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Effects of cover crops and tillage in a muskmelon production system

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Effects of cover crops and tillage in a muskmelon production system

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The student and the program of study committee are solely responsible for the content of this thesis. The Graduate College will ensure this thesis is globally accessible and will not permit alterations after a degree is conferred.

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DEDICATION

I dedicate this thesis to Rachel. Whose presence in my life compelled me to begin, and whose love, grace, and support saw me through until the very end.

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ABSTRACT

Most muskmelon (*Cucumis melo* L.) production in the upper Midwest relies on intensive tillage and plasticulture. An alternative system starts with the use of a roller-crimper to terminate winter cover crops, thus forming a thick organic mulch. Then, all tillage performed is restricted to a narrow strip in which muskmelons are transplanted. Cover crops and strip-tillage can increase soil health, suppress weeds, and improve net profitability. Muskmelons are an important crop for vegetable growers and are among the top consumed produce items in the U.S. Foodborne illness outbreaks of *Salmonella* and *Listeria monocytogenes* associated with muskmelon consumption have resulted in consumer fatalities, and negatively impacted the livelihood of producers.

A study was carried out over two seasons (2014-15 and 2015-16) to assess the effect of cover crops and tillage on the performance of muskmelon production. Data was collected on cover crop growth, soil temperature, soil moisture, weed biomass, the concentration of nitrate-nitrogen in leachate, soil nutrient concentrations, muskmelon plant growth, soil microbial biomass carbon, soil microbial functional diversity, muskmelon yield, net profitability, and fruit quality. Our goal was to take a comprehensive view of the differences between the use of cover crops [no cover, cereal rye (*Secale cereale* L.), and cereal rye-hairy vetch (*Vicia villosa* Roth)] with conventional tillage and strip-tillage. We also assessed how treatments would affect the survival of soilborne *Listeria innocua*, a non-pathogenic surrogate for the human pathogen *L. monocytogenes*, either applied near the time of cover crop planting or near cover crop termination. We hypothesized that cover crop based ST would increase soil moisture, reduce weed biomass, reduce nitrate-nitrogen leaching, increase soil microbial biomass carbon, increase microbial functional diversity, and fruit

quality, without sacrificing yield or net profitability. We also tested the hypothesis that cover crop mulch would prevent the contamination of muskmelon fruits by soilborne *L. innocua*.

In one year, the earlier termination of cover crops in conventional tillage plots and also the use of a rye-vetch biculture lowered the C:N ratio of cover crop biomass. Cover crops and strip-tillage did reduce weed biomass, though not consistently over both years. In-row soil moisture was higher in strip-tillage, and in-row soil temperature was higher in conventional tillage. Strip-tillage occasionally reduced the concentration of NO_3^--N in leachate, this effect was inconsistent and only observed at a few sampling dates for only one year of the study. Rye-CT increased microbial biomass carbon over no cover-CT. During one year of the study, microbial functional diversity increased in rye and rye-vetch plots. The proportion of fruits that were marketable was increased under strip-tillage, as were several measures of fruit quality, but only in 2016. Populations of *L. innocua* introduced to the field in Oct. were able to overwinter and were detected the following May. The survival of May-applied *L. innocua* was measured in the first year of the study and showed that populations were reduced under both rye and rye-vetch cover crops. Treatments had no effect on the contamination of fruits at harvest. An economic analysis had mixed results, no cover strip-till plots had the lowest profit in both years, and rye strip-tillage and rye-vetch strip-tillage out performed their respective conventional tillage treatments in one year.

CHAPTER 1. GENERAL INTRODUCTION AND THESIS ORGANIZATION

The muskmelon (*Cucumis melo* L. reticulatus group) is an orange-flesh, odorous, fruit with a reticulated (netted) rind. This crop is often referred to as cantaloupe, but this is a misnomer. True cantaloupes belong to the group cantalupensis and are rarely grown in the U.S. From 1985-2015 annual muskmelon sales averaged $305 million; in 2015 21,882 ha. of this crop was harvested, with a total weight of 607,905 Mg (USDA-ERS, 2016).

Because Iowa and much of the upper-Midwest have a relatively short growing season, vegetable production systems which maximize soil temperature are beneficial to growers. Using conventional tillage (e.g. plowing, disking, rototilling) to prepare fields, and install black plastic mulch (i.e. plasticulture) is common for muskmelon production. Solar radiation intercepted by the black plastic mulch warms the soil, and the polyethylene mulch insulates the warmed soil. Plasticulture has been shown to increase yield in Iowa over bare-ground conventional tillage (Taber, 1993). Plasticulture can allow for earlier yields, which gives growers access to higher early-season price premiums.

Muskmelons prefer warm conditions, reduced root zone temperature decreases biomass accumulation in muskmelon seedlings (Klock et al., 1996). A greenhouse study found that content of P, Zn, and Mn, as well as the biomass of young muskmelon plants, increased linearly with increasing root zone temperatures, maximum biomass and nutrient content were observed at 36 °C (Stoltzfus et al., 1998).

Though conventional tillage and plasticulture have served vegetable producers well, concerns over soil health, erosion, plastic mulch disposal, and agriculture-derived water pollution has spurred interest in reduced tillage. Conventional tillage can increase soil erosion and reduce indicators of soil health such as aggregation and microbial biomass (Montgomery, 2007, Roper et al., 2010) Plastic mulches used in horticultural crop production are primarily disposed of by incineration or are sent to a landfill (Hemphill, 1993).

Reduced tillage is a broad term that describes tillage practices which minimize soil disturbance and leave a partial cover of crop residue on the surface. Both no-tillage and strip-tillage are considered reduced tillage practices. For agronomic and vegetable production, reduced tillage has the potential to increase profitability over conventional tillage (Jackson et al., 2004, Sijtsma et al., 1998, Zentner et al., 2002). Perhaps the greatest opportunity for producers to increase profits in reduced tillage systems is by maintaining adequate yields while reducing input costs. Multiple tractor passes across the field are necessary to perform conventional tillage and to install plastic mulch, reduced tillage can limit equipment and fuel costs (Jackson et al., 2004). Though not always the case, it is possible for reduced tillage systems to have disease, weed, and insects suppressive characteristics (Sturz et al., 1997, Jackson et al., 2004), potentially limiting costs associated with weeding and spraying.

Most reduced tillage systems produce agronomic row crops and depend on herbicides to control weeds and to terminate cover crops, whereas vegetable growers are more limited in their herbicide management decisions. In the United States reduced

tillage is widely practiced in agronomic row crops, though in vegetable production systems, adoption remains low for multiple reasons.

First, there is no economically feasible technology or method we are aware of which allows growers to integrate plasticulture into reduced tillage systems, and capture the benefits from early season soil warming. The potential loss of earliness deters the widespread adoption of reduced tillage among vegetable producers (Walters, 2011).

The lack of effective weed management tools also deters vegetable growers from adopting reduced tillage (Walters, 2011). In contrast, agronomic crop producers can easily use reduced tillage because of the availability of herbicide-resistant crop varieties (Givens et al., 2009). Similar herbicide resistance for vegetable crops is largely unavailable. Vegetable grower practicing reduced tillage cannot always apply a broad-spectrum herbicide after crop emergence as many agronomic crop producers can. In fact, most vegetable crops lack either pre-emergence or post-emergence herbicides that provide broad-spectrum weed control (Duke, 1995). Further complicating vegetable grower's reliance on chemical weed control is the heterogeneous nature of herbicide sensitivity among different vegetable crops. For example, a study by Greenland (2003) showed that cabbage (*Brassica oleracea* L.), squash (*Cucurbita pepo* L.), onion (*Allium fistulosum* L.), and tomatoes (*Lycopersicon esculentum* Mill) showed injury from herbicide applied in the previous year, whereas potato (*Solanum tuberosum* L.) and carrot (*Daucus carota* L.) were unaffected.

Finally, the lack of specialized tillage and planting equipment for reduced-tillage vegetable crops remains a barrier to adoption (Luna et al., 2012, Mitchell et al., 2007). Agronomic systems tend to rely on only a few crop species compared to those producing

vegetable crops (Padgitt et al., 2000). A less diverse cropping system allows agronomic row crop growers to use similar equipment and practices for all crops (McPhee et al., 2015).

Herbicides are commonly used in reduced tillage systems to terminate cover crops before planting. Avoiding potential economic costs, potential human health risks and possible environmental harm associated with herbicide use is desirable for many growers. An alternative method of cover crop termination is the use a roller-crimper, a tractor mounted implement that rolls over the cover crop and crimps the stem at several points, rupturing vascular tissue. The roller-crimper terminates cover crops without uprooting or severing the plants, thus creating an organic mulch that can stay in place during the growing season.

Cereal rye (*Secale cereale* L.) and hairy vetch (*Vicia villosa* Roth) are commonly used cover crops in Iowa. When planted in the fall both will effectively overwinter and commence growth in the spring. After planting, rye establishes quickly and can provide complete groundcover over winter, and achieves high biomass production through rapid early-season growth. As rye approaches anthesis, total C increases, and N concentration decreases as a result of a dilution effect (Wagger, 1989). The result is a higher C:N ratio that can decrease net N mineralization and reduce N available to subsequent crops (Alonso-Ayuso et al., 2014). When cover crop residue with a high C:N (>32) begins to decompose in the soil, inorganic N may be allocated to microbes thus "immobilizing" soil N and making it temporarily unavailable for plant uptake (Quemada and Cabrera, 1995). Allowing rye and vetch to grow beyond their optimum stages for roller-crimper termination (anthesis and early-pod stage respectively) is unlikely to have an effect on

percent kill, though continued growth increases the likelihood of non-desirable seed formation and dispersal within the field.

Listeria monocytogenes is a rod-shaped, gram-positive, non-spore forming, bacterial pathogen (Farber and Peterkin, 1991). Infection by *L. monocytogenes* causes listeriosis, a potentially fatal condition especially for the very young, the elderly, and those who are immunocompromised (Ramaswamy et al., 2007). Though commonly associated with ready-to-eat meat and unpasteurized dairy products, contaminated muskmelon and other produce items have been the causal agent for outbreaks of *L. monocytogenes* in the past. For example, a 2011 outbreak of contaminated muskmelons originating from a farm in Colorado caused 147 illnesses, 33 fatalities and one miscarriage (CDC, 2011, McCollum et al., 2013). Highlighting the risk to producers is the fact that the owner-operators of the farm faced both civil and criminal charges for their role in the outbreak and eventually filed for bankruptcy (Booth and Brown, 2013).

Previous research has focused on understanding and controlling for contamination of muskmelons post-harvest (Svoboda et al., 2016, Ukuku et al., 2004, Ukuku and Fett, 2002, Behrsing et al., 2003, Duckson, 2014). Little work has been done on understanding in-field contamination of muskmelon and other fresh produce items.

Capable of functioning as a saprophyte, *L. monocytogenes* is ubiquitous in the environment and has been found in agricultural soils (Locatelli et al., 2013, McLaughlin et al., 2011, Dowe et al., 1997, Welshimer, 1960). Because muskmelons are in contact with the soil surface throughout the growing season, are consumed raw, and have a textured exterior which hinders the detachment of soil and microorganisms, they are a

possible carrier of foodborne illness. Using rolled cover crop mulches may limit fruit contact with the soil, and prevent contamination.

Field trials were conducted and replicated over two seasons (2014-15 and 2015-16) to assess the effect of cover crops (no cover, rye, and rye-vetch) and tillage (conventional tillage and strip-tillage) on the performance of a muskmelon production. Data was collected on cover crop growth, soil temperature, soil moisture, weed biomass, the concentration of nitrate-nitrogen in leachate, soil nutrient concentration, muskmelon plant growth, soil microbial biomass carbon, soil microbial functional diversity, muskmelon yield, net profitability, and fruit quality. We sought to gain a holistic understanding of how cover crop and tillage affected the agricultural components of the system. We also assessed how treatments would affect the survival of soilborne *Listeria innocua*, a non-pathogenic surrogate for the human pathogen *L. monocytogenes*, applied near the time of cover crop planting and again near cover crop termination.

I have organized this thesis into four chapters. Chapter 2 is an assessment of the study as an agroecosystem and reports data such as plant growth, soil physical and chemical characteristic, soil biology, nitrate-nitrogen leaching, and marketable yield. Chapter 2 focuses on the data which would be of more direct concern to growers and consumers of muskmelons: marketable yield, fruit physical characteristics, fruit quality, survival of soilborne *L. innocua*, the incidence of fruit contamination by *L. innocua*, and net profitability. In chapter 4 I will present a conclusion to my thesis and highlight needs for future research.

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Fig. 1.1. Cereal rye and hairy vetch biculture at the Horticulture Research Station in Ames, IA on 9 May 2016.

Fig. 1.2. Muskmelons planted into roller crimped cereal rye at the Horticulture Research Station in Ames, IA on 8 July 2016.

CHAPTER 2. EFFECTS OF COVER CROP BASED STRIP-TILLAGE ON PLANT GROWTH AND SOIL PROPERTIES IN A MUSKMELON PRODUCTION SYSTEM

Modified from a paper to be submitted to *Soil and Tillage Research*

John Krzton-Presson[1], Ajay Nair[2], and Cynthia Cambardella[3]

Abstract

Diminished soil health, herbicide resistant weeds, increasingly erratic climate patterns, and contamination of waterways by agricultural nitrate (NO_3^-) have prompted interest in reduced tillage and cover crops in the Midwest. The roller-crimper crushes cover crops forming an organic mulch layer capable of weed suppression, and may spur adoption of reduced tillage for vegetable production. A study was carried out over the course of two growing seasons (2014-15 and 2015-16) in Ames, IA, USA using a split-plot design with four replications. The whole plot factor was cover crop [no cover, cereal rye (*Secale cereale* L. 'Wheeler'), and cereal rye-hairy vetch (*Vicia villosa* Roth 'Purple Bounty'), the split-plot factor was tillage [conventional tillage (CT) and strip-tillage (ST)]. This experiment was designed to compare the effects of different tillage and cover crops practices on weed biomass, soil temperature, soil moisture, soil fertility, plant growth, NO_3^--N leaching, marketable yield of muskmelons, soil microbial biomass carbon, and soil microbial functional diversity. The C:N ratio of the rye-vetch biculture biomass was lower than rye

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only in 2016. In 2016 no cover-ST had the greatest weed biomass. In 2015 weed biomass was unaffected by cover crops but was higher under CT. Soil moisture was generally greater in ST, whereas CT often had greater soil temperatures and soil inorganic N. Plant growth was generally greater under CT, with greater vine length in both years, and higher SPAD and petiole sap NO_3^--N values in 2016. During both years CT plots produced significantly greater marketable yield. Concentrations of NO_3^--N in leachate were often unaffected by treatments. In both years soil microbial biomass carbon in cereal rye-CT plots was consistently than no cover-CT plots. In 2016 soil microbial functional diversity was higher in rye and rye-vetch treatments than in no cover. Though weed biomass for cereal rye-ST and cereal rye-hairy vetch-ST was low in both years, compared to other treatments weed biomass was not consistently reduced. Reduced yield for ST- possibly as a result of limited N and lower soil temperature- will likely continue to be a challenge for ST muskmelon production.

Introduction

For decades, producers of muskmelon (*Cucumis melo* L.) and other vegetables (i.e. annual horticultural food crops) have depended on conventional tillage (CT; e.g. plowing, disking, rototilling) to incorporate surface residue, control weeds, and to establish a finely textured seedbed for planting. Soil inversion and burying of surface residue are characteristic of CT. As a result of greater exposure and less cover, soil temperature increases more quickly under CT (Johnson and Lowery, 1985), by encouraging drying near the surface (Erbach et al., 1992, Fortin, 1993). During the cool, wet springs typical of the upper Midwest (North Central U.S.) absence of surface residue could create seedbed conditions favorable for direct-seeding or transplanting of vegetable crops, promote early growth, and

require fewer days until harvest. Additionally, loose soil conditions as a result of CT permit vegetable growers to utilize plasticulture, the covering of soil with polyethylene plastic mulch. Plasticulture can regulate soil moisture, aid in-row (IR) weed control, increase IR soil, and root zone temperature (Lamont, 2005). Some crops perform poorly in cool conditions and many growers find that muskmelon is well-suited for plasticulture systems. Plastic mulch can increase muskmelon yield in CT systems (Ibarra et al., 2001, Taber, 1993).

Despite the benefits of CT, in recent years producers have become more aware of the non-desirable aspects of CT and are interested in modifying tillage practices to improve agricultural sustainability, without excessively sacrificing yield. An alternative to CT is reduced tillage (e.g. no-till, strip-till), that describes a set of tillage practices that minimize soil disturbance and leaves a partial cover of crop residue in place. Previous studies have shown that CT can have more detrimental effects on soil health and many ecosystem services than reduced tillage: reduction of microbial biomass, total soil C, and aggregation (Roper et al., 2010), reduced water infiltration rate (Abid and Lal, 2009), increased NO_3^--N leaching (Hansen and Djurhuus, 1997), and increased soil erosion (Montgomery, 2007). One form of reduced tillage, strip-tillage (ST), has been proposed as a way of capturing the desirable conservation and agronomic aspects of no-till systems while simultaneously benefiting from loose seedbed conditions and increased soil temperature in the IR area, similar to CT. Under ST, residue removal and soil disturbance are restricted to a narrow strip where the crops are planted, and the remainder of the field is left undisturbed. This strip of tilled soil is typically 15 - 30 cm wide, and tillage usually covers no more than 25% of the entire field.

Weed control continues to be a challenge for ST vegetable production. For many vegetable growers, CT is an important part of their weed management strategy because

tillage terminates weeds across the whole field before planting. For this reason, most ST systems depend largely on herbicide for weed control (Morrison, 2002). Avoiding economic costs, human health risks, and environmental harm potentially associated with herbicide use is desirable for many growers. In ST systems, because tillage is restricted to the IR area, weeds can thrive in the untilled between-row (BR) area. As an alternative to depending on intensive chemical weed control across the entire field in ST systems, integration of cover crops allows growers to manage weeds in the untilled BR area by leaving cover crop residue on the soil surface after termination. Herbicides are also commonly used in reduced tillage systems to terminate cover crops before planting. An alternative method of cover crop termination is the use a roller-crimper, a tractor mounted implement that rolls over the cover crop and crimps the stem at several points, rupturing vascular tissue. The roller-crimper terminates cover crops without uprooting or severing the plants, thus creating an organic mulch that can stay in place during the growing season. Using a roller-crimper to terminate cereal rye (hereupon referred to as rye; *Secale cereal*e L.) at anthesis has been shown to be as effective as herbicide termination (Ashford and Reeves, 2003). Cover crop dry weight biomass ≥ 8 Mg·ha^{-1} is capable of suppressing annual weed germination (Mirsky et al., 2013), making the roller-crimper a compatible tool for reducing herbicide use in ST vegetable production systems. Roller-crimper termination of winter cover crops can lower weed density for reduced tillage vegetable production (Leavitt et al., 2011).

Both rye and hairy vetch (hereupon referred to as vetch; *Vicia villosa* Roth) are commonly used winter annual cover crops in roller-crimper systems. A roller-crimper can effectively kill rye at anthesis (Ashford and Reeves, 2003), and vetch at early-pod stage (Mischler et al., 2010). After planting, rye establishes quickly, providing complete

groundcover during winter, and achieves high biomass production through rapid early-season growth the following spring. As rye approaches anthesis total C content increases, and N concentration decreases as a result of a dilution effect (Wagger, 1989). The result is a higher C:N ratio that can decrease net N mineralization and reduce N available to subsequent crops (Alonso-Ayuso et al., 2014). To address the potential for N immobilization in rye monocultures, using a rye-vetch biculture has been proposed (Ranells and Wagger, 1996). The C:N ratio of the rye-vetch biculture can be lower compared to a rye monoculture, as a result of the contribution of atmospherically fixed N accumulated in the leguminous vetch tissue. The desired result of cereal-legume cover crop biculture is increased N availability to the subsequent crop.

Previous research on yields using ST for vegetable production has varied, though in several vegetable crops ST has produced higher yields than CT : carrot [*Daucus carota* L. (Brainard and Noyes, 2012)], cabbage [*Brassica oleracea* L. (Haramoto and Brainard, 2012)], pepper [*Capsicum annuum* L. (Delate et al., 2008)], pumpkin [*Cucurbita pepo* L. (Rapp et al., 2004)], sweet corn [*Zea mays* L. (Luna and Staben, 2002)], and watermelon [*Citrullus lanatus* L. (Leskovar et al., 2016)]. Cover crop based ST requires different farm machinery than CT (i.e. a strip-tiller, a roller-crimper). Because many vegetable growers are diversified, their farm machinery should be effective in the production of multiple crops. Proven efficacy in multiple crop species will be a prerequisite for successful adoption of cover crop based ST. Despite the fact that muskmelon is an important crop for vegetable growers, few studies have examined muskmelon production under ST, and to our knowledge none have compared both roller-crimped rye and rye-vetch. In muskmelon production systems, both Lilley and Sánchez (2016) and Tillman et al. (2015) compared CT with

plasticulture to ST with roller-crimped cover crops, in the former study all treatments used rye-vetch biculture, and in the latter, all treatments used a rye monoculture. In the upper Midwest muskmelon is an important crop for both wholesale and direct market sale. In 2015 muskmelons sales in the U.S. were valued at $261 million (USDA-NASS, 2016). Compared to other vegetable crops muskmelons require high levels of fertility (56-135 $kg \cdot ha.^{-1}$ N), precise irrigation for acceptable growth and yield, and are also sensitive to pH and other soil conditions. Additionally, muskmelon crops in the upper Midwest benefit greatly from the frequent application of pesticides to control foliar diseases and arthropod pests. For these reasons any nuances in growing conditions as a result of cover crop and tillage treatments are likely to manifest in the growth and yield of muskmelon plants.

In this study, we compared, over two years, six different muskmelon production systems, which differ, based on their cover crop and tillage management. The purpose of this study was to evaluate the use of roller-crimped cover crops and ST as an alternative to plasticulture and CT in muskmelon production for the upper Midwest. We sought to better understand how these management tools affected cover crop growth, weed biomass, NO_3^--N leaching, soil moisture, soil temperature, soil nutrient levels, soil biological properties, muskmelon plant growth, and marketable yield. This study took a broad approach to understanding how tillage and cover crops affect a muskmelon production system in the upper Midwest and formed several hypotheses. (1) The use of a rye-vetch cover crop mixture will produce a lower C:N ratio than a rye monoculture, and increase soil inorganic N. (2) Both rolled cover crop mulch treatments (rye-ST and rye-vetch-ST) will have the lowest weed biomass. (3) Both rolled cover crop mulch treatments (rye-ST and rye-vetch-ST) will increase soil moisture and all CT treatments will increase soil temperatures. (4) Levels of

soil inorganic N will be increased under rye-vetch. (5) Cover crops and ST will reduce NO_3^--N leaching. (6) Cover crops and ST will increase soil microbial biomass and soil microbial functional diversity. (7) Muskmelon plant growth and yield will be similar between production systems.

Materials and Methods

Site description

The study was conducted at the Iowa State University Horticulture Research Station in Ames, IA, USA (lat. 42°06'24.4"N long. 93°35'22.5"W) over two growing seasons 2014-15 and 2015-16. Because cover crops needed to be planted before muskmelon harvest had completed, two separate, yet similar sites were used. Soil at both sites was a Clarion Loam, moderately well drained, fine-loamy, Typic Hapludoll on a 2% to 6% slope. At the time of cover crop planting soil at the 2014-15 site had pH ranging from 5.6 to 6.3, and soil organic matter ranging from 2.2% to 2.9% (Table 2.2). Before this study, the 2014-15 site was in a rotation of conventionally managed corn (*Zea mays* L.) and soybeans (*Glycine max* L.). At the time of cover crop planting, soil at the 2015-16 site had pH ranging from 5.1 to 6.5, and soil organic matter ranging from 2.6% to 3.7% (Table 2.2). Before the 2015-16 study, a Persian (Carpathian) walnut (*Juglans regia* L.) trial, removed in 2009, and a rotation of conventionally managed corn and soybeans, from 2009-2014, occupied the site. Sorghum-sudangrass (*Sorghum bicolor* L. × *Sorghum bicolor* L. var. *sudnaese*) cover crop was established in June 2015 and terminated in Aug. 2015 before seeding cover crops for this study in Sept. 2015.

Experimental design

The experimental design was a split-plot design with four replications. The whole-plot factor was cover crop with three levels, no cover, a monoculture of rye 'Wheeler' and a biculture of rye-vetch 'Purple Bounty'. The subplot factor was tillage with two levels, CT and ST. Whole-plot dimensions were 12.2 m × 16.8 m in 2014-15. Whole-plot dimensions were increased to 13.7 m × 16.8 m in 2015-16 to include a 1.5 m drive for equipment between subplots. Each subplot consisted of two 7.6 m long rows spaced 3.0 m apart on-center, plants were spaced 0.6 m apart within the row. Experimental units consisted of 13 muskmelon plants in 7.6 m long rows.

Field implementation

A timeline of field operations is summarized in Table 2.1. On 18 Sept. 2014 and 16 Sept. 2015 the entire field was rototilled with a Terra Force GM102 rotary tiller (Terra Force, Inc., Carrollton, TX). Immediately after tillage cover crops were planted with a 107 cm-wide Gandy drop spreader (Anertec & Gandy Co., Owatonna, MN). For plots in a monoculture, rye was seeded at 123 $kg \cdot ha^{-1}$. Plots in a biculture of rye-vetch were seeded at 100 $kg \cdot ha^{-1}$ and 28 $kg \cdot ha^{-1}$ respectively. Shortly before planting vetch seeds were inoculated in a slurry of deionized water and N-DURE rhizobium inoculant *(Rhizobium leguminosarum* biovar *viceae*, INTX Microbials LLC, Kentland, IN) and allowed to air dry. After seeding, the soil was rototilled to a depth of 5 cm to incorporate seeds, and lightly compacted with a 1.5 m cultipacker to optimize seed to soil contact.

For ST plots a Hiniker 6000 strip-tiller (Hiniker Co., Mankato, MN) was used to terminate cover crops and create a 30 cm-wide strip on 22 Oct. 2014 and 23 Oct. 2015. By tilling strips in the fall, at the early stages of cover crop establishment, the growth of cover

crop in the IR area was reduced. Fall tillage of ST plots increased the efficiency of residue removal from the IR area at the final tillage event in the spring. On 1 June 2015 and 2 June 2016, two weeks before planting when rye was at anthesis, and vetch was at early pod stage, cover crops in ST plots were terminated using a 3.2 m roller crimper (I & J Manufacturing, Gap, PA). Cover crops were rolled a second time one week later to ensure adequate termination. Glyphosate (CropSmart® Glyphosate 41%, Cropsmart LLC., Morrisville NC) was applied to the entire areas of no cover-ST plots on 27 May 2015, and 5 June 5, 2016. This post-emergence, broad-spectrum herbicide was applied to terminate weeds that had grown in the absence of a cover crop while maintaining no-till conditions in the BR area of no cover-ST plots. After glyphosate injury had become visually apparent, entire no cover-ST plots were mowed and sprayed with Clomazone (Command 3ME, FMC Corporation, Philadelphia, PA), a pre-emergence herbicide, on 12 June 2015 and 10 June 2016. The Hiniker 6000 strip-tiller was used to perform the final tillage and create the seedbed for planting for all ST plots on 7 June 2015 and 9 June 2016.

Trickle irrigation was used for all plots, John Deere T-Tape 502-12-220 (John Deere Irrigation, Moline, IL) was placed 10-12cm below the soil surface in all plots. For ST plots, drip-tape was installed by hand on 9 June 2015, and on 9 June 2016 was installed using a custom build implement consisting of a fluted coulter, a shank modified to bury drip-tape followed by closing discs. Clomazone was applied to the exposed soil in the tilled strips of all ST plots on 12 June 2015 and 10 June 2016.

For CT plots, cover crops and overwintering weeds were terminated using a Rhino flail mower (Alamo Group Inc., Seguin, TX) three weeks before planting on 22 May 2015, and 24 May 2016, then immediately incorporated into the soil using a rototiller. The CT

plots were rototilled a second time immediately before the installation of drip-tape and raised beds covered in polyethylene black plastic mulch on 10 June 2015, and 10 June 2016. We used plasticulture on all CT plots.

'Aphrodite' muskmelon seeds treated with Mefenoxam, Thiamethoxam, Azoxystrobin, and Fludioxonil (Syngenta Seeds, Minneapolis, MN) were sown on 21 May 2015, and 10 May 2016, into 72 cell flats filled with LC1 soilless potting mix (Sun Gro Horticulture Canada Ltd, Seba Beach, AB, Canada). Seedlings were fertigated weekly during the first two weeks of growth with a water-soluble fertilizer (17N-5P-16K; J.R. Peters, Inc., Allentown, PA) and then every five days until transplant. Seedlings were moved outdoors seven days before being transplanted into the field; all transplanting was done by hand on 16 June 2015, and 13 June 2016. All plots received an imidacloprid (Admire Pro, Bayer Crop Science, Research Triangle Park, NC) soil drench the day of transplanting to manage emerging striped cucumber beetle (*Acalymma vittata* F.).

Fertility requirements were based on pre-plant soil tests performed at cover crop planting. These values were the basis for determining fertility rates, that were modified from the Midwest Vegetable Production Guide recommendations (Egel et al., 2014). In both years of the study total N requirement was 112 $kg \cdot ha^{-1}$. In 2015 no additional P or K was needed. In 2015 half of the required 112 $kg \cdot ha^{-1}$ of N was applied in the form of water-soluble urea (46N-0P-0K) through drip irrigation one week before planting, and the other half was applied four weeks after planting. A Dosmatic SuperDos 20 (Hydro Systems Company, Cincinnati, OH) water-driven proportional fertilizer injector was used for all fertigation. For each fertigation event N concentrations were 200-300 $mg \cdot L^{-1}$. In 2016 half of the required 112 $kg \cdot ha^{-1}$ of N was applied in the form of granular urea (46N-0P-0K) and all of the required

112 kg·ha^{-1} of P as triple superphosphate (0N-45P-0K). The preplant granular fertilizer was applied by hand after the final tillage, but before installation of plastic mulch in CT and before final strip-tillage in ST. In 2016 the remaining 56 kg·ha^{-1} of N was applied through drip irrigation at 5.6 kg·ha^{-1} N per week for ten weeks, alternating between potassium nitrate (13N-0P-46K) and calcium nitrate (15N-0P-0K). Potassium nitrate fertigations fulfilled K requirements in 2016.

Crops were scouted weekly for signs of arthropod and disease pests. In 2016 the MELCAST disease forecasting system (Latin, 2001) was used to determine the timing of preventative fungicide sprays during the first eight weeks of crop growth in the field. Though the system is suitable for forecasting alternaria leaf blight [*Alternaria cucumerina* (Ellis & Everh.)], anthracnose [*Colletotrichum orbiculare* (Berk. & Mont.)], and gummy stem blight [*Didymella bryoniae* (Auersw.)], it is ill-suited for diseases that are typically a problem late in the season and near harvest such as downy mildew [*Pseudoperonospora cubensis* (Berk. & M.A. Curtis)] and powdery mildew [*Sphaerotheca fuliginea* (Schlechtend.:Fr.)]. In Aug. 2015 symptoms consistent with powdery mildew were observed. In Aug. and Sept. 2015 symptoms of water-soaked lesions on fruit and fruit rot, were found after periods of heavy rain and wet field conditions. In both years spotted cucumber beetles and striped cucumber beetles (*Diabrotica undecimpunctata* L. and *Acalymma vittatum* F., respectively) were major arthropod pests. The threshold for chemical control of cucumber beetles was an average of 1 beetle per plant.

Cover crop and weed measurements

Cover crop biomass was determined on the day of termination by collecting samples consisting of aboveground plant portions from two 50 × 50 cm quadrats per subplot. Plant

samples were dried at 67 °C until samples reached a constant weight before biomass was weighed. After drying whole-plant samples were ground (Thomas-Wiley laboratory mill Model #4, Arthur H. Thomas Co., Philadelphia, PA) passed through a 2mm mesh and analyzed for total C and N (ISU Soil and Plant Analysis Lab, Ames, IA). Biomass samples were collected the day of the first weeding event on 8 July 2015, and 15 July 2016. Whole-plant samples of the weeds in the BR area of two 25 × 25-cm quadrats were taken from each subplot, and dried at 67 °C until constant weight before weighing.

Soil temperature and moisture

In each subplot, one Hobo Pendant Data Loggers (Onset Computer Corporation, Bourne, MA) was placed 15 cm below the soil surface between two muskmelon plants in the in IR area. Soil temperature (°C) was recorded in each subplot every 60 min. Soil moisture sensors (10HS, Decagon Devices, Pullman, WA) were installed horizontally into the IR soil profile 15 cm below the soil surface between two muskmelon plants in each subplot. Sensors were connected to data loggers (Emb5 logger, Decagon Devices, Pullman, WA), which recorded volumetric water content (VWC; $m^3 \cdot m^{-3}$) every 60 min.

Measurements of soil nutrients and chemical properties

Three soil sampling events occurred throughout the growing season: at planting, mid-season and at harvest. At each sampling event, four 2.9 × 15 cm soil cores (two from each row) were taken from the IR area of each subplot, the four subsamples combined into a single composite sample representing each subplot. Organic matter was measured by combustion, NO_3^- and NH_4^+ were extracted using 2N potassium chloride solution, P and K were extracted using a Mehlich III reagent (Mehlich, 1984).

Nitrate-nitrogen in leachate

Suction lysimeters (Model 1900; Soil Moisture Equipment Corp., Santa Barbra, CA) were installed vertically within IR area of each subplot to a depth of 61 cm. Below this depth the muskmelon root system is poorly developed and less extensive (Weaver and Bruner, 1927). Lysimeters were installed using a method described in Linden (1977). A 5 cm hole was bored using a soil auger and slurry of deionized water, and silica powder (200 mesh; Soil Moisture Equipment Corp., Santa Barbra, CA) was poured into the hole to provide good hydraulic contact between soil and porous ceramic cup during sampling. The lysimeters were inserted, and the remaining silica powder slurry was then poured into the hole. The hole was then partially filled with bentonite clay pellets (Soil Moisture Equipment Corp., Santa Barbra, CA) which were allowed to absorb water for several minutes before a backfill of previously excavated soil was added and tamped to firmness. A skirt made of plastic sheeting with a diameter of 30 cm was placed around the lysimeters and held in place by soil. The addition of bentonite clay, tamped soil, and plastic skirt prevented the flow of surface water down the bored lysimeter hole to the sampling area. In 2015, sampling occurred every 7-14 d after a rain or irrigation event. In 2016 samples were collected after each weekly fertigation event. Approximately 24 h after a rain, irrigation, or fertigation event, a hand pump was used to apply 40 kPa of pressure to each lysimeter to create enough suction to draw soil pore water through the ceramic cup. 24 h after applying the vacuum a thin tube connected to a Buchner flask was inserted into the lysimeter. Using a hand pump, pressure a partial vacuum was created in the Buchner flask to draw all of the collected leachates into the flask. A 60 mL aliquot was collected, and frozen at -20 °C until time of analysis.

Muskmelon plant growth

Vine length (cm) and SPAD measurements were taking on 31 Aug. 2015 and 25 Aug. 2016. SPAD meters provide a rapid and nondestructive measurement that correlates with extractable chlorophyll content in muskmelon leaves (Azia and Stewart, 2001). A handheld SPAD-502 Plus meter (Konica Minolta Sensing America Inc., Ramsey, NJ) was used to estimate leaf chlorophyll content. SPAD meters provide a rapid and nondestructive measurement that correlates with extractable chlorophyll content in muskmelon leaves (Azia and Stewart, 2001). All SPAD measurements were taken from the most-recently-mature-leaf (MRML) of six plants within each subplot at mid-day on a sunny day. For each MRML the average of five SPAD measurements was recorded. The vine length of two plants from each subplot was determined on by measuring the length from the soil surface to the tip of the most distal leaf, along the longest central vine. On 18 Aug. 2016 the concentration of NO_3^--N and K^+ in the petiole sap was measured from the MRML petioles of twenty-five plants within each subplot following recommended procedures of (Hochmuth et al., 1991). On a sunny day, at midday, MRML and petiole portions were collected and immediately transported to the laboratory for analysis. Samples were bagged and kept cool during transportation. Leaf tissue was removed, petioles were cut into 1 cm portions, and were then pressed with a handheld garlic press. The petiole sap of the twenty-five MRML from each subplot was combined into a single composite. The NO_3^--N and K^+ concentration of extracted petiole sap was immediately measured in triplicate using an LAQUA Twin Nitrate Meter and an LAQUA Twin Potassium Meter (Spectrum Technologies, Aurora, IL). The average of the triplicate measurements was recorded.

Muskmelon yield

Muskmelons were harvested at half-slip two to three times per week from 21 Aug. - 15 Sept 2015 for a total of 7 harvests and 12 Aug -13 Sept. 2016 for a total of 11 harvests. Fruits were classified as marketable or non-marketable, counted, and weighed. Individual fruits were considered marketable if they were uniform in shape and free from the following defects: cracks, bruises, scars, insect damage, soft spots, rot (USDA-AMS, 2008).

Microbial biomass carbon

A portion of the soils collected on 16 Sept. 2015 and 14 Sept. 2016 for chemical analysis was analyzed for microbial biomass carbon (MBC), using a chloroform fumigation-extraction method modified from Vance et al. (1987). After collection from the field, soil samples were kept cool during transport. Within 24 h of sample collection field moist soil was sieved (<4.75mm) rocks, roots, and other large debris was removed by hand. Immediately after sieving one 50 g subsample was extracted with 0.5 M potassium sulfate (K_2SO_4) in sterile water, one 50 g subsample was fumigated with ethanol-free chloroform for 24 h before K_2SO_4 extraction, and one 10 g subsample was dried at 100 °C for 48 h to determine gravimetric water content. Extracts were transferred to 60 mL plastic bottles, one drop of phosphoric acid was added before storage at -20 °C until the time of analysis. Fumigated and non-fumigated extracts were analyzed for total organic carbon (TOC) using a Torch Combustion TOC/TN Analyzer (Teledyne Tekmar, Mason, OH). A correction factor (k=0.33) was used to calculate MBC (Sparling and West, 1988).

Microbial functional diversity

The microbial functional diversity of the soil was assessed by developing a community level physiological profile (CLPP). Using Biolog-EcoPlate® (BIOLOG Inc., CA, USA), the sole-C-source utilization of culturable heterotrophic soil microbes was characterized by the method of Nair and Ngouajio (2012). From the samples that had been taken 16 Sept. 2015 and 14 Sept. 2016 and sieved for MBC analysis, 10 g of field moist soil was combined with 90 mL of a sterile 0.85% sodium chloride (NaCl) solution, shaken and then incubated for 18 h before being brought to a final dilution of 10^{-3} in sterile 0.85% NaCl. A 150 µl aliquot was pipetted into each of the 96 wells of the Biolog-EcoPlate®. The 96 well Biolog-EcoPlate® consist of three replications of 31 individual C sources, and a blank that serves as a control. The reduction of a tetrazolium dye which turns purple indicates the C substrate utilization rate of the inoculated microbes. Immediately after plating (day 0) color change was recorded as optical density (OD) at 590 nm, with a spectrophotometer (Bio-Rad iMark; Bio-Rad Laboratories, Hercules, CA). For 7 d thereafter OD was recorded every 24 h, and day 0 reading was subtracted from each subsequent reading to account for any background coloration. Additionally, the OD value of the blank well was subtracted from the response of the 31 C sources in each replicate. Substrate richness (S), the number of substrates utilized by soil microbes in each sample is a count of the positive OD measurements. Average well color development (AWCD), a combined measure of the diversity and abundance of soil microbes was calculated for each sample on days 1-7 using the following equation:

$$AWCD = \frac{\sum OD_i}{31}$$

The Shannon-Wiener diversity index (H) and Evenness (E) were used as measures of soil microbial diversity and calculated using the following equations (Shannon and Weaver, 1969, Zak et al., 1994):

$$H = -\sum p_i(\ln p_i) \text{ and } E = \frac{H}{\log S}$$

Where p_i is the ratio of the corrected absorbance value of each well, to the sum of absorbance value of all wells. To reduce bias as a result of differences in inoculum densities, well color responses were normalized by dividing the blanked OD values by AWCD (Garland, 1997).

Statistical analysis

Data were analyzed using SAS (version 9.4; SAS Institute, Cary, NC). Analysis of variance (ANOVA) was performed using proc GLIMMIX with type three sums of squares and the Satterthwaite adjustment was used for degrees of freedom. Block was included as a random factor, both tillage and cover crop were considered fixed. Means separation was carried out using the "lsmeans" and "pdiff" statement. Significance was considered < 0.05 for all variables. Because there were significant interactions with year, the data from each year were analyzed and presented separately.

Results and Discussion

Weather

In Feb. 2015 the average monthly air temperature was 5.8 °C lower than the 30-year average of -4.4 °C (Fig. 2.1). This deviation from the 30-year average can largely be accounted for by several short periods of cold air temperatures near the end of Feb 2015. In 2015, during the months the muskmelon crop was growing, the air temperature was

comparable to the 30-year average. From the time cover crops were planted for the 2015-16 study in Sept. 2015, until the cessation of muskmelon harvest in Sept. 2016 the average monthly air temperature was consistently above than the 30-year average. In June 2016 total precipitation was 2.6 cm, which is 10.6 cm less than the 30-year average. During both years of the study total monthly precipitation for the months of July and Aug. were greater than the 30-year average, resulting in saturated soil at the beginning of muskmelon fruit harvest.

Cover crop measurements

During both years of the study cover crop dry-weight biomass was not different ($P < 0.05$) between treatments (Table 2.3). In both years, rye-ST surpassed the recommendation of 8 $Mg \cdot ha^{-1}$ dry-weight biomass necessary to suppress annual weed germination in reduced tillage systems from Mirsky et al. (2013). However, rye-vetch-ST plots only exceeded that recommended value in 2016.

There was a significant cover × tillage interaction effect on cover crop C% in 2016 (data not shown). In 2016, rye-vetch-CT had a lower C% (36.7%) than rye-vetch-ST, rye-CT, and rye-ST with means of 43.7%, 43.4%, and 41.5% respectively. In 2016, rye-vetch had greater N% than rye (Table 2.3). Because plant samples from rye-vetch plots were ground and analyzed as a mixture, the increased percent N observed in 2016 can be attributed to fixation of atmospheric N by the vetch.

In 2016 there were significant main effects of both cover crop and tillage on cover crop C:N ratio (Table 2.3). The C:N ratio of rye was greater than rye-vetch, and ST plots had a higher C:N ratio than CT plots. Cover crops from ST plots had a greater C:N ratio than cover crops from CT plots. As rye approaches anthesis, lignin, cellulose, and hemicellulose

accumulate in the plant tissue at greater concentrations, causing a dilution of N in plant tissue (Wagger, 1989). The earlier termination date of cover crops in CT plots prevented the additional accumulation of C in the rye tissue. In 2015, there was an increased C:N ratio in rye and in ST treatments, though the differences were not significant. Cover crop residue with C:N ratio >32:1 is likely to cause N immobilization (Quemada and Cabrera, 1995). In 2016 average C:N ratios were ≥40 for all treatments.

In 2015, for all treatments, mean values for aboveground biomass, C%, and C:N were less than in 2016. Because cover crop planting dates and methods were nearly identical for both years, these yearly differences in cover crop performance between years are likely due to variability in weather and study sites.

Weed biomass

To determine treatments effects on weed biomass when the muskmelon crop is most vulnerable to weed pressure, we collected weed biomass 3-4 w after transplanting. The critical weed-free period for muskmelons is described as 4-6 w after emergence by Nerson (1989). In 2015, ST weed biomass pooled across cover crop treatments was 81% less than CT (Fig. 2.2). In 2016, there was a significant cover × tillage interaction effect; weed biomass in no cover-ST plots was higher than all other cover × tillage treatments. In 2016, we applied glyphosate in no cover-ST plots nine days later than in 2015 (Table 2.1). Early glyphosate applications have been shown to more effective than late applications (Krausz et al., 1996, Jordan et al., 1997). Weeds in the 2016 no cover-ST plots were likely at more advanced growth stages possibly making the glyphosate application less effective, leading to incomplete termination or allowing seed dispersal before termination. It is possible that in 2016 after mowing, these weeds re-grew and increasing weed biomass from no cover-ST

plots compared to 2015. This year-to-year variability suggests that exclusive dependence on herbicide for weed management in ST systems may not be a reliable weed control strategy.

Soil temperature

In both years of the study, CT increased IR soil temperatures throughout the season; this difference was not significant during the 2016 late period (Table 2.4). Absorption of solar radiation by the black plastic mulch, present in all CT plots, as well as the mulch's ability to insulate the soil increased IR soil temperature for CT plots. Differences in soil temperatures between tillage treatments were greatest during the early period. Early period soil temperate for CT was increased by 2.5 °C in 2015, and 1.3 °C in 2016. Soon after transplanting young muskmelon plants will undergo rapid growth, allowing vines and foliage to quickly cover the IR area. During the mid and late periods, the muskmelon canopy likely intercepted most solar radiation in the IR area, allowing less surface interception. This reduction in solar radiation could have led to smaller difference among the soil temperatures for ST and CT treatments during the mid and late periods.

In both years, no cover plots had a higher soil temperature than rye and rye-vetch during the early period. As shown in Table 2.4, significant cover × tillage interactions were observed at each period during the 2015 growing season, but at no point in 2016. Generally, soil temperature in 2015 was greatest for all three CT treatments, lowest for rye-ST and rye-vetch -ST, and no cover-ST was an intermediary. It would be expected that among ST plots, no cover plots would have higher soil temperatures because the cover crop mulch in rye and rye-vetch plots would reflect more solar radiation than bare soil. Reduced IR soil temperature may be a limiting factor for vegetable crop production systems utilizing a rolled cover crop mulch.

Soil moisture

Soil moisture (VWC) was often increased by ST (Table 2.5). There was a significant main effect of tillage on soil moisture for each period in 2016. Soil moisture was increased by ST only for the late period in 2015, however the trend was similar for the early and mid periods. Haramoto and Brainard (2012), studying the effect of tillage and an oats (*Avena sativa* L.) cover crop and tillage on irrigated cabbage, similarly found that ST periodically increased IR soil moisture (gravimetric water content) irrespective of whether or not an oats cover crop was used. For our study, there was no significant main effect of cover crop. Contrary to our findings, the same study by Haramoto and Brainard (2012) found that an oats cover crop increased IR soil moisture regardless of whether the oats cover crop was incorporated into the soil (CT) or left on the soil surface (ST). For our study, it is unlikely that greater soil temperature (Table 2.4) in CT increased evaporation, thus depleting soil moisture; plastic mulch can reduce evaporation, and increase transpiration compared to no mulch (Tarara, 2000, Li et al., 2003). Because vine length (Table 2.8) and yield (Table 2.9) were greater in CT it is likely that CT increased muskmelon plants transpiration, thus depleting soil moisture in CT plots.

Soil nutrient measurements

In 2015 CT increased soil NO_3^-- N concentration at each sampling date, however in 2016 CT increased soil inorganic N (NO_3^-- N and NH_4^+-N) only at the final sampling date (Table 2.6). Higher soil NO_3^-- N concentrations in CT plots could be attributed to higher soil temperatures in those plots (Table 2.4) that encourages mineralization of organic N from cover crops and from soil. Mineralization of organic N can increase with temperature (MacDonald et al., 1995). Tillage did not affect soil NH_4^+-N in 2015, which were relatively

lower than in 2016. For the 2016 end of season sampling, CT increased soil concentrations of NH_4^+-N by 0.8 mg·kg^{-1} and concentrations of NO_3^--N by 3.9 mg·kg^{-1}.

In 2016 a main effect of cover crop on P concentrations was observed only for the end of season sampling. The end of season sampling in 2016 had highest soil P concentrations in rye-vetch plots, lowest P concentrations in no cover plots, and rye was intermediate and statistically indistinguishable from no cover and rye-vetch treatments. Winter cover crops have been shown to cause an increase in P uptake by a subsequently planted cash crops (Kabir and Koide, 2002). In 2016 end of season soil P concentrations were greater that at-planting for rye and rye-vetch treatments, but not for no cover treatments, a pattern that would be expected with the uptake and subsequent release of P by cover crops.

The main effect of cover crops on soil K that was observed in 2015 for the end of season sampling was likely due to plot effects that were present before the establishment of treatments. Soil samples taken at the time of cover crop seeding in 2014, before treatments had been established, indicate, that on average, rye plots had soil K concentrations 60% and 32% higher than no cover, and rye-vetch, respectively (Table 2.2). Soil K concentrations were higher in CT for the mid-season and end of season sampling dates. Contrary to our results, Shao et al. (2016) reported higher soil K levels in reduced tillage systems than CT. In our study, differences in soil K may be related to main effects of tillage on NH_4^+-N (Table 2.6). Dynamic interactions between soil N and K have been well documented (Zhang et al., 2010). More specifically, uptake of K^+ can be inhibited by NH_4^+ (Wang et al., 1996). In our study it is possible that in 2016 greater concentrations of NH_4^+-N in CT plots (Table 2.6) may have limited the uptake and removal of soil K by muskmelon plants, allowing K to accumulate in soil. In 2016 rye and rye-vetch had higher soil K concentrations than no cover

for the mid-season sampling date indicating a direct effect of cover crop on soil K concentrations. Rye has been shown to increase soil K in the top 5 cm of soil on both a silt loam and a silty clay (Eckert, 1991).

Nitrate-nitrogen in leachate

There was often no effect of treatments on concentrations of NO_3^--N in leachate. Concentrations of NO_3^--N in leachate were only occassionally reduced by ST (Table 2.7). In 2015 CT increased NO_3^--N concentrations in leachate at only one date 12 Aug, and in 2016 there were three consecutive dates where CT increased NO_3^--N concentrations in leachate, 6 July, 13 July, and 22 July. Similarly, Jokela and Nair (2016) found that early season NO_3^--N leaching was reduced under no-till and ST organic pepper plots compared to CT, but only during one year of study. Of the 18 sampling dates during both years of our study, there was an effect of cover crop at only one date. On 16 Aug. 2016, no cover plots had a higher concentration of NO_3^--N in leachate than rye-vetch, and rye was intermediate and statistically indistinguishable from no cover and rye-vetch. During both years of the study concentrations of NO_3^--N in leachate for all treatments were greatest in July. Despite the use of NO_3^- fertilizers (potassium nitrate and calcium nitrate) only in 2016, concentrations of NO_3^--N across all treatments in July were higher in 2015 than in 2016. A possible contributing factor to this year-to-year difference is site history. The entire 2016 site had been in a sorghum-sudangrass the previous year, whereas soybeans had been grown on the entire 2015 site prior to establishment of plots for this muskmelon study. The soybean crop would increase levels of soil NO_3^--N, that could have escaped uptake by cover crops during the fall, and moved through the soil profile during the winter before being collected by lysimeter sampling (sampling depth = 61 cm) the following July.

Muskmelon plant growth

Averaged across both years, vine length for plants grown in ST plots was 53 cm less than plants from CT plots. Tillman et al. (2015) similarly found that ST reduced vine length of muskmelon plants. Reduced vine length in ST plots is likely a result of lower soil temperatures (Table 2.4) and less plant available N in the soil (Table 2.6).

There was a significant main effect of tillage on SPAD, a unitless measurement, during both years of the study (Table 2.8). In 2015 ST increased SPAD by 5.5, however in 2016 ST decreased SPAD by 3.1. In Aug. 2015 symptoms of foliar diseases and incidences of chlorotic and necrotic leaf lesions were observed in all treatments, but for unknown reason appeared to be more severe in CT plots. Leaf chlorosis as a result disease can reduce SPAD values in muskmelon (Nolte et al., 2011). In 2015, we believe that leaf chlorosis and necrosis lowered SPAD values for plants in CT plots and is not representative of plant nutrient status.

In 2016 concentrations of NO_3^--N and K^+ in petiole sap were measured as harvest began for all treatments. For NO_3^--N, there was a significant cover × tillage interaction; petioles from no cover-CT and no cover-ST plots had highest concentrations of NO_3^--N (Table 2.8; Fig. 2.3). Petioles from rye-CT and rye-vetch -CT contained lower NO_3^--N concentrations, but were still greater than petioles from rye-ST and rye-vetch-ST. Both no cover-CT and no cover-ST were within the NO_3^--N sufficiency range described by Hochmuth et al. (1991) for muskmelons at first harvest. Pooled together, rye-CT and rye-vetch -CT showed an average NO_3^--N deficiency of 224 $mg \cdot kg^{-1}$; rye-ST and rye-vetch-ST were on average 551 $mg \cdot kg^{-1}$ below the sufficiency range. Increased C:N ratio of ST cover

crops (Table 2.3) could have reduced net N mineralization in rye-ST and rye-vetch-ST compared to their respective CT treatments.

Significant main effects of both cover and tillage on concentrations of K^+ in petiole sap showed a reduction for no cover treatments as well as CT treatments (Table 2.8). For CT, a K^+ deficiency of 289 $mg \cdot L^{-1}$ was observed, ST was slightly above the maximum of the sufficiency range of 3000-3500 mg $K^+ \cdot L^{-1}$ (Hochmuth et al., 1991). For muskmelons production K, is an important nutrient because deficiencies can lead to reductions in shelf-life and fruit quality (Lester et al., 2010). In previous discussion, we proposed that increased levels of NH_4^+ in the soil at the end of the season may explain increased soil K in CT plots, due to NH_4^+ inhibiting uptake of soil K, causing subsequent accumulation of soil K. Soil N can affect the movement of soil K, as well as the uptake of soil K by plants (Zhang et al., 2010, Wang et al., 1996, Pettersson, 1984). If soil NH_4^+ did inhibit K removal and uptake among CT plots in 2016, we would expect to find, as we did, that plants from CT plots were deficient in K. In summary, a possible explanation for lower concentrations of K^+ in petiole sap of muskmelon plants from CT plots is that greater levels of NH_4^+-N in the soil reduced the uptake and removal of soil K, allowing K fertilizer to accumulate in the soil.

Petiole sap from no cover plots had K^+ concentration 889 $mg \cdot L^{-1}$ below the minimum of the sufficiency range, whereas rye and rye-vetch both exceeded the K^+ sufficiency range of 3000-3500 $mg \cdot L^{-1}$ (Hochmuth et al., 1991). Unlike tillage, differences in soil NH_4^+-N levels do not help explain differences in petiole sap K^+ concentration among cover crop treatments. We realize that in addition to NH_4^+, NO_3^- can also interact with the movement and uptake of K. While this study was not designed to elucidate how N and K

interact in the soil and in muskmelon plants, the effect of cover crops and tillage on plant and soil nutrient status is not insignificant and warrants further research.

Muskmelon yield

In both years of the study, CT increased both marketable weight and total weight of fruits (Table 2.9). Our findings are consistent with previous studies, that ST decreased muskmelon yield (Lilley and Sánchez, 2016, Tillman et al., 2015). Marketable number and total number of fruit was greater for CT plots in 2016. Among CT plots increased soil temperature (Table 2.4), greater availability of mineralized N (Table 2.6), and higher petiole sap NO_3^--N content (Table 2.8) likely led to more vigorous plant growth, and thus increased yields. In 2015 marketable yield was a lower proportion of total yield compared to 2016 because of higher populations of striped cucumber beetles, higher incidences of foliar disease, and saturated field conditions near harvest that led to soft spots and cracking on fruits. In 2016, cucumber beetle pressure was much lower, and our disease management program used the MELCAST disease forecasting system (Latin, 2001) to optimize the timing of fungicide application.

In 2016 only, there was a significant main effect of cover crop on total weight, marketable number, and total number of fruits. Generally, no cover and rye-vetch were greater than rye for these values. It is unclear why there were significant differences between rye and rye-vetch for marketable number and total number of fruits. While it is reasonable to speculate that this is a result of increased muskmelon plant growth due to greater percent N in leguminous vetch tissue, the soil and petiole sap data do not support this.

Microbial biomass carbon

Measurements of MBC taken from the final IR soil sampling of both years were consistently greater in rye-CT treatments compared to no cover-CT (Fig. 2.4). Mendes et al. (1999) found that winter cereal cover crops can increase MBC. Soil microbes were provided with an abundant source of C when the rye cover crop was tilled into the soil. Though surprisingly, rye did not consistently increase MBC within ST plots. In 2015, all other tillage × cover treatments were statistically indistinguishable from rye-CT and no cover-CT. However, in 2016 rye-CT and rye-vetch-CT had a greater MBC than their respective ST plots. A study in China found that plastic mulch left in place throughout the growing season can increase MBC (Li et al., 2004). In muskmelon plots with rye cover crops, Tillman et al. (2015) found that CT, with plasticulture, occasionally increased MBC over ST. For rye and rye-vetch, increased MBC among CT plots may be due to higher soil temperature (Table 2.4) that could increase the rate of metabolic processes among soil microbes. In both years of the study no cover-ST and no cover-CT were not different. Differences in MBC may be a function of an interaction between cover crops and plastic mulch induced soil temperature increases. In the absence of a cover crop, higher soil temperature may be ineffective in increasing MBC.

Microbial functional diversity

Species evenness (which encompasses richness) and the Shannon-Weiner index are measures of soil microbial diversity, whereas AWCD is a combined measure of diversity and abundance. In 2016 Shannon-Weiner index and species evenness were lowest in no cover compared to rye and rye-vetch (Table 2.10). Tillage had no effect during either year of our study. Values shown in Table 2.10 are calculated from measurements of optical density after

7 d of incubation. Values from days 1-6 are not shown, and there were no significant differences during either year.

Soil microbial communities can receive root exudates from actively growing cover crops, and also a considerable input of C when the cover crops are terminated. Both plant root exudates (Baudoin et al., 2003), and the addition of organic soil amendments (Nair and Ngouajio, 2012) can affect microbial communities. Regardless of tillage treatments, we observed that rye and rye-vetch were able to increase soil bacterial diversity in 2016. Previous studies suggest that even when IR soil disturbance is minimal, difference in soil microbial diversity may be limited to the BR area. For example, using similar methods, Jokela and Nair (2016) compared AWCD of the IR and BR area for both ST and CT plots, only finding differences between tillage treatments in the BR area where cover crop residue was covering the soil; in ST plots AWCD was greater than CT in the BR area. Similarly Lupwayi et al. (1998) found that measures of microbial diversity were increased for reduced tillage practices in the BR area only, but equal between tillage treatments in the IR area.

Conclusion

Though rye-ST and rye-vetch-ST did have low weed biomass in both years, due to the mixed performance of other treatments we cannot definitively conclude that a rolled cover crop mulch provided superior weed suppression. Weeds that do penetrate cover crop mulch may require more labor to remove. The potentially high cost of hand-weeding highlights the need for practical technologies and methods of high-residue cultivation in vegetable crops. Because waiting for rye anthesis is requisite for successful roller-crimper termination, growers must delay the planting of the subsequent cash crop by several weeks.

In addition, in waiting for sufficient cover crop biomass to accumulate for weed suppression, C:N of cover crops will increase, increasing the likelihood for N immobilization, and as a result cash crops may not be provided with sufficient N. Future research and plant breeding efforts should develop early-maturing rye cultivars that can also provide season long weed suppression without detrimentally impacting N availability. Contrary to our hypothesis, muskmelon plant growth and marketable yield were reduced under CT. Compared to rye monoculture, the rye-vetch biculture did not increase levels of soil N, and did not impact plant growth or yield. Differences in cover crop C:N ratio, soil N levels, and plant N measurement indicate reductions in net N mineralization may have led to less plant-available N. Consistently producing high yields with cover crop based reduced tillage systems may depend on research that identifies the optimum N levels in these systems, as opposed to depending on current recommendations, that were developed for CT systems. It will be necessary to elucidate how N cycling in ST vegetable systems differs from CT. Modified fertility requirements may be needed to spur adoption, and ensure that grower experience success with on-farm ST. Though N is considered the foremost limiting nutrient in agroecosystems, our results show that future research should also consider the effect of tillage and cover crops on P, K, and other nutrients.

The results of this study did not corroborate our hypothesis that ST and cover crops would increase soil microbial functional diversity, and reduce NO_3^--N leaching. There were some trends in improved microbial diversity for cover crops and reduced NO_3^--N leaching for ST, but only during one year of the study. Curiously, rye-CT did increase MBC compared to no cover-CT treatments indicating the value of rye cover crops for CT production with plastic mulch. It is important to mention that measurement was from the IR

area, which accounts for a smaller proportion of field surface area than the BR area. Studies long-term studies that measure changes across the entire field may be necessary to better determine the effect of ST on soil health.

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Table 2.1. Timing of field operation for muskmelon studies at the Horticulture Research Station, Ames, IA in 2014-15 and 2015-16.

Event	Date	
	2014-15	2015-16
Cover crops seeded	18 Sept. 2014	16 Sept. 2015
Fall strip-tillage	22 Oct. 2014	23 Oct. 2015
Seedlings started in greenhouse	21 May	10 May
Glyphosate applied[z]	27 May	5 June
Cover crop sampled and terminated (CT)[y]	22 May	24 May
Cover crop sampled and terminated (ST)[x]	1 June	2 June
Final strip-tillage (ST)	7 June	9 June
Raised beds and plastic mulch installed (CT)	10 June	10 June
Drip tape installed in ST	11 June	9 June
Preplant fertilizer applied	11 June	9 June
Clomazone applied[w]	12 June	10 June
Muskmelon transplanted	16 June	13 June
Soil sampling	18 June	17 June
	17 July	19 July
	16 Sept.	14 Sept.
Lysimeter sample collection period	1 July-15 Sept.	30 June-9 Sept.
Weed biomass samples taken	8 July	15 July
Microbial biomass and CLPP soil samples	16 Sept.	14 Sept.
Vine length and SPAD measurements taken	31 Aug.	25 Aug.
Petiole sap measurements	---	18 Aug.
Harvest period	21 Aug.-15 Sept.	12 Aug.-13 Sept.

[z] No cover-ST plots only
[y] CT= conventional tillage
[x] ST= strip-tillage
[w] In-row area of all ST plots, and between row area of no cover-ST plots

Table 2.2. Initial soil measurements at the time of cover crop seeding at the Horticulture Research Station, Ames, Iowa.

	2014[z]				2015[y]			
Cover	OM[x]	pH	P[w]	K[w]	OM	pH	P	K
No cover	3.2	5.9	39.3	104.3	2.5	6.2	76.1	302.4
Rye	3.0	5.6	46.7	111.6	2.7	5.8	99.1	484.1
Rye-vetch	3.5	5.3	48.3	112.2	2.8	5.6	111.4	385.8

[z] Soil samples collected 18 Sept. 2014
[y] Soil samples collected 16 Sept. 2015
[x] Percent soil organic matter
[w] $mg \cdot kg^{-1}$

Table 2.3. Cover crop dry weight biomass, carbon, and nitrogen content as affected by cover crop and tillage treatments at the Horticulture Research Station, Ames, IA in 2015 and 2016.

Treatment	2015				2016			
	Biomass ($Mg \cdot ha^{-1}$)	Percent C	Percent N	C:N	Biomass ($Mg \cdot ha^{-1}$)	Percent C	Percent N	C:N
Cover crop (C)								
No cover	-	-	-	-	-	-	-	-
Rye	8.2	37.2	1.2	33.1	12.1	41.6	0.9 B	48.8 A
Rye-vetch	7.8	34.1	1.2	30.8	12.0	39.1	1.0A [y]	40.0 B
Tillage (T)[z]								
CT	7.5	34.9	1.2	29.8	11.7	39.5	1.0	40.7 b
ST	8.6	36.4	1.1	34.2	12.4	41.3	0.9	48.1 a
Significance								
Cover crop	ns	ns	ns	ns	ns	ns	0.0075	0.0068
Tillage	ns	ns	ns	ns	ns	ns	ns	<0.0001
C × T	ns	ns	ns	ns	ns	0.0004	ns	ns

[z]CT= conventional tillage, ST= strip-tillage.

[y]Mean separation of cover crop (uppercase letters) and tillage (lowercase letters) in columns based on least significant difference at $P < 0.05$. Within each column and factor labels not containing the same letter are different. ns = non-significant.

Table 2.4. Soil temperature at a 15 cm depth of the in-row areas of muskmelon crop as affected by cover crops and tillage at the Horticulture Research Station, Ames, IA in 2015 and 2016.

	2015			2016		
Treatment	Early[z]	Mid	Late	Early	Mid	Late
Cover crop (C)						
No cover	24.5 A[x]	21.6	20.6	26.7 A	23.7	21.1
Rye	23.7 B	21.5	20.2	25.0 B	23.6	21.1
Rye-vetch	23.8 B	21.6	20.2	24.3 B	23.2	20.7
Tillage (T)						
CT[w]	25.3 a	21.9 a	21.1 a	26.0 a	23.9 a	21.2
ST	22.8 b	21.3 b	19.6 b	24.7 b	23.0 b	20.7
Significance						
Cover crop	0.0025	ns	ns	0.0093	ns	ns
Tillage	<0.0001	0.0001	<0.0001	0.0258	0.0009	ns
No cover- CT	25.0 A	21.8 B	21.2 A	27.0	23.9	21.2
No cover-ST	24.0 B	21.5 BC	21.5 BC	26.3	23.5	20.9
Rye-CT	25.3 A	21.9 AB	20.9 A	25.5	24.0	21.2
Rye-ST	22.2 C	21.2 C	19.6 BC	24.6	23.1	20.9
Rye-vetch- CT	25.5 A	22.2 A	21.2 A	25.5	23.9	21.3
Rye-vetch- ST	22.2 C	21.1 C	19.3 C	23.0	22.5	20.1
Significance						
C × T	0.0001	0.0405	0.0145	ns	ns	ns

[z]Early: 26 June -26 July 2015, 24 June – 23 July 2016, Mid: 27 July -28 Aug. 2015, 24 July – 26 Aug. 2016, Late: 29 Aug. - 26 Sept. 2015, 27 Aug. -28 Sept. 2016.

[x]Within each year mean separation of cover crop(uppercase letters) and tillage (lowercase letters) in columns based on least significant difference at $P < 0.05$. Within each column and factor labels not containing the same letter are different. ns = non-significant

[w]CT= conventional tillage, ST= strip-tillage

Table 2.5. Soil moisture ($m^3 \cdot m^{-3}$; Volumetric Water Content) at a 15 cm depth of the in-row areas of muskmelon plots as affected by cover crops and tillage at the Horticulture Research Station, Ames, IA in 2015 and 2016.

	2015			2016		
Treatment	Early[z]	Mid	Late	Early	Mid	Late
Cover crop (C)						
No cover	0.29	0.31	0.32	0.34	0.35	0.35
Rye	0.30	0.31	0.32	0.35	0.36	0.37
Rye-vetch	0.29	0.31	0.29	0.34	0.35	0.36
Tillage (T)						
CT[y]	0.29	0.30	0.29 b[x]	0.33 b	0.33 b	0.33 b
ST	0.30	0.33	0.33 a	0.36 a	0.37 a	0.38 a
Significance						
Cover crop	ns	ns	ns	ns	ns	ns
Tillage	ns	ns	0.0275	0.0267	0.0129	0.0116
C × T	ns	ns	ns	ns	ns	ns

[z]Early: 26 June - 26 July 2015, 24 June - 23 July 2016 Mid: 27 July - 26 Aug. 2015, 24 July - 26 Aug. 2016 Late: 27 Aug. - 26 Sept., 2015, 27 Aug. - 28 Sept. 2016.

[y]CT= conventional tillage, ST= strip-tillage.

[x]Within each year mean separation of cover crop (uppercase letters) and tillage (lowercase letters) in columns based on least significant difference at $P < 0.05$. Within each column and factor labels not containing the same letter are different. ns = non-significant.

Table 2.6. Soil nutrient concentrations of muskmelon plots as affected by cover crops and tillage at the Horticulture Research Station, Ames, IA in 2015 and 2016.

Treatment	2015[z]											
	At planting				Mid-Season				End of Season			
	Nitrogen				Nitrogen				Nitrogen			
	NH_4^+-N	NO_3^--N	P	K	NH_4^+-N	NO_3^--N	P	K	NH_4^+-N	NO_3^--N	P	K
Cover crop (C)												
No cover	1.4[y]	3.3	77.7	286.7	0.6	3.2	73.0	232.7	0.1	2.4	66.9	193.4 B[x]
Rye	1.5	2.7	78.2	408.7	0.6	2.7	73.8	362.3	0.1	3.1	73.0	321.4 A
Rye-vetch	1.5	2.8	78.4	274.8	0.6	3.0	75.1	255.0	0.1	2.4	79.8	206.9 B
Tillage (T)[w]												
CT	1.4	4.3 a	78.0	337.9	0.6	4.3 a	80.3	294.5	0.1	3.6 a	75.9	257.8
ST	1.5	1.6 b	78.0	309.0	0.6	1.6 b	81.0	272.3	0.1	1.7 b	70.6	226.6
Significance												
Cover crop	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.0386
Tillage	ns	<0.0001	ns	ns	ns	0.0004	ns	ns	ns	<0.0001	ns	ns
C × T	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	2016[v]											
Cover crop (C)												
No cover	4.0 B	5.7	64.9	117.1	4.2	2.5	59.2	88.0 B	1.9	4.2	52.5 B	130.6
Rye	5.2 AB	5.3	58.4	117.8	2.3	2.0	53.5	121.4 A	2.2	4.0	67.1 AB	131.1
Rye-vetch	7.3 A	6.1	58.1	120.8	2.4	2.9	63.2	110.0 A	2.5	4.1	79.6 A	162.3
Tillage (T)												
CT	5.6	6.0	57.6	132.9	3.9	2.4	58.1	115.7 A	2.6 A	6.0 A	71.9	160.7 A
ST	5.4	5.4	63.4	104.3	2.1	2.4	50.2	97.2 B	1.8 B	2.1 B	60.9	122.0 B
Significance												
Cover crop	0.0447	ns	ns	ns	ns	ns	ns	0.0028	ns	ns	0.0260	ns
Tillage	ns	ns	ns	ns	ns	ns	ns	0.0144	0.0242	0.0007	ns	0.0165
C × T	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[z]Soil samples were taken from the in row area on 18 June, 17 July, and 16 Sept. 2015.
[y]All measurements displayed as $mg \cdot kg^{-1}$
[x]Within each year mean separation of cover crop (uppercase letters) and tillage (lowercase letters) in columns is based on least significant difference at $P < 0.05$. Within each column, year, and factor labels not containing the same letter are different. ns = non-significant.
[w]CT= conventional tillage, ST= strip-tillage.
[v]Soil samples were taken from the in-row area 17 June, 19 July, and 14 Sept. 2016.

Table 2.7. Concentration of nitrate-nitrogen in leachate collected from the in-row area of muskmelon plots as affected by cover crops and tillage at the Horticulture Research Station, Ames, IA in 2015 and 2016 in. Leachate was collected using suction lysimeters installed to a depth of 61 cm.

	2015								
Treatment	1 July	10 July	17 July	31 July	12 Aug.	25 Aug.	4 Sept.	15 Sept.	30 Sept.
Cover crop (C)									
No cover	32.1[z]	56.2	80.5	34.4	4.1	3.5	9.4	10.4	12.5
Rye	38.8	63.8	66.7	8.6	1.4	2.6	10.0	14.7	16.0
Rye-vetch	41.8	54.7	68.0	26.2	4.9	3.1	5.7	14.5	17.5
Tillage (T)[y]									
CT	37.4	57.7	67.6	24.5	5.4 a[x]	3.7	8.5	15.4	17.2
ST	37.9	58.7	75.9	21.7	1.6 b	2.4	8.2	11.0	13.5
Significance									
Cover crop	ns	ns	ns	ns	ns	ns	ns	ns	ns
Tillage	ns	ns	ns	ns	0.0185	ns	ns	ns	ns
C × T	ns	ns	ns	ns	ns	ns	ns	ns	ns
	2016								
	30 June	6 July	13 July	22 July	8 Aug.	9 Aug.	16 Aug.	25 Aug.	1 Sept.
Cover crop (C)									
No cover	31.0	29.4	23.7	21.4	9.0	6.2	12.0 A	12.0	14.8
Rye	19.7	25.3	21.6	14.5	12.9	4.3	7.9 AB	7.2	10.9
Rye-vetch	16.8	18.5	25.3	17.1	4.0	1.6	2.9 B	7.3	16.5
Tillage (T)									
CT	24.7	32.8 a	32.0 a	24.3 a	6.2	3.8	8.5	10.5	16.4
ST	19.3	16.0 b	15.2 b	11.1 b	6.2	4.3	6.6	7.2	11.7
Significance									
Cover crop	ns	ns	ns	ns	ns	ns	0.0272	ns	ns
Tillage	ns	0.0005	0.0014	0.0260	ns	ns	ns	ns	ns
C × T	ns	ns	ns	ns	ns	ns	ns	ns	ns

[z] NO_3^--N ($mg \cdot L^{-1}$)

[y] CT= conventional tillage, ST= strip-tillage

[x] Within each year, mean separation of cover crop (uppercase letters) and tillage (lowercase letters) in columns is based on least significant difference at $P < 0.05$. Within each column, year, and factor labels not containing the same letter are different. ns = non-significant.

Table 2.8. Measurements of plant growth (vine length, SPAD, and petiole sap) as affected by cover crops and tillage at the Horticulture Research Station, Ames, IA in 2015 and 2016.

Treatment	2015[z]		2016[y]			
					Petiole sap	
	Vine length (cm)	SPAD[x]	Vine length (cm)	SPAD[x]	NO_3^--N ($mg \cdot L^{-1}$)	K^+ ($mg \cdot L^{-1}$)
Cover crop (C)						
No cover	262.8	51.8	356.6	46.6	771.5 A[w]	2111.2 B
Rye	265.6	44.3	327.7	45.5	339.2 B	3572.2 A
Rye-vetch	243.1	51.0	316.9	47.9	318.0 B	3755.7 A
Tillage (T)[v]						
CT	282.4 a	46.3 b	356.9 a	48.2 a	566.3 a	2711.1 b
ST	231.9 b	51.8 a	301.6 b	45.1 b	386.1 b	3581.6 a
Significance						
Cover crop	ns	ns	ns	ns	0.0008	0.0005
Tillage	0.0015	0.0231	0.0005	0.0412	0.0003	0.0001
C × T	ns	ns	ns	ns	0.0023	ns

[z]In 2015 SPAD and vine length were measured on 25 Aug.
[y]In 2016 SPAD and vine length were measured on 19 Aug., petiole sap measurements were taken on 17 Aug.
[x]Data were log-transformed for analysis and converted to original values for presentation.
[w]Within each year mean separation of cover crop (uppercase letters) and tillage (lowercase letters) in columns is based on least significant difference at $P < 0.05$. Within each column and factor labels not containing the same letter are different. ns = non-significant.
[v]CT=conventional tillage, ST=strip-tillage.

Table 2.9. Marketable muskmelon yield (weight and number of fruit) of muskmelon fruit as affected by cover crop and tillage treatments at the Horticulture Research Station, Ames, Iowa in 2015 and 2016.

Treatment	2015				2016			
	Marketable wt. ($Mg \cdot ha^{-1-}$)	Total wt. ($Mg \cdot ha\text{-}^{1}$)	Marketable no. ($no. \cdot ha\text{-}^{1}$)	Total no. ($no. \cdot ha^{-1}$)	Marketable wt. ($Mg \cdot ha^{-1}$)	Total wt. ($Mg \cdot ha^{-1}$)	Marketable no. ($no. \cdot ha^{-1}$)	Total no. ($no. \cdot ha^{-1}$)
Cover crop (C)								
No cover	17.4	44.4	2545	6770	40.2	58.3 A[z]	4831 AB	7146 A
Rye	23.7	46.2	3287	6871	34.7	44.3 B	4161 B	5408 B
Rye-vetch	17.4	43.3	3093	6734	43.3	51.5 AB	5461 A	6598 A
Tillage (T)[y]								
CT	23.8 a	48.6 a	3074	6755	42.5 a	59.3 a	5237 a	7484 a
ST	12.8 b	40.7 b	2876	6835	36.1 b	43.4 b	4398 b	5278 b
Significance								
Cover crop	ns	ns	ns	ns	ns	0.0062	0.0080	0.0016
Tillage	0.0250	0.0051	ns	ns	0.0341	<0.0001	0.0125	<0.0001
C × T	ns	ns	ns	ns	ns	ns	ns	ns

[z]Within each year mean separation of cover crop (uppercase letters) and tillage (lowercase letters) in columns is based on least significant difference at $P < 0.05$. Within each column and factor, labels not containing the same letter are different. ns= non-significance.

[y]CT=conventional tillage, ST= strip-tillage.

Table 2.10. Microbial functional diversity of the in-row areas of muskmelon plots as affected by cover crop and tillage at the Horticulture Research Station, Ames, IA in 2015 and 2016. Data obtained from Biolog-EcoPlate® incubated for 168 h.

Treatment	2015[z]				2016[y]			
	Shannon-Wiener Index	Evenness	Richness	AWCD	Shannon-Wiener Index	Evenness	Richness	AWCD
Cover Crop (C)								
No cover	1.49	1.00	16	0.01	1.26 B	0.85 B[x]	24	0.30
Rye	1.58	1.06	17	0.04	1.47 A	0.98 A	24	0.39
Rye-vetch	1.60	1.07	17	0.06	1.43 A	0.96 A	23	0.30
Tillage (T)[w]								
CT	1.54	1.03	17	0.04	1.39	0.93	24	0.37
ST	1.57	1.05	16	0.02	1.39	0.93	22	0.30
Significance								
Cover crop	ns	ns	ns	ns	0.0143	0.0143	ns	ns
Tillage	ns	ns	ns	ns	ns	ns	ns	ns
C×T	ns	ns	ns	ns	ns	ns	ns	ns

[z]Soil Samples collected on 16 Sept. 2015.

[y]Soil Samples collected on 14 Sept. 2016.

[x]Within each year mean separation of cover crop (uppercase letters) and tillage (lowercase letters) in columns is based on least significant difference at $P < 0.05$. Within each column and factor labels not containing the same letter are different. ns = non-significance.

[w]CT= conventional tillage, ST= strip-tillage.

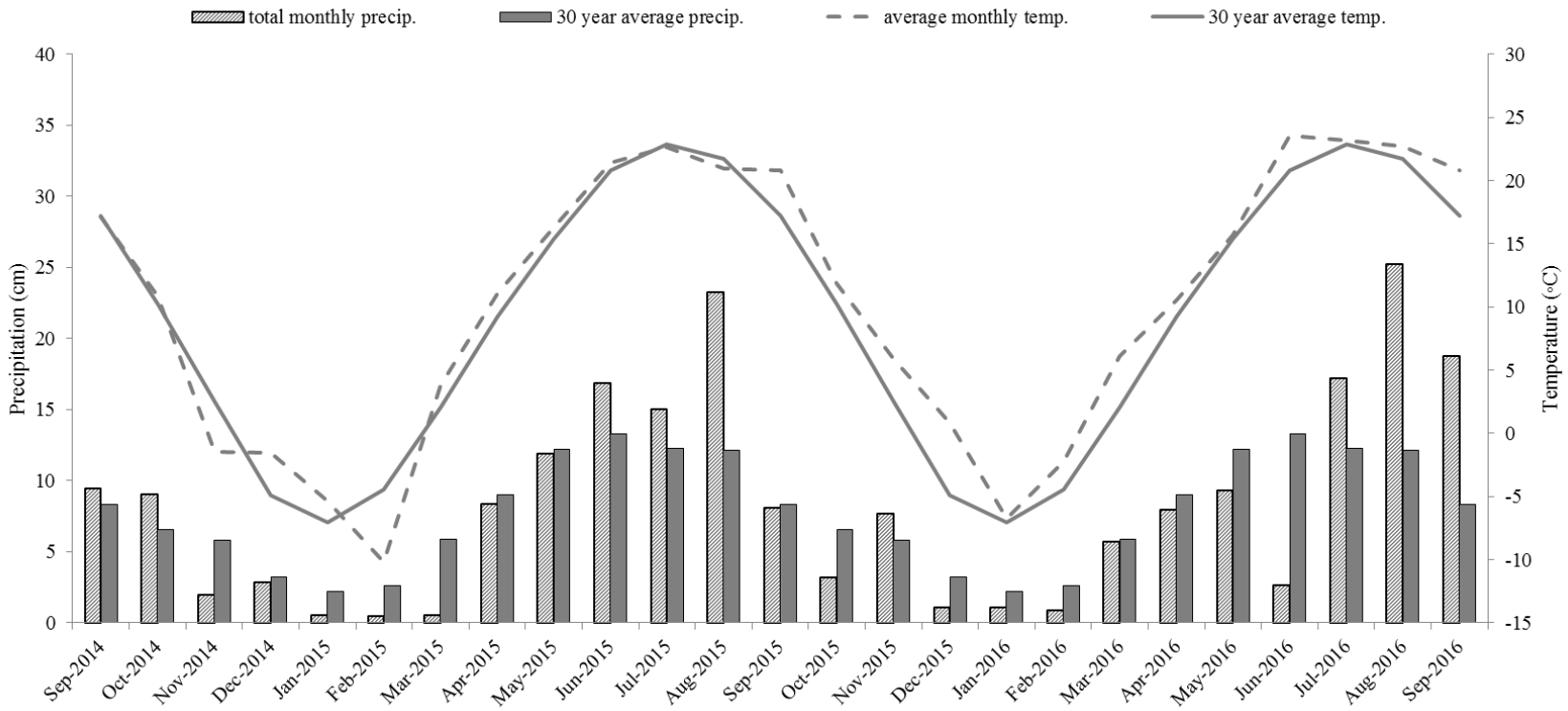

Fig. 2.1 Average monthly air temperature and total monthly precipitation from Sept. 2014-Sept. 2016 compared to 30-year averages in Ames, IA. Average monthly temperature and total monthly precipitation data obtained from Iowa Environmental Mesonet Network, Iowa State University. Data for 30-year averages obtained from National Centers for Environmental Information, National Oceanic and Atmospheric Administration.

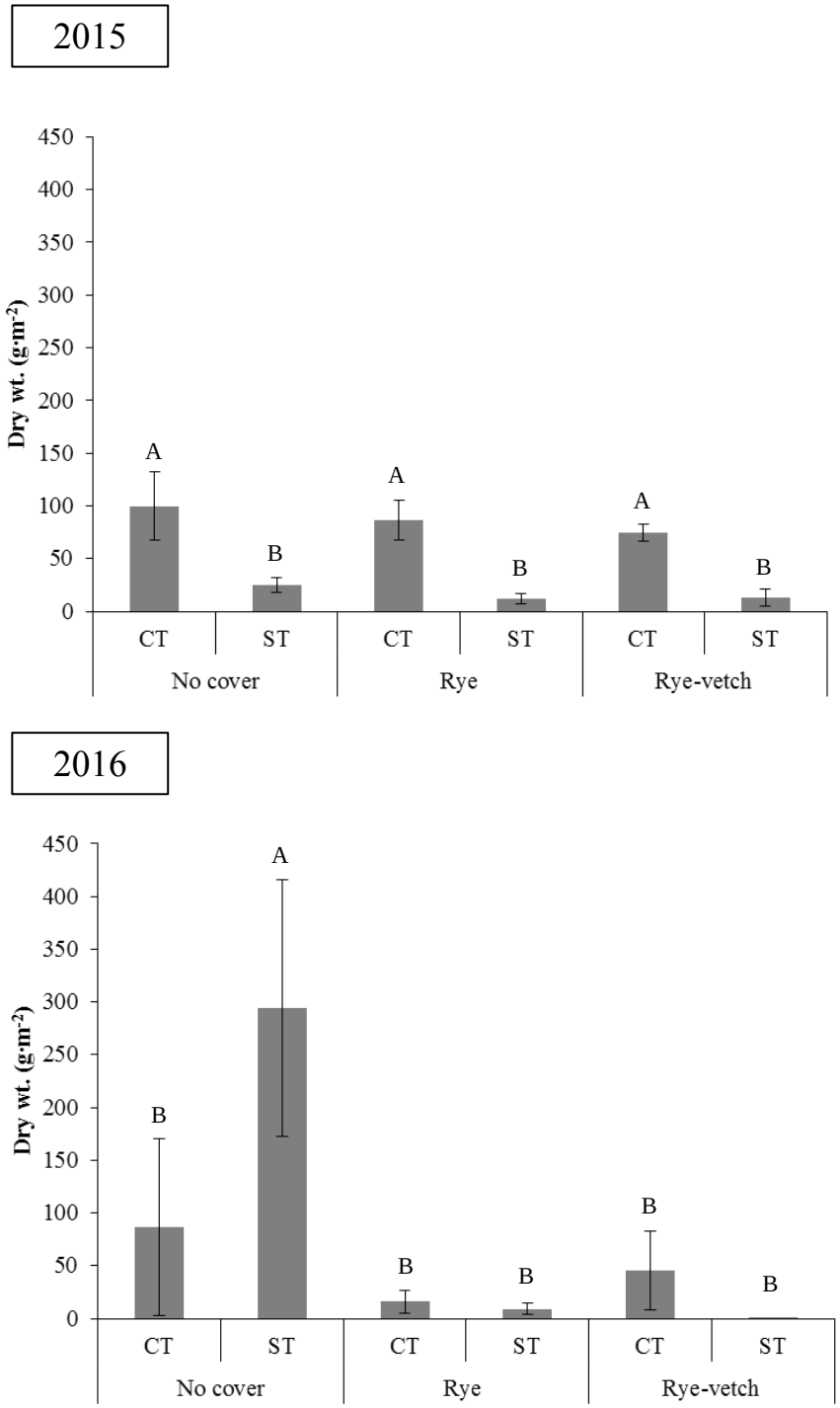

Fig. 2.2. Weed dry weight biomass from the between row area of muskmelon plots, as affected by cover crop and tillage (CT=conventional tillage, ST=strip-tillage) in 2015 (above) and 2016 (below), at the Horticulture Research Station, Ames, IA. Within each year mean separation based on least significant difference at $P < 0.05$. Within each year labels not containing the same letter are different. ns = non-significant. Error bars represent standard error of the mean.

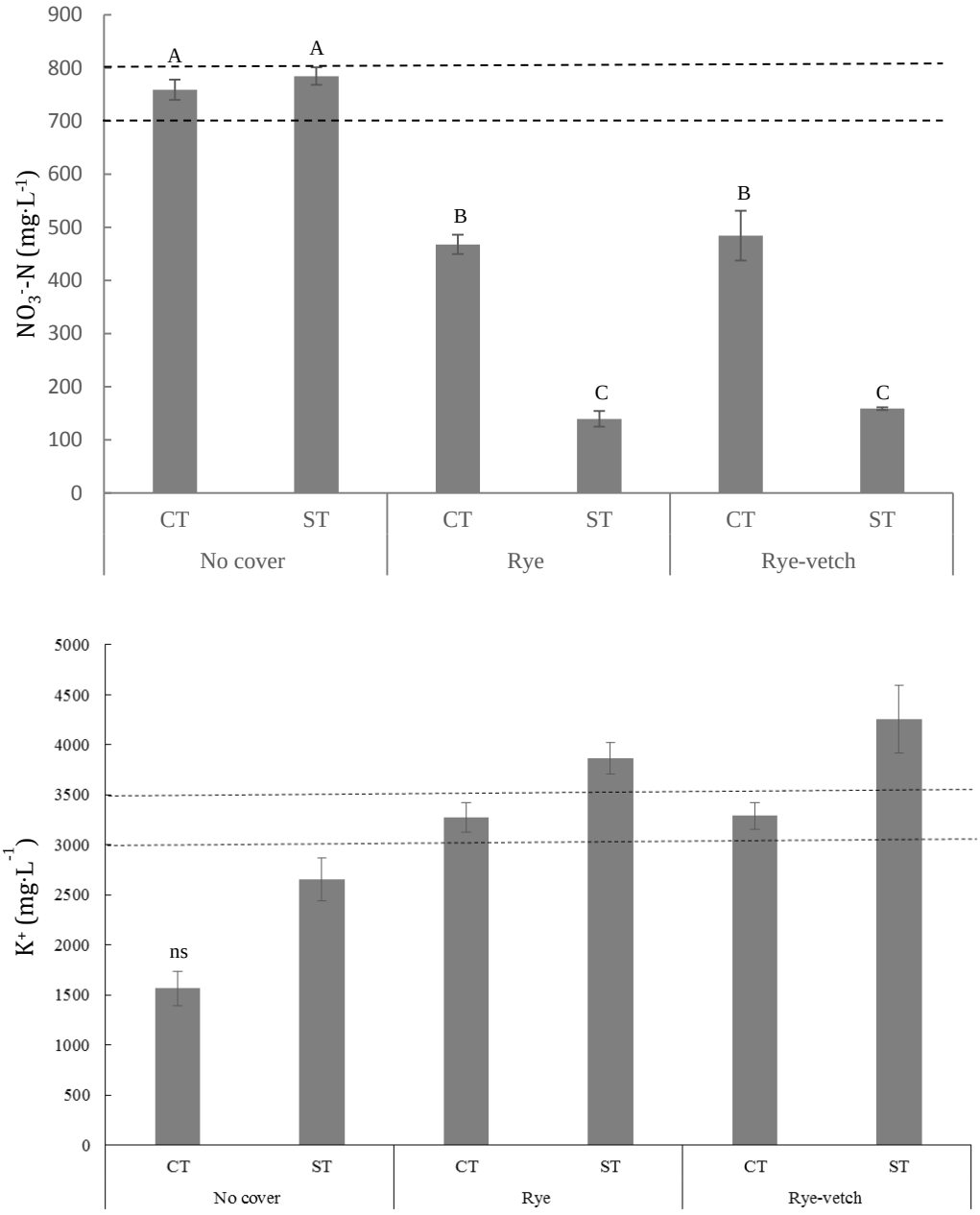

Fig. 2.3. Interaction effects of nitrate-nitrogen and potassium ion concentrations in muskmelon petiole sap as affected by cover crops and tillage (CT=conventional tillage, ST=strip-tillage) sampled on 18 Aug. 2016 at the Horticulture Research Station, Ames, IA. Mean separation of NO_3^--N (uppercase letters) and K^+ (lowercase letters) based on least significant difference at $P < 0.05$. Labels not containing the same letter are different. ns = non-significant. Error bars represent standard error of the mean. Horizontal dashed line represent upper and lower limits of sufficiency ranges for NO_3^--N (700-800 mg·L^{-1}) and K^+ (3000-3500 mg·L^{-1}) as recommended by Hochmuth et al. (1991) .

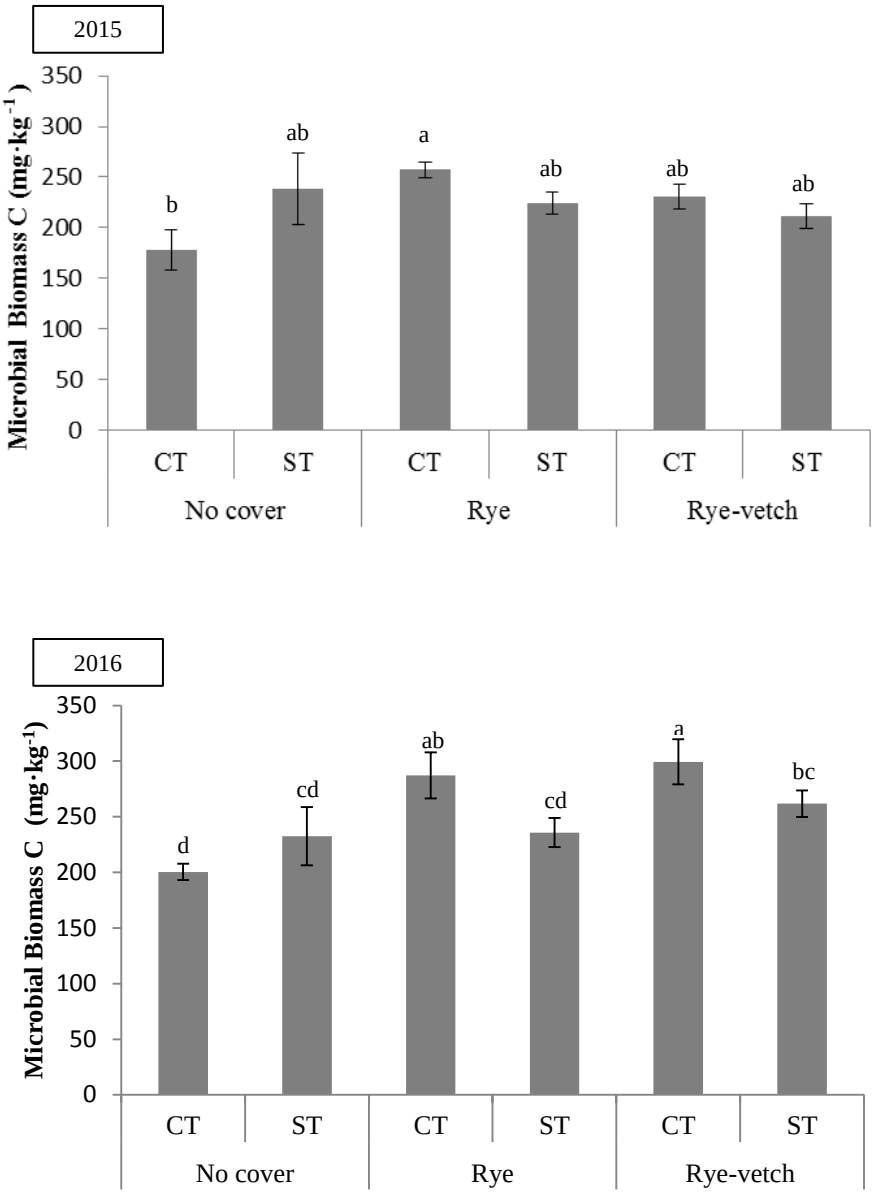

Fig. 2.4 Microbial biomass carbon of the in-row area as affected by cover crops and tillage (CT= conventional tillage, ST= Strip-tillage) in 2015 (left) and 2016 (right) at the Horticulture Research Station, Ames, Iowa. Within each year, bars with labels not containing the same letter are significantly different according to least significant difference ($P < 0.05$). Error bars represent standard errors of means.

CHAPTER 3. COVER CROP BASED STRIP-TILLAGE FOR MUSKMELON PRODUCTION: YIELD, FRUIT QUALITY, AND FOOD SAFTY

Modified from a paper to be submitted to *HortScience*

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Abstract

Using a roller-crimper to terminate cover crops in strip-tillage (ST) systems has the potential to improve soil health and reduce weed pressure for vegetable production, but other benefits unexplored. We examined the potential for cover crop-based strip-tillage to enhance fruit quality of netted muskmelon (*Cucumis melo* L.) and prevent contamination with soilborne human pathogens. We used three cover crop treatments: no cover, a cereal rye (*Secale cereal*e L.) monoculture and a cereal rye and hair vetch (*Vicia villosa* Roth) biculture. For each cover crop treatments two tillage treatments were used, conventional tillage (CT) and strip-tillage (ST). *Listeria innocua*, a non-pathogenic surrogate for the human pathogen *Listeria monocytogenes* was applied to the soil either in Oct., following cover crop seeding or in May. The experimental design was a split-split-plot; cover crop was the whole-plot factor, tillage was the subplot factor, and month of *L. innocua* application was the subsubplot factor. Data was collected on yield, fruit dimensions, soluble-solid concentration, survival of soilborne *L. innocua*, and incidence of fruit contamination with *L. innocua.* Yield was increased under CT, though ST increased the proportion of marketable fruit. In 2016, ST as well as cereal rye and cereal rye-hairy vetch

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increased soluble-solid concentration and produced more spherically shaped fruits. In cereal rye plots, flesh thickness of muskmelon fruit was greater than no cover for only one year. Winter survival of Oct.-applied *L. innocua* was high, and ranged from 88% to 100% for all cover × tillage treatments for both years. For data collected in 2015 only, soilborne *L. innocua* was eliminated from cereal rye and cereal rye-hairy vetch plots, but persisted in no cover plots. Treatments had no effect on contamination of fruit by soilborne *L. innocua* for either year; frequency of contamination ranged from 0% to 22%. An economic analysis had mixed results, no cover-ST plots had the lowest profit in both years, and cereal rye-ST and cereal rye-hairy vetch-ST out performed their respective CT treatments in one year.

Introduction

Muskmelon is an important crop for both wholesale and fresh market sale in Iowa. This orange-fleshed, odorous, sweet-flavored melon, commonly referred to as cantaloupe, is a high-value crop; 2016 U.S. fresh-market sales were valued at $208 million (USDA-NASS, 2017). Muskmelon is consistently among the top-consumed fresh produce items in the U.S.; 2015 per-capita consumption was 3.1 kg (USDA-ERS, 2016). Muskmelons are commonly grown using conventional tillage (CT; e.g. plowing, rototilling, disking) and plasticulture. Plasticulture uses a film of polyethylene plastic mulch, often black, to cover the soil. Black plastic mulch absorbs solar radiation, increasing root-zone temperature, and increases muskmelon yield in Iowa (Taber, 1993) and other regions (Nesmith, 1997, Ibarra et al., 2001, Lamont, 1993). However, CT, which is necessary for installation of plastic mulch, can increase soil erosion (Montgomery, 2007) and reduce microbial biomass, total soil C, and aggregation (Roper et al., 2010). Strip-tillage (ST), a less intensive technique than CT invloves tilling only a 15- to 30- cm-wide strip where the crop is planted; and the remainder of the field is undisturbed. Researchers are

interested in ST as a way to improve seedbed conditions over no-till while avoiding downsides of CT. ST can lower the cost of tillage operations (Luna and Staben, 2002), which could lead to increased profit if adequate yields are maintained. Recently, cover crop mulches have been investigated as means to address the challenges of weed control in ST vegetable systems. Using a roller-crimper, cereal rye (hereupon refered to as rye; *Secale cereale* L.) can be effectively terminated at anthesis (Ashford and Reeves, 2003), and hairy vetch (hereupon refered to as vetch; *Vicia villosa* Roth) at early-pod stage (Mischler et al., 2010). The result is a thick mulch that can protect the soil, suppress weeds, and limit contact of muskmelon fruit with the soil.

Growers benefit from producing high-quality fruits with attributes that align with consumer preference. A detailed assessment of muskmelon fruit quality often includes ratings by a sensory panel, as well as instrumental analysis of nutritional content (Vallone et al., 2013). However, these evaluations are costly and inaccessible to growers and consumers. Determination of soluble-solid concentration (SSC) with a refractometer gives growers a practical and relatively inexpensive indication sugar content and fruit quality. Kader (2002) recommended a minimum SSC of 9% for fruits of muskmelon, which do not have starch reserves that can be converted to sugars post-harvest. Therefore, the fruit derives all accumulated sugars in the edible mesocarp (flesh) from current photosynthate in the leaves (Hulme, 1971). For this reason, fruit quality can be greatly affected by pre-harvest environmental and soil conditions (Bouwkamp et al., 1978, Bett-Garber et al., 2005). To our knowledge, effects of ST on fruit quality of muskmelon have not been investigated, though Leskovar et al. (2016) showed that ST increased SSC for watermelon (*Citrullus lanatus* L.).

As consumer preference continues to drive the consumption of fresh produce for health benefits, muskmelons may serve as a vector for foodborne-illness. Fresh produce causes more

foodborne-illness outbreaks than any other food category (Fischer et al., 2015). Muskmelons have been associated with foodborne-illness outbreaks of *Escherichia coli* O157: H7 (Del Rosario and Beuchat, 1995), *Salmonella* (CDC, 2002), Norovirus (Iversen et al., 1987), and *Listeria monocytogenes* (CDC, 2011, McCollum et al., 2013). The moderate food safety risks of muskmelon consumption are attributed to several factors: the fruit is in contact with the soil throughout the growing season, the netted rind is difficult to wash and sanitize, fruits are eaten raw, fruits are rarely washed by consumers, and the moderate flesh pH does not discourage microbial growth. In the years 1998-2015, foodborne-illness outbreaks associated with muskmelon have resulted in 39 individual outbreaks, 1547 illnesses, 364 hospitalizations, and 40 deaths (CDC, 2015). A 2011 outbreak of *L. monocytogenes* of contaminated whole muskmelons from a farm in Colorado resulted in 33 fatalities (McCollum et al., 2013). The *L. monocytogenes* bacterium causes Listeriosis, a potentially fatal illness (Farber and Peterkin, 1991b). Of concern for producers and consumers of muskmelon is the ability of *L. monocytogenes* to function as a saprophyte, living in the soil and among decaying plant matter (Welshimer and Donker-Voet, 1971, Welshimer, 1960). Soil and crop residue within produce fields may act as a reserve for *L. monocytogenes*, increasing risks of pre-harvest contamination (Strawn et al., 2013). Survival of *L. monocytogenes* depends on soil texture, pH, temperature, and background microflora (Dowe et al., 1997, Welshimer, 1960, McLaughlin et al., 2011b, Locatelli et al., 2013). Locatelli et al. (2013) identified the basic cation saturation ratio as the main soil chemical characteristic that determined short-term survival (< 14 d) of *L. monocytogenes*, whereas soil texture was the main variable explaining long-term survival (< 84 d). In this study, to understand how *L. monocytogenes* may respond to field conditions, we used the non-pathogen surrogate *Listeria innocua*. The *L. innocua* bacterium has been used as an indicator species for *L. monocytogenes*

in laboratory experiments and shows similar survival tendencies in the soil (McLaughlin et al., 2011b).

Because the ecology of soilborne *L. monocytogenes* is not well understood, there is a need for on how agricultural management and regional weather affect pathogen survival. Produce growers have inadequate access to science-based recommendations for managing soilborne human pathogens in produce fields. Some guidelines have been modified from the National Organic Program standards, which restricts the number of days that must pass between the application of non-composted animal manure and crop harvest (USDA-AMS, 2017). However, these wait periods may limit the likelihood of detecting manure-derived organisms on fresh produce but are unlikely to guarantee their absence (Ingham et al., 2004). The Food Safety and Modernization Act (FSMA) does not set specific time intervals for how soon before harvest non-composted animal manure may be applied to produce fields. Initially, FSMA imposed a nine-month wait period between applications of untreated biological soil amendments of animal origin (e.g. raw manure) and crop harvest but has since rescinded that requirement after criticism over its efficacy and practicality (Yang and Swinburne, 2016).

We investigated whether ST and a rolled cover crop mulch can impact food safety, fruit quality, and yield of muskmelon. An objective was to determine the effects of ST on SSC, fruit dimensions, and flesh thickness of fruits. We investigated the survival of soilborne *L. innocua* populations introduced in Oct. and exposed to winter conditions, as well as soilborne populations introduced in May, the month before planting. We hypothesized that a rolled cover crop mulch will prevent contamination of fruits by providing a physical barrier from soil contaminated with *L. innocua*.

Materials and Methods

Site description

The study was conducted at the Iowa State University Horticulture Research Station in Ames, IA, USA (lat. 42°06'24.4"N long. 93°35'22.5"W) over two growing seasons, 2014-15 and 2015-16. Because cover crops for the second year of the study needed to be planted before muskmelon harvest had been completed for the first, two different, yet similar sites were used. Soil at both sites was a Clarion Loam, moderately well drained, fine-loamy, Typic Hapludoll on a 2% to 6% slope. At the time of cover crop planting soil at the 2014-15 site pH and soil organic matter ranged from 5.6 to 6.3, and 2.2% to 2.9 % respectively. Before this study, the 2014-15 site was in a rotation of conventionally managed corn (*Zea mays* L.) and soybeans (*Glycine max* L.). At the time of cover crop planting, soil at the 2015-16 site generally had more acidic soil, with more soil organic matter. The pH and soil organic matter ranged from 5.1 to 6.5, 2.6% to 3.7% respectively. Before the 2015-16 study, a Persian (Carpathian) walnut (*Juglans regia* L.) trial, removed in 2009, and a rotation of conventionally managed corn and soybeans, from 2009-2014, occupied the site. Sorghum-sudangrass (*Sorghum bicolor L.* × *Sorghum bicolor L.* var. *sudnaese*) cover crop was established in June 2015 and terminated in Aug. 2015 before seeding cover crops for this study in Sept. 2015.

Experimental design

The design was a split-split-plot with four replications. The whole-plot factor was cover crop with three levels, no cover, a monoculture of ‘Wheeler’ rye and a biculture of rye and ‘Purple Bounty’ vetch. The subplot factor was tillage with two levels, CT and ST. Subsubplots factor was the month plot soil was populated with *L. innocua*, Oct.-applied or May-applied. Whole-plot dimensions were 12.2 m × 16.8 m in 2014-15. Whole-plot dimensions were

increased to 13.7 m × 16.8 m in 2015-16 to include a 1.5-m drive for equipment between subplots. Each subplot was 6.0 m wide and consisted of two 7.6-m-long rows spaced 3.0 m apart on-center, plants were spaced 0.6 m apart within the row. Subsubplots were 3.0 m wide, and consisted of a single 7.6-m-long row. Row spacing for commercial muskmelon fields is between 1.2 and 1.8 m (Egel et al., 2014). For this study, we increased row spacing to separate subsubplots further and prevent effects of *L. innocua* in adjacent subsubplots. Experimental units consisted of 13 muskmelon plants in 7.6-m-long rows.

Field implementation

A timeline of field operations is summarized in Table 3.1. On 18 Sept. 2014 and 16 Sept. 2015 the entire field was rototilled with a Terra Force GM102 rotary tiller (Terra Force, Inc., Carrollton, TX). Immediately after tillage, cover crops were planted with a 107-cm-wide drop spreader (Anertec & Gandy Co., Owatonna, MN). For plots in a monoculture, rye was seeded at 123 $kg \cdot ha^{-1}$. Plots in a biculture of rye-vetch were seeded at 100 $kg \cdot ha^{-1}$ and 28 $kg \cdot ha^{-1}$ respectively. Shortly before planting, vetch seeds were inoculated in a slurry of deionized water and N-DURE rhizobium inoculant (*Rhizobium leguminosarum* biovar *viceae*, INTX Microbials LLC, Kentland, IN) and allowed to air dry. After seeding, the soil was rototilled to a depth of 5 cm to incorporate seeds, and lightly compacted with a 1.5-m cultipacker to optimize seed-to-soil contact.

A Hiniker 6000 strip-tiller (Hiniker Co., Mankato, MN) was used for ST plots to terminate cover crops and create a 30-cm-wide strip on 22 Oct. 2014 and 23 Oct. 2015. By tilling strips in the fall, at the early stages of cover crop establishment, the growth of cover crop in the in-row area was reduced. Fall tillage of ST plots increased the efficiency of residue removal from the in-row area at the final tillage event in the spring. We terminated rye and

vetch in ST plots on 1 June 2015 and 2 June 2016 using a 3.2-m roller crimper (I & J Manufacturing, Gap, PA). Cover crops were rolled a second time one week later to ensure adequate termination. Glyphosate (CropSmart® Glyphosate 41%, Cropsmart LLC., Morrisville NC) was applied to the entire areas of no cover-ST plots on 27 May 2015, and 5 June 2016. This post-emergence, broad-spectrum herbicide was applied to terminate weeds that had grown in the absence of a cover crop while maintaining no-till conditions in the between-row area of no cover-ST plots. After glyphosate injury had become visually apparent, entire no cover-ST plots were mowed and treated with Clomazone (Command 3ME, FMC Corporation, Philadelphia, PA), a pre-emergence herbicide on 12 June 2015 and 10 June 2016. The Hiniker 6000 strip-tiller was used to perform the final tillage and create the seedbed for planting for all ST plots on 7 June 2015 and 9 June 2016.

We used trickle irrigation was used for all plots. Drip-tape (John Deere T-Tape 502-12-220, John Deere Irrigation, Moline, IL) was placed 10-12 cm below the soil surface in all plots. For ST plots, drip-tape was installed by hand on 9 June 2015. On 9 June 2016, drip-tape was installed using a custom build implement consisting of a fluted coulter, a shank modified to bury drip-tape followed by closing discs. Clomazone was applied to the exposed soil in the tilled strips of all ST plots on 12 June 2015 and 10 June 2016.

For CT plots, cover crops and overwintering weeds were terminated using a Rhino flail mower (Alamo Group Inc., Seguin, TX) three weeks before planting on 22 May 2015, and 24 May 2016 and immediately incorporated into the soil using a rototiller. We used plasticulture on all CT plots. The CT plots were rototilled a second time immediately before the installation of drip-tape and raised beds covered in polyethylene black plastic mulch on 10 June 2015, and10 June 2016.

‘Aphrodite’ muskmelon seeds treated with Mefenoxam, Thiamethoxam, Azoxystrobin, and Fludioxonil (Syngenta Seeds, Minneapolis, MN) were sown on 21 May 2015, and 10 May 2016, into 72-cell flats filled with LC1 soilless potting mix (Sun Gro Horticulture Canada Ltd, Seba Beach, AB, Canada). Seedlings were fertigated weekly during the first 2 w of growth with a water-soluble fertilizer (17N-5P-19K; J.R. Peters, Inc., Allentown, PA) and then every 5 d until transplant. Seedlings were moved outdoors 7 d before being transplanted into the field; all transplanting was done by hand on 16 June 2015, and 13 June 2016. All plots received an imidacloprid (Admire Pro, Bayer Crop Science, Research Triangle Park, NC) soil drench the day of transplanting to manage emerging striped cucumber beetle (*Acalymma vittata* F.).

Crops were scouted weekly for signs of arthropod and disease pests. In 2016 the MELCAST disease forecasting system (Latin, 2001) was used to determine the timing of preventative fungicide sprays during the first 8 w of crop growth in the field. Though the system is suitable for forecasting alternaria leaf blight [*Alternaria cucumerina* (Ellis & Everh.)], anthracnose [*Colletotrichum orbiculare* (Berk. & Mont.)], and gummy stem blight *[Didymella bryoniae* (Auersw.)], it is ill-suited for diseases that are typically a problem late in the season and near harvest such as downy mildew [*Pseudoperonospora cubensis* (Berk. & M.A. Curtis)] and powdery mildew [*Sphaerotheca fuliginea* (Schlechtend.:Fr.)]. In Aug. 2015 symptoms of powdery mildew were observed. In Aug. and Sept. 2015 symptoms of water-soaked lesions on fruit and fruit found after periods of heavy rain and wet field conditions. In both years spotted and striped cucumber beetles (*Diabrotica undecimpunctata* L. and *Acalymma vittatum* F., respectively) were major arthropod pests. The threshold for chemical control of cucumber beetles was an average of one beetle per plant.

Muskmelon yield

Muskmelons were harvested at half-slip two to three times per week from 21 Aug. - 15 Sept 2015 for a total of seven harvests and 12 Aug - 13 Sept. 2016 for a total of 11 harvests. Fruits were classified as marketable or non-marketable, counted, and weighed. In 2015 marketable fruits were weighed in batches, whereas in 2016 marketable fruits were weighed individually. Individual fruits were considered marketable if they were uniform in shape and free from defects described in (USDA-AMS, 2008): cracks, bruises, scars, insect damage, soft spots, rot.

Muskmelon fruit quality

On 8 - 10 Sept. 2015 and 1 - 3 Sept. 2016 four randomly selected marketable fruits from each cover × tillage subplot were assessed for quality within 24 h of harvest. Fruit density was determined by measuring mass as well as the volume of room-temperature water each fruit displaced. Volume was determined by measuring the volume of water each fruit displaced. Fruits were submerged in a 19-L bucket that had been modified to divert overflow water into a collection container; displaced water was measured. After fruits were cut in half longitudinally, we measured fruit and cavity length (longitudinal diameter) as well as fruit and cavity width (equatorial diameter). Fruit shape (S), a unitless ratio, and flesh thickness (T) were determined (Davis et al., 1967).

$$S = \frac{\text{fruit length (cm)}}{\text{fruit width (cm)}} \text{ and } T = 0.5[\text{fruit width(cm)} - \text{cavity width(cm)}]$$

The SSC of individual muskmelons was determined with a digital refractometer (Pocket Pal-1 refractometer; Atago, Tokyo, Japan). An equatorial flesh sample of approximately 15 g,

directly adjacent and inferior to the seed cavity, was taken from each fruit. From each sample juice was extracted with a handheld garlic press, and immediately measured for SSC.

Listeria innocua *inoculation and analysis*

Fields were inoculated with *L. innocua* on 15 Oct. 2014 and 1 Oct. 2015 for the Oct.-applied treatments. The May-applied treatments were inoculated before cover crop termination on 15 May 2015 and 20 May 2016. Preparation and application of the inoculation solution were similar for all treatments. The *L. innocua* cells were combined with deionized water to obtain an inoculation solution of 3.1 ± 0.2 log CFU·mL^{-1} (mean ±standard deviation). The solution was applied with a modified 7.6-L handheld garden sprayer (Smith Performance Sprayers, New York Mills, New York). Walking down the center of each 7.6-m-long subsubplot, we made approximately 10 evenly spaced applications along the 3.0-m width of the subsubplot. This process was repeated approximately every 0.7 m along the 7.6-m length of the subsubplot. For each application, the nozzle of the sprayer was put in direct contact with the soil before inoculation solution was expelled. Field soil from each subsubplot then was analyzed 3 d after applying the solution to ensure successful inoculation. Averaged across both years, and for all treatments, mean inoculum level 3 d after application was 2.7 ± 0.2 log CFU·mL^{-1}. Detection and quantification of *L. innocua* for all sample types (i.e. soil, cover crop residue, and muskmelon rind) followed the similar procedures of collection, enrichment, detection, and enumeration of positive samples by direct plating on agar selective for Listeria spp. From the surface of each subsubplot, approximately 120 g of soil was collected into sterile bags (write-on sterile sampling bags, 3M Inc., St Paul, MN) with sanitized plastic spoons. From this composite soil sample 10 g of soil was stomached for 1 min with 90 mL of VIDAS® UP Listeria broth (LPT; bioMérieux, Marcy-l'Etoile, France) in a stomacher bag (3M Inc., St Paul, MN) and

incubated at 30 °C for 24 to 26 h. A 0.5 mL aliquot was then pipetted into each well of VIDAS® UP Listeria strips (bioMérieux, Marcy-l'Etoile, France), and placed on VIDAS® Heat & Go for 5 min. Prepared VIDAS® UP Listeria strips were then assayed with a VIDAS® automated immunoassay system. Soil samples that returned a positive result from the assay were subsequently plated for enumeration. For soil, 10 g received a serial dilution in buffered peptone water (HiMedia) and was directly plated onto modified Oxford agar (MOX; Difco, BD, Sparks, MD) with TSA overlay. The inoculated plates were then incubated at 35 °C for 24 h. Colonies that were round, black and surrounded by a black zone were counted. Using the same method, winter survival of *L. innocua* from each Oct.-applied subsubplot was determined on 14 May 2015 and 23 May 2016. The summer survival of *L. innocua* from each May-applied subsubplot was determined on 15 June, 15 July, and 18 Aug. 2015. Because of high cost of detection and enumeration, summer survival of May-applied soilborne *L. innocua* was only considered in 2015.

On 15 Sept. 2015 and 6 Sept. 2016 muskmelon fruits were analyzed for the presence of *L. innocua* on the exterior rind with a method modified from Svoboda et al. (2016). Two marketable, mature fruits from each subsubplot were harvested and placed into individual plastic bags, we used a new pair of latex gloves for each fruit harvested. In 2015 fruits were immediately transported to the laboratory for analysis, in 2016 fruits were stored at 2 °C for 18 h before analysis. Muskmelon rind was sampled by removing cores of ring and flesh with a steel apple corer (Mercer Cutlery, Deer Park, NY). Orange and green flesh was removed with a sterilized knife and discarded. The two fruits from each subsubplot were analyzed as a single sample. Muskmelon rind (50 g) was collected, mixed, and segregated into two 25 g aliquots. One aliquot was stored in a sterile plastic bag for subsequent enumeration. In a sanitized

commercial blender (Oster, Sunbeam Products, Boca Raton, FL) the second rind aliquot was homogenized with 225 mL of VIDAS® UP Listeria broth for 1 min. The homogenate was then poured into a stomacher bag and incubated at 30 °C for 24 to 26 h. Detection of *L. innocua* on muskmelon rind was similar to soil samples; the incubated aliquots were assayed, and positive results were plated for enumeration. For enumeration, the unused aliquot was placed in a sanitized commercial blender and homogenized with 225 mL of buffered peptone water for 1 min, serial diluted in buffered peptone water, and immediately plated.

The same day fruits were analyzed, samples of cover crop mulch were taken to the lab for detection of *L. innocua.* For rye-ST and rye-vetch-ST, four cover crop mulch samples were collected from a 20- × 20-cm area from each subsubplot and combined into a single sample. Similar to soil samples, 10 g of cover crop mulch was placed into a stomacher bag with 90 mL of VIDAS® UP Listeria broth for 1 min and stomached for 1 min before VIDAS® automated immunoassay system detection and enumeration by plating on selective MOX agar.

Economic analysis

Enterprise budgets were prepared from Chase (2011) to estimate costs and returns for each combination of cover and tillage combination, irrespective of *L. innocua* application. Wholesale price ($322.90 per Mg marketable fruit) was based on the three-year average of U.S. fresh market cantaloupe prices (USDA-AMS, 2017). Direct market price ($3.70 per marketable fruit) is the average price of individual cantaloupe from ten Iowa farmers' markets (USDA-AMS, 2016). Input costs consist of cover crop seed, muskmelon seed, seedling trays, potting mix, drip-tape, plastic mulch, fertilizer, herbicide, insecticide, and fungicide costs. Equipment and ownership costs include farm machinery, greenhouse overhead, irrigation equipment, and land-rent. Costs associated with ownership and operation of farm equipment were determined

using the method of Edwards (2015). Greenhouse overhead costs per 0.09m^2 per week were $0.267 (Brumfield, 1992). Land-rent price ($575 per ha) was based on 2016 state averages for Iowa (Plastina et al., 2016). Records were kept for time elapsed during transplanting, fertigation, and weeding events to determine pre-harvest labor costs. To reflect differences in marketable yields between treatments, harvest costs per kg-marketable fruit were adjusted to $0.222 (Ogbuchiekwe et al., 2004). Interest expense was based on a 6 month loan for input costs, equipment and ownership costs, pre-harvest labor, and harvest costs at 5.5% interest. Wholesale and direct market profit was determined by subtracting costs from respective gross revenue.

Statistical analysis

All data were analyzed using SAS (version 9.4; SAS Institute, Cary, NC). For all data with numerical independent variables (i.e. yield and fruit quality), analysis of variance (ANOVA) was performed using proc GLIMMIX with type three sums of squares, and the Satterthwaite adjustment was used for degrees of freedom. Means separation was carried out using the "lsmeans" and "pdiff" statements. Significance was considered < 0.05 for all variables. Because there were significant interactions with year, the data from each year were analyzed and presented separately. Yield and fruit quality data were initially analyzed as a split-split-plot design, block was included as a random factor, tillage, cover crop, and inoculation month were considered fixed. As expected, there was no effect of inoculation month on yield or fruit quality. These data were then analyzed and are presented as a split-plot design, irrespective of inoculation month. Block was included as a random factor, while tillage and cover crop were considered fixed.

Binary categorical responses (positive or negative) from detection of *L. innocua* on fruit, on cover crop, and in soil with cover crop, tillage, and inoculation month as explanatory

variables were analyzed in SAS using proc LOGISTIC (Agresti, 1996). This logistic regression procedure was performed to determine if distributions of incidences differed ($P < 0.05$) as a result of cover crop, tillage, and inoculation month. The option SELECTION=FORWARD was used to identify significant main effects and interactions.

Results

Weather

In Feb. 2015 the average monthly air temperature was 5.8 °C lower than the 30-year average (Fig. 3.1). This deviation was largely due to several short cold periods late in the month. During the 2015 muskmelon growth period, the air temperature was similar to the 30-year average. During the entirety of the 2015-16 study the average monthly air temperature consistently exceeded the 30-year average. During both years of the study total monthly precipitation for the months of July and Aug. was above than the 30-year average. This increased rainfall resulted in saturated soil at the beginning of the muskmelon harvest period.

Muskmelon yield

Marketable yield and proportion marketable. Total weights of marketable muskmelon fruits were increased under CT during both years (Table 3.2). In 2016, CT led to more marketable fruits. In 2016, rye-vetch increased number of marketable fruits by 31% over those from rye. In 2016, there were main effects of both cover crop and tillage on the proportion of total fruits that were marketable by weight. The proportion of fruits marketable by weight in rye-vetch plots was 0.13 greater than the proportion for no cover plots. By number, a greater proportion of fruits were marketable in rye and rye-vetch than no cover plots. The marketable by number was greater in rye and rye-vetch than in no cover plots. ST increased the proportion of

fruits marketable by both weight and number by 0.12 and 0.05, respectively, over the proportion associated with CT. There were no interactions of cover and tillage for either year.

Weight distribution of marketable fruits. There were no main effects of cover or tillage on the number of fruits in the ranges ≤ 2.9 kg, 3.0 - 3.9 kg, or 4.0 - 4.9 kg (Table 3.3). However, CT increased the number of fruits ≥ 5.0 kg. Fruits harvested from CT plots were 0.4 kg larger than fruits in ST plots.

Muskmelon fruits quality

There were no differences in fruit density, fruit shape, flesh thickness, or SSC in 2015 (Table 3.4). In 2016, fruits harvested from rye and rye-vetch plots had a more spherical shape than those from no cover crop. Values for fruit shape of CT were 0.05 greater than those of ST. The flesh thickness of fruits harvested from rye plots was 0.6 cm greater than those harvested from no cover plots. SSC was greater for all treatments in 2016 than in 2015. Fruits from rye and rye-vetch had a combined SSC 0.9% greater than fruits from no cover. ST increased SSC of muskmelon fruits by 1.2% over CT.

Survival of soilborne Listeria innocua

Survival of Oct.-applied L. innocua. When tested the following May, there were no effects of treatments on winter survival of Oct.-applied *L. innocua* (Table 3.5). Across cover crop and tillage treatments, survival in 2015 ranged from 88% to 100% of plots testing positive. In 2016, 100% of plots inoculated in Oct. tested positive for *L. innocua* the following May. The concentration of inoculum recovered from the soil was much lower in 2015 than in 2016, and we were unable to develop a count (log CFU·mL^{-1}). In contrast, inoculum levels were much higher in 2016, average count across for treatments was 2.8±0.1 log CFU·mL^{-1}.

Survival of May-applied L. innocua. In 2015, 3 d after inoculating soil with *L. innocua,* 100% of plots tested positive and initial inoculum concentrations were 2.7±0.1 log CFU·mL^{-1} (Table 3.6). In June, July, and Aug. cover crops affected survival of soilborne *L. innocua;* there was a greater frequency of positive detecting *L. innocua* in no cover plots than rye and rye-vetch. In June 2015, mean inoculum concentrations for no cover, rye, and rye-vetch were 1.6, 1.5, and 1.6 log CFU·mL^{-1}, respectively. No rye or rye-vetch plots sampled in July or Aug. 2015 tested positive for *L. innocua.* In July and Aug., inoculum concentrations for no cover plots were 1.7±0.1 log CFU·mL^{-1} and 1.6±0.4 log CFU·mL^{-1}, respectively.

Presence of Listeria innocua *on fruit and cover crop mulch*

There were no main effects or interactions for the frequency of detecting *L. innocua* on the surface of fruits at harvest (Table 3.7). For both years and across all treatments, frequencies of positive detection ranged from 0% to 20%. Positive melon samples in 2015 had an average *L. innocua* concentration of 3.5±0.2 log CFU·mL^{-1} and in 2016 average concentrations were 5.5±0.3 log CFU·mL^{-1}. In 2015 and 2016 *L. innocua* was detected on a single sample of cover crop mulch from a rye-ST plot with May-applied *L. innocua,* concentration were 3.7 log CFU·ml^{-1} and 5.5 log CFU·mL^{-1}, respectively.

Economic analysis

In 2015 wholesale profit was greatest for the rye-CT ($996/ha.) and was lowest for no cover-ST ($2735/ha.; Table 3.8). The only other system resulting in a positive return for wholesale was rye-vetch-CT ($278/ha.). In 2015, only no cover-ST produced a negative profit for direct market sale (-$175/ha.), rye-ST produced the greatest direct market profit. In 2015, direct market profit for rye-vetch-ST was greater than rye-vetch-CT by $716/ha.

In 2016, no cover-CT resulted in the greatest profit for both wholesale ($1019/ha.) and direct market ($6292/ha.), whereas no cover-ST resulted in the lowest profit for both wholesale ($-2789/ha.) and direct market ($420/ha.; Table 3.9). For wholesale, rye-CT and rye-ST both resulted in negative profits of -$720/ha. and -$438/ha., respectively. Though rye-vetch produced positive profits for both CT and ST, values were much less than for no cover-CT. For rye and rye-vetch, CT increased direct market profits by an average of $1784/ha. over ST.

Discussion

We investigated the use of cover crops and reduced tillage to improve fruit quality, food safety, and profitability in an Midwest muskmelon production system. The performance of cover crop based ST showed mixed results; yield was reduced, some measures of fruit quality were improved, and contamination was not prevented.

The increased marketable muskmelon yield we observed under CT is consistent with the finding of previous studies comparing plasticulture based CT to ST (Tillman et al., 2015, Lilley and Sánchez, 2016). However, studies that have compared CT, without plastic mulch, to ST have shown increased yield of other cucurbit crops in ST [cucumber (*Cucumis sativus* L.) and watermelon (Wang and Ngouajio, 2008, Leskovar et al., 2016)] or produced similar yields [pumpkin (*Curcubitia pepo* L.), summer squash, (*Cucurbita pepo* L.), and winter squash (*Cucurbita pepo* L.) (Rapp et al., 2004, O'Rourke and Petersen, 2016, Hoyt, 1999, Walters and Kindhart, 2002)]. Because the contributions of plasticulture to plant growth and yield are lost in ST, cucurbit crops best-suited for ST production in the Midwest may be those that are not always grown in plasticulture systems such as winter squash and pumpkin.

The increase in the proportion of total fruit that were marketable under ST may be attractive to growers. Handling non-marketable fruits and removing them from the field can increase harvest labor costs, without increasing gross revenue. It is likely that the rolled cover crop mulch limited fruit contact with the soil. Though we did not collect data to measure this effect, fruits resting on a cover crop mulch appeared to be cleaner than those resting on the soil surface. Wyenandt et al. (2011) found that plots with a rye mulch often produced cleaner pumpkins that plots with bare soil.

In 2016, CT increased the number of marketable fruits weighing ≥ 5 kg in CT plots, and also increased average marketable fruit weight compared to ST. The greater number of heavy fruits from CT treatments caused the increased marketable yield observed in 2016. However, if growers do not have a market for large fruit, the decreased yield under ST production will not affect gross revenue and may be acceptable.

In our study, ST produced more spherical-shaped fruits with a higher SSC than CT, as did the use of a rye or rye-vetch cover crop compared to no cover. Flesh thickness for rye was increased over no cover. More rounded fruits, thicker flesh, and higher SSC are desirable for growers and consumers. Vegetable breeders have pursued the development of round-shaped melons in the past. Round fruits appear more symmetrical to consumers and pack well into boxes. While flesh thickness is difficult for consumers to assess when purchasing whole muskmelons, this quality may be important in the fresh-cut market. For honeydew melon (*Cucumis melo* L. inodorous group) SSC correlates highly with sensory panel ratings of sweetness and flavor, main indicators of quality (Lester and Shellie, 1992). These results show that despite a reduction in yield, ST may improve fruit quality, as might a rye or rye-vetch. The specific mechanisms of these changes in fruit quality are unknown. We speculate that changes in

soil conditions as a result of cover crop and tillage treatments affected plant growth, flowering, and ultimately physio-chemical aspects of fruit development that enhanced fruit quality. In Iowa, many growers rely on direct-market sales, and providing a high-quality product is important. In addition to the conservation benefits, ST and cover crops can improve fruit quality for growers in the Midwest.

During the winter in Iowa, soilborne *L. innocua* was capable of surviving, and was not affected by cover crop management. In Maryland, USA when organic fields were populated with *L. innocua* in the fall, the bacteria persisted and were recoverable the following spring (Reed-Jones et al., 2016). Contaminated water and animal manure are likely sources of human pathogens in produce fields. After a contamination event, leaving a field fallow for several months over the winter may not guarantee the absence of human pathogens.

Data collected only in 2015 showed that among May-inoculated subsubplots, a stark decline in *L. innocua* populations occurred in plots where a cover crop was present, but there was no effect of tillage. In July and Aug. of 2015, no *L. innocua* was detected in any rye or rye-vetch plots. In contrast, Reed-Jones et al. (2016) found that *L. innocua* in rye and rye-vetch plots can persist for the several weeks after inoculation, while a vetch monoculture and bare ground plots can show an immediate decline. In a different year of the same study, vetch monoculture and rye-vetch plots had significantly higher populations of soilborne *L. innocua* than rye monoculture plots. In our study, *L. innocua* seemed to have been eliminated from both rye and rye-vetch plots. We suspect that this observation was caused by at least one of three mechanisms: increased microbial competition, rye allelopathy, or changes in the basic cation-saturation ratio. Buyer et al. (2010) found that cover crop increased the soil microbial biomass (quantity) and soil microbial community composition (diversity), but decreased the proportion of

gram-positive bacteria in the soil. *Listeria* spp. are gram-positive (Farber and Peterkin, 1991a). Buyer et al. (2010) concluded that gram-positive bacteria were less active in accessing cover crop-derived carbon, favoring other microbial groups. Sterilization of soil encourages the growth of *L. monocytogenes*, likely by eliminating competition. In one of the first studies on survival of *L. monocytogenes* in soil, researchers were unable to detect the pathogen after inoculation, and were then forced to sterilize soil samples before inoculation (Welshimer, 1960). To confirm that increased survival of *L. monocytogenes* was not due to release of nutrients during autoclaving, McLaughlin et al. (2011a) reconstituted sterile soil samples with aerobic bacteria. They found lower *L. monocytogenes* survival in reconstituted sterilized soil samples compared to in sterilized soil samples, confirming the influence of competition. After we had terminated cover crops, rye and rye-vetch could have impacted soil microbial communities and made *L. innocua* less competitive. Locatelli et al. (2013) determined that soil chemistry was the primary factor determining the short-term survival of *L. monocytogenes.* At 7 and 14 d after inoculation, 55.4% and 44.7% respectively, of the variability of *L. monocyt*ogenes survival was explained by the basic cation saturation ratio. It is possible that in our study, after termination, cover crops changed the basic cation saturation ratio and discouraged *L. innocua* survival. Rye, wheat (*Triticum aestivum* L.), and corn contain a group of allelochemicals called benzoxazinoids, that are known to exhibit toxicity against plants, bacteria, and fungi (Schulz et al., 2013). After rye termination benzoxazinoids within plant tissue undergo a cascade of transformations in the soil, resulting in different degradants with varying toxicity and persistence in the soil. The degradation process is dependent on soil microbes and does not occur in sterilized soil, or in soils where benzoxazinoid containing crops have not been recently grown (Macías et al., 2004). One compound that results from benzoxazinoid degradation, 2-amino-3H-

phenoxazin-3-one (APO), persisted in the soil for 90 d with little variation (Macías et al., 2004). Considered one of the more toxic rye allelochemicals, APO has bactericidal properties. In fact, APO has been described as an antibiotic and referred to as Questiomycin A (Anzai et al., 1960, Gerber and Lechevalier, 1964, Atwal et al., 1992). The elimination of *L. innocua* from the soil by rye allelochemicals is an attractive hypothesis because the decline and eventual absence of positive detections of *L. innocua* in rye and rye-vetch plots could conceivably align with the degradation of benzoxazinoids and the appearance of the bactericidal APO compound.

The similar frequency of fruit contamination by soilborne L. innocua across treatments refutes our hypothesis that a rolled cover crop mulch would prevent contamination. Contamination frequency was low for each year and treatment. Though fruits from rye-ST and rye-vetch-ST appeared cleaner compared to fruits that were directly on the soil surface, they were not completely free from soil. This indicates that soil movement during heavy rainfall events is likely responsible for the limited quantities of soil present on fruits from rye-ST and rye-vetch-ST plots. It is unlikely that a cover crop mulch will completely prevent the transfer of soilborne human pathogens to the surface of muskmelon fruits. In 2015 no soil samples collected from rye or rye-vetch plots tested positive for *L. innocua* in July and Aug. Despite this, in Sept. 2015, *L. innocua* was recovered from the surface of muskmelon fruits grown in cover crop plots. This surprising observation suggests that cover crop mulch in ST and limited cover crop surface residue in CT may be acting as a reserve for *L. innocua*. May-applied *L. innocua* could have transferred to cover crop surface residue after termination and avoided soil conditions that eliminated the soilborne populations. Surface residue harboring *L. innocua* could have contamination muskmelon fruits. This explanation is supported by the fact that during both years of the study samples of cover crop mulch from ST plots tested positive for *L. innocua*.

Cover crop based ST treatments had higher profits than the respective CT treatment in only one year of the study, and only for direct market sale. No cover-ST consistently had the lowest profit, this was largely impacted by labor costs associated with hand weeding.

We conclude that while yields may be reduced under ST, there is potential to increase fruit quality. If field soil becomes contaminated with human pathogens, growers cannot rely on a cover crop mulch to prevent fruit contamination. Though rye did not prevent fruit contamination, given its potential role in degrading soilborne human pathogens it may have a role in mitigation strategies. However, further research is needed to elucidate the chemical and biological factors that affect populations of *L. monocytogenes* and other human pathogens.

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Table 3.1. Timing of field operations for muskmelon studies at the Horticulture Research Station, Ames, IA in 2014-15 and 2015-16.

Event	Date	
	2014-15	2015-16
Cover crops seeded	18 Sept. 2014	16 Sept. 2015
Listeria innocua applied (Oct. application)	15 Oct. 2014	1 Oct. 2015
Fall strip-tillage	22 Oct. 2014	23 Oct. 2015
Seedlings started in greenhouse	21 May 2015	10 May 2016
Listeria innocua applied (May application)	15 May 2015	20 May 2016
Cover crop terminated (conventional tillage plots)	22 May 2015	24 May 2016
Cover crop terminated (strip-tillage plots)	1 June 2015	2 June 2016
Muskmelon transplanted	16 June 2015	13 June 2016
Soil sampling for May-applied *Listeria innocua*	18 May 2015	23 May 2016
	15 June 2015	---
	15 July 2015	
	18 Sept. 2015	
Harvest Period	21 Aug.–15 Sept. 2015	12 Aug.–13 Sept. 2016
Detection of *Listeria innocua* on fruit	15 Sept. 2015	6 Sept. 2016
Determination of fruit quality	8-10 Sept. 2015	1-3 Sept. 2016

[z]No cover-strip-tillage plots only.

[y]In-row area of all strip-tillage plots, and between row area of no cover-strip-tillage plots.

Table 3.2. Number and weight of marketable fruit and the proportion of total muskmelon harvest as affected by cover crop and tillage at the Horticulture Research Station, Ames, IA in 2015 and 2016.

	2015				2016			
	Marketable wt.		Marketable no.		Marketable wt.		Marketable no.	
Treatment	Proportion of total	(Mg·ha^{-1})	Proportion of total	(no.·ha^{-1})	Proportion of total	(Mg·ha^{-1})	Proportion of total	(no.·ha^{-1})
Cover crop (C)								
No cover	0.39	17.4	0.38	2545	0.71 B[z]	42.6	0.70 B	4831 AB
Rye	0.51	23.7	0.48	3287	0.80 AB	34.7	0.79 A	4161 B
Rye-vetch	0.51	21.2	0.48	3093	0.84 A	43.3	0.85 A	5461 A
Tillage (T)[y]								
CT	0.49	23.8 a	0.46	3074	0.72 b	42.8 a	0.70 b	5237 a
ST	0.45	17.8 b	0.43	2876	0.84 a	37.6 b	0.85 a	4398 b
Significance								
Cover crop	ns	ns	ns	ns	0.0369	ns	0.0154	0.0080
Tillage	ns	0.0250	ns	ns	0.0005	0.0341	<0.0001	0.0125
C × T	ns	ns	ns	ns	ns	ns	ns	ns

[z]Mean separation of cover crop (uppercase letters) and tillage (lowercase letters) is based on least significant difference at $P < 0.05$. Labels within each column and factor not containing the same letter are significantly different.

[y]CT= conventional tillage, ST= strip-tillage.

[ns]Non-significant.

Table 3.3. Size distribution and average size of marketable muskmelon fruits as affected by cover crops and tillage at the Horticulture Research Station, Ames, IA in 2016.

	No. fruit·ha. $^{-1}$				
Treatment	≤ 2.9 kg	3.0 - 3.9 kg	4.0 - 4.9 kg	≥ 5.0 kg	Average fruit wt. (kg)
Cover crop (C)					
No cover	934	2395	3938	1583	4.2
Rye	1096	2720	2964	1218	4.1
Rye-vetch	1177	3126	3248	974	3.9
Tillage (T)					
CT[z]	1083	2274	3519	1732 a[y]	4.3 a
ST	1056	3221	3248	785 b	3.9 b
Significance					
Cover crop	ns	ns	ns	ns	ns
Tillage	ns	ns	ns	0.0048	0.0001
C × T	ns	ns	ns	ns	ns

[z]CT=, ST=strip-tillage.

[y]Mean separation of cover crop (uppercase letters) and tillage (lowercase letters) is based on least significant difference at $P < 0.05$. Within each column and factor labels not containing the same letter are different.

[ns]Non-significant.

Table 3.4. Density, shape, flesh thickness, and soluble-solids concentration (SSC) of marketable muskmelon fruits as affected by cover crops and tillage at the Horticulture Research Station, Ames, IA in 2015 and 2016.

Treatment	Density ($g \cdot cm^{-3}$)	Fruit shape[z]	Flesh thickness (cm)	SSC (%)
	2015			
Cover crop (C)				
No cover	0.92	1.12	4.7	7.8
Rye	1.03	1.09	4.8	8.5
Rye-vetch	0.95	1.12	4.7	7.9
Tillage (T)[y]				
CT	0.96	1.11	4.7	8.3
ST	0.96	1.11	4.7	7.9
Significance				
Cover crop	ns	ns	ns	ns
Tillage	ns	ns	ns	ns
C × T	ns	ns	ns	ns
	2016			
Cover crop (C)				
No cover	0.89	1.12 A[x]	4.7 B	9.3 B
Rye	0.89	1.08 B	5.3 A	10.7 A
Rye -vetch	0.91	1.09 B	5.1 AB	9.7 A
Tillage (T)				
CT	0.89	1.13 a	5.0	9.3 b
ST	0.90	1.08 b	5.1	10.5 a
Significance				
Cover crop	ns	0.0059	0.0196	0.0301
Tillage	ns	<0.0001	ns	<0.0001
C × T	ns	ns	ns	ns

[z]Fruit shape = fruit length divided by fruit width.
[y]CT= conventional tillage, ST= strip-tillage.
[x]Mean separation of cover crop (uppercase letters) and tillage (lowercase letters) is based on least significant difference at $P < 0.05$. Labels within each column, year, and factor not containing the same letter are different.
[ns]Non-significant.

Table 3.5. Winter survival of soilborne *Listeria innocua* in muskmelon plots as affected by cover crop and tillage at the Horticulture Research Station, Ames, IA in 2015 and 2016.

	Positive (%)	
Treatment	2015[z]	2016
Cover crop (C)		
No cover	100[y]	100
Rye-vetch	88	100
Rye	88	100
Tillage (T)[x]		
CT	92	100
ST	92	100
Significance[w]		
Cover crop	ns	ns
Tillage	ns	ns

[z]Soil was populated with *Listeria innocua* Oct. 2014 and 2015, soil was sampled May 2015 and 2016.
[y]Indicate the percentage of samples that were positive for *Listeria innocua*.
[x]CT= conventional tillage, ST= strip-tillage.
[w]Frequencies within a column and factor determined using logistic regression analysis. Significant differences ($P < 0.05$) were identified using automatic forward selection option.
[ns]Non-significant.

Table 3.6. Summer survival of soilborne *Listeria innocua* in muskmelon plots as affected by cover crops and tillage treatments at the Horticulture Research Station, Ames, IA in 2015.

	Positive (%)			
Treatment	May[z]	June	July	August
Cover crop (C)				
No cover	100	100	86	75
Rye-vetch	100	25	0	0
Rye	100	37	0	0
Tillage (T)				
CT	100	67	33	33
ST	100	42	33	9
Significance[y]				
Cover crop	ns	0.0055	<0.0001	0.0003
Tillage	ns	ns	ns	ns
C×T	ns	ns	ns	ns

[z]Soil was inoculated with *Listeria innocua* on 14 May 2015. Samples were collected on 17 May, 15 June, 15 July, and 18 August 2015.
[y]Frequencies within a column and for each factor were determined with logistic regression analysis. Significant differences ($P < 0.05$) were identified using automatic forward selection option.
[ns]Non-significant.

Table 3.7. Detection of *Listeria innocua* on the exterior of muskmelon fruits at the Horticulture Research Station, Ames, IA in 2015 and 2016. Treatment factors were cover crop, tillage, and the month soil was inoculated with *L. innocua*.

	Positive (%)	
Treatment	2015	2016
Cover Crop (C)		
No cover	20[z]	0
Rye-vetch	13	6
Rye	13	6
Tillage (T)[y]		
CT	10	4
ST	4	4
Inoculation month (M)		
Oct.	8	4
May	6	4
Significance[x]		
C	ns	ns
T	ns	ns
M	ns	ns
C×T	ns	ns
C×M	ns	ns
C×T×M	ns	ns
T×M	ns	ns

[z]Percentages of samples that were positive for *Listeria innocua*.
[y]CT= conventional tillage, ST= strip-tillage.
[x]Frequencies within a column were determined with logistic regression analysis. Significant differences ($P < 0.05$) were identified using automatic forward selection option.
[ns]Non-significant.

Table 3.8. Profitability (U.S. $/ha.) of muskmelon production in 2015 as affected by cover crop and tillage treatments at the Horticulture Research Station, Ames, IA.

	2015					
	No cover		Rye		Rye-vetch	
	CT[z]	ST	CT	ST	CT	ST
Muskmelon yield (Mg·ha^{-1})	21.0	13.9	26.6	20.9	23.8	18.6
Muskmelon yield (no.·ha^{-1})	2790	2301	3248	3326	3184	3001
Wholesale gross revenue[y]	8750	5792	11084	8708	9917	7750
Direct market gross revenue[x]	10128	8353	11790	12073	11558	10894
Inputs[w]	1328	1252	1394	1302	1507	1415
Equipment and ownership costs[v]	1349	1324	1506	1493	1506	1493
Pre-harvest labor[u]	1371	2671	1049	1436	1124	1038
Harvest costs[t]	4662	3086	5905	4640	5284	4129
Interest expense[s]	203	195	233	208	218	183
Total costs	8913	8527	10087	9079	9639	8259
Wholesale profit	-163	-2735	996	-370	278	-509
Direct market profit	1214	-175	1703	2995	1919	2635

[z]CT= conventional tillage, ST=strip-tillage.
[y]Three-year average (2014-16) U.S. prices ($416.65/Mg; USDA-NASS, 2017).
[x]Average price for cantaloupe from Iowa farmers markets($3.63/fruit; USDA-AMS, 2016).
[w]Pesticide, fertilizer, drip-tape, plastic mulch, potting mix, seedling trays, cover crop seed, and muskmelon seed
[v]Cost of farm machinery ownership and operation (Edwards, 2015), greenhouse overhead costs ($0.267/ft^2-wk.; Brumfield, 1992) irrigation equipment, and average cash rent rate for Iowa ($575/ha; Plastina et al., 2016).
[u]Labor for weeding, transplanting, and fertilizer application.
[t]Harvest costs were $0.222/kg marketable fruit (Ogbuchiekwe et al., 2004).

Table 3.9. Profitability (U.S. $/ha.) of muskmelon production in 2016 as affected by cover crop and tillage treatments at the Horticulture Research Station, Ames, IA.

	2016					
	No cover		Rye		Rye-vetch	
	CT	ST	CT	ST	CT	ST
Muskmelon yield ($Mg \cdot ha^{-1}$)	48.8	36.4	34.4	35.0	45.0	41.4
Muskmelon yield ($no. \cdot ha^{-1}$)	5928	4222	4385	4060	5765	5197
Wholesale gross revenue[y]	16245	12117	11452	11651	14980	13782
Direct market gross revenue[x]	21519	15326	15918	14738	20927	18865
Inputs[w]	2256	2180	2322	2230	2435	2343
Equipment and ownership costs[v]	1396	1371	1554	1540	1554	1540
Pre-harvest labor[u]	333	2875	333	226	405	262
Harvest costs[t]	10834	8081	7637	7770	9990	9191
Interest expenses	408	399	326	324	396	367
Total costs	15227	14906	12171	12090	14779	13703
Wholesale profit	1019	-2789	-720	-438	201	79
Direct market profit	6292	420	3746	2648	6148	5162

[z]CT= conventional tillage, ST=strip-tillage.
[y]Three-year average (2014-16) U.S. prices ($416.65/Mg; USDA-NASS, 2017).
[x]Average price for cantaloupe from Iowa farmers markets ($3.63/fruit; USDA-AMS, 2016).
[w]Pesticide, fertilizer, drip-tape, plastic mulch, potting mix, seedling trays, cover crop seed, and muskmelon seed
[v]Cost of farm machinery ownership and operation, (Edwards, 2015) greenhouse overhead costs ($0.267/$ft^2$-wk.; Brumfield, 1992) , irrigation equipment, and average cash rent rate for Iowa ($575/ha; Plastina et al., 2016).
[u]Labor for weeding, transplanting, and fertilizer application.
[t]Harvest costs were $0.222/kg marketable fruit (Ogbuchiekwe et al., 2004).

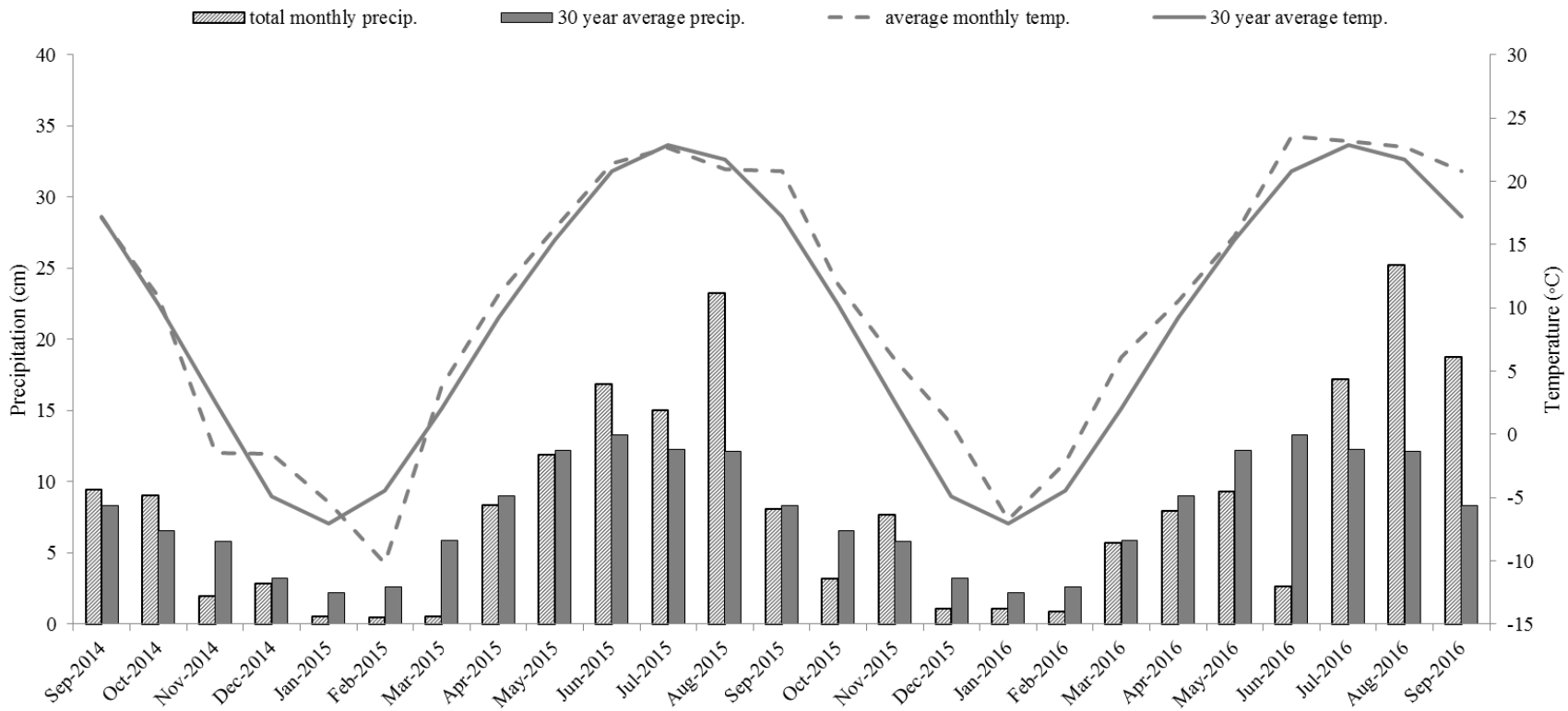

Fig. 3.1 Average monthly air temperature and total monthly precipitation from Sept. 2014-Sept. 2016 compared to 30-year averages in Ames, IA. Average monthly temperature and total monthly precipitation data obtained from Iowa Environmental Mesonet Network, Iowa State University. Data for 30-year averages obtained from National Centers for Environmental Information, National Oceanic and Atmospheric Administration.

Fig. 3.2 Sampling muskmelon rind for detection of *Listeria innocua* on 6 Sept. 2016. To obtain 50 g of rind, cores were taken from fruits, orange and green flesh was removed and discarded.

CHAPTER 4. CONCLUSIONS

From this research we conclude that conventional tillage with plasticulture produced a greater muskmelon yield than strip-tillage. These results are consistent with Tillman et al. (2015) and Lilley and Sánchez (2016) who also found that strip-tillage reduced yield of muskmelons compared to conventional tillage with plasticulture. Reduced yield under strip-tillage is likely a result of less vigorous plant growth due to limited N availability and low soil temperature, although other factors should not be ruled out. It is likely that crops that most benefit from plasticulture (e.g. muskmelon) will have reduced yield in strip-tillage production. For reduced tillage to be practical for growers, crop species that can perform adequately without plasticulture should be selected. In Iowa, pumpkin (*Cucurbita pepo* L.) is an important horticultural crop and may be ideal for strip-tillage production for several reasons. (1) Pumpkins are direct seeded and small no-till corn planters, which are readily available in Iowa, can be modified for pumpkin seeding. (2) Pumpkin crops are not always irrigated and may respond well to increased soil moisture under strip-till. (3) Demand for pumpkins is highly seasonal, and the loss of earliness attributed to strip-till production systems may not be an issue.

As mentioned in Chapter 2, 2016 significant effects of cover crop and tillage treatments on the concentration of NO_3^--N and K^+ in petiole leave sap indicate that N is likely being immobilized by cover crop residue and that the effect is greater in strip-tillage than in conventional tillage. In contrast to NO_3^--N, K^+ concentrations were greater in strip-tillage plots and also in rye and rye-vetch plots. Soil data showed that cover crop and tillage treatments had effects on inorganic N as well as K levels. Despite potential yield losses for some crops, cover crop based strip-tillage should not be discounted. To date, many studies

on plant nutrition have been performed in conventional tillage systems, and thus fertility recommendations specifically for strip-till systems may need to be developed. It should also be taken into account that because rye is most effectively roller-crimped at anthesis, the residue has a very high C:N ratio. This residue may break down more slowly than less mature rye that is tilled into the soil. Growers are often interested in the long-term nutrient availability from the roller-crimped rye mulch to crops.

Chapter 2 highlights two measures of microbial soil health, microbial biomass carbon, and microbial functional diversity of which there were no consistent trends. This was contrary to our hypothesis that cover crops with strip-tillage would positively impact soil health. This may be explained by the fact that cover crop and tillage treatments were not in the same location from the first year to the second. Long-term studies that assess soil microbiology and other measures of soil health across the entire field may be more useful in elucidating the effects of reduced tillage and cover crops.

The data presented in chapter 3 showed some redeeming qualities of cover crops and strip-tillage that we believe have not been previously explored in muskmelon. In 2016, we observed higher soluble solid concentration and more spherically shaped muskmelon fruits produced by strip-tillage, as well as by cover crops. Leskovar et al. (2016) compared seedless triploid watermelon (*Citrullus lanatus* L.) produced in strip-till and conventional till fields, and found that soluble solid concentration was increased by strip-tillage during each of the three years of the study. It is possible that strip-tillage affected soil moisture and reduced drought stress, which can detrimentally affect soluble solid content. The study by Leskovar et al. (2016) was conducted in Uvalde, Texas, which experiences a warmer and more arid climate than Ames, Iowa.

A primary focus of this thesis research was to determine if a rolled cover crop mulch could prevent contamination by soilborne human pathogen surrogates, which it did not. Incidences of fruit contamination were rather low for all treatments, making the identification of statistical differences difficult. One of the most surprising results of this study was the elimination of May-applied *L. innocua* from rye and rye-vetch plots in 2015. After being applied to in May, frequencies of positive detection declined to 0% for rye and rye-vetch treatments, whereas the frequency of positive detection only declined from 100% to 75% from May to Aug. The implementation of the Food Safety and Modernization Act highlights the need for science-based data that leads to practical management recommendation for growers to prevent pre-harvest contamination.

After two years of field trials, this study produced mixed results. The topic of reduced tillage for vegetable production, and human pathogens in the agroecosystem should continue to be addressed, and I have several thoughts for future work. It is my hope that this work can contribute to the corpus of knowledge on produce safety, and that eventually growers are provided with more practical strategies to prevent foodborne illness.

1. Future research should explore how cover crops and tillage affect plant nutrition, and directly measure the mineralization, immobilization, uptake, and leaching of N throughout the season.
2. Future studies should determine how N, C, and other nutrients are cycled in systems where strip-tillage is practiced for consecutive years. Long-term studies will help to elucidate the role that strip-tillage plays in chemical, physical, and biological properties of soil health.

3. Conducting long-term studies of strip-tillage for vegetable production would track progressive changes to soil health. Future studies of soil biology in cover crop based strip-tillage systems should make efforts to quantify fungal populations. Fungi have a specialized ecological niche in decomposing biomass with a high C:N ratio, and are more efficient in converting biomass C to soil organic matter.
4. The changes in physical characteristics of muskmelon fruit and soluble solid concentration we observed indicate that in-depth nutritional and sensory panel assessments are worthwhile.
5. The potential for rye, and other cover crops to eliminate soilborne human pathogens warrants future studies.

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