 2015. Small different letters represent the significant differences in infiltration rate are due to residue removal (A) and cover crops (B) for each year.

treatments compared with the NCC treatments (Osborne et al., 2014). Another study conducted in clay loam soil in San Joaquin Valley, CA, showed that infiltration with CC was 2.8 and 2.2 times higher compared with the NCC treatment (Mitchell et al., 2017). Overall, data from the present study suggested that RR and CC treatments resulted in the higher SOC and SWR, lower BD and SPR, which overall plays significant roles in increasing q_s as compared to RNR and NCC treatments.

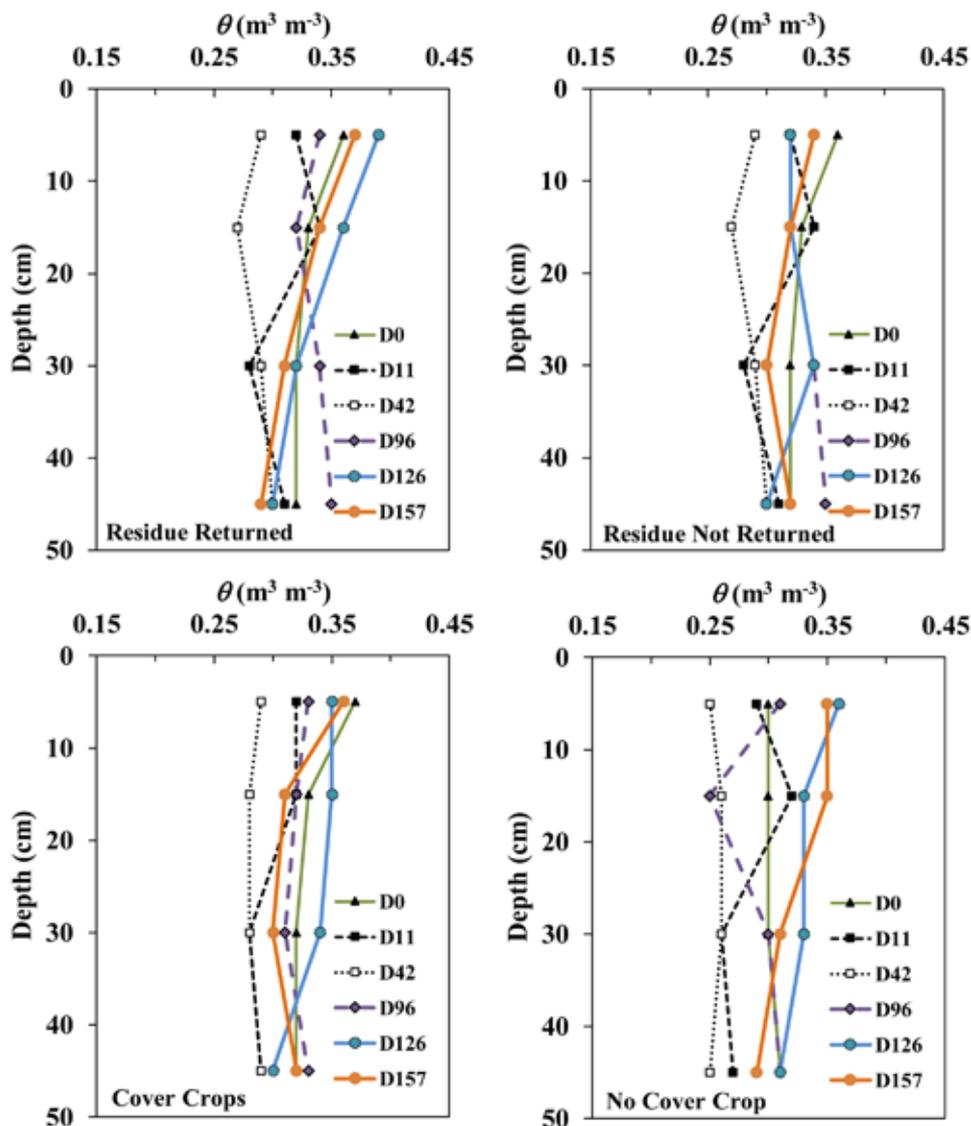


Fig. 3. Volumetric water content (θ) as influenced by residue returned (RR) and residue not returned (RNR), and cover crops for the 0–5, 5–15, 15–30 and 30–45 cm depths under soybean. The θ of samples collected on 0 d (before planting); 11, 42, 96, 126 d (after planting); and 157 d (after harvesting sample) are represented as D0, D11, D42, D96, D126, and D157, respectively.

Volumetric Water Content and Soil Water Storage

Volumetric water content (VWC, θ) of samples collected on 0 d (before planting sample), 11, 42, 96, 126 d (after planting samples), and 157 d (after harvesting sample) from 0–5, 5–15, 15–30, and 30–45 cm depths are presented in Fig. 3 where 0, 11, 42, 96, 126, and 157 d sampling are represented as D0, D11, D42, D96, D126, and D157, respectively. In general, the plots with RR and CC treatment had higher θ compared with RNR and NCC treatment respectively (Fig. 3). At 0–5 cm depth, θ under CC was 16% higher for 42-d sampling, compared with that under NCC treatment. For depth 5–15 cm, θ under RR treatment was 23% higher compared with RNR treatment for 96-d sampling. Similarly, θ for CC treatment was 28% higher compared with NCC treatment for 96-d sampling. For depth 15–30 cm, the θ for RR treatment was 26% higher compared with RNR treatment at 96-d sampling. However, no significant impact of cover crops was observed in this depth.

Present data showed that there was a significant impact of RR treatment compared to RNR treatment on θ . Govaerts

Table 5. Average monthly temperature and monthly precipitation at the experimental site.

Month	Temperature	Precipitation
	°C	mm
Apr.	7.7 (1.2)†	55.6 (–0.1)
May	14.1 (0.6)	69.5 (–14.2)
June	21.0 (2.0)	95.2 (–13.8)
July	21.4 (0.0)	154.8 (71)
Aug.	20.9 (0.9)	119.3 (39.5)
Sept.	16.44 (1.24)	102.8 (24.8)
Oct.	9.6 (1.9)	48.4 (3.7)
Avg/total	17.0	651

† The numbers in parenthesis is the deviation from 30 yr average.

Table 6. Soil water storage (SWS) as influenced by residue returned and residue not returned, and cover crops for the 0–5 and 5–15 cm depths under soybean (9 mo following residue removal) phase of corn–soybean rotation for 2016.

Treatment†	Days after planting					
	0	11	42	96	126	157
	0–5 cm depth					
	SWS (mm)					
Residue						
RR	23.0a‡	20.5a	18.6a	21.9a	25.2a	23.9a
RNR	21.4b	20.0a	17.6a	21.1a	22.0b	23.5a
Cover crops						
CC	24.4a	21.2a	19.4a	20.4a	23.2a	23.6a
NCC	20.1b	19.2a	16.7a	22.7a	24.0a	23.8a
	Analysis of variance ($P > F$)					
Residue (R)	0.04	0.79	0.47	0.60	0.04	0.72
Crop (C)	0.0001	0.25	0.08	0.17	0.54	0.89
R×C	0.002	0.54	0.39	0.52	0.02	0.15
	5–15 cm depth					
Residue						
RR	44.1a	44.8a	36.0a	43.0a	48.2a	45.5a
RNR	41.2a	41.8a	38.1a	35.6b	44.9a	45.2a
Cover crops						
CC	43.1a	42.4a	37.0a	43.1a	46.4a	41.9b
NCC	42.1a	44.2a	37.1a	35.5b	46.6a	48.8a
	Analysis of variance ($P > F$)					
Residue (R)	0.30	0.31	0.28	0.03	0.39	0.92
Crop (C)	0.70	0.52	0.97	0.02	0.95	0.03
R×C	0.79	0.26	0.25	0.07	0.54	0.22

† RR, Residue returned; RNR, Residue not returned; CC, cover crop; NCC, no cover crop.

‡ Means values followed by different letters within a column for different treatments are significantly different at $P < 0.05$.

et al. (2007) also reported higher soil moisture content when residues were retained on the soil surface compared to when the residue were removed. Preserving high moisture at surface depth was due to less evaporation and high SOC at surface depth (VanLoocke et al., 2012; Zhang, 1996). Present data showed fluctuation in soil moisture during planting through harvesting. A study conducted in Iowa concluded that the impact of cover crops on soil moisture depends on the biomass of cover crops (Daigh et al., 2014). The present study suggested that maximum retention of residue is required to maintain higher θ . The reason for higher θ in RR and CC treatment may be because of returning stover and adopting CC protects the aggregates from breakdown and improves soil physical and hydrological properties (Johnson et al., 2016; Osborne et al., 2014; Stetson et al., 2012).

Table 5 represent average monthly temperature and monthly precipitation on the experimental site for year 2016. Monthly cumulative temperature was generally similar to 30-yr monthly mean temperature. However, monthly average precipitation was higher during the month of July, August, and September. Thus, the conclusion made from this study represents such year with adequate rainfall. Tables 6 and 7 represent the soil water storage (SWS) data for the six sampling days, which include sampling before planting (d 0), and the samples taken 11, 42, 96, 126 d after planting and after harvesting sampling (d –157) from the depth 0–5, 5–15, 15–30, and 30–45 cm depth. In general, the plots under RR and CC treatment had higher SWS compared with RNR and NCC treatments, respectively. At the 0–5 cm

Table 7. Soil water storage (SWS) as influenced by residue returned and residue not returned, and cover crops for the 15–30 and 30–45 cm depths under soybean (9 mo following residue removal) phase of corn–soybean rotation for 2016.

Treatment†	Days after planting					
	0	11	42	96	126	157
	15–30 cm depth					
	SWS (mm)					
Residue						
RR	63.5a‡	56.0a	57.4a	68.0a	64.7b	62.7a
RNR	63.6a	55.8a	52.5a	57.0b	71.9a	63.1a
Cover crops						
CC	64.0a	56.9a	56.3a	61.4a	67.2a	59.8b
NCC	63.1a	54.8a	53.6a	63.6a	69.5a	66.0a
	Analysis of variance ($P > F$)					
Residue (R)	0.94	0.94	0.26	0.03	0.03	0.88
Crop (C)	0.64	0.53	0.53	0.59	0.39	0.04
R×C	0.55	0.65	0.13	0.52	0.07	0.97
	30–45 cm depth					
Residue						
RR	67.1a	65.3a	62.1a	73.3a	63.2a	60.4b
RNR	68.5a	54.1b	51.5b	63.7b	65.3a	69.0a
Cover crops						
CC	67.2a	59.4a	59.0a	68.6a	61.8a	66.0a
NCC	68.4a	60.1a	54.6a	68.4a	66.8a	63.4a
	Analysis of variance ($P > F$)					
Residue (R)	0.70	0.004	0.003	0.001	0.64	0.003
Crop (C)	0.73	0.76	0.09	0.90	0.30	0.18
R×C	0.73	0.53	0.06	0.04	0.60	0.60

† RR, residue returned; RNR, residue not returned; CC, cover crop; NCC, no cover crop.

‡ Means values followed by different letters within a column for different treatments are significantly different at $P < 0.05$.

depth, RR treatment increased SWS by 7 and 14.5% for the 0-d and 126-d sampling, respectively, compared to the RNR treatment. The interaction between residue by cover crops was significant for 0-d and 126-d sampling ($P < 0.05$; Table 6). For the 5–15 cm depth, SWS with RR treatment was significantly higher by 20.7% as compared to that under RNR treatment at 96-d sampling. No significant interaction between cover crops and crop residue was observed for this depth. For 15–30 cm depth, residue removal treatment significantly impacted SWS on 96-d and 126-d sampling. The SWS on RR treatment was 19% higher compared with RNR treatment at 96-d sampling. However, for 126-d sampling, the RNR had significantly higher SWS by 11% compared with that under RR treatments. Significant impact of CC treatment was observed on 157-d sampling. The NCC had significantly higher SWS by 10% compared with that under CC treatments. The interactions between residue and CC were not significant for this depth. For the 30–45 cm depth, significant impact of CC treatment was observed on 11-d, 42-d, and 157-d sampling. The SWS for RR treatment was higher by 20.7 and 20.5% compared with RNR treatment for 11 and 42-d sampling, respectively. However, for the 157-d sampling, the RNR had significantly higher SWS by 14% compared with RR treatment. No significant impact of cover crops was observed for this depth through the season. The interaction between residue and CC was significant ($P < 0.05$; Table 7) on 96-d sampling for 30–45 cm depth. Significant interactions were observed on 0 d for 0–5 cm depth and 126 d

Table 8. Interaction effects of residue and cover crops on soil water storage (SWS) under soybean (9 mo following residue removal) phase of corn–soybean rotation.†

Treatment	SWS					
	0 d		126 d		96 d	
	0–5 cm				30–45 cm	
	CC	NCC	CC	NCC	CC	NCC
RR	26.7aA‡	19.2aB	26.7aA	23.6aA	75.5aA	71.0aA
RNR	22.0bA	20.8aA	19.6aB	24.3aA	61.8bA	65.7aA

† RR, residue returned; RNR, residue not returned; CC, cover crop; NCC, no cover crop.

‡ Average value followed by same lowercase letter within a column and by capital letter within row are not significantly different at $P < 0.05$.

for 0–5 cm and 30–45 cm depth (Table 8). For 0-d sampling, the RR with CC treatments had significantly higher SWS (39%) compared to the RR with NCC treatment 0–5 cm depth. Similarly, the RR with CC treatments had 21% higher SWS compared under RNR with CC treatments. However, for 126-d sampling, the RNR with NCC had higher SWS by 24% compared with RNR with CC treatments for 0–5 cm depth. For 30–45 cm depth, the RR with CC treatments had significantly higher SWS by 22% compared with RNR with CC treatments.

Data from the present study showed that RR treatment had higher SWS compared to RNR treatments in 0–5 cm depth. Results corroborating these findings were observed in a study where the addition of mulch in no-till soybean cropping system increased mean seasonal soil water storage by 55 and 59 mm in years 2006 and 2007 respectively, compared to no mulch added (Obalum et al., 2011). Data from the present study showed that, in general, CC treatment has higher SWS compared with NCC treatments. Similar results were observed in another study conducted in Iowa where long-term (>14 yr) use of winter rye CC increased soil water storage (Basche et al., 2016b). Several previous studies showed that cover crops can reduce water availability for next crops in semiarid and water limited areas (Nielsen et al., 2015; Nielsen et al., 2016). However, another study conducted in Iowa showed that winter cover crops increased SWS during the drought of 2012 (Daigh et al., 2014). The interactions showed that, in general, RR with CC treatment increased SWS compared with RR with NCC. Similarly, SWS was higher under RR with CC compared with RNR with CC. However, on 126-d sampling RNR with NCC had 24% higher SWS. This inconsistent effects may have been due to seeding of cover crops. The 126-d samples were taken after the seeding of cover crops. Similar results were observed on the previous study, which showed that cover crops reduced SWS compared with no cover crop treatment (Gabriel et al., 2012; Nielsen et al., 2016). Another reason could be due to enough precipitation occur in the month of September. Rainfall during the month was above average which may fill soil profile in all CC, NCC, RR, and RNR plots. However, the present study was designed to observed impacts of cover crops on the soybean growing season. Our results indicate that cover crops did not negatively impact the SWS for the soybean growing season i.e., May through August sampling.

Soybean Yield

Residue removal and CC effects on soybean yield are presented in Table 9. No significant impacts of residue removal

Table 9. Grain yield as influenced by residue returned and residue not returned, and cover crops and no cover crop treatment under soybean (9 mo following residue removal) phase of corn–soybean rotation for 2016.

Treatment†	Grain yield kg ha ⁻¹
Residue	
RR	2708a‡
RNR	2738a
Cover crop	
CC	2906a
NCC	2540b
Analysis of Variance ($P > F$)	
Residue (R)	0.71
Crop (C)	0.003
R × C	0.38

† RR, Residue returned; RNR, Residue not returned; CC, cover crop; NCC, no cover crop.

‡ Means values followed by different letters within a column for different treatments are significantly different at $P < 0.05$.

treatment were observed on grain yield (Table 9). However, cover crops significantly impacted grain yield. There was an increase in soybean yield by 14% with CC treatment compared with that of NCC treatment. The interaction between cover crops and crop residue on grain yield were not statistically significant. A study conducted on Loess Plateau showed that the addition of leguminous CC increased wheat yield by 28% (Zhang et al., 2016). However, Kramberger et al. (2009) reported reduction of crop yield due to competition for water by cover crops, whereas Basche et al. (2016b) reported that long-term use of cover crops improved soil water dynamics. Data from the present study suggested that the use of cover crops has positive impacts on soil hydrological properties such as water infiltration and water retention, those eventually help to store more water in the soil profile. Additionally, improved soil aggregate size distribution and a lower erodible fraction can be beneficial in conserving the soil moisture, and enhancing the crop yield.

CONCLUSIONS

The Northern Great Plains region of the United States is very important for corn–soybean production, but very little is known about the impacts of cover crops and corn residues on soil properties. The present study was conducted to make a comprehensive understanding of the impacts of cover crops and crop residue on soil hydrological properties and soybean yield. Data showed that RR increased SOC and TN as compared to that under RNR at the 0–5 cm depth. Further, the incorporation of cover crops in RR treatment resulted in lower soil bulk density compared under RNR with NCC treatment for the 0–5 cm depth in 2014. The RR treatment reduced bulk density in 2015 compared to that under RNR. Soil bulk density was lower under RR compared with RNR for 0–5 and 5–15 cm depths in 2016 (after 16 yr of residue returned practice).

Soil water retention was higher under RR treatment as compared to RNR treatment in the 0–5 cm depth. The infiltration rate was 1.6 and 1.2 times higher in RR treatment compared with the RNR treatment in 2014 and 2015, respectively. Similarly, infiltration rate was 1.8 and 1.3 times higher in CC treatment compared with NCC treatment for 2014 and 2015, respectively. Volumetric water content and soil water storage

were, in general, higher under the RR treatment compared to RNR treatment. Similarly, volumetric moisture content and soil water storage were, in general, higher under the CC treatment compared to NCC treatment. However, the trend was not consistent from May through October sampling days. There was an increase in soybean yield by 14% with CC treatments compared with NCC treatment. However, no significant impact of residue removal treatment was observed on grain yield.

This study suggests that residue returned with incorporation of cover crops is beneficial for improving the soil hydrological properties compared to those with residue not returned without cover crop treatments.

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