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Impact of no-till, crop rotation, cover crop, and drainage on soil physical and hydraulic properties

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Abstract

Conservation agriculture and associated soil health practices potentially enhance soil resilience by improving the soil's physical, chemical, and biological properties and processes. This study assessed the impact of tillage (conventional tillage [CT] and no-till [NT]); crop rotation: 2-year corn (*Zea mays* L.)–soybean (*Glycine max* L.), 3-year corn–soybean–oat (*Avena sativa* L.), and 4-year corn–soybean–oat–wheat (*Triticum aestivum* L.)]; cover crops (cover crop [CC] and no cover crop [NC]); and drainage (tile drainage [TD] and without drainage [ND]) on soil organic matter (SOM), bulk density, wet aggregate stability (WAS), and field-saturated hydraulic conductivity (K_{fs}). Soil samples were collected over 2 years apart from five depths (0–10, 10–20, 20–30, 30–60, and 60–90 cm) and analyzed for SOM, bulk density, and WAS. In-situ infiltration tests were conducted in each plot to determine field-saturated hydraulic conductivity. This study showed that NT practice significantly increased SOM by 5.4%, WAS by 7.7%, and bulk density by 6.7% within 0–10 cm soil profile but decreased K_{fs} by 47.6% compared to CT through increased bulk density in the topsoil. NT increased SOM for every soil depth and, similarly, increased WAS for every depth but only statistically significant increases occurred at 0–10 cm and 60–90 cm. Further, higher crop diversity decreased bulk density and increased WAS. Nine years of CC and six years of tile drainage practices had no significant effect on SOM, bulk density, WAS, and K_{fs}.

1 | INTRODUCTION

Soil, water, and nutrients are essential components for a healthy plant community in most agroecosystems. Soil underpins this system as a properly functioning soil under effective management practices and provides resilience to plants against extreme weather events through the continued supply of water and nutrients under fluctuating conditions. Parent material, organic matter, and soil biology govern many critical functions within the soil system (Wander et al., 2019). Gradually, national and global leaders are focusing on soil health

Abbreviations: ACP, agricultural conservation practice; CC, cover crop; CT, conventional tillage; ND, without drainage; NT, no-till; SOM, soil organic matter; TD, tile drainage; WAS, wet aggregate stability.

practices to achieve a more sustainable agriculture system under different climate scenarios (Kassam et al., 2010).

Many agricultural practices can influence soil health. For example, soil disturbance through tillage has a large effect on numerous soil functions; however, reduced tillage practices generally improve soil health by preserving microbial community size and function (Zuber & Villamil, 2016). Moreover, minimum or zero tillage increases soil organic matter (SOM), enhances nutrient cycling, reduces bulk density (Sapkota et al., 2012), and builds soil structure (Pagliai et al., 2004). Over the last few decades, researchers have reported various changes to soil quality under no-till (NT) compared to conventional tillage (CT). For example, in long-term NT, bulk density in the surface soil was decreased along with increased soil organic carbon (Blevins et al., 1983; Rhoton, 2000). Likewise, NT increased soil aggregate stability by 19% for 0- to 2.5-cm soil depth after 4 years of practice (Rhoton, 2000). In contrast, Thomas et al. (2007) observed that after 9 years of NT practice, the bulk density was greater than CT; however, they found higher organic matter (organic carbon [C] and total nitrogen) and exchangeable potassium in the NT at 0- to 10-cm depth than under conventional and reduced tillage.

A well-designed crop rotation is one of the keys to soil health management strategy to cope with impending climatic change (Gaudin et al., 2015). Crop diversity nurtures a diverse range of soil flora and fauna and contributes to building soil structure, utilizing nutrients from different soil depths, and preventing pests and diseases. In a broader sense, diverse agricultural management practices impact different functions of soil's physical, chemical, and biological properties (Connolly, 1998; Franzluebbers et al., 2021; Jangid et al., 2008; Sapkota et al., 2012).

Similarly, cover crop (CC) practices have also been promoted as a sustainable strategy to improve soil health (Freidenreich et al., 2022) and are widely recommended by conservation specialists as a part of conservation agriculture to cover the soil with living mulch. CC adoption lags in the United States due to various factors (economical, biological, farm operation, farmers education, and government policy) even though CC practices contain many positive values for soil and environmental health (Sarrantonio & Gallandt, 2003). The benefits of CCs adoption include enhancing soil organic C (Blanco-Canqui et al., 2015), reducing soil erosion (Strock et al., 2004), improving subsurface tile water quality (Ruffatti et al., 2019), increasing infiltration rate (Blanco-Canqui, 2018), and reducing bulk density (Blanco-Canqui et al., 2011; Çerçioğlu et al., 2019). CC utilization can also improve soil hydraulic conductivity by leaving preferential water flow channels in the soil profile after CC roots degrade (Çerçioğlu et al., 2019). Some researchers reported that CC use increases field volumetric water content by an average of 20%–35% at the upper soil layer (0- to 20-cm depth; Blanco-Canqui et al., 2011; Calderon et al., 2016; Haruna & Nkongolo, 2015), organic matter content by 74% (Nieto et al., 2013), infiltration capacity by 14%–43% (Mailapalli et al., 2011), saturated hydraulic conductivity by 64% (Çerçioğlu et al., 2019), and decreased soil bulk density by 4%–5% (Blanco-Canqui et al., 2011).

Core Ideas

- Long-term no-till (NT) has a significant impact on soil physical and hydraulic properties.
- NT increased soil bulk density, soil organic matter (SOM), and wet aggregate stability (WAS) by 6.7%, 5.4%, and 7.7%, respectively, for 0- to 10-cm depth but decreased K_{fs} by 47.6% within profile than conventional tillage (CT).
- Compaction decreased at 0–10 cm in CT but increased within the 10–60 cm soil profile.
- NT with more diverse rotation and cover crop (CC) practices showed limited or no positive impact on K_{fs} for silt clay loam.
- CC and tile drainage(TD) had minimal impact on SOM, bulk density, WAS, and K_{fs} under silt clay loam in southeastern South Dakota.

Lastly, including tile drainage can create a better soil ecosystem: tile drainage reduces water logging in the root zone, increases root depth, and enhances crop growth by providing better aeration in the root zone (Kokulan, 2019; Skaggs et al., 1994). This makes the soil system more conducive for plant and microbe growth through better respiration capacity thanwithout drainage systems. In addition, the drier soil warms faster (Easton et al., 2017), which provides more active microbial communities. Jacinthe et al. (2001) found that tile-drained systems have a higher readily mineralizable C, basal soil respiration, and metabolic quotient (qCO_2 or ratio of the rate of CO_2-C evolution during the 20-day incubation/microbial biomass C). A more active microbial community in a tile drainage system will convert higher crop residues to organic matter and release organic nutrients. Tile drainage systems allow deep root systems that increase organic matter and decrease bulk density at deeper depths (Easton et al., 2017). Drained systems increase infiltration capacity and reduce the magnitude of peak runoff rate and total runoff volume than undrained systems (Golmohammadi et al., 2017).

The Food and Agriculture Organization's (FAO) Intergovernmental Technical Panel on Soils (ITPS) estimated that, globally, 33% of the land is moderately to highly degraded (ITPS, 2015). The ITPS stated that soil erosion, SOM loss, nutrient depletion, and loss of soil biodiversity are the four major threats to the soil's ability to function. Therefore, conventional farming practices (intensive tillage, mono-cropping, excess nutrient application, etc.) are increasingly challenged in meeting ecological and environmental needs to maintain soil, air, and water quality, biodiversity, and human health.

Agricultural conservation practices (ACPs) such as NT, CC, and drainage management could address these challenges by regenerating soil physical and hydraulic properties that significantly influence plant root development and movement of water and nutrients into plant bodies from the soil profile and reduce soil erosion. Sustainable soil management is expected to improve soil health or ecosystem services. FAO recommends practicing all ACPs for the highest benefit and sustainable soil management. Farmers practice single or combinations of ACPs in their natural fields.

Several years are required to change soil properties and productivity through continuous soil health practices, depending on the weather, soil type, land management, and cropping pattern (Bindraban et al., 2000; Bünemann et al., 2018; Doran, 1996; Doran & Parkin, 2015). Most researchers investigated ACP impacts on soil properties for the short or medium term (3–10 years) and analyzed soil up to 0- to 30-cm soil layer (Aziz et al., 2013; Ghimire et al., 2019; Graham et al., 2021). Some research has identified longer term (>25 years) effects of soil health practices (Fuentes et al., 2004; Tarkalson et al., 2006) but less research has been conducted under South Dakota climate conditions (Alhameid et al., 2020; Bawa et al., 2021; Graham et al., 2021; Ozlu et al., 2019). Limited research has investigated soil properties change in deeper soil depths and in colder and drier climates. The interactive effect of tillage, rotation, CC, and tile drainage on soil physical and hydraulic properties has been little studied in the Northern Great Plains of the United States.

Therefore, the specific objectives of this study are to investigate the effect of crop rotation, tillage, CCs, and drainage on bulk density, SOM, wet aggregate stability (WAS), and saturated hydraulic conductivity within 0- to 90-cm depth. This study also explored the interaction across these variables. This study hypothesizes that ACPs significantly impact the soil profile (0–90 cm). The second hypothesis is that an individual or combination of ACPs will provide better soil functioning than conventional practices.

2 | MATERIALS AND METHODS

2.1 | Experimental site and treatments description

Experimental plots were located at the South Dakota State University Southeast Research Farm (SERF) near Beresford, South Dakota (SD (43°02′ 58″N, 96°53′30″W) (see Figure 1). In 1991, a long-term rotation study was initiated at SERF utilizing three crop rotations: 2-year corn (*Zea mays* L.)–soybean (*Glycine max* L.); 3-year corn–soybean–oat (*Avena sativa* L.); and 4-year corn–soybean–oat–wheat (*Triticum aestivum* L.) in a randomized complete block design to assess the impact of tillage and crop rotation on soil quality and crop production. Each crop rotation was split into two levels of tillage (CT and NT), comprising a total of six plots (each size: 18.2 m by 91.4 m) per replication. The experiment was conducted with three replications separated by a 9.1-m alley. In 2013, cover crop treatments (CC and no cover crop [NC]) were included in each tillage treatment (subplots: 9.1 m by 91.4 m). In 2017, tile drainage was installed on each end of the plot (9.1 m from the edge of the road and covered all six plots in replications), which drained 20% of plot area on each plot side and kept the middle 60% undrained. Therefore, each tillage plot was laid out as a split plot for both cover crops (CC and NC) and drainage treatments (tile drainage [TD] and without drainage [ND]). NT fields were maintained with zero disturbance unless planted with a furrow opener. In tilled plots, a fall chisel plow was used after corn and small grain harvest, and in Spring, a field cultivator was used prior to planting. Regarding CC treatment, rye CCs were planted in half of the corn plot (within tillage treatments) after harvesting, and mixed-species CC consisting of rye/radish/turnips/pea mixed were planted in half of the plot (within tillage treatments) after small grains. See Table 1 for further details on farm management practices (cash crop planting date, tillage operation, fertilizer application, CC planting date, and seed rate) after the addition of CC and tile drainage practices.

The current study was conducted for 3 years (2020–2022) to investigate the impact of 31 years of NT practice, 9 years of CC, and 6 years of tile drainage on soil physical properties.

2.2 | Climate

The site has a 70-year average precipitation of 645 mm per year and a mean monthly air temperature ranging from −8.7˚C in January to 23.4˚C in July (Figure 2). During the study period, the annual precipitation values were lower than average: 369, 599, and 374 mm, respectively, for 2020, 2021, and 2022 (see Figure 2b).

2.3 | Soil sampling and lab analysis

Using a truck-mounted hydraulic probe (Giddings Machine Company), undisturbed soil cores were collected (0–90 cm from surface) and separated into five depths 0–10 cm, 10–20 cm, 20–30 cm, 30–60 cm, and 60–90 cm to identify the impact of crop rotation, tillage, CCs, and tile drainage practice with a total of 360 observations. Samples were collected in Spring 2021, Fall 2021, and Spring 2022 and combinely

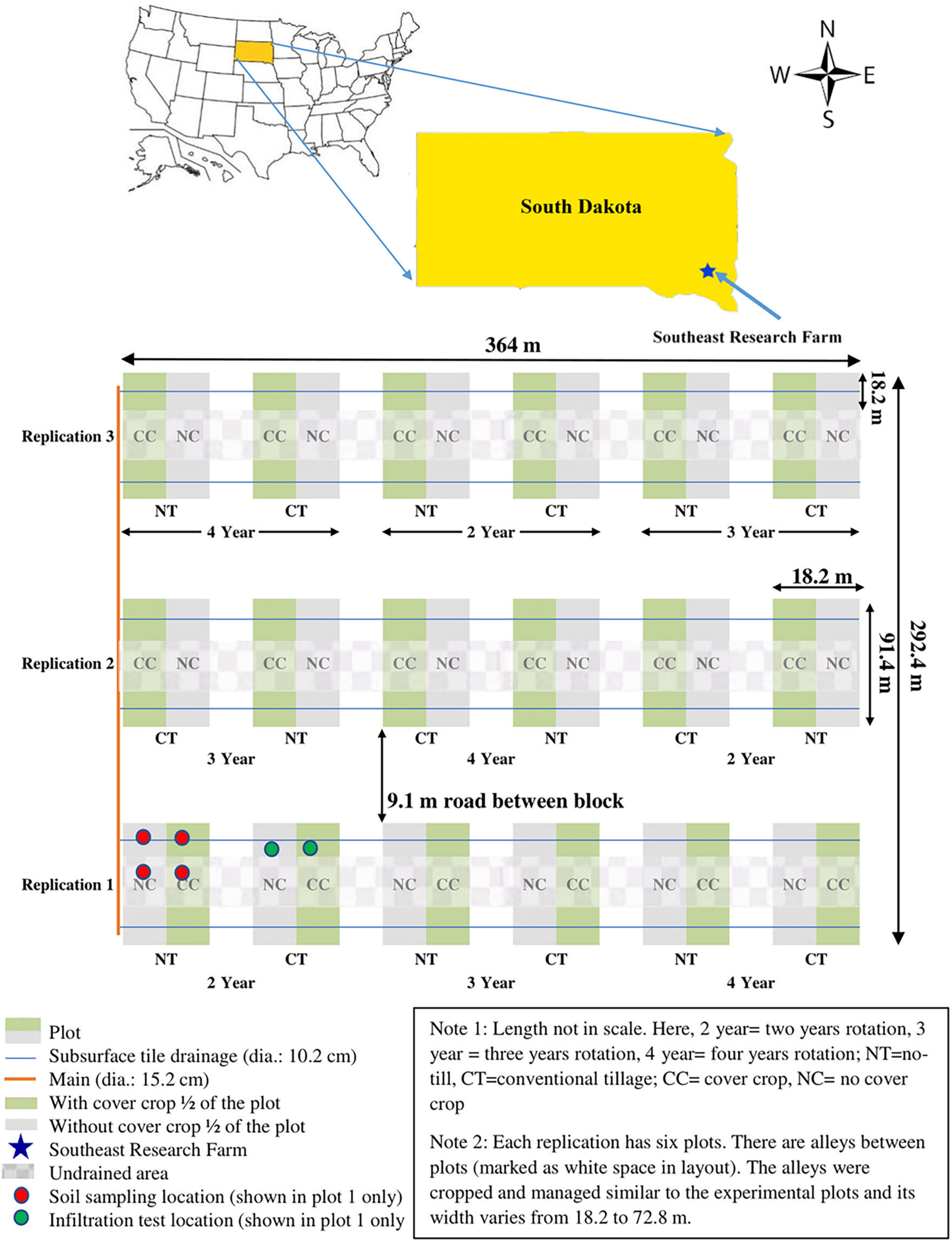

FIGURE 1 Location and layout of the experimental field at South Dakota State University Southeast Research Farm (SERF), Beresford, SD. CC, cover crop; CT, conventional tillage; NC, no cover crop; NT, no-till.

analyzed for SOM, pH, texture, bulk density, and WAS. Fall and Spring sampling were done respectively after harvesting (November) and prior to planting (April) of cash crop.

SOM was measured by the loss on ignition method (Schulte & Hopkins, 1996). Briefly, oven-dry (at 105°C) soil samples were ignited in a muffle furnace for 2 h at 360°C, and the percentage of weight loss of the soil sample was recorded as SOM. Soil pH was determined by 1:1 soil-water (Ward Laboratories Inc.)—20 g of air-dried soil was dispensed in 20 mL of deionized water for a 1:1 ratio. The soil slurry was placed in a horizontal shaker for 30 min and measured with a calibrated pH meter.

TABLE 1 Farm management practice details in the experimental plot during 2012–2022.

Rotation	Crop	Fertilization	Crop planted	Cover crop planted
2022				
2 Year	Soybean	Not applied	May 13, 2022: Plant AG26XF1 soybean, 140,000 s/ac	August 10, 2022: plant 3/4 radius, 1/4 turnips; re-planted on November 8, 2022: Hazlett rye cover crop; 60 lb/ac
3 Year	Soybean	Not applied	May 13, 2022: plant AG26XF1 soybean, 140,000 s/ac	August 10, 2022: plant 3/4 radius, 1/4 turnips; re-planted on November 8, 2022, plant hazlett rye cover crop; 60 lb/ac
4 Year	Corn	April 21, 2022: urea 217 lb/ac	May 10, 2022: plant P0622AML Corn, 33,000 s/ac	August 10, 2022: Drilled 3/4 radius, 1/4 turnips; re-planted on November 8, 2022, drilled hazlett rye cover crop; 60 lb/ac
2021				
2 Year	Corn	April 15, 2021: urea 178 lb/ac; AMS 62 lb/ac; July 8, 2021: urea (untreated) 60 lb/ac and urea 130 lb/ac	April 30, 2021: plant DKC53-56, 32,000 s/ac	September 8, 2021: drilled broadleaf cover crop mix 30 lb/ac; JD drill setting #7
3 Year	Corn	April 15, 2021: urea 102 lb/ac; AMS 62 lb/ac of product using a commercial spreader; April 30, 2021: UAN banded 20 gal/ac 28% July 8, 2021: urea (untreated) 60 lb/ac; urea 130 lb/ac	April 30, 2021: plant DKC53-56, 32,000 s/ac	September 8, 2021: drilled broadleaf cover crop mix 30 lb/ac
4 Year	Rye	March 22, 2021: urea 155 lb/ac, AMS 42 lb/ac	March 22, 2021: red clover, 5 lb/ac and sweet clover 5 lb/ac	October 7, 2021: drilled rye 70 lb/ac
2020				
2 Year	Soybean	Not applied	May 12, 2020: plant soybean PI021XX,150,000 s/ac	August 7, 2020: drilled radish/pea/rye mixed 25 lb/ac
3 Year	Oat	March 17, 2020: urea 165 lb/ac (N 76 lb/ac, AMS 35 lb/ac (7 lb N, 8 lb S)/ac	April 7, 2020: plant saddle oats, 100 lb/ac	August 7, 2020: drilled radish/pea/rye mixed 25 lb/ac
4 Year	Oat	March 17, 2020: urea 165 lb/ac (N 76 lb/ac, AMS 35 lb/ac (7 lb N, 8 lb S)/ac	April 7, 2020: plant saddle oats, 100 lb/ac	August 7, 2020: drilled radius/pea/rye mixed 25 lb/ac
2019				
2 Year	Corn	May 6, 2019: urea 140 lb/ac and AMS 24 lb/ac	May 15, 2019: plant corn DKC53-56RIB,33,700−31,7000 s/ac	August 20, 2019: drilled cover crop mix; 16 lb/ac
3 Year	Soybean	Not applied	May 16, 2019: plant soybean AG21 × 7,140,000 s/ac	August 20, 2019: drilled cover crop mix; 16 lb/ac
4 Year	Soybean	Not applied	May 16, 2019: plant soybean AG21 × 7,140,000 s/ac	August 20, 2019: drilled cover crop mix; 16 lb/ac
2018				
2 Year	Soybean	Not applied	May 18, 2018: plant soybean ASGROW AG24×7, 140,000 s/ac	August 3, 2018: drilled cover crop 15 lb/ac; hairy vetch 15 lb/ac
3 Year	Corn	May 9, 2018: Surface band with N @ 50 lb/ac; May 16, 2018: urea [41#N] 90 lb/ac, AMS 40 lb/ac [8.4 #N; 9.6# S]	May 9, 2018: plant corn DKC54-38RIB, 34,000 s/ac	August 3, 2018: drilled cover crop 15 lb/ac; hairy vetch 15 lb/ac

(Continues)

TABLE 1 (Continued)

Rotation	Crop	Fertilization	Crop planted	Cover crop planted
4 Year	Corn	May 9, 2018: Surface band with N @ 50 lb/ac; May 16, 2018: urea [41#N] 90 lb/ac, AMS 40 lb/ac [8.4 #N; 9.6# S]	May 9, 2018: plant corn DKC54-38RIB, 34,000 s/ac	August 3, 2018: drilled cover crop 15 lb/ac; hairy vetch 15 lb/ac
2017				
2 Year	Corn	May 10, 2017: urea, AMS, sulfur (340 # urea, 43# AMS, 10# elemental sulfur)	May 16, 2017: planted corn DKC56-45RIB, 32,000 s/ac	November 8, 2017: drilled hazlet rye cover 50 lb/ac
3 Year	Oat	April 3, 2017: urea 175 lb/ac and sulfur 15 lb/ac with a commercial spreader	May 16, 2017: drilled oat, 100 lb/ac	August 14, 2017: drilled cover crop mix 24 lb/ac
4 Year	Wheat	April 3, 2017: urea 175 lb/ac and sulfur 15 lb/ac with a commercial spreader	NA	August 14, 2017: drilled cover crop mix 24 lb/ac
2016				
2 Year	soybean	April 14, 2016: MAP 100 lb/ac	June 8, 2016: plant soybean P22T39R and P20T79R2, NA s/ac	July 20, 2016: drilled broadleaf cover crop mix, NA lb/ac
3 Year	soybean	April 14, 2016: MAP 100 lb/ac	June 8, 2016: plant soybean P22T39R and P20T79R2, NA s/ac	July 20, 2016: drilled broadleaf cover crop mix, NA lb/ac
4 Year	Oat	Not applied	April 14, 2016: hayden oats, 90 lb/ac	August 17, 2016: drilled mix cover crop, NA lb/ac
2015				
2 Year	Corn	March 24, 2015: MAP 150 lb/ac with commercial spreader; April 15, 2015: Sprayed 28% liquid nitrogen 160 lb/ac	June 2, 2015: plant corn P9188AMX, 33,000 s/ac	October 30, 2015: drilled rye planted, NA lb/ac
3 Year	Corn	March 24, 2015: MAP 150 lb/ac with commercial spreader; April 15, 2015: Sprayed 28% liquid nitrogen 160 lb/ac	June 2, 2015: plant corn P9188AMX, 33,000 s/ac	October 30, 2015: drilled rye planted, NA lb/ac
4 Year	Soybean	March 24, 2015: MAP 150 lb/ac with commercial spreader	May 22, 2015: plant soybean P25T51, 150,000 s/ac	August 11, 2015: drilled mix cover crop, 25–35 lb/ac
2014				
2 Year	Soybean	April 2, 2014: Potash broadcast with spreader 80 lb K_2O/ac (133 lb potash/ac);	May 23, 2014: plant soybean AG2135, 150,000 s/ac	August 21, 2014: drilled cover crop, NA lb/ac
3 Year	Oat	April 2, 2014: Potash broadcast with spreader goal 80 lb K_2O/ac (133 lb potash/ac); April 25, 2014: Spread dry fertilizer urea 100 lb/ac	April 12, 2014: drill oat, NA lb/ac	August 21, 2014: drilled cover crop, NA lb/ac
4 Year	Corn	April 2, 2014: K_2O (potash) 80 lb /ac broadcast with spreader; April 10, 2014: Sprayed 28% liquid nitrogen with varying rates; May 5, 2014: urea 260 lb/ac (120-0-0); June 26, 2014: UAN 15 gal/ac	May 16, 2014: plant corn PIO0193AM, 32,300 s/ac	November 10, 2014: drilled rye, NA lb/ac

(Continues)

TABLE 1 (Continued)

Rotation	Crop	Fertilization	Crop planted	Cover crop planted
2013				
2 Year	Corn	May 9, 2013: liquid fertilizer 10-34-0 (10% nitrogen and 34% phosphate) 6 gal/ac	May 14, 2013: plant corn DKC 59–83, 28,900 s/ac	August 20, 2013: drilled broadleaf cover crop mix, NA lb/ac; October 10, 2013: Rye cover crop, NA lb/ac
3 Year	Soybean	Not applied	June 3, 2013: plat soybean AG2031, 152,480 s/ac	August 20, 2013: drilled broadleaf cover crop mix, NA lb/ac; October 10, 2013: Rye cover crop, NA lb/ac
4 Year	Oat	Not applied	3Aril 30, 2013: drill oats, 70 lb/ac	August 20, 2013: drilled broadleaf cover crop mix, NA lb/ac; October 10, 2013: Rye cover crop, NA lb/ac
2012				
2 Year	Soybean	May 21, 2012: urea treated and untreated, 62 lb/ac	May 21, 2012: plant soybean AG1832, NA s/ac	August 27, 2012: drilled winter wheat, some radish, rapeseed, and turnip mix, NA lb/ac
3 Year	Corn	May 9, 2012: liquid fertilizer 10-34-0 (10% nitrogen and 34% phosphate) 10 gal/ac	May 9, 2012: plant corn DKC 59-35, 30,000 s/ac	August 27, 2012: drilled winter wheat, some radish, rapeseed, and turnip mix, NA lb/ac
4 Year	Winter wheat	October 3, 2012: MAP 50 lb/ac	October 3, 2012: drill winter wheat 27–35 s/19 in.	August 27, 2012: drilled winter wheat, some radish, rapeseed, and turnip mix, NA lb/ac

Note: In conventional tillage fields, disking corn stalks before the winter (fall tillage). No artificial irrigation water was applied.
Abbreviations: AMS, ammonium sulfate [$(NH_4)_2SO_4$]; gal/ac, gallon per acre; JD drill/planter, John Deere drill/planter; lb/ac, pound per acre; MAP, mono ammonium phosphate; NA, information not available; s/ac, seed per acre; UAN, urea ammonium nitrate.

Soil texture (the percentages of sand, silt, and clay) was analyzed by integral suspension pressure using a PARIO meter (Meter Group Inc.) for each plot from five different depths. The soil textural class showed that the experimental plot's soil class was dominated mainly by the percentage of silt, and the USDA textural classification varied from silt to silty clay loam (see Figure 3). To analyze soil texture, 50 g air-dry soil was taken after sieving with a 2-mm sieve, and then the sample was placed in the oven at 105˚C. Once dry, SOM was removed using hydrogen peroxide (30%), and the sample was placed in the oven at 105˚C to record soil's exact dry mass (Durner et al., 2017). In this study, no other binding agents, such as iron oxides or carbonates were removed. After SOM pretreatment, a 1 L soil suspension was prepared by adding deionized water and dispersion solution (50 g sodium hexametaphosphate per liter) and the solution was shaken overnight. A PARIO device (Durner & Iden, 2021) was placed inside the homogenized suspension and ran using plus mode. After 2.5 h, a fixed amount of soil suspension was drained (as effluent) above the PARIO pressure sensor and collected in a beaker. The effluent was dried in the oven at 105˚C and dry mass was recorded. After draining the effluent, the rest of the suspension in the sedimentation cylinder was (wet) sieved with a 53-µm sieve and the retained sand particles (size 53–2000 µm) were placed in an oven at 105˚C. Dry sand was then sieved with 500-, 250-, and 53-µm sieves. Finally, the particle density soil (2.65 g/cm^3), dispersion mass (5 g), dry effluent mass, and the percentage of retained sand within 2000–500 µm, 500–250 µm, and 250–53 µm were input in the PARIO control panel to fit particle size distribution and get soil texture results (percentage of sand, silt, and clay).

The soil bulk density (ρ_b) was analyzed using the core method (Blake & Hartge, 1986). For measuring bulk density, the soil cores were dried in a convection oven at 105˚C until a constant mass was obtained. Then, ρ_b was calculated by dividing the mass of oven-dry soil by the total soil volume (solids and pores together). The WAS was analyzed for a set of soil samples collected in Spring 2021, Fall 2021, and Spring 2022 by following the standard procedure (Kemper & Rosenau, 1986). The wet sieving apparatus (Eijkelkamp, Soil & Water, Model no. 08.13) was designed according to the specifications of Kemper (1965). A 4 g of sieved, air-dried aggregate subsample was taken into a 60-mesh screen sieve (opening 0.25 mm). Before submerging aggregates into distilled water, the soil aggregates were premoistened using capillary action by placing a sieve with aggregates over wet tissue paper for 10 min. Then, the sieve with soil aggregates was placed with sufficient distilled water in the weighing and numbered cans. Aggregates were washed for 3 min at 35 rpm. The unstable soil particles were detached from soil aggregates and collected in distilled water cans. The retained stable soil aggregate (with sand) was further washed in 100 mL dispersing solution cans (containing 2 g sodium hexametaphosphate/L deionized water for soil pH > 7 or 2 g sodium hydroxide/L deionized water for

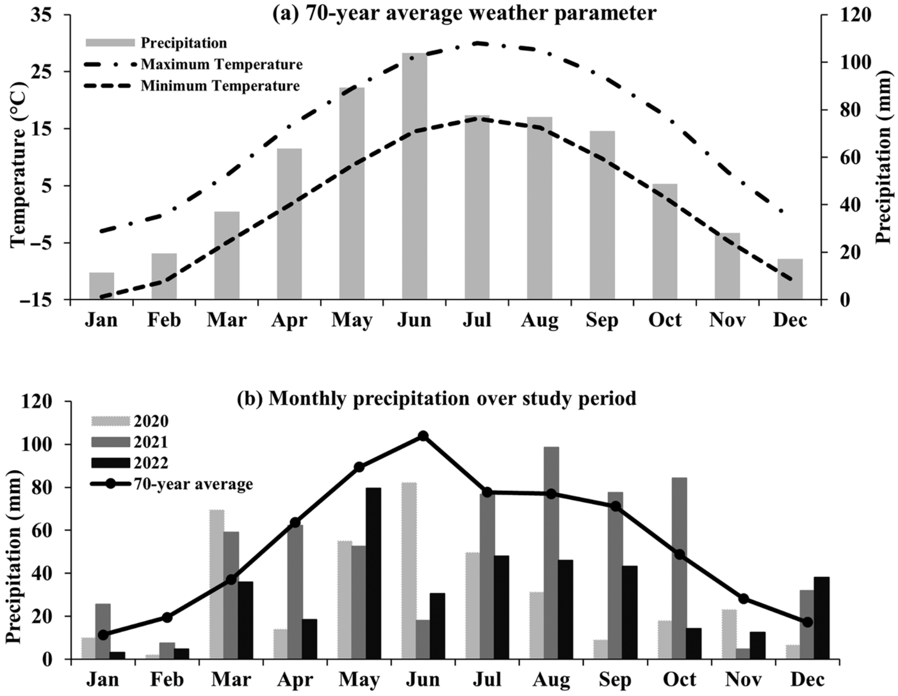

FIGURE 2 Meteorological 70-year average of monthly maximum temperature, minimum temperature, and precipitation in Beresford, SD. (b) Monthly precipitation comparison between 70-year average and precipitation during the study period 2020–2022 (Southeast South Dakota Research Farm, 2022).

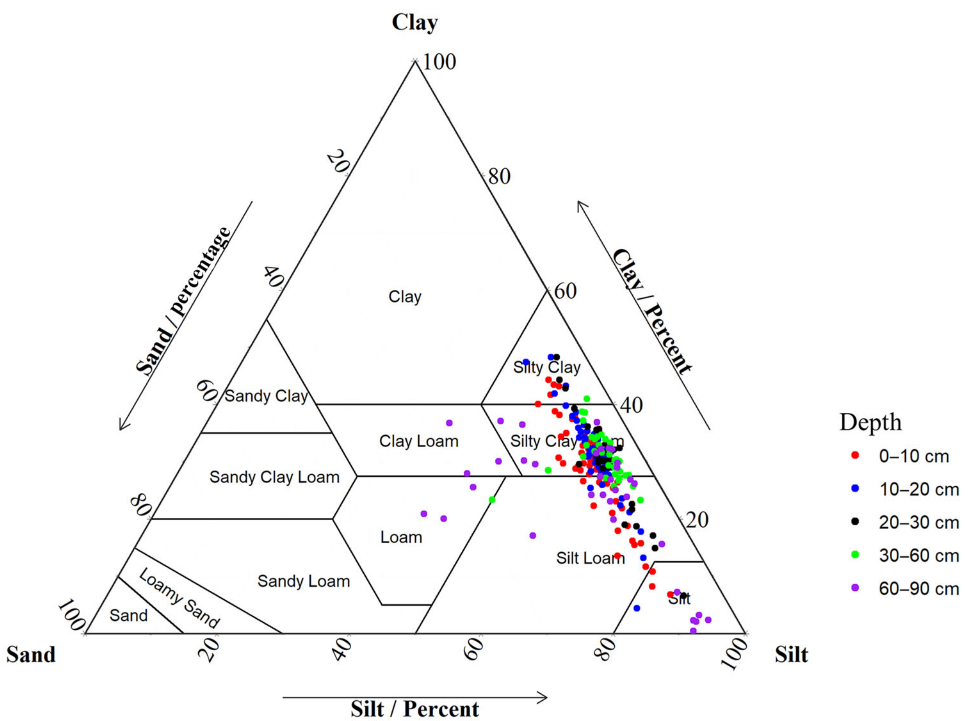

FIGURE 3 Distribution of sand, silt, and clay on soil texture triangle of 18 experimental plots for the soil sample collected in spring 2022. Legends with red, blue, black, green, and purple color dots indicatng soil texture for 0- to 10-, 10- to 20-, 20- to 30-, 30- to 60-, and 60- to 90-cm depths, respectively.

soils pH < 7) for 10–20 min to correct the sand fraction in soil aggregate stability analysis. Washing time in dispersion solution varies depending on the presence of clay particles in soil aggregates that require longer to release stable soil particles into the dispersion solution. The wet sieving stopped when only sand particles were retained over the sieve. Stable and unstable soil particle-containing cans were placed in a convection oven at 110˚C and dried until constant weight. The following equation was used to calculate the WAS:

$$\text{WAS} = \frac{(W_{\text{stable}})}{(W_{\text{unstable}} + W_{\text{stable}})} \times 100\% \quad (1)$$

where WAS is the wet aggregate stability (%), W_{stable} is the weight of dry soil obtained in dispersing solution cans having 0.2 g subtracted to exclude dispersing solute, and W_{unstable} is the weight of the dry soil obtained in distilled water cans.

2.4 | In situ infiltration test

In the summer of 2021 and 2022, in situ infiltration tests were conducted with SATURO, an automated field dual-head infiltrometer (METER Group Inc., ISO 9001:2005) to identify the impact of crop rotation, tillage, and CCs (36 total treatments over 2 years: three rotation levels × two tillage levels× two CCs levels × three replications). The SATURO was designed to be an automated instrument to measure field-saturated hydraulic conductivity (K_{fs}) by the end of the field test run. It uses a dual-pressure head approach to eliminate the need to assume an alpha value for the three-dimensional flow from a single-ring infiltrometer, and thus, it reduces the error in hydraulic conductivity assessment (METER Group Inc, 2017; Reynolds & Elrick, 1990).

In this field test, a single ring (inner diameter of 14.4 cm and insertion depth of 10 cm) was used in every in situ field test. The SATURO control unit maintains a 5 cm constant water level (with a water level sensor) and a specific pressure head inside the infiltrometer head (with the help of constant circulating water and an air pump). The SATURO unit ponded water on the ground surface for 150 min, including 30 min soak time and 120 min for three pressure cycles. This allows sufficient time to achieve steady-state flux at two different pressure heads, with configurations set according to the SATURO manual based on the soil type and condition (METER Group Inc, 2017). For each field test, a pressure cycle consisted of a 20 min low-pressure head at 5 cm and a 20 min high-pressure head at 15 cm controlled inside the infiltrometer. It allowed water to infiltrate through the soil profile in controlled (two different) pressure heads and constant ponding depth (5 cm). SATURO control unit generated real-time infiltration rates, water level, pressure head, and estimated K_{fs} at the end of each test.

2.5 | Statistical analysis

Using R statistical software, histogram and Shapiro–Wilk tests were performed and found that each specific depth's data were unimodal in histogram (graphic distribution) and were normally distributed for $p < 0.05$ (in statistical test). The main and interaction effects were tested using the analysis of variance (ANOVA) function (aov) from the package "agricolae" in R statistical software (R Core Team, 2022) for the combined data set by considering seasonal sampling as replicating the number of observations. ANOVA was used to test the main and interaction effect of tillage, rotation, CC, drainage, and depths on soil physical and hydraulic properties. Fisher's least significant difference, a commonly used post hoc test for agricultural research, was used for grouping treatments based on multiple treatment mean comparisons. The statistical differences were stated as significant at $\alpha = 0.05$.

3 | RESULTS AND DISCUSSION

3.1 | Effect of tillage on bulk density, SOM, WAS, and field-saturated hydraulic conductivity

The variation of soil bulk density, SOM, WAS, and K_{fs} under tillage treatment are presented in Figure 4. We found that NT significantly affected soil bulk density, SOM, WAS, and K_{fs}. NT significantly increased bulk density, SOM, and WAS across the soil depth 0–90 cm by 1.5%, 7%, and 6.3%, respectively, but decreased K_{fs} by 47.6% compared to CT (see Figure 4a,c,e,g). Gantzer and Blake (1978) investigated the physical characteristics of clay loam soil in the US corn belt under NT and CT systems and found that bulk density was significantly higher in the NT than in CT.

The bulk density for topsoil (0–10 cm) under the NT was 6.7% higher than the CT. The significantly lower saturated hydraulic conductivity in NT could be due in part to the higher bulk density in the NT compared to the CT. In previous studies, several researchers reported that the long-term NT cultivation increased soil macroporosity and structural stability, thus increasing saturated hydraulic conductivity (Nebo et al., 2020; So et al., 2009). At the same time, many researchers found that the NT and CT soils had similar saturated hydraulic conductivity (Conyers et al., 2019; Fuentes et al., 2004; Liao et al., 2022), while others reported that the NT reduced the hydraulic conductivity (Blanco-Canqui et al., 2017a; Gantzer & Blake, 1978; Heard et al., 1988; Soracco et al., 2019). There is a common concept about the CT system that the macro pores of the top layer in the CT system are quickly clogged/trapped with finer particles during heavy rainfall; thus, it breaks/prevents downward water flow

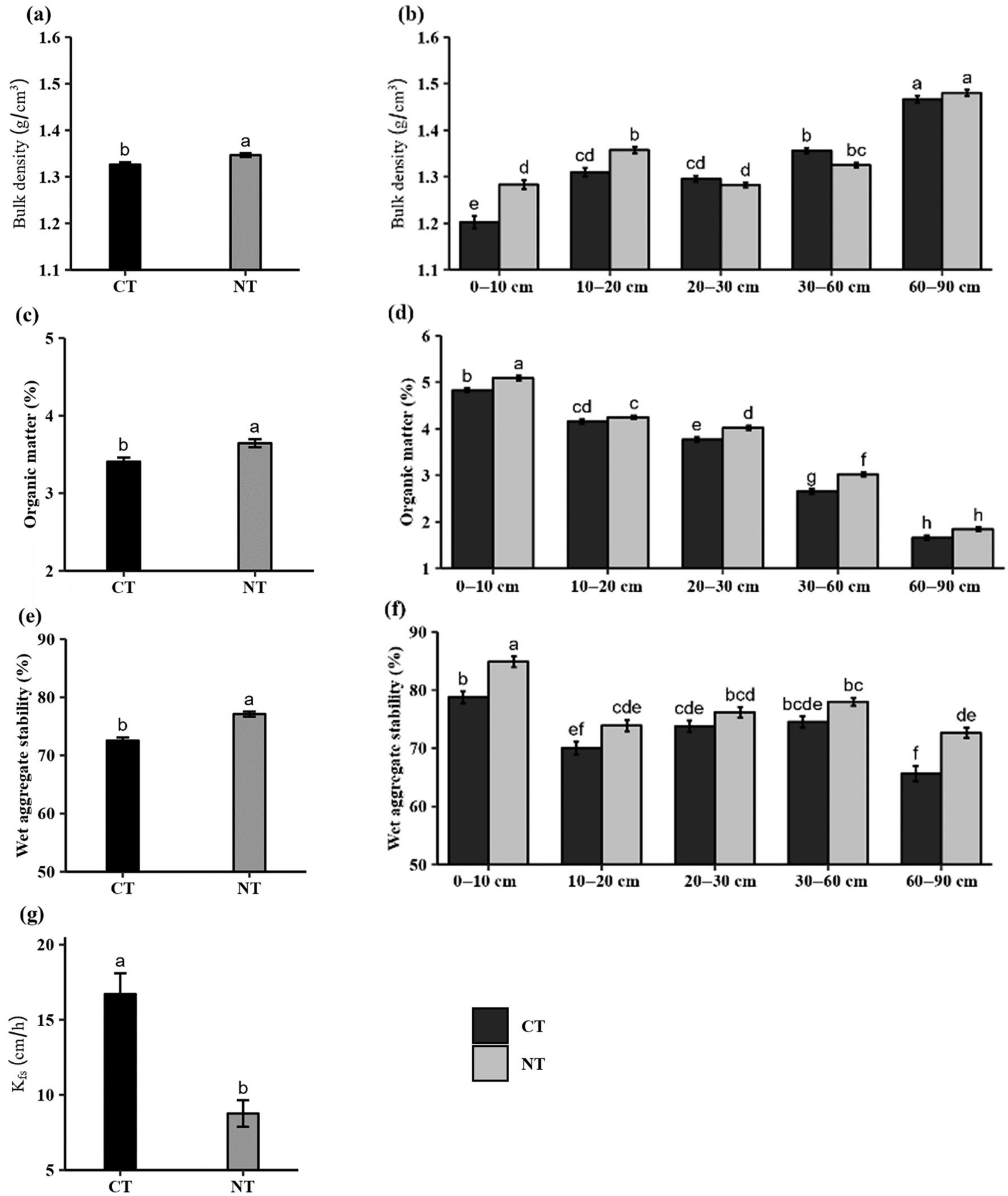

FIGURE 4 Illustration of the variation of (a and b) soil bulk density, (c and d) soil organic matter, (e and f) wet aggregate stability, and (g) field-saturated hydraulic conductivity due to the effect of tillage treatments. Panels (a), (c), and (e) represent the variation of average bulk density, organic matter, wet aggregate stability, respectively, for 0- to 90-cm soil depth. (b, d, and f) Representation of the variation of bulk density, organic matter, wet aggregate stability respectively for each specific soil depth (0–10, 10–20, 20–30, 30–60, and 60–90 cm). (g) The variation of field-saturated hydraulic conductivity for the soil profile is shown. CT means conventional tillage and NT means no-till. The error bar indicates the standard error. Groups sharing the same superscript letter a, b, c, d, e, f, g, and h at the top of the error bar are not significantly different at $p = 0.05$.

and reduced infiltration capacity. This phenomenon was not observed in this study period due to the significantly lower precipitation observed during the in situ infiltration test (in June–August 2021 and 2022), see Figure 1c. Moreover, 30 years of the undisturbed soil profile and the additional impact of heavy machinery use for field operations (planting, spraying, fertilizing, and harvesting) in the NT plots may have contributed to soil compaction (for 0- to 20-cm depth). Several researchers similarly reported that bulk density is greater in NT than in the CT field under different soil, crop pattern, and climate conditions (Blanco-Canqui et al., 2022; Jabro et al., 2021; Thomas et al., 2007; Topa et al., 2021).

In contrast, some researchers have observed a decrease in bulk density under NT after 5–7 years of practice (Blevins et al., 1983; Fiorini et al., 2020). Interestingly, the NT practice has a lower bulk density for 20- to 30-cm soil depth and 30- to 60-cm soil depth by 1.5% and 2.9%, respectively, and almost unchanged for 60- to 90-cm soil depth compared to CT (See Figure 4b). This indicates that CT systems increased soil compaction at deeper depths (20–90 cm), supporting the commonly understood theory that tillage operation/heavy traffic movement creates a plow pan or hard pan below the Ap horizon (Birkás et al., 2004; Botta et al., 2006; Jabro et al., 2014; Temesgen et al., 2009; Zink et al., 2010).

Our study found that the NT system increased SOM and WAS for every soil depth (0–10, 10–20, 20–30, 30–60, and 60–90 cm), indicating differential organic matter turnover and distribution through the 0–90 cm soil profile when compared to CT. Previous work has shown that in NT systems, a reduction in mineralization rates stimulates liter concentration (i.e., crop residues), which directly influences the SOM (Alvarez & Steinbach, 2009). Moreover, this effect also directly influences the stability of soil aggregates and improved soil structure. More specifically, NT significantly increased SOM for 0- to 10-cm soil depth, 20- to 30-cm soil depth, and 30- to 60-cm soil depth by 5.4%, 6.6%, and 13.5%, respectively, and WAS increased by 7.7% and 10.7% for 0- to 10-cm soil depth and 60- to 90-cm soil depths, respectively. Other researchers observed similar results: SOM and WAS increased in the NT field (Castro Filho et al., 2002).

However, as measured in this study, the NT system decreased field-saturated hydraulic conductivity, which could negatively impact water infiltration during rainfall. Previous studies also observed similar outcomes (Blanco-Canqui et al., 2017a; Jones et al., 1994) that infiltration under the NT was lowered compared to moldboard plowed tillage system and had no differences from disk and cheisel plow tillage systems. As the topsoil compacted significantly in the NT field, it is expected that rainwater entry into the top layer would be a great limitation in silty clay loam soil, even with NT practices over 30 years.

3.2 | Effect of rotation on soil bulk density, SOM, WAS, and field-saturated hydraulic conductivity

Crop rotations significantly impacted soil bulk density and SOM but did not show any considerable variation for WAS and K_{fs}. Bulk density was significantly higher for the 2-year rotation than the 3-year and 4-year rotations but did not vary considerably across all depths. It was found that a longer rotation provides lower bulk density which may support the concept of diverse microbial species actively working in the field. The average bulk density under 2-year rotations (1.35 g/cm^3) was 1.5% higher than the 3- and 4-year rotations (1.33 g/cm^3) (Figure 5a). However, the 3-year rotation (corn–soybean–oat) showed significantly less compacted topsoil (0–10 cm) and 1.21 g/cm^3 compared to the other two rotations (bulk density of 1.28 g/cm^3 and 1.25 g/cm^3 for 2-year and 4-year rotations, respectively). In contrast, Alhameid et al. (2020) found a 4-year rotation had low bulk density for 0- to 7.5-cm soil depth and 7.5- to 15-cm soil depth from >25 years of rotation study under silt clay loam soil.

The lowest SOM was observed in the 3-year rotation across the 0–90 cm soil profile and each specific soil depth compared to the 2-year and 4-year rotations (Figure 5c,d). The average SOM under the 3-year rotation was 3.4%, whereas the 2-year and 4-year had average SOM of 3.6% for 0- to 90-cm depth (Figure 5c). The topsoil (0–10 cm) organic matter decreases in order from 4-year (5.1 %) >2-year (5.0 %) > 3-year (4.8%). Past research has found that higher crop rotations supply diverse crop biomass, which slows down the decomposition rate and reduces carbon emissions to the atmosphere (Bayer et al., 2009); thus, diverse crop rotations produce higher SOM. The SOM at 60- to 90-cm depth was significantly higher for the 2-year rotation than other diverse rotations. The trend of SOM for 10- to 20-, 20- to 30-, 30- to 60-, and 60- to 90-cm depth ranked as 2-year > 4-year > 3-year rotation. The 2-year rotation might receive more crop biomass as corn was planted once every 2 years and might supply a bulk amount of crop residue after harvest, significantly contributing to the higher organic matter in a corn–soybean rotation.

In this study, longer rotations did not affect aggregate stability, as our study results showed that variation of WAS was not significant between rotation treatments. Diverse crop rotation increased average WAS for 0- to 90-cm soil depth and for 0–10 and 10–20 cm topsoil (Figure 5e,f). Field-saturated hydraulic conductivity was not significantly affected by 30 years of rotation treatment, and it measured higher for 2-year rotation (14.3 cm/h) than for 4-year (12.6 cm/h) followed by 3-year rotation (11.4 cm/h).

3.3 | Effect of CCs and drainage on soil bulk density, SOM, WAS, and field-saturated hydraulic conductivity

In this study, the CC did not significantly impact bulk density, SOM, WAS, and K_{fs} within CC treatment. CC practices slightly increased the SOM within soil profile (at 0- to 90-cm soil depth) and in specific soil depth (0–10, 10–20, 20–30, 30–60, and 60–90 cm). However, the variations were minimal and nonsignificant within the CC treatments. Past research reported that the CC has been practiced in this region to remove excess water, scavenge residual nutrients, add more

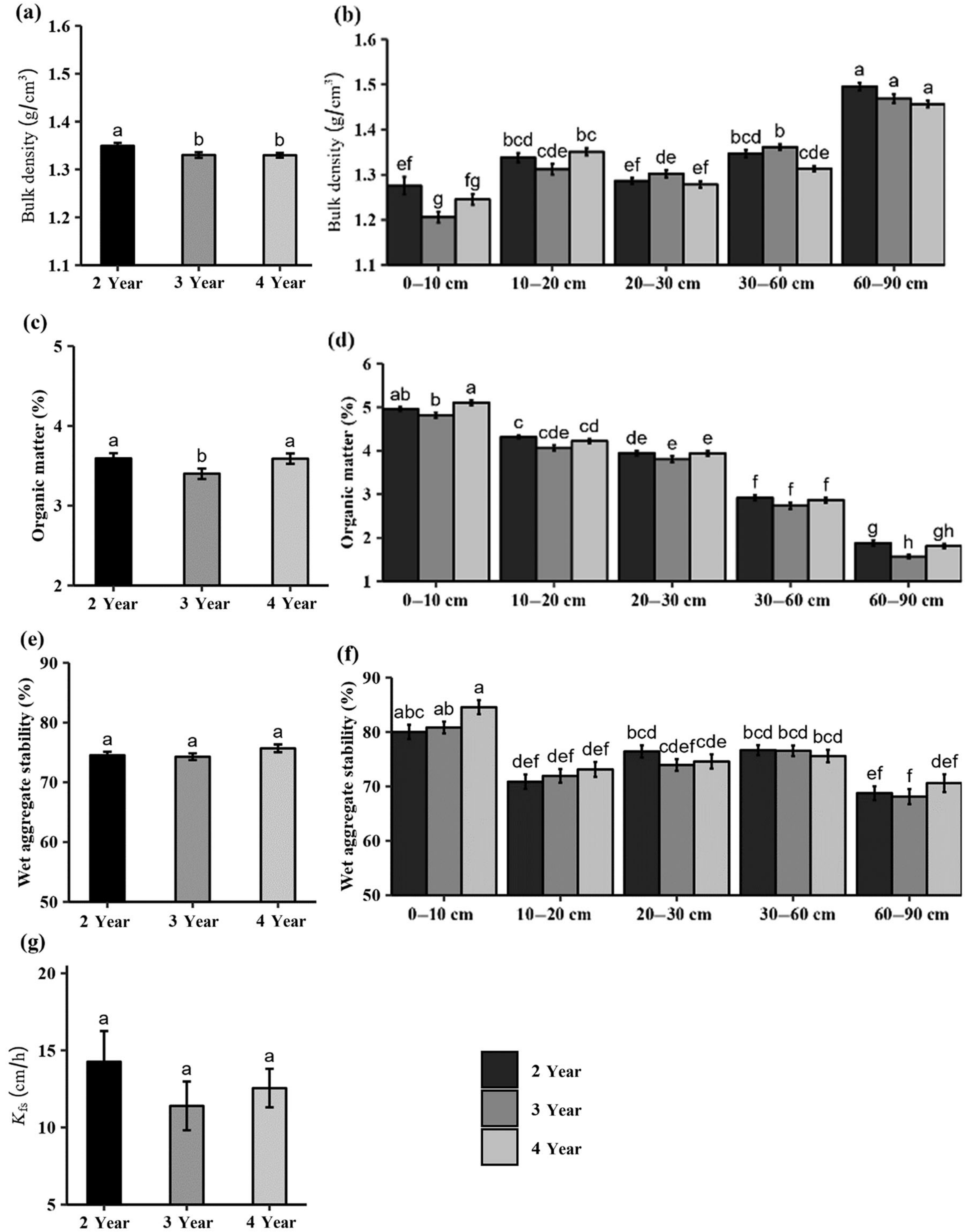

FIGURE 5 Illustration of the variation of (a and b) bulk density, (c and d) soil organic matter (SOM), (e and f) wet aggregate stability (WAS), and (g) field-saturated hydraulic conductivity (K_{fs}) due to the effect of rotation treatments. Panels (a), (c), and (e) represent the variation of average bulk density, SOM, and WAS, respectively, for 0- to 90-cm soil depth. (b, d, and f) Representation of the variation of bulk density, SOM, and WAS, respectively, for each specific soil depth (0–10, 10–20, 20–30, 30–60, and 60–90 cm). (g) The variation of K_{fs} for the soil profile is shown. 2-year = corn-soybean, 3-year = corn–soybean–oat, 4-year = corn–soybean–Oat–wheat rotation. The error bar indicates the standard error. Groups sharing the same superscript letter a, b, c, d, e, f, g, and h at the top of the error bar are not significantly different at $p = 0.05$.

biomass, and improve soil fertility (Brennan & Boyd, 2012; Fageria et al., 2005). CC treatment was established in this study in 2013; however, after 7 years, it had no considerable impact on the soil physical and hydraulic properties. Additionally, during this study period, minimal CC biomass was observed (by visual inspection) in the establishment period (in fall and winter) due to the adverse climatic condition (drought and very cold, respectively, at Beresford in southeastern South Dakota). The limited CCs biomass production was observed during 9 years of field study with CC practice (by visual inspection and no biomass data recorded), resulting in the smallest variation of SOM. Thus, it does not significantly alter other soil properties (soil bulk density, WAS, and field-saturated hydraulic conductivity). Ruis et al. (2020) similarly reported that due to the low biomass production (<1 Mg/ha) from single and mixed species, the CC had limited effects on soil properties after 4 years of CC study in south-central and eastern Nebraska. However, several researchers found that CC practices reduce bulk density (Çerçioğlu et al., 2019; Ruis et al., 2020), increase WAS (Ruis et al., 2020; Steele et al., 2012), and enhance saturated hydraulic conductivity (Çerçioğlu et al., 2019). In contrast, some researchers also reported that CC had no significant influence on bulk density (Nouri et al., 2019), SOM (Steele et al., 2012), WAS (Blanco-Canqui et al., 2017b; Nouri et al., 2019; Velykis et al., 2014), and K_{fs} (Haruna et al., 2018; Irmak et al., 2018).

Similarly, the tile drainage (TD) system has no significant impact on the bulk density, OM, and WAS compared to the without drainage (ND) system. It was expected that microbial activity (Jacinthe et al., 2001) and deep root systems (Easton et al., 2017) in tile drainage systems would alter soil bulk density and organic matter and thus would reflect in WAS as well. However, our study results revealed that 6 years of tile drainage practices along with silty clay loam soil has limited drainage treatment effects. From 2020 to 2022, soil sampling years were dry, having recorded precipitation as 369, 599, and 374 mm, respectively. The long term average annual precipitation for this study area was 645 mm. It may also show that the influence of TD on these properties are only significant under prolonged wet conditions.

3.4 | Effect of interaction of treatments on soil bulk density, organic matter, WAS, and field-saturated hydraulic conductivity

The soil bulk density, organic matter, and WAS were not significantly influenced by interaction treatment except interaction of tillage × rotation. The topsoil had the most impact by tillage × rotation; however, there were some significant impacts in deeper depth. Under 2-year and 3-year rotation at 0–10 cm, the bulk density was significantly higher in the NT (1.32 and 1.26 g/cm^3) than the CT (1.23 and 1.15 g/cm^3) system, see Table 2. Alhameid et al. (2020) found that NT 4-year rotation had lower bulk density (1.19 g/cm^3) for 0–7.5 cm than CT. For 10- to 20-cm depth, the bulk density was significantly higher in the CT system than in NT under the 3-year rotation. NT tillage significantly increased bulk density for 0- to 10-cm soil depth (see Figure 4c) but the inclusion of 4-year and 2-year rotation in NT significantly decreased bulk density at 30- to 60-cm depth than the CT (see Table 2). There were no significant differences at 20- to 30-cm depth and 60- to 90-cm depth. Conversely, the NT field in all rotations had higher organic matter and WAS than CT across all depths. More specifically, the 4-year rotation with the NT system had a significantly higher SOM for 0- to 10-, 20- to 30-, 30- to 60-, and 60- to 90-cm depth compared to CT under 2-year and 3-year rotations. Similarly, the 4-year rotation with the NT system had significantly higher WAS for 0- to 10-cm depth than the CT under 2-year and 3-year rotations.

Bulk density, SOM, and WAS values did not significantly differ among 2-year, 3-year, and 4-year rotation under NT field at every depth except bulk density (1.29 g/cm^3) at 30- to 60-cm depth. Bulk density for the 4-year rotation was significantly lower than the 2-year rotation (1.33 g/cm^3; Table 2). In contrast, rotation significantly affects CT systems with respect to bulk density, SOM, and WAS.

The K_{fs} was significantly higher by 63% in the CT system compared to NT under the 2-year rotation, but it did not vary substantially within tillage treatment under 3-year and 4-year rotations. The K_{fs} decreased with increasing crop rotation in the CT system, and K_{fs} increased with increasing crop rotation in the NT system (see Table 2). The K_{fs} was found higher in the CT system under different rotations 2-year (20.8 cm/h) > 4-year (15.1 cm/h) > 3-year (14.2 cm/h) compared to the NT system as found as 2-year (7.7 cm/h) > 3-year (8.6 cm/h) > 4-year (10 cm/h). The CT × 2-year rotation showed significantly higher K_{fs} than any NT system rotations. Previous research reported that increasing soil compaction (higher bulk density) reduces the water infiltration capacity, thus decreasing saturated hydraulic conductivity (Bormann & Klaassen, 2008). Thus, the higher bulk density for 0- to 20-cm soil depth in the NT system may have resulted in lower field-saturated hydraulic conductivity than in the CT system.

3.5 | Correlations of soil physical and hydraulic properties

Soil bulk density, SOM, WAS, and soil pH were significantly correlated with each other for $p < 0.001$ (Figure 6). Bulk density was negatively correlated with SOM and WAS. Previous research also reported similar correlation between bulk density and SOM (Heuscher et al., 2005; Zacharias & Wessolek, 2007). Conversely, SOM had a strongly negative correlation

TABLE 2 Comparison of the impacts of tillage × rotation interaction treatment on soil bulk density, soil organic matter, wet aggregate stability, and field-saturated hydraulic conductivity. Soil bulk density, soil organic matter, and wet aggregate stability were presented for 0- to 10-, 10- to 20-, 20- to 30-, 30- to 60-, and 60- to 90-cm soil depths. The field-saturated hydraulic conductivity represented the soil profile.

Treatment Tillage	× Rotation	Depth 0–10 cm	10–20 cm	20–30 cm	30–60 cm	60–90 cm
		Bulk density (g/cm^3)				
	2 Year	1.23b	1.33a	1.29a	1.37a	1.49a
CT	3 Year	1.15c	1.26b	1.31a	1.37a	1.45a
	4 Year	1.23bc	1.34a	1.28a	1.33ab	1.46a
	2 Year	1.32a	1.35a	1.28a	1.33bc	1.50a
NT	3 Year	1.26ab	1.36a	1.29a	1.36ab	1.48a
	4 Year	1.27ab	1.36a	1.28a	1.29c	1.45a
		Soil organic matter (%)				
	2 Year	4.88bc	4.33a	3.87ab	2.75abc	1.9a
CT	3 Year	4.65c	3.93b	3.61b	2.55c	1.4b
	4 Year	4.96abc	4.21ab	3.84ab	2.68bc	1.67ab
	2 Year	5.04ab	4.30a	4.02a	3.09a	1.85a
NT	3 Year	4.99ab	4.21ab	4.01a	2.92abc	1.73a
	4 Year	5.24a	4.23a	4.04a	3.06ab	1.95a
		Wet aggregate stability (%)				
	2 Year	76.2c	68.2a	74.6a	75.1ab	68.0ab
CT	3 Year	78.4bc	69.9a	74.1a	73.4b	61.6b
	4 Year	81.7abc	72.0a	72.6a	75.1ab	67.3ab
	2 Year	83.9ab	73.6a	78.2a	78.3ab	69.5ab
NT	3 Year	83.3ab	73.9a	73.8a	79.7a	74.6a
	4 Year	87.4a	74.2a	76.6a	76ab	73.9a
		Field saturated hydraulic conductivity[a] (cm/h)				
	2 Year			20.8a		
CT	3 Year			14.2ab		
	4 Year			15.1ab		
	2 Year			7.7b		
NT	3 Year			8.6b		
	4 Year			10b		

Note: Mean values followed by different lowercase letters between each treatment within each depth represent significant differences at $p < 0.0.5$

Abbreviations: CT, conventional tillage; NT, no-till.

[a]Field saturated hydraulic conductivity is for the whole soil profile.

($R^2 = -0.76$) with soil pH. WAS had moderately positive correlation with SOM ($R^2 = 0.33$) and negative correlations with bulk density ($R^2 = -0.28$) and soil pH ($R^2 = -0.34$).

The field saturated hydraulic conductivity largely depends on the pore size distribution and connectivity of macropores within the soil profile. Although soil physical properties and management practices influenced pore size distribution, the field saturated hydraulic conductivity exhibits relatively high spatial variability (Picciafuoco et al., 2019; Usowicz & Lipiec, 2021). We found that the field saturated hydraulic conductivity (for soil profile) had weak correlation between soil bulk density, SOM, WAS, and soil pH of five different soil depths (0–10, 10–20, 20–30, 30–60 and 60–90 cm). This regression correlation indicates that the field-saturated hydraulic conductivity is a more complex parameter and not governed by any specific soil parameters.

4 | CONCLUSION

Soil hydro-physical properties are affected by agricultural management and in turn affect crop growth, field water balance, soil microbiology, and nutrient cycling. Although significant research has been performed on the effects of tillage, CCs, and drainage on soil physical properties, very few have explored the interaction across these variables. In

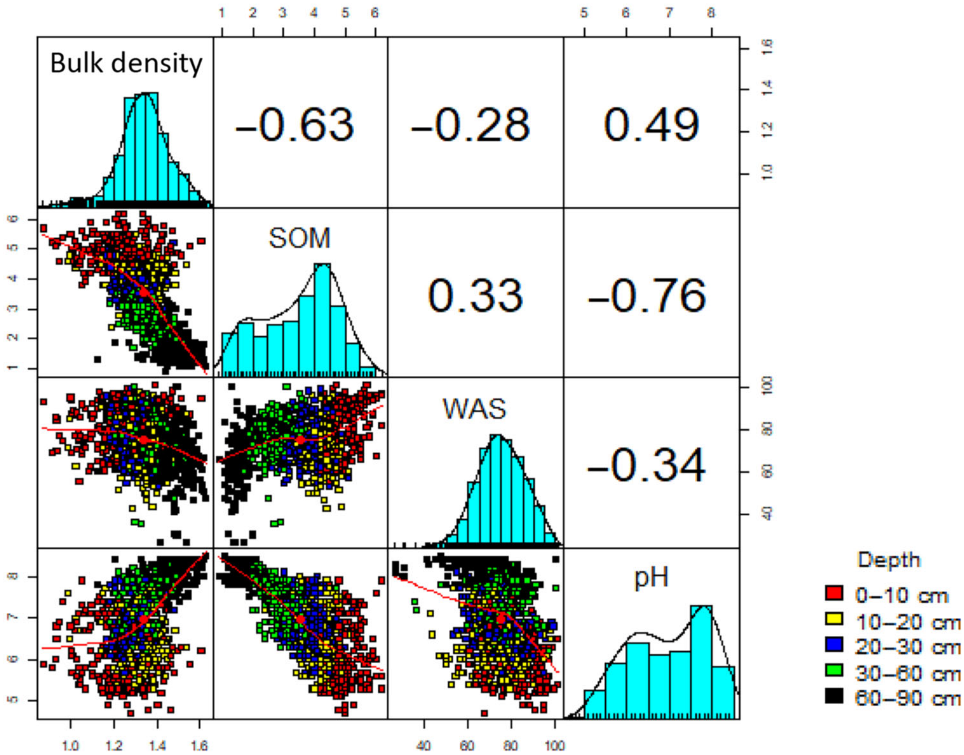

FIGURE 6 Scatter plot and correlation coefficient (*r*) between soil variables bulk density, soil organic matter (SOM), wet aggregate stability (WAS), and soil pH in the study region. In scatter plot, color points represent different soil sampling depths.

addition, there has been little investigation in the Northern Great Plains of the United States, which is likely to see continued conversion of both crop ground and non-crop ground to the corn and soybean rotation that is common in the midwestern United States.

This research demonstrated the impact that tillage has on soil physical and hydraulic properties, in particular, WAS, K_{fs}, and organic matter. More diverse crop rotation decreased bulk density and increased SOM and WAS. CCs (9 years after establishment) and tile drainage (6 years after establishment) had minimal impact on SOM, bulk density, WAS, and K_{fs} under silty clay loam and South Dakota climate conditions. Overall, the research demonstrated that agricultural management practices have some potential to alter and improve soil physical and hydraulic properties but did not demonstrate that stacking practices (NT plus CCs) had a significant effect. This may be due to the limited time that the CCs and tile drainage had been established in these plots, or it may be due to challenging growing conditions that prevented the effects of these practices from being fully realized since establishment.

As corn and soybean rotations continue to migrate north and west in response to climate and market drivers, it will be important to continue to identify practices and combinations of practices that increase resilience of agricultural systems to climate extremes. Although these management systems show promise and partially reflect past research, some results diverge from past research in other locations. This may indicate that a longer establishment period is needed in colder, drier climates, or these systems perform better in different soils. Further research is needed for longer periods of time in additional soils in the Northern Great Plains of the United States to identify agricultural systems that benefit farm productivity and environmental health in the face of a more extreme climate.

AUTHOR CONTRIBUTIONS

Ajoy Kumar Saha: Conceptualization; data curation; formal analysis; methodology; software; validation; visualization; writing—original draft; writing—review and editing. **John T. McMaine**: Conceptualization; data curation; funding acquisition; investigation; methodology; project administration; supervision; validation; visualization; writing—review and editing. **Todd Trooien**: Investigation; methodology; supervision; validation; writing—review and editing. **Peter Sexton**: Conceptualization; investigation; methodology; resources; supervision; validation; writing—review and editing. **Christopher Graham**: Investigation; methodology; supervision; validation; writing—review and editing.

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