Published online March 9, 2017

Crop Yield and Soil Organic Carbon in Conventional and No-till Organic Systems on a Claypan Soil

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ABSTRACT

Organic crop production is dependent on tillage for weed control, but because tillage can lead to decreased levels of soil organic carbon (SOC) alternative management needs to be explored. This study was conducted in Boone County, Missouri, in 2012 to 2014 to determine the effects of three organic production systems and four poultry compost rates on crop yield and SOC on a claypan soil. The production systems included tillage with no cover crop, tillage with a mowed and incorporated cover crop, and no-till with a crimped cover crop in a wheat (*Triticum aestivum* L.)–corn (*Zea mays* L.)–soybean (*Glycine max* L.) rotation. Cover crops included cereal rye (*Secale cereale* L) and hairy vetch (*Vicia villosa* L.). Compost rates were 0, half the recommended rate, the recommended rate, and 1.5 times the recommended rate. Achieving cover crop biomass sufficient for weed suppression was a challenge when soil fertility declined during the study. Corn yield was reduced 30% in 2013 in no-till plots compared to tilled although plant populations were nearly equal, indicating that N immobilization may be significant in crimped cover crops. When there was adequate soil moisture and weed control from the cover crop, soybean grown under organic no-till was competitive with tilled treatments. Optimum timing of cover crop crimping for acceptable weed control was more successful in a soybean system compared with corn. Organic no-till in this study was more successful in soybean and wheat than in corn, when the cover crop biomass was sufficient to suppress weeds.

Core Ideas

- Soybean in organic no-till yielded as well as conventional organic.
- Corn in organic no-till had lower yield than conventional organic.
- A crimped cover crop can cause N immobilization and reduced corn yield.

A relatively new organic production practice is the use of no-till planting into rolled/crimped cover crop residue to provide weed control and reduce soil erosion and SOC loss (Carr et al., 2013a; Mirsky et al., 2011; Mischler et al., 2010a; Teasdale et al., 2007). This system is still in its infancy and many questions remain unanswered on its efficacy and viability. Unincorporated residue from a cover crop such as winter rye provides early season weed control, giving the grain crop a chance to outgrow yield-limiting weeds (Mirsky et al., 2011; Teasdale et al., 2012). Cover crops inhibit weed germination and growth through allelopathy or physical suppression through resource competition (Creamer et al., 1996). To be successful for early season weed control, cover crops must be completely killed before commercial crop planting (Mischler et al., 2010a). In organic no-till (ONT) this is usually done with a roller/crimper and may require multiple passes with the roller to sufficiently kill the cover crop (Wayman et al., 2014).

Tillage is currently a primary weed control method in many organic production systems (Bond and Grundy, 2001; Guthman, 2000) and may lead to SOC loss due to oxidation or mineralization, leaching and translocation, and accelerated erosion (Doran, 1987; Lal, 2002). Soil organic C is one of the most important constituents of soil due to its capacity to affect plant growth as both a source of energy for microorganisms and a trigger for nutrient availability through mineralization (Anderson and Domsch, 1985). Soil organic C may also increase crop yield by increasing plant available water content and enhancing soil structure (Lal, 2006). Continuous cropping, complex crop rotations and reduced tillage can all lead to increased C sequestration in soil (Sherrod et al., 2003; West and Post, 2002). Although organic production systems have been found to increase SOC pools over conventional tilled systems (Liebig and Doran, 1999; Wander et al., 1994), an organic system with a winter cover crop and tillage may accumulate less C in surface soils than a conventional no-till (NT) system (Jokela et al., 2011; Robertson et al., 2000). Sequestration of C in a no-till system is generally attributed to reduced tillage while in a tilled organic system it is generally

Published in Agron. J. 109:588–599 (2017)
doi:10.2134/agronj2016.06.0367
Received 21 June 2016
Accepted 11 Jan. 2017

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Abbreviations: CR, cereal rye; DM, dry matter; HV, hairy vetch; NTCC, no-till with cover crop; ONT, organic no-till; RCBD, randomized complete block design; SOC, soil organic carbon; TCC, tillage with cover crop; TCCP, tillage/cover crop practice; TNCC, tillage without cover crop.

attributed to increased plant biomass from a winter cover crop or animal manure additions. When coupled with a cover crop and manure additions, an organic reduced tillage system can sequester increased SOC over a NT system after several years (Teasdale et al., 2007). This highlights the importance of organic systems that utilize reduced tillage or no-tillage in improving soil quality and the sustainability of organic production.

Yield results in ONT are varied and largely dependent on both past production history and cover crop biomass production. At the Rodale Institute in Pennsylvania, improved hairy vetch (*Vicia villosa* Roth) cover crop stands and a previous history of compost additions, cover cropping and diverse crop rotations likely contributed to improved yield in ONT corn (*Zea mays* L.). Yields of 7 to 10 Mg ha^{-1} were achieved under favorable conditions at Rodale compared to non-Rodale research sites in the same study with ONT corn yields as low as 1.1 to 3.4 Mg ha^{-1} (Mischler et al., 2010a). The lower yields were also attributed to reduced biomass of the cover crop and incomplete kill of the hairy vetch using a roller/crimper. Although a rye mulch treatment effectively suppressed early season weeds in Wisconsin, rye regrowth competed with soybean (*Glycine max* L.) to reduce crop yield by 24% in ONT treatments compared to tilled (Bernstein et al., 2011). Corn yield in Iowa was reduced up to 92% in ONT compared to organic tilled when low precipitation, competition from the cover crop and possible N immobilization led to reduced plant stands and smaller no-till corn plants (Delate et al., 2012). Soybean yields were not as negatively affected by production practice, but still had an average yield of 2.8 Mg ha^{-1} in ONT compared to 3.2 Mg ha^{-1} in tilled treatments. Several studies stress that factors affecting ONT success include adequate soil fertility, optimal performance of the cover crops, and control of low weed populations (Carr et al., 2013b; Mirsky et al., 2012; Teasdale et al., 2012). When weeds are present in low populations, yield may not be adversely affected but lack of weed control measures can contribute to increases in the bank of weed seeds in the soil, leading to large weed density increases in subsequent years of ONT.

Adequately fertilized soil will not only improve crop growth but may also lead to increased cover crop growth and weed control in ONT (Mirsky et al., 2011; Ryan et al., 2011a). In Ryan et al. (2011a), increased addition of poultry litter led to increased rye biomass while increasing the rye seeding rate did not increase rye biomass production. However, at high fertility rates, increasing rye seeding rate decreased weed biomass. It was speculated that early ground cover from the cover crop may be the most important driver of weed suppression. Very little research has been aimed at investigating fertility issues in ONT.

It has also been suggested that soil taxonomy could be a factor in attaining consistent crimping of the cover crop with reduction of competition to the commercial crop. The sandier soils of the mid-Atlantic regions might be more amenable to crimping than silty clay loam soils in Iowa (Delate et al., 2012). Soils with high clay content are extensive in the central Midwest with nearly 4 million hectares designated the central claypan region (USDA-NRCS, 2006). These soils are characterized by very slow permeability, restricted root penetration, low natural fertility, and varying topsoil thickness (Jamison et al., 1967; Kitchen et al., 1999). Claypan soils are prone to structural degradation by compaction induced by farm equipment, although this may be mediated through additions of organic amendments such as poultry litter (Pengthamkeerati et al., 2011). No previous studies have been published on the efficacy of ONT in claypan soils.

The objective of this research was to determine the effects of three organic production systems and four poultry compost rates on crop yield and SOC on a claypan soil. Organic no-till was compared to a tilled organic system using a winter cover crop and to a system using tillage and no winter cover crop. We hypothesized that cover crops, reduced tillage, and increased compost would increase SOC, and that yield in ONT would be competitive to yield in the two tilled systems.

MATERIALS AND METHODS

Research Site and Design

This research was conducted from 2012 to 2014 at the University of Missouri Bradford Research Center (BREC), located in Boone County, 8 km east of Columbia, MO. Soils at this site are primarily Mexico silt loam (fine, smectitic, mesic Vertic Epiaqualf) and are on the central glacial till claypan plain. This site has an argillic horizon, which is a claypan, typically 25 cm below the soil surface. This research site had previously been managed as a conventional row crop field until 2011 when organic management practices were initiated. Land used in this study was certified in organic transition by Quality Certification Services (QCS, Gainesville, FL). All practices used in this study were organic certified. The research area was split into three sections (27 by 67 m) for the three grain crops in the rotation. The crop rotation was wheat (*Triticum aestivum* L.)–corn–soybean.

Each crop section was in a randomized complete block split-plot design with main plot treatments of tillage/cover crop practice (TCCP), including tilled, no cover crop (TNCC); tilled, cover crop (TCC); and no-till, cover crop (NTCC). The TNCC treatments were tilled with no winter cover crops between grain crop sequences and were cultivated for weed control. The TCC treatments utilized a winter cover crop that was mowed just prior to crop planting and incorporated with tillage, followed by cultivation for weed control. The NTCC utilized a crimped winter cover crop for weed control and was planted using no-till practices. Subplot treatments consisted of compost rates, which were zero compost (0x), half the recommended rate (0.5x), the recommended rate (1x), and 1.5 times the recommended rate (1.5x). An organic poultry compost product (Central Missouri Poultry Producers, Inc., High Point, MO) was applied in amounts based on the soil-test P recommendation (Buchholz et al., 2004) and the compost P content to prevent potential P loss. Amounts of applied compost, total P, and total N are listed in Table 1. Each crop section had four replications for a total of 48 plots (4.6 by 6.1 m per plot). The TCCP and compost treatments were located in the same plot positions for the 3 yr of the study.

Weather

Due to extreme drought in 2012, irrigation using approximately 2.5 cm of water was applied five times equally to all plots and occurred on 6 June, 6 and 20 July, and 3 and 17 August. The average temperature from May through September in 2012, 2013, and 2014 was 23.3, 21.3, and 21.3°C; and the

Table 1. Compost applied per compost treatment (0x, 0.5x, 1x, 1.5x recommended rate) for corn, soybean, and wheat from 2012 to 2014.

Crop	Year	Compost treatment	Compost applied	Total P	Total N
			kg ha^{-1} yr^{-1}		
Corn	2012	0x	0	0	0
		0.5*x*	3,528	71	106
		1*x*	7,000	140	211
		1.5*x*	10,528	211	316
	2013	0*x*	0	0	0
		0.5*x*	3,714	71	74
		1*x*	7,368	140	148
		1.5*x*	11,082	211	222
	2014	0*x*	0	0	0
		0.5*x*	4,341	83	122
		1*x*	8,681	165	243
		1.5*x*	13,022	248	365
Soybean	2012	0*x*	0	0	0
		0.5*x*	2,520	50	76
		1*x*	5,040	101	151
		1.5*x*	7,560	151	227
	2013	0*x*	0	0	0
		0.5*x*	2,652	50	74
		1*x*	5,305	101	148
		1.5*x*	7,958	151	222
	2014	0*x*	0	0	0
		0.5*x*	2,713	52	76
		1*x*	5,426	103	152
		1.5*x*	8,139	155	227
Wheat	2012	0*x*	0	0	0
		0.5*x*	2,240	45	67
		1*x*	4,480	90	134
		1.5*x*	6,720	134	202
	2013	0*x*	0	0	0
		0.5*x*	2,358	45	66
		1*x*	4,716	90	131
		1.5*x*	7,074	134	197
	2014	0*x*	0	0	0
		0.5*x*	2,035	39	57
		1*x*	4,070	77	114
		1.5*x*	6,105	116	171

total rainfall from May through September in those years was 177.3, 440.9, and 516.7 mm, respectively. The annual cumulative rainfall for 2012 to 2014 is shown in Fig. 1 and is plotted against the 30-yr average for Boone County, Missouri.

Crop Management

Composted turkey litter was broadcast surface-applied by hand once annually each spring at Zadoks growth stage 24 (Zadoks et al., 1974) in winter wheat and just after winter cover crop termination in other treatments (Table 2). Zadoks is a scale for measuring the growth stages of cereals. In tilled plots, the compost was incorporated into the soil and in no-till plots the compost remained on the soil surface.

Pre-plant tillage in TNCC and TCC plots was conducted using a 1.5 m wide plot disk and weed control was done using a Danish S-tine four-row cultivator. Management dates and processes are shown in Table 2. Cover crops in NTCC plots were terminated at Zadoks growth stage 61 before corn (Mirsky et al., 2009) and Zadoks 68 before soybean using three passes with a roller-crimper (I&J Mfg., Gap, PA). Multiple passes were needed to achieve adequate kill of the cover crops. Cover crops in TCC were first mowed with a flail mower (John Deere 25A, Moline, IL) and then disked into the soil at the same growth stage. Organic corn (Welter Seed hybrid WS2292) and soybean (Blue River Hybrids 389F.Y) were planted using a four-row John Deere 7000 planter (Moline, IL) in 76 cm wide rows at 86,400 and 385,300 seeds ha^{-1}, respectively. Because we had difficulty placing seed through the thick cover crop residue with our no-till planter, the no-till coulters were removed in 2013 and 2014, which caused the planter weight to be centered on the double disk openers and allowed deeper penetration of the seed tubes through the cover crop residue. Additionally, spiked closing wheels (Schoup Mfg., Kankakee, IL) were installed on the planter to effectively close the seed-row furrow.

The winter cover crop cereal rye (CR) was planted before soybean, and a mixture of cereal rye and hairy vetch (CR–HV)

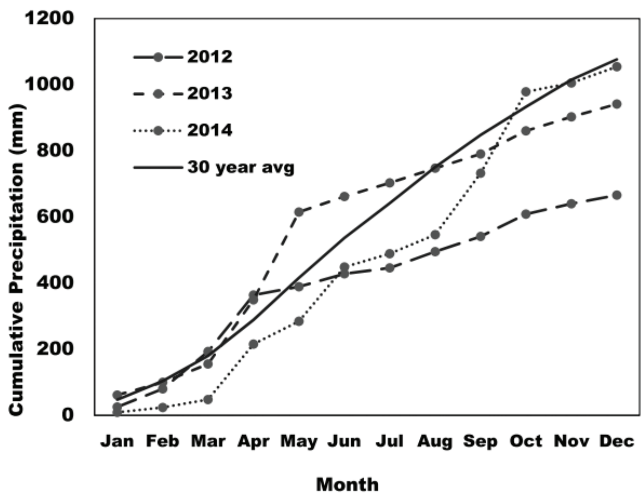

Fig. 1. Cumulative precipitation 2012 to 2014 compared to 30-yr average cumulative precipitation for Boone County, Missouri.

was planted before corn. All cover crops and the organic wheat (variety Bess) were planted using a Tye (AGCO, Duluth, GA) no-till drill at 19-cm row spacing. Wheat was planted at 100 kg ha^{-1}. In 2012, a summer cover crop of buckwheat (*Fagopyrum esculentum* Moench) was planted in the wheat section after the wheat harvest and in 2013–2014 a cover crop mixture of sunn hemp (*Crotalaria juncea* L.) and cowpea [*Vigna unguiculata* (L.) Walp.] was planted after wheat (Table 3).

Crop Data Collection

Field chlorophyll measurements were taken at VT stage in corn and R3 in soybean (Abendroth et al., 2011; Pedersen and Elbert, 2004) with a hand-held chlorophyll meter (SPAD-502 Chlorophyll Meter, Minolta Camera Co., Ltd., Osaka, Japan). To determine cover crop yields, a 0.25 m^2 quadrat was randomly placed in two places in the plots and aboveground cover crop biomass was removed from each frame area, dried and weighed. To determine crop plant density at harvest, a 3 m stick was randomly dropped twice next to the plant row and plants were counted and averaged. The middle two rows of corn and soybean and the middle 1.5 m of wheat were harvested at physiological maturity using a two-row Kincaid research combine (Kincaid Equipment Mfg., Haven, KS) for corn and a Wintersteiger research combine (Wintersteiger Inc., Salt Lake City, UT) with a 1.5 m standard reel platform header for soybean and wheat. Grain moisture was adjusted to 155 g kg^{-1} for corn, to 130 g kg^{-1} moisture for soybean, and 135 g kg^{-1} for wheat. Harvest dates are shown in Table 2.

Soil Data Collection

For characterization of SOC, soil was collected just prior to harvest each fall using a probe with a 19.05 mm diam. to a depth of 15 cm. Eight samples were taken in a grid pattern in each plot and were composited and homogenized using a 6.35-mm sieve. Soil organic C was determined on sieved (<2 mm), air-dried, ground soil samples by dry combustion at 900°C using a LECO Tru-Spec C/N Analyzer (Nelson and Sommers, 1996).

Table 2. Planting, fertilizing, cultivation, harvest, and termination dates for corn, soybean, wheat, and cover crops, 2012 to 2014.

Crop	Year	Planting date	Compost application date	Cultivation date	Harvest or termination date
Cover crops	2011	8 Oct.			
	2012	19 Oct.			22 May (corn) 28 May (soybean)
	2013	17 Oct.			3 June (corn) 11 June (soybean)
	2014				4 June (corn) 16 June (soybean)
Wheat	2011	8 Oct.	27 Mar.		8 June
	2012	19 Oct.	25 Apr.		3 July
	2013	14 Oct.	16 Apr.		30 June
Corn	2012	23 May	22 May	21 June	16 Oct.
	2013	4 June	5 June	28 June	17 Oct.
	2014	5 June	3 June	19 June, 2 July	8 Oct.
Soybean	2012	29 May	29 May	21 June	17 Oct.
	2013	12 June	11 June	11 July	14 Oct.
	2014	16 June	15 May	2 July, 29 July	21 Oct.

Table 3. Seeding rates, seasons and varieties of cover crops.

Crop	Season	Variety	Seeding rate
			kg ha^{-1}
Cereal rye (*Secale cereale* L.)	winter	VNS†	130
Winter cover crop mix			
Hairy vetch (*Vicia villosa* Roth)	winter	VNS	30
Cereal rye	winter	VNS	100
Buckwheat (*Fagopyrum esculentum* Moench)	summer	VNS	67
Summer cover crop mix			
Sunn hemp (*Crotalaria juncea* L.)	summer	VNS	17
Cowpea [*Vigna unguiculata* (L.) Walp.]	summer	Iron and clay	67

† VNS = variety not stated.

Statistical Analysis

Statistical analysis was completed with SAS Enterprise Guide 6.1 (SAS, Cary, NC). Results were analyzed using PROC MIXED at a = 0.05 by crop and year with the ANOVA run as a RCBD split-plot design. The fixed effects in the model were TCCP, compost (subplot factor) and TCCP × compost. The random effects were block and block × TCCP (whole plot factor). All means separation differences were tested using Tukey's HSD. Visual inspection of frequency distributions showed that normality assumptions were valid.

RESULTS AND DISCUSSION

Cover Crop

An aboveground dry matter yield of 8000 kg ha^{-1} for winter cover crops has been identified as the threshold biomass production for consistent suppression of annual weeds in ONT (Mirsky et al., 2013). Dry matter yield of the cereal rye/hairy vetch mixture (CR–HV) in this study was 94% of the threshold in spring 2012, but was only 55 and 35% of the threshold in 2013 and 2014 (Fig. 2). The dry matter yield of the cereal rye (CR) was 98 and 114% of the threshold in 2012 and 2013, but the yield was only 40% of the necessary biomass in 2014. Cover crop biomass was affected by the species used, fall planting date, perennial weed competition and soil fertility.

Cereal rye has been found to have the highest biomass production of winter cover crops in most agricultural regions of the United States (Delate et al., 2012; Reberg-Horton et al., 2012; Teasdale, 1996) and provided the best weed control in ONT (Mirsky et al., 2013; Ryan et al., 2011b). However, a mixture of cereal rye and hairy vetch may be utilized before a corn crop in ONT due to N immobilization that can occur in a pure rye stand and for the N contribution from biological N fixation by hairy vetch (Clark et al., 1994; Rosecrance et al., 2000). A problem with growing hairy vetch as a cover crop component in ONT is that it may produce lower yield and more readily degradable biomass compared with cereal rye (Wagger, 1989) and an early fall planting for good establishment is required in many climates. The ideal planting date for hairy vetch in central Missouri is before 25 September (USDA-NRCS, 2014) but cover crops in ONT are usually drill-seeded rather than broadcast into a standing crop to achieve optimum plant density for weed control (Bernstein et al., 2011; Wayman et al., 2014). Planting of the cover crops in this study was delayed until corn and soybean were harvested in the fall. The CR–HV mixture used in this study resulted in biomass reductions from 4 to 52% compared to cereal rye in a pure stand (Fig. 2).

The fall 2011 cover crop planting date was 10 and 8 d earlier than in fall 2012 and 2013 (Table 2) because cover crop planting in 2011 followed an early harvest of conventional soybean. Once the field was converted to organic production with a no-till component, crop planting in 2012 to 2014 was delayed until the cereal rye was past Zadoks growth stage 61 in the spring, which is the recommended time for cover crop crimping (Mirsky et al., 2009). In 2012 and 2013, crimping occurred in the first week of June, which is significantly later than the 4 April average date of initial spring corn planting in Missouri (Kucharik, 2008). Mischler et al. (2010a) also indicated that this delay in corn planting may lead to reduced yield potential in an ONT system. Early corn planting often

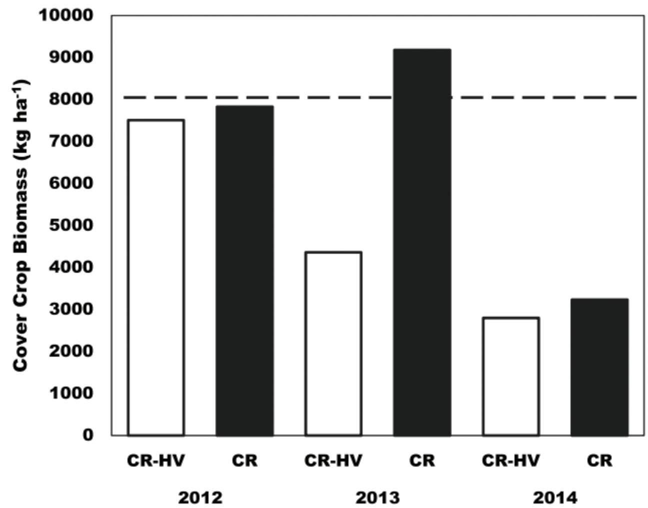

Fig. 2. Yield of aboveground biomass of winter cover crop as affected by species (CR = cereal rye, CR–HV = cereal rye/hairy vetch mix and year [2012–2014]). The dashed line represents the weed biomass suppression threshold of 8000 kg ha^{-1} (Mirsky et al., 2013).

results in increased yields because of increased likelihood that flowering will occur before midsummer heat stress and that maturity will be reached before a killing frost in the fall (Hu and Buyanovsky, 2003). In central Missouri, the federal crop insurance last plant date for corn to avoid coverage reductions is 31 May (USDA-RMA, 2015).

Crimping of the cereal rye cover crop before soybean planting was delayed to Zadoks growth stage 68 due to weather issues but was still planted before the federal crop insurance last plant date for soybean of 20 June. (USDA-RMA, 2015). Although the effect of planting date on soybean yield can vary substantially from variation in environmental conditions, relative yield responds to delayed planting with a rapid decline in yield beginning on 30 May in the Midwest (Egli and Cornelius, 2009).

By year three of the study, perennial weed species such as white clover (*Trifolium repens* L.) and curly dock (*Rumex crispus* L.) began to proliferate in the no-till plots, similar to numerous other studies assessing organic no-till (Carr et al., 2013b; Halde et al., 2015; Mirsky et al., 2012). Poor weed control combined with diminished soil fertility from 3 yr of applying compost based on P recommendation led to cereal rye and CR–HV cover crop yields that were insufficient for annual weed control in 2014 (Fig. 2). Because cover crop biomass was well below the recommended threshold for weed suppression, yields of corn and soybean in the NTCC treatments were only 40 and 26% of the mean yields of the tilled treatments in 2014 compared to 70 and 100% in 2013 (Table 4). Yield reduction from insufficient cover crop biomass was also found by Delate et al. (2012). Ryan et al. (2011a) confirmed that poor soil fertility is one of the primary challenges in achieving adequate cover crop biomass to suppress weeds and prevent yield reduction in an ONT system.

Corn Population and Yield

Corn population was reduced in no-till plots in 2012 and 2014 (Fig. 3). In 2012, this was a result of poor seed to soil contact in corn planted through the thick cover crop residue resulting from high biomass produced that year. After that initial

Table 4. Mean yield of organic corn, soybean and wheat from 2012–2014 as impacted by tillage/cover crop (TCCP) and compost rates. Standard errors are stated in parentheses.

		Yield											
		2012				2013				2014			
		TCCP											
Crop	Compost†	TNCC‡	TCC	NTCC	Mean	TNCC	TCC	NTCC	Mean	TNCC	TCC	NTCC	Mean
		Mg ha^{-1}											
Corn	0*x*	4.25 (0.50)	4.62 (0.25)	1.43 (0.17)	3.43b§	2.98 (0.44)	4.11 (0.28)	0.86 (0.50)	2.65d	0.68 (0.20)	2.62 (0.36)	0.097 (0.06)	1.13b
	0.5*x*	5.62 (0.50)	4.92 (0.38)	3.86 (0.37)	4.80a	4.61 (0.52)	3.86 (0.36)	2.99 (0.16)	3.82c	1.53 (0.64)	2.72(0.70)	0.931 (0.36)	1.73b
	1*x*	4.26 (0.18)	4.59 (0.27)	4.90 (0.57)	4.58a	5.05 (0.38)	5.22 (0.38)	4.72 (0.47)	4.96b	3.34 (0.58)	3.43 (0.73)	0.87 (0.44)	2.55ab
	1.5*x*	3.89 (0.08)	4.71 (0.33)	4.74 (0.41)	4.45a	6.92 (0.91)	6.37 (0.44)	5.07 (0.37)	6.12a	4.37 (1.16)	2.92 (0.78)	2.55 (0.95)	3.28a
	Mean	4.50a	4.71a	3.73b		4.89a	4.89a	3.41b		2.48a	2.92a	1.09b	
Soybean	0*x*	2.91 (0.14)	2.32 (0.32)	2.10 (0.52)	2.44	2.37 (0.17)	2.13 (0.18)	1.75 (0.21)	2.08	2.85 (0.26)	3.03 (0.04)	0.55 (0.17)	2.15b
	0.5*x*	3.31 (0.22)	2.41 (0.35)	2.34 (0.42)	2.68	1.99 (0.13)	1.88 (0.17)	2.02 (0.12)	1.96	3.45 (0.38)	3.24 (0.017)	0.84 (0.11)	2.51ab
	1*x*	3.25 (0.24)	2.77 (0.26)	2.51 (0.23)	2.84	2.35 (0.23)	1.93 (0.11)	2.48 (0.08)	2.25	3.42 (0.12)	2.82 (0.06)	0.82 (0.08)	2.35ab
	1.5*x*	3.26 (0.26)	2.52 (0.39)	2.20 (0.26)	2.65	2.26 (0.18)	2.26 (0.26)	2.35 (0.20)	2.29	3.49 (0.27)	3.26 (0.10)	1.08 (0.17)	2.61a
	Mean	3.17a	2.51b	2.29b		2.24	2.05	2.15		3.30a	3.09a	0.82b	
Wheat	0*x*	2.41 (0.09)	2.35 (0.16)	2.31 (0.11)	2.35d	2.11 (0.09)	2.70 (0.09)	2.05 (0.15)	2.32c	2.87 (0.34)	2.41 (0.43)	2.58 (0.53)	2.62
	0.5*x*	2.75 (0.09)	2.74 (0.09)	2.58 (0.05)	2.69c	3.30 (0.18)	3.02 (0.30)	2.84 (0.07)	3.05b	3.59 (0.20)	2.61 (0.43)	2.38 (0.18)	2.86
	1*x*	3.12 (0.09)	3.14 (0.17)	3.09 (0.13)	3.12b	3.67 (0.12)	4.14 (0.21)	2.98 (0.09)	3.59a	3.08 (0.29)	2.87 (0.43)	2.50 (0.16)	2.81
	1.5*x*	3.61 (0.12)	3.27 (0.04)	3.43 (0.07)	3.44a	4.24 (0.26)	3.92 (0.037)	3.95 (0.45)	4.04a	2.74 (0.66)	2.95 (0.58)	3.32 (0.15)	3.00
	Mean	2.97	2.87	2.86		3.33ab	3.47a	2.95b		3.67	2.71	2.69	

† 0***x*** = zero compost, 0.5*x* = 0.5 × recommended rate, 1*x* = recommended rate, and 1.5*x* = 1.5 × recommended rate, each relative to the soil-test recommended P fertilizer rate.
‡ TNCC = tillage no cover crop, TCC = tillage with cover crop, NTCC = no-till with cover crop.
§ Values followed by a different lowercase letter within each column, row and year are significantly different (using Tukey's HSD) at $\alpha = 0.05$.

planting, the no-till coulters were removed from the planter and improved seed to soil contact was achieved in 2013 and 2014. This was in contrast to Mirsky et al. (2013), who found that a lightly fluted coulter provided the necessary residue cutting to prevent hair-pinning of residue in the seed furrow. Our success with coulter removal may be linked to planting the cash crop in the same direction that the cover crop was planted and crimped while Mirsky et al. (2011, 2009) reported crimping the cover crop and planting the cash crop perpendicular to cover crop planting direction. Removal of the coulters allowed more weight to be placed on the double disk row openers, thereby allowing deeper placement of seeds. Our successful use of a spiked closing wheel agrees with observations of Mirsky et al. (2013) that a spiked or spaded closing wheel helped close the seed slit better than a solid closing wheel.

Reduced corn plant population in the TCC treatment was likely caused by interference of the macerated cover crop residue with the germinating corn seeds. This interference could have been an allelopathic effect due to allelochemical release from the decomposing rye residue (Barnes and Putnam, 1986), although reduced emergence was not evident in wetter years. Interference was more likely a result of the dry cover crop residue entering the seed furrow and either causing a reduction of soil contact with the germinating crop seed or absorption by residue fragments of the small amount of soil moisture present during the harsh drought in 2012 (Fig. 1). Several other studies have reported decreased soil to seed contact from similar residue hair-pinning (Carr et al., 2003; Kornecki et al., 2009; Luna et al., 2012). In 2014, corn populations were adversely affected in the NTCC treatment by the extremely low biomass of cover crop and subsequent suppression of corn emergence and growth by weeds. The cover crop did not achieve sufficient biomass for effective weed control due to diminished fertility in Year 3 of the study. This was a result of annual compost applications based on P content and utilization rather than basing application on N use. Corn plant populations did not exhibit a response to compost rate, but were adversely affected by wet, cold climatic conditions in early summer 2014.

Corn yields were lower in NTCC treatments in all years (Table 4). Although low populations may be partially responsible for this, there were two indications that a low population was not the sole cause of reduced yield. In 2012, TCC had very low plant population but had similar yield to the TNCC treatment, suggesting that more resource availability per plant (water, sunlight, nutrients) may have prevented a yield reduction due to low population. Similar responses to wider between-plant spacing were described in Nelson (2014) and Kremer and Deichman (2014). Additionally, the 2013 plant population was nearly equal in the three TCCP treatments, but yield was reduced by 30% in NTCC compared to the average of the two tilled treatments. This was likely due to N deficiency and immobilization. Compost in the tilled treatments was disked into the soil, making it readily available for microbial transformation to inorganic forms of N. However, compost in the NTCC was placed on top of the crimped cover crop, possibly leading to slower mineralization of N and slower plant uptake leading to reduced plant growth. Although previous research found that surface-applied compost in a no-till system did not affect corn yield when compared to incorporated compost (Eghball and Power, 1999; Singer et al., 2004), SPAD readings taken at the VT stage of corn showed that NTCC corn had a significantly lower reading of 32 SPAD units compared to 39 in TNCC corn and 40 in TCC corn. The cover crop residue in NTCC remained intact, was very slow to break down and likely immobilized nutrients compared to the cover crop in the TCC treatment. The TCC treatment was mowed/chopped into small pieces and incorporated into the soil, leading to more rapid microbial transformation and availability of nutrients assimilated by the cover crop during its growth. Our data confirm previous work by Wells et al. (2013) that N immobilization could result from a crimped rye cover crop.

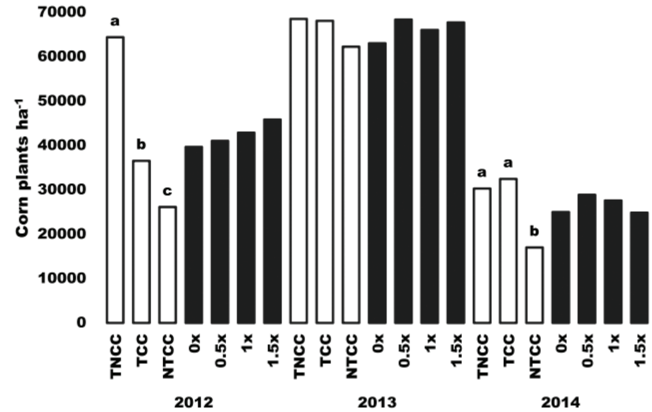

Fig. 3. Mean plant density of organic corn from 2012 to 2014 as impacted by tillage/cover crop (TCCP) and compost rates. TCCP management: TNCC = tillage no cover crop, TCC = tillage with cover crop, and NTCC = no-till with cover crop. Compost rates: 0*x* = 0 compost, 0.5*x* = 0.5 × the recommended rate, 1*x* = recommended rate, and 1.5*x* = 1.5 × recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different lowercase letter within TCCP and year are significantly different (using Tukey's HSD) at a = 0.05. Planting population was 86,400 seeds ha^{-1}.

Increased compost application resulted in increased yield because crop N needs were being supplied solely by compost additions and the hairy vetch cover crop. In 2012, only the 0x compost rate had reduced yield, probably due to the high fertility of the soil following the completion of conventional production. The mean corn yield in the TNCC treatment at 1.5x compost rate from 2012 to 2014 was 5.1 Mg ha^{-1} compared to 9.3 Mg ha^{-1} in non-organic plots at the same location (Wiebold et al., 2014a). This 55% yield decrease was likely a result of low fertility in the organic field and an indication that compost application based on P levels does not provide adequate fertility to organic corn. A trend toward higher yields in the TCC treatments compared to TNCC indicates that the hairy vetch in the winter cover crop may have been providing additional N for corn growth. Late planting dates may also have contributed to lower yields in organic corn compared to non-organic.

Soybean Population and Yield

Soybean plant population showed a decrease in NTCC only in 2014, when limited cover crop growth led to very high weed density (visual observation) and inhibition of soybean germination, emergence and growth (Fig. 4). Cover crop growth in 2014 was limited by poor fertility brought about by annual compost applications based on the recommended P rate for

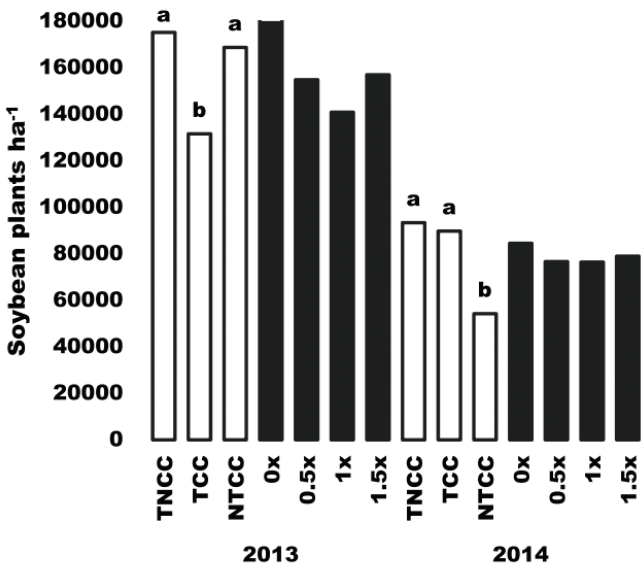

Fig. 4. Mean plant density of organic soybean from 2012 to 2014 as impacted by tillage/cover crop (TCCP) and compost rates. TCCP management: TNCC = tillage no cover crop, TCC = tillage with cover crop, and NTCC = no-till with cover crop. Compost rates: 0*x* = 0 compost, 0.5*x* = 0.5 × the recommended rate, 1*x* = recommended rate, and 1.5*x* = 1.5 × recommended rate, each relative to the soil-test recommended P fertilizer rate. Values followed by a different lowercase letter within TCCP and year are significantly different (using Tukey's HSD) at a = 0.05. Planting population was 385,300 seeds ha^{-1}.

corn and soybean, rather than on N needs of the cover crop. Cover crop biomass in 2014 fell far short of the 8000 kg ha^{-1} recommended for annual weed suppression in no-till (Fig. 2), leading to a 74% yield reduction in the NTCC treatment compared to TCC.

In 2013, soybean showed a similar population reduction as corn in 2012 in the TCC treatment. Although adequate moisture was available at planting in 2013, the mowed cover crop residue apparently physically interfered with seed to soil contact when cover crop biomass levels were high. The lack of response in TCC in 2014 was likely a result of a much lower cover crop biomass levels compared to 2013.

Soybean yield was only affected by compost rate in 2014, but this was an indirect effect due to lower compost rates reducing cover crop growth, which led to reduced weed suppression and reduced soybean yield from weed interference (Table 4). In 2012, soybean in TNCC yielded higher than the tilled and no-till treatments that utilized cover crops, possibly because deep soil moisture was reduced by cover crop growth and was not replenished during the severe drought that year. This theory is supported by research in Wisconsin showing that in a dry year, soil moisture at soil depths below 20 cm was less in a NT treatment with rye than in a tilled treatment (Bernstein et al., 2011). Although soybean plant populations were not measured in 2012, visual clues that would otherwise explain the yield decrease in cover crop plots were not observed. In 2013, when soil moisture was adequate and cover crop biomass was sufficient for weed suppression, NTCC soybean yielded similar to the two tilled treatments, indicating that soybean in ONT can be competitive with soybean grown in tilled production systems under favorable environmental conditions. Poor environmental conditions in 2012 (severe drought) and 2014 (poor soil fertility) led to reduced yields of soybean in ONT. Data from 2013 agrees with Smith et al. (2011) and Mischler et al. (2010b) who reported that soybean yield can be maintained under ONT compared to tilled production systems. In contrast, Delate et al. (2012) and Bernstein et al. (2011) showed yield reductions of soybean in ONT. Ryan et al. (2011b) suggested that increasing soybean seeding rate in ONT above normally recommended levels may further contribute to establishment and yield success of soybean in ONT.

Additionally, mean soybean yield in the TNCC treatment across all compost applications (2.9 Mg ha^{-1}) was nearly equivalent to yields of conventionally produced soybean (3.1 Mg ha^{-1}) at the same location (Wiebold et al., 2014b). This indicated that fertility was less limiting in organic soybean than in organic corn. Organic soybean competed equally with conventionally grown soybean when weeds were controlled.

Wheat Yield

Wheat in the study received all N from compost additions resulting in increased yields with increased compost amounts in 2012–2013. Although yields generally increased with increased compost amounts in 2014, yields were not significantly different (Table 4). The mean wheat yield in a non-organic variety trial during 2012 to 2014 at the same location was 5 and 11% higher (Wiebold et al., 2013) than in the organic TNCC treatment at 1.5x and 1x compost rates, indicating that compost application based on P levels may not provide adequate fertility for acceptable organic wheat production.

Wheat yields responded to TCCP only in 2013, when wheat in a NTCC rotation yielded significantly lower than the two tilled systems. This resulted when the crimped cereal rye from the previous year reseeded and established in the following wheat crop. This confirms the assumption by Wayman et al. (2014) that cover crops allowed to mature to the point of producing seed can become a weed in the subsequent crop. Producers who use cereal rye and wheat in their rotations should be wary of this problem and all cereal rye should be terminated well before producing viable seed. Crimping requires that rye reach Zadoks growth stage 61 (Mirsky et al., 2009), which can be a challenge in an organic no-till system that includes wheat because of the likelihood that some rye will set seed either before or after the cover crop is crimped.

Soil Organic Carbon

Although we expected that treatments with tillage would negatively affect SOC compared to no-till, this generally did not occur (Table 5). Although there was some response of SOC to tillage and cover crop practice, no discernable patterns could be seen. In 2012 in soybean, SOC was higher in TCC than in TNCC or NTCC but in 2014 it was higher in NTCC than the two tilled treatments. This lack of response to tillage may have been due to the low number of tillage events we conducted. Our field started with very low weed population density, which remained low in 2013 due to drought in 2012. In 2014, weed pressure was high in the NTCC treatment, but still fairly low in the two tilled treatments (visual observation). The short-term nature of the experiment may also affect SOC results. Cover crop breakdown was slow in the NTCC treatment so the effects from increased residue might not be

Table 5. Mean of soil organic carbon (SOC) at 0- to 15-cm soil depth from 2012 to 2014 as impacted by tillage/cover crop (TCCP) and compost rates. Standard errors are stated in parentheses. The pre-study was sampled in the spring of 2012 prior to treatments being started.

		SOC												
		Pre-study	2012				2013				2014			
		TCCP												
Crop	Compost†	Mean	TNCC‡	TCC	NTCC	Mean	TNCC	TCC	NTCC	Mean	TNCC	TCC	NTCC	Mean
		g kg soil^{-1}												
Corn	0x	19.7 (0.4)	20.1 (0.5)	22.1 (0.6)	21.9 (0.5)	21.3b§	25.9 (1.1)	27.1 (2.8)	25.5 (0.7)	26.2	19.9 (0.8)	20.0 (0.3)	19.7 (0.4)	19.8
	0.5x		21.0 (0.4)	22.9 (0.8)	23.0 (0.5)	22.6ab	27.3 (1.3)	24.8 (0.7)	26.4 (0.9)	26.2	21.3 (0.6)	20.6 (0.7)	21.3 (1.1)	21
	1x		23.0 (1.1)	22.7 (0.9)	22.5 (0.7)	22.7ab	27.4 (0.8)	27.9 (2.2)	26.5 (1.1)	27.3	21.6 (1.4)	20.2 (0.7)	26.3 (4.6)	22.7
	1.5x		22.9 (0.3)	23.3 (1.4)	22.9 (0.4)	23.0a	27.6 (0.7)	27.9 (0.4)	28.4 (0.3)	27.9	21.2 (0.6)	20.3 (0.8)	20.8 (0.4)	20.8
	Mean		22.7	22.6	21.9		27	26.9	26.7		20.9	20.2	22	
Soybean	0x	22.2 (0.7)	21.0 (0.4)	22.3 (0.1)	20.6 (0.3)	21.3	23.4 (0.4)	25.2 (0.7)	24.3 (1.0)	24.3b	19.2 (0.4)	18.8 (0.6)	21.7 (0.5)	19.9ab
	0.5x		20.8 (0.4)	21.3 (0.5)	21.4 (0.6)	21.1	24.3 (0.6)	27.4 (1.2)	27.6 (0.6)	26.4ab	18.5 (0.3)	18.9 (0.3)	21.1 (0.7)	19.5b
	1x		21.1 (0.3)	22.1 (0.4)	21.3 (0.1)	21.5	27.2 (0.9)	24.9 (0.7)	27.8 (1.2)	26.8a	19.7 (1.0)	19.9 (0.9)	21.7 (0.5)	20.5ab
	1.5x		20.5 (0.4)	22.7 (0.6)	21.2 (1.5)	21.4	24.1 (0.6)	28.1 (1.2)	26.1 (0.7)	26.2ab	20.8 (0.1)	21.0 (0.7)	21.7 (0.8)	21.2a
	Mean		20.8b	22.1a	21.1b		24.8	26.5	26.4		19.5b	19.6 b	21.5a	
Wheat	0x	19.8 (0.5)					23.3 (0.4)	26.5 (0.2)	26.5 (1.3)	25.4	22.2 (0.9)	20.8 (0.6)	22.8 (1.4)	21.9
	0.5x						24.8 (0.1)	26.5 (0.9)	27.9 (1.2)	26.4	21.2 (1.3)	21.5 (0.2)	21.8 (0.8)	21.5
	1x						26.0 (1.0)	28.1 (0.9)	26.0 (1.0)	26.7	22.3 (0.7)	21.7 (0.5)	22.4 (0.8)	22.1
	1.5x						25.1 (1.0)	27.8 (0.4)	28.3 (0.9)	27.1	21.6 (0.4)	22.0 (0.7)	22.7 (0.5)	22.1
	Mean						24.8b	27.2 a	27.2 a		21.8	21.5	22.4	

† 0*x* = zero compost, 0.5*x* = 0.5 × recommended rate, 1*x* = recommended rate, and 1.5*x* = 1.5 × recommended rate, each relative to the soil-test recommended P fertilizer rate.

‡ TNCC = tillage no cover crop, TCC = tillage with cover crop, NTCC = no-till with cover crop.

§ Values followed by a different lowercase letter within each column, row and year are significantly different (using Tukey's HSD) at $\alpha = 0.05$.

evident after only a few years. This was confirmed by several studies showing that changes in SOC were relatively insensitive to short-term management changes (Lefroy et al., 1993; Weil et al., 2003). Compost application, which is a direct addition of decomposed organic material, did lead to slightly increased SOC levels in corn in 2012 and in soybean in 2013 and 2014 (Table 5). Soil organic C was higher in the two cover crop treatments in wheat in 2013, which was most likely due to the presence of increased residue biomass from high amounts of rye growing in the wheat.

CONCLUSION

Although it was suspected that ONT might be very challenging in a claypan soil, partial success indicates that organic producers in high clay soils may be able to utilize this production system as part of an overall effort to control weeds while reducing tillage. Although we saw potential in using an organic no-till production system, its efficacy at weed suppression was heavily dependent on the health and growth of the cover crop. If soil fertility is low, cover crop growth will not be sufficient for weed suppression and yields will be negatively impacted. Cover crop growth was also highly dependent on climatic conditions, a difficult-to-predict production factor. Additionally, the longer a system was in ONT the more likely that perennial weeds became problematic. Perennial weeds were not affected by the roller/crimper and if they emerge prior to or during cover crop growth, tillage to break their life cycle may be required. Hairy vetch used in the winter cover crop was difficult to kill with crimping and required three passes with the crimper to achieve adequate control. Planting through the cover crop residue was a significant production challenge and might require equipment modifications. Because soybean is planted at a much higher rate and is less affected by reduced plant population than corn, lower seed emergence did not affect final soybean yield as much as it did in corn, which was severely impacted by organic no-till production in this study. Delayed planting while waiting for the cover crop to reach the proper stage for crimping coupled with reduced N availability to corn in ONT make it questionable that field corn can be successfully integrated into an ONT system. Timing of cover crop crimping is better suited for a soybean production system. Wheat in an ONT system can be impacted by self-seeding of cover crops that are crimped after reaching reproductive growth stages. This may cause wheat to be unmarketable due to contamination of the harvested grain. Corn and wheat yields were reduced by basing compost application on P needs. Growing a cover crop at the biomass level needed for ONT may have repercussions for a producer who later decides to incorporate the cover crop. High cover crop biomass would necessitate mowing before disking but mowing may lead to reduced soil to seed contact from physical interference from cover crop residue, which might be ameliorated with higher crop seeding rates.

Because weed suppression is dependent on the biomass of cover crop produced, further study is recommended on fertility requirements of the cover crop to achieve ideal cover crop growth for increased weed suppression. Depending on weather conditions, the crimped cover crop may also decompose enough during the growing season to allow germination of weeds. Thus, further study is needed on mid- to late-season weed control in an organic no-till production system. Mirsky et al. (2012) has proposed a management system termed "cover crop-based organic rotational no-till" in which some tillage is done prior to cover crop seeding to control perennial weeds and to optimize cover crop establishment. A producer might reduce risk by following this suggested rotational no-till system or by incorporating no-till soybean or wheat into an organic production system using hairy vetch for fertility and tillage for weed control during the corn production phase of the rotation.

ACKNOWLEDGMENTS

This material is based on work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award no. MO-ESCG1171. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the U.S. Department of Agriculture.

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