2012

Evaluation of cover crops in reduced tillage systems for organic production

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by

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A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Sustainable Agriculture

Program of Study Committee:
Kathleen Delate, Major Professor
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Iowa State University

Ames, Iowa

2012

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ABSTRACT

Negative environmental impacts associated with intensive pesticide use and over–fertilization in conventional production have encouraged many producers to investigate organic methods. In the most current (2008) U.S. Department of Agriculture (USDA) statistics on organic agriculture, land under certified organic production increased to 4.8 million acres, with 194,637 acres of organic corn (*Zea mays* L.), 125,621 acres of organic soybean [*Glycine max* (L.) Merr.], and 164,888 acres in organic vegetable crops. In order to enter the expanding organic market and meet certified organic requirements, producers must implement a soil-building plan that focuses on preserving soil organic matter. The majority of organic grain production occurs in the Midwestern U.S. where growers are aware of the need to balance meeting increasing demand with maintaining soil health. A countervailing event that affects soil quality in organic systems is weed management, which currently relies extensively on tillage operations. Beginning in 2002, the Rodale Institute (Kutztown, PA) piloted an Organic No-Till system to reduce tillage operations and the carbon footprint of organic production. This system is based on a roller/crimper implement (a large, 10.5 ft. wide x 16 in. diameter, steel cylinder with steel blades welded in a chevron pattern to facilitate a crimping motion) that is used to mechanically terminate fall-planted cover crops the following spring in place of synthetic herbicides, which are disallowed in organic production.

A series of organic no-till experiments was established in Iowa from 2008 to 2011 to examine the effect of cover crops, crop sequences, and tillage operations on organic grain crop growth, weed management and yields. In the first set of experiments (2008–2011) at the Iowa State University (ISU) Agronomy Farm (Boone, IA), organic no-till soybeans in the wheat–rye/soybean–oat–rye/soybean crop sequence produced equivalent yields to tilled

organic soybeans in the same crop sequence, averaging 34 bu/acre over two seasons. Weed management mirrored tilled plots until later in the season when rye tillers emerged in no-till plots; these grasses did not affect yields, however. Organic no-till corn in the wheat–hairy vetch/corn–oat–hairy vetch/corn sequence did not achieve acceptable yields in either year, due to competition with hairy vetch re-growth and poor weed management from lack of sufficient cover crop mulch. Tilled corn also suffered from lack of supplemental nitrogen in this experiment, leading to the conclusion that cover crops should not be considered as a sole nutrient source in organic corn production.

In the organic no-till corn experiment at the ISU Neely-Kinyon Farm (Greenfield, IA) from 2010 to 2011, five cover crops, including hairy vetch (*Vicia villosa*), rye (*Secale cereale*), winter triticale (*Triticosecale* sp.), Austrian winter pea (*Pisum arvense*), and a combination of rye/hairy vetch, were evaluated against a control plot with no cover crop under two main treatments of no tillage (no-till) and conventional tillage (tilled). Tilled corn crops out-performed no-till crops both years of the experiment. In 2010, due to extensive rains and late planting, all corn was harvested as silage, with biomass yields of 25 tons/acre in tilled plots and 6.5 tons/acre in no-till plots. Cover crops were not uniformly associated with increased yields, but higher silage yields were obtained in the hairy vetch treatments in no-till plots compared to rye and triticale treatments. Corn grain yield in 2011 in the legume cover crop treatments in tilled plots averaged 120 bu/acre compared to only 57 bu/acre in the cereal cover crop treatments. Corn in the no-till plots again suffered from lack of N, weed competition and cover crop re-growth, and was harvested as silage, averaging 13.3 tons/acre, with no significant difference between cover crop treatments. Other problems in organic no-till corn included corn borer damage, which may have been associated with greater attraction by insect pests to crops under stress. As a result of these experiments, organic no-till corn is now considered too difficult for Midwest conditions, and a new crop rotation including alfalfa as a cover crop prior to the no-till segment of rye/soybean is currently under investigation. Based on the beneficial effects from increased carbon inputs in long-term organic no-till crop rotations, economic benefits could also be obtained from soil carbon enhancement and greenhouse gas reduction if Clean Energy legislation and carbon markets support such practices in the future.

CHAPTER 1: LITERATURE REVIEW AND THESIS ORGANIZATION

Organic Agriculture and Importance of Soil Quality

Negative environmental impacts associated with intensive pesticide use and over-fertilization in conventional production (Pimentel et al., 1989; Venterea and Rolston, 2000) have encouraged many producers to investigate organic methods. In the most current (2008) U.S. Department of Agriculture (USDA) statistics on organic agriculture, land under certified organic production increased to 4.8 million acres, with 194,637 acres of organic corn (*Zea mays* L.), 125,621 acres of organic soybean [*Glycine max* (L.) Merr.], and 164,888 acres in organic vegetable crops (USDA-ERS, 2012). Consumer demand continues to drive the organic industry due to individual preferences for lower pesticide residues in food and consistent federal standards for products marketed as "organic" (Baker et al., 2002; USDA-AMS, 2012). At the heart of organic regulations is the protection or enhancement of carbon (C) and other nutrients in soil organic matter, which maintains soil fertility and soil structure in sustainable systems (Manley et al., 2007).

The majority of organic grain production occurs in the Midwestern U.S., where growers are aware of the need to balance meeting increasing demand with maintaining soil health. In order to enter the expanding organic market and meet certified organic requirements, producers must implement a soil-building plan in accordance with sections 205.203 and 205.205 of the USDA National Organic Program (NOP), Agriculture Marketing Service (USDA-AMS, 2012).

A countervailing event that affects soil quality in organic systems is weed management. Some of the most critical needs of transitioning and certified organic growers are methods for maintaining effective, long-term soil quality and managing weeds (Walz, 2004; Delate and

DeWitt, 2004). In the Organic Farming Research Foundation national survey of organic farmers, 28% of respondents ranked weed management among their top production challenges and 62% rated weed management as a highest priority for organic research. Although weeds are managed through a multi-pronged approach that includes cultural, biological and mechanical methods, currently, organic producers primarily rely on tillage systems for weed management and field preparation. Increased use of strategies that enhance or sequester soil carbon on organic farms, such as reduced or no-tillage systems, will lead to decreased erosion and facilitate participation in government programs supporting reductions in soil erosion and in carbon emissions. Some of the most critical needs of transitioning and certified organic growers are methods for enhancing soil fertility and managing weeds (Delate and Dewitt, 2004; Reimens et al., 2007). The potentially negative effects of mechanical tillage on soil carbon can be mitigated by carbon additions from crop residues, cover crops and compost, but organic farmers also have expressed interest in reducing tillage operations (Delate and Cambardella, 2004; Sooby et al., 2007).

Benefits of Reduced Tillage in Agricultural Systems

Many conventional no-till farmers around the world have shown interest in using cover crops to suppress weeds, conserve moisture, and build soil tilth (Heer et al., 2006; Teasdale et. al., 2007; Carerra et. al, 2004; McGuire, 2003; Pester, 1998). The benefits of reduced tillage on soil quality have been well documented. In a study by Ismail et al. (1994), soil organic C and N were 170 and 11 g m^{-2} cm^{-1} depth greater, respectively, in the top 5 cm of soil in a no-till, continuous corn system compared with a tilled system under identical fertility regimes after 20 years in Kentucky. Similarly, extractable P, exchangeable Ca, Mg, and K also were more abundant in the 0- to 5-cm soil depth under no-till. Similar results were found in other studies comparing no-till to tilled systems (e.g., Elliott et al., 1987), demonstrating the positive impact that no-till has on soil organic C and N near the soil surface, along with other plant macronutrients. Soil aggregate stability, total carbon, microbial populations contributing carbon, and earthworm populations were enhanced after eliminating tillage over a 12-yr period in a continuous corn system in Wisconsin (Karlen et al., 1994). Frey et al. (1999) found that organic C and N fractions and mean weight diameter of water-stable aggregates were enhanced significantly at the 0- to 5-cm soil depth under no-till compared with tilled systems in three long-term (>20 year duration) field studies, but not in three other studies lasting from 11 to 15 years. Similarly, Green et al. (2005) found lower bulk density and greater aggregate stability in no-till systems. Frey et al. (1999) also found that fungal hyphae length, an indicator of microbial health, was greater under no-till in all six field studies and bacterial abundance was elevated under no-till in two of the three long-term studies. Six et al. (2006) found that no-till and organic farming practices with cover crops increased microbial biomass and shifted the community toward a more fungal-dominated community, similar to findings by Kennedy and Schillinger (2006) for no-till wheat systems. Peigné et al. (2007) point out that conservation tillage practices, where at least 30% of the soil surface is covered by a dead vegetative mulch after seeding, could reduce fuel use, enhance soil microbial activity and increase water infiltration rates, as well as reduce soil erosion and leaching of plant nutrients if adopted by organic farmers.

Corn grain yield was significantly lower under no-till than tilled systems in four of the first 10 years of a study by Ismail et al. (1994), but higher yields were produced under no-till in five of the final 10 years. A summary of over 80 different studies involving barley, corn, soybean, wheat and other grain crops failed to reveal a consistent yield advantage for no-till compared with tilled systems (Franzluebbers, 2004). Economic risks from variable yields in no-till are often weighed against the positive benefits of prevention of soil erosion and improvements in soil quality (Schillinger et al., 2007). Yield reductions in no-till have been associated with cooler soils (Licht and Al-Kaisi, 2005), insufficient fertility (Bermudez and Mallorino, 2004), or less effective weed management in some cases (Davis et al., 2005). However, Franzluebbers' (2004) evaluation of studies involving small-grain crops in semiarid regions revealed a consistent yield advantage for no-till, presumably because evaporation was reduced in maintaining crop residues on the soil surface. In a review of no-till vegetable systems by Rogers et al. (2004), increased yields over tilled systems were determined in 10 out of 16 studies. Conservation of soil moisture, provided in some cases by no-till practices, also can increase soil microbial populations and activity. For example, fungal biomass was positively correlated with increasing amounts of soil moisture under no-till (Frey et al., 1999). Those data indicate the overall positive impact that reducing tillage can have on soil health in crop production systems despite yield variability.

Along with other conservation tillage methods such as ridge-till and mulch-till, no-till is justly lauded for its ability to reduce soil erosion, reduce leaching (Beckwith et al., 1998), build soil organic matter, improve water dynamics and increase farm management efficiency (Domanico et al., 1986; Lu et al., 1999). Because soil carbon sequestration is a key factor in mitigating global climate change, no-till farming, with its capacity to increase soil carbon, is gaining popularity as a key environmental strategy for the future of agriculture. On the negative side, there is also evidence that the improved soil quality resulting from no-till methods facilitates percolation of agricultural chemicals into groundwater (Heimlich, 2003). Additionally, studies have shown increased acidification of soils under no-till

(Tarkalson et al., 2006), which can negatively impact soil microbial activity (Fuentes et al., 2006). Concerns about water quality, escalating fuel prices, signs of herbicide resistance in weeds, and increased U.S. dependence on foreign oil all suggest that current chemically-based no-till farming systems are not sustainable and need to be improved.

Cover crop termination methods utilizing reduced tillage approaches offer the greatest potential for the dual purpose of weed management and enhancement of soil quality, as demonstrated by many conventional no-till studies (Ismail et al., 1994; Karlen et al., 1994). Despite soil quality enhancement, however, grain crop yields are often equivalent or inferior in no-till systems; results from over 80 studies involving barley, corn, soybean, wheat and other grain crops failed to reveal a consistent yield advantage for no-till compared with tilled systems (Franzluebbers, 2004). In semiarid portions of the North Central region, however, crop performance has been shown to improve by eliminating tillage, due to proposed more efficient plant water use (Carr et al., 2009; Tanaka et al., 2002). In a comparison between organic and conventional no-tillage systems over a 4-year period, equal or greater winter wheat yields and superior grain quality was reported in the organic system compared to the conventional, no-tillage cropping system (Miller et al., 2008). Despite inconsistent yield advantages, planting small grains and N-fixing cover crops together may be an effective management strategy to simultaneously increase soil C and optimize soil N cycling processes, thereby reducing leaching loss of N.

Cover Crops in Organic Systems

Natural mulches, including crushed and dessicated cover crops, have been proposed as an option in organic weed management. The most common cover crops planted in organic systems have included single species or combinations of rye (*Secale cereale* L.), barley (*Hordeum vulgare* L.), wheat (*Triticum vulgare* L.), hairy vetch (*Vicia villosa* Roth), and crimson clover (*Trifolium incarnatum* L.), due to their quick establishment, ability to over-winter, competitiveness with weeds, and ease of termination using mechanical methods (Creamer and Bennet, 1997; Nelson et al., 2001). The cover crop combination of winter rye and hairy vetch offers great potential for enhancing crop yields and soil quality. Benefits ascribed to winter rye include carbon acquisition through biomass accumulation, residual soil nitrogen (N) scavenging, and reduced nitrate leaching (Feyereisen et al., 2006; Snapp et al., 2005). In addition, increased weed management from rye cover crops can be obtained through physical interference, antagonism and allelopathy (Ngouajio and McGiffen, 2002; Teasdale and Mohler, 1993). Hairy vetch is considered an excellent cover crop in terms of biomass production, providing some degree of weed suppression and nitrogen supplementation up to 138 kg N ha^{-1} (Brandsaeter and Netland, 1999; Hoffman et al., 1993; Teasdale et al., 1991).

Organic No-Till in the U.S.

While typical methods for terminating cover crops in organic systems can include mowing, roll-chopping, undercutting, and roto-tilling (Carrera et al., 2004), the rolling or rolling/crimping system recently has been promoted for optimum termination and mulch layering. Steel rollers with blunt blades welded onto cylindrical drums have been used to terminate cover crops in conservation tillage systems for many years in South America (Ashford and Reeves, 2003), but the roller/crimper designed by The Rodale Institute (Kutztown, PA) in 2002 consists of a large steel cylinder (10.5 ft. wide x 16 in. diameter) with steel blades welded in a chevron pattern to facilitate a crimping motion to more effectively terminate fall-planted cover crops the following spring (Sayre, 2005). Prior to cover crop termination, the roller/crimper is filled with water to provide an additional 2,000 lb of weight to aid in mechanical termination, with the goal of creating a dense cover crop-mulch capable of suppressing weeds and eliminating additional weed control throughout the season. In contrast to mowing, the roller/crimper is a more controlled operation, typically resulting in a more flattened, uniform mulch layer amenable to no-tillage planting equipment. Grain is planted simultaneously or in another pass into the flattened cover crop, using no-till drilling of seeds. The ability to mount the roller/crimper on the front of the tractor so that cover crop termination and no-till seeding of the subsequent crop can occur in a single pass has led to successful production of corn, soybean, tomatoes, pumpkins (*Cucurbita pepo* L.), and strawberries (*Fragaria* x *ananassa*) in Pennsylvania (Sayre, 2005).

Of all cover crops studied in organic no-till systems, rye has been shown to be superior in biomass production and ability to suppress weeds through light impedance, allelopathy, immobilization of N and/or microclimate alteration (Reberg-Horton et al., 2012). Weed biomass in soybeans following vetch or rye was reduced by 26 and 56%, respectively, in the rolled system compared to herbicides (Davis, 2010), and weed interference was found to be less connected with soybean yield loss in soybean following rye than hairy vetch (Ryan et al., 2009). Kornecki et al. (2009) found that the rate of rye termination did not vary between roller designs or speed, but varied based on the date of rolling and cover crop stage of growth. Consistent rye termination was achieved after Zadoks growth stage 61 (rye anthesis) (Mirsky et al., 2009), as time of rolling/crimping is essential for successful termination. Delaying cover-crop termination reduced weed density, especially for early- and late-emerging summer annual weeds (Mirsky et al., 2011), and decreases in weed biomass in no-till soybean fields were associated with increasing amounts of rye residue (Ryan et al., 2009). Good seed-to-soil contact is also essential, as variation in soybean yield among cover crops and cover-crop termination treatments was found to be more associated with soybean establishment, rather than differences in soil environments. Increasing soybean planting rates was found to compensate for lower rates of rye biomass and help with weed management. Excess cover crop biomass has also been shown to restrict seed placement and crop establishment, creating habitat for herbivores, and impeding placement of supplemental fertilizers (Mirsky et al., 2012). While control of annual weeds in no-till systems, particularly with rye cover crops, has been relatively successful, the build-up of perennial weeds in organic no-till systems has been reported (Mirsky et al., 2011; Mäder and Berner, 2012). Yield response for soybeans has been variable, and includes yields in rolled rye equivalent to a weed-free treatment (Smith et al., 2011), a 25% reduction compared to tilled plots (Bernstein et al., 2011), and a 32% reduction averaged over two years (Delate et al., 2012). No-till corn yields have been reported as equivalent to tilled systems in Pennsylvania (Mischler et al., 2010) but dramatically lower in the Midwest (Delate et al., 2012). While equivalent no-till tomato yields were obtained in Iowa (Delate et al., 2012), Leavitt et al. (2011) obtained 65%, 41% and 79% reduced yields for tomato, zucchini and bell pepper, respectively, compared to tilled controls. Reductions were attributed to cooler soils under no-till and poor establishment. Soil growing degree-days were lower in cover crop treatments, which delayed early vegetable growth (Leavitt et al., 2011).

The greatest benefit from organic no-till systems to date has been demonstrated through soil improvements. Mäder and Berner (2012) found that soil organic carbon, microbial activity and soil structure improved in the upper soil layer under reduced tillage organic systems compared with tilled soils. Leguminous cover crops provide the greatest fertilization potential, but synchronization of N release from legumes with subsequent cash crop demands remains a challenge for organic producers (Cavero et al. 1996). Nitrogen mineralization was found to be limited in spring in reduced tillage systems (Mäder and Berner 2011; Leavitt et al. 2011). While zero tillage remains a goal in these systems, it is more likely that certain phases of a long-term rotation will include tillage to deal with build-up of perennial weeds. Grandy et al. (2007) found that soil quality improved at the 7.5–15 cm soil depth even with occasional tillage, concluding that strategic tillage may result in stratification rather than an overall decline in soil quality.

Future Challenges

All farmers are under increasing pressure–both internal and external–to reduce energy use in fertilization and pest management strategies, minimize nutrient leaching, reduce soil erosion, and build soil quality. Many organic and conventional vegetable farmers also seek substitutes for plastic mulch, which is expensive, difficult to dispose, and may have negative impacts on soil microbial activity (Rogers et al., 2004). With inexpensive petroleum feedstocks declining, alternative sources of fertility, based on the ecological principles of biological nitrogen (N) fixation and nutrient recycling as opposed to fossil fuel-based fertilization, must be developed for organic, as well as, conventional farms (Badgley et al., 2007). Removing carbon from the atmosphere and recycling it through plant-based systems may prove to be a key factor in mitigating the rate of global climate change. While routine application of carbon-containing sources in organic systems, including manure and plant residues from crop rotations and cover crops (Gaskell et al., 2000), will help mitigate carbon loss, increased use of strategies that enhance or sequester carbon in agricultural soils will greatly reduce the ‘carbon footprint’ of organic production. Thus, there is a pressing need to further refine organic no-till techniques to reduce, rather than eliminate, tillage completely, for a wide range of climates and production systems in organic agriculture.

Thesis Organization

This thesis is organized into three chapters. Chapter 1 consists of a literature review and discussion of thesis organization. Chapter 2 represents the results of the USDA-Integrated Organic Program Organic No-Till experiment. Chapter 3 details the results of the USDA-SARE project on organic no-till corn production at the Neely-Kinyon Farm in Greenfield, Iowa.

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CHAPTER 2: EVALUATION OF AN ORGANIC NO-TILL SYSTEM IN TWO CROP SEQUENCES IN IOWA

Introduction

Because organic crop production currently primarily relies on tillage for weed management, much attention has been focused on developing an organic no-till system in recent years to counter the perception of poor soil stewardship on organic farms (Kuepper, 2001). Because tillage can deplete soil quality by increasing erosion and carbon loss, along with requiring additional labor and energy use (Pimentel et al., 2005), the Rodale Institute (Kutztown, PA) began experimenting with an Organic No-Till Plus system in 2004, where commercial crops (corn, soybean, pumpkin) were no-till drilled or planted into cover crops that were terminated with a roller/crimper (Moyer, 2011). The Rodale Institute supplied Iowa State University with a roller in 2005 for experimentation in Iowa. Initial response was mixed, with excellent no-till organic soybean and irrigated tomato yields in 2007, but organic no-till corn production suffered from weed and cover crop re-growth competition and lack of N (Delate et al., 2012a). In order to further refine the organic no-till system and compare results across a broader geographical range, a multi-state, long-term USDA–CSREES–IOP (Integrated Organic Program) organic experiment was established in six states (Iowa, Minnesota, Michigan, Wisconsin, North Dakota, and Pennsylvania) in 2008 as a comprehensive examination of the effects of organic no-till production on crop productivity, yields, soil quality, and economic performance. Results from the first phase (2008–2011) of the experiment are reported here.

Materials and Methods

Plots for the organic no-till experiment were laid out on the Iowa State University Agronomy Farm in Boone, Iowa, in a randomized complete block design of four treatments and four replications: 1) a tilled (cover crops tilled/tillage used after planting) crop sequence of wheat–hairy vetch/corn–oat–hairy vetch/corn; 2) no-till wheat–hairy vetch/corn–oat–hairy vetch/corn; 3) tilled wheat–rye/soybean–oat–rye/soybean; and 4) no-till wheat–rye/soybean–oat–rye/soybean. Soils at the site include Nicollet (1-3% slope, poorly drained) and Webster (0-3% slope). In order to create a uniform study background (rotation history), wheat was grown on all experimental plots in the spring of 2008. Following wheat harvest in July, five randomly located 1.3-in-diameter soil cores were collected to a depth of 6 inches on 5 September 2008 in all plots to compare soil quality before the no-till phase of the experiment was initiated. Following pre-experimental soil sampling in 2008, soil samples were collected in the Fall of 2009 and 2011, and analyzed for soil quality parameters at the USDA-ARS National Laboratory for Agriculture and the Environment (Ames, IA) and at the USDA-ARS Lab in Morris, MN.

On 17 September 2008, hairy vetch or rye cover crops for the no-till corn and soybean phase of the experiment, respectively, were drilled in appropriate plots. Hairy vetch (VNS) was seeded at 25 lb/acre and rye (‘Aroostock’) was seeded at 225 lb/acre. A similar pattern was followed in 2010 when cover crops were drilled on 1 October 2010 following oat harvest. Due to a thin hairy vetch stand the first year, field peas were drilled at a rate of 18.75 lb/acre into hairy vetch plots on 11 May 2009. Cover crops in tilled treatment plots were disked on 8 May and 3 June 2009 and on 24 May 2011. Tilled plots were also field cultivated on 2 June 2011. Both hairy vetch and rye cover crops were rolled with a roller/crimper mounted on a tractor in no-till plots on 4 June 2009 and on 2 June 2011. Cover crops were rolled/crimped at anthesis (pollen shedding in the small grains).

Corn and soybeans were planted in the no-till treatments on the same day as rolling/crimping in one pass in 2009 and in two passes in 2011 when the front-mounted tractor was unavailable. Soybeans (BR 34A7) were planted at 200,000 seeds/acre in 30-inch rows and the corn (BR 63H07) at 30,000 seeds/acre both years. Corn and soybeans were planted at the same rates in the tilled plots. After planting both years, it was evident that the hairy vetch cover crop was not killed by the roller/crimper, so the hairy vetch cover crops were rolled again on 12 June 2009 and mowed on 17 July 2009. The hairy vetch was mowed on 7 June 2011 before the corn emerged. In 2010, oats were drilled into the no-till plots, while the conventional tillage plots received pre-planting disking. 'Spur' oats were planted on 5 April 2010 at a rate of 3 bu/acre.

Corn and soybean tilled plots were rotary hoed on 12 and 17 June 2009, but were not rotary hoed in 2011 because of excessive rains in the spring of that year. Tilled plots were row cultivated on 29 June, 7 and 15 July 2009 and on 29 June, 7 and 14 July 2011.

Corn and soybean plant populations were determined on 22 June 2009 and 18 May 2011 by counting all living plants in 17.4 ft of three randomly selected rows per plot. Oat stands were determined on 17 May 2010 by counting all plants within three randomly selected square-foot quadrants per plot. Cover crop stands were determined on 12 May 2009 and on 18 May 2011 in a similar manner as oat stand counts. Cover crop plant height was measured on 4 June 2009 and on 24 May 2011. Cover crop and weed biomass was estimated on 14 September 2009 after the first-year cover crop growing season; on 7 July 2010 during the oat year; and in the final year on 18 May 2011, by harvesting all above-ground biomass within three randomly selected square-foot quadrants per plot, drying at 140° F until at a constant weight, and sorting into cover crop and weed components. Weed populations were estimated in crop rows on 22 June, 2 July, and 4 August 2009, on 17 May 2010, and on 20 June and 1 September 2011. Soil moisture differences were determined in 2011 by collecting five randomly located 1.3-in-diameter soil cores at a depth of 6 inches on 1 September 2011; weighing each sample; drying at 140° F until at a constant weight, and re-weighing to determine percent moisture. Corn stalk nitrate sampling was conducted on 12 October 2009 by removing three randomly selected corn stalk samples per plot, following methods of Blackmer and Mallorino (1996). Soybean plots were harvested with a combine on 26 October 2009 and on 28 October 2011. Corn was combined on 4 November 2009 and on 28 October 2011. Due to competition and re-growth of cover crops, the no-till oats could not be harvested for grain and were instead harvested for oatlage biomass on 27 July 2010. The tilled oats were combined on 16 July 2010.

Results and Discussion

2009

Initial soil analysis

Pre-experimental soil analysis showed no significant differences between any soil parameters across plots before initiating the no-till grain crop production component of the experiment in Fall 2008 (Table 1). The average NO_3-N nitrogen for the plots was 0.40 ppm, with potassium at 139 ppm and a Bray phosphorus concentration of 15 ppm. Soil quality differences following the no-till phases of the experiment are discussed below under the Soil Quality section.

Soybean crop performance

In the first soybean season of the experiment, soybean plant populations were significantly higher in the no-till treatment with the rolled/crimped rye cover crop compared to the tilled treatment, where the rye was tilled under prior to planting, with stands averaging 133,750 plants/acre and 149,083 plants/acre, respectively (Table 2). Weed suppression was adequate in both the no-till plots and in the tilled plots (Table 2). Broadleaf weeds were initially higher in the tilled plots, but after two row cultivations, weed pressure was reduced from 4 broadleaves/ft^2 and 17 grasses/ft^2 on 22 June to 2 broadleaf and grass weeds/ft^2 on 2 July, and, at last sampling on 4 August, to 2 broadleaves/ft^2 and 5 grasses/ft^2. No-till soybean plots exhibited low early-season weed pressure, with 2 broadleaves/ft^2 and 17 grasses/ft^2 on 22 June, followed by 1 broadleaf/ft^2 and no grass weeds on 2 July. Later in the season, broadleaf weeds remained at the same populations as in tilled plots on 4 August (3 vs. 2 broadleaves/ft^2), but volunteer rye plants were observed in no-till plots beginning mid-July, and there were significantly greater grass weeds in the no-till plots (51 grasses/ft^2) than in tilled plots (5 grasses/ft^2) on 4 August. Fortunately, competition from the volunteer rye did not appear to adversely affect the no-till soybean yield (Table 2). Soybean yields in both the no-till and tilled treatments were very successful in 2009, averaging 42.6 bu/acre in the tilled plots and 36.6 bu/acre in the no-till treatments, which was exceptional, considering the late planting date (4 June). Yields were not significantly different between the two treatments.

Corn crop performance

Corn plants in the no-till treatments suffered from competition with hairy vetch re-growth during initial growth stages until the vetch reached maturity. As a result, corn plant populations in the no-till treatments, averaging 19,917 plants/acre, were significantly lower than the tilled treatments (29,250 plants/acre) (Table 2). Weeds were excessive in the no-till system, with broadleaf weed populations three to five times higher than the tilled treatment throughout the entire season (Table 2). Broadleaf weeds were higher in the no-till plots, at 7 broadleaves/ft^2 compared to 2 broadleaves/ft^2 in tilled plots on 22 June and on 2 July; on 4 August, broadleaf weed levels reached 9 broadleaves/ft^2 compared to 1 broadleaf/ft^2 in tilled plots. Although there was a trend towards higher grass weed populations in no-till corn plots at the last two sampling periods, statistically equivalent grass weed levels were observed in tilled and no-till plots on all sampling dates. On 22 June, there were 9 grass weeds/ft^2; on 2 July, 10 grasses/ft^2; and, at last sampling on 4 August, 9 grasses/ft^2.

The corn stalk nitrate test at the end of the season revealed very low levels of nitrogen in both treatments, with no-till corn averaging 20 ppm stalk NO_3-N compared to 33 ppm in the tilled plots (Table 2). Yields in the no-till treatment averaged 29.9 bu/acre, and were as low as 10 bu/acre in some plots, compared to the 99.4 bu/acre average yield in tilled plots (Table 2). Limited competition from cover crop re-growth, better broadleaf weed management, and additional decomposition and mineralization of N from tilled hairy vetch, led to higher yields in tilled plots.

Grain quality

Corn grain quality was not significantly different between no-till and tilled treatments (Table 3). Protein content averaged 6.8% and 7% for the tilled and no-till plots, respectively. Corn was harvested at a high moisture level (above 40%), due to a later planting date with a longer maturing corn and other weather conditions which were not supportive of adequate dry-down in 2009. Soybean grain quality was not obtained in 2009, due to inadvertent mixing of grain from experimental plots with bulk plots by the farm staff.

Cover crop performance

Since the success of the organic no-till system is dependent upon adequate cover crop germination and growth prior to rolling/crimping, cover crop performance is key. Rye germination and stand were excellent in 2009, with a population of 2,408,868 plants/acre on 12 May (Table 4). The one pass of the roller/crimper was sufficient to suppress the rye cover crop, with no interference between the rye and soybean crop until later in the season when tillers from the crushed cover crop emerged. Rye cover crop height was 23 inches on 4 June prior to rolling/crimping. The hairy vetch cover crop, on the other hand, produced only 135,036 plants/acre, and reached 9 inches in height on 4 June. The hairy vetch cover crop yielded 5,298 lb/acre of biomass, while the rye produced 13,794 lb/acre of above ground growth (Table 4). The hairy vetch cover crop was never completely terminated with the roller/crimper, which impacted corn growth throughout the growing season, eventually leading to significantly reduced yields.

2010

Oat crop performance

During the oat crop year (2010), in both crop sequences, no tillage operations were employed in all plots post-planting, but plots retained their original designation of “tilled” or “no-till” based on the tillage used in the previous year for corn or soybean production. There was a trend towards greater oat stands in the tilled plots of the rye/soybean–oat crop sequence, at 1,422,961 plants/acre, than in the tilled hairy vetch/corn–oat crop sequence, at 994,619 plants/acre (Table 2). Plant populations in the no-till hairy vetch/corn–oat plots, at 631,620 plants/acre, were similar to the 577,170 plants/acre in the no-till rye/soybean–oat crop sequence, but both no-till stands were lower than their tilled counterpart. On 7 July, oat biomass averaged

5,330 lb/acre in the tilled plots in both crop sequences compared to only 420 lb/acre in the no-till plots (Table 5). The tilled rye/soybean–oat crop sequence treatment, which had the highest crop stand, also had the greatest biomass production at 6,780 lb/acre. Volunteer rye and hairy vetch cover crop plants were observed in no-till plots that had been planted to these cover crops in 2008: the no-till rye/soybean–oat plots and the hairy vetch/corn–oat plots had approximately 3,740 and 3,380 lb/acre of rye and hairy vetch biomass in oat plots, respectively, on 7 July (Table 5). Volunteer hairy vetch plants were also observed in tilled plots, where vetch plants had survived disking/cultivation and re-seeded in these plots.

Weed suppression was considered inadequate in all plots, with weed biomass reaching 20 lb/acre in tilled rye/soybean–oat plots; 320 lb/acre in no-till hairy vetch/corn–oat plots; and 760 lb/acre in no-till rye/soybean–oat plots. Many of the weeds were perennial species, including dandelion, Canadian thistle and quackgrass. There was an average of 16 broadleaf weeds/ft^2 in the rye/soybean–oat sequence plots compared to an average of 19 broadleaf weeds/ft^2 in the hairy vetch/corn–oat sequence plots (Table 2). Grass weeds, however, averaged 22 weeds/ft^2 in rye/soybean–oat sequence plots compared to 5 grasses/ft^2 in the hairy vetch/corn–oat sequence plots. Overall, broadleaf weeds in tilled plots averaged 12 weeds/ft^2 compared to 23 broadleaves/ft^2 in no-till plots. Grass weeds averaged 9 weeds/ft^2 in tilled plots and 17 grasses/ft^2 in no-till plots. In examining individual crop sequence and tillage treatment responses, broadleaf weed populations were found to be greater in no-till hairy vetch/corn–oat sequence plots, at 33 weeds/ft^2, compared to 4 broadleaves/ft^2 in tilled hairy vetch/corn–oat sequence plots, while broadleaf weed populations were equivalent, averaging 16 broadleaves/ft^2, over both tilled and no-till rye/soybean–oat sequence plots.

Weed biomass near harvest was greatly reduced in previously tilled treatments despite early-season high levels of weeds and no post-planting tillage in these plots (data not shown). Thus, oat grain yield was obtained only in tilled plots, with statistically greater yields obtained in the tilled rye/soybean–oat crop sequence plots (75 bu/acre) compared to 46 bu/acre in the tilled hairy vetch/corn–oat crop sequence plots (Table 2). Because the no-till plots did not produce adequate grain, oatlage was harvested instead, and averaged 5.5 tons/acre in the no-till plots, with no yield differences between crop sequence treatments. Because of extensive weed populations, it was decided that a light disking of all plots was necessary on 2 September 2010 before planting the hairy vetch and rye cover crops for the next no-till corn and soybean segment.

2011

Soybean crop performance

Soybean plant populations were significantly higher in the no-till plots in 2011 compared to the tilled plots, with no-till plots averaging 129,667 plants/acre compared to 99,833 plants/acre in tilled plots (Table 2). Weed suppression in the no-till plots was satisfactory early in the second no-till soybean season, with broadleaf and grass weed populations averaging <2 weeds/ft^2 on 20 June (Table 2). Broadleaf weeds were lower in the tilled plots but, with such low populations in all plots, biological differences were not recognized. Later in the season, however, volunteer rye plants, along with other grass and broadleaf weeds, emerged in no-till plots, leading to significantly greater populations of 5 broadleaf weeds/ft^2 and 37 grass weeds/ft^2 on 1 September compared to <1 broadleaf weed/ft^2 and 11 grasses/ft^2 in tilled plots.

Weed and volunteer rye competition again did not appear to adversely affect the soybean yield in no-till plots in 2011 (Table 2). Soybean yields in both no-till and tilled treatments were successful in 2011, averaging 28 bu/acre in the tilled plots and 31 bu/acre in no-till plots, which was considered an excellent yield for organic soybeans in 2011. Yields were not significantly different between treatments.

Grain quality

Soybean grain quality was not significantly different between no-till and tilled treatments in 2011 (Table 3). Protein content averaged 36.7%, with 17.3% oil, and 23.2% carbohydrates. Soybean staining (percentage of soybeans stained from insect feeding/fungal infection) was low, at 1.31%, and no difference between treatments.

Soil moisture

Tilled plots averaged 18% soil moisture, which was significantly greater than the 16% soil moisture in no-till plots (Table 1). Since yields were equivalent between tillage treatments, it is unknown what effect, if any, this difference had on plant growth during the season. The emergence of rye tillers later in the season may have led to a decrease in soil moisture levels in no-till plots, but this effect was not measured.

Corn crop performance

In 2011, as occurred in 2009, corn plants in the no-till treatments suffered from competition with hairy vetch re-growth and excessive weed populations. Plant populations in the no-till treatments averaged 21,167 plants/acre, which were significantly lower than the tilled treatments at 26,917 plants/acre (Table 2). Despite an increase of 1,250 plants/acre in no-till corn plant populations from the 2009 season, weed and hairy vetch competition prevented adequate corn growth. Broadleaf weed populations were low in tilled plots, averaging <1 broadleaf weed/ft^2 on 20 June and on 1 September (Table 2). Grass weeds in tilled plots averaged 4 grasses/ft^2 on 20 June and 14 grasses/ft^2 on 1 September. Weed populations in the no-till corn plots greatly exceeded those in tilled plots: on 1 September, there were 25 broadleaf weeds/ft^2 and 39 grass weeds/ft^2. In terms of weed biomass production, there were 723 lb/acre of annual grasses in no-till corn plots compared to 1,135 lb/acre in tilled plots, but because of high variability among plots, there was no statistical difference between treatments (Table 5). Perennial broadleaf weeds totaled 225 lb/acre in no-till plots compared to none in tilled plots, where annual broadleaf weeds predominated.

Because of poor hairy vetch growth and no composted manure application, N appeared to be limited in all plots, including tilled plots, which averaged only 77 bu/acre (Table 2). No-till corn yields averaged dramatically less, at 10 bu/acre, due to both low N and high weed populations. Corn grain was not analyzed for grain quality in 2011 due to poor yields.

Cover crop performance

In 2011, the germination and stand of the hairy vetch cover crop was greater than in 2009 (Table 4). Plant populations averaged 640,550 plants/acre over all hairy vetch plots on 18 May, compared to 135,036 plants/acre in 2009. Rye stands averaged 2,259,675 plants/acre, which were lower than 2009 stands of 2,408,868 plants/acre, but plant height of the rye cover crop height was 48 inches on 24 May prior to rolling/crimping. Hairy vetch plant height averaged 9 inches, which was similar to 2009. Despite a more extensive hairy vetch stand in 2011 than in 2009, cover crop ratings in no-till plots on 24 May determined that hairy vetch plots consisted of only 16% cover crop, with 83% of the plot in weeds, and 1% in bare ground (Table 4). This high proportion of weeds in hairy vetch plots led to extensive weed problems in corn plots throughout the growing season, particularly when hairy vetch was not suppressed by the roller/crimper. Rye plots, on the other hand, consisted of 93% cover crop, with only 6% in weeds and 1% in bare ground.

Soil quality

There was no difference in soil moisture in no-till or tilled corn plots, which averaged 16.3% across all plots (Table 1). Prior to cash crop planting in Spring 2009, soil quality analysis revealed no significant differences in any parameters between the no-till and the tilled treatments in samples taken in Fall 2008 (Delate et al., 2012b). After the first corn and soybean season, in Fall 2009, soil microbial biomass carbon (MBC) values were significantly greater in no-till than in tilled plots (Weyers and Cambardella, 2011). Higher MBC and microbial biomass nitrogen (MBN) continued in no-till plots after the oat year in 2010. Additionally, residual soil nitrate-N, pH and electrical conductivity were greater under no-till than tilled plots. These findings were explained by Weyers and Cambardella (2011) as suggestive of MB-C and N quickly reacting to soil management changes as experienced with the no-till treatment. The reduced soil disturbance from no-till and higher available C and N concentration in the top soil layer may have led to increased microbial populations.

Conclusions

The organic no-till system is still considered experimental in Iowa and across the U.S., with less than a decade of results to utilize in developing recommendations. Organic no-till soybeans were very successful in 2009 and 2011 in the Iowa Organic No-Till experiment, averaging 34 bu/acre over both years, equivalent to tilled organic soybean yields that averaged 35 bu/acre. The rolled/crimped rye cover crop led to comparable weed management early in the season, with similar weed populations in tilled plots that received an average of four tillage operations compared to no post-planting tillage in no-till plots. Despite a volunteer rye crop later in the season, soybean yields were not adversely affected. These results were similar to previous no-till experiments in Iowa, where the highest organic no-till soybean yield of 47 bu/acre was obtained in Greenfield, Iowa, in 2007 (Delate et al., 2012a). In Wisconsin, a 25% organic no-till soybean yield reduction was reported compared to tilled plots (Bernstein et al., 2011).

The organic no-till corn system suffered from multiple problems, including inability of the roller/crimper to successfully terminate the hairy vetch cover crop, leading to hairy vetch re-growth and extensive competition with the corn crop. In addition, weeds emerged through the many gaps created by the limited hairy vetch mulch, affecting corn plant growth and ear filling. The no-till system led to drastically reduced corn yields, which were 30% and 12% of tilled corn yields in 2010 and in 2011, respectively.

Rolling/crimping the vetch at later dates in June has been shown to potentially alleviate both problems by allowing for larger biomass growth and better control of the hairy vetch (Mischler et al., 2010) and will be taken into consideration in future experiments. While the no-till organic corn system was a failure in 2009 and 2011, the tilled organic corn system in this experiment also suffered from lack of sufficient N for adequate yields. Organic corn yields based on cover crops, such as alfalfa, and composted manure to provide 120 lb N/acre, can reach 202 bu/acre under ideal weather conditions (Delate and Cambardella, 2004). Thus, both organic no-till and tilled corn systems should include a supplemental form of N in addition to cover crops for optimum yields.

The oat crop in the third year of this long-term rotation helped build soil quality and create a uniform crop history before starting the second no-till phase of the experiment. Extensive rainfall throughout the season in poorly drained plots, however, increased disease pressure and led to a lower-than-average oat grain yield of 60 bu/acre compared to 82 bu/acre in long-term organic plots (Delate and Cambardella, 2004). Volunteer rye and hairy vetch cover crops also competed with the oat crop, leading to minimal grain fill in the no-till plots. In addition, perennial weed species emerged, particularly in no-till plots, leading to the multi-state team decision to till all plots prior to the second no-till phase of the experiment. Although the organic no-till system has shown success, particularly for organic soybeans, greater modifications are needed before recommending as a broad-scale approach for organic growers across the Midwest. The rye cover crop can be sufficiently terminated (i.e., limited re-growth), since both height and stage of maturity needed for successful rolling/crimping matched more closely Iowa soybean-planting dates than the lesser mature hairy vetch stage of growth at proper corn planting dates. Second-phase experimental protocols will include the use of alfalfa, prior to the no-till component, in a new oat/alfalfa–alfalfa–rye/soybean–oat/alfalfa rotation to continue examination of soil quality and crop performance under this new system. Environmental value, such as the soil quality benefits from reduced tillage practices demonstrated in this experiment, will be evaluated against economic and social benefits, if any, from organic no-till farming.

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Table 1. Soil parameters in the Organic No-Till experiment, Agronomy Farm, 2009 and 2011.

Treatment	Bray phosphorus (ppm)	Potassium (ppm)	Calcium (ppm)	Magnesium (ppm)	Total Nitrogen (%)	Ammonium nitrogen (ppm)	Nitrate nitrogen (ppm)	Moisture (%) 2011
2009								
Soybean								
Tilled	14.14	145	5126	513	2.42	0.607	0.433	17.98a
No-till	19.30	144	4342	511	2.43	0.337	0.533	16.16b
LSD $_{0.05}$	NS[z]	NS	NS	NS	NS	NS	NS	1.42
Corn								
Tilled	19.95	133	4084	547	2.26	0.255	0.315	16.27
No-till	9.08	133	5317	466	2.55	0.570	0.353	16.40
LSD $_{0.05}$	NS	NS	NS	NS	NS	NS	NS	NS

[z]Means within a column are not significantly different (NS), or significantly different at $p \leq 0.05$ (Fisher's protected LSD test).

Table 2. Soybean and corn parameters in the Organic No-Till experiment, Agronomy Farm, 2009-2011.

Treatment	Stands (plants/acre)	Corn stalk nitrate (ppm)	Yield (bu/acre)	Weed population (weeds/ft^2)					
				Broadleaves			Grasses		
2009				22 June	2 July	4 Aug	22 June	2 July	4 Aug
Soybean									
Tilled	133,750a[z]	---	42.60	3.92a	2.25	1.58	17.08	1.58	5.33a
No-till	149,083b	---	36.58	1.50b	1.19	3.167	17.33	0.00	51.25b
LSD $_{0.05}$	14,950	---	NS	2.23	NS	NS	NS	NS	25.77
Corn									
Tilled	29,250a	32.63a	99.39a	2.17a	1.58a	1.25a	16.67	6.00	5.50
No-till	19,917b	20.00b	29.94b	7.17b	7.08b	8.75b	9.33	10.08	9.17
LSD $_{0.05}$	5,229	9.63	27.49	2.39	3.14	4.53	NS	NS	NS
2010: Oats				17 May			17 May		
Previously rye/soybean									
Tilled	1,422,961a	---	74.92a	19.83	---	---	13.58b	---	---
No-till	577,170b	---	5.83 t/ac	13.00	---	---	30.25a	---	---
LSD $_{0.05}$	243,551	---	---	NS	---	---	8.59	---	---
Previously hairy vetch/corn									
Tilled	994,619a	---	45.59b	4.25b	---	---	5.08	---	---
No-till	631,620b	---	5.10 t/ac	33.00a	---	---	4.33	---	---
LSD $_{0.05}$	207,334	---	13.76	18.66	---	---	NS	---	---
2011				20 June		1 Sept	20 June		1 Sept
Soybean									
Tilled	99,833b	---	28.21	0.03b	---	0.11b	1.42	---	11.30b
No-till	129,667a	---	31.04	1.57a	---	4.73a	1.08	---	37.14a
LSD $_{0.05}$	21,680	---	NS	0.65	---	4.20	NS	---	20.02
Corn									
Tilled	26,917a	---	77.16a	0.66	---	0.87b	3.50	---	13.89b
No-till	21,167b	---	10.04b	N/A	---	24.65a	N/A	---	38.53a
LSD $_{0.05}$	4,660	---	5.89	N/A	---	17.65	N/A	---	18.19

[z]Means within a column are not significantly different (NS), or significantly different at $p \leq 0.05$ (Fisher's protected LSD test).

Table 3. Soybean and corn grain quality parameters in the Organic No-Till experiment, Agronomy Farm, 2009 and 2011.

Treatment	Moisture (%)	Protein (%)	Oil (%)	Fiber (%)	Carbohydrates (%)	Soybean staining (%)
2009						
Corn						
Tilled	40.23	6.82	4.33	---	62.63	---
No-tilled	40.40	7.00	4.25	---	62.15	---
$LSD_{0.05}$	NS[z]	NS	NS	---	NS	---
2011						
Soybean						
Tilled	11.05	36.60	17.48	4.76	23.16	1.24
No-tilled	11.23	36.88	17.20	4.76	23.16	1.38
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS

[z]Means within a column are not significantly different (NS), or significantly different at $p \leq 0.05$ (Fisher's protected LSD test).

Table 4. Cover crop parameters in the Organic No-Till experiment, Agronomy Farm, 2009 and 2011.

Treatment	Stand (plants/acre)	Plant height (inches)	Cover crop biomass (lb/acre)		
2009	12 May	4 Jun	4 June		
Hairy vetch	135,036	8.66	5,298		
Tilled	---	---	---		
No-till	---	---	---		
LSD $_{0.05}$	---	---	---		
Rye	2,408,868	22.60	13,794		
Tilled	---	---	---		
No-till	---	---	---		
LSD $_{0.05}$	---	---	---		
			Total cover (%)	Weed cover (%)	Bare ground (%)
2011	18 May	24 May	24 May	24 May	24 May
Hairy vetch					
Tilled	831,125	---	---	---	---
No-till	449,975	9.15	16.25	83.08	1.67
LSD $_{0.05}$	NS[z]	---	---	---	---
Rye					
Tilled	2,105,255	---	---	---	---
No-till	2,414,095	47.80	92.58	6.33	1.08
LSD $_{0.05}$	NS	---	---	---	---

[z]Means within a column are not significantly different (NS), or significantly different at $p \le 0.05$ (Fisher's protected LSD test).

Table 5. Oat crop and cover crop biomass and weed parameters in the Organic No-Till experiment, Agronomy Farm, 2010 and 2011.

Treatment	Oat biomass (lb/acre)	Volunteer rye biomass (lb/acre)	Volunteer hairy vetch biomass (lb/acre)	Weed biomass (lb/acre)
2010: Oats				
Rye/soybean crop sequence				
Tilled	6,780a	0.00b	80.00b	20.00b
No-till	280c	3,740a	0.00b	760.00a
LSD $_{0.05}$				
Hairy vetch/ corn crop sequence				
Tilled	3,880b	0.00b	40.00b	0.00b
No-till	560c	0.00b	3,380a	320.00b
LSD $_{0.05}$	1,220	1,200	1,260	420.00

Treatment	Cover crop biomass (lb/acre)	Total biomass (lb/acre)	Annual grass weeds (lb/acre)	Annual broadleaf weeds (lb/acre)	Perennial broadleaf weeds (lb/acre)
2011	18 May				
Soybean					
Tilled	248.09	582.65b	560.20	0.00	0.00
No-till	235.28	4198.2a	952.40	31.97	42.41
LSD $_{0.05}$	NS	1337.4	NS	NS	NS
Corn					
Tilled	2283.19	1176.39	1134.84	0.00	0.00
No-till	4767.25	1020.31	722.69	0.00	224.86
LSD $_{0.05}$	868.14	NS	NS	N/A	194.18

[z]Means within a column are not significantly different (NS), or significantly different at $p \leq 0.05$ (Fisher's protected LSD test).

CHAPTER 3: EVALUATION OF AN ORGANIC NO-TILL SYSTEM WITH VARIOUS COVER CROPS FOR ORGANIC CORN PRODUCTION

Introduction

Organic farming has been suggested as promoting poor soil stewardship because of the perception that intensive tillage practices are needed for weed control and contribute to excessive erosion and overall soil degradation (Kuepper, 2001). Conservation tillage, including no-till crop production, addresses tillage and soil quality concerns (Uri, 2000); however, conventional no-till relies on herbicides as the primary form of weed management, which are disallowed in organic production. Despite increasing demand and high prices for organic corn in 2012 ($11/bu), many conventional farmers considering transitioning to organic methods question the extent of tillage operations in organic systems. This is due, in part, to regulatory pressure on farmers to reduce tillage as part of their conservation plans (Uri, 2000), and also to the lack of effective weed management solutions for organic systems. While conventional no-till farmers find that the measurable reductions in soil erosion and labor costs are good for the environment and their bottom line (Juergens et al., 2004), additional research into no-till applications for organic systems is needed. No-till practices pose specific challenges to organic farming systems.

Cover crops have been routinely promoted for soil quality benefits and mitigating soil erosion. In addition to termination with herbicides, cover crops have been killed using a roller/crimper with steel blades welded onto a cylindrical drum in conservation tillage systems (Ashford and Reeves, 2003). The Rodale Institute (Kutztown, PA) supplied Iowa State University with a roller/crimper in 2005 for experimentation in Iowa. Mixed results have occurred in organic no-till production in Iowa and across the U.S. since the inception of the use of the roller/crimper. Organic no-till corn in Iowa has presented growers with the greatest number of challenges, with yields as low as 10 bu/acre compared with a 124 bu/acre average for tilled corn at the Neely-Kinyon Farm (Greenfield, IA) in 2007 when the roller/crimper was first tested (Delate et al., 2007). Although yields in Iowa have been disappointing, Pennsylvania yields have been more successful, with reported yields as high as 153 bu/acre when planting corn into a rolled/crimped hairy vetch cover crop (Mischler et al., 2010). Results are presented here from the organic no-till corn experiment conducted at the Neely-Kinyon Farm in 2010 and 2011.

Materials and Methods

Cover crops for the organic no-tillage corn experiment were planted on 24 September 2009 and on 18 October 2010 on land that was certified organic by the Iowa Dept. of Ag. and Land Stewardship (IDALS). The site was moved each year to a new location on land previously planted in organic soybeans. The predominant soil at the site is a moderately well-drained Macksburg silty clay loam (fine, smectitic, mesic Aquic Argiudolls) with 0 to 2% slope. Plots were laid out in a randomized complete block design consisting of two main treatments of no-tillage (no-till) and conventional tillage (tilled), with six cover crop sub-treatments of hairy vetch (*Vicia villosa*) planted at 30 lb/acre; rye (*Secale cereale*) planted at 240 lb/acre; winter triticale (*Triticosecale* sp.) planted at 240 lb/acre; Austrian winter peas (*Pisum arvense*) planted at 30 lb/acre; a combination of rye (180 lb/acre) and hairy vetch (20 lb/acre); and a control plot with no cover crop.

Cover crops in the tilled treatment were disked on 25 May, 17 June, and 8 July 2010; and on 2 June and 6 June 2011. Multiple disking operations were required to completely terminate cover crops prior to corn planting. In the no-till plots, cover crops were terminated with a roller/crimper mounted on a tractor on 12 July 2010 and on 7 June 2011. Corn seed (certified-organic Blue River 45R37) was planted in all plots on 12 July 2010 and on 7 June 2011 at 35,000 seeds/acre in 30-inch rows. The tilled corn plots were not rotary hoed in 2010 because of wet weather, but second-year tilled plots were rotary hoed on 24 June 2011. Tilled plots were row-cultivated on 27 July and 12 August 2010 and on 29 June, 7 July, and 15 July 2011.

Cover crop stand and weed populations were estimated on 19 October 2009, on 19 April 2010, and on 29 June 2011 by counting the number of living plants per square foot in five randomly selected areas within each plot. Cover crop height was measured and visual percent ground coverage of stand was estimated on 19 May 2010 and from 11–19 May 2011. Cover crop biomass dry weight was determined on 27 May 2010 and on 10 May 2011 by harvesting all above-ground plants at ground level in three randomly selected square-foot sections and drying at 140° F until a constant weight was achieved. Corn and weed populations were estimated on 5 August 2010 and on 29 June 2011 by counting corn plants in three randomly selected 17.4-ft row lengths in each plot, and by following weed counting protocols previously described. Corn height was measured on 16 August 2010 and on 22 July 2011. Additionally, European corn borer (*Ostrinia nubilalis*) damage was recorded on 16 August 2010 and on 14 July 2011 by counting the number of living corn borers on three randomly selected plants and providing an overall estimation of percentage of plants with corn borer damage in each plot.

No mid-season soil or end-of-season corn stalk samples were taken in 2010, due to labor constraints, but in 2011, soil samples were taken on 14 July 2011 to determine any soil NO_3-N differences between treatments by sampling to a depth of six inches with a 1-inch-diameter probe in five random locations per plot. Corn stalk nitrate samples were taken on 28 September 2011 following methods of Blackmer and Mallorino (1996) after removing three randomly selected corn stalk samples per plot. SPAD (Minolta Chlorophyll Meter SPAD-502, Konica Minolta, Ramsey, NJ) readings were taken on three randomly selected leaves per plot on 28 September 2011 to determine leaf chlorophyll differences between treatments. In 2010, due to late planting and subsequent failure of corn plants to reach maturity, all tilled and no-till plots were harvested for corn silage biomass on 30 September 2010 with a self-propelled biomass harvester. In 2011, tilled corn plots were harvested for grain on 24 October, but, as in 2010, no-till corn plants had insufficient ear formation, and were harvested for corn silage biomass on 5 October. Soils were sampled prior to harvest (30 September 2010 and 5 October 2011) by sampling to a depth of six inches with a 1-inch-diameter probe in five random locations per plot. All soils in this experiment were analyzed at the Plant and Soils Diagnostic Laboratory at Iowa State University (Ames, IA).

Data analysis. Since there was a significant difference in data between years (data not shown), data were analyzed by each year separately. Data for corn and cover crop growth, pest populations, soil nutrients and yields within each year, and grain quality in 2011, were subjected to analysis of variance and mean separation using Fisher's Protected LSD at $p \leq 0.05$. Any significant interaction between tillage system and cover crop combinations was determined at the $p \leq 0.05$ level.

Results and Discussion

2010

Corn crop performance

The late planting date in 2010 (12 July), due to excessive rains, was a major detriment for both tilled and no-till corn production. Although corn plant populations a month after planting were equivalent between treatments, averaging 28,875 plants/acre in the no-tillage treatments and 27,520 plants/acre in the tillage treatments (Table 1), corn plants in the no-till treatments suffered from competition with weeds and cover crop re-growth, as reflected by a diminished corn height (Table 1). Corn height in the tilled plots averaged 64 inches compared to an average of only 35 inches in the no-till plots. The corn in the no-till hairy vetch plots was significantly taller than the other no-till plots, averaging 46 inches, compared to 32 inches in the other four cover crop treatments.

Corn borer damage was observed in many corn plants in 2010, particularly in the no-till plots (Table 1). Damage ranged between 3 and 23% of plants infested per plot, with greater damage observed in the no-till hairy vetch and control plots. Because of the high variability in damage among plots, there was no significant difference in damage between tillage treatments, however. No difference was also observed between tillage and cover crop treatments in the percentage of plants with live corn borers, but, similar to damage ratings, there was a trend towards greater numbers of live corn borers in the no-till hairy vetch plots, along with the tilled winter pea and rye/hairy vetch plots, which averaged 1 corn borer every 5 plants. The lowest numbers tended to be in the no-till rye plots, where no corn borers were observed.

At harvest, corn silage yields in the no-till treatments were significantly lower than in the tilled cover crop treatments (Table 1). No-till biomass yields ranged between 5 and 9 tons/acre, while the tilled yields ranged from 22 to 28 tons/acre of biomass. There was no statistical yield difference between cover crop sub-treatments in conventional tillage plots. However, there were statistical differences between cover crop sub-treatments in the no-till plots. Biomass yield in the no-till hairy vetch treatment averaged 9 tons/acre, which was equivalent to the control plots, at 8.7 tons/acre, and the rye/hairy vetch treatment, at 6 tons/acre (Table 1). Silage biomass in the remaining no-till cover crop treatments averaged 5.1 tons/acre.

Poor yields in tilled plots were associated with a late planting date and weed pressure in corn plots in 2010. Wet weather led to an inability to plant on time and rotary hoe, which led to poor weed management in tilled plots, particularly for broadleaf weeds. There were no grass weeds in tilled plots at sampling on 5 August after plots were row cultivated (Table 2), but broadleaf weeds reached 30 weeds/ft^2 in plots where rye had been tilled under, compared to an average of 8 weeds/ft^2 in all other tilled plots. Because weed populations were so high in no-till plots, an estimation of weed coverage in plots on 5 August showed that grass weed coverage ranged from 1.5% to 29% (Table 2). Due to large variations in weed coverage between plots, there was no statistical difference between cover crop treatments (Table 2). Broadleaf weeds in the no-till plots were greater than grass weed populations. The rye and rye/hairy vetch plots exhibited the lowest weed populations of the no-till cover crop treatments, with 19% and 25% weed cover, respectively. Despite this lower amount of weeds, competition severely impacted corn plant growth and ear formation, as previously discussed.

Cover crop performance

Germination and stands of cover crops containing winter annual grasses (rye, triticale and rye/hairy vetch mix) were excellent in the fall of 2009, averaging 27 plants/ft^2, but winter pea and hairy vetch seed germination was inconsistent, averaging only 8 and 10 plants/ft^2, respectively, across all plots (Table 3). In the spring, it was evident that many of the winter pea plants winter-killed, with fall stands of 8 plants/ft^2 reduced to 3 plants/ft^2 in the spring, averaged across all plots (Table 3). Rye and triticale cover crop plant height averaged 43 and 37 inches, respectively, across all plots at spring sampling, significantly higher than hairy vetch at 20 inches and winter pea at 13 inches (Table 3). Rye/hairy vetch plants were intermediate at 30 inches in height. In addition to excellent stands, rye and triticale plants provided 93–100% cover in plots (Table 4). Hairy vetch plants, however, covered only 84% of the ground in the no-till plots and 63% in the plots that would be tilled, which was significantly lower. It is unclear why there were differences between plots to be tilled vs. no-tilled, when all plots had similar soil and moisture, and were treated exactly the same in cover crop seed drilling. Winter pea cover was significantly lower than all other treatments, with 16% and 25% ground cover in plots to be no-tilled and tilled, respectively. Triticale produced the greatest amount of biomass at 3.7 tons/acre dry matter, followed by rye at 3.5 tons/acre, and the rye/hairy vetch mix at 3.3 tons/acre (Table 4), with no significant differences among these treatments. Hairy vetch alone produced a biomass of 1.5 tons/acre, which was equivalent to Austrian winter pea biomass at 0.94 tons/acre (Table 4).

When weeds were censused in cover crop plots in the fall, there were some differences between plots. Weeds in cover crop plots to be tilled averaged 3 weeds/ft^2 in all but the control plots, where weeds reached 5 weeds/ft^2 (Table 2). In cover crop plots that would be no-tilled, there was an average of 2 weeds/ft^2 in winter pea and hairy vetch plots, compared to <1 weeds/ft^2 in triticale and rye alone and with hairy vetch. Weeds, including dandelions, velvetleaf, and lambsquarters that were present in cover crops in the fall, were reduced or dormant at spring sampling. Weed biomass dry weight in no-till plots on 27 May was highest in the control, at 10.5 g/ft^2, and in the Austrian winter pea plots, at 3.8 g/ft^2, compared to no weed biomass in the other cover crop samples (Table 3).

Soil fertility

There was no clear advantage in tilling or no-tilling cover crops in relation to soil nutrient concentrations between treatments at the end of the season (Table 6). Despite no significant differences at the p=0.05 level, nitrate nitrogen tended to be higher in the tilled hairy vetch plots, averaging 3.73 ppm, compared to an average of 2.80 ppm over all other cover crop plots and 2.63 ppm in control plots. In the no-till plots, soil nitrate-N levels tended to be lower overall, averaging 1.2 ppm over all cover crops plots and 0.95 ppm in control plots. Ammonium nitrogen (NH_4-N) was not significantly different between cover crop treatments or tillage treatments, although there was a trend towards higher levels in the no-till plots, with no-till cover crop plots averaging 1.15 ppm, compared to 0.53 ppm in tilled cover crop plots. The highest numerical NH_4-N content was 1.43 ppm in the no-tillage hairy vetch plots. Organic matter averaged 4.35% in tilled cover crop plots and tended to be higher in the tilled hairy vetch plots (4.70%) and in the tilled triticale plots (4.68%) compared to the no-tillage control (4.15%). In the no-till plots, organic matter levels differed between treatments, with a lower amount (4.15%) in control plots, compared to an average of 4.38% in the cover crop plots. No other soil nutrients, including Ca, Mg, Bray P and K, were statistically different between cover crop or tillage treatments, but some trends emerged, including Bray P concentrations averaging 48.5 ppm in tilled cover crop plots compared to 33 ppm in control plots; no-till cover crop plots Bray P concentrations averaged 47.2 ppm compared to 39 ppm in control plots. Potassium levels were equivalent in tilled and no-till cover crop plots, averaging 218 ppm, compared to 194 and 189 ppm in tilled and no-till control plots, respectively. Average soil pH levels were 7.33 in tilled cover crop plots and 7.36 in no-till cover crop plots, compared to 7.16 in both tilled and no-till control plots.

Yields in 2010 were depressed due to wet weather delaying planting date and weed management, and insufficient N from cover crop additions only, which is not typical for Iowa organic farmers, who generally apply up to 120 lb N/acre from composted manure prior to corn planting. Both the tilled and no-till corn were harvested as biomass due to lack of adequate growth and poor ear formation. While the tilled corn yielded an average of 24 tons/acre silage, which is an acceptable silage yield in the Midwest, the no-till corn only produced an average of 6 tons/acre. Competition from weeds and cover crop re-growth, along with insufficient N and corn borer damage, led to much lower yields in no-till plots. Some soil differences were observed, however, with the most apparent related to improvements in soil NO_3-N and organic matter from the hairy vetch cover crop compared to control plots with no cover crop.

2011

Corn crop performance

In 2011, corn stands were again equivalent in tilled and no-till plots, averaging 27,000 and 29,000 plants/acre, respectively (Table 1). Lower stands were observed where cereal cover crops had been tilled under prior to corn planting, averaging 23,556 plants/acre, but in no-till plots, where cereal crops had been rolled/crimped, stands averaged 30,278 plants/acre (Table 1). Nitrogen limitations were observed early in the season in both systems, with soil NO_3-N content averaging 4 ppm in tilled plots on 14 July, and only 1 ppm NO_3-N in no-till plots (Table 1). On 22 July, corn height was greater in the tilled system, averaging 51 inches, compared to 34 inches in the no-till system (Table 1). Legume cover crop treatments in the tilled system were associated with taller corn plants, which averaged 56 inches (Table 1). In the no-till plots, this pattern was not as apparent, except that the shortest corn plants were observed in the rolled/crimped triticale treatment (28 inches). SPAD readings, reflective of chlorophyll and N content, were also higher in the tilled plots (34) compared to a reading of 25 in the no-till plots (Table 1).

Corn borers were again observed in 2011 (Table 1), but at lower populations than observed in 2010 (average of <1 per plant across all plots). While censusing corn borer damage in the field, there was a trend towards greater damage in no-till plots, but since populations were so low, biological differences were insignificant between tillage or cover crop treatments.

Corn growth in tilled plots was adequate in 2011 to produce a grain yield. Yields in the tilled system ranged from 53 bu/acre in the rye/hairy vetch treatment to 144 bu/acre in the control plots (Table 1). The hairy vetch and winter pea cover crop treatments were associated with higher yields in the tilled plots, compared to the cereal cover crops, presumably due to the N added through nitrogen fixation from legume cover crops, potential allelopathy and N immobilization with cereal cover crops. Corn grain yield in the legume cover crop treatments (hairy vetch and winter pea) averaged 120 bu/acre compared to the cereal cover crop treatments averaging only 57 bu/acre. Allelopathy and N immobilization with cereal cover crops appeared to affect corn yields the most, given that yields in control plots (with no cover crop) were equivalent to legume cover crop treatments. Control plots, however, had a long-term organic rotation history, with potential N additions from the previous organic soybean crop.

Corn in the no-till plots again suffered from lack of N, weed competition, and cover crop re-growth. Plots were harvested as corn silage, with silage biomass averaging 13.3 tons/acre across all plots, with no significant difference between cover crop treatments (Table 1). Corn grain quality from tilled plots was not significantly different between cover crop treatments

(Table 7). Protein content averaged 7.1% across all treatments, with oil and starch content averaging 3.5% and 61.5%, respectively. Moisture content averaged 23%.

Weed management was more successful overall in 2011 than in 2010. Weeds were managed more successfully in the no-till system, with grass and broadleaf weed populations averaging 1 plant/ft^2 three weeks after planting compared to an average of 8 grass weeds/ft^2 and 2 broadleaf weeds/ft^2 in the tilled plots (Table 2).

Cover crop performance

When germination and stand of cover crops was assessed in spring 2011, the leguminous cover crops of hairy vetch and winter pea again experienced lower germination rates and/or winter-kill, with only 24% and 55% ground cover, respectively, before termination (Table 4). In contrast, cover crops that contained a cereal (rye, triticale, rye/hairy vetch) covered over 99% of sampled plot area (Table 4). Cereal cover crops alone or in a mixture (rye/hairy vetch) yielded significantly greater amounts of biomass, averaging 3,201 lb/acre across all plots, compared to 277 lb/acre across all winter pea plots, and 608 lb/acre across all hairy vetch plots (Table 4).

The roller/crimper adequately suppressed cereal cover crop re-growth, with less than 10% re-growth in these plots (Table 5). The hairy vetch and winter pea re-growth, however, averaged 100% and 97%, respectively (Table 5). The average weed cover in the cereal cover crop plots was <1%, while legume cover crop samples consisted of 16% weeds across all plots, compared to the control plots where 33% of the sampling area contained weeds. Bare ground (area other than cover crop plants or weeds) averaged 0% in plots containing cereal cover crops, 42% in legume cover crop plots, and 56% in control plots (Table 4).

Legume cover crops were associated with significantly more plant tissue N, at 4.8%, compared to 1.9% in the other three cover crops in no-till treatments (Table 5). In the tilled treatments, there was 3.7% N in the legume cover crops compared to 2.1% N in the other three cover crop treatments. There was a significant interaction between tillage and cover crop treatment, with a higher percentage of N in no-till legume cover crop plants. There was no difference in cover crop plant carbon content between cover crops in the tilled plots, but, in no-till plots, the rye and rye/hairy vetch cover crops had greater carbon content, averaging 42.5%, followed by a 41% average C content in the winter pea and triticale plots. The lowest C level was in the hairy vetch alone treatment at 39.6%.

Soil fertility

At the end of the season, soil nutrients (Ca, Mg, K, and Bray P) were not significantly different between cover crop treatments in the tilled plots (Table 6), but in the no-till plots, lower K concentrations were determined in the triticale cover crop treatment compared to the legume cover crop treatments. Nitrate-N was not statistically different between tilled and no-till systems, averaging 2.8 ppm, but there was a trend towards greater NO_3-N in the no-till plots, which averaged 3.1 ppm, with significantly lower NO_3-N in rye and triticale plots (Table 6). Total N, total C, and organic matter content were equivalent between tilled and no-till systems and cover sub-treatments, averaging 0.18 ppm, 2.6%, and 4.7%, respectively.

Conclusions

Overall, the organic corn no-till system experienced many setbacks in Iowa in 2010 and 2011, particularly in 2010, when wet weather prevented timely planting and led to subsequent weed and insect problems. The later planting date prevented rolling/crimping the cover crops at the ideal stage (e.g., anthesis for the grass cover crops and flat-pod stage for the vetch) and, combined with excessive precipitation, led to high populations of weeds in the cover crop mulch. The tilled plots yielded approximately three times the corn silage biomass as the no-till plots. Nitrogen fixed by the hairy vetch cover crop did tend to increase corn silage yield, since no additional nitrogen was added to any of the plots. In 2011, cereal cover crops produced adequate biomass and ground coverage after the roller/crimper operation, while single legume cover crops (hairy vetch and winter pea) again suffered from poor winter survival and low biomass in the spring. Although corn planting occurred at an earlier date than 2010 (7 June), and corn stands were equivalent in both tillage treatments, corn plants in the no-till treatments again suffered from competition with cover crop re-growth and nitrogen shortages, as observed in SPAD leaf readings and in mid-season soil nitrate content. Insufficient grain was produced in the no-till corn to warrant a grain harvest, while tilled corn in tilled legume cover crops averaged twice the yield of corn in cereal cover crops, suggesting that legume cover crops are needed to enhance soil fertility. With a greater C:N ratio in the cereal cover crops, and more decomposing material, N immobilization probably occurred, which was demonstrated in lower soil NO_3-N levels in rye and triticale plots.

Many modifications to the organic no-till system are required before recommending as a broad-scale approach for organic growers in the Midwest. Rolling/crimping the hairy vetch cover crop in late June has been associated with greater biomass and less re-growth (Mischler et al., 2010), later corn planting can lead to lower yields in the Midwest, as was observed with a 12 July planting in 2010. The inability of legume cover crops to supply adequate amounts of N for the corn crop and/or limited nitrogen mineralization in spring was observed in both the no-till and tilled system; thus, in future experiments, supplemental N (manure or compost) must be added to provide adequate nutrients to support corn grain yields.

These results were similar to previous no-till experiments in Iowa, where successful organic no-till corn production was constrained by a late planting date and obtaining sufficient termination of the cover crops through rolling/crimping at the same time (Delate et al., 2012a). In addition, hairy vetch in a mixture with rye was associated with greater yields than hairy vetch or winter pea alone in previous organic no-till experiments. Higher yields in organic no-till corn systems in Pennsylvania (up to 153 bu/acre) have been associated with a milder winter, facilitating greater hairy vetch biomass production, and a longer growing season to allow planting at a later date into a rolled/crimped cover crop (Mischler et al., 2010). Future recommendations in Iowa may also include a high-residue cultivator for a one-pass rescue tillage system if the cover crops are not adequately terminated from the rolling/crimping and/or weeds continue to emerge through the cover crop mulch. Although progress has been made for other crops in the organic no-till system, with organic no-till soybeans averaging 31 bu/acre in 2011 (Delate et al., 2012b), organic no-till corn continues to be a more challenging system. Even in conventional farming, however, the major benefits of no-till production relate to soil and water conservation as opposed to yield advantages (Schillinger et al. 2007). As described in the long-term organic no-till crop rotation experiment in Boone, Iowa, economic benefits could be obtained from soil carbon enhancement and greenhouse gas reduction in the organic reduced-till systems (Singerman et al. 2011) when Clean Energy legislation and carbon markets support such practices in the future.

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Table 1. Corn plant performance in the No-till Organic Corn experiment, Neely-Kinyon Farm, 2010-2011.

Treatment	Corn borer damage (%)	Corn borer presence (%)	Corn stand (plants/acre)	Corn height (inches)	Silage biomass (tons/ac)
2010					
Tilled					
Austrian winter pea	13.75	20.00	26,250	64.69	27.93
Hairy vetch	15.00	15.00	27,500	63.43	25.76
Rye	11.75	10.00	27,000	61.06	22.34
Rye/hairy vetch	18.75	20.00	26,875	65.79	22.08
Winter triticale	10.00	5.00	28,500	65.85	22.99
Control	10.00	10.00	29,000	64.84	25.95
$LSD_{0.05}$	NS [z]	NS	NS	NS	NS
No-Till					
Austrian winter pea	7.50ab	5.00	29,125	33.35bc	4.96b
Hairy vetch	22.50a	20.00	26,750	45.71a	9.30a
Rye	2.50b	0.00	29,500	29.15c	4.98b
Rye/hairy vetch	5.00b	15.00	28,000	33.50bc	6.11ab
Winter triticale	8.75ab	15.00	29,875	32.91bc	5.14b
Control	22.50a	10.00	30,000	37.05b	8.68a
$LSD_{0.05}$	15.73	NS	NS	5.64	3.46
Significance of interaction (p value: tillage x cover crop)	NS	NS	NS	0.0011	NS

2011	Corn borer damage (%)	Corn borer presence (%)	Corn stand (plants/acre)	Corn height (inches)	Grain yield (bu/ac)	Silage Biomass (tons/ac)	Soil NO_3-N (ppm)	SPAD reading
Tilled								
Austrian winter pea	0.00	0.00	32,250a	56.26a	123.26a	---	5.0	37.65ab
Hairy vetch	0.00	0.00	28,833ab	55.16a	118.36a	---	5.5	36.05bc
Rye	0.00	0.08	22,583c	45.12b	62.32b	---	4.8	30.15cd
Rye/hairy vetch	0.00	0.00	22,917c	45.96b	52.69b	---	2.7	30.49cd
Winter triticale	0.08	0.00	25,167bc	45.06b	57.59b	---	2.6	23.59d
Control	0.08	0.00	31,000a	57.05a	144.32a	---	3.0	43.02a
$LSD_{0.05}$	NS	NS	3,756	4.10	39.17	---	NS	6.55
No-Till								
Austrian winter pea	0.00	0.00	30,500ab	33.37ab	---	15.36	0.3	29.45a
Hairy vetch	0.00	0.00	28,167bc	32.34b	---	12.35	1.3	24.85abc
Rye	0.17	0.00	32,833a	34.88ab	---	12.79	1.3	23.92bc
Rye/hairy vetch	0.25	0.00	27,917bc	35.51a	---	13.52	0.5	22.18c
Winter triticale	0.08	0.00	30,083ab	28.43c	---	11.98	1.1	28.16ab
Control	0.17	0.00	25,231c	33.09ab	---	14.01	0.3	23.90bc
$LSD_{0.05}$	NS	NS	3,895	2.62	---	NS	NS	4.68
Significance of interaction (p value: tillage x cover crop)	NS	NS	NS	NS	---	NS	NS	<0.0001

[z] Means within a column are not significantly different (NS), or significantly different at $p \le 0.05$ (Fisher's protected LSD test).

Table 2. Weed parameters in the No-till Organic Corn experiment, Neely-Kinyon Farm, 2010-2011.

Treatment	Weeds (plants/ft²) Fall	Weeds (plants/ft²) Spring	Grass weeds (plants /ft²)	Grass weed ground cover (%)	Broadleaf weeds (plants/ft²)	Broadleaf weed ground cover (%)
2010	19 Oct. 2009	19 April	5 Aug.	5 Aug.	5 Aug.	5 Aug.
Tilled						
Austrian winter pea	3.20b[z]	1.40b	0.00	---	7.75b	---
Hairy vetch	3.10b	0.85ab	0.00	---	11.75b	---
Rye	2.60b	0.00c	0.00	---	30.38a	---
Rye/hairy vetch	3.15b	0.10c	0.00	---	5.50b	---
Winter triticale	2.75b	0.00c	0.00	---	13.63b	---
Control	4.90a	2.35a	0.00	---	2.75b	---
LSD $_{0.05}$	1.43	0.92	NS	---	14.58	---
No-Till						
Austrian winter pea	1.25bc	2.45a	---	29.25	---	80.38a
Hairy vetch	2.50ab	0.00b	---	18.38	---	38.75bc
Rye	0.80c	0.00b	---	14.38	---	19.00de
Rye/hairy vetch	0.60c	0.00b	---	1.50	---	25.25cd
Winter triticale	0.80c	0.00b	---	7.88	---	42.50b
Control	3.50a	1.50a	---	4.00	---	7.13e
LSD $_{0.05}$	1.51	1.23	---	NS	---	16.62
Significance of interaction (p value: tillage x cover crop)	NS	NS	---	---	---	---

	Grass (plants/ft²)	Broadleaves (plants/ft²)
2011	29 June	29 June
Tilled		
Austrian winter pea	8.03	1.40bc
Hairy vetch	7.90	2.18ab
Rye	4.07	0.90c
Rye/hairy vetch	9.29	1.54bc
Winter triticale	4.36	1.94bc
Control	11.53	3.20a
LSD $_{0.05}$	NS	1.19
No-Till		
Austrian winter pea	0.88c	2.18a
Hairy vetch	1.94b	1.13bc
Rye	0.27cd	0.11d
Rye/hairy vetch	0.04d	0.20d
Winter triticale	0.09cd	0.33cd
Control	2.77a	1.87ab
LSD $_{0.05}$	0.82	0.82
Significance of interaction (p value: tillage x cover crop)	NS	0.0174

[z]Means within a column are not significantly different (NS), or significantly different at $p \leq 0.05$ (Fisher's protected LSD test).

Table 3. Cover crop and weed parameters in the No-till Organic Corn experiment, Neely-Kinyon Farm, 2010.

Treatment	Cover crop height (in)	Cover crop stand (plants/ft^2)	Cover crop stand (plants/ft^2)	Weed biomass in cover crop (g/ft^2)		
				Annual grasses	Annual broadleaves	Perennial broadleaves
2010	19 April	19 Oct. 2009	19 April		27 May	
Conventional Tillage						
Austrian winter pea	12.95d[z]	7.20d	3.80c	---	---	---
Hairy vetch	20.57c	9.70c	10.95b	---	---	---
Rye	44.00a	29.50a	24.00a	---	---	---
Rye/hairy vetch	30.80b	22.80b	22.90a	---	---	---
Winter triticale	37.46a	28.55a	24.35a	---	---	---
Control	0.00	0.00e	0.00d	---	---	---
$LSD_{0.05}$	5.85	2.36	2.15	---	---	---
No-Till						
Austrian winter pea	12.83c	8.30b	2.35d	0.33b	1.57	2.24ab
Hairy vetch	18.44c	9.25b	10.45c	0.00b	0.00	0.00b
Rye	42.20a	26.40a	21.85ab	0.00b	0.00	0.00b
Rye/hairy vetch	28.33b	23.75a	20.10b	0.00b	0.00	0.00b
Winter triticale	36.36a	26.45a	22.70a	0.00b	0.00	0.00b
Control	0.00d	0.00c	0.00d	3.77a	1.34	5.41a
$LSD_{0.05}$	5.33	3.17	2.51	1.15	NS	3.06
Significance of interaction (p value: tillage x cover crop)	NS	NS	NS	---	---	---

[z]Means within a column are not significantly different (NS), or significantly different at $p \leq 0.05$ (Fisher's protected LSD test).

Table 4. Cover crop performance in the No-till Organic Corn experiment, Neely-Kinyon Farm, 2010-2011.

Treatment	Biomass (ton/acre)	Total cover (%)		
2010				
Tilled				
Austrian winter pea	---	25.00c[z]		
Hairy vetch	---	63.00b		
Rye	---	92.50a		
Rye/hairy vetch	---	55.63b		
Winter triticale	---	100.00a		
Control	---	---		
LSD $_{0.05}$	---	17.22		
No-Till				
Austrian winter pea	0.94b	15.75c		
Hairy vetch	1.53b	83.75a		
Rye	3.53a	100.00a		
Rye/hairy vetch	3.26a	55.00b		
Winter triticale	3.70a	100.00a		
Control	---	---		
LSD $_{0.05}$	0.76	15.60		
Significance of interaction (p value: tillage x cover crop)	---	NS		
	Biomass (ton/acre)	**Cover crop cover (%)**	**Weed cover (%)**	**Bare ground (%)**
2011				
Tilled				
Austrian winter pea	0.10c	57.92b	9.92b	32.17b
Hairy vetch	0.54b	33.33c	14.17ab	52.50a
Rye	1.63a	99.67a	0.33c	0.00c
Rye/hairy vetch	1.67a	99.92a	0.08c	0.00c
Winter triticale	1.39a	99.42a	0.58c	0.00c
Control	---	22.50c	20.83a	56.67a
LSD $_{0.05}$	0.004	15.78	7.27	15.70
No-Till				
Austrian winter pea	0.18b	55.42b	20.00b	24.58b
Hairy vetch	0.07b	23.75c	20.00b	56.25a
Rye	1.80a	99.92a	0.08c	0.00c
Rye/hairy vetch	1.57a	99.75a	0.25c	0.00c
Winter triticale	1.55a	99.33a	0.67c	0.00c
Control	---	----	45.00a	55.00a
LSD $_{0.05}$	0.25	6.87	9.71	10.82
Significance of interaction (p value: tillage x cover crop)	0.0392	NS	0.0004	NS

[z]Means within a column are not significantly different (NS), or significantly different at $p \leq 0.05$ (Fisher's protected LSD test).

Table 5. Cover crop nutrient content and post-rolling cover crop re-growth in the Organic No-Till Corn experiment, Neely-Kinyon Farm, 2011.

Treatment	Carbon (%)	Nitrogen (%)	Cover crop regrowth after cutting (%)
2011			
Conventional Tillage			
Austrian winter pea	43.80	4.09a[z]	N/A
Hairy vetch	41.41	3.31a	N/A
Rye	42.36	1.94b	N/A
Rye/hairy vetch	40.53	2.30b	N/A
Winter triticale	41.68	2.06b	N/A
Control	N/A	N/A	N/A
$LSD_{0.05}$	NS	0.73	N/A
No-Till			
Austrian winter pea	40.86b	4.48a	97a
Hairy vetch	39.61c	5.01a	100.a
Rye	42.48a	1.84b	9b
Rye/hairy vetch	41.09b	2.07b	7b
Winter triticale	42.43a	1.90b	7b
Control	N/A	N/A	---
$LSD_{0.05}$	0.79	0.19	4.4
Significance of interaction (p value: tillage x cover crop)	0.0990	0.0002*	N/A

[z]Means within a column are not significantly different (NS), or significantly different at $p \leq 0.05$ (Fisher's protected LSD test).

Table 6. Soil fertility parameters in the Organic No-Till Corn experiment, Neely-Kinyon Farm, 2010–2011.

Treatment	Ca (ppm)	Mg (ppm)	K (ppm)	Bray P (ppm)	pH	NH_4 (ppm)	NO_3^-N (ppm)	Total N (%)	Total C (%)	Org. matter (%)
2010										
Tilled										
Austrian winter pea	4913.0	340.0	212.3	48.75	7.44	0.40	3.03	0.24	2.39	4.35
Hairy vetch	4158.5	344.0	207.5	53.25	7.34	0.58	3.73	0.24	2.57	4.70
Rye	3599.8	342.0	180.3	35.25	7.34	0.60	2.43	0.24	2.41	4.38
Rye/hairy vetch	4288.8	329.0	244.8	48.50	7.29	0.48	2.38	0.23	2.43	4.45
Winter triticale	4302.0	330.0	243.5	58.50	7.26	0.60	3.35	0.25	2.55	4.68
Control	3948.5	324.0	194.8	33.00	7.16	0.38	2.63	0.23	2.46	4.50
$LSD_{0.05}$	NS[z]	NS	NS	NS	NS	NS	NS	NS	NS	NS
No-Till										
Austrian winter pea	4664.5	373.8	233.3	51.50	7.29	1.10	1.35	0.25a	2.43a	4.45a
Hairy vetch	4747.8	379.0	198.0	41.00	7.33	1.43	1.68	0.24a	2.40ab	4.38ab
Rye	4208.3	394.8	211.3	38.25	7.38	1.18	0.83	0.23b	2.35bc	4.30b
Rye/hairy vetch	4643.5	360.8	203.3	41.75	7.44	1.08	1.08	0.24ab	2.38ab	4.35ab
Winter triticale	4606.5	364.8	245.8	63.50	7.35	0.98	1.05	0.24a	2.40ab	4.40ab
Control	4648.3	398.8	188.5	39.00	7.16	1.38	0.95	0.23b	2.29c	4.15c
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS	0.01	0.08	0.15
Significance of interaction (p value: tillage x cover crop)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2011										
Tilled										
Austrian winter pea	28.75	334.00	239.5	59.50	---	2.88	2.68	0.18	2.43	4.45
Hairy vetch	21.75	354.75	244.8	59.75	---	3.65	2.48	0.18	2.36	4.30
Rye	22.25	339.75	251.8	52.00	---	2.45	2.03	0.19	2.52	4.60
Rye/hairy vetch	35.50	339.25	260.0	55.00	---	2.60	2.35	0.19	2.46	4.53
Winter triticale	21.75	368.75	276.0	60.50	---	2.63	2.08	0.19	2.50	4.55
Control	17.50	338.75	231.5	56.75	---	2.83	2.63	0.18	2.39	4.35
$LSD_{0.05}$	NS	NS	NS	NS	---	NS	NS	NS	NS	NS
No-Till										
Austrian winter pea	15.00	323.50	278.3a	56.50	---	2.53	4.43a	0.17	2.67	4.85
Hairy vetch	16.00	349.75	279.8a	55.25	---	2.95	3.60ab	0.18	2.63	4.80
Rye	19.00	366.50	270.5a	54.25	---	3.45	1.90c	0.17	2.58	4.70
Rye/hairy vetch	18.25	330.75	255.3ab	53.00	---	2.88	2.30bc	0.23	2.73	4.98
Winter triticale	22.25	335.50	215.3b	43.25	---	2.68	1.65c	0.18	2.76	5.05
Control	21.00	354.25	251.3ab	51.00	---	2.75	3.48ab	0.17	2.76	5.00
$LSD_{0.05}$	NS	NS	42.8	NS	---	NS	1.38	NS	NS	NS
Significance of interaction (p value: tillage x cover crop)	NS	NS	0.0250*	NS	N/A	NS	NS	NS	NS	NS

[z]Means within a column are not significantly different (NS), or significantly different at $p \leq 0.05$ (Fisher's protected LSD test).

Table 7. Corn grain quality in the No-till Organic Corn project, Neely-Kinyon Farm, 2011.

Treatment	Moisture (%)	Protein (%)	Oil (%)	Starch (%)	Density (g/cc)	Ethanol Yield (gal/bu)
2011						
Tilled						
Austrian winter pea	23.06	6.93	3.51	61.60	1.25	2.91
Hairy vetch	22.90	7.40	3.58	61.34	1.26	2.93
Rye	22.49	6.91	3.36	61.91	1.25	2.92
Rye/hairy vetch	23.33	7.18	3.45	61.60	1.26	2.90
Winter triticale	22.38	7.10	3.48	61.55	1.25	2.94
Control	21.06	7.04	3.43	61.68	1.26	2.91
$LSD_{0.05}$	NS[z]	NS	NS	NS	NS	NS

[z]Means within a column are not significantly different (NS), or significantly different at $p \leq 0.05$ (Fisher's protected LSD test).

ACKNOWLEDGEMNENTS

First, I would like to thank my Program of Study Committee members. I would not have been able to accomplish what I completed without the constant guidance and support of Dr. Cindy Cambardella, Dr. Michael Duffy and especially my Major Professor, Dr. Kathleen Delate. Without the mentoring of Dr. Delate, this thesis would not have been completed during my most difficult times. I would like to extend a special thanks to my wife Michelle for her support and assistance in this project, my mother Mary for her encouragement to complete my graduate degree, and especially to my father Gary, who instilled in me a love for organic agriculture and the mindset to think outside of the box and to always experiment with new ideas.

I would also like to acknowledge the hard work of my numerous colleagues and lab mates throughout my two-and-a-half years at Iowa State University. I owe a tremendous debt to Vivian Bernau, Jon Brunsvold, Jared Flater, James Nguyen, Sean Gao, Hang Qian, Jake Petersen, Evan Duyvejonck, Ning Wang, Ben Offenberger, Ryan Rice and Andrea McKern of Iowa State University. I would also like to thank Jeff Butler, Bernie Havlovic, Randy Breach and Kirk Schwarte of the Armstrong Farm at Iowa State University and Mike Fiscus and Will Emley of the Agronomy Farm at Iowa State University for their fieldwork with the experiments. Additional support was provided by Charles Sauer of the Graduate Program in Sustainable Agriculture and Jaci Seversen of the ISU Agronomy Department.

For funding support, I would like to acknowledge Patrick Carr, North Dakota State University and the USDA-NCR-SARE Program, the USDA-CSREES Integrated Organic Program, the Leopold Center for Sustainable Agriculture and The Rodale Institute for their support of the Organic No–Till project. Thanks also go to Maury Johnson and Scott Ausborn of

Blue River Hybrids in Kelley, Iowa, for supplying the corn and soybean seed, and to Albert Lea Seedhouse in Albert Lea, Minnesota, for oat and cover crop seed.