Final Report: The Details That Matter: Second Generation Questions On Organic No-Till Practices

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Note to funders: I sincerely thank the CERES Trust for their support and participation in this exciting research. This work improved our understanding of no-till techniques in diversified organic systems and served as an important contribution to the current state of scientific knowledge on the subject. The number of organic farmers reached and impacted by this work is in the thousands, with hundreds of organic acres now under organic no-till management, which improves soil stewardship, soil health, and profitability. We are currently undertaking a survey of organic farmers to more specifically quantify the number of acres under organic management and remaining challenges faced by organic no-till farmers. Outreach products with respect to this data can be found here under the resources tab: https://ograin.cals.wisc.edu/. Associated YouTube videos (which have reached well over a half million viewers across the globe) can be accessed here:
https://www.youtube.com/channel/UCbIqPECXj3WfeUEjYGAgdYg
https://www.youtube.com/user/uwipm/search?query=erin+silva

Introduction

The amount of land under certified organic management continues to expand in response to growing consumer demand. According to the 2016 United States Department of Agriculture's Certified Organic Survey, 1.1 million ha of crop land were certified organic (USDA 2017). Additionally, in 2018, 57.8 million ha are managed organically across the globe, a growth of 7.5 million ha from 2015, the largest increase ever recorded (Willer and Lernoud 2018).

Organic farmers must implement a soil-building plan as set forth in the regulations (7 CFR §205.203 and 205.205) of the United State Department of Agriculture's National Organic Program. These strategies include cover cropping, diverse crop rotations, additions of compost and manure, and judicious use of tillage and cultivation. The ability of organic farmers to integrate no-till practices into their crop management strategies would further expand their potential to protect and enhance their soil, as no-till practices have been demonstrated to reduce soil erosion (Langdale et al. 1992a; Moldenhauer et al. 1983), increase soil organic matter and soil carbon (Edwards et al. 1992; Langdale et al. 1992b; Cooper et al. 2016), decrease runoff and improve water infiltration (Uri 1999), and improve soil physical and biological qualities (Angers and Eriksen-Hamel 2008). However, the no-till practices used on conventional farms do not translate well into organic management, as the use of synthetic herbicides are prohibited and tillage and cultivation remain as the primary in-season weed management tools.

Cover crop-based reduced tillage (CCBRT) practices (also known as “organic no-till”) are being increasingly adopted by organic farmers as an alternative approach to no-till that does not rely upon the use of synthetic chemicals (Silva and Delate 2017; Vincent-Caboud et al. 2017). In CCBRT systems, terminated cover crop residues create physical barrier on the soil surface, preventing weeds for emerging and providing in-season weed management in the cash crop phase (Teasdale and Mohler 1993; Williams et al. 1998; Silva 2014). Adequate production of biomass and effective termination of a cover crop are critical aspects of CCBRT practices, with termination typically achieved through roller-crimpers or mowers. To successfully mechanical terminate cereal grains while limiting regrowth of the crop, operations must occur at the specific maturity stage of anthesis (Zadoks’ stage 69) (Zadoks et al.1974; Mirsky et al. 2011). However, this necessitates delaying the sowing of the cash crop several weeks later than would be optimal, which may result in lower yields.

While CCBRT systems can produce organic soybean (*Glycine max* L.) yields that are within regional averages, yields continue to lag behind organic soybeans produced using typical tillage and cultivation practices. Research in Iowa and Wisconsin has demonstrated that, while during some seasons CCBRT yields are not significantly different than typically managed organic soybean, in many circumstances yield reductions of up to 24% are observed in CCBRT systems as compared to typical organic soybeans (Bernstein et al. 2011; Delate et al. 2012). One factor affecting final soybean yields may be the slow early-season growth of CCBRT soybeans (Silva and Delate 2017). Reasons for slow initial growth may be multi-fold: 1) cooler soil temperatures under the rye residue delaying soybean germination; 2) slower or inhibited root growth under the rye mulch; 3) nutrient tie-up under the rye mulch; and 4) allelopathic effects of cereal rye (*Secale cereale* L.) (Silva and Delate 2017).

Research conducted in conventional soybean production supports the hypothesis that delayed planting dates and suppressed early growth of the soybeans under CCBRT management could be contributing to reduced yields. In a study using field survey data from conventional farms providing 3568 field-year observations across the upper Midwestern US, late-sown fields were limited in their ability to achieve yields comparable to early-sown fields under any suite of management practices and soil and terrain parameters (Mourtzinis et al. 2018). Similarly, Bastidas et al. (2008) found that delaying soybean planting beyond May 1 resulted in significant linear seed yield declines of 17 kg ha^{-1} d^{-1} to 43 kg ha^{-1} d^{-1}, indicating that early planting is critical to reach the crop’s yield potential. Further, in a study investigating the yield effects of a series of soybean planting dates from April to June, the late April/early May planting dates demonstrated clear yield advantages, with yield reductions between late April and June reaching 12-41% depending on field location (De Bruin and Pedersen 2008).

Beyond the impact of later planting dates, decreased nodulation may also be contributing to the slower early growth of soybean in CCBRT systems. Soybean can obtain up to 50% or more of their nitrogen (N) needs through symbiotic relationships with the N_2–fixing rhizobium bacteria *B. japonicum* and *B.elkanii* (Elmore 1984; Collino et al. 2015). Schipanski et al. (2010) found that biological nitrogen fixation provided 36 to 82% percentage of plant N, with the total N_2 fixed ranging from 40 to 224 kg N ha $^{-1}$. However, lower early season soil temperatures and high soil moisture content, which can be exacerbated under reduced tillage practices, can delay nodulation and contribute to lower exudation of flavanoids (the compounds responsible for signaling by the rhizobia), leading to reduced nodulation (Zhang et al. 1995; Zhang and Smith 1994; Pan and Smith 1998). Between the temperature range of 17°C and 25°C, the onset of N_2 fixation was found to be linearly delayed by 2.5 days for each degree decrease in temperature, and below 17°C, each °C appears to delay the onset of N_2 fixation by about 7.5 days. With the cooler soil temperatures resulting from the thick cereal rye residues, nodule development on soybeans could be delayed or reduced in CCBRT systems. The effects of delayed nodulation with respect to limiting yields may be more pronounced in CCBRT systems, as biologically available N may also be decreased with low soil temperatures (Abberton et al. 1998).

While the termination date of the rye is limited by the date of anthesis, several approaches could allow for earlier planting of soybean. First, cereal rye cultivars can vary in their time to maturity, with some reaching anthesis before others. 'Aroostook' is a variety that has been consistently demonstrated to reach anthesis 5-7 days earlier than most other open-pollinated commercially-available cultivars in the U.S. (eg, Collins et al. 2012; Neu and Nair 2017). A second approach would be to decouple the soybean planting date from the rye termination date, planting the soybeans earlier and subsequently terminating the rye at the correct stage over the emerged soybean. While this approach may appear to risk physically injuring the soybeans, techniques such as land rolling over emerged soybean for the purpose of field leveling have demonstrated that rolling up to the V3 stage of soybeans will not reduce yields (Rueber and Holmes 2011).

The objectives of this study were twofold: 1) Evaluation of cover crop cultivars, soybean cultivars, and planting date and 2) Impact of organic no-till soybean phases on soil physical and biological properties. The study was conducted over three seasons, 2016-2018.

Materials and Methods

Objective 1: Evaluation of cover crop cultivars, soybean cultivars, and planting date

Site and treatment description

Research was conducted during 2015-2018 at the University of Wisconsin-Arlington Agricultural Research Station (UWAARS) (43°18’ N; 89°21’ W; 315 m above sea level). The experimental plots were located within the 31-hectare block of certified organic land at the research station (certified organic by the Midwest Organic Services Agency, Viroqua, WI). The soil type was a Plano silt loam (fine-silty, mixed, superactive, mesic Typic Argiudoll). Soil tests indicated 3.7% organic matter and pH 7.3. Prior to planting the cover crop, an alfalfa stand was terminated though chisel plowing (Glenco SS7400, AGCO, Duluth, GA), and disking (Sunflower 1434, Sunflower Mfg., Beloit, KS), with these field operations occurring from August 16 through October 23, depending on year and treatment. The experimental design was a split-plot design with four replications, with cereal rye cover crop as the main factor and planting date as the subplot factor. The control treatment included standard management (tillage and cultivation) typical of organic row crop production in Wisconsin.

Two varieties of winter cereal rye were planted, and two varieties of triticale and one of winter wheat over the course of all years of the experiment. Seed was purchased from Albert Lea Seed Co. (Albert Lea, MN) and Wisconsin Foundation Seeds (Arlington, WI). Rye planted with a 3-m wide no-till (NT) drill (Model 750, John Deere, Moline, IL) at a depth of 2.5 cm and a row width of 19 cm at a rate of 269 kg ha^{-1}. All treatments were tilled using a quackdigger, field cultivator, or disk chisel to manage early season weeds, and then prepared for row crop planting using a soil finisher if needed (7.7 m wide) prior to planting.

Soybean planting occurred at two different rye maturity stages: at boot stage (‘Early Planting Strategy’ (Zadoks stage 45): May 18, 2016 and May 12, 2017) and at cereal rye anthesis (‘Late Planting Strategy’ (Zadoks stage 69); May 31 (‘Aroostook) and June 7 (‘Spooner’), 2016 and May 26 (‘Aroostook’) and June 8 (‘Spooner’), 2017). Soybeans were planted at a rate of 555 750 seeds ha^{-1} into each of the treatment plots with a 4.6-m wide conservation-tillage planter (Model 1750 Max Emerge Plus, Conservation Tillage, John Deere, Moline, IL$_1$) set at a 76-cm row width at the same time as crimping and mowing to simulate a typical organic rotation. Soybean seeds (‘Viking O.1706’, maturity group 1.7) were treated with a liquid inoculant (Cell-Tech SCI Soybean Custom Inoculant, EMD Crop BioScience, Inc., Brookfield, WI 53005). In the early-planting strategy treatments, the soybeans were planted into standing rye; subsequently the rye was then terminated with a roller-crimper (4.6-m wide) (I and J Manufacturing, Gap, PA) when the cereal rye reached anthesis, approximately 15 days after planting. In the late-planting strategy treatments, the plots were managed in a one-pass operation, with the roller-crimper mounted on the front of the tractor, and the planter pulled behind, with the all operations occurring at rye anthesis. In each roller-crimping operation, the roller-crimper was filled with water, for a total mass of 1360 kg. The control treatments included typical organic row crop production management, including weed management with flex-tine weeding (4.6-m wide) and inter-row cultivation (4.6-m wide) (Table 1).

A soybean variety trial was also conducted using a range of varieties of soybeans, to evaluate their suitability in no-till systems.

Data Collection

Cover crop aboveground biomass (excluding weeds) was measured by harvesting three 0.25-m^{-2} quadrats per plots at a 2.5 cm cutting height three to seven days before termination in mid-May. Samples were dried at 50°C until constant weight. Rye regrowth was measured at four weeks after planting (WAP) by placing three 0.25-m^{-2} quadrats per plot randomly in each plot, harvesting all regrowth at ground level, and drying at 50°C to constant weight. Soybean stand counts were achieved by counting 5.3m of row length in 3 random rows in each plot at five WAP. Weed biomass was determined in each of the plots by counting all emerged weeds at 10 WAP in three 0.25-m^{-2} quadrats per plot randomly placed in each plot and harvesting all weeds at ground level and drying at 50°C to constant weight. In 2017 and 2018, weeds populations were characterized in more detail, measuring both weed biomass and numbers of weeds within and between row weeds at 10 and 16 WAP. Similar to 2016, in 2017, three 0.25-m^{-2} quadrats per plot were randomly placed in each plot either in or between the rows and harvesting all weeds at ground level. In 2017, prior to drying at 50°C to constant weight, weeds were counted.

Soybean yields

Soybeans were harvested in each plot with a 4.57 m gleaner combine. The harvested soybeans were weighed, and the yield in kg ha^{-1} was standardized at 13% moisture.

Data Analysis

Data analyses were performed using JMP® Pro Software Version 14.0.0 (JMP, 2018). The experimental design was analyzed as a split-plot design with cover crop type (‘Aroostook’, ‘Spooner’, and tilled treatments) as the main factor and soybean planting dates as the subplot factors.

The following model was used for analysis:

$$Y_{ijkl} = Y_i + B_j + WP_k + Y^*WP_{ij} + WPEijk + SP_l + Y^*SP_{il} + WP^*SP_{kl} + Y^*WP^*SP_{ikl} + SPEijkl$$

Where Y = year
B = Block
WP = whole plot factor (cover crop variety)
SP = subplot factor (planting strategy)
WPE = whole plot error term
SPE = subplot error term
i = a particular year
j = a particular block
k = a particular rye variety
l = a particular planting strategy

Year, cover crop treatment, and planting date are considered fixed effects and block is considered a random effect. Prior to analysis, all variables were checked for assumptions of normality (Kolmogorov-Smirnov-Lilliefors test of normality) and homogeneity of variance (Levene’s test for equality of variances). Where assumptions were violated ($P = 0.05$), weed number and density data were normalized by subjecting them to square root transformation (Steel and Torrie, 1980); however, means presented in tables represent untransformed data. If overall F values were found to be significant, means were separated using the Tukey-Kramer method.

Results, 2016-2017

Cover Crop Biomass and Regrowth

Cover crop biomass production varied between year (P= 0.0010) but not between varieties (2016: ‘Aroostook’, 7 907 kg DM ha^{-1} and ‘Spooner’, 9 511 kg DM ha^{-1}; 2017: ‘Aroostook’, 10 218 kg DM ha^{-1} and ‘Spooner’, 11 466 kg DM ha^{-1}). These values fell within the reported ranges found in other research with cereal rye at similar planting dates and seeding rates (3 400 kg DM ha^{-1} to 9 000 kg DM ha$^{-1)}$ (Doll and Mueller 2005; Smith et al. 2011; Ashford and Reeves 2003; Mischler et al. 2010). Overall, rye biomass was greater in 2017 as compared to 2016. Biomass did not differ the early- and late-planting strategy soybean treatments. Rye regrowth was greater in 'Aroostook' (2016: 42.7 g m^{-2} and 2017: 36.0 g m^{-2} as compared to 'Spooner' (2016: 5.6 g m^{-2} and 2017: 19.8 g m^{-2}) although only significant in 2016 (P>0.0001). Furthermore, while the differences were not significant, early-planting strategy soybean plots tended to exhibit higher levels of regrowth as compared to late-planting strategy plots (Table 2).

Soybean Stand Establishment

Soybean stands were significantly lower in the CCBRT plots as compared to the control treatments (2016: 'Aroostook', 273 680 plants ha^{-1}; 'Spooner', 267 650 plants ha^{-1}; control, 379 990 plants ha^{-1}; 2017: 'Aroostook', 245 713 plants ha^{-1}; 'Spooner', 234 495 plants ha^{-1}; control 373 956 plants ha^{-1}) (P<0.0001). Soybean stands did not differ in the early- versus late-planting strategy treatments, although stand numbers trended lower in the early-planting strategy in treatments in 2017 and were marginally significant (P=0.0627).

Weed Numbers and Densities

The dominant weed species identified in the plots included lambsquarters (*Chenopodium album* L.), pigweed (*Amaranthus hybridus* L.), dandelion (*Taraxacum officinale* L.), common chickweed (*Stellaria media* L.), quackgrass (*Elymus repens* L.), barnyard grass (*Panicum Crus-Galli* L.), and yellow foxtail (*Setaria glauca* L). In 2016, total weed biomass was greater in the control treatments (165 g m^{-2}) as compared to the CCBRT treatments (27 g m^{-2}) (P<0.0001), with no differences observed between the rye varieties. In 2017, however, this trend was reversed, with the less weed biomass harvested from the control treatments (15 g m^{-2}) versus the CCBRT treatments (77 g m^{-2}) (P=0.0031). In both years, more weeds were collected from the early-planting strategy treatments (P=0.0043 and P=0.0052, respectively). In 2017, with more detailed data was collected regarding in-row versus between-row weeds measured on both a per-weed number and per-weed biomass basis, more weeds were observed in the CCBRT plots at 10 and 16 WAP with respect to in- and between-row weed number (10 WAP: P=0.0240 and P=0.0003; 16 WAP: P=0.0004 and P=0.0002), and in- and between-row weed biomass (P=0.0235 and P<0.0001; 16 WAP: P=0.0135 and P<0.000). Additionally, at both 10 WAP and 16 WAP, the early-planting strategy treatments contained more weeds as compared to the late-planting strategy treatments as measured by in-row number (P=0.0008 and P=0.0203), in-row biomass (P=0.0042 and P=0.0177), between row number (P=0.0033 and P= 0.0012), and between-row biomass (P=0.0051 and P=0.0012).

Soybean nodulation

Significant differences were observed in soybean nodulation present on the roots of plants grown in the CCBRT plots as compared to the control plots (Table 3). Fewer nodules were collected from plants grown under CCBRT across both rye varieties as compared to the tilled control plots (*P*<0.0001). Further, nodulation was improved in the late-planting strategy soybeans as compared to the early-planting strategy soybeans (*P*=0.0051). Significant system X planting strategy interactions were also observed (*P*=0.0305).

Soybean yields

Soybean yields differed by year (*P*>0.0001), with overall higher yields seen in 2017 as compared to 2016 (Table 2). Within a given year, significant differences were observed in the CCBRT treatments and planting strategies. In 2016, the early-planting strategy treatments yielded significantly greater than the late-planting strategy treatments across all rye varieties and the control treatments (*P*>0.0001). Within each planting strategy, however, no differences were measured between the rye varieties and the control treatments. In 2017, the opposite trend was observed, with the late-planting strategy plots resulting in higher soybean yields than the early-planting strategy plots across all CCBRT treatments (*P*=0.0005). Also in contrast to 2016, while no differences between the rye varieties were observed, in the early-planting strategy treatment in 2017, the control plots yielded greater than either CCBRT plots (*P*=0.0015), although no significant differences were observed within the late-planting strategy treatments.

Soybean variety trial

Of the varieties of soybeans tested across the range of maturity groups, Viking O.1706 had superior performance. Yields of all varieties ranged between 48-51 bu/ac (Table 1).

Table 1: Soybean variety yield comparisons

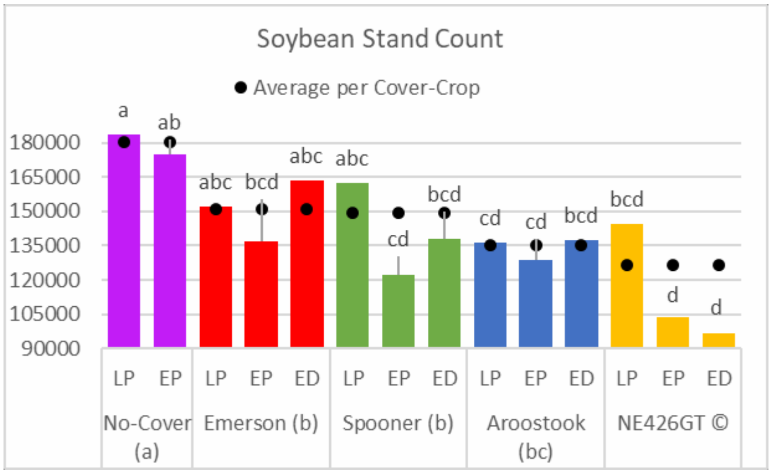
Soybean Variety	**Yield**
Viking O.1706	48.8
IA 1029	41.1
Viking O.1955	39.5

Results, 2018

Soybean stand count

As shown by the soybean stand count data, the establishment was affected both by the cover crop and the soybean planting strategy (Figure 1). The late planted soybeans in bare ground showed the best establishment (183,667 plants/ac), while the early planted and early drilled soybeans into triticale had the poorest (103,583 and 96,416 plants/ac). The average stand count was 148,506 plants/ac, which represent 66% of the target seeding rate (225,000 seeds/ac).

Figure 1: Soybean Stand Count in plant/acre (p-value = 0.05)



The no cover, ‘Emerson’ wheat and ‘Spooner’ rye treatments averaged above 148,506 plants/ac while ‘Aroostook’ rye and ‘NE426GT’ triticale resulted in lower stand counts. Early planting and drilling soybeans resulted in significantly lower stand counts as compared to planting into the rolled cover crop (133,685 and 140,278 vs. 155,750 plants/ac).

Evaluating treatments individually, late- and early- planted without cover crops, late- and early-drilled soybeans into rolled-crimped wheat, and late-planted soybeans into ‘Spooner’ rye resulted in greater soybean stand counts as compared to all other treatments. However, it is important to note that the wheat cover crop was not effectively terminated by the roller crimper at anthesis – much of the stand began to regrow. Thus, the soybeans were established into a standing wheat cover crop as opposed to a flat, rolled cover crop mat in every other cover crop treatment.

Table 2: Rye cover crop biomass before rolling for the 2014 - 2018 period in pounds of dry matter/acre

	2014	**2015**	**2016**	**2017**	**2018**
Rye biomass (lbs of dry matter/acre)	9,203	10,567	8,617	11,315	5,679

Yields

The cover crop treatment had a significant impact on the yields, but the planting strategy did not. The no-cover treatment had the greatest yield (57 bu/ ac), which was significantly higher than the yields with 'Spooner' rye, wheat and triticale cover crops, but not different from the yields with 'Aroostook' rye. The 'Spooner' rye treatment yielded less than the 'Aroostook' rye treatment (49 vs. 54 bu/ac) but the difference was not significant. The wheat treatment yielded significantly less than the rye and the no-cover treatments (35 bu/ac) and the triticale significantly less than any other treatment (26bu/ac).

Table 3: Soybean yields in bushels/acre at 13% moisture and bushels/10,000 plants

	Yield (bu/ac 13%moist)	**Bushels/ 10,000 plants**
No Cover	57 a	3.2 bc
Aroostook	54 ab	4.1 a
Spooner	49 b	3.4 ab
Emerson	35 c	2.5 cd
NE426GT	26 d	2 d

Looking at the number of bushels produced by 10,000 plants is a way to correlate the yields and the stand count. The soybeans planted into 'Aroostook' rye produced significantly more bushels/10,000 plants than the ones planted into bare ground. Soybeans planted into triticale produced significantly fewer bushels/10,000 plants than those planted into rye and bare ground.

Weed control

In August, the weed biomass *in the row* was influenced by both the cover crop and the soybean planting strategy, but the weed biomass *between the rows* was only influenced by the cover crop. With 1 lbs of DM/ ac, the no-cover treatment had the lowest weed biomass *between the rows*. However, while being significantly lower than the biomass *between the rows* of soybeans planted into triticale and 'Spooner' rye (702 and 315 lbs of DM/ ac respectively) it was not significantly different from the weed biomass *between the rows* in the wheat and 'Aroostook' rye plots (139 and 19 lbs of DM/ac respectively). The triticale plots had significantly more weed biomass *between the rows* compared to any other treatments.

Table 4: Soybean yields in bushels/acre at 13% moisture and bushels/10,000 plants

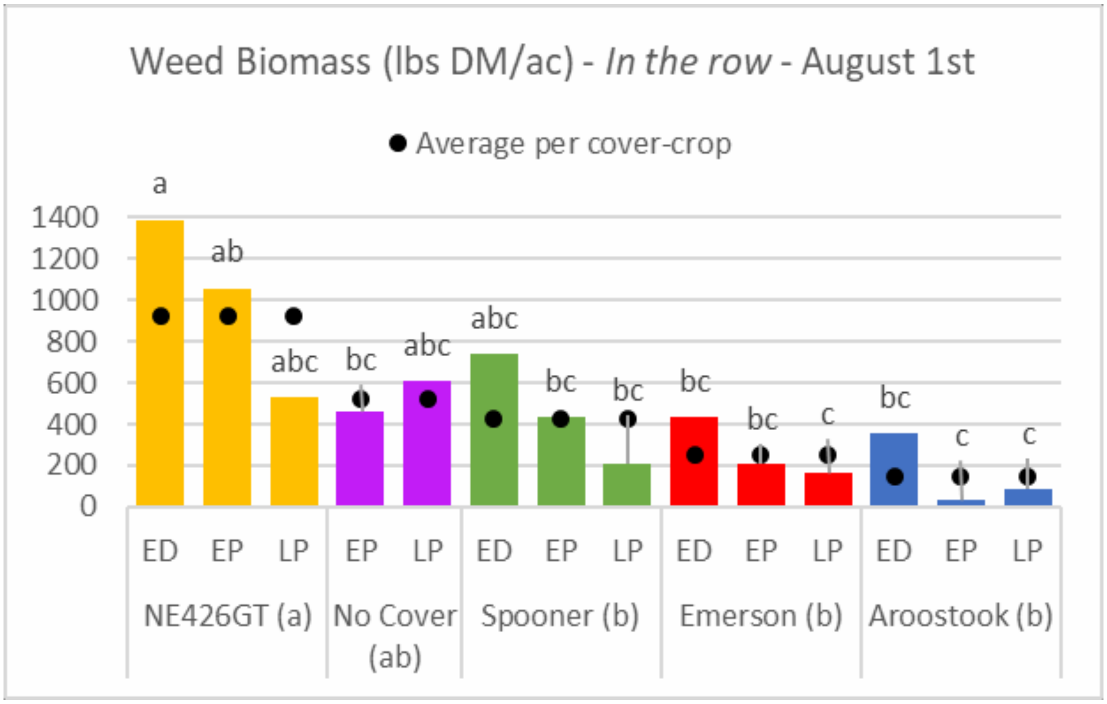
	Weed Biomass *Between Rows* (lbs DM/ac)
NE426GT	702 a
Spooner	315 b
Emerson	139 bc
Aroostook	19 bc
No Cover	1 c

With respect to the average weed biomass *in the rows* per cover crop, the triticale treatments had significantly more weeds than all the other cover crop treatments (925 vs. 149 to 525 lbs DM/ac); however, in-row weed biomass was not significantly different from the no- cover treatment (525 lbs DM/ac).

Overall, the late-planted treatments were less weedy than the early-drilled treatments *in the rows* (319 vs. 730 lbs of DM/ ac). With 443 lbs of DM/acre, the early- planted treatments were not significantly different from the two other planting strategies.

Early- and late-planted soybeans into 'Aroostook' rye, as well as late-planted soybeans into wheat, had the lowest weed biomass *in the rows* (35, 86 and 163 lbs of DM/ ac respectively). However, this was only significantly lower than the weed biomass found *in the rows* in the early- planted and drilled triticale plots (1,057 and 1,389 lbs of DM/ac respectively). The weed biomass *in the rows* of the early-drilled soybeans into triticale was the greatest and significantly higher than in every 'Aroostook' rye and wheat treatments as well as early and late planted into 'Spooner' rye.

Figure 2: Weed biomass in the rows on August 1st in pounds of dry matter/acre (lbs DM/ac)



In September, weeds growing in the rows were not differentiated from those growing between the rows. However, we differentiated broadleaf weeds from grassy weeds.

The total weed biomass in pounds of dry matter/acre was influenced both by the cover crop and the planting strategy.

Overall, the triticale had a significantly higher weed biomass than any other treatment (1,397 vs. 207 to 592 lbs of DM/ ac). As in August, the late-planted treatments had less weeds on average than the early-drilled ones, and the early-planted treatments were not significantly different from the two other planting strategies (late, 381 lbs DM/ ac; early-drilled, 911 lbs DM/ ac; and early-planted, 661 lbs DM/ ac).

Early- and late-planted 'Aroostook' rye treatments and the no-cover treatment, as well as late-planted 'Spooner' rye and early-drilled wheat treatments, had the lowest total weed biomass (from 48 to 423 lbs DM/ ac). These biomasses were only significantly lower than those found in the early-planted and drilled triticale plots (1,635 and 2,090 lbs DM/ac respectively). With 2,090 lbs DM/ ac, the early-drilled triticale treatment had significantly more weed biomass than any other treatment other than its early- planted equivalent.

With respect to differences in weed populations, the percent of broadleaf vs. grass weeds was only influenced by the cover crop. The no cover treatment had significantly fewer broadleaves and more grasses than the soybeans planted or drilled into 'Spooner' rye (24% vs. 63% broadleaf.; 76% vs. 37% grass). 'Aroostook' rye, wheat, and triticale were not significantly different from the two other treatments, but the no-till treatments tended to have proportionally less grasses than the no-cover treatment.

Soybean variety trial

Of the varieties of soybeans tested across the range of maturity groups, no variety with superior performance emerged. Yields of all varieties ranged between 48-51 bu/ac with no significant differences seen)

Table 5: Soybean variety performance, 2018.

	Stand (plants/acre)		Yield (bu/ac)
AL 0.1706N	148926	a	48
BR 17C2	150148	a	48
Bluestem 1809N	139074	a	51

Experiment 2: Impact of organic no-till soybean phases on soil physical and biological properties

Methodology

Soil sampling

Soil samples (0-15 cm) were collected in the spring of 2016 -2018 in each treatment. In each of the three replicated plots in each treatment, soil samples were collected as a composite of six soil cores per plot collected across the whole plot, bulked, and homogenized. The bulk soil was then divided for soil chemical properties analysis and PLFA extraction. For chemical properties analysis, the soil was stored at ambient temperature and then at 4°C until shipped to the soil and forage analysis laboratory. For PLFA analysis, soils were placed in labeled plastic bags and stored in a cooler for transport to UW-Madison where they were immediately placed in cold storage at 4◦C until processing.

Soil chemical properties

Analysis of soil physical and chemical properties was performed by the University of Wisconsin Soil and Forage Analysis Laboratory. Seventeen soil chemical properties were analyzed: soil pH, available phosphorus (P), available potassium (K), percent organic matter (OM), exchangeable calcium (Ca), exchangeable magnesium (Mg), available boron (B), available manganese (Mn), available zinc (Zn), sulfate-sulfur (S), percent total nitrogen (TN), percent total organic carbon (TOC), nitrate-N (NO3-N), ammonium-N (NH4-N) and soil texture (percent sand, silt and clay).

Phospholipid Fatty Acid (PLFA) extraction

Within 48 h of collection, soils were sieved (2-mm) free of rocks and roots, and hand homogenized. Subsamples (3 g) were weighed out, lyophilized, and stored at − 20◦ C until used for lipid extraction analysis. Membrane lipids were extracted from the soil (White and Ringelberg, 1998), purified using the modified Bligh-Dyer (1959) method and then separated by silicic acid chromatography. This process was carried out by applying the extract to a disposable silica gel cartridge and the running a succession of solvents through the cartridge. The PLFAs are retained by the silica, while the glyco- and neutral-lipids are washed off and discarded. Lastly, a solvent was used to strip off the PLFAs and they were collected. The PLFAs were then saponified and subjected to a mild base methylation to yield fatty acid methyl esters (FAME) phospholipid fatty acid extraction (PLFA) which was combined with fatty acid methyl ester (FAME) analysis as described by Microbial ID Inc. (Hayward, CA). A 2-µl aliquot was analyzed using a Hewlett-Packard 6890 gas chromatograph (Agilent Technologies, Santa Clara, CA). Lipid peak identification was carried out using MIDI peak identification software and bacterial fatty acid standards ("Sherlock microbial identification system", MIDI Inc., Newark, DE). Using peak areas from two internal standards of known concentrations, nonanoic methyl ester (9:0) and nonadecanoic methyl ester (19:0), fatty acids were quantified and converted to nmol lipid g soil^{-1}.

Total nmol lipid g soil−1 was used as an index of microbial biomass and to calculate fungal-to-bacterial ratio (F:B) (White et al., 1979; Zelles et al., 1992; Balser et al., 2005). The relative contribution of specific lipid biomarkers to the microbial community was determined by calculating the moles of a given lipid/total moles lipid per sample (mol%). We then combined the mol% of chemically similar fatty acids into groups representing segments of the microbial community, commonly referred to as 'guilds'. Only fatty acids that were identifiable and present in amounts greater than 0.5 mol% were used for analyses (Table 2). A total of 41 of PLFA biomarkers with chain lengths of 14 to 20-C were summarized into a community composition matrix. The matrix represents the absolute abundance of each PLFA biomarker per sample. Nineteen PLFA biomarkers were used as single or ecological group indicators to calculate the following groups and ratios: Actinomycetes, AMF, Saprotrophic Fungi, Gram-positive (Gm+) bacteria, Gram-negative (Gm−) bacteria, Fungal:Bacterial ratio (F:B) and Gm+:Gm− bacterial ratio (White et al., 1979; Zelles et al., 1992; Balser et al., 2005).

Soybean Nodule Counts

To determine the degree of soybean nodulation by rhizobium bacteria in each treatment, soybean roots were obtained when the crop reached the R5 stage of maturity. Soybean roots were harvested from three plants in three locations per plot within a 25 X 25 cm X 30.5 cm soil cube around each plant. Roots and soil were placed in a paper bag and brought into the laboratory for further analysis. Soil was gently removed from the roots manually and all nodules associated with the roots and the soil were counted.

Results

In-depth chemical and biological analysis of soil and soybean leaves

The soil chemical analysis ran in the middle of the summer revealed differences in the soil potassium content. The potassium content was on the higher end in both Aroostook and Spooner rye treatments (appr.130 ppm), on the lower end in the Control (under 100 ppm) treatment, and intermediate in both triticale treatments (appr. 110 ppm). The other soil properties did not differ between the different treatments. Some variations were observed in several nutrient compounds in the soybean leaves (N, P, K, Mg, Zn). The soybean leaves had higher nitrogen and phosphorus content in the control treatment compared to each of the cover crop treatments. Conversely, the potassium content was lower in the soybean leaves of the control treatment compared to all the cover crop treatments.

The leaf's nitrogen content was the only nutrient measured that was only affected by the cover cro. The soybeans with the highest leaf nitrogen content were the ones planted in 'Aroostook' rye. Their nitrogen content (5.5%) was significantly higher than that of the soybeans planted into triticale and bare ground. The soybeans planted into bare ground had the lowest nitrogen content (5.0%) and significantly less leaf N than the ones planted into both varieties of rye.

Table 6: Soil and soybean leaves nutrient status only affected by the cover crop treatment. % Leaf N = % of nitrogen in the soybean leaves. p-value = 0.05

	No Nodule/Plant
No Cover	86 a
Aroostook	45 b
Spooner	42 b
Emerson	41 b
NE426GT	33 b

Table 7: Soil and soybean leaf tissue chemical analysis

Observation		**Early Planting**	**Late Planting**	***p-value***
Soil	**pH**	6.8	6.7	*0.03*
	P (ppm)	54	57	*0.457*
	K (ppm)	128	109.8	*0.01*

	OM (%)	3.3	3.6	*10^{-5}*
Soybean Leaves	**N (%)**	4.9	4.8	*0.645*
	P (%)	0.54	0.53	*0.59*
	K (%)	2.2	2.2	*0.7*
	Ca (%)	0.40	0.41	*0.908*
	Mg (%)	0.40	0.41	*0.304*
	S (%)	0.29	0.31	*0.02*
	Zn (mg/kg)	41.4	42.5	*0.171*
	Mn (mg/kg)	65.3	63.5	*0.213*
	B (mg/kg)	40	43	*0.04*
	Fe (mg/kg)	93.1	94.3	*0.622*
	Cu (mg/kg)	6.2	6.2	*0.948*

Table 8: Soil and soybean leaf tissue chemical analysis

Observation		**Early Planting**	**Late Planting**	***p-value***
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Table 9: Soil and soybean leaves nutrient status affected by both the cover crop and the soybean planting strategy. % Leaf K = % of potassium in the soybean leaves; % Leaf Mg = % of magnesium in the soybean leaves; Leaf Zn = zinc content in the soybean leaves. p-value = 0.05

	% Leaf K	**% Leaf Mg**	**Leaf Zn (mg/Kg)**
Spooner LP	2.2 a	0.42 abc	47.2 a
Aroostook LP	2.2 a	0.43 abc	45.7 ab
NE426GT LP	2.1 ab(2)	0.44 ab	39.0 cd
Emerson EP	2.0 abc(2)	0.40 bcd	37.5 cd
NE426GT EP	2.0 abc(2)	0.38 cdef	33.6 d
Emerson LP	2.0 abc(2)	0.47 a	39.1 cd
Aroostook EP	1.9 abc(2)	0.35 def	39.1 cd
Spooner EP	1.8 bc(2)	0.34 ef	36.9 cd
No-Cover LP	1.8 bc(2)	0.40 bcde	45.4 ab

No-Cover EP	1.7 c(2)	0.34 f	39.9 bc

Nodule count

Soybean nodulation peaks when the plant is in the 5th reproductive stage (R5), the stage characterized by the beginning of seed formation in the pods (For more in- formation, see the UW Extension webpage “Soybean Growth and Development”, http://corn.agronomy.wisc.edu/Crops/Soybean/ L004.aspx).

Figure 3: Pictures of soybean rooting systems extracted at R5 (beginning seeds) in order to count the nodules. On the left roots of no-tilled soybeans into rolled cover crop; on the right roots of soybeans planted into bare ground

Figure 3 shows the rooting system of a no-tilled soybean plant and the rooting system of a soybean planted into bare ground. While the no-tilled soybean plant was composed of a taproot, four or five secondary roots, and few fine roots, the soybean plants growing in bare ground had greater numbers of roots. This structural difference may be related to the difference observed in the number of nodules/plant. The no-tilled soybeans had between 33 and 45 nodules/plant and the soybeans growing without cover significantly greater numbers at 86 nodules/plant.

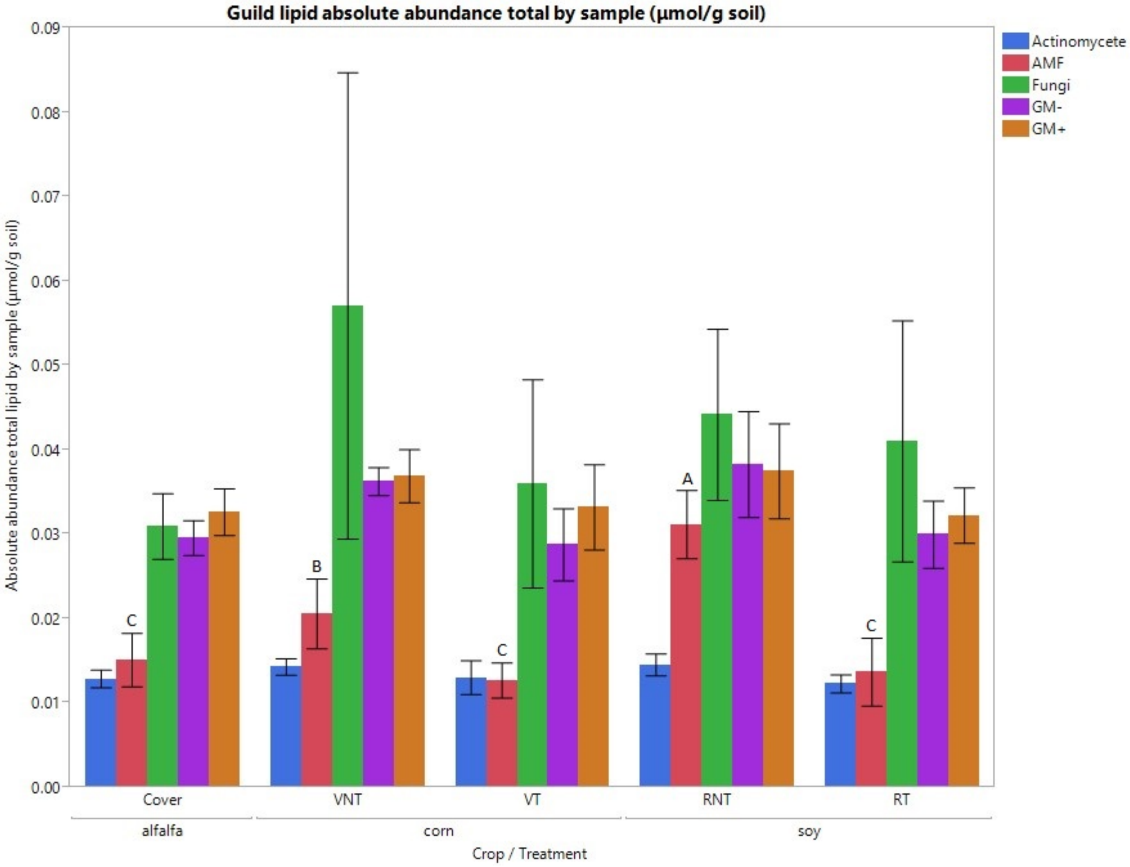
Soil biology as determined by PLFA

The presence of a rolled cover crop increased the soil microbial biomass as measured by PLFA. This is consistent with other data which measured soil microbial biomass as soil microbial carbon.

Table 10. Soil Microbial Biomass as measured by PLFA.

Management	AvgBiomass (nmol/g soil)
Aroostook	125,2256
Control	109,8561
Spooner	142,8867
Triticale	148,6853
Wheat	127,2989

Figure 4. Guild lipid absolute abundance in tillage intensive versus reduced till plots. VNT: Vetch no-till; VT: Vetch tillage intensive; RNT: Rye no-till; RT: Rye tillage intensive.



Conclusions

These results show that cereal rye remains to the best candidate for successful organic no-till soybean production. The allelopathic effect of cereal rye increases the chances of obtaining adequate weed control until soybean harvest. In addition, cereal rye is more winter hardy and reaches anthesis earlier than triticale which can ease termination with a roller-crimper. Results also showed that obtaining sufficient cover crop biomass is crucial to limit weed competition with cash crop until soybean harvest. The impact of soybean variety selection, however, remains less clear, with more work needed to determine if breeding cash crops for organic no-till production is useful.

Overall, though, this work shows that incorporating organic no-till phases into the organic row crop rotation is a viable management strategy for organic grain producers aiming to limit soil disturbance during cash crop production while maintaining equivalent yields to organic soybeans produced using tillage and cultivation. Overall, yields of CCBRT soybeans were comparable to those produced using cultivation, with superior weed management achieved during certain site-years. While yields of CCBRT soybeans may not necessarily be superior to those planted using typical organic techniques, this study does demonstrate that yields can be equivalent, which, as demonstrated through previous research, can provide the farmer with greater net returns due to the labor and fuel savings inherent in the system. Planting soybeans earlier into standing rye at the boot stage and terminating later at cereal grain anthesis (versus both planting soybeans and terminating rye at anthesis, as is currently the most common practice) may provide yield advantages in certain years; however, our data also illustrates that farmers also must consider the risks that accompany this approach, including greater rye regrowth. Within the genotypes of cereal rye tested, the earlier anthesis date of 'Aroostook' did not provide a yield advantage to the soybean crop. While this study did not demonstrate a consistent advantage to planting soybeans 5-21 days earlier than is typical practice in CCBRT systems, practices that promote early soybean growth may be important contributors in achieving higher yields in the CCBRT system.

This work also shows that incorporating organic no-till phases can increase soil biological activity. While overall increases in soil microbial activity is an indicator of improved soil health, more work needs to be done to understand the more precise functional outcomes of these increases.

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