SOIL QUALITY ASSESSMENT FOR AN ALFISOL UNDERGOING ALTERNATIVE ORGANIC WEED MANAGEMENT SYSTEMS

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By

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The undersigned, appointed by the Dean of the Graduate School,

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SOIL QUALITY ASSESSMENT FOR AN ALFISOL UNDERGOING ALTERNATIVE

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Presented by Jill Souliere Staples

A candidate for the degree of

Master of Science

And hereby certify that, in their opinion, it is worthy of acceptance.

Dr. Robert Kremer

Dr. Stephen Anderson

Dr. Reid Smeda

DEDICATION

This thesis is dedicated to the best steward of the land I know…

My Dad

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ABSTRACT

As organic agriculture farmland continues to increase on a global scale with 6.5 million hectares added during 2014-2016, the increased number of organic producers will be expected to fulfill sustainability obligations. However, tillage is the dominant practice for weed control in organic agriculture, but because tillage reduces soil organic carbon (SOC) and can alter soil properties this leads to soil degradation and erosion. This study utilized propane flaming, hot water spraying, cultivation, and between-row mowing for suppression of weeds. Furthermore, the use of summer cover crops (SCC), representing an opportunity to benefit annual cropping systems by improving soil quality without drastically altering management practices, was also studied. Alternative weed treatments were integrated into an organic system that included grain crops and winter cover crops in a two year rotation, consisting of corn (*Zea mays* L.), soybean (*Glycine max* L.), and winter wheat (*Triticum aestivum* L.). Post-wheat harvest practices consisted of SCC and double crop soybean (DCS). Other organic practices included compost application, crimped cover crops, and tillage after harvest. Multiple soil quality indicators were analyzed for the three properties of soil, physical, biological, and chemical. Crimped cover crop plots with hot water spray had highest overall soil quality indicator values. Soil physical properties achieved optimal values under mowing. Flaming had decreased soil quality indicator values similar to the cultivation treatment; however this showed potential improvement in soil quality when combined with high compost rates. Hot water spray had significant yield results in soybeans, but was not as effective in corn. SCC had higher overall soil quality indicator values compared to a cultivated DCS. However, with minimal cultivation and high compost rates DCS had similar soil biological values to

SCC. Combined with additional organic practices, alternative weed practices can conserve and sustain soil. Inclusion of a SCC has potential to build soil productivity within a grain row-crop rotation.

CHAPTER I

INTRODUCTION

Organic Agriculture

Organic is a labeling term for food or other agricultural products that have been produced according to United States Department of Agricultural (USDA) organic regulations. These standards require management of an organic agriculture production system to respond to site-specific conditions by integrating cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance and conserve biodiversity (USDA, 2017). This means that organic agriculture operations focus on renewable resources, soil and water conservation, and management practices that restore, maintain and enhance ecological balance.

Additional USDA organic regulations include specific production and processing requirements that became law under the Organic Food Production Act in 1990. Agricultural plant-based products that bare the certified USDA organic label must be grown without the use of synthetic pesticides, fertilizers, and genetically modified organism (GMO) or engineered seeds. Organic production relies on natural products and biological systems to maintain or enhance soil and water sustainability. In addition to regulations on additives, organic products cannot contact non-organic food during processing. Producers that have conventional and organic in the same location must be mindful of fertilizer drift, and handling of equipment. Per regulation, a buffer strip around organic crop land is needed if the location has non-organic aquiculture on site (AMS, 2014).

Organic operations that exceed $5,000 in profit annually must be certified to claim organic on their products. The certification process can take up to six months or more, however there is a transition period of three years before a plot of land can be certified organic. During the transition period the land must be free of synthetic fertilizers and chemicals. To become a certified organic grower, producers must submit an application to a USDA-accredited certifying agent with the following details: description of operation, a history of substances applied during transition period, organic products to be grown or processed, and a written Organic System Plan. The Organic System Plan is utilized by the certifier at time of certification and at annual inspections (USDA-AMS, 2011).

The Organic System Plan is an agreement with the certifying agency, and is essential at time of certification. The system plan outlines all management practices to be used and their frequency, a list of substances to be used and their composition/source, monitoring practices, and recordkeeping system. The Organic System Plan is tailored to the specific conditions of the facility and updated once a year. A change in management practice requires editing the Organic System Plan. The certifier agency reviews the Organic System Plan for the organic principles of sustainability (USDA-AMS, 2011).

Organics focus on renewable resources, and conservation. One of their goals is to restore, maintain, and enhance soil quality with best management practices. Soil quality is “the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation” (Karlen et al., 1997). The concept of soil quality has evolved in the past decade in response to increased emphasis on sustainable land use and the acknowledgment that sustainable soil requires more than soil erosion control (Karlen et al., 2003). The complexity of the role of soil in sustainable land management consists of multiple processes of nutrient and water cycling, filtering, buffering of contaminants, decomposition of residues, and providing plant nutrients (Karlen et al., 2003).

Soil Quality Indicators

Soil quality research focuses on indicators. Indicators are measurable soil characteristics representing one or more of the three properties of soil: physical, biological, and chemical. The indicators are researched for selection, evaluation, accuracy, sensitivity, and usefulness for indicating soil quality (Islam and Weil, 2000). Research on indicators is useful in measuring soil quality, however measuring soil quality with a single or few indicators is not a true soil quality measurement. Soil quality must be evaluated based on multiple indicators in all three soil properties (Warkentin and Fletcher, 1977).

Soil organic matter (SOM) is one of the most widely acknowledged soil quality indicators with its dominant constituent, soil organic carbon (SOC), being a common soil measurement (Weil et. al., 2003). SOM can be oxidized and lost as CO_2 when soil is tilled or when heat is applied, such as in a system that utilizes flame weed control (Knicker, 2007). SOM is vital to soil structure, aggregate stability, infiltration, aeration, and nutrient and water holding capacity (Franzluebbers, 2002: Bronick and Lal, 2005; Chenu et al., 2000). SOC is one of the most important constituents of the soil due to its capacity to affect plant growth via soil microbes as both a source of energy for the microscopic ecosystem that is catalytic for plant nutrient availability through mineralization (Haynes and Tregurtha, 1999). Therefore, a direct effect of decreased SOC levels within the soil is reduced microbial biomass/activity, and reduced nutrient mineralization due to a lack of energy source. SOM contributes to soil chemical properties by buffering against changes in soil pH and greatly increasing the cation exchange capacity (CEC) (Binkley and Fisher, 2012, Neary et al., 2009).

Small changes in SOC can have large effects on soil and microbial properties, but are often difficult to measure (Sikora et al., 1996). However, the active fraction of SOC is relatively easy to measure and can serve as an early indicator of soil responses to management practices (Weil et. al., 2003). The active carbon fraction consists of microbial biomass carbon, particulate organic matter and soil carbohydrates. These active carbon fractions are the fuel of the soil food web and influence nutrient cycles, and many biological soil properties (Weil et al., 2003). Active carbon serves as a sensitive indicator in management effects on soil quality. Several studies have shown that analysis of active carbon fractions is appropriate for estimating soil reaction to different management systems (Islam and Weil, 2000; Blair and Crocker, 2000; Deluca and Keeney, 1993; Lefroy et al., 1993).

Organic Management Practices

Organic producers use multiple practices to obtain goals of sustainability, conservation, and productivity. Crop rotation, winter cover crops, crimped cover crops, green manure, and compost facilitate organic principles. Crop rotation is a required component of organic agricultural systems. Crop rotation has been used in conventional production for decades as producers rotate a different crop each season on the same plot of land in a systematic, reacurring sequence (Power and Folett, 1987). Beneficial effects of crop rotation have also been reported to include improvements in soil moisture, soil nutrients, soil microbes, soil structure, and insect and disease control (Crookston, et al., 1991).

Cover crops provide substantial increases to soil properties, as well as improve soil quality and conservation. The benefits of reduced water erosion from cover crops is widely acknowledged, water loss can decrease by up to 80%, and sediment loss decreased by 96% (Kaspar et al., 2001). The amount of runoff is a function of biomass produced, and cover crop species. Studies have reported rye and winter triticale to have more efficient water runoff reduction capabilities (Kaspar et al., 2001; Blanco-Canqui et al., 2013). The reduction of water erosion suggests cover crops also reduce water pollution by reduction of dissolved nutrients in runoff, which results in improved water quality, soil fertility, and crop productivity (Kaspar et al., 2001).

Cover crops can be an element of weed control as they create a physical barrier mat covering the soil after termination by crimping with a roller-crimper (Figure 1.1). Crimping cover crops such as winter rye (*Secale cereale*) and hairy vetch (*Vica villosa)*, can often sufficiently smother weeds for the critical 6 weeks after desiccation, giving the cash crop a chance to outgrow yield limiting weeds (Teasdale and Rosecrance, 2003). However, if insufficient biomass is produced by the cover crop, a significant increase in weed pressure under no-till organic production has been observed (Cavigelli et al., 2008). Cover crop polycultures of 6-12 different species are becoming increasingly popular. A Nebraska study used spring-planted mixtures of 2, 4, 6 and 8 cover crops to compare effects on weed suppression, soil nitrogen availability, soil moisture and grain yield

(Wortman et al., 2010). Wortman et al. (2010) found cover crop biomass to be greatest in the 6 crop mixture, and broadleaf weed suppression greatest in the 8 crop mixture.

Green manure is created by leaving crop parts to wither on a field so they can serve as a mulch and soil amendment. Crimped cover crops and crop residue after harvest are considered green manures. Both additives can raise SOM levels in the soil and potentially increase soil carbon.

Compost is the decomposition of organic matter by aerobic conditions formulating a stable humus structure. Compost is added as a soil amendment and the primary source of nitrogen (N), phosphorus (P), and potassium (K) for organic productions. There are multiple conditions that affect the nutrient level content in compost: material components, condition of composting, and storage type. Poultry litter compost and cattle manure are lowest and highest in N/P ratios respectively (Havlin et al., 2005). These two most commonly used composts are used with caution as high excesses of nitrates and phosphorus have environmental consequences by polluting waterways and soil (Eghball and Power, 1994; Chang et al., 1996).

Organic Weed Management

Tillage is the dominant practice for reducing weeds in organic agriculture (Bond and Grundy, 2001), however mechanical disturbance alters many soil properties and decreases overall soil quality (Karlen et al., 1994; Reiocosky, 1997). Tillage causes losses of SOC through oxidation and mineralization, translocation, or erosion (Doran, 1987; Lal, 2002). Furthermore, conventional tillage reduces the percentage of stable soil aggregates and significantly increases the potential of water erosion (Elliott, 1986; Cambardella and Elliott, 1993; Beare et al., 1994, Six et al., 2000). The USDA reported

871 Mt of agricultural cropland was lost due to water erosion in 2007. A conservative average of one mm of soil per two hectares per year is displaced by water (Mader, 2017), and approximately 500 years are required to form 25 mm of topsoil (Pimental, 1998). A study that looked at the potential erodibility of a reclaimed Conversation Reserve Program (CRP) site found that a conventional tilled field supported soil loss at a 20 g $m^{-2}h^{-1}$ while no-till and permanent hay production reduced losses to 7 to 8 g $m^{-2}h^{-1}$ respectively, (Zheng et al., 2004).

Weed seed bank management is an important factor in organic crops. Some weeds can produce over half a million seeds per plant (Massinga et al., 2001), while others can survive in the soil for 20 or more years (Lewis, 1973). One study showed that the total number of seeds in the soil weed seed bank increased from 4,050 to 17,320 after converting from conventional to organic farming practices (Albrecht, 2005). One purpose of tillage in organic cropping is to reduce sprouted weeds, but tillage can also increase germination of seeds in the soil bank by exposing seeds to light and moisture (Yenish, et al., 1992). Tillage impacts weeds by affecting their vertical distribution in the soil, as well as the number and species of weed seeds in the soil (Ball, 1992). In a non-organic study comparing tillage and weed seed in soil, no-till decreased weed seed numbers by 40% relative to herbicides alone (Yenish et al., 1992).

Alternative Weed Management

The present study looks at two relatively new weed treatments for row-crop grain production; a mounted three point hitch propane flamer with five between-row burners (Figure 2.2), and a mounted three point hitch hot water sprayer with three between-row canopy dispensers (Figure 2.3). Propane burns at 1,995°C, to be lethal on weed plants the leaf tissue must be exposed to 55-70°C for a period of time ranging from 65 to 130 microseconds (Knezevic, 2017). The cell walls of the plant tissue desiccate causing mortality (Diver, 2002). The hot water spray is approximately 110°C when it contacts weed leaf tissue.

Thermal weed control with a propane flamer has recently been rediscovered in agriculture and has entered the early research stages. Small self-propelled or hand-held flamers made a come-back in the 1980's; however, large tractor-mounted propane flamers are a relatively new and re-invented way to combat weeds in row-crop organic production. There is little reported information on propane flame weed treatments in a row-crop rotation or organic agriculture production. Most studies are methodical and not field applicable at this point.

Thermal weed control with hot water spray eliminates the danger of flame application in arid regions where open fires are a hazard. Unlike the flame weed treatment, hot water spray can be used with a crimped cover crop to optimize weed control. Hot water spray has been primarily geared to municipal and institutional use for vegetation control, around parks, lakes, athletic fields, sidewalks, streets, and parking lots where herbicides are prohibited. Efficacy of weed injury by steam was comparable to glyphosate on green foxtail (*Setaria italic*), and was effective on downy brome (*Bromus tectorum*) at anthesis. Steam treatment did not affect lambs quarters (*Chenopodium album*), redroot pigweed (*Amaranthus retroflexus*), and black nightshade (*Solanum nigrum*). The study reported the factors that determined steam effectiveness to be amount of steam applied, weed species, and growth stage (Kolberge and Wiles, 2002).

Weather has an effect on the efficiency of hot water treatment on weeds. Air temperature had minimal effect, however, a precipitation event increased the requirement of water needed for termination (Hansson and Mattsson, 2002). Hot water treatments applied at least 3 days after a rainfall event increased weed control, and reduced water needed for termination (Hansson and Mattsson, 2002).

Flame Effects on Soil Properties

The energy from the ignition and combustion of fuels is responsible for any changes that occur in the physical, chemical, and biological properties of soil under a fire. The mechanisms responsible for heat transfer in soils are radiation, conduction, convection, mass transport, vaporization and condensation (Beyers et. al., 2005). Vaporization and condensation are both important mechanisms for rapid heat transfer through dry soils, as water and organic materials can be moved through the soil be these two processes. The depth of heat penetration into the soil depends on the water content of the soil, as well as magnitude and duration of the flame with the topsoil (Frandsen 1987). Long duration can cause heat to travel 40-50 cm. downward into the soil profile. Likewise, a moist soil can increase the thermal conductivity, and raise soil temperatures deeper within the profile in comparison to a dry soil via vaporization. The temperature in moist soils do not rise much above 95C° until the water within the soil is vaporized resulting in lethal temperatures for microorganisms (Beyers et. al., 2005). Dry soils are poor conductors and do not heat substantially below 5 cm, however there are a great abundance of soil microbes within the target heat layer (Beyers et. al., 2005).

Soil microorganisms have many influential roles that contribute to a quality soil ecosystem: nutrient cycling, decomposition of OM, improvement of soil physical properties, and control of disease (Stevenson et. al., 1999). Microorganisms can also have a symbiotic relationship with plants by providing essential nutrients for uptake; this unique relationship can be affected by fire. Soil moisture is again another crucial factor in determining microbial survival. Water is capable in absorbing large amounts of heat, and soil temperatures are drastically reduced when the prescribed area is moistened prior to a flame treatment (Frandsen et al., 1986). However, because water is a better conductor of heat, the microbes are in lethal danger if a target temperature is reached or if vaporization occurs (Dunn et. al., 1985). Even at low-severity, fires can damage or kill microorganisms on the soil surface, however, most reviews have variable responses to the changes in population sizes and activity. As an example, recolonization of ectomycorrhizae was poor after fire treatment for Harvey et al. (1980), but rapid decline of populations were normally short lived and by the end of growing season the populations where the same or surpassed pre-burn levels (Renbuss et al., 1973). Organic amendments of poultry manure combined with cover crops may hasten reestablishment of soil microbial populations (Villar et al., 2004).

Temperature Thresholds

The impact a flame on SOM and soil microbes largely depends on the severity of the fire. The intensity relates to the rate at which fire produces thermal energy. Fire temperatures can have a wide range from 50°C to 1,500°C (Knicker, 2007). With low-severity fires, soil heating typically did not exceed 100°C at the surface and 50°C at the 0-5 cm. depth (Campbell et al., 1995). A grass fire resulted in a soil surface temperature increase to 300°C, however, temperatures above 100°C lasted 80 seconds, and at the depth of 2 cm. the temperatures did not exceed 35°C with no change in temperature at the 4 cm. depth (Scotter, 1970).

Microbial biomass is concentrated at the soil surface, the region of highest biological activity receives the highest temperature during a fire. Soil temperatures of 120°C have been implicated in decreasing microbial biomass (Knicker, 2007). Fungi are more affected by fire than bacteria (Dunomtet et. al., 1996). Temperatures <50°C moderately reduced mycorrhizae, while 50-60°C significantly reduced the fungi, and at 94°C a total loss (Klopatek et al., 1988). Bacteria can be affected by low temperatures as well, as gram-negative organisms or other thin walled organisms can be killed by a temperature of 50°C. A temperature of 200°C is lethal to all bacteria (Wells et. al., 1979).

Losses of organic matter can occur at temperatures below 100°C, further components are lost up to 200°C, and by 300°C, 85% of the organic matter is destroyed. Temperatures above 300°C will have ignited all residual parts left of organic matter (Beyers, et. al., 2005).

Rational and Significance

The quality, or health, of a soil reflects its capacity to function and leads to sustained biological productivity, environmental quality, and plant and animal health (Karlen et al., 1997). Improving plant health through improved soil quality is a major goal of organic growers, and should be emphasized in a weed management system.

A shortage of integrated research on organic weed control, along with a need to reduce the use of tillage, makes alternative organic weed control research an important topic. Soil water erosion may decrease topsoil depth considerably, therefore alternative management systems that can sustain the soil while increasing quality need to be considered.

Organic farmers require multiple management tools to combat weedy *Amaranthus* species including water hemp (*Amaranthus rudis*) and Palmer amaranth (*Amaranthus palmeri*) in their fields. Because of late season germination and growth, and the competitive advantage of these weeds over the crop, tillage alone is unlikely to be successful in achieving adequate control. This illustrates why it is important for organic growers to have a systems approach to weed control. Adequate control while maintaining soil quality might be achieved if pre-growing season practices and within growing treatments are executed to prevent weed germination; these are effective to control small weeds between crop rows, and escapes, thereby preventing large plants from producing viable seed in the field. Ultimately, populations of weeds in the soil seed bank can be reduced.

A shortage of integrated research on organic weed control practices, along with a need to reduce tillage to conserve soil, has gained recognition of alternative organic weed control research as an important topic.

Objective 1:

To examine the effects of organic weed management systems within a row-crop corn/soybean rotation for changes in soil quality. The alternative weed management treatments of propane flame, between-row cultivation, hot water spray, and between-row mowing were evaluated for changes in soil physical, biological, and chemical properties. The null hypothesis is there will be no soil quality changes in either physical, biological, or chemical properties for soil undergoing alternative organic weed management practices.

Objective 2:

To examine the effects of a polyculture cover crop and double cropping system after wheat harvest within a row-crop corn/soybean/wheat rotation for changes in soil quality. The management practices of summer cover crop and double cropping soybeans were evaluated for changes in soil physical, biological, and chemical properties. The null hypothesis is there will be no soil quality changes in either physical, biological, or chemical properties for soil undergoing the crop rotations for a double crop soybean or summer cover crop polyculture preceding a wheat crop.

There is a necessity for improved best management practices, along with a need to reduce tillage to conserve soil. Research is needed to evaluate management practices that increase soil productivity and sustain environmental quality.

Figure 1.1. I&J Manufacturing roller crimper.

Figure 1.2. Red Dragon 4-row propane flamer.

Figure 1.3. Custom made 3-row hot water sprayer with Beckett industrial burner.

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CHAPTER II

EFFECT OF ORGANIC WEED MANAGEMENT ON SOIL CHARACTERISTICS

ABSTRACT

Tillage is the dominant practice for weed control in organic agriculture, but because tillage reduces soil organic carbon (SOC) and can alter soil properties alternative organic weed management practices need to be explored. This study looks at two relatively new weed treatments for row-crop grain production; thermal weed control with propane flame and hot water spray, and their effects on soil quality indicators. The study included between-row mowing and a conventional tillage practice of between-row cultivation for comparison. All four weed treatments were integrated into an organic system that included grain crops and winter cover crops in a two year rotation, consisting of corn (*Zea mays* L.), soybean (*Glycine max* L.), winter wheat (*Triticum aestivum* L.). Other organic practices were utilized including compost application, crimped cover crops, and tillage after harvest. This study site was located in central Missouri in Mexico silt loam soil and indicators analyzed were aggregate stability (AgStab), bulk density (BD), β-glucosidase activity (BG), acid phosphatase activity (AP), phospholipid fatty acid (PLFA) biomass indicators, permanganate oxidizable carbon (POXC), soil organic matter (SOM), pH, CEC and soil P, K, Ca, and Mg levels. Crimped cover crop plots with hot water spray had highest overall soil quality indicator values. AgStab, POXC, and BD had optimal values in between-row mowing. Propane flame had decreased soil quality indicator values similar to the cultivation treatment, exception are: although not

significant, AgStab, AP, Fungi community, total PLFA, K, and SOM. Hot water spray had significant yield results in soybeans, but was not as effective in corn. Propane flame has potential in corn, but caution must be used for flaming soybeans until improved methods can be employed. Both thermal weed suppressor practices have the capability to sustain soil quality when coupled with crimped cover crops, and compost.

INTRODUCTION

Organic agriculture continues to increase as 2.4 million producers were reported globally in the current World of Organic Agriculture-Statistics (IFOAM) Demand for organic products have reached an estimated global market of 81.6 billion dollars, with America leading that demand with 37 billion. The general assembly of International Federation of Organic Agriculture Movement (IFOAM) established a definition of organic agriculture based on the four core principles of organic agriculture: health, ecology, fairness, and care. The definition further states that organic agriculture is a system that sustains the health of soil (IFOAM, 2017). As organic agriculture farmland continues to increase on a global scale with 6.5 million hectare added to 2014-2016, (IFOAM, 2017) the increased number of organic producers will be expected to fulfill sustainability obligations.

However, the fundamental policy of no herbicides uses in organic farming requires producers to find other means of managing weeds. Tillage is the dominant practice for reducing weeds in organic agriculture (Bond and Grundy, 2001), however mechanical disturbance alters many soil properties and decreases overall soil quality (Karlen et al., 1994; Reiocosky, 1997). Tillage causes losses of SOC through oxidation and mineralization, translocation, or erosion (Doran, 1987; Lal, 2002). Soil organic matter (SOM) is one of the most widely acknowledged soil quality indicators with its dominant constituent, soil organic carbon (SOC), serving as a common soil quality measurement (Weil et. al., 2003). Decreased SOC contents affects microbial communities that mediate soil mineralization, releasing nutrients used by plants for optimal growth and yields (Haynes and Tregurtha, 1999).

Furthermore, conventional tillage reduces the percentage of stable soil aggregates and increases the potential of water erosion significantly (Elliott, 1986; Cambardella and Elliott, 1993; Beare et al., 1994, Six et al., 2000). The USDA reported 871 Mt of agricultural cropland was lost due to water erosion in 2007. A conservative average of one mm of soil per two hectare per year is displaced by water (Mader, 2017), and approximately 500 years are required to form 25 mm of topsoil (Pimental, 1998). A study that looked at the potential erodibility of a reclaimed Conversation Reserve Program (CRP) site found that a conventional till field supported soil loss at a 20 g $m^{-2}h^{-1}$ while no-till and permanent hay production reduced losses to 7, 8 g $m^{-2}h^{-1}$ respectively, (Merrill et al., 2004); however, erodibility of a pre-plant disk harrow tillage practice before a no-till system was significantly higher than that of a pre-plant disk permanent hay production. This confirms the stability of grasslands and root systems that maintain and could potentially increase soil quality.

Winter cover crops are planted after harvest so the field is not left fallow during the non-growing crop season. There are many benefits of cover crops which include water infiltration, soil moisture retention, and nutrient cycling efficiency (Teasdale, 1996). The popularity of cover crops is growing, however many producers terminate the cover crop with herbicide or mowing before planting the cash crop. Although these methods have been shown to increase SOC pools with organic conventional tilled systems with compost (Liebig and Doran; 1999; Wander et al., 1994), these may not accumulate the same amount of SOC as a crimped winter cover crop in a no-till organic system (Jokela et al., 2011; Robertson et al., 2000). In organic systems, SOC increases are either attributed to reduced tillage including no till, addition of compost, and winter cover crop biomass. The current study will include these common organic management practices so comparisons can be evaluated within the same organic system.

Crimped cover crops provide a blanketed mat that not only helps add organic biomass and reduce soil erosion, but also provides weed control (Carr et al., 2013; Teasdale et al., 2007). Studies have shown that crimped winter rye (*Secale ceral* L.) suppresses weeds during the early growth stages of grain crops long enough for the seedlings to outgrow the weed seedlings thereby reducing the risk of limiting yield (Teasdale et al., 2012). The effectiveness of crimped cover crops is dependent on past history management practices and cover crop biomass production. For no-till to successfully contribute to acceptable grain yields, several studies concluded that a pre-existing soil quality and optimal performance of the cover crop in weed suppression was necessary (Carr et al., 2013; Mirsky et al., 2012; and Teasdale et al., 2012). Organic agriculture accomplishes this with fall compost applications and optimal timing of cover crop termination. The cover crop must be terminated completely to be a successful weed suppressor, which may require two or three passes with a roller crimper or mower days after termination (Creamer et al., 2002).

Another key factor for no-till crimped cover crops to be successful in weed suppression is sufficient biomass production to provide a dense rolled mat (Creamer et al., 2002). Increased seeding rates to acquire a dense cover crop stand may lead to problems with seed-to-soil contact and hair-pinning at cash crop planting (Carter et al., 2002). Hair-pinning results when the planter coulters do not slice cleanly through the surface residue and pieces of cover crop get into the seed furrow, causing delayed or uneven emergence. Carter et al. (2002) found that yield losses decreased by 10% because of uneven emergence.

The present study looks at two relatively new weed treatments for row-crop grain production; a mounted three point hitch propane flamer with five between-row burners (Figure 2.1), and a mounted three point hitch hot water sprayer with three between-row canopy dispensers (Figure 2.2). Comparative treatments included between-row mowing and a conventional tillage practice of between-row cultivation. All four weed treatments were within an organic system that included mainstream organic management practices for row-crop grain production: winter cover crops, compost application, crimped cover crops, and tillage after harvest.

Thermal weed control with a propane flamer has recently been rediscovered in agriculture and has entered the early research stages. Small self-propelled or hand-held flamers made a come-back in the 1980's; however, large tractor-mounted propane flamers are a relatively new and re-invented way to combat weeds in row-crop organic production. There is little reported information on propane flame weed treatments in a row-crop rotation or organic agriculture production. Most studies are methodical and not field applicable at this point.

Thermal weed control with hot water spray eliminates the danger of flame application in arid regions where open fires are a hazard. Unlike the flame weed treatment, hot water spray can be used with a crimped cover crop to optimize weed control. Hot water spray has been primarily geared to municipal and institutional use for vegetation control, around parks, lakes, athletic fields, sidewalks, streets, and parking lots where herbicides are prohibited. There has been interest in hot water weed control by the fruit and vine growers and in almond tree planting sites where hot water is used for controlling replant disease (Fennimore, 2010). Research is lacking on the effects of hot water spray on weeds under field conditions. A custom-built prototype steam generator was used in one study that provided steam at an average temperature of 175°C for application to pre-planted selected weed species (Kolberge and Wiles, 2002). Efficacy of weed injury by steam was comparable to glyphosate on green foxtail, and was effective on downey brome at anthesis. Steam treatment did not affect lambs quarters, redroot pigweed, and black nightshade. The study reported the factors that determined steam effectiveness to be amount of steam applied, weed species, and growth stage (Kolberge and Wiles, 2002).

Several phenomena in the past 10 years have prompted a search for alternative methods of weed control. Regulations for decreased pesticide residues in foods, increased restrictions on use of agriculture chemicals, increased resistance by weeds to common herbicides, public awareness of food production, increased land devoted to organic agriculture production, and increased demand for organic products. A shortage of integrated research on organic weed control practices, along with a need to reduce the usage of tillage to conserve soil, has led to recognition of alternative organic weed control research as an important topic

The objective of this research was to examine the effects of organic weed management systems within a row-crop corn/soybean rotation for changes in soil quality indicators. The alternative weed management treatments of propane flame, between-row cultivation, hot water spray, and between-row mowing were evaluated for changes in soil physical, biological, and chemical properties.

MATERIALS AND METHODS

The first year of the study (2015) had multiple variables that differed from those measured in 2016. Although this document reports results for 2015 and 2016, the experiment will continue through fall 2019, and a follow-up report will be issued summarizing data from the entire five years of the study. Therefore a more consistent repetition of the study will be analyzed than what is reported here. Variations between years will be considered in the discussion and conclusions, with variables mainly analyzed within year not transversely for this report.

The field study was conducted at Bradford Research Center, a facility for agronomic research at the University of Missouri, just east of Columbia (38.8929 ^{O} N, 92.2010 ^{O} W). The predominant soil series at the research site is Mexico silt loam (fine, smectitic, mesic, Vertic, Epiaqualfs). The USDA-NRCS classifies this series' location as Central Claypan Till Plains. The parent material for this soil is primarily loess, over loamy sediment derived from pre-Illinoian glacial till.

The field study site is 1.17 hectare (Figure 2.3), organically certified through Quality Certification Services (QCS, Gainesville FL), and has been in organic production for at least 4 years. Previously, half of the 1.17 hectare were used for a greenhouse gas experiment under organic management that implemented similar corn/soybean/wheat crop rotation and cover crops. However, the study involved compost treatments at different application amounts in a split split plot design. The other half of the area was under organic corn, then overgrew with native grasses and forages two years before initiating the current study.

The study site was prepared for initiation of the experiment in the fall of 2014. After the termination of the greenhouse gas experiment, the entire site was mowed with a 4.6 m John Deere Bush hog (John Deere, Moline, IL) and ploughed with a mouldboard plough. Organic compost made from poultry manure (3-2-2) which meets National Organic Program (NOP) guidelines was obtained from Early Bird Composting California, Missouri and applied with a New Holland 155 spreader (New Holland Ag., New Holland, PA) at 3.6 mT ha^{-1}. The amount of compost applied was based on the relatively low nutrient contents provided by composts used in the previous experiment. The site was then disked with a True-Tandem disk harrow 375 with 61 cm blades and 23 cm spacing (Case IH, Racine, WI) two times to incorporate the compost, and prepare a seedbed.

The experimental design for this study is a split plot design accounting for the two crop types, corn and soybean. Each plot is 61 m. x 64 m or 0.96 acre, each containing one crop that is rotated with the other for the next year. Additional wheat plots in a similar size area are within the weed management study and rotated with the corn and soybean plots. The corn and soybean crop sections are subdivided into 4 blocks that have randomized weed treatment plots measuring 6.1 m. x 9.1 m. Each weed treatment has 4 replications, 2 for each crop, in each block (Figure 2.4).

A winter cover crop mix was planted on 22 October 2014 and 20 October 2015 consisting of cereal rye (*Secale cereal* L.) at (89.7 kg ha^{-1}), oats (*Avena sativa*) at (20.2 kg ha^{-1}), hairy vetch (*Vicia villosa*) at (11.2 kg ha^{-1}), Austrian winter pea (*Pisum sativum L. ssp.*) at (10.1 kg ha^{-1}), crimson clover (*Trifolium incarnatum* L.) at (11.2 kg ha^{-1}), and Essex rapeseed (*Brassica napus*) at (3.0 kg ha^{-1}) with a Tye no-till drill (Tye CO. Lockney, TX), at 19 cm row spacing. Crop varieties and seed sources used in the study are presented in table 2.1. The cover crop mix for fall 2015 did not include oats, therefore the cereal rye seeding rate was increased (123.3 kg ha^{-1}). The oat stand was non-existent for the first year, so was omitted from the rest of the study.

The winter cover crop stand was terminated on 7 June 2015 and 6 May 2016 either with a John Deere brush hog mower (John Deere, Moline, IL) or a roller crimper (I&J Mfg., Gap, PA) depending on the weed treatment. The propane flamer and between row cultivation weed management treatments followed termination of winter cover crop by mowing, and the hot water and between row mowing weed management treatments followed crimping of winter cover crops. A crimped cover crop adds an extra layer of decomposing material, can be a natural weed suppressor, and protects against soil erosion (Jokela et al., 2001). A fundamental difference between 2015 and 2016 is the absence of the crimped cover crop for the hot water and between row mowing weed management treatments. The spring and early summer months of 2015 experienced heavy rainfall, with a total precipitation of 732.0 mm for late March- mid July, while 252.5 mm was recorded in 2016. The annual precipitation for 2015 was 1263.65 mm, a total reached once (2008) in the past 20 years for Columbia, Missouri (National Weather Service, 2017). The increased rainfall delayed termination of the cover crop, and corn and soybean planting. This also led to seed produced by cover crops, an extreme abundance of emerged weed species, and poor establishment of cash crops. The site had to be disked on 24 June to salvage the study by eliminating the weeds; however, this process eliminated the crimped cover crop. Secondly, at the time of re-disc additional compost (1.5-1-1) was added at 18 mT ka^{-1} to the plots to be planted with corn. The compost added at pre-planting of corn in 2015 came from Bradford Research Center's organic composting site. The material is predominantly University of Missouri campus food waste, and bedding from their equine center.

On 25 June 2015 and 5 May 2016, organic corn hybrid Master's Choice 5300 was planted at a seeding rate of 45,000 seeds ha^{-1} with a John Deere 4 row planter (John Deere, Moline, IL). The rate was increased to 45,700 seeds ha^{-1} for no-till plot treatments, and decreased to 33,500 seeds ha^{-1} for tilled plot treatments in 2016. Corn was planted into the standing winter cover crop for all no-till weed treatment plots. The cover crop was terminated by crimping shortly after planting; therefore, the seeding rate was increased to assure an acceptable corn stand. Row spacing was 76 cm, providing eight-row treatment plots. The corn was replanted for both years. The first planting date of 11 June 2015 resulted in 0% germination due to excessive rainfall of 192 mm. On 25 May 2016 replanting of corn in the no-till plots was necessary due to only a 30% stand emerging from the crimped cover crop. Specific management practices and dates for corn and soybean trials are presented in table 2.2.

Nitrogen in the form of Chilean sodium nitrate ($NaNO_3$, 16-0-0) was applied by a Vicon pendulum fertilizer spreader to V4 stage corn on 31 July 2015 at 67.3 kg ha^{-1} and 20 June 2016 at 56.0 kg ha^{-1}. However, only the no-till weed treatment plots received $NaNO_3$ in 2016, which was a side dressed application with a hand-held fertilizer spreader. The National Organic Program (NOP) considers non-synthetic $NaNO_3$ a restricted substance. Article 7 CFR section 205.602(g) of NOP's National List states $NaNO_3$ can only be applied for 20% of a crop nitrogen requirement in organic farming (USDA-NOP, 2012). The application rates for 2015-2016 followed these guidelines based on soil fertility testing and in 2016, additional measurements from a chlorophyll SPAD 502 meter (Spectrum Technologies Inc., Aurora, IL). The crimped cover crop plots and non-cover crop plots each had 30 randomly selected V5 growth stage corn plants analyzed for chlorophyll concentration, and $NaNO_3$ was applied per NOP regulation.

On 25 June 2015 and 13 May 2016, organic soybean cultivar Emerge E3782S was planted at a seeding rate of 165,000 seeds ha^{-1} with a 4 row John Deere planter (John Deere, Moline, IL). The rate was increased to 192,000 seeds ha^{-1} for no-till plot treatments in 2016. The rate for till plot treatments remained constant for 2016. Soybean was planted into the standing winter cover crop for all no-till weed treatment plots. The cover crop is terminated by crimping shortly after; therefore, seeding rate was increased to assure an acceptable soybean stand. Row spacing was 76 cm, providing eight-row treatment plots. Because soybeans are symbiotic nitrogen fixators, the only nutrients applied were those in the initial fall compost amendment before experiment initiation.

Weed treatments were first applied to 10.2 cm high weed seedlings and repeated as necessary until crop was too tall for safe clearing of tractor mounted implement. Each weed treatment was implemented on average once every 9 days weather permitting (Table 2.3). Soybean plants are smaller in stature and received approximately two more applications per treatment than the corn plants. However, the exception is the propane flamer Red Dragon (Flame Engineering Inc, LaCrosse, Kansas) weed suppressor treatment; because of the soybean plant's small seedling stature and tender hardiness, flame treatments had to be delayed until emerging plants were 25.4 cm. Adjustments had to be made to the propane flamer even after the desired height of the plant. Flame treatment plots experienced soybean stand loss in 2015 (5%-70%) due to semi and/or completely charred seedlings. Therefore, in 2016 shields were attached on either side of the propane burners to facilitate desired treatment effect on between-row weeds only. The flame treatment plots still experienced soybean stand loss in 2016 (0%-30%) with the shield outfitted implement. We decided to delay flame treatment until the soybean plants were 25.4 cm high, and further adjust the burners by lowering them 15 cm above the soil surface. As a result of the delayed flame treatment, between-row cultivation was used in 2016 on soybean flame treatment plots until plants were of acceptable height. This allowed the study to maintain weed management at a critical stage of established growth in germinated soybean seedlings.

The hot water sprayer (Largo Ind., Decaturville, TN) weed suppressor treatment applied a topical spray of water at 150°C onto the weed leaf surface. This treatment was not applied as frequently in 2016. The dense crimped cover crop supplied the needed weed management. Furthermore, equipment malfunctions delayed hot water treatment; even though these were remedied quickly, the growth rate of corn allowed only 1 hot water treatment application in 2016. The second weed management treatment with a crimped cover crop, between-row mowing was done with a self-propelled push mower (Swisher Acquisition Inc., Warrensburg, MO) was also less frequently applied in 2016 for the same reason. And lastly, the conventional organic row crop weed management practice, between-row cultivation was done with a Danish S-tine 4 row cultivator. The frequency of between-row cultivation was on average less than the other weed treatments, approximately every 13 days, this was consistent for both years.

Corn was harvested on 19 October 2015 and 30 September 2016 with a Kincaid research combine, (Kincaid Equip. Mfg., Haven KS), using the two middle rows for yield and moisture data. Similarly, soybean plots were harvested on 14 October 2015 and 4 October 2016 with a 2-row Wintersteiger research combine (Wintersteiger Inc., Salt Lake City, UT), using the two middle rows for yield and moisture data.

After harvest the area is prepared by mowing any crop residue with the Brush hog, spreading Early Bird compost (2-1-1) with the manure spreader at a rate of 18 mT ha^{-1} and disked twice with the disc harrow. The winter cover crop mix followed either the double crop soybean or the corn section of the outlined project (Figure 2.2) and planted with the Tye no-till drill planter at the same rates discussed in the top of this section.

Soil Evaluation Methods

Both predominant soils at the study site, Mexico silt loam and Leonard silt loam are taxonomically similar, but vary in slope and thickness of the silt loam horizon. Mexico has 0-4 percent slope, and up to 38 cm. of silt loam; in comparison, Leonard has 2-14 percent slope, and 18 cm. of silt loam. Since the study is mainly concerned with weed suppression treatment effects within the topsoil (8 cm.), the difference of silt loam thickness likely will not skew results. Slope differences are considered as erosion or ponding may occur due to heavy rainfall in 2015 or excessive hot water spray treatment.

Soil was collected for analysis before crop harvest on 13 October 2015, and 26 September 2016 with a JMC back-saver soil probe (Newton, Iowa). Soil cores (1.9 cm diameter) were randomly pulled within each treatment plot 55.5 m^2 area at a depth of either 0-5 cm or 0-15 cm depending on soil analysis. Twelve soil cores of 0-5 cm were collected from each treatment plot to determine active carbon, β-glucosidase, and acid phosphatase activities; and phospholipid fatty acid (PLFA) composition. Six soil cores of 0-15 cm were collected from each treatment plot to determine aggregate stability, organic matter, phosphorus, potassium, calcium, magnesium, cation exchange capacity (CEC), and pH characteristics. Soil samples were homogenized, air-dried, and passed through a 2 mm sieve; except for aggregate stability analysis, which utilizes a 1 mm particle size for analysis.

A soil bulk density extraction was taken on 28 April 2015 and 10 May 2016 as outlined by Grossman and Reinsch (2002). Bulk density samples were collected with metal rings 7.62 cm in length with a 7.62 cm diameter. One soil core sample was removed from the center of each weed treatment plot each spring, and analyzed using the Grossman and Reinsch method (2002).

Soil sample analyses were conducted at three locations. The Soil Health Assessment Center (Columbia, MO) analyzed PLFA composition using extraction and gas chromatograph (Agilent 7890A, Santa Clara, California) methods formulated by Buyer and Sasser (2012) with PLFA detection using the Sherlock Microbial Identification System software.

The University of Missouri Soil and Plant Testing Laboratory analyzed multiple soil characteristics associated with a common soil fertility test, i.e. macronutrients, pH, SOM, and CEC following protocols of methods and procedures outlined in Nathan (2012). SOM is calculated via weight loss resulting from ignition in a 360°C oven, pH is determined with a dilute salt solution (0.01 M C_aCl_2) and glass electrode pH meter that measures the concentration of H^+. Soil phosphorus content was determined with a concentration of 0.25 N HCl (Bray I) as the extractant and ascorbic acid as the color developing reagent and samples were read on a spectrophotometer at 660 nm. Soil potassium, calcium, and magnesium content were determined with a concentration of 1 N ammonium acetate (pH 7.0) as the extractant, and samples were read on an atomic absorption spectrophotometer. The CEC of soil was estimated from the sum of extractable potassium, calcium, and magnesium results plus the measure of neutralizable acidity (NA). NA can be calculated when measuring for soil pH by adding a 7.0 buffer.

The rest of the soil characteristics were analyzed at the soil quality Agriculture Research Service (ARS) soil lab. Active carbon present in the soil was determined by the permanganate oxidizable carbon method outlined by Weil et. al. (2003). Modifications were as follows; settling time for suspension was reduced to 5 minutes from 10 minutes, amount of soil used was 2.50 g., and lastly soil used was air-dried and crushed. Results were more consistent when crushed. Weil recommends 2.5-5.0 g of soil for the analysis, and 2.50 g was sufficient. The two soil enzyme concentrations, β-glucosidase and acid phosphatase, were estimated by the methods of Eivazi and Tabatabai (1988), and Tabatabai and Bremner (1969). Modifications were as follows; the use of Toluene was omitted per suggestion of Acosta-Martinez (2011), and wavelength 405 nm was used for both enzymes spectral analysis. The wet aggregate stability method from the National Soil Survey Center (Soil Survey, 2014) was used to calculate percentage of soil aggregates that may survive a disturbance within each soil sample. Soil aggregates of a certain particle size were placed on a 0.5 mm sieve in water and dunked, remaining soil was potential stable aggregates.

Data were analyzed using SAS Enterprise Guide 4.3 statistical software (SAS Inst., 2001). Proc Mixed was used to perform the analysis of variance. Treatment replication was considered random whereas crop phase was considered fixed. Statistical significance was at $P \leq 0.05$. When treatment effects were significant, means were separated using Tukey's honest significant difference (HSD)

RESULTS AND DISCUSSION

Weather Conditions

As stated previously precipitation during the first year of the project caused overall organic management practices to be incongruent within the two year study. The 30 year average cumulative precipitation for Boone County is 1,083.0 mm; 1,263.65 mm, and 1017.52 mm were recorded for 2015 and 2016 respectively (Figure 2.5).

The greatest precipitation amounts were recorded during prime planting season and termination of cover crops. The months of March-July 2015 had a total accumulation of 732.0 mm whereas the 30 year average precipitation for Boone County for these months is 644.90 mm; 2016 precipitation was well below average at 257.3 mm for the same time period (Figure 2.6). A major precipitation event occurred in 2016 during the last week of July (277.1 mm), which caused minimal impairment to the study (Figure

2.6). The majority of cumulative precipitation for 2016 continued August through September which delayed harvest by two weeks.

Soil Physical Property Analysis

Bulk density is related to the total amount of porosity (Carter and Ball, 1993), which is a measurement of open pore space within the soil for the movement of air and water. When the pore space decreases, bulk density increases and soil compaction can occur. High bulk density parameters can lead to decreased water infiltration (Karlen et al., 1994), limit rooting depth (Cassel, 1982) via penetration resistance, and influence microclimates of soil microbes with altered habitat (Warkentin, 2001). The optimal bulk density differs over the range of soil textures, the soil in the present project is a silt loam with ideal bulk density of <1.4 g/cm^3.

Bulk density was sampled in the spring of 2015 & 2016 per protocol’s optimal time for sampling. The sampling in 2015 did not have any of the weed treatments subjected to the soil, therefore will be considered as a baseline and not included in the 5 year report unless relevant.

Bulk density was not significantly different among treatments for 2016 (Table 2.4). Bulk density is mostly influenced by soil disturbance, tillage and cultivation (Lampurlanes et al., 2003; Moran et. al., 1988; Cogger et al., 2016) and soil organic matter (Blanco-Canqui and Benjamin, 2013; Cogger et al., 2016). The spring 2016 bulk density results reflect 2015 management practices which included unforeseen increased tillage and no additional crimped cover crop biomass. Although not significantly different, flame treatment (1.31 g/cm^3) was similar to between-row cultivation (1.3 g/cm^3), as was the hot water bulk and mowing treatments with similar bulk density values. Overall density values increased in the second year. Soil bulk density usually decreases as soil organic matter increase (Kladivko, 1994). This would suggest that organic matter from the winter cover crops and compost did not lower bulk density values even though the study underwent intensive uniform cultivation and treatment disturbances in the previous spring. However, any conclusions would be premature as a previous long-term study (Lampurlanes et al., 2003) did not see any yield conclusive results regarding tillage effects on bulk density until three years into the experiment.

Aggregate stability is related to soil structure, as soil particles bind to each other to form aggregates. The relative stability of soil aggregates to resist separation is measured when disruptive forces are applied. Aggregate stability is an important soil quality factor as it affects movement of water, aeration, nutrient availability, root penetration, and seedling emergence for plants (Gallardo-Carrea et al., 2007). It also facilitates soil conservation as it decreases the rate of soil erosion and crusting (Bajracharya et al., 1998; Wang et al., 2013). Similar to bulk density, soil organic matter is a contributing factor that indirectly increases aggregate stability (Lynch and Bragg, 1985; Six et al., 2002). The decomposition of organic matter, as in compost, results in the production of biological binding agents such as polysaccharides, and lipids (Lynch and Bragg, 1985), and along with intertwined fungal hyphae, the pliancy of soil aggregates increases (Tisdall and Oades 1982).

Aggregate stability was not significantly affected by treatments for 2015 but was for 2016 (Table 2.4). Values for 2016 were lower than values for 2015. The plots that received weed treatments of mowing and hot water increased aggregate stability compared to the between row cultivation plots. This is consistent with findings that show soil disturbance decreases aggregate stability (Six et. al. 1999; Wander et al., 2000, Kasper et al., 2009), while the no till weed treatment plots were buffered with a crimped cover crop providing potential active organic matter decomposition. The flamed weed treatment had neither crimped cover crop nor cultivation disturbance; therefore, the aggregate stability value was intermediate for both years. This is consistent with long-term studies (Teague et al., 2010 & 2008) with rotated burn patches in prairies and short-term field burn projects that did not find decreases in aggregate stability (Parlak et al., 2015). Although 2015 showed no significance differences among treatments (p=0.051) aggregate stability values were considerably higher with an overall average of 65.98% compared to 33.21% for 2016.

Soil Biological Property Analysis

PLFA

Since the introduction in the early 1990's of the phospholipid fatty acid (PLFA) analysis for differentiating soil microbes based on biochemical patterns, it has become one of the more popular techniques to assay the biomass and composition of soil microbial communities (Frostegard et al., 2010). The PLFA method is a rapid, effective way to evaluate effects of soil management on bacteria or fungal communities (Frostegard et al., 1996). In addition to total PLFA concentrations for specific microbial groups, overall PLFA totals for treatments, and the relative abundance of fungi and bacteria which is referred to as the bacteria/fungi ratio can be calculated from PLFA analysis.

Several PLFA components significantly differed within treatments with an emerging pattern of significance among the weed treatments that was dominant for both years of the study (Table 2.5). The between-row mowing and hot water spray weed treatments frequently had higher concentrations of specific microbe groups than the between-row cultivation and propane flame weed treatments. The water spray and mowing treatments terminate weeds that add moisture and organic substances to the soil. Soil moisture and organic matter content are closely related to an increased microbial PLFA as Brockett et al., (2012) found in a forest ecosystem study. Additionally, findings from Guenet et al., (2011) also indicated increased soil moisture significantly contributed to higher bacteria PLFA contents.

The specific microbe groups that were significantly different for the hot water, mowing, and cultivation treatments for 2015 were: gram negative bacteria, gram positive bacteria, actinomycetes, and eukaryotes (Table 2.5). Flame was also significantly different for gram negative bacteria and eukaryotes in 2015 in contrast to the mowing and hot water spray treatments respectively (Table 2.5). Similarly, in 2016 gram negative bacteria, with the addition of actinomycete concentration in the flame treatment plots were lower compared to the mowing and hot water treatments. This contrasts with a study that found no differences in PLFA biomarkers for prescribed prairie burns at four different sites (Veum et al., 2015). Other studies have also shown gram negative bacteria to be a more robust microbial group that prefers drier environments (Guenet et al., 2011), is not as affected by tillage, and will rebound to previous no-till environmental conditions faster than other microbe groups (Wortmann et al., 2008; Guenet et al., 2011). However, in the current study the average PLFA total for microbial groups within cultivation and flame treatments are similar for both years.

Arbuscular mycorrhiza (AM) fungi had significantly elevated PLFA concentrations for 2016 in mowing, and hot water treatments (Table 2.5). Even though 2015 precipitation was high, and pre-season winter cover crops contributed below-ground root biomass, the AM fungi community did not significantly differ for any weed treatment. A one-time tillage event can significantly decrease the AM fungal soil population (Wortmann et al., 2008). Their short-term study of three years did not indicate that the AM fungal community recovered to former levels. A similar study over five years (Drijber, 2002) also found a one-time tillage event significantly decreased AM fungi levels that never rebounded. The current study shows an overall drop in AM fungi population from 2015-2016.

The one PLFA biomarker group not affected by weed treatments was the general fungi community. However, the overall population decreased by approximately half in the second year with no response to increased compost application, or the presence of cover crops. This is in contrast to previous findings where cover crop practices increased fungal biomass (Carrera eta al., 2007; Jokela et al., 2009). The ideal environment for microbial groups with extended hyphae is reduced physical disturbance.

Overall, total biomass PLFA was significantly different for weed treatments in both years 2015-2016 (Table 2.5). Mowing and water spray consistently showed increased microbial biomass compared to cultivation and propane flame.

<u>Soil Enzymes</u>

The enzyme β-glucosidase (BG) EC 3.2.1.21; obsolete: cellobiase plays a major role in the degradation of soil organic matter and plant residues as it catalyzes the hydrolysis of β-D-glucopyranosides within cellulose, and provides simple sugars (glucose) to soil microorganisms (Dick et al., 1996). Since soil microorganisms are the major source for soil enzymes it is theorized that increasing soil microbial populations will increase enzyme concentrations within the soil (Tabatabai, 1994). However, despite significant treatment effect for total PLFA biomass (Table 2.5) and soil organic matter (Table 2.7) no significant differences between treatments were detected for BG in either year of the study (Table 2.6). These results contrast previous studies reporting sensitivity of BG in residue management, and serving as an early indicator of changes in soil organic matter, (Miller and Dick et al., 1995; Acosta-Martinez et al., 2003; Roldan et al., 2005).

Considering that BG enzyme activity increases more effectively under cover crop practices and higher residue crops (Bandick and Dick, 1999; Stott et al., 2010), it is reasonable to not expect increased BG because of the absent crimped cover crops in 2015. Although crimped cover crops were included in the no till weed treatment in 2016, BG activity was not different among any treatment likely due to the high rate of compost (18 mT ha^{-1}) applied to the entire field after the 2015 grain harvest. Activity of BG enzyme may increase with the addition of an organic manure-based compost (Melero et al., 2007; Bastida et al., 2008; Ros et al., 2003). Since there was an increase in overall BG concentration across treatments in 2016, this management practice may have diluted any potential effects due to applied weed treatments.

Although BG activity has been observed to quickly respond time to the addition of organic matter, flame treatment has little effect in the short term (Boerner et al., 2000). Although the intensity of the fire and repeated treatment of flame on the above ground vegetation ecosystem must be considered, the general trend for long-term studies see declines in BG activity no matter the intensity or recurrence. Studies on a managed prairie for over a 10- year period (Ajwa et al., 1999) and a forest over a 30- year period (Eivazi and Bayan, 1996) reported significant decreases in BG activity. This suggests a longer time frame may be needed to see any effects due to propane weed treatment on BG soil enzyme levels.

The phosphatases are the general group of soil enzymes that catalyze the hydrolysis of both esters and anhydride bonds of phosphoric acid (H_3PO_4), and play a major role in mineralization and transformation of a large portion of soil organic phosphorus (Dalal, 1977). The acid phosphatase (AP) enzyme (EC 3.1.3.2) is a phosphomonesterase that transforms organic phosphorus (P) into inorganic phosphate that effects soil biogeochemical cycling and plant nutrition (Martinez and Tabatabai, 2011).

There were significant differences for AP enzyme levels within weed treatment plots for 2015 (Table 2.6). The AP activity in the mowing weed treatment was higher than flame and cultivation weed treatments. Since AP is linked to mineralizing P from organic matter, several studies show decreased AP enzyme activity under conventional tillage possibly because of the lack of organic substrate (Acosta-Martinez et al., 2002, 2007, 2008; Nannipieri, 1994, Deng and Tabatabai 1996). AP enzyme activity also decreases significantly in prescribed burns in both long-term and short-term forest studies (Boerner et al., 2000, 2005; Eivazi and Bayan, 1996). However, in controlled, low intensity burns <50°C AP activity was not significantly changed (Saa et al., 1993) for a shrubland location, but increased for a 10 year study tallgrass prairie location (Ajwa et al., 1999). A possibility for the contrasting results may be due to decreased AP activity when a supply of inorganic phosphate is adequate for metabolism, which occurs when organic phosphorus is charred (Cade-Menum et al., 2000).

AP will increase with addition of soil organic matter, and is significantly higher when poultry litter is applied (Acosta-Martinez and Harmel, 2006). The compost used in the current study was based on poultry litter. The corn plot sections had an additional compost application (18 mT ha^{-1}) in the spring 2015, which was not repeated for 2016. Phosphorus levels tripled in 2015 compared to 2016 (Table 2.7); therefore, the overall AP enzyme activity was higher for 2015, coinciding with a crop effect ($p = 0.01$) due to the corn section showing higher AP values.

There were no significant differences for AP enzyme levels within weed treatment plots for 2016. Although cultivation had the lowest AP it was not significant, and there were no statistically different crop effects that affected AP activity from the previous year spring application. Interestingly, the highest value for AP in 2016 was under hot water spray (280 μgPNP g soil^{-1} hr^{-1}), and nearly the same value as for the lowest AP activity in the 2015 cultivation treatment (286 μgPNP g soil^{-1} hr^{-1}).

Soil Chemical Property Analysis

<u>Soil Carbon</u>

Soil organic matter (SOM) is one of the most widely acknowledged soil quality indicators with its dominant constituent, soil organic carbon (SOC), being a common soil measurement (Weil et. al., 2003). The active carbon fraction of SOC consists of microbial biomass carbon, particulate organic matter and soil carbohydrates. Active carbon fractions include carbohydrates that initiate metabolism by the soil microbial food web that influences nutrient cycles, and physical soil properties (Weil et al., 2003).

Active carbon, the permanganate oxidizable soil carbon fraction (POXC) was significantly affected by treatments for 2015 but not for 2016 (Table 2.7). Although not significant, values for 2016 were higher than values for 2015. Mowing weed treatments increased POXC levels compared to the between row cultivation and flame plots in 2015 (Table 2.7). Studies have demonstrated a relationship between POXC and SOC (Culman et al., 2012; Lucas and Weil, 2012; Morrow et al., 2016; Plaza-Bonilla et al., 2014) as tillage reduces the availability of SOM while additions of cover crop biomass and compost increase potential labile carbon. Despite an absence of crimped cover crop and reduced application of compost in 2015, the mowing weed treatment was associated with increased POXC. An explanation for this could be the increased precipitation in 2015, which is supported by Culman et al., (2012) who concluded that environmental factors have a significant effect on measured POXC. Because soil moisture was high, fast breakdown of compost or fresh weed plant biomass may lead to greater accumulation of organic material.

Interestingly the cultivation and flame weed treatments had similar values for POXC. Studies have shown with low intensity, prescribed wildfires SOC can increase due to the input of partially charred material or decaying roots from burnt plants (Knicker et al., 2005). On the other hand, in grassland landscapes subjected to frequent burning result in decreased SOC over time in the upper centimeters (Bird et al., 2000; Parker et al., 2001). The current study provides a low intensity, frequent burn treatment, resulting in the lowest POXC values for the flame treatment in both years (Table 2.7). However, average total PLFA biomass (Table 2.5), and total soil organic carbon (Table 2.7) were not the lowest due to flame treatment plots. Although POXC is reported as a sensitive indicator of management practices (Weil et al., 2003) propane flame weed treatment effects on POXC may need to be evaluated long-term to fully describe its impact.

Although 2016 showed no significance differences among treatments (p=0.075), POXC values were considerably higher with an overall average of 0.99 g kg soil^{-1} compared to 0.74 g kg soil^{-1} for 2015. POXC values were not different among any treatment likely due to the high rate of compost (18 mT ha^{-1}) applied to the entire field after the 2015 grain harvest. The decomposition of SOM and the availability of labile carbon will increase with the addition of an organic manure-based compost. Since there was an increase in overall POXC concentration across treatments in 2016, this uniform application of compost to the study area may have diluted any potential effects due to applied weed treatments.

Macronutrients, pH, SOM, CEC

The macronutrients Bray 1 phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) are important constituents in soil that promote plant and microbial growth. After nitrogen, P and K are the second and third limiting factors for plant growth, and are normally included in inorganic fertilizers. The secondary macronutrients, Ca and Mg are utilized by plants and microbes in reduced amounts but are essential for nitrogen metabolism and chlorophyll production, respectively.

Potassium was the only nutrient that was significantly different affected by weed treatments in 2015 (Table 2.7). Hot water spray contributed to the highest (320 mg kg soil^{-1}), and between-row cultivation the lowest soil K contents (248 mg kg soil^{-1}). Additionally, soil organic matter had the same significant difference within treatments. The applied moisture from the hot water spray treatments accelerated decomposition rate of the compost and increased K release. Multiple studies have reported increased K levels with applied manure-based compost (Chen and Samson, 2002; Askegard et al., 2003; Reider et al., 2000).

The variability of soil organic matter affects most soil nutrients by concentration and rate of release (Williams and Wailkins, 1973). Although there were no crimped cover crops, compost was added spring 2015 to the corn section causing increased values in all the macronutrients compared to 2016, and possible dilution effects to any differences between weed management practices. Furthermore, because of the additional compost application in 2015, there was a crop effect for corn plots ($p= 0.020$ and lower) causing all macronutrients values to be considerably higher than soybean plots.

Calcium was the only nutrient that significantly differed among weed treatments in 2016 (Table 2.7). Between-row cultivation had significantly higher Ca levels (2,164 mg kg soil^{-1}) compared to the hot water spray treatment (2,026 mg kg soil^{-1}). This result may be an effect of cation competition with other increased levels of soil cations, K and Mg. High levels of K have been known to reduce Ca uptake in plants (Parsons et al., 2007), along with high levels of P that react with free Ca to form insoluble Ca-P compounds, with both interactions resulting in less K or P within the soil and increased amounts of Ca.

The average totals of macronutrients decreased in 2016, which was expected since the last application of compost was eleven months before. There was a crop effect for K in soybean for 2016 ($p=0.032$). This is most likely a carry-over effect from the previous year high K levels and crop effect ($p= <0.001$) in corn, prior to the soybean rotational crop.

Soil pH and CEC were not affected by weed treatments (Table 2.8). The average CEC value was higher in 2015 (15.3) compared to 2016 (13.5). Manure-based compost may elevate CEC sites (Saharinen, 2013) and when applied to soil may influence the soil CEC and ability to hold onto nutrients. The additional compost in 2015 may have also contributed to higher soil CEC values.

SOM contents were significantly affected by weed control treatments throughout 2015-2016 (Table 2.8). SOM contents in 2015 were significantly higher for water spray and between-row mowing compared to cultivation and flame. A crop effect was present in 2015 for corn ($p= 0.01$). In 2016, hot water spray was significantly higher in SOM (3.9%) relative to other weed control treatments. The remaining weed treatments were similar in SOM in 2016 (Table 2.8), and no carry-over crop effect was detected from last year with additional compost to corn.

Crop Yield

Crop yield was not the main goal of the current study, but rather assessment of soil quality in an organic system under alternative weed management practices. However, yield can be viewed as an indirect measurement of soil quality as it presents productivity of that soil under a particular weed management. The corn and soybean yields were measured separately for both years.

Significant weed treatment effects were detected for both crops in the 2015 and 2016 growing season (Table 2.9). A pattern emerged for corn yields for both years; between-row cultivation and mowing had significantly higher yields compared to hot water spray and flame treatments. The overall average yields increased in the second year, with similar and highest yields in the mowing (7,273 kg ha^{-1}) and cultivation (7,351 kg ha^{-1}) treatments. An adequate biomass of the second year winter cover crop provided effective weed suppression after crimping during early corn growth stages; however, surviving weeds were predominately broadleaves which could not be terminated effectively with hot water spray.

Weed management effects on soybean yield in 2015 were significant for mowing only (1,993 kg ha^{-1}), as all other treatments produced similar yield (Table 2.9). Flame treatment had the lowest yield for 2016 (1,107 kg ha^{-1}) while mowing continued to have the significantly highest yield value (2,178 kg ha^{-1}) compared to cultivation (1,707 kg ha^{-1}). Low yields in the flame treatment could have resulted from excess soybean mortality from mis-directed flaming early in the soybean growth stage.

CONCLUSIONS

Although there have been numerous studies on the effects of conventional tillage, no-till, cover crops, compost and crop rotations on soil quality, there are few that utilize a multiple suite of these practices together as a management system. This study introduced alternative weed management treatments that were integrated with commonly used organic practices, to assess their effects on soil quality.

In an organic system that utilizes a winter cover crop, manure-based compost, and no-till during the growing season, between-row mowing for weed management resulted in highest values for physical and biological soil quality indicators. Hot water spray with the same suite of organic practices showed highest values for chemical soil quality indicators. However, with crimped cover crops in a no-till organic system, hot water spray had the highest values for biological and the majority chemical of soil quality indicators.

The hot water spray treatment is a new method for suppressing weeds. The high temperature of water did not reduce soil quality, and was found to be the treatment yielding the highest soil quality values in biological and chemical properties. Combined with a crimped cover crop, the addition of water increased decomposing of SOM more readily and likely increased microbial populations and available nutrients. Further research is needed for hot water treatment without a crimped cover crop to assess separately possible compaction, no-till throughout year with cover crop, and to sample soil leachates for nutrient losses.

Between-row cultivation had the lowest values for all three soil quality indicator categories, physical, biological, and chemical. Soil quality under propane flaming was similar to the cultivation treatment, except for higher values for aggregate stability, acid phosphatase activity, total PLFA, and SOM. Propane flame has potential as an alternative to tillage in organic weed management, however, further research is needed for effects on possible soil crusting, microbial short-term response to between-row flame, and different compost rates needed to increase soil quality indicators.

The effectiveness of the weed suppressing treatments was indirectly measured by grain yield. Adoption of alternative weed management practices will be moderate to none if the treatment does not terminate weeds that interfere with harvestable yields.

In corn, the highest yield was for between-row cultivation (7,351 kg ha^{-1}); however, when a crimped cover crop was present in the second year of the study, between-row mowing showed yield similar to that under cultivation (7,273 kg ha^{-1}). Flame showed the third highest in yield (6,643 kg ha^{-1}). Lowest corn yields were obtained under hot water spray (5,712 kg ha^{-1}) due to the hardiness of broadleaf weeds that survived the crimped cover crop mat and were competitive with corn throughout the growing season.

In soybeans, the highest yield was found for between-row mowing with or without crimped cover crop (2,178 kg ha^{-1}, 1,993 kg ha^{-1}). When crimped cover crop was not combined with other weed management, between-row cultivation provided the second highest yields (1,620 kg ha^{-1}); however, in the presence of a crimped cover crop hot water spray is second highest (2,098 kg ha^{-1}) and similar in yields to that under mowing. The lowest soybean yield occurred with propane flaming (1,107 kg ha^{-1}) due to intense heat of the treatment resulting in severe injury or death. Precautions need to be made to protect early stage soybean plants.

The added benefits of combined organic management practices are apparent as cover crops and compost utilized together effect soil quality and crop yields undergoing alternative weed treatments. Soil quality was the highest in hot water spray treatments with crimped cover crops, or mowing without crimped cover crops. Crop yields were overall higher in the second year as a good winter cover crop stand was established and terminated by crimping or mowing.

Although between-row mowing was found to have the highest yields with a crimped cover crop in both corn and soybeans, the species of cash crop needs to be taken into consideration when applying thermal alternative weed practices. Hot water spray had yield results statistically same as between-row mowing for soybean; however, hot water spray is not as effective to yield results in corn. Propane flame has potential in corn, but caution must be used for flaming soybeans until improved methods can be employed.

Figure 2.1. Red Dragon 4-row propane flamer.

Figure 2.2. Custom made 3-row hot water sprayer with Beckett industrial burner.

Figure 2.3. Arial view of project site located at Bradford Research Center. Study was sectioned off into 3 equal 61 m x 64 m for a crop rotation consisting of wheat/corn/soybeans. Rotation shifted in the Southern direction for the following year. Landscape image provided by WebSoilSurvey.com.

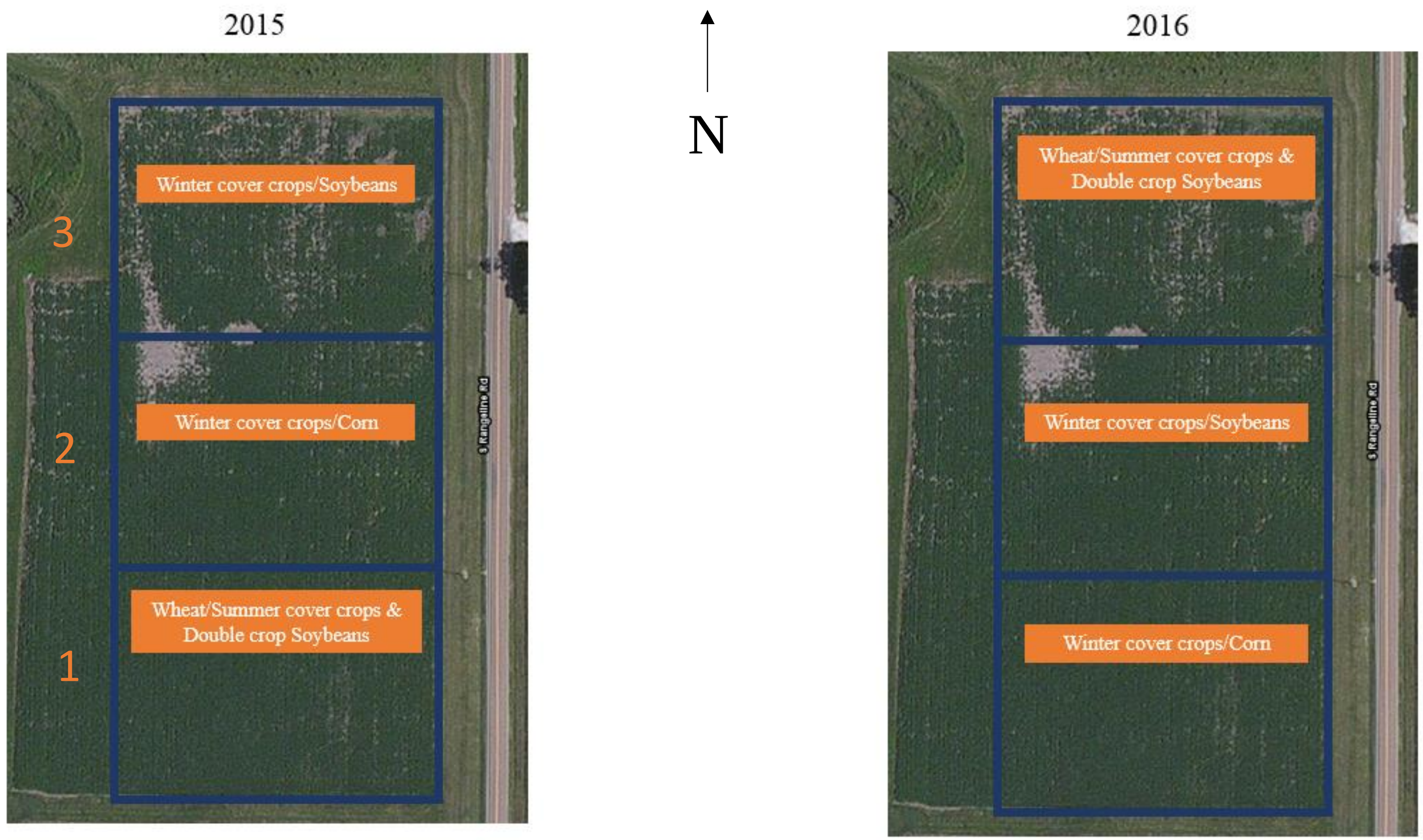

Figure 2.4. Study design layout for 2015-2016. The blocks containing corn or soybean had weed treatments plots of 6.1 m x 9.1 m. T= between row cultivation, F= propane flame, W= hot water spray, and M= string mow. Crops were rotated each year but the weed treatments remained in the same location throughout the two year rotation. The blocks containing wheat had treatment plots of 6.1 m x 9.1 m. SCC= summer cover crop, DC= double crop soybean. When the crops rotated, corn followed wheat, soybeans followed corn, and wheat followed soybeans.

Section 1
Wheat 2015

Block 1	Block 2	Block 3	Block 4
SCC	SCC	DC	DC
SCC	SCC	SCC	DC
SCC	SCC	DC	SCC
DC	SCC	SCC	DC
DC	DC	SCC	SCC
SCC	DC	DC	SCC
DC	DC	SCC	DC
DC	DC	DC	SCC
SCC	SCC	SCC	SCC
DC	DC	DC	DC

Section 2
Corn 2015

T	T	T	F
T	F	F	T
M	T	W	T
W	F	W	W
M	W	M	F
W	W	T	M
F	M	M	W
F	M	F	M

Section 3
Soybean 2015

W	W	T	M
F	T	W	W
M	W	M	T
W	F	F	W
T	F	M	F
M	M	W	M
T	M	F	T
F	T	T	F

Section 1
Corn 2016

Block 1	Block 2	Block 3	Block 4
T	F	T	F
M	T	W	M
T	W	M	T
F	T	M	W
M	W	F	F
W	F	T	M
W	M	W	W
F	M	F	T

Section 2
Soybeans 2016

T	T	T	F
T	F	F	T
M	T	W	T
W	F	W	W
M	W	M	F
W	W	T	M
F	M	M	W
F	M	F	M

Section 3
Wheat 2016

SCC	DC	SCC	SCC
DC	DC	DC	SCC
DC	SCC	DC	SCC
DC	SCC	DC	SCC
DC	SCC	SCC	DC
DC	SCC	DC	DC
SCC	DC	DC	SCC
SCC	SCC	SCC	DC
SCC	DC	SCC	DC
SCC	DC	SCC	DC

Figure 2.5. Cumulative precipitation for years 2015-2016 compared to the 30-year average cumulative precipitation for Boone County, Missouri.

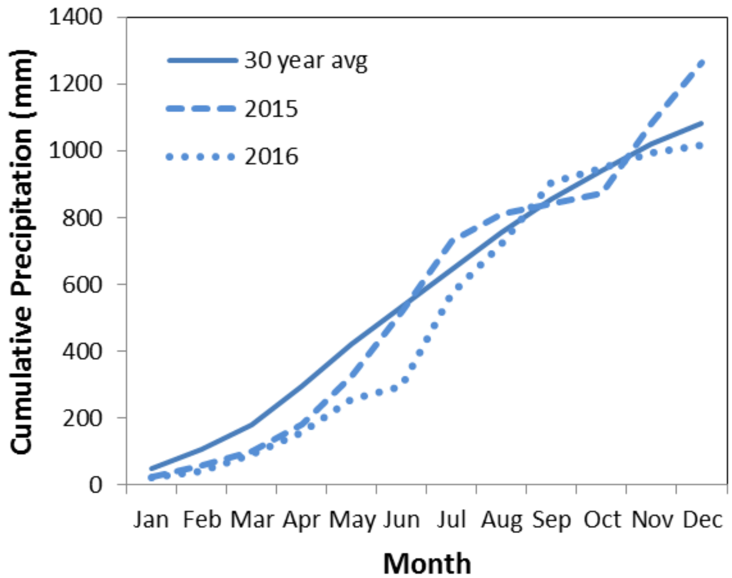

Figure 2.6. Precipitation for years 2015-2016 compared to the 30-year average precipitation for Boone County, Missouri.

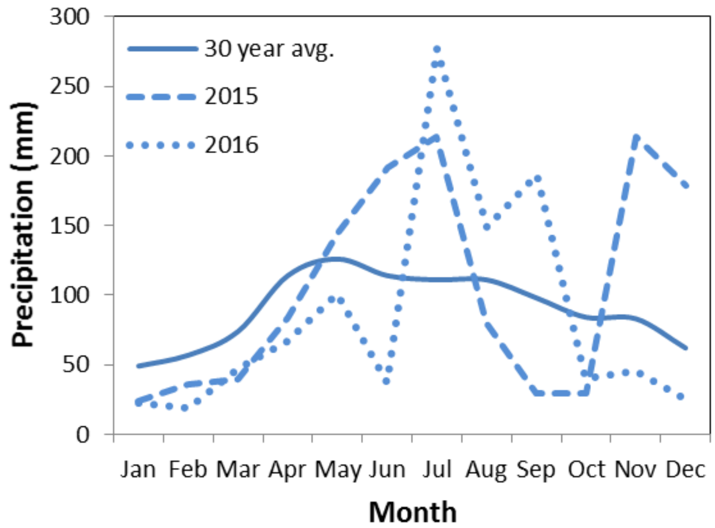

Table 2.1. Variety, source, and seeding rate of each seed species used in 2015-2016

Crop	Variety	Company	2015	2016
			Seeding Rate	
			--------------kg ha^{-1}--------------	
Corn	MC5300	Master's Choice	22.4	17(T), 23(NT)
Soybean	E3782S	Emerge	67.3	67(T), 79(NT)
Cereal Rye	VNS	Welter Seed CO	89.7	123.3
Austrian Winter Pea	VNS	Welter Seed CO	10.1	10.1
Crimson Clover	VNS	Hancock Seed	11.2	11.2
Oats	Jerry	Welter Seed CO	20.2	N/A
Rapeseed	Dwarf Essex	Welter Seed CO	3.0	3.0
Hairy Vetch	VNS	Welter Seed CO	11.2	11.2

VNS= Variety not stated, (T)= seeding rate in tilled treatments i.e. flame/cultivation, (NT)= seeding rate in no-till treatments i.e. hot water/mow, N/A= information not available as oats were not repeated in second year.

Table 2.2. Planting, fertilizing, harvest and termination dates for corn, soybean, and winter cover crops 2015-2016.

	2015			2016		
Crop	Planting	Fertilize	Harvest/Termination	Planting	Fertilize	Harvest/Termination
Corn	11-Jun, 25-Jun‡	24-Jun, 31-Jul§	19-Oct	5-May	20-Jun§	30-Sep
WCC (C)	22-Oct†	21-Oct†	11-Jun	20-Oct†	15-Oct†	6-May
Soybean	25-Jun		14-Oct	13-May		4-Oct
WCC (SB)	22-Oct†	23-Oct†	11-Jun	20-Oct†	15-Oct†	13-May

†Management was implemented in the fall previous of year stated, ‡Replant of a crop, §fertilization with Chilean sodium nitrate
WCC (C)= Winter cover crop pre-corn section, WCC (SB)= Winter cover crop pre-soybean section

Table 2.3. Dates for alternative weed management practices for 2015-2016

	2015		2016	
Weed Treatment	Corn	Soybean	Corn	Soybean
Propane Flamer	14-Jul, 24-Jul, 31-Jul	17-Jul, 31-Jul, 7-Aug	24-May, 7-Jun, 14-Jun	1-Jun, 7-Jun, 29-Jun, 11-Jul
Between-row Cultivator	14-Jul, 24-Jul, 31-Jul	17-Jul, 31-Jul, 9-Aug	23-May, 7-Jun, 14-Jun	1-Jun, 7-Jun, 16-Jun, 29-Jun, 11-Jul
Hot Water Sprayer	14-Jul, 24-Jul, 31-Jul	17-Jul, 31-Jul, 7-Aug	29-Jun	29-Jun, 21-Jul
Between-row Mower	14-Jul, 24-Jul, 31-Jul	17-Jul, 31-Jul, 7-Aug	14-Jun, 29-Jun, 8-Jul	14-Jun, 29-Jun, 8-Jul, 26-Jul

Table 2.4. Mean % aggregate stability at 0-15 cm soil depth, and bulk density at 7.62 cm soil depth 2015-2016 as impacted by weed management practices. Values followed by a different lowercase letter within each column are significantly different (using Tukey's HSD) at α=0.05.

	2015		2016	
	Bulk Density	Aggregate Stability	Bulk Density	Aggregate Stability
	-------Mg/m^3-------	----------%----------	-------Mg/m^3-------	----------%----------
Propane Flamer	1.08	66.73	1.31	31.17 ab
Between-row Cultivator	1.05	63.81	1.30	26.51 b
Hot Water Sprayer	1.08	68.23	1.20	34.63 a
Between-row Mower	1.04	69.71	1.20	35.97 a

Table 2.5. Mean biomass of soil PLFA at 0-5 cm soil depth from 2015-2016 as impacted by weed management practices. Values followed by a different lowercase letter within each row are significantly different (using Tukey’s HSD) at α=0.05.

	2015				2016			
	Propane Flame	Between-row Cultivator	Hot Water Sprayer	Between-row Mower	Propane Flame	Between-row Cultivator	Hot Water Sprayer	Between-row Mower
	----------nanomoles g soil^{-1}----------							
Fungi	8.73	7.02	8.97	10.10	3.93	4.00	4.13	3.65
AM Fungi	12.41	12.44	13.70	14.02	8.85 a	8.81 a	10.16 b	9.92 b
GNEG	75.46 ab	72.94 b	84.63 ac	86.49 c	62.06 a	60.22 a	68.82 b	68.46 b
GPOS	48.95 ab	47.97 b	52.56 ab	53.90 c	41.71 ab	40.58 b	45.97 c	45.46 bc
ACT	27.43 ab	26.28 b	29.18 a	29.83 a	22.33 a	21.24 a	24.46 b	24.42 b
EUK	3.44 a	3.32 a	4.20 b	4.25 b	3.80	3.62	4.43	3.64
Total	176.4 ab	169.97 b	193.23 bc	198.59 c	142.70 ab	138.46 b	157.97 bc	155.55 c

AM Fungi= arbuscular mycorrhiza fungi, GNEG= gram negative bacteria, GPOS= gram positive bacteria, ACT= actinomycetes, EUK= eukaryotes.

Table 2.6. Mean β-glucosidase, and acid phosphatase activity at 0-5 cm soil depth, 2015-2016 as impacted by weed management practices. Values followed by a different lowercase letter within each column are significantly different (using Tukey's HSD) at α=0.05.

	2015		2016	
	β-glucosidase	Acid Phosphatase	β-glucosidase	Acid Phosphatase
	----------μg PNP g soil^{-1} hr^{-1}----------			
Propane Flamer	141.00	288.75 a	184.92	256.25
Between-row Cultivator	143.46	286.02 a	180.29	237.53
Hot Water Sprayer	155.57	328.20 ab	197.29	279.53
Between-row Mower	158.54	356.82 b	188.25	262.52

Table 2.7 Mean POXC, at 0-5 cm soil depth, and % SOM, meq/100g CEC, and soil pH at 0-15 cm soil depth, 2015-2016 as impacted by weed management practices. Values followed by a different lowercase letter within each column are significantly different (using Tukey's HSD) at α=0.05.

	2015				2016			
	POXC	SOM	CEC	pH	POXC	SOM	CEC	pH
	g kg soil^{-1}	%	meq 100g		g kg soil^{-1}	%	meq 100g	
Propane Flamer	0.72 a	4.7 a	15.2	6.7	0.95	3.6 a	13.4	6.7
Between-row Cultivator	0.72 a	4.5 a	15.2	6.7	0.97	3.5 a	13.8	6.7
Hot Water Sprayer	0.74 ab	5.1 b	15.4	6.7	1.00	3.9 b	13.1	6.7
Between-row Mower	0.79 b	5.0 b	15.3	6.7	1.02	3.7 ab	13.6	6.7

POXC= permanganate oxidizable carbon, SOM= soil organic matter, and CEC= cation exchange capacity.

Table 2.8 Mean Bray 1 P, and extractable K, Ca, and Mg at 0-15 cm soil depth, 2015-2016 as impacted by weed management practices. Values followed by a different lowercase letter within each column are significantly different (using Tukey's HSD) at α=0.05.

	2015				2016			
	P	K	Ca	Mg	P	K	Ca	Mg
	----------mg kg soil^{-1}----------							
Propane Flamer	115.22	288.91ab	2,276.9	332.5	37.66	167.10	2,084.2 ab	257.70
Between-row Cultivator	101.84	248.44 a	2,298.7	320.34	36.53	158.34	2,164.0 a	262.91
Hot Water Sprayer	125.69	319.94 b	2,289.0	335.34	46.63	194.10	2,025.5 b	254.66
Between-row Mower	14.0	288.91ab	2,267.6	334.94	40.88	182.22	2,126.1 ab	257.97

P= phosphorus, K= potassium, Ca= calcium, Mg= magnesium.

Table 2.9. Mean yield of organic corn and soybean from 2015-2016 as impacted by weed management practices. Values followed by a different lowercase letter within each column are significantly different (using Tukey's HSD) at α=0.05.

	2015		2016	
	Corn	Soybean	Corn	Soybean
	------------------kg ha^{-1}------------------			
Propane Flamer	4,578.7 a	1,361.6 a	6,642.5 ab	1,107.6 a
Between-row Cultivator	5,591.5 b	1,620.2 a	7,351.1 a	1,707.1 b
Hot Water Sprayer	4,403.9 a	1,482.4 a	5,713.9 b	2,095.2 bc
Between-row Mower	5,196.2 b	1,992.6 b	7,272.8 a	2,178.2 c

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CHAPTER III

EFFECTS OF SUMMER COVER CROP AND DOUBLE CROP SOYBEAN ON SOIL CHARACTERISTICS

ABSTRACT

Substantial research has been conducted on winter cover crops, but summer cover crops have received less attention. Benefits reported are reduced soil erosion, suppression of nematodes and weed populations, nitrogen fixation, and increase soil organic matter. Summer cover crops have been used in the southern United States between spring and fall vegetable crops. This study evaluates summer cover crops (SCC) as a second option after wheat harvest, and a potential management practice to improve soil quality and agricultural sustainability. The study included the post-wheat harvest practice of double-cropped soybean (DCS) (*Glycine max* L.) compared with conventional tillage. Both treatments were integrated into an organic system that included grain crops and winter cover crops in a two year rotation, consisting of corn (*Zea mays* L.), soybean (*Glycine max* L.), and winter wheat (*Triticum aestivum* L.). Other organic practices included compost application, and tillage after harvest. The summer cover crop consisted of one grass species sorghum sudangrass (*Sorghum sudanese*), and two legumes, cowpea (*Vigna unguiculata*), and sunn hemp (*Crotalaria juncea*). The study site was located in central Missouri on Mexico silt loam soil and indicators analyzed were aggregate stability (AgStab), bulk density (BD), β-glucosidase activity (BG), acid phosphatase activity (AP), phospholipid fatty acid (PLFA) biomass indicators, permanganate oxidizable carbon (POXC), soil organic matter (SOM), pH, CEC and soil P, K, Ca, and Mg levels. SCC had

higher overall soil quality indicator values compared to a cultivated double crop soybean. For the first year SOM percent difference increased by 12% in SCC compared to DCS, and by 19% in total PLFA. The root biomass of SCC enhanced arbuscular mycorrhiza fungi with a 26% higher value than DCS. The cultivation treatments decreased AgStab by 27% in DCS compared to SCC. The second year of the study was confounded by reduced rainfall, a higher compost rate, and reduced cultivation for DCS. Soil quality indicator values were similar in SCC and DCS. This suggests that minimal tillage and high compost rates in the DCS can attain values for POXC and PLFA biomarkers similar to those for SCC. In an organic practice with moderate compost rates, and average rainfall, SCC has the capability to sustain soil quality.

INTRODUCTION

The increasing pressure on agriculture to provide food security for an increasing global population of 7.4 billion people has been a consistent reminder of inefficiencies of current agriculture technology. There is also an increasing demand for enhanced environmental quality that requires agriculture to consider how to change current systems to become more sustainable. In developing countries access to food is taken for granted, and producers are unrecognized for their efforts and poorly rewarded for being good stewards of the land (Reicosky et al., 2011). In high outputs of grain row-crop production there is little emphasis on the conservation ethic. Intensive agriculture will likely increase as the global population increases and grows to ten billion in the next three decades (Reicosky et al., 2011).

Much of the environmental damage from present-day agriculture production systems is related to intensive tillage methods (Lal et al., 2007). The agriculture damage comes in multiple forms: soil erosion, deforestation, fertilizer run off and “dead zones”, pollution of soil and water, decrease of biodiversity, and fresh water scarcity (Lal et al., 2007). Developing countries’ agriculture systems produce abundance while ignoring long-term consequences, similar to the previous agricultural societies – Greeks, Romans, Babylonians- who decreased soil production in efforts to feed a growing population and collapsed as a result (Lal et al., 2007).

As the global population grew in the 20th century, agriculture increased yields by decreasing land-resource. Given our current knowledge of the planet’s capacity, growing a sufficient amount of food is not enough, it must be done sustainably to conserve resources for future generations (Reicosky et al., 2011). The balance between agriculture productivity and environmental quality relies on proper resource management. Organic management practices of no till in conjunction with cover crops have the potential for increasing sustainable agriculture.

Soil quality is the fundamental foundation for environmental quality, and key for sustainable agriculture. Soil quality is evaluated by measuring three soil property grooups, physical, biological, and chemical. Soil organic matter (SOM) interacts with the three soil properties and governs soil quality. High levels of SOM are strongly correlated with increased values of soil quality indicators (ref). SOM responds to soil management practices, mainly tillage and carbon input (Lal, 2003). Maintaining soil quality by carbon management can reduce soil degradation, and increase soil fertility (Lal 1995, 2003).

Cover crops increase SOM and soil carbon with above ground foliage biomass, and belowground root system biomass (Blanco-Canqui et al., 2013). The amount of carbon cover crops accumulates is significant. Olson et al., (2014) found hairy vetch

(*Vicia villosa* Roth) and cereal rye (*Secale cerale* L.) sequestered 0.88 Mg ha^{-1} yr^{-1} under no till, 0.49 Mg ha^{-1} yr^{-1} under chisel plow, and only 0.1 Mg ha^{-1} yr^{-1} under moldboard plow after 12 years of management. Summer cover crop species also can have a high biomass for carbon input, and increase soil fertility. Balkcom and Reeves (2005) reported sunn hemp (*Crotalaria juncea* L.) produced 7.6 Mg ha^{-1} and increased corn yield by 1.2 Mg ha^{-1}. Cherr et al., (2006) reported sunn hemp biomass as 12.2 Mg ha^{-1} with an increase of 52% in the second year of the study. A 15 year summer cover crop assessment study reported sunn hemp increased sorghum (*Sorgham bicolor*) yields 1.54 times in low nitrogen application treatments (0 kg N ha^{-1}), and increased wheat yield 1.6 times with higher nitrogen application (66 kg N ha^{-1}); soil quality was also effected by summer cover crops, aggregate stability, soil organic carbon, and total nitrogen concentrations were all significantly increased (Blanco-Canqui et al., 2012).

Cover crops provide substantial increases to soil properties, improve soil quality and conservation. The benefits of reduced water erosion from cover crops is widely acknowledged, water loss can decrease by up to 80%, and sediment loss by 96% (Kaspar et al., 2001). The amount of runoff is a function of biomass produced, and cover crop species. Studies have reported rye (*Secale cereal*) and winter triticale (*Triticale hexaploide* Lart.) to more efficiently change water runoff reduction capabilities (Kaspar et al., 2001; Blanco-Canqui et al., 2013). The reduction of water erosion suggests cover crops also reduce water pollution by reduction of dissolved nutrients in runoff which results in improved water quality, soil fertility, and crop productivity (Kaspar et al., 2001).

The soil nutrient accumulation, recovery, storage, and cycling is affected by cover crops. Legume cover crop species can symbiotically fix nitrogen, and supply low-fertility soil with nitrogen (N), therefore reducing N application requirements for the next year's crop. Blanco-Canqui et al., (2011) found an increase in total N by 279 kg ha^{-1} with sunn hemp after a four year rotation of winter wheat and sorghum. Summer cover crops have been found to effect N amounts more readily than winter cover crops; since they grow rapidly in a shorter amount of time producing large amounts of biomass and depositing higher amounts of N (Wang et al., 2009). However, winter cover crops have been found to increase N levels in long-term studies (Sainju et al., 2003).

Improvement of soil quality increases macro- and microorganism populations within the soil. Blanco-Canqui et al. (2011) with a 15 year summer cover crop study reported the number of earthworms (*Lumbricus terrestris L*.) increased by sixfold compared to plots that did not have summer cover crops. Microbial enzyme activity, an indirect measure of soil microbial population increases with the presence of summer cover crops (Kirchner et al., 1993; Bolton et al., 1985; Mullen et al., 1998). There is a correlation with increased cover crop root biomass with increased microbial biomass (Fae et al., 2009).

For comparison, the study planted a soybean crop after winter wheat harvest, the soybeans received conventional agriculture practices. This is called double-crop rotation, or double crop soybean (DCS). The wheat-soybean double crop rotation is widespread in temperate areas, and mainly found in the Southern regions of the United States (Kyei-Boahen and Zhang, 2006). Producers that double-crop can have the added income of two crops in one season, however, it is not without risk. Successful double cropping is dependent on the length of the growing season with reports estimating soybean yield decline approximately three-fourths of a bushel for each day planting is delayed (Shapiro, 1992). The double cropping practice advanced into the Midwest region as the early maturity soybean was designed. Even though this cropping system established potential increased income, crop diversity, and a cover for fallow soil during winter months, weather is unpredictable for North Central states and the practice is not common in Missouri.

When DCS is practiced in Missouri, the objective cash crop is wheat, and soybeans follow with no guaranteed profit.

Several studies from location sites in the Southern states reported soybeans that were planted in the full season cropping system have increased yields compared to early-maturity soybeans planted in a double crop after wheat (LeMahieu and Brinkman, 1990; Wesley, 1999; Ashlock et al., 2000; Kyei-Boahen and Zhang, 2006). DCS yields range from 258 to 988 kg ha^{-1} in a high precipitation year and 1452 to 1694 kg ha^{-1} in an average precipitation year with optimal planting dates (Kyei-Boahen and Zhang, 2006). However, the combined net returns from the DCS system are higher than a full soybean season in the Sothern region of the United States. Kyei-Boahen and Zhang (2006), reported a net profit of \$134 to \$278 ha^{-1} with the wheat accounting for 75% of the return. These studies used conventional practices and herbicides. While winter wheat is sometimes considered a winter cover crop, timing of soybean harvest and wheat planting does not include favorable weather.

A six year study with two location sites in Oklahoma used a modified double crop system with wheat as a mid-season cover crop. The modified double crop system was as follows: planted early-maturity soybeans in April, harvested in early August, planted wheat which was forage harvested until fall then seed harvested in June, planted full-season soybeans and harvested those in late October. A fallow period was in the second year (Farno et al., 2002). The modified double cropping system produced a significantly higher average net return of $310 ha^{-1}, as the conventional monocrop full-season soybean had the lowest net return $214 ha^{-1}, significant differences were found at both locations (Farno et al., 2002). The modified DCS has shown that it is possible through increased soil quality to have increased soil productivity and achieve higher yields without forfeiting environmental quality.

A fundamental reevaluation of agricultural systems, knowledge, science, and technology is necessary to achieve a sustainable food production (Reicosky et al., 2011). The Earth has ~163 million hectares of arable land for crops, with the current global population of 7.4 billion people, the annual food for each individual must be produced on ~0.22 hectares. For each hectare of agriculture cropland, 4.5 persons per ha are supported. That is assuming all arable land is productive, and not degraded or contaminated to a degree that cannot be used to grow crops (Lal et al., 1998). There is a necessity for improved best management practices, along with a need to reduce the usage of tillage to conserve soil. Research is needed to evaluate management practices that increase soil productivity and sustain environmental quality.

The objective of this research was to examine the effects of a polyculture cover crop and double cropping system after wheat harvest within a row-crop corn/soybean/wheat rotation for changes in soil quality indicators. The management practices of summer cover crop and double cropping soybeans were evaluated for changes in soil physical, biological, and chemical properties.

MATERIALS AND METHODS

The first year of the study (2015) has multiple variables that differed from those measured in 2016. Although this document reports results for 2015 and 2016, the experiment will continue into fall 2019, and a follow-up report will be issued summarizing data from the entire five years of the study. Therefore a more consistent repetition of the study will be analyzed than what is reported here. Variations between years will be considered in the discussion and conclusions, and with variables mainly analyzed within year not transversely for this report.

The field study was conducted at Bradford Research Center, a facility for agronomic research at the University of Missouri, just east of Columbia (38.8929 ^{O} N, 92.2010 ^{O} W). The predominant soil series at the research site is Mexico silt loam (fine, smectitic, mesic, Vertic, Epiaqualfs). The USDA-NRCS classifies this series' location as Central Claypan Till Plains. The parent material for this soil is primarily loess, over loamy sediment derived from pre-Illinoian glacial till.

The field study site is 1.17 hectare (Figure 2.1), organically certified through Quality Certification Services (QCS, Gainesville FL), and has been in organic production for at least 4 years. Previously, half of the 1.17 hectares were used for a greenhouse gas experiment under organic management that implemented similar corn/soybean/wheat crop rotation and cover crops. However, the study involved compost treatments at different application amounts in a split split plot design. The other half of the area was under organic corn, then overgrew with native grasses and forages two years before initiating the current study.

The study site was prepared for initiation of the experiment in the fall of 2014. After the termination of the greenhouse gas experiment, the entire site was mowed with a 4.6 m John Deere Bush hog (John Deere, Moline, IL) and ploughed with a moldboard plough. Organic compost made from poultry manure (3-2-2) which meets National Organic Program (NOP) guidelines was obtained from Early Bird Composting California, Missouri and applied with a New Holland 155 spreader (New Holland Ag., New Holland, PA) at 3.6 mT ha^{-1}. The amount of compost applied was based on the relatively low nutrient contents provided by composts used in the previous experiment. The site was then disked with a True-Tandem disk harrow 375 with 61 cm blades and 23 cm spacing (Case IH, Racine, WI) two times to incorporate the compost, and prepare a seedbed.

The experimental design for this study is a randomized plot design accounting for the two treatments following the harvest of winter wheat, summer cover crops and a double crop of soybean. The total wheat area is 61 m. x 64 m or 0.389 hectare, which is a part of a larger crop rotation design that involves corn and soybean. Three sections each containing one crop that will rotate for the next year. The wheat section is subdivided into 4 blocks that each have 10 plots measuring 6.1 m. x 9.1 m. The summer cover crop mix and double crop soybeans were randomly planted within each block, giving each planting treatment 5 replications in each block or 20 observations total. The overall project layout is presented in figure 3.1.

Two cultivars of organic soft red winter wheat (*Triticum aestivum*), Welter WS44 and LimaGrain L34 were planted on 22 October 2014, and 20 October 2015, respectively at (100.88 kg ha^{-11}) with a Tye no-till drill (Tye, Lockney, TX) after soybean. Nitrogen in the form of Chilean sodium nitrate ($NaNO_3$, 16-0-0) was applied with a Vicon pendulum fertilizer spreader to Feekes stage 6 wheat on 14 April 2015 at 89.67 kg N/ ha^{-1}. The second year of the wheat study did not receive $NaNO_3$ due to the high demand, and time requirement of mining and shipping of $NaNO_3$; therefore, it was not available for application in the spring of 2016. The National Organic Program (NOP) considers non-synthetic $NaNO_3$ a restricted substance. Article 7 CFR section 205.602(g) of NOP's National List states $NaNO_3$ can only be applied for 20% of a crop nitrogen requirement in organic farming (USDA-NOP, 2012). The application rate for 2015 followed these guidelines per soil fertility testing data received March 2015. However, the fertilizer spreader was calibrated incorrectly and application nearly doubled. An attempt to compensate for lost nitrogen for study year 2016 was made by over applying compost (Early Bird 2-1-1) end of the growing season in the fall of 2015 at a rate of 18 mT ha^{-1} .

The winter wheat was harvested on 29 June 2015 and 20 June 2016 2016 with a 2-row Wintersteiger research combine (Wintersteiger Inc., Salt Lake City, UT), using the two middle rows for yield and moisture data.

The harvested wheat area was prepared by disk harrow. The original design study did not have this additional soil disturbance practice in place after wheat harvest. However, it was a necessity as the spring and early summer of 2015 received heavy rainfall, with a total precipitation of 458.98 mm for March-July, as compared to 252.48 mm in 2016 (Figure 3.4). The annual precipitation for 2015 was 1263.65 mm, a total reached once (2008) in the past 20 years (National Weather Service, 2017). The increased rainfall delayed harvest of the wheat crop, and planting of the two treatments. The wet spring also lead to a high density of weed species within the late stages of the wheat crop. The site was disked on 29 June to provide a favorable seedbed for soybean emergence and acceptable summer cover crop density. The post-wheat disk management practice was repeated in 2016.

On 30 June 2015 and 22 June 2016, organic soybean (*Glycine max*) cultivar Emerge E3782s was planted at a seeding rate of 165,000 seeds ha^{-1} John Deere 4-row planter (John Deere, Moline, IL). Row spacing was 76 cm, providing eight-row plots of soybeans. Because soybeans are symbiotic nitrogen fixators, the only nutrient additives applied to the double crop soybean plots were the post-harvest fall compost and any residual nitrogen from the $NaNO_3$ 2015 spring application.

A summer cover crop mix was planted in the summer after the wheat harvest. On 30 June 2015, and 22 June 2016, sorghum sudangrass (*Sorghum sudanese*) at (22.4 kg ha^{-1}), cultivar iron-clay cowpea (*Vigna unguiculata*) at (33.6 kg ha^{-1}), sunn hemp (*Crotalaria juncea*) at (22.4 kg ha^{-1}), were planted with the Tye no-till drill. All species within the summer cover crop study were certified organic. A complete list of seed and sources is presented in table 3.2. No additional fertilizers were applied since the objective of the study was to compare soil quality indicator values of summer cover crops and double crop soybeans.

The double crop soybean plots were managed in a conventional manner with between row cultivation for weed control. A Danish S-tine cultivator was used for the between-row cultivator treatments and was used as early as soybean V1 growth stage through V5-R1 until canopy was too large for a tractor implement to safely clear the crop. Cultivation started 29 July 2015 and 11 July 2016 and occurred normally every 9 days for a month. However, since 2016 had lower precipitation and weeds were not as prolific, cultivation was applied once during the growing season. Specific management practices and dates are presented in table 3.3. The summer cover crops within the cover crop plots were allowed to grow until 5 October 2015 and 21 September 2016 when they were terminated by mowing with a Bush hog. The double crop soybean plots were harvested on 13 October 2015 and 15 October 2016 with a Wintersteiger research combine, using the middle two rows for yield and moisture data.

After harvest the area was prepared by mowing the soybean crop residue with the Bush hog, spreading Early Bird compost (2-1-1) with the manure spreader at a rate of 18 mT ha^{-1} and disking twice with a the disc harrow. The winter wheat was rotated to follow soybean in the alternative weed management practice study, and planted with the no-till drill planter at the same rates used previously.

Soil Evaluation Methods

Both predominant soils at the study site, Mexico silt loam and Leonard silt loam are taxonomically similar, but vary in slope and thickness of the silt loam horizon. Mexico has 0-4 percent slope, and up to 38 cm. of silt loam; in comparison, Leonard has 2-14 percent slope, and 18 cm. of silt loam. Since the study is mainly concerned with weed suppression treatment effects within the topsoil (8 cm.), the difference of silt loam thickness likely will not skew results. Slope differences are considered as erosion or ponding may occur due to heavy rainfall in 2015 or excessive hot water spray treatment.

Soil was collected for analysis before crop harvest on 13 October 2015, and 26 September 2016 with a JMC back-saver soil probe (Newton, Iowa). Soil cores (1.9 cm diameter) were randomly pulled within each treatment plot 55.5 m^2 area at a depth of either 0-5 cm or 0-15 cm depending on soil analysis. Twelve soil cores of 0-5 cm were collected from each treatment plot to determine active carbon, β-glucosidase, and acid phosphatase activities; and phospholipid fatty acid (PLFA) composition. Six soil cores of 0-15 cm were collected from each treatment plot to determine aggregate stability, organic matter, phosphorus, potassium, calcium, magnesium, cation exchange capacity (CEC), and pH characteristics. Soil samples were homogenized, air-dried, and passed through a 2 mm sieve; except for aggregate stability analysis, which utilizes a 1 mm particle size for analysis.

A soil bulk density extraction was taken on 28 April 2015 and 10 May 2016 as outlined by Grossman and Reinsch (2002). Bulk density samples were collected with metal rings 7.62 cm in length with a 7.62 cm diameter. One soil core sample was removed from the center of each weed treatment plot each spring, and analyzed using the Grossman and Reinsch method (2002).

Soil sample analyses were conducted at three locations. The Soil Health Assessment Center (Columbia, MO) analyzed PLFA composition using extraction and gas chromatograph (Agilent 7890A, Santa Clara, California) methods formulated by Buyer and Sasser (2012) with PLFA detection using the Sherlock Microbial Identification System software.

The University of Missouri Soil and Plant Testing Laboratory analyzed multiple soil characteristics associated with a common soil fertility test, i.e. macronutrients, pH, SOM, and CEC following protocols of methods and procedures outlined in Nathan (2012). SOM is calculated via weight loss resulting from ignition in a 360°C oven, pH is determined with a dilute salt solution (0.01 M C_aCl_2) and glass electrode pH meter that measures the concentration of H^+. Soil phosphorus content was determined with a concentration of 0.25 N HCl (Bray I) as the extractant and ascorbic acid as the color developing reagent and samples were read on a spectrophotometer at 660 nm. Soil potassium, calcium, and magnesium content were determined with a concentration of 1 N ammonium acetate (pH 7.0) as the extractant, and samples were read on an atomic absorption spectrophotometer. The CEC of soil was estimated from the sum of extractable potassium, calcium, and magnesium results plus the measure of neutralizable acidity (NA). NA can be calculated when measuring for soil pH by adding a 7.0 buffer.

The rest of the soil characteristics were analyzed at the soil quality Agriculture Research Service (ARS) soil lab. Active carbon present in the soil was determined by the permanganate oxidizable carbon method outlined by Weil et. al. (2003). Modifications were as follows; settling time for suspension was reduced to 5 minutes from 10 minutes, amount of soil used was 2.50 g., and lastly soil used was air-dried and crushed. Results were more consistent when crushed. Weil recommends 2.5-5.0 g of soil for the analysis, and 2.50 g was sufficient. The two soil enzyme concentrations, β-glucosidase and acid phosphatase, were estimated by the methods of Eivazi and Tabatabai (1988), and Tabatabai and Bremner (1969). Modifications were as follows; the use of Toluene was omitted per suggestion of Acosta-Martinez (2011), and wavelength 405 nm was used for both enzymes spectral analysis. The wet aggregate stability method from the National Soil Survey Center (Kellogg, 2014) was used to calculate percentage of soil aggregates that may survive a disturbance within each soil sample. Soil aggregates of a certain particle size were placed on a 0.5 mm sieve in water and dunked, remaining soil was potential stable aggregates.

Data were analyzed using SAS Enterprise Guide 4.3 statistical software (SAS Inst., 2001). Proc Mixed was used to perform the analysis of variance. Treatment replication was considered random. Statistical significance was at $P \leq 0.05$. When treatment effects were significant, means were separated using least significant difference (LSD).

RESULTS AND DISCUSSION

Weather Conditions

As stated previously, above-normal precipitation during the first year of the project required additional tillage practices to combat prolific weed infestation. The 30 year average cumulative precipitation for Boone County is 1,083.0 mm; 1,263.7 mm, and 1017.52 mm were recorded for 2015 and 2016 respectively (Figure 3.3).

The greatest precipitation amounts were recorded during wheat harvest and during DCS/SCC planting. The months of March-July 2015 received a total accumulation of 732.0 mm whereas the 30 year average precipitation for Boone County for these months is 644.90 mm; 2016 precipitation was well below average at 257.3 mm for the same time period (Figure 3.4). Although the increased precipitation delayed wheat harvest and DCS/SCC planting by only two weeks in 2015, the increased precipitation lowered soybean and summer cover crop seed emergence. The majority of cumulative precipitation (374.6 mm) for 2016 occurred August through September, which caused a two-week delay in soybean harvest and termination of the summer cover crops.

Soil Physical Property Analysis

Bulk density is related to the total amount of porosity (Carter and Ball, 1993), which is a measurement of pore space within the soil for the movement of air and water. When the pore space decreases, bulk density increases which is a reflection of soil compaction. High bulk density parameters can decrease water infiltration (Karlen et al., 1994), and limit rooting depth (Cassel, 1982) via penetration resistance, and influence microclimates of soil microbes with altered habitat (Warkentin, 2001). The optimal bulk density differs over the range of soil textures; the soil in the present project is a silt loam with ideal bulk density of <1.4 g/cm^3.

Soils collected for bulk density analysis in 2015 were not subjected to post-wheat management practices and therefore, will be considered as a baseline and not included in the 5 year report unless relevant.

Bulk density was not significantly different ($p<0.05$) among post-wheat practices of double crop soybean (DCS) or summer cover crop (SCC) for 2016 (Table 3.3). Bulk density is mostly influenced by soil disturbance such as, tillage and cultivation (Lampurlanes et al., 2003; Moran et. al., 1988; Cogger et al., 2016), and soil organic matter content (Blanco-Canqui and Benjamin, 2013; Cogger et al., 2016). The spring 2016 bulk density results reflect 2015 management practices which included unforeseen increased tillage required for weed control. Although Snapp et al., (2005) reported sorghum sudangrass contributes to SOM content by producing high amounts of biomass (8 Mg ha^{-1}) and root volume, bulk density values were similar in DCS (1.3 g/cm^3), and SCC (1.2 g/cm^3). In contrast, other studies reported significant decrease in bulk density for plots under sorghum and sunnhemp cover crops (CC) compared to non-CCO plots

(Blanco-Canqui et al., 2001; Blanco-Canqui et al., 2012). Overall density values increased in the second year. Soil bulk density usually decreases as soil organic matter increases (Kladivko, 1994). This would suggest that organic matter from the summer cover crops and fall compost amendments did not lower bulk density values even though the study underwent intensive uniform cultivation. However, conclusions would be premature based on a previous long-term study (Lampurlanes et al., 2003) that did not yield effects due to tillage on bulk density until three years into the experiment.

Aggregate stability is related to soil structure, as soil particles bind to each other to form aggregates. The relative stability of soil aggregates to resist separation is measured when disruptive forces are applied. Aggregate stability is an important soil quality factor as it affects movement of water, aeration, nutrient availability, root penetration, and seedling emergence for plants (Gallardo-Carrea et al., 2007). It also facilitates soil conservation as it decreases the rate of soil erosion and crusting (Bajracharya et al., 1998; Wang et al., 2013). Similar to bulk density, soil organic matter is a contributing factor that indirectly increases aggregate stability (Lynch and Bragg, 1985; Six et al., 2002). The decomposition of organic matter, as in compost, results in the production of biological binding agents such as polysaccharides, and lipids (Lynch and Bragg, 1985), and along with intertwined fungal hyphae, the pliancy of soil aggregates increases (Tisdall and Oades 1982).

Aggregate stability was significant for 2015 ($p= 0.006$) but was not for 2016 ($p= 0.07$) as shown in table 2.4. SCC plots had increased aggregate stability in both years compared to the DCS plots. This is consistent with findings that show cultivation and tillage soil disturbances decreases aggregate stability (Six et. al. 1999; Wander et al., 2000, Kasper et al., 2009), while SCC increases aggregate stability values by providing surface protection, root volume, and potential active organic matter decomposition (Blanco-Canqui et al., 2012). A 1.8 fold increase was reported for mean weight diameter of stable aggregates found in SCC plots (Blanco-Canqui et al., 2011). Although 2016 showed no significance differences among treatments, aggregate stability was considerably lower due to overall tillage for 2015 spring weed control and pre-plant tillage practices. The overall average of 65% AgStab in 2015 contrasted with 36% for 2016.

Soil Biological Property Analysis

PLFA

Since the introduction in the early 1990's of the phospholipid fatty acid (PLFA) analysis for differentiating soil microbes based on biochemical patterns, it has become one of the more popular techniques to assay the biomass and composition of soil microbial communities (Frostegard et al., 2010). The PLFA method is a rapid, effective way to evaluate effects of soil management on bacteria or fungal communities (Frostegard et al., 1996). In addition to total PLFA concentrations for specific microbial groups, overall PLFA totals for treatments, and the relative abundance of fungi and bacteria which is referred to as the bacteria/fungi ratio can be calculated from PLFA analysis.

All PLFA components were significantly different with increased microbial populations in the SCC plots in 2015 (Table 3.4). Soil moisture and organic matter content are closely related to increased microbial PLFA as Brockett et al., (2012) found in a forest ecosystem study. Additionally, findings from Guenet et al., (2011) also indicated increased soil moisture significantly contributed to higher bacteria PLFA contents. Surface cover provided by cover crops increases water infiltration and may enhance soil water content (Blanco-Canqui and Lal, 2007). Multiple studies have reported increased total microbial populations when utilizing cover crops (Carrera eta al., 2007; Jokela et al., 2009; Feng et al., 2003; Lupwayi et al., 1998; Zablotowicz et al., 2000; White and Rice, 2009; Locke et al., 2013).

However, for 2016 there were no significant differences in PLFA microbial biomass content. These results are similar to studies comparing conventional tillage to no-till that did not include cover crops (Zablotowicz et al., 2010). Within production systems with low SOC, spatial variation associated with soil moisture levels positively correlated to changes in microbial biomass (Feng et al., 2003). Precipitation for 2015 was lower compared to 2016 and could have contributed to no significant differences between treatments for PLFA groups; however, the similar values obtained for SCC and DCS were likely due to the high rate of compost (18 mT ha^{-1}) applied the previous fall to the entire field.

Although some previous studies show increased PLFA biomarker concentrations with applied compost (Ros et al., 2003; Bastida et al., 2008; Treonis et al., 2010), others report that changes in microbial activity, size and composition do not persist past six months after applying compost (Saison et al., 2005). In the current study, although not significant, PLFA concentrations for SCC and DCS were higher than the previous year. This supports studies that have reported increased soil fertility and crop yield when compost amendments were used with either conventional or reduced tillage practices (Cavigelli et al., 2008; Singer et al., 2004, 2010). Since there was an increase in overall

PLFA concentrations in 2016, increased compost rate may have masked any potential effects due to tillage in the DCS or the presence of SCC.

PLFA concentrations of (AM) fungi (27%) were significantly elevated for 2015 in SCC compared to DCS (Table 3.4). The established below-ground root biomass for SCC and pre-season winter cover crops can increase AM fungi establishment and interaction with living roots (Fae et al., 2009) However, a one-time tillage event can significantly decrease the AM fungal soil biomass (Wortmann et al., 2008). Their short-term study of three years did not indicate that the AM fungal community recovered to former levels. A similar study over five years (Drijber, 2002) also found a one-time tillage event significantly decreased AM fungi levels that never rebounded.

Similarly, the non-AM fungi community was significantly higher (24%) in SCC for 2015, but not 2016. The overall population decreased in the second year with no response to increased compost application, or the presence of summer cover crops. This is in contrast to previous findings where cover crop practices increased fungal biomass (Carrera eta al., 2007; Jokela et al., 2009). The ideal environment for microbial groups with extended hyphae is one with minimal physical disturbance.

Overall, total biomass PLFA was significantly higher (19%) for SCC compared to DCS in 2015 (Table 3.4). SCC consistently showed increased microbial biomass in all groups compared to DCS. Total PLFA was not significant for 2016 possibly due to high compost application rates to the entire area and decreased precipitation.

Soil Enzymes

The enzyme β-glucosidase (BG) EC 3.2.1.21; obsolete: cellobiase plays a major role in the degradation of soil organic matter and plant residues as it catalyzes the hydrolysis of β-D-glucopyranosides within cellulose, and provides simple sugars (glucose) to soil microorganisms (Dick et al., 1996). Since soil microorganisms are the major source for soil enzymes it is theorized that increasing soil microbial populations will increase enzyme concentrations within the soil (Tabatabai, 1994). However, despite significant treatment effects for total PLFA biomass (Table 3.4) and soil organic matter (Table 3.6), no significant differences between SCC or DCS were detected for BG in 2015 (Table 3.5). These results contrast previous studies reporting sensitivity of BG response to residue management and its subsequent consideration as an early indicator of changes in soil organic matter, (Miller and Dick et al., 1995; Acosta-Martinez et al., 2003; Roldan et al., 2005). Additionally multiple cover crop species including, crimson clover, winter wheat, Austrian winter pea, and hairy vetch have been reported to increase BG activity (Kirchner et al., 1993; Bolton et al., 1985; Mullen et al., 1998).

Because BG enzyme activity increases more effectively under compost amendment and cover crop practices with high residue crops (Bandick and Dick, 1999; Stott et al., 2010), it is reasonable that expected increases in BG activity did not occur because of the lower biomass density of SCC in 2015. BG activity significantly increased in 2016 (Table 3.5) as the SCC biomass was considerably higher.

The phosphatases are the general group of soil enzymes that catalyze the hydrolysis of both esters and anhydride bonds of phosphoric acid (H_3PO_4), and play a major role in mineralization and transformation of a large portion of soil organic phosphorus (Dalal, 1977). The acid phosphatase (AP) enzyme (EC 3.1.3.2) is a phosphomonesterase that transforms organic phosphorus (P) into inorganic phosphate that aids in soil biogeochemical cycling and benefits plant nutrition (Martinez and Tabatabai, 2011).

Treatments differed significantly (p=0.05) for effects on AP enzyme activity in 2015 (Table 2.6). The AP activity in SCC was higher than with the DCS practice. Activity of AP is linked to mineralizing P from organic matter, which often decreases under conventional tillage possibly because of the loss of organic substrate (Acosta-Martinez et al., 2003, 2007, 2008; Nannipieri, 1994, Deng and Tabatabai 1996).

AP increases with addition of soil organic matter, as shown by significantly increased activity higher when poultry litter is applied (Acosta-Martinez and Harmel, 2006). The compost used in the current study was prepared from poultry litter. The fall compost application rate increased to (18 mT $ha^{-}1$) in 2016 leading to doubled soil available P contents compared to 2015 (Table 3.7); therefore, the overall AP enzyme activity was higher and similar for both post-wheat practices for 2016.

Soil Chemical Property Analysis

Soil Carbon

Soil organic matter (SOM) is one of the most widely acknowledged soil quality indicators with its dominant constituent, soil organic carbon (SOC), used as a common soil measurement (Weil et. al., 2003). The active carbon fraction of SOC consists of microbial biomass carbon, particulate organic matter and soil carbohydrates. Active carbon fractions include carbohydrates that initiate metabolism by the soil microbial food web that influences nutrient cycles, and soil physical properties (Weil et al., 2003).

Active carbon, the permanganate oxidizable soil carbon fraction (POXC), was not significantly affected by SCC of DCS throughout 2015-2016 (Table 3.6). Although not significant, values for 2016 were higher (1.0 g kg soil^{-1}) than values for 2015 (0.6. g kg soil^{-}1). SCC plots had increased POXC levels compared to the DCS plots. Studies have demonstrated a relationship between POXC and SOC (Culman et al., 2012; Lucas and Weil, 2012; Morrow et al., 2016; Plaza-Bonilla et al., 2014) as tillage reduces the availability of SOM while additions of summer cover crop biomass and compost increase potential labile carbon. Despite less dense summer cover crops and reduced application of compost in 2015, the SCC plots were associated with slightly increased POXC. An explanation for this could be the increased precipitation in 2015, also observed by Culman et al., (2012) who concluded that environmental factors significantly affect measured POXC. Because soil moisture was high, fast breakdown of compost or fresh weed plant biomass may lead to greater accumulation of organic material.

Although no differences among treatments were detected in 2016, POXC values were considerably higher with an overall average of 1.0 g kg soil^{-1} (Table 3.6). POXC did not differ between the post-wheat practices likely due to the high rate of compost (18 mT ha^{-1}) applied to the entire field after the 2015 grain harvest. The decomposition of SOM and the availability of labile carbon increase with the addition of an organic manure-based compost. Since overall POXC concentration increased in 2016, the uniform application of compost to the study area in 2015 may have diluted any potential effects due to DCS cultivation or SCC management.

Macronutrients, pH, SOM, CEC

The macronutrients Bray 1 phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) are important constituents in soil that promote plant and microbial growth. After nitrogen, P and K are the second and third limiting factors for plant growth, and are normally included in inorganic fertilizers. The secondary macronutrients, Ca and Mg are utilized by plants and microbes in reduced amounts but are essential for nitrogen metabolism and chlorophyll production, respectively.

P, K, Ca, and Mg levels did not differ significantly throughout the study (Table 3.7). P and K increased in 2016 as the compost rate increased, however levels of P and K were lower in the SCC. Cover crops can absorb and convert available P into organic forms reducing the P concentrations in soil (Villamil et al., 2006). Multiple studies have reported increased K levels when manure-based compost are applied (Chen and Samson, 2002; Askegard et al., 2003; Reider et al., 2000). Soil pH and CEC were not affected by SCC or DCS (Table 3.6).

SOM content was significantly higher in SCC plots compared to the DCS in 2015 (Table 3.6). High precipitation and increased tillage made SCC SOM value 12% higher than DCS. However, in 2016 the high compost rate caused SOM values in DCS similar to the increased density SCC.

CONCLUSIONS

Although there have been numerous studies on the effects of conventional tillage, no-till, cover crops, compost, and crop rotations on soil quality, there are few that utilize a multiple suite of these practices together as a management system. This study analyzed the possibility of increasing soil quality with a green manure management practice that could potentially increase the productivity of degraded soils.

The first year of the study had high precipitation, and increased tillage practices to eliminate weed populations; therefore, summer cover crop densities were low and weekly cultivation of the double crop soybean was required for weed control. Comparisons between the two post-wheat management practices showed statistically differences as the precipitation facilitated decomposition of SOM in the summer cover crops and increased weed populations required more frequent tillage treatments in the DCS. Significant treatment differences and higher soil quality indicator values for SCC compared to DCS for 2015 included: aggregate stability (27% increase), acid phosphatase activity (15%), AM fungi (23%), fungi (11%), gram positive bacteria (13%), gram negative bacteria (21%), actinomycetes (14%), eukaryotes (28%), total PLFA biomass (19%), and SOM (12%).

The second year of the study had reduced precipitation, and an increased rate of compost application. Summer cover crop densities were higher and cultivation of the double crop soybean was considerably decreased compared to 2015. Soil quality indicators measured for the two post-wheat management practices were similar due to the decrease in precipitation, reduced tillage treatments, and high compost rate that possibly diluted SCC and DCS effects on soil quality. Significantly higher values for glucosidase activity and eukaryotes were detected in SCC during 2016.

Therefore, both years were evaluated separately since multiple variables differed throughout the two years of the study. In an organic system with moderate compost rates a summer cover crop planted after wheat may increase soil quality in terms of aggregate stability and most of the soil biological indicators. Low biomass densities of SCC may contribute to increased SOM content under sufficient precipitation. In an organic system with high compost rates and minimal tillage, a double crop soybean practice may show similar soil quality values for POXC and most of the soil biological indicators compared to a summer cover crop.

Soil quality chemical indicators did not change in either SCC or DCS in 2015-2016. However, lower levels were observed in the SCC plots as compost rates increased P and K levels.

Although this short-term study exhibited multiple differences in soil quality measurements, a snapshot of the potential multiple benefits of summer cover crops was apparent. The ecosystem advantages of cover crops are not independent but rather strongly interrelated and transcend across the three soil property groups (Blankco-Canqui et al., 2015). For example, under cover crop management increased SOC contributes to increased microbial populations, which increases aggregate stability and porosity, which results in increased water infiltration. Also, enhanced infiltration decreases soil erosion and affects available water to plants, which directly affects soil conservation and agriculture production.

The use of summer cover crops represents an opportunity to intensify sustainable practices within an annual cropping systems and also improve soil quality without drastically altering management practices. Further research is needed within organic systems that utilize till and no-till practices with intergraded summer cover crops and their effects on soil productively and rotational crop grain yield on a wider range of soil, different crop rotations, and different geographic regions.

Figure 3.1. Arial view of project site located at Bradford Research Center. Study was sectioned off into 3 equal 61 m x 64 m for a crop rotation consisting of wheat/corn/soybeans. Rotation shifted in the Southern direction for the following year. Landscape image provided by WebSoilSurvey.com.

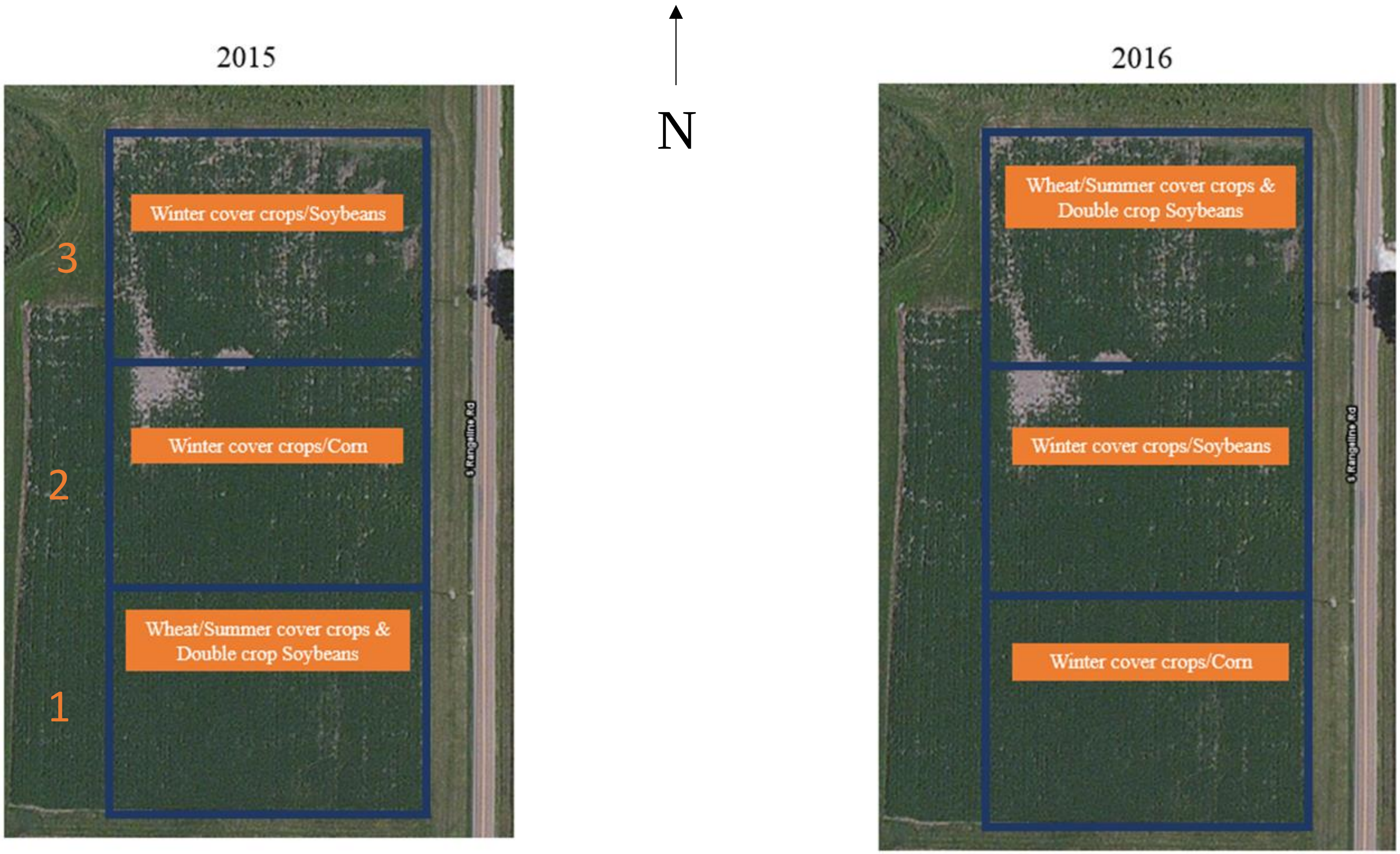

Figure 3.2. Study design layout for 2015-2016. The blocks containing corn or soybean had weed treatments plots of 6.1 m x 9.1 m. T= between row cultivation, F= propane flame, W= hot water spray, and M= string mow. Crops were rotated each year but the weed treatments remained in the same location throughout the two year rotation. The blocks containing wheat had treatment plots of 6.1 m x 9.1 m. SCC= summer cover crop, DC= double crop soybean. When the crops rotated, corn followed wheat, soybeans followed corn, and wheat followed soybeans.

Section 1
Wheat 2015

Block 1	Block 2	Block 3	Block 4
SCC	SCC	DC	DC
SCC	SCC	SCC	DC
SCC	SCC	DC	SCC
DC	SCC	SCC	DC
DC	DC	SCC	SCC
SCC	DC	DC	SCC
DC	DC	SCC	DC
DC	DC	DC	SCC
SCC	SCC	SCC	SCC
DC	DC	DC	DC

Section 2
Corn 2015

T	T	T	F
T	F	F	T
M	T	W	T
W	F	W	W
M	W	M	F
W	W	T	M
F	M	M	W
F	M	F	M

Section 3
Soybean 2015

W	W	T	M
F	T	W	W
M	W	M	T
W	F	F	W
T	F	M	F
M	M	W	M
T	M	F	T
F	T	T	F

Section 1
Corn 2016

Block 1	Block 2	Block 3	Block 4
T	F	T	F
M	T	W	M
T	W	M	T
F	T	M	W
M	W	F	F
W	F	T	M
W	M	W	W
F	M	F	T

Section 2
Soybeans 2016

T	T	T	F
T	F	F	T
M	T	W	T
W	F	W	W
M	W	M	F
W	W	T	M
F	M	M	W
F	M	F	M

Section 3
Wheat 2016

SCC	DC	SCC	SCC
DC	DC	DC	SCC
DC	SCC	DC	SCC
DC	SCC	DC	SCC
DC	SCC	SCC	DC
DC	SCC	DC	DC
SCC	DC	DC	SCC
SCC	SCC	SCC	DC
SCC	DC	SCC	DC
SCC	DC	SCC	DC

Figure 3.3. Cumulative precipitation for years 2015-2016 compared to the 30-year average cumulative precipitation for Boone County, Missouri.

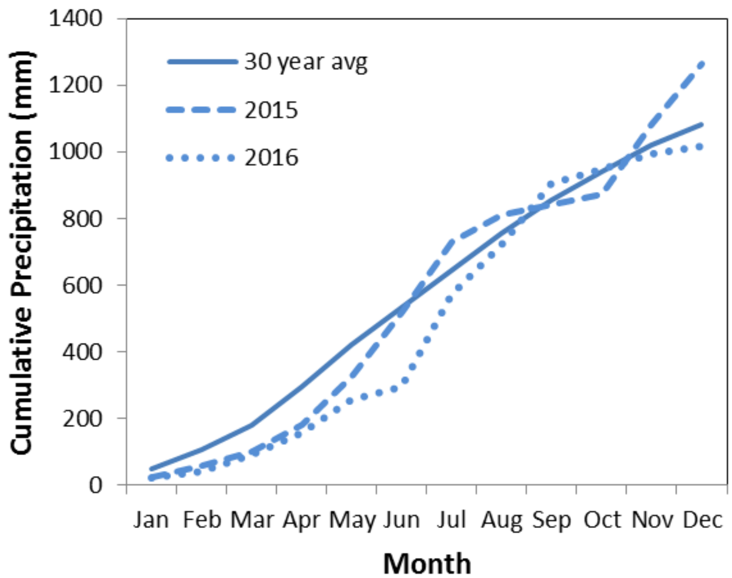

Figure 3.4. Precipitation for years 2015-2016 compared to the 30-year average precipitation for Boone County, Missouri.

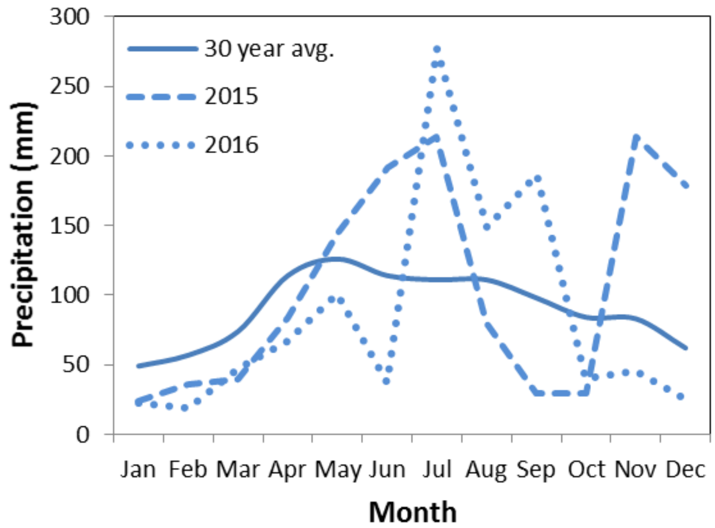

Table 3.1. Variety, source, and seeding rate of each seed species used in 2015-2016

			2015	2016
Crop	Variety	Company	Seeding Rate	
			--------------kg ha^{-1}--------------	
Wheat	WS44 (2015) L34 (2016)	Welter Seed CO, LimaGrain	100.88	100.88
Soybean	E3782S	Emerge	67.3	67.3
Sorghum sudangrass	VNS	Hancock Seed	22.4	22.4
Cowpea	Iron-Clay	Hancock Seed	33.6	33.6
Sunn hemp	VNS	Hancock Seed	22.4	22.4

VNS= Variety not stated

Table 3.2. Planting, fertilizing, cultivation, harvest and termination dates for wheat, soybean, and summer cover crops 2015-2016.

	2015				2016			
Crop	Planting	Fertilize	Cultivation	Harvest/Termination	Planting	Fertilize	Cultivation	Harvest/Termination
Wheat	22-Oct†	21-Oct† 14-Apr§		29-Jun	20-Oct†	15-Oct†		20-Jun
DSB	30-Jun	21-Oct†	29-Jul, 9-Aug, 17-Aug	13-Oct	22-Jun	15-Oct†	11-Jul	15-Oct
SCC	30-Jun	21-Oct†		5-Oct	22-Jun	15-Oct†		21-Sep

†Management was implemented in the fall previous of year stated, §fertilization with Chilean sodium nitrate.

DSB= Double crop soybean, SCC= Summer cover crop.

Table 3.3. Mean % aggregate stability at 0-15 cm soil depth, and bulk density at 7.62 cm soil depth, 2015-2016 as impacted by post-wheat management. Values followed by a different lowercase letter within each column are significantly different (using LSD) at α=0.05.

	2015		2016	
	Bulk Density	Aggregate Stability	Bulk Density	Aggregate Stability
	-------Mg/m^3-------	----------%----------	-------Mg/m^3-------	----------%----------
Summer Cover Crop	1.15	73.82 a	1.14	34.61
Double Crop Cultivation	1.19	56.40 b	1.10	38.65

Table 3.4. Mean biomass of soil PLFA at 0-5 cm soil depth from 2015-2016 as impacted by post-wheat management. Values followed by a different lowercase letter within each row are significantly different (using LSD) at α=0.05.

	2015		2016	
	Summer Cover Crop	Double Crop Cultivation	Summer Cover Crop	Double Crop Cultivation
	--------------------nanomoles g soil^{-1}--------------------			
Fungi	4.57 a	3.68 b	3.95	3.55
AM Fungi	10.90 a	8.59 b	9.31	8.88
GNEG	68.72 a	56.60 b	63.82	60.51
GPOS	38.92 a	34.37 b	42.79	40.81
ACT	22.21 a	19.53 b	22.30	21.51
EUK	2.94 a	2.21 b	3.68 a	3.21 b
Total	148.26 a	124.98 b	145.85	138.46

AM Fungi= arbuscular mycorrhiza fungi, GNEG= gram negative bacteria, GPOS= gram positive bacteria, ACT= actinomycetes, EUK= eukaryotes.

Table 3.5. Mean β-glucosidase, and acid phosphatase activity at 0-5 cm soil depth, 2015-2016 as impacted by post-wheat management. Values followed by a different lowercase letter within each column are significantly different (using LSD) at α=0.05.

	2015		2016	
	β-glucosidase	Acid Phosphatase	β-glucosidase	Acid Phosphatase
	---µg PNP g soil^{-1} hr^{-1}---			
Summer Cover Crop	202.60	254.83 a	223.90 a	307.30
Double Crop Cultivation	174.34	220.82 b	210.51 b	280.90

Table 3.6 Mean POXC, at 0-5 cm soil depth, and % SOM, meq/100g CEC, and soil pH at 0-15 cm soil depth, 2015-2016 as impacted by post-wheat management. Values followed by a different lowercase letter within each column are significantly different (using LSD) at α=0.05.

	2015				2016			
	POXC	SOM	CEC	pH	POXC	SOM	CEC	pH
	g kg soil^{-1}	%	meq 100g		g kg soil^{-1}	%	meq 100g	
Summer Cover Crop	0.64	4.3 a	14.5	6.7 a	1.00	3.9	13.5	6.7
Double Crop Cultivation	0.58	3.9 b	14.9	6.5 b	1.03	3.9	12.9	6.7

POXC= permanganate oxidizable carbon, SOM= soil organic matter, and CEC= cation exchange capacity.

Table 3.7 Mean Bray 1 P, and extractable K, Ca, and Mg at 0-15 cm soil depth, 2015-2016 as impacted by post-wheat management. Values followed by a different lowercase letter within each column are significantly different (using LSD) at α=0.05.

	2015				2016			
	P	K	Ca	Mg	P	K	Ca	Mg
	---mg kg soil^{-1}---							
Summer Cover Crop	29.45	146.85	2,292.5	277.20	54.45	161.75	2,136.1	247.03
Double Crop Cultivation	26.05	148.65	2,342.0	285.13	56.10	188.40	2,022.3	232.88

P= phosphorus, K= potassium, Ca= calcium, Mg= magnesium.

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CHAPTER IV

CONCLUSIONS OF THESIS

Alternative Weed Management Project

Organic agriculture continues to increase as 2.4 million producers were reported globally in the current World of Organic Agriculture-Statistics (IFOAM). A key element of organic agriculture is sustainability, and with an increase of 6.5 million hectares to organic production during 2014-2016, producers will be expected to fulfill sustainability obligations. However, the fundamental policy of no herbicides uses in organic farming requires producers to find other means of managing weeds. Mechanical tillage is the dominant practice for reducing weeds in organic agriculture, however; tillage is widely known to reduce soil quality as it affects SOM, the main constituent of soil health. SOM affects the three soil properties, physical, biological, and chemical. A decline in SOM or soil carbon causes soil resiliency to decrease leading to soil degradation.

The present study evaluated three alternative weed control treatments; two thermal weed suppressors, a propane flamer and hot water spray; - and between row mowing. Conventional cultivation was included for comparison. Other organic practices were integrated with the treatments for a systematic approach.

In an organic system that utilizes a winter cover crop, manure-based compost, and no-till during the growing season, between-row mowing for weed management resulted in highest values for physical and biological soil quality indicators. However, with crimped cover crops in a no-till organic system, hot water spray had the highest values for biological and the majority chemical of soil quality indicators.

The hot water spray treatment is a new method for suppressing weeds. The high temperature of water did not reduce soil quality, and was found to yield the highest soil quality values in biological and chemical properties. Combined with a crimped cover crop, the addition of water readily increased decomposition of organic residue and likely increased microbial populations and released viable nutrients.

Between-row cultivation had the lowest values for all three soil quality indicator categories, physical, biological, and chemical. Soil quality under propane flaming was similar to the cultivation treatment, except for higher values for aggregate stability, acid phosphatase activity, total PLFA, and SOM.

In corn, the highest yield was for between-row cultivation (7,351 kg ha^{-1}); however, when a crimped cover crop was present in the second year of the study, between-row mowing showed yields similar to that under cultivation (7,273 kg ha^{-1}). In soybeans, the highest yield was found for between-row mowing with or without crimped cover crop (2,178 kg ha^{-1}, 1,993 kg ha^{-1} , respectively).

Although between-row mowing was found to have the highest yields with a crimped cover crop in both corn and soybeans, the species of cash crop needs to be considered when applying alternative thermal weed practices. Hot water spray had statistically similar yields as between-row mowing for soybean; however, hot water spray was not as effective for corn yields. Propane flame has potential in corn, but caution must be used for flaming soybeans until improved methods can be employed.

The null hypothesis was rejected as physical, biological, and chemical soil properties were affected by alternative organic weed management practices.

Summer Cover Crop /Double Crop Soybean Project

The increasing pressure on agriculture to provide food security for an increasing global population of 7.4 billion people has been a consistent reminder of inefficiencies of current agriculture technology. There is also an increasing demand for enhanced environmental quality that requires agriculture to consider changing current systems to become more sustainable. As the global population grew in the 20th century, agriculture increased yields by decreasing land-resource. The balance between agriculture productivity and environmental quality relies on proper resource management.

Substantial research has been conducted on winter cover crops, and little on summer cover crops. Benefits reported are reduced soil erosion, suppression of nematodes and weed populations, nitrogen fixation, and increase soil organic matter.

This study evaluated summer cover crops (SCC) as a second option after wheat harvest, and as a potential management practice to improve soil quality and agricultural sustainability. The study included the post-wheat harvest practice of a double crop soybean (DCS) with conventional tillage for comparison. Other organic practices were integrated with the treatments for a systematic approach.

This study could not be compared across years. Two key differences affected soil quality indicators that either diluted or biased the treatment effects. The first year had increased rainfall that favored SCC. Even though increased weed species decreased the density of the SCC, crop residue decomposition was increased making all biological soil quality values significantly higher compared to DCS: acid phosphatase activity (+15%), AM fungi (+26%), fungi (+24%), gram positive bacteria (+13%), gram negative bacteria (+21%), actinomyces (+14%), eukaryotes (+33%), total PLFA biomass (+19%), and

SOM (+12%). The reduction of runoff and soil erosion was apparent in the SCC based on the 31% higher aggregate stability value compared to DCS.

The second year results of soil quality indicators of the two post-wheat management practices were similar due lower levels of precipitation, and the increased rate of compost application. Summer cover crop densities were higher and cultivation of the double crop soybean was decreased significantly compared to 2015.

Low densities in SCC may have significant SOM levels when under sufficient amounts of precipitation. In an organic system with high compost rates and minimal tillage a double crop soybean practice may show similar soil quality values compared to a summer cover crop.

The null hypothesis was rejected as physical, biological, and chemical soil properties were affected by double crop soybean and summer cover crop management practices preceding wheat.

The use of summer cover crops represents an opportunity to intensify annual cropping systems and also improve soil quality without drastically altering management practices.

VITA

Jill Souliere Staples was born in urban Adams Massachusetts. At an early age her father picked up the family and moved west to fulfill a dream in agriculture. Southern Missouri is where the Souliere family planted roots. She grew up on a 78 acre grade A Holstein farm that grew alfalfa, raised chickens, rabbits, sheep, and picked walnuts for extra money to spend at the annual town fair.

After high school Jill toured Europe twice before going to College in Columbia Missouri. She attended Columbia College for her double major B.S. in Environmental Science and Biology. During her undergraduate per a requirement for one of her majors Jill interned at Bradford Research Center. The internship would turn into a full time research assistant after graduation. Two years later she attended the University of Missouri on an assistantship funded by OREI for an organic weed project. Graduating in May 2017 with a MS degree in Natural Resources with an emphasis in Soil Science. Jill currently works for the USDA-ARS Cropping Systems and Water Quality Unit in Columbia Missouri. Her position keeps her in Columbia on MU campus as manager for the ARS soil quality lab in ABNR.