LONG-TERM tillage management affects claypan soil properties and soybean cyst nematode

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Abstract

Use of cover crops with conservation tillage systems can affect soil chemical and biological properties. The objectives of this research were to evaluate the effect of long-term (1994-2016) no-till (NT) and reduced-till (RT) cropping systems on soil chemical properties and soybean cyst nematode (SCN, *Heterodera glycines* Ichinohe) egg population densities on claypan soils in northeast Missouri. Treatments included a corn (*Zea mays* L.)-soybean [*Glycine max* (L.) Merr.]-wheat (*Triticum aestivum* L.) rotation with three tillage/cropping systems: 1) no-till corn-soybean-wheat with double-crop soybean (NTDCS), 2) no-till corn-soybean-wheat with frost-seeded red clover (*Trifolium pretense*) cover crop (NTFSC), and 3) reduced-till corn-soybean-wheat (RT). Each crop (corn, soybean, and wheat) and tillage system (NTDCS, NTFSC, and RT) was represented every year in nine large plots and replicated four times. Soil was sampled to a 15 cm depth to evaluate soil chemical properties (1994, 2002-2016) and soybean cyst nematode (SCN) egg densities (2002-2015). Soil test pH_s, P, and K were ranked RT=NTDCS>NTFSC, RT>NTDCS=NTFSC, and RT>NTFSC>NTDCS, respectively. Long-term NTFSC cover crop had the greatest SOM levels in four of the sixteen years. When combined over years, SCN egg densities were lowest in NTFSC following corn, soybean, or wheat which indicates the benefit of NT and extended crop rotations to help managed this pest.

Core Ideas

- Lowest soybean cyst nematode (SCN) egg population densities were in no-till (NT) cover crop system.
- Reduced tillage (RT) had greater levels of SCN in all rotational crops than NT cover crop system.
- NT cover crop system had greatest soil organic matter followed by NT double-crop soybean.

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- Soil test P and K were 8 to 22% higher in the top 15 cm of soil with RT compared to NT.

Introduction

Mechanical tillage mineralizes soil organic matter (SOM), manages weeds, loosens compacted soil, and develops a seedbed that aids mechanical planting and seed-to-soil contact (Ofori, 1993; Ryan et al., 2011). Crop residue management, rotation practices, and changes in tillage prompt alterations in soil properties (Govaerts et al., 2007) and influence the timing and amount of nutrient cycling (Martens, 2001). Slight deviations in cultural farming practices can have significant long-term results; therefore, long-term experiments are necessary to quantify these effects under fluctuating weather conditions (Varvel, 2006).

Soil productivity is affected by tillage systems which can subsequently impact soil properties (Martens, 2001). Multiple deep tillage passes, specifically prior to corn, were common historically in Northeast Missouri affecting weed growth, soil crusting, crop establishment, surface water runoff, and compaction (Whitaker et al., 1966). Since, research on reduced and no-till cropping systems have intensified with an increased focus on the importance of soil conservation (Ghidey & Alberts, 1998). The effects of intensive tillage can amass over time leading to compaction, degradation of SOM, loss of soil physical properties, and development of a hardpan (Al-Kaisi and Hanna, 2004) which have a negative effect on plant growth and crop production. In addition, Stecker (1993) reported immobilization of surface applied N was an indirect result of increased crop residue in no-till production systems in claypan soils.

Claypan soils include over 4 million hectares in the Midwest U.S. (Buckley et al., 2010) and are characterized by an abrupt, slowly permeable subsoil layer with much greater clay content than overlaying horizons (SSSA, 2008). Previous research on claypan soils has shown that response to crop management practices is often different from soils with no claypan. Claypan soils are poorly drained, have shallow rooting depths and limited water availability, and require additional N management for high yielding crops relative to soils without a claypan (Ghidey and Alberts, 1998; Sweeney, 2017). In southeastern Kansas, a 20-year study of conventional, reduced, and no-tillage in a soybean-grain sorghum [Sorghum bicolor (L.) Moench] rotation on a claypan soil reported conventional and reduced tillage treatments had no significant effect on soil pH in the top 15 cm or on extractable P or K from the surface to a 7.5 cm depth, compared to soil tests at project initiation (Sweeney, 2017). The no-till treatment had significantly lower soil test P and K, and SOM at a 7.5-15 cm depth. In the absence of a claypan soil, soil test K stratification in long-term no-till cropping systems in Kentucky was reported along with enhanced corn K uptake in comparison to conventional tillage that included a moldboard plow (Blevins et al., 1986). In addition to nutrient stratification, no-till's effect on field conditions at planting can be challenging for establishment of crops such as corn (Belknap and Nelson, 2021). Soils that are not tilled or that are covered in residue often dry and warm up more slowly (Buchholz et al., 1993; Drury et al., 1999). No-till soils had cooler soil temperatures and higher moisture levels during the spring (Al-Darby and Lowery, 1987; Drury et al., 1999) which may be the reason cereal grains and corn produced on poorly drained soils were lower yielding compared with tilled soils (DeFelice et al., 2006; Belknap and Nelson, 2021).

Soil organic matter is an important soil property that provides physical benefits such as increased water holding capacity and improved water infiltration along with biological benefits which can help suppress disease and pests (Fenton et al., 2008). As SOM decomposes, plant nutrients are mineralized and can be available for plant uptake (Martens, 2001). Composing approximately 58% of the mass of SOM, soil organic carbon (SOC) is often used to estimate SOM (Griffin, 2017). A corn-soybean rotation with no-till, chisel plow, and moldboard plow treatments evaluated for eight years in southern Illinois reported SOC levels (0-75 cm) in no-till plots with and without a cover crop remained similar; therefore, the cover crop system did not sequester significant levels of SOC (Olson et al. 2014). In a separate twelve-year study in southern Illinois, Olson et al. (2014) reported chisel plow treatments decreased SOC (0-75 cm) in both cover and non-cover crop treatments. In moldboard plow treatments, significant losses of SOC occurred in surface soil layers (0-15 cm) in cover and non-cover crop treatments. Overall, moldboard plow treatments had a numerical loss of SOC in comparison to SOC at project initiation (0-75 cm). In an 18-year study in Nebraska, Varvel (2006) reported increased levels of SOC (449 kg ha^{-1}) in the top 30-cm of soil in rotational cropping systems for the first eight years. An increase in tillage depth from 10-15 cm to 15-20 cm in the subsequent 10 years resulted in a loss of SOC. In long-term research, crop rotations with increased complexity, especially those including a perennial legume, have been reported to increase SOC levels (Russell et al., 2005; Varvel, 2006; Wilts et al., 2004). Understanding the long-term effects of management decisions such as selected tillage and crop rotations on SOM levels are important to help farmers improve the resiliency of cropping systems especially in claypan soils.

Soybean cyst nematode (SCN, *Heterodera glycines* Ichinohe) is a major pathogen of soybean causing an estimated $1.2 billion in losses yearly in the U.S. (Koenning and Wrather, 2010). Soybean cyst nematode egg population densities can be affected by tillage, water management, cover crops, weed control, cultivars (resistant or non-resistant), and soybean maturity and planting date (Niblack and Chen, 2004). In a 2015 and 2016 study evaluating SCN populations throughout Missouri, Howland et al. (2018) reported SCN was detected in 88% of soil samples (82% in upstate Missouri) which was a 38% increase from a 2005 evaluation (Mitchum et al., 2007). Over 75% of the samples had egg counts above the level at which yields may be significantly reduced. Winter annual weeds, such as purple deadnettle (*Lamium purpureum* L.), henbit (*Lamium amplexicaule* L.), shepherd's purse [*Capsella bursa-pastoris* (L.) Medik], and field pennycress (*Thlaspi arvense* L.) are common in no-till systems and have been reported to host a complete reproductive life cycle of SCN in greenhouse scenarios (Creech et al., 2007; Venkatesh et al., 2000). Though SCN has also been reported to complete a reproductive lifecycle on purple deadnettle in field conditions, environmental conditions for winter annual weeds and SCN reproduction do not always align (Creech and Johnson, 2006; Creech et al., 2005; Hill and Schmitt, 1989). Cover crops have been reported to reduce winter annual weeds (Barnes and Putnam, 1983; Myers et al., 2015; Teasdale et al., 1991) which could affect pests such as SCN.

Management of SCN is an important biological consideration when evaluating tillage and cover crop systems. In short-term experiments in upstate Missouri, the effects of cover crops and fall applied weed control programs on SCN over a two-year and two-location experiment showed limited effects on SCN egg densities (Nelson et al., 2006). It is recommended that non-host cover crop species be used to help manage SCN (Hershman and Bachi, 1995). In a review, Niblack and Chen (2004) reported that an ideal cover crop should reduce or suppress nematodes through multiple modes and can do so by being non- or poor hosts, producing inhibitory or toxic allelochemicals, trapping nematodes, or providing niches for antagonistic organisms. No long-term research has evaluated cover crops for their impact on soil properties and SCN in claypan soils compared to reduced tillage. Therefore, the objective of this research was to evaluate the effect of long-term tillage and cropping systems management on soil chemical properties, SOM, and SCN egg densities.

Materials and Methods

A long-term cropping systems site was established in 1994 at the University of Missouri Greenley Memorial Research Center near Novelty (40° 01' 8.56"N, 92° 11' 21.20"W). The study design was a randomized complete block with treatments arranged in a split-plot with three rotational crops (corn, soybean, and wheat) as the main plot and three tillage systems as the sub-plot. The sub-plot tillage systems were as follows: 1) no-till corn-soybean-wheat with double-crop soybean following wheat (NTDCS), 2) no-till corn-soybean-wheat with frost-seeded red clover (cover crop) into wheat (NTFSC), and 3) reduced-till corn-soybean-wheat (RT). All three of the crops in the cropping systems were represented each year in nine large plots (9.1 x 91 m) and replicated four times. The management year was defined by any management action that was implemented to affect the crop harvested in the year yields were determined. Field and crop management information of each crop was described in Belknap and Nelson (2021). Although specific dates were occasionally not available, fall tillage occurred each year and spring tillage occurred prior to planting the RT treatment.

The main soil series at the site was a Kilwinning silt loam (fine, smectitic, mesic Vertic Epiaqualfs). Soil samples (composite of 10 sub-samples) were collected to a 15-cm depth using a stainless-steel push probe from the main plots prior to the establishment of the site in 1994 (Table 1), and soil samples were collected annually from individual plots in early to mid-March 2002-2017 before planting to evaluate the effects of cropping systems (sub-plots) on soil chemical properties (Table 2). Soils were analyzed using standard methods (Table S1) of the University of Missouri Soil and Plant Testing Laboratory (Nathan et al., 2012). A subsample of the soil collected from each plot was also analyzed for SCN egg densities (2002-2015) (Table S1) and HG type was determined in the spring of 2004 and 2015 using standard procedures (Mitchum et al., 2007; Niblack et al., 2002).

Data from 15 years of soil samples and 14 years of SCN egg densities were analyzed using the PROC GLM model using SAS v9.3 statistical program (SAS Institute, 2013) to determine significant treatment effects. Year and treatment were considered as fixed effects and replication was a random effect. Before the analysis, variables were tested for normality of data, and based on those results, no data transformations were performed. Soybean cyst nematode egg population densities prior to planting corn, soybean, or wheat for no-till double-crop soybean, no-till frost-seeded clover, and reduced till cropping systems were analyzed separately for each crop. Data were combined over years (2002-2016) since there was an absence of a significant interaction between cropping system and years. Soybean cyst nematode (SCN) egg population densities prior to planting soybean in no-till double-crop soybean (NTDCS), no-till frost seeded clover (NTFSC), and reduced tillage (RT) cropping systems in a corn-soybean-wheat rotation were analyzed and reported by individual years over time to illustrate changes in population densities following extended crop rotations and HG analysis. Organic matter measured prior to planting corn was reported for individual years since it followed the frost-seeded red clover cover crop in wheat. Evaluation of soil test values focused on differences in tillage systems data; therefore, data were pooled over crops prior to analysis. Means were separated using Fisher's Protected LSD (P=0.05 or P=0.1) and letters or asterisks indicate significant differences among treatments. Similar letters indicate no significant differences between treatment means.

Results and Discussion

Soil Chemical Properties

At the initiation of this experiment, no significant differences in soil chemical properties were observed (Table 1). After the establishment of no-till and cover crops, differences in soil properties between NT and RT have been reported (Granatstein et al., 1987; Karlen et al., 1994; Schmidt et al., 2018). Soil data were collected annually beginning in 2002, analyzed, and combined (Table 2) over years (2002-2016) since there was no significant year*cropping system interaction (P=0.2005 to 0.9994). Significant differences in soil test pH_s, P, and K occurred between cropping systems ($P \leq 0.05$). Soil pH_s was 0.07 units greater in RT and NTDCS compared to NTFSC. Decomposition of SOM and nitrification of ammonia-based fertilizers produces H^+ (Havlin et al., 2014) and can contribute to a decrease in soil pH over time (Tables 1 and 2) which is pertinent since no additional lime had been applied during the 25-year time period (1994-2016). Rengel (2003) reported H^+ production from red clover to be 128-180 cmol kg shoot^{-1} which may explain lower pH values with the clover cover crop compared to the other cropping systems. A three-year central Missouri study of continuous corn, continuous soybean, and corn-soybean rotation examining tillage practices (moldboard plow and NT) and cereal rye cover crop effects on soil properties reported crop rotation and cover crop implementation did not affect soil pH; however, tillage increased soil pH levels in one year of the study (Haruna and Knongolo, 2019).

Stratification is the non-uniform vertical distribution of soil properties within a soil profile and occurs more frequently in no-till soils due to the lack of mixing, loosening, and inverting that occurs in tilled soils (Blevins et al., 1986; Deiss et al., 2021). There is little research on tillage dependent nutrient stratification on specifically claypan soils (Sweeney, 2017). Soil test K was greater in RT than in NTFSC and NTDCS, and greater in NTFSC than in NTDCS (Table 2). Similarly, the RT cropping system had higher levels of soil test P than NTFSC or NTDCS. However, a long-term no-till study in Maryland reported there was increased plant available P in various cover crop treatments, especially those including radishes, compared to winter fallow treatments (Grove et al., 2007). In an Iowa study, 3.5 times greater soil test P and K values were in the upper 5 cm of soil compared to the 5 to 15 cm zone in ridge and no-till cropping systems (Robbins and Voss, 1991). In NT systems, Grove et al. (2007) reported greater P and K in the top 15 cm of soil when compared with a fall chisel plow and disk system, which was counter to our results. Following cover crop termination, cover crop decomposition releases P and K back into the soil. Therefore, P and K, which are relatively immobile soil nutrients, are deposited back into the upper layers of the soil profile. In no-till systems, P and K can become stratified (Sweeney, 2017) which results in the accumulation of nutrients in the upper soil profile unlike systems that include tillage which mixes soil. While there is specific research the impact of clover on N mineralization (Breland, 1994; Vallancourt et al., 2018), less is known on the impact of a clover cover crop on soil test P and K. Stratification of P and K in the NT systems may have been diluted due to waterlogging of claypan soils which may have leached nutrients deeper than the soil depth tested (15 cm) resulting in greater amounts of P and K in RT systems due to incorporation and increased crop residue breakdown. Different soil testing depths have been reported for no-till systems and may need to be evaluated to determine if there was stratification of nutrients in the topsoil similar to other claypan soil research (Sweeney, 2017), since soil samples at the 15 cm depth indicated no differences among treatments including a grain sorghum and soybean rotation in southeast Kansas.

Soybean P and K removal is generally higher per unit of grain produced than corn (Nathan et al., 2006). In the NTDCS cropping system, soybean was planted twice in a three-year rotation whereas in RT and NTFSC soybean was planted only once. Therefore, lower levels of soil test K were expected in NTDCS since nutrient management was static across all cropping systems and there was greater overall removal with NTDCS grain yields compared to RT or NTFSC. When combined over years (1994-2016), NTDCS and NTFSC soybean yields were significantly greater compared with RT systems, wheat yields were greatest with RT, and corn yields were lowest with NTFSC and equally greater with RT and NTDCS, but corn and wheat yields were generally greater with RT (Belknap and Nelson, 2021). Phosphorus and K fertilizer was managed similarly among cropping systems; therefore, the NTDCS cropping system had higher nutrient removal rates in overall grain production which probably affected soil test P and K amounts.

Niblack and Chen (2004) reported that P, K, Mg, and Ca may be altered in the soybean plant by SCN infection and that yield variably was affected by the addition of these nutrients in soils infested with SCN. Greater amounts of soil test P and K in infested soils may decrease SCN population densities while lower rates of P and K in infested soils may increase SCN populations (Leudders, 1979). Overall, soil test P and K were optimal in this research (Nathan et al., 2012). Soil test values from this study were ranked RT>NTFSC=NTDCS for P and RT>NTFSC>NTDCS for K (Table 2). Interestingly, SCN egg population densities were low from 2002 to 2006 (Table 3). It was not until 2007 that possible yield affecting SCN egg densities were observed in the NTDCS system. Egg population densities, regardless of the subsequent rotational crop, were greatest in NTDCS. Prior to planting soybean or wheat, egg population densities were equally greatest in RT and before corn egg populations were ranked NTDCS>RT>NTFSC (Figure 1). This was probably due to the transport of SCN eggs with tillage equipment from infested fields to this field over time.

There was a significant interaction between cropping system and year for organic matter; therefore, data were reported over time. Significant differences between cropping systems for soil organic matter (SOM) (P=0.05) occurred in 2003, 2005, 2008, and 2012 (Figure 2). In 2003, 2008, and 2012, NTFSC and NTDCS had 0.8 to 3.0 g kg^{-1} greater SOM levels than RT. In 2005, SOM in NTFSC was 6.3 and 6.8 g kg^{-1} greater than in RT and NTDCS, respectively. While 2005 and 2012 were extremely dry in the spring and summer, 2003 and 2008 were wet through the summer months (Singh and Nelson, 2021). Extreme weather conditions could affect the variability observed in organic matter levels in this research and affect soil functions (Baveye et al., 2020). Soil organic matter averaged over all the cropping systems and years evaluated (2002-2016) was significantly different and was ranked NTFSC (33.6 g kg^{-1}) > NTDCS (32.4 g kg^{-1}) > RT (31.6 g kg^{-1}). Several other studies have reported cropping systems that included a cover crop had increased SOM (Buchholz et al., 1993; Bowman et al., 2007).

It is likely that higher SOM levels in the NT systems, were a result of four crops in three years compared to RT which experienced three crops in three years along with the tillage component that is known to affect SOM over time. No-till DCS and NTFSC soil OM were equally highest in all years excluding 2005 where NTFSC was greater than NTDCS. We were surprised that after 22 years differences in soil OM were not more pronounced. Finally, our research also indicated that soil OM levels weren't static over time with extensive yearly variability with the cover crop system with no clear trend except extreme droughts were observed in 2005 and 2012.

Soybean Cyst Nematode

In 2002, no SCN eggs were detected in this experiment; therefore, no HG type could be determined (Table 3). Monitoring of SCN continued until adequate egg densities were present to determine the HG type in 2005 (Type 1.2.5.7). The last SCN HG tests were determined in 2015 when SCN were no longer monitored from this site and it was determined to be Type 1.2.4. In more than 95% of currently available SCN resistant soybean varieties, the resistance source is PI 88788 (HG type test indicator line 2) (Tylka and Mullaney, 2015). In years that a SCN resistant soybean variety was planted (Belknap and Nelson, 2021), it is unlikely that it protected the crop against SCN. However, a longer rotation period between soybean plantings with NTFSC maintained low (<100 eggs 250 cm^{-3} $\pm$ 112) average egg densities prior to planting soybean. The increased presence of SCN egg density in the RT treatment was probably due to movement of SCN on tillage equipment from other locations on the farm where SCN egg density is high.

When evaluating SCN prior to planting soybean, significantly greater egg densities were detected in 2011 in the NTDCS cropping system which was similar to the RT treatment (Table 3). Egg densities in all years and cropping systems were categorized as low (<4,000 eggs 250 cm^{-3}) (Tylka, 2018). No significant interaction between treatments and years (n=13) was detected; therefore, data were combined over years (Figure 1). Soybean cyst nematode egg densities were greatest in RT and NTDCS while they were lowest in NTFSC cover crop prior to planting soybean. Likewise, SCN egg density was greatest in RT and NTDCS following soybean and prior to planting wheat. However, prior to planting corn, SCN egg densities were ranked NTDCS>RT>NTFSC. This indicates the time period after planting soybean influenced SCN egg densities. The greatest egg density in NTDCS relative to RT or NTFCS prior to planting soybean was likely due to the presence of the soybean crop during two of the three years of the rotation and served as a host for SCN both years. Whereas, the NTFSC and RT cropping systems only had a soybean host crop in one of three years indicting extended rotations were beneficial for managing SCN.

The clover cover crop in the NTFSC treatment may have reduced winter annual weeds (Barnes and Putnam, 1983; Myers et al., 2015; Teasdale et al., 1991) which can serve as a host to SCN. Although there were limited effects of grass cover crops and fall weed control on SCN egg densities in upstate Missouri, the study was short-term (2 years) (Nelson et al., 2006). As demonstrated in Table 3, it takes long-term research to evaluate the impact of tillage management and cropping systems on SCN egg densities. In other research, SCN egg densities decreased 25-93% in corn-soybean rotations with reduced tillage intensity in Indiana (Westphal et al., 2009). Edwards et al. (1988 reported increased soybean yields in northeast Alabama with conservation tillage which was attributed to water conservation and reduced SCN population densities. In a study examining the effect of tillage and wheat in a soybean wheat rotation in Kentucky, minimum tillage with residue had greater SCN levels than no-till with residue in years where an interaction was detected. In the absence of wheat residue 26.8% fewer cysts developed in no-till compared with minimum till plots in one year of the study (Hershman and Bachi, 1995). Nonetheless, there was no effect of tillage on SCN in a Minesota study examining tillage treatments and soybean row spacing(Chen et al., 2001). Overall, a longer rotation between soybean crops in the NTFSC system maintained low overall egg densities (51 to 81 eggs 250 cm^{-3}) which was a 79 to 97% reduction in average egg densities compared to NTDCS or RT (Figure 1) systems depending on the number of years following the soybean crop. In extended rotations (4-yr), the response of double-crop and full-season soybean was similar (Long and Todd, 2001). This research supports more diversified cropping systems particularly in states like Missouri where there are 1.6 ha of soybean for every one ha of corn (USDA, 2021). This indicates that several farmers grow continuous soybean with limited corn or wheat in the rotation.

Conclusions

Long-term and diversified cropping systems involving several crops in a rotation (corn-soybean-wheat) are important to understand changes in soil properties and determining improved pest management strategies. The NTFSC cropping system had the highest levels of SOM (29.3 to 37.8 g kg^{-1}) prior to planting corn in four of the years evaluated from 2002 to 2016, but this effect was inconsistent over time and extensive variability in SOM was observed over the duration of this experiment. Overall, SOM (2002-2016) was ranked NTFSC (33.6 g kg^{-1}) > NTDCS (32.4 g kg^{-1}) > RT (31.6 g kg^{-1}); however, soil pH_s was 0.1 point lower with NTFSC compared to the other cropping systems. Soil test P and K were 8 to 22% higher in the top 15 cm of soil with RT compared to the NT cropping systems. The lowest soil test K levels were observed with NTDCS (283 kg ha^{-1}) compared to RT (348 kg ha^{-1}) or NTFSC (321 kg ha^{-1}) indicating greater nutrient removal, due to harvest of four crops in three years with the NTDCS system. Combined over 13 years of data (2002-2015), SCN egg densities were the lowest in the NTFSC system (51 to 81 eggs/250 cm^3) prior to planting corn, soybean, or wheat. The NTFSC cover crop system maintained SCN egg densities that were 79 to 97% lower than in NTDCS or RT treatments which is a long-term benefit of including a cover crop in diversified cropping systems. Based on this long-term cropping systems research, tillage and cropping system decisions that include diversified cropping systems significantly affected soil chemical properties and the management of SCN.

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sUPPLEMENTAL mATERIAL

Table S1 includes methods of soil analysis, necessary equipment, and procedures for evaluating pH, P, K, Ca, Mg, NA, and CEC used in 1994 and from 2002-2017 by the University of Missouri Soil and Plant Testing Laboratory (Nathan et al., 2012). Table S1 also includes methods of soil analysis, necessary equipment, and procedures for SCN HG (*Heterodera glycines*) type test and egg count used from 2002-2017 by the University of Missouri SCN Diagnostics Lab (Howland et al., 2018; Meinhardt, personal communication).

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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FIGURES AND TABLES

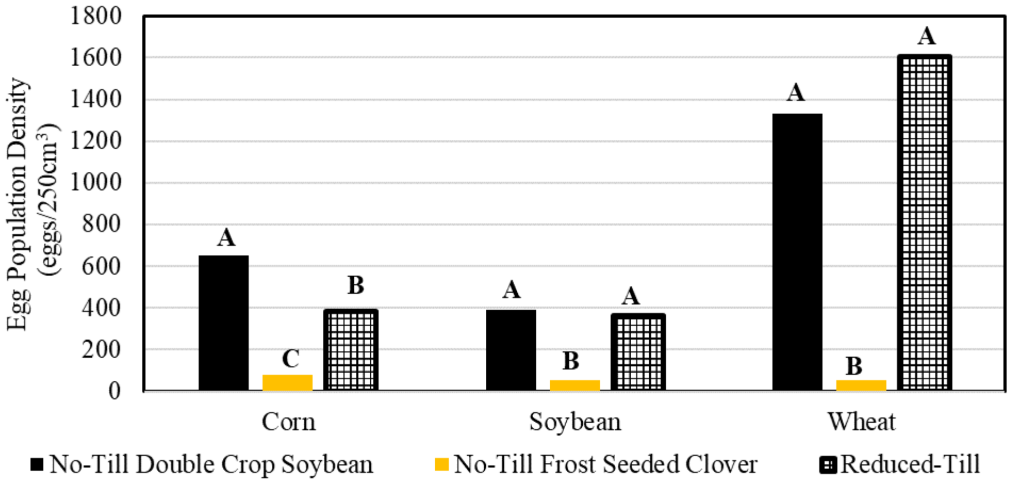

Figure 1. Soybean cyst nematode egg population densities prior to planting corn, soybean, or wheat for no-till double-crop soybean, no-till frost-seeded clover, and reduced-till cropping systems. Data were combined over years (2002-2016) since there was an absence of a significant interaction between cropping system and years. Lettered bars represent significant differences among cropping systems (P=0.1). Comparisons within a crop are valid.

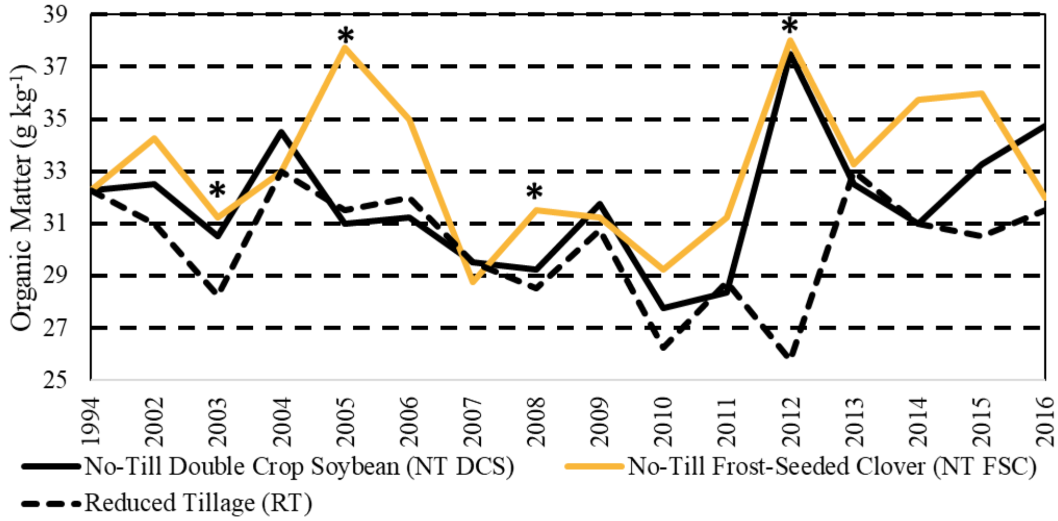

Figure 2. Differences in soil organic matter measured prior to corn (1994, 2002-2016) for NT DCS, NT FSC, and RT cropping systems. Asterisks represent significant differences in soil organic matter levels among cropping systems (P=0.05).

Table 1. Baseline soil test values (± standard deviation) for corn, soybean, and wheat collected to a 15-cm depth at project initiation in the spring of 1994.

Soil properties	Corn	Soybean	Wheat	LSD (*P*=0.05)
pH_s (0.01 *M* $CaCl_2$)	7.1±0.1	7.1±0.2	7.0±0.1	NS
Bray 1-P (kg ha^{-1})	45±11.1	54±9.1	42±2.9	NS
K (kg ha^{-1})	264±50.8	320±38.2	276±8.9	NS
Ca (kg ha^{-1})	5604±208	5798±587	5610±259	NS
Mg (kg ha^{-1})	326±42	349±63	342±12	NS
CEC (cmol kg^{-1})	14.0±0.7	14.7±1.7	14.2±0.6	NS

Table 2. Soil test values for no-till double-crop soybean (NTDCS), no-till frost seeded clover (NTFSC), and reduced tillage (RT) cropping systems evaluated in the spring at a 15-cm depth for 2002 to 2016. Data were combined over years (2002-2016) due to the absence of a significant interaction between years.

Soil properties	RT	NTFSC	NTDCS	LSD	Cropping system	Cropping system*year
				(*P*=0.05)	P>F	P>F
pH_s (0.01 M $CaCl_2$)	6.62 a	6.55 b	6.62 a	0.04	0.0013	0.9994
Bray 1-P (kg ha^{-1})	65 a	54 b	51 b	4	<.0001	0.8850
K (kg ha^{-1})	348 a	321 b	283 c	12	<.0001	0.2005
Ca (kg ha^{-1})	5380	5300	5400	NS	0.2130	0.9765
Mg (kg ha^{-1})	460	460	450	NS	0.5542	0.9230
CEC (cmol kg^{-1})	15	15	15	NS	0.8925	0.9589

Table 3. Soybean cyst nematode (SCN) egg population densities prior to planting soybean in no-till double-crop soybean (NTDCS), no-till frost seeded clover (NTFSC), and reduced tillage (RT) cropping systems in a corn-soybean-wheat rotation.

	SCN egg population densities			
Year	NTDCS	NTFSC	RT	LSD (*P*=0.1)
	---------- eggs 250 cm^{-3} ----------			
2002	0	0	0	NS
2003	0	0	31	NS
2004	0	0	0	NS
2005	0	69	69	NS
2006	138	138	378	NS
2007	1685	125	66	NS
2008	NC[†]	NC	NC	NS
2009	35	97	35	NS
2010	731	0	0	NS
2011	2253	103	1657	2077
2012	103	69	28	NS
2013	947	47	563	NS
2014	1716	422	1166	NS
2015	797	47	985	NS

[†]Data were not collected this year.