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Comparison of Soil Properties between Paired No-till and Conventional Tillage Systems in Central Illinois

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ABSTRACT

Various studies have shown that no-till agriculture has the potential to improve soil moisture retention, structure, quality, and carbon sequestration. The objective of this study was to compare paired conventional tillage (CT) and no-till (NT) agricultural systems 8 to 10 years after conversion from CT to estimate the effects of NT management on soil properties in Central Illinois. Samples were collected from the upper 20 cm of the soil profile from 8 paired sites in Cass and Morgan Counties, Illinois. No-till soils showed significantly greater mean SMC, 13.4% (1.4, SE)%, compared to paired CT soils, 11.9 (1.2)%, which represented a 13.2% increase in NT compared to CT. No-till soils also showed significantly greater mean SOM, 4.5 (0.5)%, compared to CT, 3.7 (0.6)%, which represented a 20.1% increase in paired NT soils. No significant differences in soil BD or temperature were observed across the paired sites, which may have been related to the relatively short time since conversion to NT. Given these results, NT systems in this region show the potential for increasing soil moisture and water availability to crops, improving soil quality, and enhancing soil carbon sequestration in decadal time scales or less. Site-specific soil, topographic, climatic, environmental, and agronomic conditions should continue to be considered in order to determine the suitability of NT versus CT systems for distinct locations in this region.

Keywords: agriculture, bulk density, central Illinois, conventional tillage, no-till, soil organic matter, soil moisture

INTRODUCTION

Farmers use conventional tillage (CT) practices for many purposes including incorporating residues and fertilizers, increasing soil aeration and seed-bed temperature, breaking up clods, and controlling pests and soil-borne diseases (Buol, 2008; Sundermeier et al., 2011). Due to the complete inversion and mixing of surface soils, tillage is also beneficial for suppressing weeds and enhancing the accessibility of fertilizers to plant uptake (Gebhardt et al., 1985; Hobbs et al., 2008; Phillips et al., 1980). While CT has provided farmers with many benefits, it also has numerous drawbacks including: 1) increasing soil compaction and decreasing water infiltration and root penetration due to frequent tillage (Azooz and Arshad, 1996); 2) increased decomposition of soil organic carbon (SOC) and loss of CO_2 to the atmosphere (Lal, 2004; Varvell and Wilhelm, 2010; West and Post, 2002); 3) changes in soil microbial and microarthropod communities (Pieri et al., 2002; Smith et al., 2016); and 4) increased wind and water erosion due to tillage and the prevalence of bare soil (Brady and Weil, 2012; Gebhardt et al., 1985; Sun et al., 2011). In in response to concerns about CT, a University of Illinois agronomist, George McKibben, implemented a no-tillage agricultural system in the 1960s that left surface crop residues undisturbed. No-till (NT) has subsequently been defined as “a system of planting (seeding) crops into untilled soil by opening a narrow slot, trench, or band only of sufficient width and depth to obtain proper seed coverage. No other soil tillage is done” (Derpsch et al., 2010). Since its introduction, the amount of land in NT agricultural systems has increased dramatically throughout Illinois and the Midwest United States, as well as around the world due to its potential to reduce soil erosion and decrease cost of inputs and labor (University of Illinois Extension, 2006). In 2006, more cropland in Illinois was planted in NT than conventional tillage (CT) systems for the first time (University of Illinois Extension, 2006). In 2009 it was estimated that the quantity of land in NT worldwide was 111 million hectares (Derpsch et al., 2010). Recent estimates indicate that conservation tillage (including no-till, strip-till, and mulch-till) was used on approximately 70% of soybean, 65% of corn, 67% of wheat, and 40% of cotton farmland in the U.S. (Classen et al., 2018).

Despite the increases in the usage and adoption of NT management, many farmers still have reservations associated with this practice. For example, Gebhardt et al. (1985) reported that one of the barriers impeding the adoption of the NT system is the farmers’ perception of the trashy appearance of crop residues left in the fields. Others argue that drawbacks of NT management may include the following: 1) slower seed germination caused by lower seed-bed temperature; 2) greater need for pesticides to combat competition from weeds early in the growth cycle; 3) residues clogging seeding equipment; 4) less precise fertilizer application; and 5) higher risks of soil-borne diseases and pests (Hobbs et al., 2008; House et al., 1984; Phillips et al., 1980). No-till agriculture may also require large initial capital expenses for specialized equipment such as NT planters designed to operate through the heavier surface residues. However, long term savings from reduced fuel and labor costs often yield significant economic benefits to farmers and allow them to quickly recoup these capital expenses. Several studies have shown that over time, NT required less energy inputs and lower costs than CT, including less labor, less fuel, and lower maintenance and repairs due to fewer passes of machinery over the fields (Duiker and Myers, 2002; Gebhardt et al., 1985).

No-till systems also require different fertilizer and pest-management strategies, and some studies have noted greater herbicide and pesticide usage in NT than CT systems (Derpsch et al., 2010). Crop rotation is essential in NT fields to discourage the build-up of weeds, diseases, and pests (Pieri et al., 2002). A study by Sainju et al. (2011) reported that practices such as banded fertilizer application, higher seeding rates, variable planting and harvest dates, increased stubble height, and diversification of crops in rotations were effective practices for controlling weeds in NT treatments. Gebhardt et al. (1985) reported that applying fertilizer in the row at planting time increased crop yields under NT treatments and decreased contaminant loads in run-off compared to CT treatments. They also noticed less pesticide loss in run-off in NT fields than in CT fields. A recent study by Smith et al. (2016) indicated that NT fields had higher nutrient levels, distinct microbial communities, and more DNA sequences associated with key nitrogen cycling processes, suggesting that microbial communities in NT fields were more active in cycling nitrogen than CT fields.

In terms of erosion, the bare, exposed soil surfaces in CT systems are more susceptible to soil loss due to decreased soil aggregate size and soil surface roughness, as well as increase decomposition and degradation of SOM (Sun et al., 2010). Rainfall events have an adverse effect on bare soil common after harvest in CT systems by destroying soil aggregates and clogging soil pores. This causes soil sealing (crusting), decreased water infiltration, and ultimately increased run-off. The surface residue present in NT systems, by contrast, intercepts raindrop kinetic energy, encourages soil aggregate stability, maintains intact soil macropores, and increases infiltration, thereby decreasing run-off (Gruver, 2013; Hobbs et al., 2007; Kumar et al., 2012). Runoff from agricultural systems often contains sediment, dissolved nutrients, and chemicals from fertilizers, pesticides, and herbicides which degrades water quality in downstream watersheds. From a water conservation perspective, reduced soil erosion and run-off in NT systems is advantageous over CT systems (Gebhardt et al., 1985). Surface residues also protect soil from wind erosion and act as insulation to aid in moderating soil temperatures. The effect of NT management on soil temperature and delayed seed germination is dependent on soil characteristics and soil moisture content (Larney et al., 2003). Higher soil moisture has been observed in NT systems compared to CT due to greater infiltration through the undisturbed soil pore systems and reduced soil-water evaporation (Mitchell et al., 2012; Williams and Wuest, 2011).

Soil OM is considered a measure of soil quality, function, and fertility due to its roles in nutrient cycling and availability, improving soil aggregate stability, and increasing water-use efficiency (Burke et al., 1995; Hammerbeck et al., 2012; Varvel and Wilhelm, 2010). Some studies reported increased soil organic matter (SOM) and soil organic carbon (SOC) in NT treatments compared to CT in surface soils relative to greater depths (Christopher et al., 2009; Bianco-Canqui and Lal, 2008). In a study by Varvel and Wilhelm (2010) SOC stocks were greater in NT than in CT treatments at all depths. Greater soil nutrient stocks in NT treatments may decrease the amount of chemical fertilizers needed to produce maximum crop yields. Analysis by West and Post (2002) suggested that eliminating tillage in agricultural systems would maintain soil C sinks. They suggested that NT systems could not only increase SOC, but also result in the sequestration of atmospheric CO_2. Another study by Lal (2004) suggested that conversion to NT agriculture reduces C emissions by as much as 35kg C ha^{-1} per season compared to CT agriculture. Lal (2004) notes the importance of retaining SOC for soil moisture and drought management and concludes that SOC stocks remain in the soil as long as the NT management is maintained. Another recent study also reported that a single year of CT management following NT was enough to significantly disrupt mineral soil properties (Mukherjee and Lal, 2015). No-till management has also been shown to support soil microbial activity and earthworm populations that regenerate soil health and function (Pieri et al., 2002; Smith et al., 2016).

Many studies have suggested the need for considering site-specific soil, topographic, climatic, environmental, and agronomic conditions when determining the suitability of different tillage systems. The purpose of this study was to compare paired CT and NT agricultural systems to estimate the effects of NT agriculture on soil properties in Central Illinois. It was hypothesized that NT agriculture improves soil carbon sequestration and soil structure compared to CT. This would lead to higher SMC and SOM in NT compared to paired CT fields of this region due to a build-up and incorporation of crop residue into the soil and less soil disturbance. It would also lead to lower bulk density (BD) and soil temperature in NT compared to paired CT fields due to less compaction from fewer passes of farm implements over the surface and less exposure of the surface soils to the atmosphere.

MATERIALS AND METHODS

Site Description. This study was conducted approximately 21 km east of the Illinois River near the town of Arenzville, in southwest Cass County and northwest Morgan County, Illinois (Figure 1). The field sampling was conducted late in the growing season on 14-15 and 21-22 September 2013. The eight sites were agricultural fields of two different tillage treatments: No-till (NT) and conventional tillage (CT) agriculture and were planted in row crops, including corn (*Zea mays* L.), soybeans (*Glycine max* (L.) Merr.), and wheat (*Triticum* L.) (Figure 2 and Table

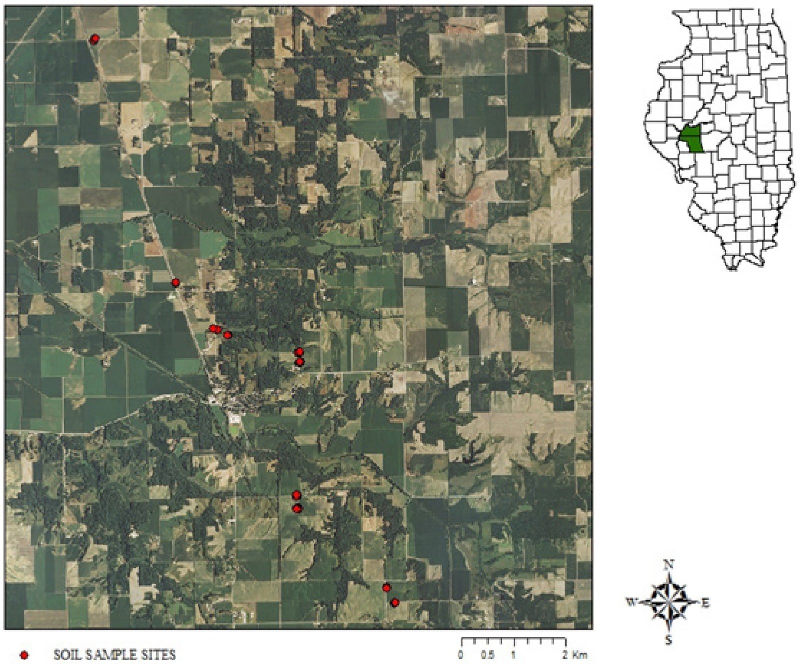

Figure 1. Land-use map of Cass and Morgan Counties, Illinois, with sample locations denoted in red dots. Land-use ortho-imagery was obtained from the USDA-FSA-APFO Digital Ortho County Mosaic (2012). A larger map of the State of Illinois with Cass and Morgan counties highlighted in green is included to the right of the figure.

Figure 2. Examples photos of paired sites sampled in this study: Site 4 (above) and Site 5 (below).

Table 1. Characterization of the tillage, crop type, and soils of the 8 study sites. Crop information was from visual observations and soil information was from the Natural Resources Conservation Service. Data from Site 1 was not included in the statistical analyses.

Site	Crop Conventional Tillage	Crop No-Till	Soil Order	Soil Series	Soil Tillage
1	corn	soybeans	Mollisols/Entisols	Littleton/Plainfield	silt loam/sand
2	wheat	soybeans	Mollisols	Sparta	loamy sand
3	corn	soybeans	Mollisols	Worthen/Lawson	silt loam
4	soybeans	corn	Mollisols	Ipava	silt loam
5	soybeans	soybeans	Alfisols	Rozetta	silt loam
6	soybeans	corn	Alfisols	Rozetta	silt loam
7	corn	corn	Mollisols	Ipava	silt loam
8	corn	corn	Mollisols	Ipava	silt loam

1). The NT sites were transferred from CT to NT within 8-10 years of the time of sampling. The eight study sites represented three soil orders (Mollisols, Alfisols, and Entisols), seven soil series (Ipava, Rozetta, Sparta, Worthen, Lawson, Plainfield, and Littleton), and three textural classes (silt loams, loamy sands, and sands) (STATSGO 2012). After the field sampling was completed, site one was dropped from the statistical analyses because it was the only site to contain Entisols.

Field Measurements. The sampling design included eight paired sites that consisted of a NT field directly adjacent to a CT field (Figures 1 and 2). Five soil cores were taken approximately 3-4 m apart along a transect inside each field (end rows were avoided to prevent sampling in soils with greater compaction) for a total of 80 soil cores (8 replicate sites * 2 tillage treatments * 5 samples = 80 cores). Cores were collected from the upper 20 cm of the soil profile in plastic sleeves within a 4.8 cm diameter piston corer and stored in a cooler to transport back to the laboratory. The soil temperature (°C) at a depth of 5 cm was recorded at each soil core location using a digital thermometer (Hanna Instruments, Smithfield, RI) at the time of sampling. A Trimble GPS unit (Juno SB, Trimble Navigation Limited, Sunnyvale, CA) was used to record the location of each soil core. Ortho-imagery for reference (USDA-FSA-APFO Digital Ortho County Mosaic 2012), and soil data map layers were created in ARCMap (Version 10.1, ESRI Corporation, Redlands, CA) (Figure 2) to delineate the soil orders and series of the study sites.

Laboratory Measurments and Calculations. In the lab, soil cores were removed from the plastic sleeves and visible pebbles, roots, twigs, and other larger organic matter were removed. The samples were placed in a drying oven at 105°C for 24 hours. The SMC (%) was calculated using the wet and dry masses of the soil. The BD was calculated with the dry mass of soil and the volume of the corer (Bookout and Bruland, 2019).

The oven dried soil cores were used for the loss on ignition (LOI) procedure to determine soil organic matter (SOM). Dried soil was weighed into crucibles and placed into a muffle furnace. The muffle furnace was heated at 450°C for four hours (Bookout and Bruland, 2019; Bruland and Richardson, 2006). The SOM (%) was calculated using the uncombusted and combusted masses of soil (Bruland and Richardson, 2006).

Statistical Analysis. One-tailed paired *t*-tests for sample means (at $\alpha = 0.1$) were conducted to determine significant differences between the tillage systems for each parameter. Data were then reorganized by soil order and tillage and a paired t-test for sample means was conducted for all parameters within each soil order. Pearson product moment correlations were used to assess correlations among the measured soil parameters at the seven NT sites and at the seven CT sites. The percent difference was calculated between the means for both treatments for each parameter with the formulas:

$$\%\,Difference = \frac{(NT\ Mean - CT\ Mean)}{CT\ Mean} \times 100 \quad (1)$$

$$\%\,Difference = \frac{(CT\ Mean - NT\ Mean)}{CT\ Mean} \times 100 \quad (2)$$

Formula 1 was used to calculate percent difference for SMC, SOM, and BD. Formula 2 was used to calculate percent difference for soil temperature.

RESULTS

Soil Mosture Content. Soil moisture content across all sites ranged from 5.1 to 17.2%. The NT mean SMC, 13.4 (1.4, SE)%, was significantly higher than the CT mean SMC, 11.9 (1.2)% (P = 0.04) (Figure 3). The NT soils showed a 13.2% increase in SMC over the paired CT soils. When sorted by soil order, the NT mean SMC for Mollisols was 13.7 (1.9)% and the CT mean SMC for Mollisols was 12.8 (1.5)%. The NT mean SMC for Alfisols was 12.7 (2.3)%, and the CT mean SMC for Alfisols was 9.4 (0.5)%. The difference in SMC within soil orders and across tillage practices were not statistically significant.

Soil Organic Matter. Soil organic matter across all sites ranged from 1.5 to 6.5%. The NT mean SOM, 4.5 (0.5)% was significantly higher than the CT mean SOM, 3.7 (0.6)% (P = 0.02) (Figure 4). The mean SOM was 20.1% higher in the NT soils than the CT soils. When sorted by soil order, the mean SOM for Mollisols was greater than the mean SOM for Alfisols for both treatments (Figure 5). The NT mean SOM for Mollisols was 4.8 (0.7)%, and the CT mean SOM for Mollisols was 4.1 (0.8)%. The NT mean SOM for Alfisols was 3.8 (0.8)%, and the CT mean SOM for Alfisols was 2.9 (0.2)%. SOM was significantly higher in the NT Mollisols than the CT Mollisols (P = 0.06). There was no significant difference in SOM between tillage practice in the Alfisol order.

Bulk Density. Soil BD across all sites ranged from 1.17 to 1.72 g cm^{-3}. The NT mean BD was 1.37 (0.04) g cm^{-3}, and the CT mean BD was 1.35 (0.04) g cm^{-3}. There was no difference in the means between the two treatments (P = 0.33), nor was there a statistically significant difference between tillage practices when the data was sorted by soil order.

Soil Temperature. The soil temperature across all sites ranged from 16.6 to 28.9°C. The NT mean temperature was 20.0 (1.1) °C, and the CT mean temperature was 20.3 (1.2) °C. While individual site mean values were slightly higher in the NT compared to their CT pairs, the overall NT mean temperature was not significantly different than the CT mean temperature (P = 0.20). The difference in soil temperature between tillage practices was also not statistically significant when sorted by soil order.

Correlations. For both tillage practices, there was a positive Pearson correlation between mean SMC and mean SOM (Tables 2 and 3). The correlation between SMC and SOM was slightly higher in the CT systems than the NT

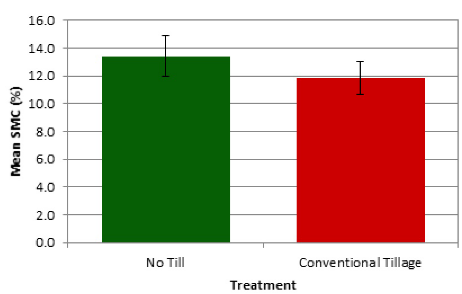

Figure 3. No-till (NT) versus conventional tillage (CT) means (±1 standard error) for soil moisture content (SMC %).

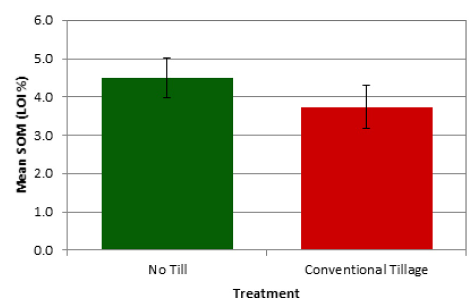

Figure 4. No-till (NT) versus conventional tillage (CT) means (±1 standard error) for soil organic matter (SOM %).

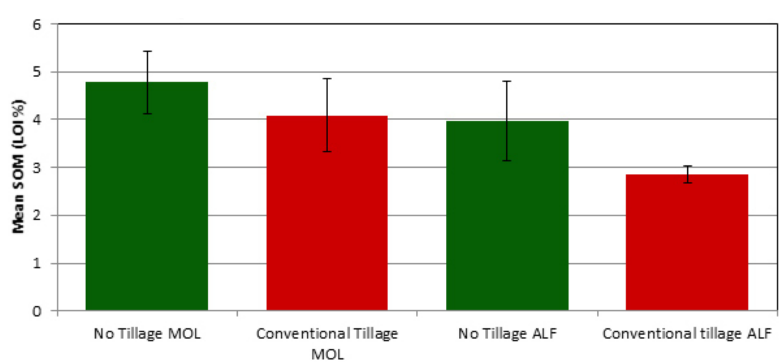

Figure 5. No-till (NT) versus conventional tillage (CT) means (±1 standard error) for soil organic matter (SOM) grouped by soil order: Mollisols (MOL) and Alfisols (ALF).

systems (Tables 2 and 3). There was a positive correlation for both systems between BD and temperature. No other correlations among soil properties were observed.

Table 2. Pearson product moment correlations for no-till (NT) means of sites 2-8.

No-till	MEAN SMC (%)	MEAN SOM (%)	MEAN BD (g/cm³)	MEAN TEMP (°C)
MEAN SMC (%)	1	0.65	-0.62	-0.93
MEAN SOM (%)		1	-0.58	-0.76
MEAN BD (g/cm³)			1	0.76
MEAN TEMP (°C)				1

Table 3. Pearson product moment correlations for conventional tillage (CT) means of sites 2-8.

No-till	MEAN SMC (%)	MEAN SOM (%)	MEAN BD (g/cm³)	MEAN TEMP (°C)
MEAN SMC (%)	1	0.89	-0.62	-0.77
MEAN SOM (%)		1	-0.65	-0.58
MEAN BD (g/cm³)			1	0.75
MEAN TEMP (°C)				1

DISCUSSION

Soil Mosture Content. The results of this study showed that mean SMC in NT soils was higher than in CT soils. These results were expected primarily due to the higher levels of surface residue and improved soil structure and organic matter in NT fields. Surface residue has been regarded as a strategy for conserving SMC (Patrignani et al., 2012). Surface residues increase SMC through reduced evaporation by shading the soil surface which, in turn, lowers surface soil temperature and reduces wind effects (Mitchell et al., 2012). Studies in Nebraska showed that tillage often dries the soil to the depth of the plow layer (Mitchell et al., 2012; van Donk, 2010). A study by Nielsen et al. (2005) showed a 20% increase in precipitation storage efficiency when comparing CT soils to NT soils. This increase was attributed to greater shading of the soil surface, cooler soil temperature, decreased wind speed at the soil surface, and greater soil surface protection from solar radiation, raindrop impact, and subsequent crusting.

Long-term NT practices keep soil pore structure and continuity intact, which contributes to higher water infiltration rates in NT than in CT. Soil macropores that are undisturbed by tillage facilitate runoff by providing inlets where moisture from precipitation is absorbed (Azooz and Arshad, 1996; Williams and Wuest, 2011). Kumar et al. (2012) found that improved soil structure and higher SOM under NT treatments expanded the available water capacity of soils which increased the proportion of water available to crops. In some cases, reduced soil water evaporation led to a reduction in the need for crop irrigation and therefore showed a reduction in costs per area associated with irrigation (Mitchell et al., 2012; van Donk, 2010).

Soil Organic Matter. The mean SOM in NT fields was significantly higher than the mean SOM in CT fields. This result illustrated the potential of NT cropping systems in this region for increased soil fertility, soil quality, and preservation of soil organic carbon (SOC). The 20.1% increase in SOM in the NT sites versus the CT sites in approximately one decade of NT management indicated that every 13 years, NT would increase SOM by approximately 1% compared to CT if the SOM accumulation rates in the NT systems continued on a positive linear trajectory. It appears that SOM in the NT systems is supplemented by crop residues that remain on the soil surface rather than being plowed under and provide more SOC and other nutrients for plant uptake. Maintaining a consistent stream of SOM inputs is important to soil fertility and crop productivity (Neill, 2011). As expected, the results of this study showed a positive correlation between SMC and SOM. Long term studies in Ohio showed that NT systems had positive effects on SOM, SOC, soil structure, and aggregate stability, as well as SMC when compared to CT, where disruption of soil aggregates and increased soil aeration lead to C and N reduction through decomposition (Elliot and Coleman, 1988; Kumar et al., 2012). Grandy and Robertson (2007) found positive correlations between SOC accumulation and soil aggregate size. They also found positive correlations between root growth and quality of residues and aggregate stability, suggesting that surface residues from NT systems improve soil structure as well as SMC and SOM. They emphasized the need to protect stabilized SOM from destruction by tillage in order to maintain a level of available SOC and N stored near the surface.

When sorted by soil order, the results for SOM were inconsistent. Specifically, for Mollisols, the NT mean was greater than the CT mean (P = 0.06). For Alfisols, on the other hand, no significant difference was observed between treatments. The lack of significant results for Alfisols may be attributed to the small sample size as this order was only represented in two site locations.

Bulk Density. In this study, unlike SMC and SOM, the mean BD in NT systems was not higher than the mean BD for CT systems. This contrasts with previous studies by Azooz and Arshad (1996) that reported BD was lower for NT soils than for CT soils. It has been shown that the fuller residue cover in NT management facilitates higher infiltration rates than in CT resulting from the flow of water through macropores and reduced surface sealing from rainfall and wind effects (Azooz & Arshad, 1996; Patrignani et al., 2012). A study by Grant and Lafond (1993) reported that BD was higher in NT management compared to CT in the top 0-10cm of the soil profile. This result was possibly due to loosening of soil by tillage operations in the plow zone of the CT fields, yet greater BD was observed in CT soils than in NT soil layers below the tillage depth. A study of CT versus NT systems in Spain with Vertisol soils reported no differences in BD after 25 years of switching from CT to NT (Lozano-Garcia and Parras-Alcantra, 2014). It has been noted that tillage is not the only factor affecting BD. Other influences that affect BD and soil compaction include soil texture, aggregation, SOM levels, cropping sequence, and the season in which the samples were taken (Grant and Lafond, 1993; Varvel and Wilhelm, 2010).

Soil Tempterature. In this study there was no significant difference in mean soil temperature between NT and CT systems. These results were inconsistent with results presented in other studies that demonstrated a lower soil temperature for NT compared to CT soils (Andrade et al, 2010; Larney et al., 2002; Mitchell et al., 2012). The results for temperature may have been affected by seasonal temperature conditions, by the time of day of the sampling (soil temperatures tend to increase through the daylight hours), or by other factors such as residue amount and type. Generally, in NT systems, surface residues reduce soil temperature due to increased shading, greater water infiltration, and higher SOM and SMC (Mitchell et al., 2012). Larney et al. (2002) reported that soil temperature of NT systems is also dependent upon residue characteristics such as quantity, age, height, placement, and previous crop type. Andrade et al. (2010) noted that the decreasing of mean temperatures between different tillage treatments was less consistent in warmer seasons and that crops were more affected by temperature conditions in their earlier stages of development. Also, surface residues in NT systems were found to have a moderating effect on soil temperature during extremely cold periods (Larney et al., 2002).

SUMMARY

Maintaining and improving soil conditions is crucial to the sustainability of soil fertility and the productivity of agricultural systems in the Midwestern U.S.A. and around the world. The results of this study supported the hypothesis that SMC and SOM would be higher in NT treatments compared to CT treatments in agricultural fields in central Illinois. No-till systems in this region and elsewhere have shown a potential for improving soil moisture status as well as SOM, soil quality, and fertility. Under drought conditions, NT may also increase water availability to crops. Also, due to their greater SOM, NT systems have the potential to sequester increased amounts of soil C and lower atmospheric C emissions from agricultural systems, which is becoming an increasing concern from a climate change perspective. The hypothesis that BD and soil temperature would be lower in the NT compared to CT systems was not supported by the data. This may be explained by a number of factors including: 1) NT operations had only been in place for 8-10 years at the time of sampling; 2) seasonal or diel variation in soil temperature values; and 3) differences in BD and temperature associated with soil texture and crop and residue characteristics. The results of this study support the idea that in less than a decade after conversion, NT systems were effective in increasing SMC and SOM which would directly lead to a variety of agricultural and environmental benefits including improved soil moisture retention, improved soil quality ad fertility, improved crop yields, and enhanced carbon sequestration in the soil profile.

Future research in this region could be conducted with larger sample sizes at each field to provide greater statistical power to detect differences in soil properties across CT and NT systems. Soil cores could also be collected from different depths to consider the effects of NT treatments on the different zones in the soil profile. If the field sampling were performed during fallow seasons as well as the growing season, results might also account for seasonal variability in temperature and moisture, shading effects from crops, and variation in crop types. Identifying site pairs that have a longer duration of NT management would also be advised in order to determine longer-term differences in soil properties of the two cropping systems. Other laboratory testing methods such as combustion methodologies for soil carbon, carbon fractionation methods, or diffuse reflectance or nuclear magnetic resonance spectroscopy methods could better quantify the differences in soil organic matter and carbon resulting from the two management approaches.

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