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Using cover crops in headlands of organic grain farms: Effects on soil properties, weeds and crop yields

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ABSTRACT

Organic producers often rely heavily on tillage for weed management, which can create compaction, especially in headlands, and favor weed growth. To address Illinois organic grain farmers' concerns, we explored the effect of cover crops in headland areas of their farms on soil properties, weeds, and yields in a participatory on-farm approach. A split-plot arrangement with two replications at each of four Illinois locations was used in two consecutive years within field areas [FA: headlands – or turn-rows – HL; non-headlands NHL] randomly selected as main plots where four cover crop treatments were randomly assigned (CC: fallow control C; forage radish FR; mix of forage radish and buckwheat FRbw; and mix of forage radish with hairy vetch and cereal rye FRhvr). Collaborating farmers planted soybean [*Glycine max* (L.) Merr.] in 2012 and corn (*Zea mays* L.) in 2013. Each fall and spring, we measured soil penetration resistance (PR), bulk density (BD), water aggregate stability (WAS), total carbon (TC), nitrate (N-NO_3), ammonium (N-NH_4), available phosphorus (P), and pH. Additionally, cover crop and weed growth, and cash crop yields were determined each year. Our results indicate HL areas had greater PR (+22%) and BD (+3%), as well as higher WAS (+4%), TC (+10%), P (+36%), and pH (+7%) in comparison to NHL areas on average through the fall and spring seasons. Though FRhvr significantly reduced spring weed biomass (−30%) compared to the controls, higher density of grass weeds (+44%) were present in HL areas through spring and summer regardless of CC treatments. Due to the resilient nature of these particular Illinois soils and extreme weather pattern observations, the cover crop treatments did not alleviate compaction nor influence soil properties for the duration of this project. However, there was a trend toward lower available P in the FRhvr treatments and reduced crop yields in those treatments within the NHL areas. Though the cover crop treatments chosen for this trial did not seem to provide clear benefits, our results point toward a beneficial feedback between the weed community and the soil properties within headland areas in these organic systems.

1. Introduction

Despite consumer demand and premium prices, adoption of organic practices for grain production has been slow and consequentially limited the expansion of organic livestock in the U.S (Greene et al., 2009). One of the main barriers to the expansion of organic management in grain crops is weed control (Sooby et al., 2007). Organic production increases the range of weed species, an important source of biological diversity, and crucial to the functioning of farming systems (Hawes et al., 2010; Zanin et al., 1997) yet weeds compete with cash crops, decreasing yields, lowering crop quality and increasing production inputs.

Organic farming uses a wide range of methods to manage weed populations, including diversified crop rotations, primary tillage for seedbed preparation, use of competitive crop cultivars, and

Abbreviations: FA, field areas; HL, headland areas; NHL, non-headland areas; CC, cover crop treatments; C, fallow control; FR, forage radish (*Raphanus sativus* L.); FRbw, forage radish and buckwheat (*Fagopyrum esculentum* Moench); FRhvr, mixture of forage radish, hairy vetch (*Vicia villosa* Roth), and cereal rye (*Secale cereale* L.); D, depth of sampling; ST, sampling time; SEM, standard error of the mean values; PR, penetration resistance; BD, bulk density; BDmax, maximum soil compactability; WAS, water aggregate stability; TC, total carbon stocks; N-NO_3, soil nitrates; N-NH_4, soil ammonium; P, available phosphorus; B:T, proportion of broadleaf weeds to total number of weeds.

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intensive between-row cultivation during the growing season (Liebman and Davis, 2009). Most of these methods require extensive time maneuvering in the field, heavy machine traffic, and intensive tillage of the soil, all of which can cause soil compaction (Ball and Crawford, 2009; Peigne et al., 2007) especially in headland areas (Bengough and Mullins, 1990). Headlands – or turn rows – are found along edges and corners of fields where heavy machinery maneuvering is more frequent than areas further within the field. Increased frequency of heavy machinery traffic causes these areas to be more susceptible to soil compaction, a densification of the soil due to the rearrangement of soil particles (Bengough and Mullins, 1990). Compaction in organic crop fields alters soil nutrient and water dynamics, reduces crop growth and yield, and increases weed problems and soil erosion (Ball and Crawford, 2009; Jackson et al., 2004; Sandhu et al., 2010). Place et al. (2008) found soil compaction limits cash crops' ability to compete with weedy species since weed roots penetrating compacted soil layers have access to nutrients and water that is otherwise unavailable to the cash crops. Cropping practices are needed that improve soil structure while reducing tillage.

Tillage profoundly shapes weed communities, for example creating microsites favoring weed seed survival and seedling emergence of annual grasses (Boyd and Van Acker, 2004; Hawes et al., 2010; Zanin et al., 1997). Often experienced organic farmers observe that weeds indicate soil quality or tilth. One reason is some perennial and annual weeds such as curly dock (*Rumex crispus* L.), bitter dock (*R. obtusifolius* L.), canada thistle [*Cirsium arvense* (L.) Scop.], Canada goldenrod (*Solidago canadensis* L.), quackgrass [*Elymus repens* (L.) Gould], sicklepod [*Senna obtusifolia* (L.) Irwin & Barneby], palmer amaranth (*Amaranthus palmeri* S. Watson), and wild oat (*Avena fatua* L.) can develop root systems in compacted soils better than crops (Boyd and Van Acker, 2004; Place et al., 2008; Zaller, 2004). With more weeds emerging, more cultivation and management is required, creating a negative cycle of tillage, compaction and increased weed emergence. Breaking this cycle is essential to improving organic grain production, and cover crops have been suggested as a critical tool to address both issues of soil compaction and weed suppression in the field.

Deep-rooted cover crops [i.e., radish and turnip (referred to as mustards)] penetrate compacted soil layers, ameliorating soil compaction (Williams and Weil, 2004), increasing nutrient use efficiency by capturing N from deeper soil layers (Kristensen and Thorup-Kristensen, 2004), and suppressing weeds through biofumigation (Haramoto and Gallandt, 2004). Yet environmental conditions, length of growing season, and management practices play a strong role in the success of these cover crops. In the U.S. Midwest region, the limited time between cash crop harvest and first winter frost in the fall and between appropriate growing conditions in early spring and cash crop planting times, can substantially limit the potential benefits from cover cropping (Acuna and Villamil, 2014). Additionally, the literature is greatly lacking cover crop research in organic grain production, especially in the poorly drained, highly fertile soils of Illinois.

Through discussions with our project collaborators, organic grain farmers around Illinois have identified potential headland compaction and weed control as major concerns. Thus a participatory on-farm research was planned with three experienced certified organic grain producers interested in the use of forage radish alone and in mixtures to alleviate soil compaction, improve nutrient cycling and suppress weed in headland areas of their farms. Our central hypothesis was that the inclusion of forage radish alone or in mixtures with cover crops of cereal rye and hairy vetch or buckwheat would help alleviate soil compaction, improve soil properties and better weed control in headland areas without affecting cash crop yields. This information is crucial for organic grain farmers to improve efficiency and productivity of their operations.

2. Materials and methods

2.1. Locations and soils

Our collaborating farmers own certified organic grain farms in three different locations in Illinois, where we set up four experimental sites, one in Cerro Gordo (39°54′N, 88°43′W), one in Malta (41°55′N, 88°56′W) and two sites at Pana (39°27′N, 89°03′W) that were less than 2.5 km apart. The 20-year climate normal for Illinois shows a mean annual total precipitation of 1015 mm with annual mean temperature of 11.3 °C (Midwest Regional Climate Center, 2015).

Farmers identified two headland areas (HL) of concern and two non-headland areas (NHL) in their fields that were examined for potential soil compaction and corroborated with measurements of penetration resistance and supported by preliminary statistical analysis. For all sites, headland areas were edges and corners of fields with heavy machinery traffic and, on two of the studied farms, manure was previously stockpiled. During our planning sessions, our farmers agreed on planting soybean the first year and corn the next and selected the three cover crop treatments under study, including a control without cover crops to satisfy research requirements. Additionally, farmers shared their machinery for tillage and soil preparation and were present during field selection, soil sampling and cover crop planting and suppression as well as during cash crop planting and harvesting each year.

Cerro Gordo plots were located on an approximately 650 ha farm with about 250 ha in organic grain production. The typical grain rotation for this farm is yellow organic corn, food grade soybeans and soft red winter wheat (*Triticum aestivum* L.). Since 1972, the farm has used a variety of cover crops, including red clover (*Trifolium pretense* L.), forage radish, cereal rye, annual rye (*Lolium multiflorum* Lam.) and oats (*Avena sativa* L.). Research plots were on Flanagan silt loam (Fine, smectitic, mesic Aquic Argiudolls) on less than 2% slopes. Flanagan silt loams are dark colored, somewhat poorly drained, and form in deep loess over loamy till. Permeability is moderately low and runoff potential ranges from low to high (Soil Survey Staff, 2012). The year prior to our study yellow organic corn was planted with 2 t of chicken litter and a mixture of cereal rye and hairy vetch as cover crops.

Malta plots were on a 770 ha farm primarily in organic grain production with 20 ha devoted to sheep and horses and 105 ha in transition to organic production. Typical crop rotation is corn, soybean, and small grains with several types of cover crops: red clover, alfalfa (*Medicago sativa* L.), radishes, oats, and buckwheat. Experimental plots were on Danabrook silt loam (Fine-silty, mixed, superacitve, mesic Oxyaquic Argiudolls) with slope of about 2%. Danabrook silt loams are dark colored, moderately well drained and form in deep loess over loamy till under prairie vegetation. Soils have moderate permeability and low to medium runoff potential (Soil Survey Staff, 2012). The year prior to our study corn was planted with spring applied manure from a local dairy.

The Pana farm is about 810 ha in total, primarily certified organic with 17 ha in transition. Grain production is the main activity on the farm with some land devoted to permanent pasture for 120 cows and hogs. The typical grain rotation is a seven year rotation of fallow, corn, oats, corn, soybean and meadow. The Pana farmer uses a variety of cover crops, including clover, alfalfa, orchard grass (*Dactylis glomerata* L.), cereal rye, hairy vetch and buckwheat. Both study sites at the Pana location were on Virden silty clay loams (Fine, smectitic, mesic Vertic Argiaquolls) with less than 2% slopes. Virden soils are dark colored, poorly drained, and form in deep loess over till plains. Soils have moderate permeability and negligible runoff potential (Soil Survey Staff, 2012). The year prior to our study corn was planted in both plots used in this study.

2.2. Experimental design and field methods

At each of the 4 farm sites, we identified the field areas (FA): 2 headland (HL) and 2 non-headland (NHL) areas and within those, we randomly allocated the cover crop treatments and the controls. Main plots measured 15 × 24 m and were split into four 6 × 15 m subplots. Main plots were the randomly selected field areas (FA: headland, HL, and non-headland, NHL) while subplots consisted of one of four randomly allocated levels of cover crop treatments (CC: fallow control C; forage radish FR; mixture of forage radish and buckwheat FRbw; or a mixture of forage radish, hairy vetch and cereal rye FRhvr). Soybean was planted in 30 in rows at Malta and Cerro Gordo and in 15 in rows at both Pana sites in 2012. Corn was planted in 2013 in 30 in rows at Malta and Cerro Gordo and in 36 in rows at both Pana sites. Cover crop planting dates, seeding rate and termination times followed the guidelines developed by the MCCC (Midwest Cover Crops Council, 2012). Cover crops were broadcasted following cash crop harvest between the end of August and beginning of September in 2011 and, in 2012, between the end of September and beginning of October for all farms. In 2011, both Pana farm sites had to be replanted on October 7 due to poor stand establishment. In 2012, soybeans were planted between the second and third week of May, and, in 2013, corn was planted around late May and early June at all sites. Cover crop seeding was done with hand seeders with seeding rates of 12.3 kg/ha for FR; 12.3 kg/ha for forage radish and 67.2 kg/ha for buckwheat, respectively for the FRbw treatment; and 12.3 kg/ha for forage radish, 16.8 kg/ha for hairy vetch, and 56 kg/ha for cereal rye, respectively within the FRhvr treatments. Cover crops were terminated by spring tillage approximately two weeks prior to the cash crop planting. The first spring tillage occurred between late March and early April in 2012 and, in 2013, between the second and third week of May. The Cerro Gordo farmer applied 2 t of poultry litter prior to corn in May 2013. The collaborating farmer at Malta applied K_2SO_4 in fall 2011 and 1 t of pelleted chicken manure with an analysis of 5–3–3 (N–P–K) prior to corn in February 2013.

Following soybean planting in 2012, inter-row cultivation was conducted each month, June, July, and August, until canopy closure to control weeds. The farmer at Pana used 15 cm row spacing for soybean in 2012 and did not require inter-row cultivation. In 2013, corn cultivation started approximately a month after planting and was repeated twice every two weeks until canopy closure at all farms.

2.3. Soil sampling and analyses

At the beginning of the study during the first week of August 2011 and to characterize our experimental plots in all sites, a soil sample representative of the A horizon was taken with a shovel from the center of each subplot to determine the particle size distribution by the hydrometer method (Gee and Bauder, 1986) and the maximum bulk density (BDmax, Mg/m^3) by the Proctor test (American Society for Testing and Materials, 1982). Soil texture was consistent among locations and classified as silt loam; soil textural class did not differ between field areas (FA) nor did their susceptibility to compaction or BDmax (Table 1). The maximum bulk density is considered an inherent soil property related to texture and carbon content; values attained with the Proctor test for our soils averaged 1.56 Mg/m^3, and are in agreement with root-restricting bulk density values reported by Kaufmann et al. (2010) for silt loam soils. Similarity in particle size distribution and susceptibility to compaction facilitates the comparison between soils in HL and NHL areas across locations since they are indicative of soils that have evolved under the same climate, occupy a similar position in the landscape and possess the same constituent material. Any modifications detected in soil properties can therefore be attributed to agronomic management.

Soil sampling was conducted four times over the course of this three year study before and after cover crop season each year. Fall sampling was conducted approximately two weeks following cover crop planting, and spring sampling was approximately two weeks prior to tillage termination in May at all sites. Penetration resistance (PR, kPa) was recorded each time with a Field Scout SC 900 Soil Compaction Meter (Spectrum Technologies, Plainfield, IL) with a cone basal area of 1.28 cm^2 and a cone angle of 30°. Five subsamples were taken per subplot and averaged to depths of 0–10, 10–20, 20–30, and 30–40 cm. At the same time, three soil core samples were taken with an automated soil sampler (Amity Tech, Fargo, ND) to 50 cm within each subplot and cut in 10 cm increments. After measuring gravimetric water content at each depth, BD was determined using the core method (Blake and Hartge, 1986). Field moist soil was analyzed for available N (N-NO_3 and N-NH_4, in mg/kg) using KCL extraction (1:5 ratio soil to solution) followed by flow injection analysis with a Lachat automated analyzer (Lachat Intruments, Loveland, CO). Soil samples were then air dried and sieved by 2 mm. Soil aggregates of the soil fraction ranging between 12 mm from the top two depths were tested for water aggregate stability (WAS, %) with an Eijkelkamp wet sieving apparatus (Eijkelkamp, Giesbeek, The Netherlands) following Kemper and Rosenau (1986). Available phosphorus (P, mg/kg) was determined with Bray-1 extraction followed by flow injection analysis with Lachat automated analyzer. Total carbon concentration (TC, %) was determined by loss on ignition (Soil and Plant Analysis Council, 1992), and the results adjusted according to equations developed by Konen et al. (2002) for Illinois soils. Bulk density values were used to convert TC in % to a basis of weight per unit area, or TC stocks in Mg/ha for each 10 cm depth. Soil pH (1:1 soil:water) was determined via potentiometry with a Mettler Toledo AG SevenEasy pH Meter (Schwerzenbach, Switzerland).

2.4. Plant sampling and analyses

Cover crop density (plants/m^2) was determined every fall before winterkill and cover crop biomass (g/m^2) was collected in the spring on the plots with overwintering species of hairy vetch

Table 1
Average soil texture and percentages (%) of sand, silt, clay, and coarse (CoSi) and fine silt (FSi), and maximum bulk density (BDmax, Mg/m^3) obtained during the preliminary characterization of field areas (FA: HL, headland and NHL, non-headlands) using blocks and blocks within sites as random factors in the statistical analysis (N = 64). Standard error of the mean (SEM) values and probability values (p-values) associated with these analysis are also shown.

Field areas (FA)	Textural class	Sand (%)		Silt (%)		Clay (%)		CoSi (%)		FSi (%)		BDmax (Mg/m^3)	
		Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
HL	SiL	6.8	0.88	68.1	1.33	25.1	1.47	23.3	0.93	44.8	0.96	1.57	0.02
NHL	SiL	6.4		68.4		25.1		22.6		45.8		1.55	
p-value	–	0.6836	0.8102	0.9647	0.4746	0.1932	0.1426						

and rye, FRhvr. Cover crop density and biomass was determined by randomly placing a 30×30 cm quadrat in each subplot three times and counting the plants within the quadrat. Above ground biomass was cut to ground level, bagged and oven dried at 45 °C for 48 h, and weighed. In both years, fall cover crop counts were taken during the first week of November. Spring biomass sampling was done for all farms during the first week of April in 2012 and in the last week of May in 2013. Weed counts and biomass used the aforementioned quadrat sampling method. Within a quadrat, all weeds were counted, broadleaves were identified to species, and all above ground biomass was cut at ground level, bagged, and dried to constant weight. First sampling was conducted before the cash crop planting, and then two more samplings were coordinated with farmers to occur before each between-row field cultivation during the summer. Thus, in 2012, sampling was done in April, June, and August, and, in 2013, sampling was done in May, June, and July. Cover crop biomass and weed data was not taken in spring 2012 at Malta due to early tillage. The dominant broadleaf weed species were henbit deadnettle (*Lamium amplexicaule* L.), field penny-cress (*Thlaspi arvense* L.), common chickweed [*Stellaria media* (L.) Vill.], and common lambsquarters (*Chenopodium album* L.). Other broadleaves included velvetleaf (*Abutilon theophrasti* Medik.), pigweed (*Amaranthus* spp.), wild mustard (*Sinapis arvensis* L. ssp. *arvensis*), field bindweed (*Convolvulus arvensis* L.), wild carrot (*Daucus* L.), and Pennsylvania smartweed (*Polygonum pensylvanicum* L.). Grasses were not identified to genus and species. Cash crops were hand harvested each fall, and to determine crop yields (kg/ha), a transect was laid between the middle two rows of the plots, and all above ground biomass was cut at ground level and taken to the lab, where plants were counted and yield was determined. The transect length for yield determinations varied with the row width the farm used. For soybean yield, transect length for Cerro Gordo, Malta, and Pana was 5.5 m, 7.6 m, and 4.6 m, respectively. For corn yield, transect length was 5.3 m for Cerro Gordo and Malta and 4.4 m for the two Pana sites.

2.5. Statistical analyses

Four fields from organic grain farms were used to set up our research plots; at each farm we identified two HL and two NHL areas as main plots and each was then split into 4 subplots to allocate the cover crop and control treatments. Thus, a 2×4 split plot arrangement of field areas (FA) and cover crop (CC) treatments with 2 replications at each of 4 locations was used in 2 consecutive years. The total number of experimental units is thus 64 with soil measurements taken at 5 successive depths (D) every fall and spring during 2 consecutive years; the total number of observations analyzed is $64 \times 5 \times 2 \times 2 = 1280$ on average per variable studied. The numerator degrees of freedom (df) available to test the factors of interest included 2 for FA, 3 for CC, and 3 for their interaction. The experimental design has a longitudinal structure in D, and 4 df were assigned to D in most cases except for soil PR that had 3 df assigned (limitation in length of the PR probe) and WAS that had 1 df since the analyses was restricted to the top 2 layers of the soil. Data was analyzed using SAS software version 9.4 (SAS Institute, Cary, NC). Most soil data was analyzed using the MIXED procedure except available P and N (N-NO_3 and N-NH_4) which due to lack of normality of model residuals were analyzed using PROC GLIMMIX with the lognormal distribution (dist = logn) within the model statement (Gbur et al., 2012). Analyses of soil properties were grouped by season, in the fall before cover crop establishment and in the spring before cover crop suppression by tillage. Field area (FA), cover crops (CC), and depth (D) were considered fixed effects, while years and replicates (blocks within sites and sites) were considered random effects. Significance of random effects was calculated with a Wald Z test statistic using the COVTEST option in the MIXED procedure and the corresponding covtest statement in GLIMMIX. Depth (D) was analyzed using a repeated measures approach with variance-covariance structure of ar(1), autoregressive, or arh(1), heterogeneous autoregressive, for each soil variable selected on the basis of the lowest Akaike's Information Criteria (Littell et al., 2006). When appropriate, lsmeans were separated using the PDIFF option of LSMEANS in SAS PROC MIXED or GLIMMIX setting the probability of Type I error or alpha level (α) at 0.05. The CORR procedure of SAS was used to evaluate the relationship between SOCs and WAS.

Cover crop data (density, plants/m^2, in fall of each year along with biomass, g/m^2, for spring times) and weed data (density, plants/m^2, and proportion of broadleaves vs total, B:T in % in spring and twice in summer of each year along with biomass data, g/m^2, for spring times) were analyzed with the PROC GLIMMIX procedure. The effect of replicates (blocks within sites and sites) were considered random, and the effects of sampling times (ST), field area (FA), and cover crop (CC) treatments were considered fixed. Due to strong departures from normality of model residuals and model heteroscedasticity, a lognormal probability distribution (dist = logn) model specification was used for the analysis of weed

Table 2

Probability values (p-values) and degrees of freedom (df) associated with the different sources of variation in the statistical analysis of soil penetration resistance (PR, kPa), bulk density (BD, Mg/m^3), water aggregate stability (WAS, %), total carbon stocks (TC, Mg/ha), nitrate (N-NO_3, mg/kg), ammonium (N-NH_4, mg/kg), available phosphorus (P, mg/kg), and soil pH across all four locations over two respective fall and spring seasons.

Source of variation	df	PR[a]	BD	WAS[b]	TC	NO_3	NH_4	P	pH
Fall p-values before cover crops									
Field areas (FA)	1	0.0021	0.0154	0.1027	0.0190	0.9347	0.5424	0.0533	<0.0001
Depth (D)	4	<0.0001	<0.0001	0.2182	<0.0001	<0.0001	<0.0001	<0.0001	0.0029
FA × D	4	0.5235	0.4052	0.0076	0.0003	0.1761	0.4115	0.0633	0.2855
Spring p-values following cover crops									
Field areas (FA)	1	0.0038	0.0255	0.0047	0.0054	0.7768	0.4253	0.0645	<0.0001
Cover crop (CC)	3	0.0983	0.8794	0.5356	0.1005	0.2605	0.8896	0.0621	0.1102
FA × CC	3	0.0054	0.4036	0.3935	0.8827	0.5813	0.9304	0.5534	0.0934
Depth (D)	4	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
FA × D	4	0.0070	0.7008	0.2254	0.0017	0.7034	0.9627	0.4631	0.4384
CC × D	12	0.0810	0.5338	0.7460	0.8867	0.0897	0.0979	0.7095	0.2119
FA × CC × D	12	0.5745	0.0678	0.8431	0.2133	0.7852	0.6513	0.8479	0.9773

[a] Due to probe length limitation, soil PR was recorded at 4 successive depths instead of 5 as most other variables thus there are 3 df for each D and FA × D instead of 4 in the fall and spring, and 9 df for CC × D and FA × CC × D instead of 12 in the spring seasons.

[b] Soil WAS determinations were conducted on the top 2 depths thus these analyses are associated with 1 df for each D and FA x D instead of 4 in the fall and spring, and 2 df for each CC × D and FA × CC × D instead of 12 in the spring seasons.

Table 3a
Soil physical properties of penetration resistance (PR, kPa), bulk density (BD, Mg/m^3), and water aggregate stability (WAS, %) determined within the different field areas (FA: HL, headland; NHL, non-headland areas) and at successive depths (D) within each field area (FA × D). Mean values and standard error of the means (SEM) are reported across all four locations over two fall seasons. Within a column and within a given factor or combination of factors, means followed by the same letter are not statistically different ($\alpha = 0.05$).

Fall soil physical properties before cover crops							
Field areas (FA)	Depth (cm) (D)	PR (kPa)		BD (Mg/m^3)		WAS (%)	
		Mean	SEM	Mean	SEM	Mean	SEM
HL		1499b	310	1.25b	0.071	88.9	3.49
NHL		1181a	310	1.22a	0.071	86.7	3.50
FA × D							
HL	0–10	942	312	1.12	0.073	90.7b	3.52
	10–20	1471	312	1.31	0.072	87.0a	3.58
	20–30	1779	312	1.31	0.072	–	–
	30–40	1803	312	1.27	0.072	–	–
	40–50	–	–	1.26	0.073	–	–
NHL	0–10	656	313	1.09	0.073	86.0a	3.53
	10–20	1144	312	1.28	0.072	87.4a	3.59
	20–30	1396	312	1.26	0.072	–	–
	30–40	1526	312	1.24	0.072	–	–
	40–50	–	–	1.26	0.073	–	–

and cover crop variables. A repeated measures approach was used for successive sampling times (ST) with variance-covariance structure of vc, variance components, selected on the basis of the lowest Akaike's Information Criterion (Littell et al., 2006; Gbur et al., 2012). Crop yield was analyzed each year with the PROC MIXED procedure with replicates (blocks within sites and sites) considered random effects and field area (FA) and cover crop (CC) treatments considered fixed effects. Plots were created using Sigma Plot 12.5 (Systat Software, Inc., San Jose, California). Statistical model and SAS codes are available upon request from the authors.

3. Results and discussion

3.1. Fall soil properties

During the fall season in both consecutive years, the comparison of soil properties at successive depths (D) within headland (HL) and non-headland (NHL) areas was the only factor under study and provided the baseline characterization of the soils receiving cover crop treatments. Table 2 shows the exact probability values (*p*-values) associated with the different sources of variation in the analysis of soil properties across the four sites and two years of the experiment during the fall (top) and spring seasons (bottom).

Penetration resistance (PR) was significantly different by field area ($p \leq 0.0021$) and, at all depths, the HL had ~30% higher PR than the NHL areas (Tables 2 and 3a). In the HL, PR averaged 318 kPa greater than in the NHL, which was about 30% more across all depths. Additionally, BD was greater in the HL than the NHL, and BD increased through the soil profile to 20 cm and then slightly decreased as it approached 50 cm (Tables 2 and 3a). These increased PR and BD values verified the presumed compaction differences between the field areas as both properties were significantly higher in the HL than the NHL throughout the soil profile. Though statistically significant, BD values were nowhere near the BDmax values found with the Proctor test (Table 1) nor near the theoretical plant root restricting BD for silt loam soils specified in the literature (Kaufmann et al., 2010). Similarly, PR values reported here are far from the 2000 to 4000 kPa threshold range suggested as restrictive for root growth (Hamblin, 1985).

Water aggregate stability (WAS) was significantly greater in the HL areas than the NHL yet only at the soil surface ($p \leq 0.0076$) (Tables 2 and 3a). There was also an increase in TC stocks in the HL areas, yet correlations between these two properties were modest across sites and years in our study [HL ($r = 0.29$, $p < 0.0001$), NHL ($r = 0.17$, $p < 0.0001$)]. Soil TC stocks were about 10% higher within HL areas compared to the NHL areas at all depths except for the 40–50 cm depth range (Tables 2 and 3b). Both forms of available N, nitrate ($N\text{-}NO_3$) and ammonium ($N\text{-}NH_4$), decreased through the soil profile, reflecting nutrient stratification by depth ($p \leq 0.0001$). Available nitrogen during the fall season did not differ between field areas (Tables 2 and 3b). Results were marginally significant for available P, with HL areas containing higher P than the NHL within the top 30 cm of the soil profile (Tables 2 and 3b). Agronomic interpretation of Bray P1 extractable soil P levels ranked all the soils in this study within the excessively high category (>25 mg kg^{-1}) with mean values greater than the maximum P test levels (32 mg kg^{-1}) recommended for corn and soybean production in Illinois (Fernandez and Hoeft, 2009).

An average increase of 0.4 pH units was also recorded for HL areas with a consistent effect through all studied depths

Table 3b
Soil chemical properties of total carbon stocks (TC, Mg/ha), nitrate ($N\text{-}NO_3$, mg/kg), ammonium ($N\text{-}NH_4$, mg/kg), available phosphorus (P, mg/kg), and soil pH, determined within the different field areas (FA: HL, headland; NHL, non-headland areas) and at successive depths (D) within each field area (FA × D). Mean values and standard error of the means (SEM) are reported across all four locations over two fall seasons. Within a column and within a given factor or combination of factors, means followed by the same letter are not statistically different ($\alpha = 0.05$).

Fall soil chemical properties before cover crops											
Field areas (FA)	Depth (cm) (D)	TC (Mg/ha)		$N\text{-}NO_3$ (mg/kg)		$N\text{-}NH_4$ (mg/kg)		P (mg/kg)		pH	
		Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
HL		26.2b	1.16	11.6	1.91	1.5	0.21	28.3	2.46	6.7b	0.13
NHL		23.8a	1.16	11.2	1.91	1.7	0.21	19.2	2.46	6.3a	0.13
FA × D											
HL	0–10	28.6f	1.24	27.1	2.77	3.2	0.37	63.6b	5.13	6.6	0.13
	10–20	28.8f	1.21	12.8	2.00	1.4	0.22	39.8b	3.94	6.7	0.13
	20–30	27.5e	1.18	7.5	1.91	1.1	0.29	19.5b	2.17	6.7	0.13
	30–40	24.2cd	1.18	5.3	1.95	1.0	0.19	10.4a	1.86	6.7	0.13
	40–50	21.7ab	1.22	5.1	2.03	1.0	0.21	8.3a	1.73	6.8	0.13
NHL	0–10	25.6d	1.24	21.9	2.77	3.4	0.37	42.9a	5.13	6.2	0.13
	10–20	25.9de	1.21	12.4	2.00	1.5	0.22	26.3a	3.94	6.3	0.13
	20–30	23.8c	1.18	7.5	1.91	1.6	0.29	11.1a	2.17	6.3	0.13
	30–40	22.2b	1.18	7.1	1.95	1.0	0.19	8.3a	1.86	6.3	0.13
	40–50	21.4a	1.22	7	2.03	1.0	0.21	7.6a	1.73	6.3	0.13

(Tables 2 and 3b) when compared to NHL areas of the field. This stratification of nutrients and pH is commonly found in agricultural soils when there is no inversion of the soil during tillage; it is likely the direct result of surface-placement of crop residues and inputs that leads to accumulation of soil organic matter and microbial biomass on the top soil (Franzluebbers, 2002). Yet additional factors could have influenced the observed increased in available P and soil pH in the HL areas. Study sites had histories of stockpiling manure on these areas; manure applications are known to significantly increase soil P (Eghball and Power, 1999) and could influence soil pH as well depending on the manure source and soil type under question (Whalen and Chi, 2000). Also, since HL are along roadsides where heavy machine traffic was frequent and in close proximity to limestone based gravel roads, we cannot discard some topsoil contamination as at least, partial explanation of this effect.

3.2. Cover crop establishment and growth

Cover crops were acceptably established on both years of this study despite important differences in the growing conditions during September–April in both 2011–2012 and 2012–2013 CC seasons. Fig. 1 shows the statewide monthly average precipitation (A) and temperatures from 2011 to 2013 along with the 1981–2010 normal for each weather variable (Midwest Regional Climate Center, 2015). Total precipitation was different for 2011–2012 (570 mm; 26 mm below normal) and 2012–2013 (722 mm; 126 mm above normal) with an average departure of 49 mm from the 20 years normal. Departures from normal temperatures showed the opposite trend with about 19 °C more accumulated during the first CC growing season compared to 3 °C below the normal during the second CC growing seasons (Midwest Regional Climate Center, 2015). Besides weather, differences in the length of the CC growing season for each

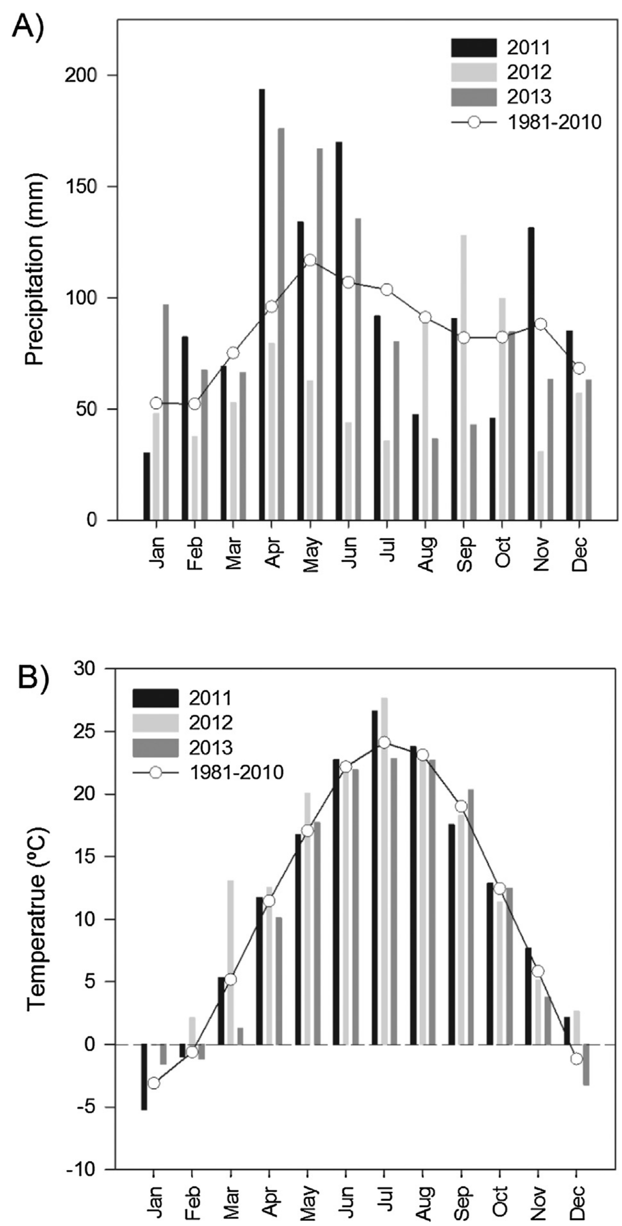

Fig. 1. (A) Precipitation (mm) and (B) temperature (°C) from 2011 to 2013 during the cover crop (September–April) and soybean and corn growing seasons (May–November) along with their respective normal for the 1981–2010 period.
Source: Midwest Regional Climate Center (2015).

Table 4
Cover crop density (plants/m^2) in late fall within the studied field areas (FA: HL, headland; NHL, non-headland areas) and under the cover crop treatments (CC: C, fallow control; FR, forage radish; FRbw, mix of forage radish and buckwheat; FRhvr, mix of forage radish, hairy vetch, and cereal rye). Cover crop biomass in the spring (g/m^2) represent the biomass of the only cover crop treatment (FRhvr) that includes overwintering species of hairy vetch and cereal rye. Back transformed mean values are reported across all four locations over two years of research. Probability values (p-values) associated with the different sources of variation for each variable is presented below. Within a column and within a given factor (FA or CC) or combination of factors (FA × CC), means followed by the same letter are not statistically different ($\alpha = 0.05$).

Field areas (FA)	Cover crop (CC)	Late fall density (plants/m^2)	Spring biomass (g/m^2)
HL		36	350
NHL		43	336
	Control	–	–
	FR	33a	–
	FRbw	33a	–
	FRhvr	56b	–
Sources of variation			
FA		0.1282	0.7616
CC		<0.0001	–
FA × CC		0.4992	–

species help explain differences in plant density before winter and in spring biomass as well. No statistical differences were detected in CC density, in plants/m^2, prior to winterkill (Table 4) between field areas, yet plant density varied among CC treatments ($p \leq 0.0001$) with some 56 plants per m^2 in the FRhvr treatment compared with an average of 33 plants per m^2 in each of the FRbw and FR plots across sites and years. Buckwheat was the most susceptible to cold temperatures and was killed by the first frost on both years. The CC that overwintered were cereal rye and hairy vetch, both part of the mixture in the FRhvr treatment. Radish was intermediate in cold hardiness but like buckwheat, it does not overwinter in our region.

3.3. Spring soil properties

During the spring season in both consecutive years, CC treatments had been established the previous fall and were under evaluation along with field areas at the time of soil sampling. The only overwintering CCs were in the FRhvr treatment, and both HL and NHL showed similar CC biomass in the spring across sites and years (Table 4). Table 2 shows the exact probability values (p-values) associated with the different sources of variation in the analysis for PR, BD, WAS, TC stocks, and available N and P along with soil pH while Tables 5a report the mean values and SEM of the soil physical properties and Table 5b for the chemical

Table 5a
Soil properties of penetration resistance (PR, kPa), bulk density (BD, Mg/m^3), and water aggregate stability (WAS, %) determined within the different field areas (FA: HL, headland; NHL, non-headland areas); under the cover crop treatments (CC: C, fallow control; FR, forage radish; FRbw, mix of forage radish and buckwheat; FRhvr, mix of forage radish, hairy vetch, and cereal rye); under each cover crop within each field area (FA × CC) and at successive depths (D) within each field area (FA × D). Mean values and standard error of the means (SEM) are reported across all four locations over two spring seasons. Within a column and within a given factor or combination of factors, means followed by the same letter are not statistically different ($\alpha = 0.05$).

Spring soil physical properties following cover crops								
Field areas (FA)	Cover crop (CC)	Depth (cm)	PR (kPa)		BD (Mg/m^3)		WAS (%)	
			Mean	SEM	Mean	SEM	Mean	SEM
HL			1891b	262.2	1.32b	0.06	85.5b	5.40
NHL			1625a	262.2	1.28a	0.06	82.3a	5.40
	Control		1670	262.3	1.29	0.06	83.8	5.46
	FR		1728	262.3	1.30	0.06	83.6	5.46
	FRbw		1816	262.3	1.30	0.06	85.3	5.46
	FRhvr		1818	262.3	1.29	0.06	83.0	5.46
FA × CC								
HL	Control		1832bc	268.9	1.31	0.06	84.0	5.58
	FR		1951c	268.9	1.31	0.06	85.1	5.56
	FRbw		1977c	269.1	1.33	0.06	87.1	5.55
	FRhvr		1801bc	268.9	1.31	0.06	86.0	5.57
NHL	Control		1508a	269.1	1.27	0.06	83.6	5.56
	FR		1504a	269.0	1.29	0.06	82.2	5.57
	FRbw		1655ab	268.9	1.27	0.06	83.5	5.58
	FRhvr		1834bc	269.0	1.29	0.06	80.1	5.57
FA × D								
HL		0–10	1155a	265.5	1.19	0.06	86.7	5.42
		10–20	1958cd	265.4	1.38	0.06	84.4	5.45
		20–30	2268f	265.1	1.36	0.06	–	–
		30–40	2182ef	265.5	1.32	0.06	–	–
		40–50	–	–	1.32	0.06	–	–
NHL		0–10	1012a	265.2	1.15	0.06	84.6	5.42
		10–20	1634b	265.1	1.34	0.06	80.1	5.45
		20–30	1857c	265.1	1.34	0.06	–	–
		30–40	1999de	265.4	1.28	0.06	–	–
		40–50	–	–	1.29	0.06	–	–

Table 5b
Soil properties of total carbon stocks (TC, Mg/ha), nitrate (N-NO_3, mg/kg), ammonium (N-NH_4, mg/kg), available phosphorus (P, mg/kg), and soil pH, determined within the different field areas (FA: HL, headland; NHL, non-headland areas); under the cover crop treatments (CC: C, fallow control; FR, forage radish; FRbw, mix of forage radish and buckwheat; FRhvr, mix of forage radish, hairy vetch, and cereal rye); under each cover crop within each field area (FA × CC) and at successive depths (D) within each field area (FA × D). Mean values and standard error of the means (SEM) are reported across all four locations over two spring seasons. Within a column and within a given factor or combination of factors, means followed by the same letter are not statistically different ($\alpha = 0.05$).

Spring soil chemical properties following cover crops												
Field areas (FA)	Cover crop (CC)	Depth (cm)	TC (Mg/ha)		N-NO_3 (mg/kg)		N-NH_4 (mg/kg)		P (mg/kg)		pH	
			Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
HL			27.1b	1.02	8.1	1.11	4.0	2.55	25.8b	5.10	6.8b	0.15
NHL			24.8a	1.02	9.4	1.11	4.4	2.55	20.4a	5.10	6.3a	0.15
	Control		26.5	1.01	9.0	3.06	3.7	2.63	22.6ab	5.39	6.6	0.15
	FR		25.3	1.01	7.8	3.06	4.4	2.63	23.2ab	5.39	6.6	0.15
	FRbw		26.3	1.01	8.9	3.06	5.0	2.63	26.5b	5.39	6.7	0.15
	FRhvr		25.8	1.01	9.0	3.06	3.7	2.63	20.1a	5.39	6.5	0.15
FA × CC												
HL	Control		27.6	1.09	8.4	3.22	3.9	2.77	25.0	5.93	6.8	0.16
	FR		26.3	1.09	7.5	3.22	4.9	2.77	27.2	5.93	6.8	0.16
	FRbw		27.6	1.09	7.5	3.22	4.4	2.77	27.7	5.93	6.9	0.16
	FRhvr		26.8	1.09	8.7	3.24	2.9	2.79	23.4	6.00	6.9	0.16
NHL	Control		25.3	1.09	9.6	3.22	3.5	2.77	20.2	5.93	6.4	0.16
	FR		24.2	1.09	8.0	3.24	3.9	2.79	19.3	6.00	6.3	0.16
	FRbw		25.0	1.09	10.4	3.22	5.5	2.77	25.2	5.93	6.4	0.16
	FRhvr		24.7	1.09	9.2	3.22	4.5	2.77	16.8	5.93	6.2	0.16
FA × D												
HL		0–10	31.0f	1.05	17.9	3.32	5.0	2.74	58.6	6.52	6.7	0.15
		10–20	29.9e	1.08	8.3	3.08	4.4	2.71	31.3	5.59	6.9	0.15
		20–30	27.7d	1.06	5.2	2.97	4.4	2.87	15.7	5.02	6.9	0.15
		30–40	24.5c	1.03	4.5	3.08	3.1	2.55	8.5	5.18	6.9	0.15
		40–50	22.5ab	1.04	4.2	2.92	3.2	2.52	15	5.81	6.8	0.15
NHL		0–10	27.4d	1.05	19.3	3.32	5.0	2.74	46.1	6.52	6.3	0.15
		10–20	27.0d	1.08	10.8	3.08	4.7	2.71	28.4	5.59	6.4	0.15
		20–30	25.6c	1.06	6.4	2.97	5.1	2.87	12.1	5.02	6.4	0.15
		30–40	22.7b	1.03	5.9	3.08	3.4	2.55	9.0	5.18	6.3	0.15
		40–50	21.3a	1.04	4.0	2.92	3.5	2.52	6.2	5.81	6.3	0.15

properties measured during the spring season across four sites and two years of initiation of experiments.

Penetration resistance (PR) was still higher in the HL compared to the NHL areas of the fields yet the differences were concentrated within the 10–30 cm depths (Table 5a). Cover crop treatment of FRhvr seemed to increase the PR slightly within the NHL areas in comparison with the other treatments likely related to the CC still growing and extracting water from the profile at the time of measurement. Similar increases in PR after CC have been previously recorded in Illinois soils (Acuna and Villamil, 2014; Villamil et al., 2006). Angers and Caron (1998) suggested that active growth and water use by CC and the resulting intensification

Table 6
Spring weed biomass (g/m^2), and weed density (plant/m^2), and proportion of broadleaf weeds (B:T, %) at three successive sampling times (ST: spring, early summer, and late summer) within the studied field areas (FA: HL, headland; NHL, non-headland areas) and under the cover crop treatments (CC: C, fallow control; FR, forage radish; FRbw, mix of forage radish and buckwheat; FRhvr, mix of forage radish, hairy vetch, and cereal rye). Back transformed mean values are reported across all four locations over two years of research. Probability values (p-values) associated with the different sources of variation for each variable are presented below. Within a column and within a given factor or combination of factors, means followed by the same letter are not statistically different ($\alpha = 0.05$).

Sampling time (ST)	Field areas (FA)	Cover crop (CC)	Weed biomass (g/m^2)	Weed density (plants/m^2)	B:T (%)
Spring			–	131c	31b
Early summer			–	52b	17a
Late summer			–	19a	18a
	HL		172	56b	19a
	NHL		157	39a	24b
		Control	252b	49	19
		FR	207b	48	22
		FRbw	201b	46	21
		FRhvr	76a	44	22
Sources of variation					
ST			–	<0.0001	<0.0001
FA			0.5912	0.0021	0.0381
ST × FA			–	0.1406	0.2556
CC			<0.0001	0.9212	0.7288
ST × CC			–	0.6296	0.8922
FA × CC			0.1573	0.9348	0.9952
ST × FA × CC			–	0.9875	0.9024

of wet–dry cycles can lead to closer contact between particles thus increasing PR values. As in the fall season, BD was consistently higher in the HL areas and was not affected by CC (Tables 2 and 5a). Following the fall trends, WAS during the spring season was significantly greater in HL than NHL areas yet now the effect was detected at both depths ($p \leq 0.0047$) and as expected, values were higher in the surface soil ($p < 0.0002$) reflecting the topsoil addition of residues and organic materials and their related increase in biological activity. Cover crops did not influence WAS ($p \leq 0.5356$) (Tables 2 and 5a) or TC stocks in the soils under study (Table 5b). We were able to measure increases in TC within the HL relative to the NHL areas again in the spring and up to the same depth of 40 cm (Tables 2 and 5b) yet no effect of CC treatments was registered for this variable ($p \leq 0.1005$).

As in the baseline fall measurements, available N in the form of N-NO_3 and N-NH_4 significantly decreased with depth ($p \leq 0.0001$) in the spring following cover crop treatments, indicating stratification through the soil profile, but there was no effect of field area or CC treatments on available N (Tables 2 and 5b). This is an interesting finding since N scavenging is one of the most important reasons for inclusion or promotion of CC use in conventional systems and the scavenging potential of rye has been found even after one growing season (Acuna and Villamil, 2014). A statistical marginal significance was recorded for available P in relation to field area ($p \leq 0.0645$) and CC ($p \leq 0.0621$) and this nutrient stratification in depth was also evident ($p < 0.0001$). Headland areas had greater P than the NHL areas at all depths, with the FRhvr treatment showing the lowest available P levels with some 11% less P than the other CC treatments across field areas (Tables 2 and 5b). Lower P levels with FRhvr indicates immobilization of this nutrient in the CC biomass, which is important from an environmental standpoint to reduce P runoff losses to waterways since P losses are greater when soil P test values are above the agronomical optimum range for a given crop and location (Hart et al., 2004). Soil pH was again significantly higher in the HL compared to the NHL areas for all the studied depths regardless of CC treatments ($p \leq 0.0001$) (Tables 2 and 5b).

3.4. Weed biomass and density through the growing season

Weed biomass in the spring following cover crop treatments was significantly lower ($p < 0.0001$) under the FRhvr treatment (Table 6) in both HL and NHL areas. The cover crop species in this mixture are known to suppress weeds through both light interception and physically impeding weed seedling growth (Teasdale, 1993; Teasdale and Mohler, 2000). Weed density (plants/m^2) was higher in HL areas compared to NHL throughout the spring and summer times and these HL areas also showed a consistent dominance of grasses over broadleaves (Table 6). These results are consistent with previous observations of increased weed seedling recruitment in response to improved seed-soil contact due to soil compaction from wheel traffic (Jurik and Zhang, 1999). Broadleaf weeds were in general more abundant in the spring and then decreased in importance along with the decrease in weed density as the season progressed. Neither weed density nor the proportion of broadleaves to grasses was affected by CC treatments at any sampling time (Table 6).

3.5. Crop yields

Cash crop yields were not different between field areas nor did the CC treatments affect soybean or corn production (Table 7). The cash crop season of 2012 (May–November, Fig. 1) was characterized by above normal temperatures during May and July and cooler than normal conditions in Sept to Nov. In addition, 2012 had important deficiencies in rain during the spring that negatively

Table 7
Soybean yields in 2012 and corn yields in 2013 determined within the different field areas (FA: HL, headland; NHL, non-headland areas); under the cover crop treatments (CC: C, fallow control; FR, forage radish; FRbw, mix of forage radish and buckwheat; FRhvr, mix of forage radish, hairy vetch, and cereal rye); and under each cover crop treatment within each field area (FA × CC). Mean values and standard error of the means (SEM) are reported across all four locations for each year-crop. Probability values (*p*-values) associated with the different sources of variation for each crop-year is presented below.

Field area (FA)	Cover crop (CC)	*n*	2012 soybean (kg/ha)		2013 corn (kg/ha)	
			Mean	SEM	Mean	SEM
HL		32	2205	316.5	10,311	722.7
NHL		32	2357	316.5	9809	722.7
	Control	16	2378	301.3	10,272	713.4
	FR	16	2290	301.3	9945	713.4
	FRbw	16	2322	301.3	10,049	713.4
	FRhvr	16	2133	301.3	9973	713.4
FA × CC						
HL	Control	8	2233	334.4	10,309	794.3
	FR	8	2218	334.4	10,219	794.3
	FRbw	8	2127	334.4	10,233	794.3
	FRhvr	8	2241	334.4	10,482	794.3
NHL	Control	8	2523	334.4	10,236	794.3
	FR	8	2362	334.4	9671	794.3
	FRbw	8	2518	334.4	9866	794.3
	FRhvr	8	2025	334.4	9463	794.3
Sources of variation		df				
FA		1	0.5508		0.3555	
CC		3	0.2513		0.8219	
FA × CC		3	0.0936		0.6560	

affected state averages of corn yield yet rains returned in August and were above normal during the following moths, preventing significant damage to soybean yields. While not statistically significant, there was a trend reflecting 20% less soybean yields in the FRhvr treatments compared to the controls within the NHL areas which could be related to less water available to the crop with overwintering CCs in these areas in this particularly dry year. Crops growing in slightly more dense soils such as those of HL areas could have an advantage under water stress conditions due to the indirect increase in plant available water with increases in BD of the soil in these areas. Weather conditions were reversed in 2013, characterized by a wet spring with slightly cooler temperatures (Fig. 1) followed by a dry summer and fall seasons which resulted in a record corn yield in the state. Particularly good corn yields were also recorded for the organic farms in our study and, as in the rest of the state of Illinois, the success is likely related to the high water holding capacity of the soils which allowed the crop to withstand those dry months without penalty.

Overall, our results indicate that HL areas are denser (higher PR and BD) and richer in nutrients (higher TC, P and pH) than the NHL areas also showing increased WAS – a reduction in the soil susceptibility to erosion with stronger soil aggregates – which points toward a more beneficial environment for microbial activities within the HL areas. Primarily, these changes the HL areas were attributed to the densification of the soil, which created more carbon and nutrients per unit area yet statistical analysis of TC as concentration or the available P and N as stocks instead of the units of concentration reported, showed similar results (data not shown). A laboratory study by De Neve and Hofman (2000) uncovered similar trends from loamy sand soil incubated under varying bulk densities with and without residue additions. The study found the increased BD to not influence nitrogen mineralization but did reduce carbon mineralization, which would allow for carbon accumulation over time. In combination with the densification, reduced decomposition rates could explain our study's increase in TC in the HL areas and associated improvement of WAS. Our hypothesis that more weeds would be present in compacted areas though the year was supported, yet we did not expect weed population densities to be related to the soil characteristics found in HL areas which could potentially indicate a positive loop: HL benefit weed growth, particularly grasses, and in turn, these weeds improve soil properties in these areas compared to the NHL parts of the fields under study.

Our results indicate that CC might not provide compaction alleviation in HL areas of these organic systems. Compaction alleviation from CC has been reported in conventional and no-till grain production systems yet reductions in BD and PR of the soil were commonly associated to changes in TC after long term use of CC (Chen et al., 2014; Villamil et al., 2006; Williams and Weil, 2004). Soils in our study are typical of Illinois with inherently high levels of TC and high shrink-swell potential, two characteristics of resilient soils (Blanco-Canqui and Lal, 2008). Thus changes in soil properties associated with agronomic practices would likely go undetected in the short term (Acuna and Villamil, 2014) and even in the long term (Zuber et al., 2015) when tillage is involved. This is particularly true in organic systems in the Midwest where the length of the growing season for cover cropping is limited in the fall by early frost and in the spring by the need to suppress the growth of these plants to allow for proper decomposition of residues and avoid interference with the cash crops. The potential benefits of cover cropping are further reduced by the heavy reliance on tillage for seed bed preparation and weed control. An important consideration in our systems is that while the compaction was present in the HL areas, it was not severe nor root limiting thus not expected to compromise crop yields. In fact HL areas seemed to benefit the soybean crop in conditions of water stress.

4. Conclusions

This participatory on farm research on the use of CC in HL versus NHL areas in organic farms showed that HL areas are denser (higher PR and BD) and richer in nutrients (higher TC, P and pH) than the NHL areas also showing increased WAS which points toward a more beneficial environment for microbial activities within the HL areas. These conditions seemed to benefit weed growth, particularly grasses, and in turn, these weeds improve soil properties in these areas compared to the NHL parts of the fields under study which point out a positive loop that requires further research. Our study shows that cover cropping with overwintering species could be used as a tool to retain P within the system and suppress weed growth. Though the lack of CC effects on soil properties could be reflecting the short duration of the present study, it also brings to question if the full benefits of cover cropping can be achieved in Midwest organic grain systems if tillage remains as the main weed control strategy.

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