INTEGRATING COVER CROPS INTO CROP ROTATIONS IN UPSTATE MISSOURI

A Thesis

Presented to

The Faculty of the Graduate School

At the University of Missouri

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science

By

RENEE LAUREN ADLER

Dr. Kelly Nelson, Thesis Supervisor

December 2018

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

have examined the Thesis entitled

INTEGRATING COVER CROPS INTO CROP ROTATIONS IN UPSTATE MISSOURI

Presented by Renee Lauren Adler

A candidate for the degree of

Master of Science

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

____

Dr. Kelly A. Nelson

____

Dr. Peter P. Motavalli

____

Dr. Randy Miles

____

Dr. Jason Weirich

ACKNOWLEDGEMENTS

The Greenley family's generous donations to the University of Missouri have made infinite opportunities for students, producers, and researchers; thank you Greenley Family for providing these opportunities. Thank you to all the farm workers, research assistants, graduate students, and superintendents that assisted with these projects over the years, most recently Max Mungyeko Mayola, John Schreck, and Brad Moore. Thank you to Logan Bishop and Matt Caldwell for serving as mentors both in and out of the field. This project would not be possible without the help of Dr. Gurbir Singh who processed data, edited writing, and provided professional guidance. MFA Inc. provided equipment and personnel to evaluate Veris data. A very special mention to Lynn Bradley for her infinite behind the scene efforts at the Greenley Center.

I am beyond grateful to my closest friends Tessa Chambers, Tyler Lane, Savannah Burnett and Cody Belknap, and my siblings, Chad and Daryn. Thank you for your continuous support in my life. To my Dad, my biggest cheerleader and my hero, thank you for instilling a strong work ethic and sense of pride in me. I certainly couldn't have completed this without the help of a few good heeler pups who were never afraid to get dirty. Thank you to Ms. Aydelott, a high school science teacher that never gave up on me, always went the extra mile, and nurtured my love of agriculture.

Lastly, I extend the sincerest gratitude to Dr. Kelly Nelson, the most conscientious, humble, and hardest working advisor, agronomist, and farmer there is. Thank you for the countless hours spent helping me to develop as a professional, researcher, agronomist, and (most graciously) as a producer. I am forever grateful for the skills you have taught me.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
LITERATURE REVIEW AND OBJECTIVES

Introduction

There is an increasing emphasis on management strategies such as reduced tillage, use of cover crops, and implementation of conservation practices (i.e. terraces, no-till, and cropping systems) in Missouri cropping systems. By combining best management practices for conservation, soil health could be improved, and farmers could obtain higher yields and economic returns. Soil health is the capacity of a soil to function for plant, animal, and microbial sustainability evaluated by set parameters and evaluated over time. A "best management practice" refers to economically-viable practices that prevent or reduce pollution generated by non-point sources (Centner et al., 1996). Field research is needed to devise optimal combinations of these management practices for farmers, while balancing them with the economic realities of crop production.

Cover Crops

Cover crops are defined as any living ground cover that is planted into or after a main crop and then commonly killed before the next crop is planted (Hartwig and Ammon, 2002). In Missouri, there is increased encouragement to implement conservation practices on highly erodible claypan soils to protect natural resources. Cover crops are a conservation practice which has various effects when examined at different latitudes (Blanco-Canqui et al., 2017; Curran et al., 2018; Noland et al., 2018). These effects could be advantageous or detrimental to net incomes of farms. In a time of low commodity prices, it is essential that implementing a conservation effort does not negatively affect farmer income. To help with the adoption and implementation of conservation practices, the Missouri Department of Natural Resources has created several cost-share programs to assist farmers. These programs may have long waiting lists, not cover all associated costs, or have limitations that impact the amount of land enrolled, or number of seasons a farmer may enroll (See, 2017). Too short a time period when cover crops are utilized make it difficult to determine the benefits of the cover crop (See, 2017). Soils, climate, cropping systems, and management practices set four regions of the United States apart from each other in terms of cover crop effectiveness (Bowman et al., 2007). Therefore, unless specifically noted, the literature cited in this review focuses on research in the Midwestern United States (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin).

Studies have found cover crops improved soil health, prevented erosion, reduced compaction, assisted in weed control, and have increased commodity yields over time (Myers et al., 2015). Cartwright (2016) found that long-term cover crop use led to improvements in soil physical and biological properties that improved overall soil health, thus resulting in net benefits that could translate into increased long-term farm profitability. In a study on agricultural water management, Her et al. (2017) reported cover crops reduced total sediment, nitrogen (N), and phosphorous (P) loss from a field, but sometimes increased the loss of soluble nutrients. Cereal rye (*Secale cereal* L.) planted as a cover crop reduced sediment and nutrient loads immediately following planting, absorbed soluble nutrients from soils, and protected the soil surface from raindrop energy with a leaf canopy; however, investigators suggested that when it was terminated nitrogen mineralizing from cover crop organic matter residue could increase the amount of soluble N lost from the field (Her et al., 2017).

Cover cropping is an increasingly popular method of soil conservation in the Midwest (Moore et al., 2014). In 2012, 133,124 farms across the U.S. had 4.1 million ha (excluding land in the Conservation Reserve Program) with a cover crop (National Agricultural Statistics Service, 2012). Cover crops were one of the most effective practices utilized to promote the reduction of phosphorous and nitrogen loss, which can contaminate surface water resources (Schnitkey et al., 2016). Cover crops have protected and improved soil health while providing roots to feed the soil microbial community (Myers et al., 2015).

In the Midwest, cover crops have been reported to reduce erosion, anchor residues in no-till (NT) systems, suppress winter annual weeds, and scavenge nitrates (Bowman et al., 2007). Cover crop establishment can be a challenge for producers. In a 41-yr period, Strock et al. (2004) found the probability of favorable conditions for both fall establishment and spring growth of cereal rye to be just 25%, while the likelihood for favorable growing conditions in the spring and fall was 27% and 22%, respectively. Cover crops can provide many ecosystem services such as improved soil structural properties, increased nutrient cycling, and reduction in wind and water erosion; however, more studies are necessary to assess cover crop performance in various management circumstances (Blanco-Canqui et al., 2015).

Blends and Monocultures

Cover crops can be planted as monocultures or as blends. When implementing conservation practices, producers often match practices such as cover crops with individual management goals. If a producer was interested in suppressing weeds, they may choose cereal rye; or if they were interested in scavenging N they may select a radish species (Groff, 2008; Myers et al., 2015). Table 1.1 outlines cover crop species that have been evaluated in the Midwestern United States both as monocultures and blends. Mixtures that assimilated grasses and legumes have been shown to produce larger biomass levels than monocultures (Hayden et al., 2014; Finney et al., 2016).

Cover crop species selection can partially affect nitrogen nutrition of grain crops (Franzluebbers and Stuedemann, 2014). Meisinger et al. (1991) summarized data from the eastern United States and reported both legumes and bon-legumes reduced N leaching 23 and 70%, respectively. Studies outside of the Midwest reported cover crop biculture composition had a significant impact on the degree and the timing of net N-mineralization (Ranells and Wagger, 1997; Yadvinder-Singh et al., 1992).

A study in California that modeled plant interspecific competitive interactions reported cover crop plant nutrient retention and biomass to be greater in plant populations containing multiple species compared with a monoculture population (Tilman et al., 1997). Compared to monocultures, using a blend of species reduced risk associated with resource limiting factors (Tilman et al., 1997).

Furthermore, as temporal variation can occur at planting, utilizing a cover crop blend can maximize productivity of a plant system (Tilman et al., 1997). Wortman et al. (2012a) found that increasing the diversity of a cover crop blend increased biomass productivity; however, it did not influence soil moisture, soil N, or crop yield. Nonetheless, cover crop termination method did influence these factors.

Though some studies have demonstrated positive effects of utilizing multiple species, other studies have found that increased cover crop diversity did not result in increased productivity, decreased weed density or increased nutrient retention (Appelgate et al., 2017; Wortman et al., 2012b). A study examining cover crop biomass and C:N ratios in Pennsylvania reported increased cover crop biomass with cover crop blends compared to monocultures; however, polycultures consisting of species with complementary phenology or N acquisition strategy did not produce greater biomass than cereal rye or canola (*Brassica napus* L.) planted as monocultures (Finney et al., 2016). This could be important in cropping systems that may also utilize the cover crop for grazing beef cattle (*Bos taurus*).

Weeds and Cover Crops

Cover crops have been reported to reduce winter annual weeds by 63-90% (Barnes and Putnam, 1983; Myers et al., 2015; Teasdale et al., 1991). Wortman et al. (2012a) found that crop yields following termination with an undercutter were consistently greater than or equal to yields where that was no cover and termination by disk-harrow. The study concluded that mixtures of common weed species could provide benefits to cropping systems equal to that of commonly recognized and intentionally seeded cover crops. Zhu et al. (1991) noted chickweed [*Stellaria media* (L.) Vill.] has the potential for use as a winter cover crop in NT soybean [*Glycine max* (L.) Merr.] with little water competition and no reseeding costs. However, there was risk involved with utilizing weeds as a cover crop. Greenhouse experiments have reported some winter annual weeds including henbit (*Lamium amplexicaule* L.), shepherd's purse [*Capsella bursa-pastoris* (L.) Medik], field pennycress (*Thlaspi arvense* L.), and purple deadnettle (*Lamium purpureum* L.) were hosts for soybean cyst nematode (*Heterodera glycines*) (SCN) (Creech et al., 2007; Venkatesh et al., 2000). Although the ability of SCN to complete a reproductive life cycle on purple deadnettle has been reported in field conditions, the cold environmental conditions typical of winter growing conditions for annual was unfavorable for SCN reproduction. Furthermore, Creech et al. (2008) found the termination of winter annual weeds had insignificant impacts on SCN egg population densities which suggested that a greenhouse setting lacked environmental factors relevant to field conditions. However, Mock et al. (2007) reported removal of winter annual weeds prior to planting during warm spring weather conditions may provide SCN juveniles time to develop on winter annual weeds and time needed to complete a reproductive life cycle.

Conversely, some studies reported that cover crops reduced weed populations. In NT cropping systems, cover crop residue can influence weed populations through a reduction of weed density and biomass due to the proximity of residue to weed seed germination on the soil surface (Teasdale et al., 1991). Cover crop type is important in determining weed interference with a cover crop (Wells et al., 2016). Cover crops can reduce moisture and light availability to fall-germinating species by creating competition for resources (Fisk et al., 2001; Teasdale and Mohler, 1993). Fisk et al. (2001) reported that weed competition with a cover crop may result in weak weed development which affects survival through the winter. Teasdale et al. (1991) determined that soil coverage by residue must be at least 42% for a reduction of weed density to occur while 97% coverage was required to reduce weed density by 75%. Corn (*Zea mays* L.) planting date after cover crop termination did not significantly impact soil volumetric water content or the weed biomass (Wells et al., 2016). In Maryland, Lawley et al. (2012) reported the dominant mechanism for winter-killed forage radish (*Raphanus sativus* L. variety *longipinnatus*) weed suppression was early and competitive fall growth. The presence or absence of decomposing residue had little effect on weed suppression (Lawley et al., 2012). For maximum weed suppression following a forage radish cover crop, producers must ensure crop rotations permit early planting (Aug. or Sep.) of forage radish cover crops (Lawley et al., 2012). In a wheat (*Triticum aestivum* L.)-cover crop-corn rotation in Michigan, Fisk et al. (2001) reported residue of clover [Berseem clover (*Trifolium alexandrinum* L. cv. Bigbee), medium red clover (*Trifolium pratense* L.), medic [burr medic (*M. polymorpha* cv. Santiago), and barrel medic (*M. truncatula* Gaertn. cv. Mogul)] cover crops reduced the dry weights of summer annual such as common lambsquarters (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus* L.), giant foxtail (*Setaria faberi* Herrm.), large crabgrass [*Digitaria sanguinalis* (L.) Scop.], and smooth crabgrass [*Digitaria ischaemum* (Schreb. Ex Schweig.) Schreb] and occasionally winter annual weeds (i.e. shepherd's purse, common chickweed, field pennycress, and volunteer wheat).

Soybean Cyst Nematode

Soybean cyst nematode (*Heterodera glycines*) is a plant-parasitic nematode of soybean that could be affected by the adoption of cover crops and cropping systems. Soybean cyst nematode causes an estimated $1.5 billion in losses yearly in the U.S. alone (Wrather and Mitchum, 2006). Therefore, SCN management is a vital consideration when evaluating cover cropping systems. In short-term experiments in upstate Missouri, the effects of cover crops [Italian ryegrass (*Lolium multiflorum*) and cereal rye] and fall applied weed control programs on SCN over a two-year and two-location experiment (Nelson et al., 2006) showed limited effects on cyst nematode egg population densities.

Heterodera glycines (HG) tests provide information on the ability of an SCN population to reproduce on currently available SCN resistant soybean varieties and should be considered when producers are experiencing less than favorable yields from resistant cultivars (Tylka, 2006). An HG test determines the fraction of a known SCN population that can reproduce on seven HG type indicator lines (Niblack et al., 2002). A positive indicator line results from 10% or more of the SCN population that is able to reproduce on any of the individual indicator lines (Golden et al., 1970). A cropping system's influence on SCN egg population densities is important; however, its effect on net profitability is critical for considering the impact of these systems on crop productivity.

Soils

Claypan soils include over four million hectares in the Midwest (Buckley et al., 2010) and are characterized by their very slowly permeable abrupt subsoil layer having a much greater clay content than the overlaying soil material (SSSA, 2008). Previous research on claypan soils has shown that response to crop management practices is often different from soils with no claypan (Ghidey and Alberts, 1998, Sweeney, 2017). Claypan soils in upstate Missouri are silty and therefore crusting can be a management challenge. Management of tillage and fertilization by producers is expected to be economically driven by regional cropping systems (Sweeney, 2017). Claypan soils have low fertility and water availability, are poorly drained, have shallow rooting depths, and pose a challenge N management (Ghidey and Alberts, 1998; Sweeney, 2017).

Claypan soils in the Salt River Basin of Northeast Missouri are highly erodible and small yielding (Lerch et al., 2008). During seedbed preparation and when crop protection chemicals are applied, surface water runoff and soil loss from the claypan region of the Midwest was relatively large raising concern for contamination of watersheds (Ghidey and Alberts, 1998). Soil loss is a costly and nearly irreversible event. In Northern Missouri, 2.5 cm of soil loss from farm ground in a corn-soybean rotation translated into a \$35.60 ha^{-1} annual loss at 2013 prices (Geist et al., 2013). A long-term study on a claypan soil in Missouri found that NT systems increased surface water runoff compared to tillage systems that caused soil disturbance (Ghidey and Alberts, 1998). Concerning runoff, Abel (2013) reported data suggesting there was little additional benefit from a cover crop in a NT system.

A 20-year study on a claypan soil in southwestern Kansas reported conventional and reduced tillage (RT) treatments had no significant effect on soil pH in the top 15 cm or on extractable P or K in the top 7.5 cm compared to initial soil tests (Sweeney, 2017). However, NT had significantly smaller levels of P, K, and SOM at a 7.5-15 cm depth (Sweeney, 2017). Neugschwandtner et al. (2014) reported similar results in Austria in a silty loam soil. However, a 1986 study in Kentucky reported potassium stratification in long-term NT cropping systems enhanced corn K uptake in comparison to plow tillage (Blevins et al., 1986). In addition to nutrient stratification, NT's effect on field conditions at planting may be problematic. Soils that are untilled or covered with residue often dry and warm up more slowly (Buchholz et al., 1993). No-till systems had cooler soil temperatures (Al-Darby and Lowery, 1987) and excess moisture during the spring may be the reason cereal grains produced on poorly drained soils were lesser yielding compared with tilled soils (DeFelice et al., 2006).

The climate, topography, drainage, and typical cropping rotation of upstate Missouri farmland make it susceptible to excessive soil erosion, resulting in losses of half of the top soil in the last 100 years (Geist et al., 2013). Both cover crops and the primary crop in rotation have the potential to change soil properties affecting the long-term productivity of the cropping system (Villamil et al., 2005). Utilizing a winter cover crop has been beneficial for soil chemical and physical characteristics to both the soil surface and deep into the soil profile. Bulk density and penetrometer resistance in a corn-soybean rotation with a cover crop have been shown to decrease compared to the absence of a cover crop due to increased residue and soil organic matter (Villamil et al., 2005).

Early humans devised primitive tools for scratching and digging in the soil between 5000 to 3000 B.C. which facilitated reliance on current conventional agriculture systems from hunting and gathering (Lal, 2009). Since that time tillage has been used to promote mineralization of soil organic matter (SOM), manage weeds, loosen compacted soil, and develop a seedbed that aids mechanical planting and seed-to-soil contact (Ofori, 1993; Ryan et al., 2011). Like other conservation practices, there are both assets and liabilities surrounding RT or NT cropping systems. Crop residue management, rotation practices, and changes in tillage programs all prompt major alterations in soil microbial properties (Govaerts et al., 2007) which influence the timing and amount of nutrient cycling (Martens, 2001). Slight deviations in cultural farming practices can have significant long-term results; therefore, long-term experiments are necessary to quantify the effects of conservation practices under fluctuating weather conditions (Varvel, 2006).

Soil productivity is affected by tillage systems which can subsequently impact soil properties (Martens, 2001). Before the 1960's, multiple tillage operations each season reaching soil depths of 18-20 cm were a commonplace and affected weed growth, soil crusting, crop establishment, surface water runoff, and compaction (Whitaker et al., 1966). Research on RT and NT cropping systems have intensified with an increased focus on the importance of soil conservation. Research in Austria reported short-term tillage altered soil physical properties through incorporation of crop residues, mineral, and organic fertilizers which influenced nutrient availability (Neugschwandtner et al., 2014). Stecker (1993) reported immobilization of surface applied N which was an indirect result of increased crop residue. These effects accumulate over time leading to compaction, degradation of SOM, loss of soil physical properties, and development of a hardpan (Al-Kaisi and Hanna, 2004) all which have a negative effect on plant growth. No-till planting systems conserve moisture; reduce erosion, labor, fuel use, and crusting; and increase soil firmness at harvest, SOM and tilth (Buchholz et al., 1993). However, a producer moving from conventional tilled corn system to a NT system can expect costs per hectare to increase for herbicide and interest on operating capital, but cost reductions for repair, fuel, labor, equipment, taxes, insurance, depreciation, and interest (Massey, 1997).

Since 1934, Missouri researchers have been investigating methods for increasing yields and reducing inputs in claypan soils (Jones and Beasley, 1943). Research has shown adoption of NT practices may produce lower crop yields (Toliver et al., 2012), but yields similar to or greater than conventional tillage have also been reported (Al-Kaisi and Kwaw-Mensah, 2007; Al-Kaisi and Licht, 2004). Implementing conservation tillage practices have decreased erosion, improved water quality, enhanced crop available water, and enhanced soil quality (Martens, 2001). Decreasing erosion increases soil productivity in the long-term (Pimentel et al., 1995). Zhu et al. (1989) reported mean annual dissolved nutrient loss in surface water runoff decreased 7 to 77% by using winter cover crops in Missouri. No-till systems result in greater soil moisture and lesser soil temperatures at planting and up to four weeks after planting (Linden et al., 2000; Toliver et al., 2012). However, an increase in annual rainfall has also increased the probability for reduced NT yields (Toliver et al., 2012). Researchers have attributed these conditions to be the cause of reduced plant emergence and delayed growth (Licht and Al-Kaisi, 2005). When comparing NT to conventional tillage, yield was affected differently by soil conditions, crop selection, and climate factors (Toliver et al., 2012). In an analysis comparing 442 tillage studies from 92 locations in the United States, Toliver et al. (2012) reported that the probability of having smaller NT corn yields increased the longer NT was implemented, and that the probability of increased yield of soybean in NT increased with the length of time using NT. Similarly, Linden et al. (2000) also reported reduced corn yields over time with NT. Toliver et al. (2012) attributed yield reductions in NT corn from increased weed, insects, and disease due to increased residue.

In soil, phosphorous and potassium are relatively immobile and potassium is relatively immobile. Due to the reduction or elimination of tillage, there is concern that stratification of these nutrients could occur and have negative effects on crop production (Grove et al., 2007; Kaschuk et al., 2010). In Austria, accumulation of P and K was found in RT systems in upper soil layers (0 to 10 cm) while a depletion of P and K occurred in lower layers (10-40 cm) (Neugschwandtner et al., 2014). However, a 1986 study in Kentucky reported K stratification in long-term, NT cropping systems enhanced corn nutrient uptake, compared to plow tillage (Blevins et al., 1986).

Additionally, vertical stratification of soil organic carbon in NT and RT systems (greatest concentration in the top 8-10 cm of soil) has been found in numerous studies across the world (Abdollahi and Munkholm, 2014; Franzluebbers and Hons, 1996; Kay and VandenBygaart, 2002). Composing approximately 58% of the mass of soil organic matter (SOM), soil organic carbon (SOC) is often used to estimate SOM (Griffin, 2017). As SOM decomposes, plant nutrients are mineralized (Martens, 2001). Soil organic matter also provides physical benefits, such as increasing water holding capacity, improving infiltration, and biological benefits, which can lead to disease and pest suppression (Fenton et al., 2008). An eight-year study in southern Illinois reported SOC levels (0-75 cm) in NT plots with and without cover crop treatments remained similar, which indicated the cover crop did not sequester significant levels of SOC (Olson et al., 2010). In a separate twelve-year study in southern Illinois, Olson et al. (2014) reported chisel plow treatments had decreased SOC (0-75 cm) in both cover crop and non-cover crop treatments. In moldboard plow treatments, significant losses in SOC occurred in surface soil layers (0-15 cm) in cover crop and non-cover crop treatments. Overall, moldboard plow treatments had loss of SOC in comparison to SOC at project initiation (0-75 cm), but this loss was not statistically significant. In an 18-year study in Nebraska, Varvel (2006) reported increased (449 kg ha^{-1}) levels of SOC in the top 30-cm of soil in rotational cropping systems for the first eight years. An increase in tillage depth from 10-15 cm to 15-20 cm in the subsequent 10 years resulted in a loss of SOC.

Benefits of cover crops were detected more quickly in NT systems when compared to conventional tillage (Blanco-Canqui et al., 2015). In NT cropping systems with cover crops compared to NT cropping systems without cover crops, Blanco-Canqui

(2013) reported that the inclusion of a cover crop had an annual variance of 0.10 to 1 Mg C ha^{-1}. Similarly, Poeplau and Don (2015) estimated that cover crops sequestered about 0.32 ± 0.08 Mg C ha^{-1} yr^{-1} to a 22-cm soil depth using data from 37 studies across the globe. However, it is important to note that soil storage and protection of SOC was positively correlated with soil clay content (Hassink and Whitmore, 1997) and soil textural class influenced soil organic carbon (OC) accrual with cover crops (Blanco-Canqui et al., 2015). A 12-year study in Illinois examining cover crops in various tillage systems ranked NT > chisel plow > moldboard plow tillage systems based on increased SOC concentrations (Olson et al., 2014). In long-term research, crop rotations with increased complexity, especially those including a perennial legume, were found to increase SOC levels (Russell et al., 2005; Varvel, 2006; Wilts et al., 2004). The University of Missouri Soil Health Assessment Center currently recommends decreasing tillage, decreasing periods of bare soil, and implementing a cover crop to increase total SOC (Soil Health Assessment Center, 2016).

Aerial Seeding

Aerially applying a cover crop presents both advantages and challenges for establishment. Producers and pilots must assess many components of this seeding method before utilizing this practice. Since smaller seeds float and may be affected by wind, producers must consider cover crop species and blended seed size before application (Wilson et al., 2014). Wilson et al. (2014) reported that field shape, wind speed and direction, broadcast width, and height of flight must be considered by pilots. Aerial application allows for little decision-making time on management practices that may affect operations in the long-term. For example, Wilson et al. (2013) reported that if dry soil conditions exist and rain was not forecasted within 7 days of aerial application, producers may want to consider alternative methods for seeding cover crops. Licht and Kaspar (2015) concurred that if the cash crop was close to maturity than an alternative seeding method should be considered. This could prove challenging as producers must consider applicator availability, cover crop seed quantity and quality, equipment availability, and forecasted weather when making cover crop establishment decisions. In addition to the challenges for management, aerial application may also require greater seeding rates due to inconsistent seed-to-soil contact (Licht and Kaspar, 2015) which can increase costs for producers. Massey (2016) noted aerial application costs averaged \$26.45 ha^{-1} (Table 1.3). A widely used aerial applicator in Northeast Missouri (Woods Flying Service, Memphis, MO) charged \$49.10 ha^{-1} for cover crop seeding. However, the custom rate cost to drill-seed small grains in Missouri is \$41.35 (Massey, 2016).

Cover Crop Selection and Application Timing

Selecting a cover crop species that is compatible with local climatic conditions is an essential first step in establishing a cover crop (den Hollander et al., 2007; Tribouillois et al., 2016). Timing of cover crop seeding can also play an important role in the successful establishment of a cover crop. Due to the difficulty of establishing cover crops in cooler northern climates (Wilson et al., 2014), Frye et al. (1988) suggested promoting earlier cover crop growth by broadcast seeding cover crop into standing crops rather than drilling post-harvest in order to time seeding during warmer conditions. Timing, environmental conditions, and standing crop stage should be evaluated by producers when selecting a cover crop species for overseeding.

In the upper Midwest, late-season establishment of cover crops can be challenging following harvest in a corn-soybean rotation (Strock et al., 2004). Several legume and broadleaf cover crops do not tolerate late establishment conditions (Singer, 2008). Cover crops such as cereal rye may experience adequate fall growth to provide cover. Table 1.2 provides recommended cover crop species that may be seeded into corn at three corn growth stages (Mutch, 2013). Cover crop type is important in determining weed interference (Wells et al., 2016), the termination timing in the spring, and the selection of the subsequent rotational crop (Johnson et al., 1998). Johnson et al. (1998) reported a 1.6 Mg ha^{-1} reduction in corn yields following soybean overseeded with a rye and oat (*Avena sativa* L.) (115 kg ha^{-1}) cover crop each year, and a reduction in soybean yields (0.2 Mg ha^{-1}) in one out of six years when an oat cover crop was overseeded. Johnson et al. (1998) concluded that in the upper Midwest an oat cover crop provided comparable shoot dry matter to winter rye in the fall. The oat cover crop was also inexpensive, widely available for purchase, and winter killed which eliminated the need for spring desiccation, and, most importantly, it did not affect subsequent corn crop yield, making it an exceptional candidate for overseeding into soybean. Similar to selecting corn hybrids and soybean varieties, Duiker (2014) emphasized the importance of using regionally adapted cover crop species.

Michigan State University Extension has recommended overseeding cover crops into standing corn at V6 (Abendroth et al., 2011) or near a side-dress fertilizer application timing and before a forecasted rain or irrigation event (Curell, 2012). In central Iowa, Licht and Kaspar (2015) advised producers to overseed between August 15 and September 15 depending on the cash crop maturity, rainfall timings, and calendar date.

Further, Licht and Kaspar (2015) offered visual cues to aid producers in deciding when to perform an aerial seeding. In corn, aerial seeding was recommended after firing had transpired to the ear leaf, while in soybean aerial seeding was recommended when crop leaves began to yellow. Geist et al. (2013) reported that Missouri farmers overseed when leaf coverage of the standing crop had decreased by 20-25%, and it was a good option only if the soil was moist. Curran et al. (2018) reported corn grain yield decreased when cover crops were interseeded into standing corn at V2-V3, but no grain yield decrease was experienced when interseeded at or after V4. Seeding earlier in the corn growing season allows for possible incorporation of seed with light tillage. However, popular cover crops that are small-seeded required only good seed-to-soil contact and did not need significant soil cover (Michigan State University Extension).

Challenges Establishing a Cover Crop

Management recommendations for establishing interseeded cover crops into tillage systems have increased as interest in conservation agriculture systems has risen. Technology development and research for interseeding cover crops into a standing crop in NT grain production is necessary for successful cash crop yields and obtaining conservation goals. Research in intercropping for more efficient cropping systems has been conducted previously (Scott et al., 1987; Triplett, 1962), and has become more prevalent in recent years due to an increasing focus on conservation practices (Belfry and Van Erd, 2016; Curran et al., 2018; Nelson et al., 2011; Sandler et al., 2015).

Aerial overseeding into a standing crop has produced mixed results, and adoption of aerial overseeding is greater in some parts of the U.S., particularly in areas that incentivize cover crop use (Wilson et al., 2014). In establishing a cover crop, seed germination and emergence of seedlings are imperative and dependent on temperature and soil water availability (Baskin and Baskin, 1988; Gummerson, 1986; Tribouillois et al., 2016), planting method, and cover crop species (Noland et al., 2018). These factors ultimately affect biomass production (Noland et al., 2018) which may be proportional to the benefits of the cover crop including weed suppression, N retention, and contribution to soil OC (Ryan et al., 2011). Meisinger et al. (1991) reported greater establishment consistency when cover crops were drill-seeded compared to broadcast overseeding due to seed to soil contact particularly under varying moisture conditions, but drill-seeding may not be as timely. Improved plant establishment consistency of intercropping cover crops may encourage farmer adoption (Curran et al., 2018). Therefore, research improving best management practices for intercropping cover crops in the Midwest is necessary.

Terraces

Terraces are "earthen embankments constructed on the contour or across a slope to intercept [surface water] runoff" (Centner et al., 1999). Terraces are designed to intercept and reduce the flow velocity of surface water on fields with farmed slopes that are typically greater than 5%. Terraces are typically implemented where slowly to very slowly permeable soils exist. They capture water in a channel and divert it from a field through waterways or surface pipe inlets that are emptied through subsurface tile drains into drainage ditches (Schottman and White, 1993). For sloping soils in Missouri where poorly drained and shallow soils are farmed in a corn-soybean rotation, terraces provide protection from surface water runoff especially during heavy rainfall events. Water that accumulates behind a terrace ridge is currently discharged through a riser on a surface inlet with a constricted discharge rate allowing suspended sediments to settle out of the water solution (Wheaton and Monke, 1981). Parallel terraces help eliminate point rows which increases a farmer's efficiency in the field (Dickey et al., 1985). Elimination of grass waterways also increases the total area of the field that can be farmed and eliminates the inconvenience of maneuvering around waterways during fieldwork. Peak discharge of water is reduced with a terrace since field runoff is temporarily stored before being removed from the field. Sediments or prospective stream contaminants (fertilizers or pesticides) may settle out of the surface water flow during this time (Wheaton and Monke, 1981). During seedbed preparation and the time when agrichemicals are applied, runoff and soil losses from the claypan region of the Midwest are relatively large and raise concerns for contamination of watersheds (Ghidey and Alberts, 1998). Terracing helps mitigate this soil loss by interrupting water flow down a slope and reducing the velocity of water available to transport soil which can cause soil loss.

Water and Nutrient Management

Many areas of heavy prairie soils in the Midwestern United States (i.e. Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin) were unsuitable for row crop production due to poor drainage. Installation of artificial drainage in these areas since the beginning of the late 1800's has increased on land that was limited to pasture production (Dinnes et al., 2002). An increased availability of N fertilizers has expedited an increase in the intensity of grain crop production in the Midwest (Hewes and Frandson, 1952). In the Midwest there over 17.7 million hectares of subsurface tile drainage. Of these states, Missouri ranks 7^{th}

in the area of tiled land with 357,790 hectares (National Agricultural Statistics Service, 2012).

Nutrient introduction into ecosystems can occur through migration the of fertilizer, animal manure, atmospheric deposition, soil erosion, and industrial discharge. Excessive nutrients in aquatic ecosystems can lead to depletion of dissolved oxygen in water bodies and at the interface of sediment and water resulting in hypoxia (Environmental Protection Agency, 2007). A reconstruction of low oxygen events on the Louisiana-Texas continental shelf revealed that the frequency of low oxygen events increased over the second half of the 20th century (Osterman et al., 2005). Following World War II, biological fertilizers were extensively substituted with manufactured N (Dinnes et al., 2002). This indicates that the increase in hypoxic events was related to increased nutrient loads and that leaching of nutrients must be carefully managed to prevent negative environmental impacts (Environmental Protection Agency, 2007; Havlin et al., 2014).

Nitrogen additions to cropping systems were largely biological prior to the extensive adoption of the Haber-Bosch process to industrially produce nitrogen fertilizers (Smil, 1999). In modern agriculture, nearly half of all nitrogen applied annually hails from synthetic fertilizers (Smil, 1999). Two major loss mechanisms of nitrogen occur through denitrification and leaching of nitrate-N (NO_3^--N) (Sawyer, 2015). Smil (1999) calculated the average global recovery rates of nitrogen into crop biomass to be 46-56% by dividing the element removed in crops by the estimates of total N inputs. Strategically applying N with periods of large crop demand, avoiding N applications during periods of large soil water transport, utilizing soil tests, diversifying crop rotations, reducing tillage, and use of nitrification inhibitors minimize NO_3^- loss (Dinnes et al., 2002; Havlin et al., 2014).

The management and reduction of nutrient losses allows farmers to reduce input costs and reduce environmental implications related to fertilizers. In a meta-analysis covering various soil types, climatic conditions, tillage practices, and cover crop species, Tonitto et al. (2006) found that post-harvest N uptake by non-legume cover crops averaged 20-60 kg N ha^{-1} and showed that cover crops reduced nitrate leaching 40-70% in comparison to fallow fields. However, no single cover crop species was appropriate for all agricultural settings. In a study examining NO_3- N loss from subsurface drainage discharge, cereal rye was found to be an effective tool 25% of the time in Minnesota (Strock et al., 2004). Cereal rye's small success rate was attributed to years with a small potential for nitrate leaching as well as unsuitable environmental conditions for establishment and growth in that region (Strock et al., 2004). Havlin et al. (2014) noted that 30-40% of applied N fertilizer or manure in a tile-drained system leached through the soil profile and was lost, while 10-30% loss of applied N is a common figure for naturally drained systems. By introducing a cereal rye cover crop after corn in a corn-soybean rotation, subsurface drainage discharge and loss of NO_3-N were reduced 11% and 13%, respectively. Reduction in drainage discharge was attributed to evapotranspiration and water uptake in the cover crop (Strock et al., 2004).

Production-scale data on nutrient loss, sediment loss, and tile flow are needed to evaluate the effect of inclusion of a cover crop in a tile-terrace field. Pollution of nitrogen (N) and phosphorous (P) from agricultural non-point sources contributes to eutrophication of surface water resources (Carpenter et al., 1998; Sharpley et al., 2003).

For over 150 years, watersheds in the Midwest have been transformed with subsurface tile drainage and ditches (Burkart and James, 1999). Skaggs et al. (1994) estimated that without subsurface tile drainage 25% of the United States and Canada could not be in crop production. Without tile drainage, wet field conditions inhibit field work (Smith et al., 2015).

Though these artificial drainage systems are a key component to modern Midwestern agricultural systems (Tomer et al., 2003), they have been reported to have negative effects on ecosystems downstream (Royer et al., 2006; Rabotyagov et al., 2014). Erosion and nutrient loss of farm ground negatively impacts humans and ecosystems as well as soil productivity ultimately affecting yield and farm profitability (Aryal et al., 2018). Nutrients are typically transported during large flow events (Tomer et al., 2003; Vanni et al., 2001). For example, Royer et al. (2006) reported that in east-central Illinois, extreme discharges (greater than 90^{th} percentile) accounted for over 80% and 50% of total P and nitrate N loss, respectively. These large flow events and loss of nutrients has been related to the development of the Gulf of Mexico hypoxic zone (Royer et al., 2006; Rabotyagov et al., 2014). Alexander et al. (2008) quantified nutrient losses in the Mississippi River Basin from corn and soybean production which accounted for 25% and 52% of the P and N transport, respectively, while 37% of the P transport originated from animal manure applied to rangeland and pasture (Alexander et al., 2008).

Reducing nutrient concentrations in streams is an essential component of protecting aquatic life and water quality in the waters of the Midwestern United States; however, temporal patterns in nutrient export are unclear (Royer et al., 2006). Royer et al. (2006) reported a time gap between periods of large algal productivity associated with dissolved O_2 depletion and large water discharge which indicated a temporal segregation between poor water quality and periods of large nutrient loads and export. Fields with tile drainage rarely experienced surface water runoff; therefore, total P losses were assessed by evaluating tile drainage water flow (Macrae et al., 2007). In literature summarized by Macrae et al. (2007), researchers reported that preferential transport of surface water through soil macropores to subsurface drainage tile caused export to be greatest early in the flow event. Total phosphorous and soluble reactive phosphorous concentrations in tile drainage were typically small during baseflow and increased during precipitation events (Macrae et al., 2007). Zhu et al. (2012) identified that N and P largely contributed to agricultural non-point source nutrient losses and cited excessive and improper fertilization, manure applications, and lack of management strategies as the cause of nutrient loss. Mitigation of nutrient and sediment losses can occur through the implementation of research-based best management conservation practices (Aryal et al., 2018). In Kansas, winter cover crops have reduced sediment loss in both conventional and NT cropping systems and reduced surface water runoff volume and total P loss in conventional tillage systems only (Abel, 2013).

Eutrophication is a water quality concern affecting marine and freshwater estuaries around the globe (King et al., 2015a; King et al., 2015b). Historically, nitrogen was believed to be the limiting factor in aquatic ecosystems. However, Maloney et al. (1972) reported that P was the limiting nutrient in the ecosystems. Schindler et al. (2008) found that P was the main cause of freshwater eutrophication and emphasized the importance of P loss mitigation in an effort for management of eutrophication. A study in a Canadian water basin examined event-based, seasonal variability of drainage tile P contribution within the basin and reported that 42% of basin runoff was a result of tile drains which primarily occurred during periods of fallow ground between crops. The study further reported that P loading from subsurface drainage tile water flow was greater during storm periods and was most prevalent during winter snow melt and thawing events (Macrae et al., 2007). In agricultural settings, P can enter surface water through subsurface flow or surface water runoff (King et al., 2015b). Many factors such as field management, climate, soil characteristics, and drainage system design influenced the degree of phosphorous transported to tile drains (King et al., 2015b).

Since the 1940's, agricultural watershed N loss has been evaluated; however, interest in this topic has increased in the last 30 years (Hatfield et al., 2009). In the Mississippi River Basin, estimates predicted agricultural sources accounted for almost 70% of the N and P transport (Alexander et al., 2008). Nitrate-N (NO_3-N) export varied with seasonal discharge and precipitation (Zhu et al., 2012). The association between agricultural land use and N concentrations in neighboring bodies of water has been investigated in many studies (Hatfield et al., 2009). Along with environmental concerns, NO_3-N is a concern for drinking water. Hatfield et al. (2009) reported the drinking water standard of NO_3-N to be 10 mg L^{-1} and emphasized that levels exceeding this standard are concerning in relation to N source and potential impacts of agricultural practices.

Suspended solid-phase material concentration in surface waters may be quantified by the laboratory method quantifying total suspended solids (TSS) (Gray et al., 2000). Gray et al. (2000) reported that TSS data was most commonly evaluated by quantifying the dry weight of sediment from a known sub-sample volume of an original sample. A study in Finland evaluating phosphorous loading in relation to suspended sediment reported that mechanical mixing and chemical properties of water layers that suspended solids encounter influence P loading of suspended material (Koski-Vähälä and Hartikainen, 2001). Many factors, and combinations of factors such as solution pH, solid concentration, and soluble P, affected P loading from suspended solids (Koski-Vähälä and Hartikainen, 2001).

Predictive environmental models in the Chesapeake Bay area reported water quality through water clarity was affected minimally by suspended solids load associated with a scour event (Cerco and Noel, 2016). Evaluating water quality and the methods used to evaluate water quality (such as TSS) was essential for protecting coastal ecosystems (Zhou et al., 2018).

Economics and Adaptation

Farmers are interested in the cost-effectiveness of conservation practices, such as RT and implementation of cover crops. Economic benefits may arise in a variety of ways. Benefits may arise by taking no action, receiving a positive return on investment, or by making a temporary reduction for a long-term benefit. A producer could switch from a conventional tillage system to NT system and see equal returns, or a producer may invest in terrace infrastructure and observe increased yields due to reduction of long-term soil loss. A farmer may consider multiple practices for a synergistic effect on crop rotation. Although best management practices, such as terracing, conservation tillage, enhanced fertilizer management, and cover crops can reduce pollution, this reduction of pollution may include associated costs (Centner et al., 1999). Wollenhaupt and Blase (1990) reported in a study specifically targeting upstate Missouri that soil conservation programs have economic impacts on farm income that extend to rural economies. Costs associated with cover crops typically include seed cost, planting, and termination. According to a 2014-15 national cover crop survey, the most common methods for planting cover crops are drilling, aerial seeding, and broadcasting seed with light tillage incorporation (Myers et al., 2015).

The Department of Agricultural and Consumer Economics at the University of Illinois estimated the cost to operate a 6.1 m NT grain drill at \$54.83 ha^{-1} and the cost for broadcast seeding was \$19.76 ha^{-1} (Schnitkey and Lattz, 2017). Self-propelled (36.6 m boom) and pull-type (27.4 m boom) spraying was priced at \$9.63 ha^{-1} and \$10.13 ha^{-1}, respectively (Schnitkey and Lattz, 2017). These cost per hectare estimates factor in tractor and implement overhead, maintenance, fuel, lubrication, and labor. In the Custom Farm Rates for Farm Services in Missouri Survey, Massey (2016) reported smaller drilling costs and larger desiccation costs. The 2015-2016 Cover Crop Survey Annual Report stated that half of survey respondents reported their average seed cost of cover crops (897) respondents was \$73.27 ha^{-1} (median \$54.34 ha^{-1}). The average cost of planting and establishing cover crops (308 respondents) was \$41.00 ha^{-1} (SARE-CTIC, 2016). The National Soil Dynamics Laboratory (2014) estimated costs to establish and terminate a cereal rye cover crop to be \$176 ha^{-1}. The costs associated with cover crops could be offset with any single factor or combination of reduction in nutrient or soil loss, or increased grain yield.

Based on a survey, farmers reported the top four motivators for using cover crops to all be soil related; 1) increased soil health; 2) increased soil organic matter; 3) reduced soil compaction; and 4) reduced soil erosion (SARE_CTIC, 2016). A 2007 study found similar results stating that Midwestern U.S. farmers believed cover crops were most effective at reducing soil erosion (96%) and increasing soil organic matter (74%) (Singer et al., 2007).

However, during periods of low commodity prices, producers may not consider improving soil quality and reducing erosion an important investment. In fact, 16.2% of farmers surveyed (n=1,399) reported that no measurable economic return was a major challenge to using cover crops while 44% considered it a minor challenge and 39% did not consider it a challenge on their farm (SARE-CTIC, 2016). Both users and non-users of cover crops that were surveyed reported that tax credit eligibility, discounted crop insurance premiums, more information on cover crop species, and increased knowledge of cover crop benefits served as the top four items that would be motivating to adopt or continue to adopt cover crops.

The overall objectives of this research were to 1) assess the effect of cover crops for overseeding on corn and soybean response; 2) determine the effect of the inclusion of a cover crop on crop production, soil health, and nutrient loss in a terrace-tile field; 3) evaluate the effect of long-term cropping system management on crop yield, soil chemical properties, farm economics and soybean cyst nematode (*Heterodera glycines*) egg population densities in upstate Missouri soil landscapes.

Table 1.1. Selected management recommendations for cover crops commonly used in the Midwest.

Cover crop	Benefits	Management suggestions	Seed cost†	Suggested blends	Seeding amount‡	References
			$ ha^{-1}		kg ha^{-1}	
Cereal rye (*Secale cereal* L.)	* Weed reduction * Long lasting residue	* N immobilization * Late season termination may deplete soil moisture	127	* Legumes * Grasses * Cereal grains	D: 84 B: 123	Groff, 2008 Myers et al., 2015 National Soil Dynamics Laboratory, 2014 Bowman et al., 2007 Teasdale et al., 1991
Annual ryegrass (*Lolium multiflorum* Lam.)	* Reduce erosion * Enhance soil tilth * Emergency forage capability	* Moisture and N immobilization * Desiccation issues	26-46	* Legumes * Small grain	D: 15 B: 26	Myers et al., 2015 Sarrantonio (1994) Bowman et al., 2007
Wheat (*Triticum aestivum* L.)	* Weed and erosion control * 80% recycling of K		37-51	* Legumes * Clovers	D: 80 B: 110	Bowman et al., 2007
Berseem clover (*Trifolium alexandrinum* L.)	* High biomass * Alfalfa nurse crop * N fixing	* Some varieties susceptible to Lygus genus insects	NA	* Oats * Spring Grains	D: 11 B: 19	Bowman et al., 2007
Crimson Clover (*Trifolium incarnatum* L).	* N fixing * Performs well in mixes	* Inoculate seed	44-68	* Grasses * Other clovers	D: 15 B: 23	Myers et al., 2015 Bowman et al., 2007 Sarrantonio (1994)
Red clover *Trifolium pretense* L.	* N fixing * Performs well in mixes * May be frost seeded with fertilizer	* Inoculate seed * Do not plant deeper than 13 mm	41-56	* Orchard grass * Oats * Rye	D: 11 B: 15	Duiker and Curran (2007) Bowman et al., 2007
Oilseed radish (*Raphanus sativus* var.*oleifer* Stoke)s	* Scavenge nutrients * Deep taproot * Good soil coverage if planted early	* Terminated by temps lower than -4°C	8-31	* Legumes * Rye	D: 6 B: 10	Bowman et al., 2007 Jacobs (2012) Myers et al., 2015
Turnip (*Brassica rapa* L.)	* Fall weed suppression * Quick decomposition * Reduce compaction	* Do not use in rotation with brassicas	18-36	* Forage species	D: 6 B: 12	Bjorkman (2009) Myers et al., 2015

†Prices quoted by MFA Inc., La Plata, Missouri

‡Abbreviations: B, broadcast seeded; D, seeded using grain drill.

Table 1.2. Cover crop options for overseeding into corn at different growth stages. Adapted from Mutch (2013).

Cover crop	Species	Seeding method†
Berseem clover	*Trifolium alexandrinum* L.	A
Crimson clover	*Trifolium incarnatum* L.	A, B
Mammoth red clover	*Trifolium pretense* L.	A, B
Medium red clover	*Trifolium pretense* L.	A, B
Sweet clover	*Melilotus officinalis* (L.) Pall.	A, B
White clover	*Trifolium repens*	A, B
Hairy vetch	*Vicia villosa* R.	A‡, B‡
Medic annual	*Medicago lupulina* L.	A
Annual ryegrass	*Lolium multiflorum* Lam.	A‡, B‡
Barley	*Hordeum vulgare* L.	C
Buckwheat	*Fagopyrum esculentum* M.	A, B
Oats	*Avena sativa* L.	B
Oilseed radish	*Raphanus sativus* var.*oleifer* Stokes	B
Rape/turnip	*Brassica rapa* L.	B
Rye	*Secale cereal* L.	B, C
Triticale	× *Triticosecale Wittm. ex A. Camus.*	C
Wheat§	*Triticum aestivum* L.	C

†Abbreviations: A, overseed corn at vegetative stages V4-V8; B, overseed corn by air or high clearance spreader; C, overseed corn by air or high clearance spreader, seeded as a cover crop; NA, not available.
‡Not recommended if being planted to wheat.
§After Hessian fly-free-date.

Table 1.3. Custom farm cost estimates of field operations for implementing cover crops in Missouri (Massey, 2016).

Operation	Cost
	$ ha^{-1}
Establishment	
No-till drill	
Small grains	41.35
Grass or clover	42.93
Broadcast seeding with spreader	38.75
Aerial broadcast seeding with airplane	26.45
Desiccation of the cover crop	
Truck sprayer	16.20
Floatation sprayer	16.06
Self-propelled row crop sprayer	15.88
Tractor-mounted or pulled sprayer	18.57

REFERENCES

Abdollahi, L., and L.J. Munkholm. 2014. Tillage system and cover crop effects on soil quality: I. Chemical, mechanical, and biological properties. Soil Sci. Soc. Am. J. 78:262-270.

Abel, D.S. 2013. Cover crop effects on soil moisture and water quality. Department of Agronomy, Kansas State University, Manhattan, Kansas. pp. 23-98.

Abendroth, L.J., R.W. Elmore, M.J. Boyer, and S.K. Marlay. 2011. Corn growth and development. PMR 1009. Iowa State Univ. Ext., Ames, Iowa.

Al-Darby, A.M., and B. Lowery. 1987. Seed zone soil temperature and early corn growth with three conservation tillage systems. Soil Sci. Soc. Am. J. 51:768-774. doi: 10.2136/sssaj1987.03615995005100030035

Al-Kaisi, M., and M. Hanna. 2004. Frequent tillage and its impact on soil quality. Ext. Pub. IC-492(13). Iowa State Univ. Ext. Pub., Ames, Iowa.

Al-Kaisi, M., and D. Kwaw-Mensah. 2007. Effect of tillage and nitrogen rate on corn yield and nitrogen and phosphorus uptake in a corn-soybean rotation. Agron. J. 99:1548-1558. doi: 10.2134/agronj2007.0012

Al-Kaisi, M., and M.A. Licht. 2004. Effect of strip tillage on corn nitrogen uptake and residual soil nitrate accumulation compared with no-tillage and chisel plow. Agron. J. 96:1164-1171. doi: 10.2134/agronj2004.1164

Alexander, R.B., R.A. Smith, G.E. Schwarz, E.W. Boyer, J.V. Nolan, and J.W. Brakebill. 2008. Differences in phosphorus and nitrogen delivery to the Gulf of Mexico from the Mississippi River Basin. Environ. Sci. Techno. 42:822-830. doi: 10.1021/es0716103.

Appelgate, S.R., A.W. Lenssen, M.H. Wiedenhoeft, and T.C. Kaspar. 2017. Cover crop options and mixes for upper Midwest corn–soybean systems. Agron. J. 109:968-984. doi: 10.2134/agronj2016.08.0453.

Aryal, N., M.L. Reba, N. Straitt, T.G. Teague, J. Bouldin, and S. Dabney. 2018. Impact of cover crop and season on nutrients and sediment in runoff water measured at the edge of fields in the Mississippi Delta of Arkansas. J. Soil Water Conserv. 73:24-34. doi: 10.2489/jswc.73.1.24.

Barnes, J.P., and A.R. Putnam. 1983. Rye residues contribute weed suppression in no-tillage cropping systems. J. Chem. Ecol. 9:1045-1057. doi: 10.1007/BF00982210.

Baskin, C.C., and J.M. Baskin. 1988. Germination ecophysiology of herbaceous plant species in a temperate region. Am. J. Bot. 75:286-305. doi: 10.2307/2443896

Belfry, K.D., and L.L. Van Erd. 2016. Establishment and impact of cover crops intersown into corn. Crop Sci. 56:1245-1256. doi:10.2135/cropsci2015.06.0351

Bjorkman, T. 2009. Forage turnip and rapeseed, Cover Crops for Vegetable Growers. Fact Sheet 8. Cornell Univ. Coop. Ext., Cornell University, Ithaca, New York.

Blanco-Canqui, H. 2013. Crop residue removal for bioenergy reduces soil carbon pools: How can we offset carbon losses? BioEnergy Res. 6:358-371. doi: 10.1007/s12155-012-9221-3.

Blanco-Canqui, H., T.M. Shaver, J.L. Lindquist, C.A. Shapiro, R.W. Elmore, C.A. Francis, and G.W. Hergert. 2015. Cover crops and ecosystem services: Insights from studies in temperate soils. Agron. J. 107:2449-2474. doi: 10.2134/agronj15.0086.

Blanco-Canqui, H., M. Sindelar, C.S. Wortmann, and G. Kreikemeir. 2017. Aerial interseeded cover crop and corn residue harvest: Soil and crop impacts. Agron. J. 109:1344-1351. doi:10.2134/agronj2017.02.0098

Blevins, R.L., J.H. Grove, and B.K. Kitur. 1986. Nutrient uptake of corn grown using moldboard plow or no-tillage soil management. Commun. Soil Sci. Plant Anal. 17:401-417. doi: 10.1080/00103628609367722

Bowman, G., C. Shirley, and C. Cramer. 2007. Managing cover crops profitably. 3rd ed. Sustainable Agric. Network Handb. Ser. Book 9. Sustainable Agric. Network, Natl. Agric. Library, Beltsville, Maryland.

Buchholz, D.D., E. Palm, G. Thomas, and D.L. Pfost. 1993. No-till planting systems. Ext. Pub. G4080. Univ. of Missouri Ext., Columbia, Missouri.

Buckley, M.E., G.J. Kluitenberg, D.W. Sweeney, K.W. Kelley, and L.R. Stone. 2010. Effect of tillage on the hydrology of a claypan soil in Kansas. Soil Sci. Soc. Am. J. 74:2109-1119. doi:10.2136/sssaj2010.0024

Burkart, M.R., and D.E. James. 1999. Agricultural-nitrogen contributions to hypoxia in the Gulf of Mexico. J. Environ. Qual. 28:850-859. doi:10.2134/jeq1999.00472425002800030016x

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley, and V.H. Smith. 1998. Nonpoint pollution of surface waters with phosphorous and nitrogen. Ecol. Appl. 8:559-568. doi: 10.1890/1051-0761

Cartwright, L. 2016. Adding cover crops and reducing tillage in a corn-corn-wheat double crop soybean furrow irrigated rotation. Missouri Cover Crop Economics Case Study 4. USDA, Columbia, Missouri. pp. 1-2.

Centner, T.J., J.E. Houston, C. Fuchs, and J. Zeddies. 1996. Employing BMPs to reduce agricultural water pollution: Economics, regulatory institutions and policy concerns. Drake Law Rev. 45:125-141. doi:10.1016/S0075-9511(99)80029-2

Centner, T.J., J.E. Houston, A.G. Keeler, and C. Fuchs. 1999. The adoption of best management practices to reduce agricultural water contamination. Limnologica 29:366-373. doi: 10.1016/S0075-9511(99)80029-2.

Cerco, C.F., and M.R. Noel. 2016. Impact of reservoir sediment scour on water quality in a downstream estuary. J. Environ. Qual. 45:894-905. doi: 10.2134/jeq2014.10.0425.

Creech, J.E., J. Faghihi, V.R. Ferris, A. Westphal, and W.G. Johnson. 2007. Influence of intraspecific henbit (*Lamium amplexicaul*e) and purple deadnettle (*Lamium purpureum*) competition on soybean cyst nematode reproduction. Weed Sci. 55:665-670. doi:10.1614/WS-07-051.1

Creech, J.E., A. Westphal, V.R. Ferris, J. Faghihi, T.J. Vyn, J.B. Santini, and W.G. Johnson. 2008. Influence of winter annual weed management and crop rotation on soybean cyst nematode (*Heterodera glycines*) and winter annual weeds. Weed Sci. 56:103-111. doi:10.1614/WS-07-084.1

Curell, C. 2012. Overseeding cover crops. Michigan State Univ. Ext., East Lansing, Michigan.

Curran, W.S., R.J. Hoover, S.B. Mirsky, G.W. Roth, M.R. Ryan, V.J. Ackroyd, J.M. Wallace, M.A. Dempsey, and C.J. Pelzer. 2018. Evaluation of cover crops drill interseeded across the Mid-Atlantic region. Agron. J. 110:435-443. doi:10.2134/agronj2017.07.0395

DeFelice, M.S., P.R. Carter, and S.B. Mitchell. 2006. Influence of tillage on corn and soybean yield in the United Sates and Canada. Crop Manage. 5. doi: 10.1094/cm-2006-0626-01-rs.

den Hollander, N.G., L. Bastiaans, and M.J. Kropff. 2007. Clover as a cover crop for weed suppression in an intercropping design: II. Competitive ability of several clover species. Euro. J. of Agron. 26:104-112. doi: https://doi.org/10.1016/j.eja.2006.08.005.

Dickey, E.C., T. Hamer, D. Hay, and P.J. Jasa. 1985. Terrace systems for Nebraska. Ext. Pub. G85-750. Univ. of Nebraska Ext., Lincoln, Nebraska.

Dinnes, D.L., D.L. Karlen, D.B. Jaynes, T.C. Kaspar, J.L. Hatfield, T.S. Colvin, and C.A. Cambardella. 2002. Nitrogen management strategies to reduce nitrate leaching in tile-drained Midwestern soils. Agron. J. 94:153-171. doi: 10.2134/agronj2002.1530.

Duiker, S.W. 2014. Establishment and termination dates affect fall-established cover crops. Agron. J. 106:670-678. doi: 10.2134/agronj2013.0246.

Duiker, S.W., and W.S. Curran. 2007. Management of red clover as a cover crop. Agron. Facts 67. Penn State Univ. Ext., State College, Pennsylvania.

Environmental Protection Agency. 2007. Hypoxia in the northern Gulf of Mexico: An update by the EPA science advisory board. EPA-SAB-08-003. Science Advisory Board, Washington D.C.

Fenton, M., C. Albers, and Q. Ketterings. 2008. Soil organic matter. Ext. Pub. 41. Cornell Univ. Coop. Ext., Ithaca, New York.

Finney, D.M., C.M. White, and J.P. Kaye. 2016. Biomass production and carbon/nitrogen ratio influence ecosystem services from cover crop mixtures. Agron. J. 108:39-52. doi: 10.2134/agronj15.0182.

Fisk, J.W., O.B. Hesterman, A. Shrestha, J.J. Kells, R.R. Harwood, J.M. Squire, and C.C. Sheaffer. 2001. Weed suppression by annual legume cover crops in no-tillage corn. Agron. J. 93:319-325. doi: 10.2134/agronj2001.932319x.

Franzluebbers, A.J., and F.M. Hons. 1996. Soil-profile distribution of primary and secondary plant-available nutrients under conventional and no tillage. Soil Tillage Res. 39:229-239. doi:10.1016/S0167-1987(96)01056-2.

Franzluebbers, A.J., and J.A. Stuedemann. 2014. Crop and cattle production responses to tillage and cover crop management in an integrated crop–livestock system in the Southeastern USA. Eur. J. Agron. 57:62-70. doi:10.1016/j.eja.2013.05.009.

Frye, W.W., R.L. Blevins, M.S. Smith, S.J. Corak, and J.J. Varco. 1988. Role of annual legume cover crops in efficient use of water and nitrogen. ASA Special Pub. Cropping Strategies for Efficient Use of Water and Nitrogen. 51: 129-154. doi:10.2134/asaspecpub51.c8

Geist, L., P. Scharf, B. Myers, and P. Guinan. 2013. Topsoil lost to rainfall costs farmers money erosion of topsoil can permanently reduce farmland productivity. News from Univ. of Missouri Ext. Univ. of Missouri Ext., Columbia, Missouri.

Ghidey, F., and E.E. Alberts. 1998. Runoff and soil losses as affected by corn and soybean tillage systems. J. Soil Water Conserv. 53:64-70.

Golden, A.M., J.M. Epps, R.D. Riggs, L.A. Duclos, J.A. Fox, and R.L. Bernard. 1970. Terminology and identity of infraspecific forms of the soybean cyst nematode (*Heterodera glycines*). Plant Dis. 54:544-546.

Govaerts, B., M. Fuentes, M. Mezzalama, J.M. Nicol, J. Deckers, J.D. Etchevers, B. Figueroa-Sandoval, and K.D. Sayre. 2007. Infiltration, soil moisture, root rot and nematode populations after 12 years of different tillage, residue and crop rotation managements. Soil Tillage Res. 94:209-219. doi:10.1016/j.still.2006.07.013.

Gray, J.R., G.D. Glysson, L.M. Turcios, and G.E. Schwarz. 2000. Comparability of suspended-sediment concentration and total suspended solids data. U.S. Geological Survey Water-Resources Investigations Report 00-4191:1-14.

Griffin, E. 2017. What is soil organic carbon? Government of Western Australia. http://www.agr ic.wa.gov.au/measuring-and-assessing-soils/what-soil-organic-carbon (accessed 20 Oct 2018).

Groff, S. 2008. Mixtures and cocktails: Soil is meant to be covered. J. Soil Water Conserv. 63:110A-111A. doi: 10.2489.

Grove, J.H., R.C. Ward, and R.R. Weil. 2007. Nutrient stratification in no-till soils. Leading Edge 6:374-381.

Gummerson, R.J. 1986. The effect of constant temperatures and osmotic potentials on the germination of sugar beet. J. Exp. Bot. 37:729-741. doi: 10.1093/jxb/37.6.729

Hartwig, N.L., and H.U. Ammon. 2002. Cover crops and living mulches. Weed Sci. 50:688-699. doi: 10.1614/0043-1745(2002)050[0688:AIACCA]2.0.CO;2

Hassink, J., and A.P. Whitmore. 1997. A model of the physical protection of organic matter in soils. Soil Sci. Soc. Am. J. 61:131-139. doi: 10.2136/sssaj1997.03615995006100010020x.

Hatfield, J.L., L.D. McMullen, and C.S. Jones. 2009. Nitrate-nitrogen patterns in the Raccoon River Basin related to agricultural practices. J. Soil Water Conserv. 64:190-199. doi: 10.2489/jswc.64.3.190

Havlin, J.L., S.L. Tisdale, W.L. Nelson, and J.D. Beaton. 2014. Soil fertility and fertilizers: An introduction to nutrient management. 8th ed. Prentice Hall, Upper Saddle River, New Jersey.

Hayden, Z.D., M. Ngouajio, and D.C. Brainard. 2014. Rye–vetch mixture proportion tradeoffs: Cover crop productivity, nitrogen accumulation, and weed suppression. Agron. J. 106:904-914. doi: 10.2134/agronj2013.0467.

Her, Y., I. Chaubey, J. Frankenberger, and J. Jeong. 2017. Implications of spatial and temporal variations in effects of conservation practices on water management strategies. Agric. Water Manag. 180:252-266. doi: 10.1016/j.agwat.2016.07.004.

Hewes, L., and P.E. Frandson. 1952. Occupying the wet prairie: The role of artificial drainage in Story County, Iowa. Annals of the Assoc. of American Geographers. 42:24-50. doi: 10.2307/2561045.

Jacobs, A.A. 2012. Plant guide for oilseed radish (*Raphanus sativus* L.). USDA-Natural Resources Conservation Service, Booneville Plant Materials Center, Booneville, Arkansas.

Johnson, T.J., T.C. Kaspar, K.A. Kohler, S.J. Corak, and S.D. Logsdon. 1998. Oat and rye overseed into soybean as fall cover crops in the upper Midwest. J. Soil Water Conserv. 53:276-279.

Jones, M.M., and R.P. Beasley. 1943. Corn tillage studies on rolling putnam silt loam. Bull 475. Univ. of Missouri Agric. Exp. Stn., Univ. of Missouri, Columbia, Missouri.

Kaschuk, G., K. Giller, M. Hungria, and T.W. Kuyper. 2010. Differences in photosynthetic behaviour and leaf senescence of soybean dependent on N_2 fixation or nitrate supply. Plant Biol. 12. doi: 10.1111/j.1438-8677.2009.00211.x.

Kay, B.D., and A.J. VandenBygaart. 2002. Conservation tillage and depth stratification of porosity and soil organic matter. Soil Tillage Res. 66:107-118. doi: 10.1016/S0167-1987(02)00019-3.

King, K.W., M.R. Williams, and N.R. Fausey. 2015a. Contributions of systematic tile drainage to watershed-scale phosphorous transport. J. Environ. Qual. 44:486-494. doi: 10.2134/jeq2014.04.0149.

King, K.W., M.R. Williams, M.L. Macrae, N.R. Fausey, J. Frankenberger, D.R. Smith, P.J.A. Kleinman, and L.C. Brown. 2015b. Phosphorous transport in agricultural subsurface drainage: A review. J. Environ. Qual. 44:467-485. doi:10.2134/jeq2014.04.0163

Koski-Vähälä, J., and H. Hartikainen. 2001. Assessment of the risk of phosphorus loading due to resuspended sediment. J. Environ. Qual. 30:960-966.

Lal, R. 2009. The plow and agricultural sustainability. J. of Sustain. Agric. 33:66-84. doi: 10.1080/10440040802548555

Lawley, Y.E., J.R. Teasdale, and R.R. Weil. 2012. The mechanism for weed suppression by a forage radish cover crop. Agron. J. 104:205-214. doi: 10.2134/agronj2011.0128.

Lerch, R.N., E.J. Sadler, N.R. Kitchen, K.A. Sudduth, R.J. Kremer, D.B. Myers, C. Baffaut, S.H. Anderson, and C.H. Lin. 2008. Overview of the Mark Twain Lake/Salt River Basin conservation effects assessment project. J. Soil Water Conserv. 63:345-359. doi: 10.2489/jswc.63.6.345

Licht, M., and T.C. Kaspar. 2015. Tips and considerations for getting started with cover crops. Integrated Crop Manage. News Pub. 823. Iowa State Univ. Ext., Ames, Iowa. pp. 1.

Licht, M.A., and M. Al-Kaisi. 2005. Strip-tillage effect on seedbed soil temperature and other soil physical properties. Soil Tillage Res. 80:233-249. doi: 10.1016/j.still.2004.03.017

Linden, D.R., C.E. Clapp, and R.H. Dowdy. 2000. Long-term corn grain and stover yields as a function of tillage and residue removal in east central Minnesota. Soil Tillage Res. 56:167-174. doi: 10.1016/S0167-1987(00)00139-2

Macrae, M.L., M.C. English, S.L. Schiff, and M. Stone. 2007. Intra-annual variability in the contribution of tile drains to basin discharge and phosphorus export in a first-order agricultural catchment. Agric. Water Manage. 92:171-182. doi: 10.1016/j.agwat.2007.05.015

Maloney, T.E., W.E. Miller, and T. Shiroyama. 1972. Algal responses to nutrient additions in natural waters. I. Laboratory assays. In: G.E. Likens, editor, Nutrients and Eutrophication. Spec. Symp. Vol. 1. Am. Soc. Limnol. Oceanogr., Allen Press, Lawrence, Kansas.

Martens, D.A. 2001. Nitrogen cycling under different soil management properties. Adv. Agron. 70:143-191. doi: 10.1016/S0065-2113(01)70005-3

Massey, R.E. 1997. No-tillage and conservation tillage: Economic considerations. Ext. Pub. G355. Univ. of Missouri Ext., Columbia, Missouri.

Massey, R.E. 2016. Custom rates for farm services in Missouri. Ext. Pub. G302. Univ. of Missouri Ext., Columbia, Missouri.
Meisinger, J. J., W.L. Hargrove, R. L. Mikkelsen, J.R. Williams, and V.W. Benson. 1991. Effects of cover crops on groundwater quality. In: W.L. Hargrove, editor, Cover Crops for Clean Water. Proceedings of an International Conference, West Tennessee Experiment Station. Jackson, Tennessee. 1-11 Apr. 1991. Soil and Water Conserv. Soc. Ankeny, Iowa pp. 57-68.
Michigan State University Extension. Getting started & management, Cover Crops, Michigan State Univ. Ext. www.canr.msu.edu/cover_crops/getting_started_and_management/planting (accessed 26 Jun 2018).
Mock, V.A., J.E. Creech, B. Johnson, J. Faghihi, V.R. Ferris, A. Westphal, and K. Bradley. 2007. Winter annual weeds and soybean cyst nematode management. Purdue Univ. Ext. Pub., West Layfette, Indiana.
Moore, E.B., M.H. Wiedenhoeft, T.C. Kaspar, and C.A. Cambardella. 2014. Rye cover crop effects on soil quality in no-till corn silage–soybean cropping systems. Soil Sci. Soc. Am. J. 78:968-976. doi: 10.2136/sssaj2013.09.0401.
Mutch, D. 2013. Incorporating cover crops into corn systems. Michigan State Univ. Ext. Michigan State Univ. http://canr.msu.edu/news/incorporating_cover-_crops_into_corn_systems. (accessed 26 Jun 2018).
Myers, R., C. Ellis, R. Hoormann, T. Reinbott, N. Kitchen, and J. Reisner. 2015. Cover crops in Missouri: Putting them to work on your farm. Ext. Pub. G4161. Univ. of Missouri Ext., Columbia, Missouri. pp. 1-6.
National Agricultural Statistics Service. 2012. Quick Stats. United States Dept. of Agriculture. https://quickstats.nass.usda.gov. (accessed 4 May 2017).
National Soil Dynamics Laboratory. 2014. Cover crop costs. Conservation Systems Facts Sheet No. 04o. USDA-ARS-NSDL, Auburn, Alabama.
Nelson, K.A., W.G. Johnson, J.D. Wait, and R. Smoot. 2006. Winter-annual weed management in corn (*Zea mays*) and soybean (G*lycine max*) and the impact on soybean cyst nematode (*Heterodera glycines*) egg population densities. Weed Sci. 20:965-970.
Nelson, K.A., R.E. Massey, and B.A. Burdick. 2011. Harvest aid application timing affects wheat and relay intercropped soybean. Agron. J. 103:851-855. doi: 10.2134/agronj2010.0384.
Neugschwandtner, R.W., P. Liebhard, H.P. Paul, and H. Wangentristl. 2014. Soil chemical properties as affected by tillage and crop rotation in a long-term field experiment. Plant Soil Envt. J. 60:57-62. doi: http://agriculturejournals.cz/publicFiles/114057.pdf.
Niblack, T.L., P.R. Arelli, G.R. Noel, C.H. Opperman, J.H. Orf, D.P. Schmitt, J.G. Shannon, and G.I. Tylka. 2002. A revised classification scheme for genetically diverse populations of *Heterodera glycines*. J. Nematol. 34:279-288.
Noland, R.L., M.S. Wells, C.C. Sheaffer, J.M. Baker, K.L. Martinson, and J.A. Coulter. 2018. Establishment and function of cover crops interseeded into corn. Crop Sci. 58:863-873. doi: 10.2135/cropsci2017.06.0375.

Ofori, C.S. 1993. The challenge of tillage development in African agriculture. In: Soil Tillage in Africa: Needs and challenges. FAO soil Bulletin 69, Rome. Chapter 7: 77- 82.

Olson, K., S.A. Ebelhar, and J.M. Lang. 2014. Long-term effects of cover crops on crop yields, soil organic carbon stocks and sequestration. Open J. Soil Sci. 4. doi: 10.4236/ojss.2014.48030.

Olson, K.R., S.A. Ebelhar, and J.M. Lang. 2010. Cover crop effects on crop yields and soil organic carbon content. Soil Sci. Soc. Am. J. 175:89-98.

Osterman, L.E., R.Z. Poore, P.W. Swarzenski, and R.E. Turner. 2005. Reconstructing a 180 year record of natural and anthropogenic induced low-oxygen conditions from Louisiana Continental Shelf sediments. Geology 33:329-332.

Pimentel, D., C. Harvey, P. Resosudarmo, K. Sinclair, D. Kurz, M. McNair, S. Crist, L. Shpritz, L. Fitton, R. Saffouri, and R. Blair. 1995. Environmental and economic costs of soil erosion and conservation benefits. Science 267:1117-1123. doi: 10.1126/science.267.5201.1117

Poeplau, C., and A. Don. 2015. Carbon sequestration in agricultural soils via cultivation of cover crops: A meta-analysis. Agric. Ecosyst. Environ. 200:33-41. doi: 10.1016/j.agee.2014.10.024.

Rabotyagov, S.S., T.D. Campbell, M. White, J.G. Arnold, J. Atwood, M.L. Norfleet, C.L. Kling, P.W. Gassman, A. Valcu, J. Richardson, R.E. Turner, and N.N. Rabalais. 2014. Cost-effective targeting of conservation investments to reduce the northern Gulf of Mexico hypoxic zone. Proc. Natl. Acad. Sci. USA 111:18530-18535. doi: 10.1073/pnas.1405837111

Ranells, N.N., and M.G. Wagger. 1997. Winter annual grass-legume bicultures for efficient nitrogen management in no-till corn. Agric. Ecosyst. Environ 65:23-32. doi: 10.1016/S0167-8809(97)00054-6

Royer, T.V., M.B. David, and L.E. Gentry. 2006. Timing of riverine export of nitrate and phosphorus from agricultural watersheds in Illinois: Implications for reducing nutrient loading to the Mississippi River. Environ. Sci. Techno. 40:4126-4131. doi: 10.1021/es052573n

Russell, A.E., D.A. Laird, T.B. Parkin, and A.P. Mallarino. 2005. Impact of nitrogen fertilization and cropping system on carbon sequestration in Midwestern mollisols. Soil Sci. Soc. Am. J. 69:413-422. doi: 10.2136/sssaj2005.0413

Ryan, M.R., S.B. Mirsky, D.A. Mortensen, J.R. Teasdale, and W.S. Curran. 2011. Potential synergistic effects of cereal rye biomass and soybean planting density on weed suppression. Weed Sci. 59:238-246. doi: 10.1614/WS-D-10-00110.1.

Sandler, L.N., K.A. Nelson, C.J. Dudenhoeffer, R.J. Miles, and P.P. Motavalli. 2015. Effect of radish overseeded planting date on interseeded soybean and corn yield. Crop, Forage, & Turfgrass Manage. 1:2015-0119. doi: 10.2134/cftm2015.0119.

SARE-CTIC. 2016. Cover crop survey: 2015-2016 annual report. Conserv. Technol. Inf. Ctr., Sust. Agric. Res. Educ., Am. Seed Trade Assoc. https://www.sare.org/Learning-Center/Topic-Rooms/Cover-Crops/Cover-Crop-Surveys (accessed 28 Aug. 2017).

Sarrantonio, M. 1994. Northeast cover crop handbook. Soil health series. Rodale Institute, Emmaus, Pennsylvania.

Sawyer, J. 2015. Nitrogen loss?. Iowa State Univ. Ext. https://crops.extension.iastate.edu/cropnews/2015/12/nitrogen-loss. (accessed 11 Sep. 2017).
Schindler, D.W., R.E. Hecky, D.L. Findlay, M.P. Stainton, B.R. Parker, M.J. Paterson, K.G. Beaty, M. Lyng, and S.E.M. Kasian. 2008. Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment. Proc. Natl. Acad. Sci. USA. 105:11254-11258. DOI: 10.1073/pnas.0805108105.
Schnitkey, G., J. Coppess, and N. Paulson. 2016. Costs and benefits of cover crops: An example with cereal rye. Farmdoc Daily 6. Dept. of Agric. and Comsumer Econ., Univ. of Illiniois, Urbana-Champaign, Illinois.
Schnitkey, G., and D. Lattz. 2017. Machinery cost estimates for 2017. Farmdoc Daily 7. Dept. of Agric. and Comsumer Econ., Univ. of Illiniois, Urbana-Champaign, Illinois.
Schottman, R.W., and J. White. 1993. Choosing terrace systems. Ext. Pub. G1500. Univ. of Missouri Ext., Columbia, Missouri.
Scott, T.W., J. Mt. Pleasant, R.F. Burt, and D.J. Otis. 1987. Contributions of ground cover, dry matter, and nitrogen from intercrops and cover crops in a corn polyculture system. Agron. J. 79:792-798. doi: 10.2134/agronj1987.00021962007900050007x.
See, C. 2017. NRCS cover crop cost share program in Knox County, Missouri, In: R.L. Adler (interviewer), NRCS.
Sharpley, A.N., T. Daniel, T. Sims, J. Lemunyon, R. Stevens, and R. Parry. 2003. Agricultural phosphorus and eutrophication. 2nd ed. USDA-Agricultural Research Serice ARS-49. U.S. Gov. Print. Office, Washington, D.C.
Singer, J.W. 2008. Corn belt assessment of cover crop management and preferences. Agron. J. 100:1670-1672. doi:10.2134/agronj2008.0151
Singer, J.W., S.M. Nusser, and C.J. Alf. 2007. Are cover crops being used in the US corn belt? J. Soil Water Conserv. 62:353-358.
Skaggs, R.W., M.A. Breve, and J.W. Gilliam. 1994. Hydrologic and water quality impacts of agricultural drainage. Crit. Rev. Environ. Sci. Technol. 24:1-32.
Smil, V. 1999. Nitrogen in crop production: An account of global flows. Global Biogeochemical Cycles. 13:647-662.
Smith, D.R., K.W. King, L. Johnson, W. Francesconi, P. Richards, D. Baker, and A.N. Sharpley. 2015. Surface runoff and tile drainage transport of phosphorus in the Midwestern United States. J. Environ. Qual. 44:495-502. doi: 10.2134/jeq2014.04.0176.
Soil Health Assessment Center. 2016. Soil health assessment results report, University of Missouri-Columbia, Columbia, Missouri.
SSSA. 2008. Glossary of soil science terms 2008. In: Glossary of soil science terms, SSSA, Madison, Wisconsin p. 1-82. doi:10.2136/2008.glossarysoilscienceterms
Stecker, J.A. 1993. Nitrogen management for no-tillage systems in Missouri. Ext. Pub. G9175. Univ. of Missouri Ext., Columbia, Missouri.
Strock, J.S., P.M. Porter, and M.P. Russelle. 2004. Cover cropping to reduce nitrate loss through subsurface drainage in the northern US Corn belt. J. Environm. Qual. 33:1010-1016.

Sweeney, D.W. 2017. Does 20 years of tillage and N fertilization influence properties of a claypan soil in the eastern Great Plains? Agric. Environ. Lett. 2:170025. doi:10.2134/ael2017.08.0025.

Teasdale, J.R., C.E. Beste, W.E. Potts. 1991. Response of weeds to tillage and cover crop residue. Weed Sci. 39:195-199.

Teasdale, J.R., and C.L. Mohler. 1993. Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. Agron. J. 85:673-680. doi: 10.2134/agronj1993.00021962008500030029x.

Tilman, D., C.L. Lehman, and K.T. Thomson. 1997. Plant diversity and ecosystem productivity: Theoretical considerations. Proceedings of the National Academy of Sciences of the United States of America 94:1857-1861. doi: 10.1073/pnas.94.5.1857

Toliver, D.K., J.A. Larson, R.K. Roberts, B.C. English, D.G. De La Torre Ugarte, and T.O. West. 2012. Effects of no-till on yields as influenced by crop and environmental factors. Agron. J. 104:530-541. doi: 10.2134/agronj2011.0291.

Tomer, M.D., D.W. Meek, D.B. Jaynes, and J.L. Hatfield. 2003. Evaluation of nitrate nitrogen fluxes from a tile-drained watershed in central Iowa. J. Environ. Qual. 2:642-653.

Tonitto, C., M.B. David, and L.E. Drinkwater. 2006. Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics. Agriculture, Ecosystems & Environment 112:58-72. doi:10.1016/j.agee.2005.07.003.

Tribouillois, H., C. Dürr, D. Demilly, M.-H. Wagner, and E. Justes. 2016. Determination of germination response to temperature and water potential for a wide range of cover crop species and related functional groups. PLoS ONE 11:1-16. doi: 10.1371/journal.pone.0161185.

Triplett, G.B. 1962. Intercrops in corn and soybean cropping systems. Agron. J. 54:106-109. doi: 10.2134/agronj1962.00021962005400020004x.

Tylka, G.L. 2006. What's your type?: An HG type test for SCN populations. ICM 496:252-253.

Vanni, M.J., W.H. Renwick, J.L. Headworth, J.D. Auch, and M.H. Schaus. 2001. Dissolved and particulate nutrient flux from three adjacent agricultural watersheds: A five-year study. Biogeochemistry 54:85-114. doi: 10.1023/A:1010681229460

Varvel, G.E. 2006. Soil organic carbon changes in diversified rotations of the western corn belt. Soil Sci. Soc. Am. J. 70:426-433. doi:10.2136/sssaj2005.0100er

Venkatesh, R., S.K. Harrison, and R.M. Riedel. 2000. Weed hosts of soybean cyst nematode (*Heterodera glycines*) in Ohio. Weed Technol. 14:156-160. doi: 10.1614/0890-037X

Villamil, M.B., G.A. Bollero, R.G. Darmody, F.W. Simmons, and D.G. Bullock. 2005. No-till corn/soybean systems including winter cover crops: Effects on soil properties. Soil Sci. Soc. Am. J.:1936-1944. doi: 10.2136/sssaj2005.0350

Wells, M.S., S.C. Reberg-Horton, and S.B. Mirsky. 2016. Planting date impacts on soil water management, plant growth, and weeds in cover-crop-based no-till corn production. Agron. J. 108:162-170. doi: 10.2134/agronj2014.0524.

Wheaton, R.Z., and E.J. Monke. 1981. Terracing as a `best management practice' for controlling erosion and protecting water quality. Ext. Pub. AE-114. Purdue Univ., West Lafayette, Indiana.

Whitaker, F.D., J.S. McKibben, and M.M. Jones. 1966. Reduced tillage in corn production. Bull. 852. Univ. of Missouri Ext., Columbia, Missouri.

Wilson, M.L., D.L. Allan, and J.M. Baker. 2014. Aerially seeding cover crops in the northern US corn belt: Limitations, future research needs, and alternative practices. J. Soil Water Conserv. 69:67A-72A. doi: 10.2489/jswc.69.3.67A

Wilson, M.L., J.M. Baker, and D.L. Allan. 2013. Factors affecting successful establishment of aerially seeded winter rye. Agron. J. 105:1868-1877. doi: 10.2134/agronj2013.0133.

Wilts, A.R., D.C. Reicosky, R.R. Allmaras, and C.E. Clapp. 2004. Long-term corn residue effects: Harvest alternatives, soil carbon turnover, and root-derived carbon. Soil Sci. Soc. Am. J. 68:1342-1351. doi:10.2136/sssaj2004.1342

Wollenhaupt, N.C., and M.G. Blase. 1990. The economic impact of conservation compliance on northern Missouri farms. J. Soil Water Conserv. 4:154-159.

Wortman, S.E., C.A. Francis, M.L. Bernards, R.A. Drijber, and J.L. Lindquist. 2012a. Optimizing cover crop benefits with diverse mixtures and an alternative termination method. Agron. J. 104:1425-1435. doi: 10.2134/agronj2012.0185.

Wortman, S.E., C.A. Francis, and J.L. Lindquist. 2012b. Cover crop mixtures for the western corn belt: Opportunities for increased productivity and stability. Agron. J. 104:699-705. doi: 10.2134/agronj2011.0422.

Wrather, J.A., and M.G. Mitchum. 2006. Soybean cyst nematode: Diagnosis and management. Ext. Pub. G4450. Univ. of Missouri Ext., Columbia, Missouri.

Yadvinder-Singh, Bijay-Singh, and C.S. Khind. 1992. Nutrient transformations in soils amended with green manures. Adv. Soil Sci. 20:237-309.

Zhou, Q., L. Tian, O.W.H. Wai, J. Li, Z. Sun, and W. Li. 2018. Impacts of insufficient observations on the monitoring of short- and long-term suspended solids variations in highly dynamic waters, and implications for an optimal observation strategy. Remote Sensing 10:345-365. doi: 10.3390/rs10020345.

Zhu, J.C., C.J. Gantzer, S.H. Anderson, E.E. Alberts, and P.R. Beuselinck. 1989. Runoff, soil, and dissolved nutrient losses from no-till soybean with winter cover crops. Soil Sci. Soc. Am. J. 53:1210-1214. doi: 10.2136/sssaj1989.03615995005300040037x.

Zhu, J.C., C.J. Gantzer, S.H. Anderson, P.R. Beuselinck, and E.E. Alberts. 1991. Water use evaluation of winter cover crops for no till soybeans. J. Soil Water Conserv. 46:446-449.

Zhu, Q., J.P. Schmidt, and R.B. Bryant. 2012. Hot moments and hot spots of nutrient losses from a mixed land use watershed. J. Hydrol. 414-415:393-404. doi: 10.1016/j.jhydrol.2011.11.011

CHAPTER 2
EFFECT OF OVERSEEDING COVER CROPS ON CORN AND SOYBEAN RESPONSE

ABSTRACT

Field trials were established at the University of Missouri Greenley Research Center (40° 01' 8.56"N, 92° 11' 21.20"W) and University of Missouri Grace Greenley Farm near Novelty (39° 57' 27.94"N, 92° 10' 38.88"W) from the spring of 2016 to the fall of 2018. Experiments were arranged in a randomized complete block design with 13 cover crop (CC) overseeding treatments in corn (*Zea mays*) and 14 CC treatments in soybean [*Glycine max* (L.) Merr] with three to four replications in 3.1 by 12.2 m plots on claypan soils. Main crops (corn or soybean) were planted in the spring and rotated to the other crop the following year. Cover crops were broadcast overseeded into the main crop at three corn growth stages (V5, V10, and VT) in separate experiments and one soybean growth stage (R6). The objective of this research was to determine the effect of CC (monoculture or blend) species for overseeding CC's into corn and soybean. on cash crop yield, CC biomass, weed biomass, and rotational crop yield. No differences in plant population (PP), moisture, test weight (TW), or yield were detected in corn or the subsequent soybean crop when corn was overseeded at V5 with a CC. Neither CC nor weed biomass was greater than the non-treated control (NTC). Year by treatment interactions were present for CC biomass and subsequent soybean yield when corn was overseeded with a CC at V10. In 2017, CC biomass was 390 to 920 kg ha^{-1} greater than NTC and Dixie increased soybean yield 490 kg ha^{-1}. In 2017 when corn was overseeded at VT with a CC treatment, red clover reduced corn yield 760 kg ha^{-1}. Biomass of CC's overseeded into soybean at R6 was 2510 to 3310 kg ha^{-1} greater in 2017 than in 2018 and

wheat, winter rye, ryegrass, and a wheat/radish/turnip blend reduced weed biomass in 2017. Cover crops reduced corn yield 1800 to 3590 kg ha^{-1} and PP following overseeded soybean. In all timings and crops, excluding wheat, CC treatments did not reduce cash crop yield in 2018. This suggests that lesser CC biomass may reduce yield loss of rotational crops caused by CC's. Earlier springtime termination of CC's might prevent excessive biomass accumulation and detrimental effects on yield and stand establishment of corn.

INTRODUCTION

The challenge of implementing cover crops (CC) into crop rotations for many farmers in the Midwest is the short period of ideal weather for CC establishment after harvest. For producers interested in utilizing CC species that grow in warm weather conditions, intercropping a CC is an option. Intercrops are two or more crops growing in a field simultaneously that were planted at or near a similar time. Interseeding CC's allows producers to plant a CC while the cash crop is in the field (Curell, 2012). Interseeding CC's can have positive conservation impacts; however, performance was sensitive to local environmental conditions (Abdin et al., 1997). Utilizing this practice can be challenging to producers. Establishment of interseeded CC plants prior to canopy closure of the rotational crop is essential yet establishing a cover too early can lead to resource competition with the rotational crop (Abdin et al., 1997).

In the upper Midwest, late-season establishment of winter cereals can be challenging following harvest in a corn-soybean rotation (Strock et al., 2004). Legume and broadleaf CC's cannot tolerate late establishment conditions (Singer, 2008). Cover crop type is important in affecting winter annual weed suppression (Wells et al., 2016) and affected termination in the spring that impacts the subsequent rotational crop (Johnson et al., 1998). Johnson et al. (1998) reported reduced corn yields following soybean overseeded with a rye and oat/rye blended CC, and reduced soybean yields in one out of six years when an oat CC was overseeded. Johnson et al. (1998) concluded that in the upper Midwest an oat CC provided comparable shoot dry matter to rye in the fall, was inexpensive and attainable, and winter killed which eliminated the need for spring desiccation and did not affect subsequent corn crop yield making it an exceptional candidate for overseeding into soybean. Duiker (2014) emphasized the importance of using regionally adapted CC species.

Aerially seeding a CC presents both advantages and challenges to both producers and pilots. Many components must be considered before aerially seeding a CC. As smaller seeds may float and be affected by wind, producers must consider CC species before aerially seeding (Wilson et al., 2014). Wilson et al. (2014) reported that field shape, soil, landscape, topography, and wind speed and direction, broadcast width, and height of flight must be considered by pilots. Wilson et al. (2013) reported that if dry soil conditions existed and rain was not forecasted within seven days of aerial seeding, then producers may want to consider alternative methods for seeding CC's. Licht and Kaspar (2015) added that the cash crop must be close to maturity or alternative application method must be considered. This could prove challenging as producers must keep aerial applicator (pilot) availability, CC seed quantity and quality, equipment availability, and forecasted weather in consideration when making seeding decisions. Aerial overseeding also requires greater seeding amounts due to inconsistent seed-to-soil contact (Licht and

Kaspar, 2015). NRCS (2010) reported the aerial seeding amount of CC's must be increased 25 to 50% more than drill-seeded recommended CC amounts.

In central Iowa, Licht and Kaspar (2015) advised producers to overseed a CC between August 15 and September 15 based on the cash crop maturity, rainfall timings, and calendar date. Further, Licht and Kaspar (2015) recommended aerial seeding in corn after firing had transpired to the ear leaf, while in soybean aerial seeding was recommended when crop leaves began to yellow. In Michigan, Curell (2012) recommended overseeding CC's into standing corn at V6 (Abendroth et al., 2011) or near a side-dress fertilizer application timing and before a forecasted rain or irrigation event. In Missouri, Geist et al. (2013) also recommended moist soils for overseeding CC's and suggested producers should overseed when standing crop leaf coverage had decreased by 20 to 25 %.

Management standards for overseeding CC's into tillage systems have been reported (Mutch, 2013); however, as interest in conservation agriculture increases, technologic development and research for interseeding CC's into a standing crop in no-till grain production is necessary (Curran et al., 2018). Aerial overseeding into a standing crop research has shown mixed results. Adoption of aerial overseeding is greater in some parts of the U.S. than others, particularly larger in areas that incentivize CC use (Wilson et al., 2014). Research has demonstrated that seed germination and CC emergence are essential for establishing a CC and these factors were dependent on climatic conditions, particularly temperature and water (Baskin and Baskin, 1988; Gummerson, 1986; Tribouillois et al., 2016), planting method, and CC species (Noland et al., 2018). These factors ultimately effect biomass (Noland et al., 2018) which may be proportional to the benefits of the CC including weed suppression, N retention, and contribution to soil OC (Ryan et al., 2011). Meisinger et al. (1991) reported greater establishment consistency when drill seeding CC's were compared to broadcast overseeding due to seed to soil contact, particularly under varying moisture conditions, but they noted that drill seeding is not as timely. Improved establishment consistency in intercropping CC's may encourage farmer adoption (Curran et al., 2018).

Research is needed to find ideal CC species to implement overseeding CC's into standing crops in upstate Missouri. The objective of this research was to determine the effect of CC (monoculture or blend) species overseeded into corn at V5, V10, and VT and soybean at R6 on cash crop yield, CC biomass, weed biomass, and rotational crop yield.

MATERIALS AND METHODS

Field trials were established at the University of Missouri Greenley Research Center and University of Missouri Grace Greenley Farm in Knox County, Missouri near Novelty (40° 01' 8.56"N, 92° 11' 21.20"W). Four separate experiments were established in the spring 2016 and ended in the fall of 2017. These experiments were repeated beginning in the spring of 2017 and concluded in the fall of 2018. Experiments were arranged in a randomized complete block design with 13 CC treatments in corn and 14 CC treatments in soybean (Table 2.1) with three to four replications. Plots were 3.1 by 12.2 m.

Corn (John Deere 7000, Moline, IL) and soybean (John Deere 7200, Moline, IL or Case 1245 Early Riser, Racine, WI) main crops were planted in the spring and rotated to the other crop the following year. Crop management information is reported in Tables

2.2 to 2.5 for the main and rotational crops as well as site specific soil descriptions. Cover crops were broadcast overseeded into the main crop in separate experiments using an EV-N SPRED hand seeder (EarthWay Products, Bristol, IN) to simulate aerial application into the primary crop at three corn growth stages (V5, V9-10, V14-VT) (Abendroth et al., 2011) and one soybean growth stage (R6) (Fehr and Caviness, 1977). Seed for each plot was weighed at the amounts listed in Table 2.1 and packaged individually for each plot. In the field, individual packages were emptied into the hand spreader. In corn, an applicator walked the length of the plot disbursing half of the appropriate CC seed. The applicator then walked the plot length back to their initial position, distributing the remaining half of the CC seed throughout the plot.

Corn and soybean main crops were harvested in the fall using a Wintersteiger Delta (Salt Lake City, UT) combine and yields were adjusted to 150 and 130 g kg^{-1} moisture, respectively. Vegetative cover of the aerial seeded CC was determined in the spring prior to a burndown herbicide application (Tables 2.2 to 2.5). Cover crops and winter annual weeds were hand harvested each year using a 0.3 m^2 quadrat randomly placed in each plot. Samples were dried, separated by species, and weighed. Species present in the harvested sample that were not intentionally seeded were quantified as weed biomass. Cover crops were desiccated using a burndown herbicide application approximately two weeks (Apr. 11 to Apr. 26) prior to planting the subsequent rotational crop (Tables 2.2 to 2.5). Soil chemical properties were evaluated in each replication to a 15-cm depth before planting rotational crops and after CC desiccation (Table 2.6). Soil classification information is located in Tables 2.2 to 2.5.

Plant populations of the main and rotational crop were determined. Yield and moisture of the rotational crop that was overseeded into was evaluated the following year. In 2016, the site with soybean had not been in row crop production for over 20 years. All other sites were in a corn-soybean rotation. Precipitation data was recorded and is reported in Table 2.7.

RESULTS AND DISCUSSION

V5 Overseeding into Corn

Corn plant population, grain moisture, test weight, and yield were not affected by the CC treatment when corn was overseeded at V5 (Table 2.8). In Maryland, Pennsylvania, and New York, Curran et al. (2018) reported a reduction in corn grain yield when CC's were interseeded into standing corn at V2-V3, but no yield decrease was reported when CC's were overseeded after V4. Neither CC biomass, nor weed biomass was significantly different among CC treatments. Curran et al. (2018) reported similar CC biomass to our results when corn was overseeded at V5. This indicated poor establishment of all of the CC cultivars evaluated when seeded into V5 corn in upstate Missouri. Combined over years (2017 and 2018), CC biomass was similar to the non-treated control; therefore, the lack of treatment effects on other evaluated parameters is expected. All herbicide applications were applied following label instructions. A burndown herbicide application in 2016 did not provide residual weed control and should not have affected CC growth (BASF Corporation, 2018; Monsanto Company, 2017). A postemergence herbicide application of mesotrione (116 g ai ha^{-1}), glyphosate (1.16 kg ae ha^{-1}), and *S*-metolachlor (1.16 kg ai ha^{-1}) was made on 24 Jun. 2016, which was five days prior to CC overseeding. This herbicide may provide 21 to 28 days of residual weed control to label specified broadleaf grass and weed species (Syngenta Crop Protection, 2015). Though none of the CC treatment species were listed for control, it is possible that this residual herbicide affected establishment of the overseeded CC and reduced CC emergence. In 2017, saflufenacil was applied as a burndown herbicide application at 50 g ai ha^{-1}. Saflufenacil applied at this rate may have had residual effects (length unlisted) on broadleaf CC treatments that were broadcast seeded 55 days after application (BASF, 2017a) and may have reduced CC emergence. A postemergence herbicide application including pyroxasulfone (240 g ai ha^{-1}) and atrazine (1.7 g ai ha^{-1}) was applied on 19 Apr. 2017 which was 47 days prior to overseeding CC treatments. Herbicides in the postemergence herbicide application had residual properties and may have attributed to the lack of CC biomass (Syngenta Crop Protection, 2013; BASF, 2017b). Glyphosate, 2,4-D, dicamba, and saflufenacil are typical burndown herbicides in the Midwest used to control winter annual weeds such as marestail (*Conyza canadensis* (L.) *Cronquist*), henbit (*Lamium amplexicaule* L.), prickly lettuce (*Lactuca serriola* L.), shepherd's purse (*Capsella bursa-pastoris* (L.) Medik), and dandelion (*Taraxacum officinale* F.H. Wigg.). These herbicides may also be used to terminate a cover crop (Redfearn and McMechan 2018). Redfearn and McMechan (2018) recommended that producers utilize these chemicals between 18 and 30 °C and use labeled adjuvants to improve herbicide efficacy. The limited effects of overseeding CC's at the V5 growth stage in corn was likely due to the close proximity of herbicide application date with CC overseeding date, as well as the herbicides that were selected.

Weed biomass was not affected by overseeded CC treatment at V5. Teasdale et al. (1991) reported that soil coverage by CC residue must be at least 42% for a reduction of weed density to occur. This research did not observe a CC treatment effect on weed biomass.

Soybean plant population, moisture, test weight, and yield were not affected when the previous corn crop was overseeded with CC's at V5. Little research has examined the effect of CC's overseeded at V5 on the subsequent soybean crop. Noland et al. (2018) reported no differences in subsequent soybean grain yield when the previous corn crop was overseeded with a clover CC at V7.

Overseeding a CC at V5 did not result in any production benefits such as increased CC biomass, decreased weed populations, or increased rotational crop yield. However, further research is needed to evaluate effective corn herbicides that may be appropriate for overseeding a CC at V5.

V10 Overseeding into Corn

Corn plant population, grain moisture, test weight, and yield weight were not affected by the CC overseeded at V10 (Table 2.9). Similarly, Noland et al. (2018) reported successful CC interseeding into V7 corn without reducing grain yield.

A significant treatment by year interaction (P=0.008) was present for CC biomass. In 2017, MFA 2249, Bounty, Bounty/Dixie, Bounty/Multicut, and Bounty/Mihi cultivars and blends had 390-920 kg ha^{-1} greater CC biomass compared to the non-treated control. The Bounty/Dixie blend had the greatest CC biomass (920 kg ha^{-1}). In 2018, no significant differences in CC biomass occurred between treatments. Small CC biomass in 2018 was observed. The ineffectiveness of the CC in 2018 on corn plant population, grain moisture, test weight, and yield may have been due to poor CC germination because of dry conditions. Curell (2012) recommended that producers overseed CC's ahead of a forecasted rain. In 2016 and 2017, CC's were overseeded on 29 Jun. and 5 Jun., respectively (Table 4). In 2016, 2.5 cm of occurred nine days after overseeding. In 2017, dry soil conditions occurred at overseeding and precipitation (3.5 cm) did not occur until nine days after overseeding. Wilson et al. (2013) reported that if dry soil conditions were present and rain was not forecasted within seven days of overseeding that producers should seek alternative seeding methods. When seeded aerially, CC seed risks becoming trapped in the corn canopy thus potentially decreasing CC establishment (Belfry and Van Erd, 2016). Cover crops in this trial were overseeded using a hand spreader. It is possible that during the V5 and V10 overseeding timings, a small amount of CC seed became trapped in the whorl of the corn plant.

Weed biomass data were combined over years and no significant differences among treatments were detected indicating no interference with weeds compared to the non-treated control. Cover crop studies using various seeding methods at different timings have reported CC reduced weed densities (Barnes and Putnam, 1983; Myers et al., 2015; Teasdale et al., 1991); however, limited research has evaluated the impact of overseeding CC's into standing corn on weed population densities.

No differences in plant population, moisture, or test weight was observed (Table 2.9). A significant year by treatment interaction (*P*=0.015) was present for soybean yield when the previous corn crop was overseeded with a CC at V10. Soybean yield was the greatest following Dixie (490 kg ha^{-1}) in 2017, but it did not affect soybean yield in 2018. In Minnesota, there were no differences in subsequent soybean grain yield the previous corn crop was overseeded with a clover CC at V7 (Noland et al., 2018). None of the V10

CC overseeding treatments reduced soybean when compared to the non-treated control (Noland et al., 2018).

Of the 13 CC treatments examined, the optimal CC's for overseeding into V10 corn were MFA 2249, Bounty, and /Dixie, Bounty/Multicut, and Bounty/Mihi varieties and blends based on CC biomass and lack of treatment reduction on cash crop yields. These treatments did not reduce corn or subsequent soybean crop plant populations, moisture, test weight, or yield. They had greater CC biomass than the non-treated control in 2017. Though Dixie raised subsequent soybean crop yield in 2017 (490 kg ha^{-1}), it did not affect corn yield in either year or soybean yield in 2018. Dixie also did not have greater biomass than the non-treated control in 2017 or 2018. Due to less CC growth in 2018 as a result of dry conditions, additional years of data are needed to observe the impact of CC's on long-term rotational and subsequent rotational crop yield when corn is overseeded at V10. Cover crops should be overseeded into corn at V10 when forecasted rain is sooner than nine days after overseeding.

VT Overseeding into Corn

Corn grain moisture and test weight were not affected by CC treatments when corn was overseeded at VT (Table 2.10). Bayou, Bounty, and Bounty/Mihi reduced corn plant population by 4,000 plants ha^{-1}. This reduction in plant population may have affected grain yield. Corn stand counts were evaluated prior to overseeding the CC treatment. Therefore, the reductions evaluated may have been a random effect. A year by treatment interaction was observed for corn yield (P=0.0277). In 2017, corn grain yield was reduced 760 kg ha^{-1} when red clover was overseeded. Red clover's small seed size may have allowed it to reach soil contact through ground residue. Red clover needs less moisture to germinate than other CC treatments (Bowman et al., 2007). Red clover may have competed with the standing corn crop for resources, reducing corn grain yield. Grain yield of all other treatments was not different than the non-treated control.

A year by treatment interaction (*P*=0.0014) was observed for CC biomass. Bounty, Bounty/Dixie, and Bounty/Mihi treatments had greater CC biomass (160 to 480 kg ha^{-1}) compared to the non-treated control in 2017. In 2016, corn overseeded at VT was planted at 76,570 seeds ha^{-1}. In 2017, corn was planted at 79,040 seeds ha^{-1} (Table 2.10). Teasdale (1996) reported that CC's suppress weeds by decreasing soil light transmittance. However, larger seeding amounts in 2017 may have decreased red to far red light ratio transmittance to the CC and prevented germination. No effects of CC treatments were observed on weed biomass indicating that CC's did not affect weed biomass in the spring. Plant population, moisture, test weight, and yield of the soybean crop planted following corn that was overseeded at VT with a CC was not affected by CC treatment.

Of the CC treatments examined, optimal CC for overseeding into VT corn was Bounty based on a lack of reduction of cash crop yield and CC biomass yield. Though Bounty reduced corn plant population, it was not great enough to affect yield. Bounty had the greatest CC biomass in 2017 and did not reduce corn or the subsequent soybean crop yield.

R6 Overseeding into Soybean

Soybean plant population, grain moisture, test weight, and yield were not affected by CC overseeded at R6 (Table 2.11). In an Iowa study where soybean was overseeded at R6 with rye and oat CC's, a reduction in soybean grain yield was recorded one in six years (Johnson et al., 1998).

A treatment by year interaction was observed for CC (*P* <0.0001) and weed (*P* =0.0005) biomass. In 2017, MFA 2259, winter rye, Bounty, Assist, Bounty/Dixie, Bounty/Multicut, and MFA 2249/EcoTill/PurpleTop CC's had 2510 kg ha^{-1} to 3310 kg ha^{-1} greater CC biomass than the non-treated control. Subsequently, these CC also had weed biomasses that were lesser than CC treatments that did not have significant CC biomass. In 2017, Bounty/Mihi had greater CC biomass (2510 kg ha^{-1}) than the non-seeded control, but it did not reduce weed biomass. Neither CC nor weed biomass was significantly different from the non-treated control in 2018 due to a lack of CC biomass.

A year by treatment interaction was present when evaluating corn plant population (*P*=0.0007). MFA 2249, winter rye, Assist, Bounty/Dixie, Bounty/Mihi, and MFA 2249/EcoTill/PurpleTop overseeded into soybean at R6 reduced the subsequent corn crop plant population 20,450 to 37,660 plants ha^{-1} in 2017. In 2018, corn plant population was not affected by the prior CC which was probably due to less CC growth in 2018 compared to 2017. EcoTill radish increased subsequent corn grain moisture by 20 g kg^{-1} compared to the non-treated control. Cover crop treatments had no effect on corn grain test weight. A year by treatment interaction (*P*=0.0066) was detected when evaluating subsequent corn grain yield; therefore, yield is presented separately for 2017 and 2018. MFA 2249, winter rye, Bounty/Multicut, Bounty/Mihi, and MFA 2249/EcoTill/PurpleTop reduced corn grain yield by 1800 to 3590 kg ha^{-1} in 2017 compared to the non-treated control. However, a monoculture of MFA 2249 reduced corn grain yield 3430 kg ha^{-1} in 2018. MFA 2249, winter rye, Bounty/Mihi, and MFA 2249/EcoTill/PurpleTop reduced both corn plant population and corn yield in 2017. Licht and Kaspar (2015) recommended increasing corn seeding rates by 10% following a cover crop. Johnson et al. (1998) attributed no yield reduction in subsequent corn crop when an oat CC was overseeded into soybean at R6 to winter kill of oat and limited interference with corn. Similar to our results, Johnson et al. (1998) reported at/rye and rye CC's reduced subsequent corn grain yield by 1.3 and 1.6 Mg ha^{-1}, respectively.

Bounty did not reduce soybean or subsequent corn crop plant population, moisture, test weight, or yield (Table 2.11). Bounty had one of the largest CC biomasses (3130 kg ha^{-1}) relative to other treatments in 2017 and reduced weed biomass in 2017. Assist and Bounty/Dixie varieties were also good options for overseeding a CC into soybean at R6. These varieties did not reduce soybean or subsequent corn crop moisture, test weight, or yield. However, Assist and Bounty/Dixie reduced corn plant population 20,450 to 31,200 plants ha^{-1}, respectively, but did not impact corn yield or soybean plant populations.

Termination date affects the performance of fall-established CC's (Duiker, 2014). Termination of a winter CC is essential to prevent competition with subsequent, spring-planted rotational crops. Licht and Kaspar (2015) recommend desiccating grass CC's 14 days prior to planting corn or when the CC was 25 to 30 cm, whichever comes first, and desiccating at least two days before planting soybean. In Missouri, NRCS (2014) recommends terminating a CC at or within five days after planting, but prior to cash crop emergence. Corn planting date post CC termination was not found to significantly impact soil volumetric water content, nor the weed biomass (Wells et al., 2016).

CONCLUSIONS

Cover crop establishment into V5 corn was unsuccessful for the species and blends evaluated in this research. Cover crops increased yield only once. Dixie clover increased the subsequent soybean cash crop yield one time in 2017 when overseeded into standing corn at V10. Bounty had greater levels of CC biomass compared to the non-treated control and did not reduce cash crop yield or plant population when overseeded at V10 and VT in corn or R6 soybean. Bounty/Dixie had greater levels of CC biomass compared to the non-treated control and did not reduce cash crop yields when overseeded at V10 and VT in corn and at R6 in soybean, but it did reduce subsequent corn plant population 31,200 plants ha^{-1} following soybean overseeding at R6 in 2017. Seven cultivars and blends overseeded at R6 in soybean reduced weed biomass in 2017. Cover crops did not produce as much biomass in 2018 as they did in 2017. However, excluding MFA 2249, CC's did not reduce cash crop yield in 2018. This suggests that lesser CC biomass may reduce yield loss of rotational crops caused by CC's which indicates earlier springtime termination of CC's may prevent excessive biomass accumulation and reduce the amount of CC interference on corn yield in particular.

Table 2.1. Cover crop monoculture and blend treatments overseeded into the main crops. Cover crops were overseeded into corn at V5, V9-10, and V14-VT (Abendroth et al., 2011) and soybean at R6 (Fehr and Caviness, 1977).

				Corn			Soybean
Cultivar	Type	Name	PLS	V5	V9-10	V14-V5	R6
			$kg\ ha^{-1}$				
Dixie[†]	Crimson clover	*Trifolium incarnatum* L.	9.8	Y	Y	Y	Y
Multicut	Berseem clover	*Trifolium alexandrinum* L.	9.8	Y	Y	Y	Y
Mihi	Persian clover	*Trifolium resupinatum* L.	9.8	Y	Y	Y	Y
VNS	Red clover	*Trifolium pretense* L.	9.8	Y	Y	Y	Y
MFA 2249	Wheat	*Triticum aestivum* L.	73.6	Y	Y	Y	Y
VNS	Winter rye	*Secale cereal* L.	73.6	Y	Y	Y	Y
EcoTill	Radish	*Raphanus raphanistrum* subsp. Sativus	9.8	Y	Y	Y	Y
Bayou	Kale	*Brassica oleracea* L.	9.8	Y	Y	Y	Y
Bounty	Annual ryegrass	*Lolium multiflorum* Lam.	30.7	Y	Y	Y	Y
Assist	Annual ryegrass	*Lolium multiflorum* Lam.	30.7	Y	Y	Y	Y
Bounty 60%[‡]	Annual ryegrass	*Lolium multiflorum* Lam.	18.4	Y	Y	Y	Y
+ Dixie 40%	Crimson clover	*Trifolium incarnatum* L.	3.9				
Bounty 60%	Annual ryegrass	*Lolium multiflorum* Lam.	18.4	Y	Y	Y	Y
+ Multicut 40%	Berseem clover	*Trifolium alexandrinum* L.	3.9				
Bounty 60%	Annual ryegrass	*Lolium multiflorum* Lam.	18.4	Y	Y	Y	Y
+ Mihi 40%	Persian clover	*Trifolium resupinatum* L.	3.9				
MFA 2249[§]	Wheat	*Triticum aestivum* L.	49.1	N	N	N	Y
+EcoTill	Radish	*Raphanus raphanistrum* subsp. Sativus	4.9				
+ PurpleTop	Turnip	*Brassica rapa* subsp. rapa	2.5				

[†]Abbreviations: N, treatment was not applied; PLS, pure live seed; VNS, variety not stated; Y, treatment was applied.
[‡]Sum of the monoculture seeding amount.
[§]Blend of MFA 2249, EcoTill, and PurpleTop was included in the soybean overseeding only experiment.

Table 2.2. Main and rotational crop management for cover crops overseeded into the main crop (corn) at V5 (Abendroth et al., 2011) and rotated to soybean the following year. Locations for the main crops were different in 2016 and 2017.

	Main	Rotational	Main	Rotational
Crop management	2016	2017	2017	2018
Crop	Corn	Soybean	Corn	Soybean
Hybrid or cultivar†	DKC 61-88	AG 38X6	DKC 62-97	AG 38X6
Planting date‡	9 June	15 Apr.	13 Apr.	1 May
Seeding amount (seeds ha^{-1})	79,040	395,200	79,040	419,900
Soil series§	PSL	PSL	KSL, PSL	KSL, PSL
Overseeding date	29 June	NA	5 June	NA
Row spacing (cm)	76	38	76	38
Tillage	VT 2x	NT	VT 2x	NT
Fertilizer amount (N-P-K kg ha^{-1})¶	15 Feb., 16-80-141	NA	6 Mar., 16-80-141	NA
	8 June, 220.9-0-0	NA	6 Mar., 209-0-0 + nitrapyrin at 560 g ai ha^{-1}	NA
Crop protection				
Timing, date	Burndown, 20 May Glyphosate at 1.5 kg ai ha^{-1} +dimethenamid-*P* at 219 g ai ha^{-1} +safflufenacil at 25 g ai ha^{-1} +MSO at 1% v/v +DAS at 20 g/L	Burndown, 14 Apr. Saflufenacil at 25 g ai ha^{-1} + MSO at 1% v/v +32% UAN at 2.3 L ha^{-1} +glyphosate at 1 kg ai ha^{-1}	Burndown, 11 Apr. Saflufenacil at 50 g ai ha^{-1} +glyphosate at 1.1 kg ai ha^{-1}	Burndown, 26 Apr. Glyphosate at 1.5 kg ai ha^{-1} +safflufenacil at 25 g ai ha^{-1} +28% UAN at 2.4 L ha^{-1} + MSO at 1% v/v
Timing, date	POST, 24 June Mesotrione at 116 g ai ha^{-1} +glyphosate at 1.2 kg ae ha^{-1} +*S*-metolachlor at 1.2 kg ai ha^{-1} +NIS at 0.25% v/v +DAS at 20 g/L	POST, 12 May Glyphosate at 1.5 kg ai ha^{-1} +*S*-metolachlor at 1.5 kg ai ha^{-1} + fomesafen at 332 g ai ha^{-1} +DAS at 20 g/L +NIS at 0.25% v/v +cloransulam-methyl at 18 g ai ha^{-1}	POST, 19 Apr. Pyroxasulfone at 240 g ai ha^{-1} +atrazine at 1.7 kg ai ha^{-1} +glyphosate1.1 kg ai ha^{-1} +28% UAN at 2.4 L ha^{-1}	PRE, 2 May *S*-metolachlor at 2.2 kg ai ha^{-1} +metribuzin at 0.5 kg ai ha^{-1}
				POST, 17 May Cloransulam-methyl at 39 g ai ha^{-1} +Glyphosate at 1.5 kg ai ha^{-1} +*S*-metolachlor at 1.41 kg ai ha^{-1} +fomesafen at 309 g ai ha^{-1}

Table 2.2 Continued

†Abbreviations: AG, Asgrow; DAS, diammonium sulfate; DKC, DeKalb; KSL, Kilwinning silt loam; NT, no-till; MSO, methylated seed oil; NIS, non-ionic surfactant; PRE, pre-emerge; POST, post-emerge; PSL, Putnam silt loam; UAN, urea ammonium nitrate; VT, vertical till.

‡Planting, John Deere 7000 (corn), 7200 (soybean), Moline, IL; Vertical tillage, Case IH 335 VT, Racine, WI. Anhydrous ammonia application, no-till coulter, mole knife, Yetter Manufacturing, Inc., Colchester, IL.

§Kilwinning silt loam, Fine, smectitic, mesic Vertic Epiaqualfs; Putnam silt loam, Fine, smectitic, mesic Vertic Albaqualfs

¶Atrazine, 1-Chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine; cloransulam-methyl, N-(2-carbmethoxy-6-chlorophenyl)-5-ethoxy-7-fluoro(1,2,4)triazolo-[1,5-c]pyrimidine-2-sulfonamide;dimethenamid-*P*, (S)-(2-chloro-N-[(1-methyl-2-methoxy)ethyl]-N-(2,4-dimethyl-thien-3-yl)-acetamide; fomesafen, 5-(2-chloro-4-(trifluoromethyl)phenoxy)-N-(methylsulfonyl)-2-nitro-glyphosate, N-(phosphonomethyl)glycine; mesotrione, 2-[4-(methylsulfonyl)-2-nitrobenzoyl]-1,3-cyclohexanedione; Nitrapyrin, 2-chloro-6-(trichloromethyl); pyroxsulfone, 3-[[[5-(difluoromethoxy)-1-methyl-3-(trifluoromethyl)- 1H-pyrazol-4-yl]methyl]sulfonyl]-4,5-dihydro-5,5-dimethylisoxazole; Saflufenacil, N'-[2-chloro-4-fluoro-5-(3-methyl-2,6-dioxo-4-(trifluoromethyl)-3, 6-dihydro-1(2H)-pyrimidinyl)benzoyl]-N-isopropyl-N-methylsulfamid; *S*-metolachlor, (S)-2-chloro-N-(2-ethyl-6-methyl-phenyl)-N-(2-methoxy-1-metnyl-ethyl)acetamide

Table 2.3. Main and rotational crop management for cover crops overseeded into the main crop (corn) at V10 (Abendroth et al., 2011) and rotated to soybean the following year. Locations for the main crops were different in 2016 and 2017.

	Main	Rotational	Main	Rotational
Crop management	2016	2017	2017	2018
Crop	Corn	Soybean	Corn	Soybean
Hybrid or cultivar†	DKC 63-33	AG 38X6	DKC 62-97	AG 38X6
Planting date‡	7 May	16 Apr.	13 Apr.	1 May
Seeding amount (seeds ha^{-1})§	76,570	395,200	79,040	419,900
Soil series‡	PSL	PSL	KSL, PSL	KSL, PSL
Overseeding date	29 Jun	NA	12 Jun.	NA
Row spacing (cm)	76	38	76	38
Tillage	NT	NT	VT 2x	NA
Fertilizer date, amount (N-P-K kg ha^{-1})	15 Feb., 16-80-141		6 Mar., 16-80-141	NA
	13 Apr., 221-0-0		6 Mar., 209-0-0 +nitrapyrin at 560 g ai ha^{-1}	
Crop protection				
Timing, date	Burndown, 14 Apr. Glyphosate at 1.5 kg ai ha^{-1} +DAS at 20 g/L	Burndown, 14 Apr. Saflufenacil at 25 g ai ha^{-1} +MSO at 1% v/v + 32% UAN at 2.3 L ha^{-1} +glyphosate at1 kg ai ha^{-1}	Burndown, 11 Apr. Saflufenacil at 50 g ai ha^{-1} +glyphosate at 1.1 kg ai ha^{-1}	Burndown, 26 Apr. Glyphosate at 1.5 kg ai ha^{-1} +safflufenacil at 25 g ai ha^{-1} +28% UAN at 2.4 L ha^{-1} +MSO at 1% v/v
Timing, date	Burndown, 18 Apr. Atrazine at 2.2 kg ai ha^{-1} +*S*-metolachlor at 1.7 kg ai ha^{-1} +glyphosate at1.1 kg ai ha^{-1} +32% UAN at 2.3 L ha^{-1} +saflufenacil at 50 g ai ha^{-1}	POST, 12 May Glyphosate at 1.5 kg ai ha^{-1} +*S*-metolachlor at 1.5 kg ai ha^{-1} +fomesafen at 332 g ai ha^{-1} +DAS at 20 g/L +NIS at 0.25% v/v +cloransulam-methyl at 17.6 g ai ha^{-1}	POST, 19 Apr. Pyroxasulfone at 240 g ai ha^{-1} +atrazine at 1.7 kg ai ha^{-1} +glyphosate at 1.1 kg ai ha^{-1} + 28% UAN at 2.3 L ha^{-1}	PRE, 2 May *S*-metolachlor at 2.2 kg ai ha^{-1} +metribuzin at 0.52 kg ai ha^{-1}
Timing, date	POST, 18 Jun. Mesotrione at 105 g ai ha^{-1} +glyphosate at 1.5 kg ai ha^{-1} +DAS at 20 g/L			POST, 17 May Cloransulam-methyl at 39 g ai ha^{-1} +Glyphosate at 1.5 kg ai ha^{-1} +*S*-metolachlor at 1.4 kg ai ha^{-1} + fomesafen at 309 g ai ha^{-1}

Table 2.3.Continued

[†]Abbreviations: AG, Asgrow; DAS, diammonium sulfate; DKC, DeKalb; KSL, Kilwinning silt loam; NT, no-till; MSO, methylated seed oil; NIS, non-ionic surfactant; PRE, pre-emerge; POST, post-emerge; PSL, Putnam silt loam; UAN, urea ammonium nitrate; VT, vertical till.
[‡]Planting, John Deere 7000 (corn), 7200 (soybean), Moline, IL; Vertical tillage, Case IH 335 VT, Racine, WI. Anhydrous ammonia application, no-till coulter, mole knife, Yetter Manufacturing, Inc., Colchester, IL.
[§]Kilwinning silt loam, Fine, smectitic, mesic Vertic Epiaqualfs; Putnam silt loam, Fine, smectitic, mesic Vertic Albaqualfs

Table 2.4. Main and rotational crop management for cover crops overseeded the main crop (corn) at VT (Abendroth et al., 2011) and rotated to soybean the following year. Locations for the main crops were different in 2016 and 2017.

	Main	Rotational	Main	Rotational
Crop management	2016	2017	2017	2018
Crop	Corn	Soybean	Corn	Soybean
Hybrid or cultivar†	DKC 62-08	AG 38X6	DKC 62-97	AG 38X6
Planting date‡	16 Apr.	16 Apr.	13 Apr.	1 May
Seeding amount (seeds ha^{-1})§	76,570	395,200	79,040	419,900
Soil series	KSL	KSL	KSL, PSL	KSL, PSL
Overseeding date	29 June	NA	5 Jul.	NA
Row spacing (cm)	76	38	76	38
Tillage	VT 2X	NT	VT 2x	
Fertilizer date, amount	15 Feb.		6 Mar.	NA
(N-P-K kg ha^{-1})	16-80-141		16-80-141	
	5 Mar.		6 Mar.	NA
	209-0-0		209-0-0 + nitrapyrin at 560 g ai ha^{-1}	
Crop protection				
Timing, date	PRE, 18 Apr.	Burndown, 14 Apr.	Burndown, 11 Apr.	Burndown, 26 Apr.
	Glyphosate1.1 kg ai ha^{-1} +*S*-metolachlor at 1.8 kg ai ha^{-1} +32% UAN at 2.3 L ha^{-1}	Saflufenacil at 25 g ai ha^{-1} +MSO‡ at 1% v/v +32% UAN at 2.3 L ha^{-1} +glyphosate at 1 kg ai ha^{-1}	Saflufenacil at 50 g ai ha^{-1} +glyphosate at 1.1 kg ai ha^{-1}	Glyphosate at 1.5 kg ai ha^{-1} +safflufenacil at 25 g ai ha^{-1} +28% UAN at 2.4 L ha^{-1} + MSO at 1% v/v
Timing, date	POST, 23 May	POST, 12 May	POST, 19 Apr.	PRE, 2 May
	Atrazine at 2.2 kg ai ha^{-1} + pyroxasulfone at 119 g ai ha^{-1} + glyphosate at 1.5 kg ai ha^{-1} + DAS at 20 g L^{-1}	Glyphosate at 1.5 kg ai ha^{-1} +*S*-metolachlor at 1.5 kg ai ha^{-1} +fomesafen at 332 g ai ha^{-1} +DAS at 20 g L^{-1} +NIS at 0.25% v/v +cloransulam-methyl at 18 g ai ha^{-1}	Pyroxasulfone at 240 g ai ha^{-1} +atrazine at 1.7 kg ai ha^{-1} +glyphosate at 1.1 kg ai ha^{-1} +28% UAN at 2.3 L ha^{-1}	*S*-metolachlor at 2.2 kg ai ha^{-1} +metribuzin at 0.52 kg ai ha^{-1}
Timing, date				POST, 17 May
				Cloransulam-methyl at 39 g ai ha^{-1} +Glyphosate at 1.5 kg ai ha^{-1} +*S*-metolachlor at 1.4 kg ai ha^{-1} +fomesafen at 309 g ai ha^{-1}

Table 2.4. Continued

†Abbreviations: AG, Asgrow; DAS, diammonium sulfate; DKC, DeKalb; KSL, Kilwinning silt loam; NT, no-till; MSO, methylated seed oil; NIS, non-ionic surfactant; PRE, pre-emerge; POST, post-emerge; PSL, Putnam silt loam; UAN, urea ammonium nitrate; VT, vertical till.

‡Planting, John Deere 7000 (corn), 7200 (soybean), Moline, IL; Vertical tillage, Case IH 335 VT, Racine, WI. Anhydrous ammonia application, no-till coulter, mole knife, Yetter Manufacturing, Inc., Colchester, IL.

§Kilwinning silt loam, Fine, smectitic, mesic Vertic Epiaqualfs; Putnam silt loam, Fine, smectitic, mesic Vertic Albaqualfs

Table 2.5. Main and rotational crop management for cover crops overseeded into the main crop (soybean) at R6 (Fehr and Caviness, 1977) and rotated to corn the following year. Locations for the main crops were different in 2016 and 2017

	Main	Rotational	Main	Rotational
Crop management	2016	2017	2017	2018
Crop	Soybean	Corn	Soybean	Corn
Hybrid or cultivar†	NK 39-U2	DKC 62-08	AG 38X6	DKC 64-09
Planting date‡	10 Jun	17 Apr.	16 Apr.	19 Apr.
Seeding amount (seeds ha^{-1})§	432,250	73,700	395,200	82,750
Soil series	PSL	PSL	KSL, PSL	KSL, PSL
Overseeding date	12 Sep.	NA	6 Sep.	NA
Row spacing (cm)	38	76	38	76
Tillage	VT 2x	NT	NT	NT
Fertilizer date, amount (N-P-K-S-Zn kg ha^{-1})	18 Apr., 50-110-123-118-2		6 Mar., 16-80-141	17 Nov., 180-0-0 11 Apr., 13-65-11.5
Lime: date, ENM and amount (kg ha^{-1})	15 Jan. 2016 424 and 2,454			
Crop protection				
Timing, date¶	POST, 21 Jul. Glyphosate at 1.5 kg ai ha^{-1} +acifluorfen at 491 g ai ha^{-1} +DAS at 20 g/L	Burndown, 10 Apr. Glyphosate at 1.5 kg ai ha^{-1} +saflufenacil at 90 g ai ha^{-1} +dimethenamid-*P* at 789 g ai ha^{-1} +MSO at 2.3 L ha^{-1} +32% UAN at 2.3 L ha^{-1}	PRE, 10 Apr. Glyphosate at 1.5 kg ai ha^{-1} +saflufenacil at 90 g ai ha^{-1} +dimethenamid-*P* at 789 g ai ha^{-1} +MSO at 2.3 L ha^{-1} +32% UAN at 2.3 L ha^{-1}	PRE, 24 Apr. Glyphosate at 1.5 kg ai ha^{-1} +Saflufenacil at 25 g ai ha^{-1} +MSO at 2.3 L ha^{-1} +32% UAN at 2.3 L ha^{-1}
Timing, date		PRE, 18 Apr. Acetochlor at 1.7 kg ai ha^{-1} +atrazine at 1.7 kg ai ha^{-1} +glyphosate at1.1 kg ai ha^{-1} +32% UAN at 2.3 L ha^{-1}	POST, 15 May Glyphosate at 1.5 kg ai ha^{-1} +*S*-metolachlor at 3.04 kg ai ha^{-1} +fomesafen at 667 g ai ha^{-1} +DAS at 20 g/L	POST, 4 May Glyphosate at 632 g ai ha^{-1} +Acetochlor at 1.7 kg ai ha^{-1} +atrazine at 2.2 kg ai ha^{-1} +mesotrione at 210 g ai ha^{-1}
Timing, date			+0.25% V/V NIS +cloransulam-methyl 18 g ai ha^{-1}	
				POST, 6 Jun. Glyphosate at 1.5 kg ai ha^{-1} +topramezone at 12 g ai ha^{-1} +MSO at 2.3 L ha^{-1} +DAS at 20 g/L
				POST, 12 Jul. Fluxapyroxad at 49 g ai ha^{-1} +pyraclostrobin at 97 g ai ha^{-1} +MSO at 575 mL ha^{-1}

Table 2.5 Continued

†Abbreviations: AG, Asgrow; DAS, diammonium sulfate; DKC, DeKalb; KSL, Kilwinning silt loam; NT, no-till; MSO, methylated seed oil; NIS, non-ionic surfactant; PRE, pre-emerge; POST, post-emerge; PSL, Putnam silt loam; UAN, urea ammonium nitrate; VT, vertical till.
‡Planting, John Deere 7000 (corn), 7200 (soybean), Moline, IL; Vertical tillage, Case IH 335 VT, Racine, WI. Anhydrous ammonia application, no-till coulter, mole knife, Yetter Manufacturing, Inc., Colchester, IL.
§Kilwinning silt loam, Fine, smectitic, mesic Vertic Epiaqualfs; Putnam silt loam, Fine, smectitic, mesic Vertic Albaqualfs
¶Acifluorfen, 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitro-; fluxapyroxad, 1H-Pyrazole-4-carboxamide, 3-(difluoromethyl)-1-methyl-N-(3',4',5'-trifluoro[1,1'-biphenyl]-2-yl)-; pyraclostrobin, (carbamic acid, [2-[[[1-(4-chlorophenyl)-1H-pyrazol-3-yl]oxy]methyl]phenyl]methoxy-, methyl ester); topramezone, [3-(4,5-dihydro-3-isoxazolyl)-2-m3thyl-4-(methylsulfonyl) phenyl] (5-hydroxy-1-methyl-1H-pyrazol-4-yl) methanone.

Table 2.6. Soil test values in the spring of each year for experiments started in 2016 and 2017.

Year	Sample timing	pHs[‡]	NA	CEC	OM	Bray-I P	Exchangeable Ca	Exchangeable Mg	Exchangeable K
			cmol kg^{-1}		g kg^{-1}	kg ha^{-1}			
Overseeded corn at V5									
2016	Spring 2016	6.2 ± 0.1[†]	0.88 ± 0.25	10 ± 0	26 ± 2	91 ± 9	3363 ± 40	295 ± 7	347 ± 10
	Spring 2017	6.3 ± 0.2	1.25 ± 0.29	14 ± 2	23 ± 1	45 ± 5	4948 ± 660	350 ± 45	262 ± 16
2017	Spring 2017	6.2 ± 0.2	1.50 ± 0.41	22 ± 2	24 ± 1	33 ± 8	7547 ± 886	770 ± 127	289 ± 31
	Spring 2018	6.2 ± 0.2	1.38 ± 0.48	18 ± 1	29 ± 1	36 ± 7	6357 ± 325	636 ± 85	310 ± 18
Overseeded corn at V10									
2016	Spring 2016	5.0 ± 0.0	3.63 ± 0.25	11 ± 1	27 ± 1	148 ± 14	2284 ± 134	332 ± 22	630 ± 13
	Spring 2017	5.6 ± 0.1	2.50 ± 0.41	15 ± 1	22 ± 1	63 ± 18	4488 ± 491	448 ± 18	327 ± 45
2017	Spring 2017	6.3 ± 0.3	1.38 ±0.75	20 ± 3	24 ± 2	29 ± 5	6898 ± 746	706 ± 157	239 ± 15
	Spring 2018	6.3 ± 0.1	1.13 ± 0.63	18 ± 2	29 ± 1	30 ± 3	6442 ± 262	642 ± 84	305 ±10
Overseeded corn at VT									
2016	Spring 2016	6.4 ± 0.0	0.50 ± 0	13 ± 1	46 ± 6	186 ± 20	4597 ± 292	438 ± 35	647 ± 51
	Spring 2017	6.0 ± 0.2	2.17 ± 0.58	16 ± 2	29 ± 2	46 ± 5	5146 ± 580	458 ± 70	259 ± 12
2017	Spring 2017	6.5 ± 0.1	0.88 ± 0.25	21 ± 2	23 ± 1	31 ± 7	7778 ± 878	779 ± 125	232 ± 16
	Spring 2018	6.5 ± 0.1	0.63 ± 0.25	19 ±1	29 ± 1	33 ± 4	6937 ± 534	674 ± 84	306 ± 19
Overseeded soybean at R6									
2016	Spring 2016	5.6 ± 0.1	2.63 ± 0.48	12 ± 1	32 ± 2	7 ± 1	3449 ± 172	353 ± 18	199 ± 17
	Spring 2017	6.1 ± 0.1	1.50 ± 0	15 ± 1	24 ± 2	21 ± 2	5204 ± 462	385 ± 49	161 ± 19
2017	Spring 2017	6.7 ± 0.2	0.38 ± 0.48	16 ± 2	26 ± 2	68 ± 16	6104 ± 701	409 ± 84	322 ± 65
	Spring 2018	6.9 ± 0.1	0.00 ± 0	15 ± 1	28 ± 2	68 ± 19	5786 ± 576	401 ± 46	344 ± 56

[†]Mean ± standard deviation.

[‡]NA = neutralizable acidity; pH_s = pH (0.01 M $CaCl_2$).

Table 2.7. Monthly and cumulative precipitation data for individual years and 18 year average for the experiment from 2000-2018.

Year	Monthly Rainfall[†]												Cumulative rainfall[‡]
	--- cm ---												
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	
2000	1.1	7.2	4.4	5.3	6.4	19.3	5.7	10.0	7.7	6.1	4.8	0.9	78.7
2001	6.5	11.1	6.0	7.1	21.0	12.8	6.9	6.7	12.5	9.3	2.2	2.4	104.3
2002	1.7	5.3	2.4	15.9	27.9	5.0	8.8	6.8	2.6	7.5	0.6	1.5	85.9
2003	0.7	2.2	3.2	16.0	9.3	8.2	8.3	15.7	15.9	5.3	7.7	10.3	102.8
2004	0.9	1.1	7.4	7.8	12.0	8.4	6.7	20.6	2.5	16.6	7.2	2.4	93.5
2005	7.0	5.5	3.1	6.9	5.6	14.5	5.7	8.2	7.0	8.5	3.4	2.3	77.4
2006	5.4	0.2	7.2	6.2	6.5	9.0	8.2	17.2	1.7	6.0	5.4	6.4	79.3
2007	2.1	6.8	12.4	10.6	14.1	7.2	4.7	9.2	6.8	8.6	2.0	4.8	89.3
2008	2.0	9.9	7.8	11.6	11.2	25.7	27.2	10.8	20.1	7.7	3.9	5.9	143.8
2009	0.0	4.2	13.2	12.1	17.0	14.5	10.8	16.7	8.6	22.5	6.5	4.4	130.5
2010	4.3	2.3	5.3	14.6	16.0	16.3	32.6	4.5	24.2	2.1	3.6	2.5	128.2
2011	0.8	3.0	3.5	11.0	13.4	19.2	5.0	5.8	1.5	3.7	14.0	7.5	88.3
2012	1.1	5.4	5.9	11.9	6.3	5.7	1.9	7.6	9.0	8.3	3.7	5.3	72.1
2013	4.7	5.8	5.4	19.4	26.1	9.2	4.8	0.0	7.9	12.1	3.2	1.8	100.3
2014	0.9	2.4	2.2	10.6	2.6	22.5	5.1	16.4	17.5	11.1	2.6	2.7	96.5
2015	2.5	2.0	2.8	7.1	11.9	32.2	25.7	10.6	3.5	5.2	14.6	11.0	129.2
2016	1.7	2.1	4.8	6.7	10.8	3.8	11.6	20.7	4.5	5.2	3.9	3.0	78.7
2017	2.3	0.9	8.1	15.6	6.1	16.0	2.3	14.4	0.6	17.5	3.7	0.3	87.8
2018	2.7	9.0	8.1	1.2	6.1	5.7	3.3	16.4	5.7	15.0	NA	NA	73.3
Mean	2.5	4.5	6.0	10.4	12.1	13.4	9.8	11.5	8.4	9.4	5.2	4.2	96.8

[†]Abbreviations: NA, not available at the time of printing.

[‡]Cumulative rainfall calculation for 2018 only includes rainfall from Jan. to Oct.

Table 2.8. Plant population, moisture, test weight, and yield for corn overseeded with a cover crop at V5 and subsequent soybean crop response, cover crop, and weed dry weight assessed between spring 2016 and fall 2018.

	Corn				Biomass		Soybean			
Cultivar	Plant population	Moisture	Test weight	Yield	Cover Crop	Weed[†]	Plant population	Moisture	Test weight	Yield
	plants ha^{-1}	g kg^{-1}	kg hL^{-1}	kg ha^{-1}	kg ha^{-1}		plants ha^{-1}	g kg^{-1}	kg hL^{-1}	kg ha^{-1}
Dixie	41060	160	75	11430	0	1750	441130	130	72	3630
Multicut	39920	150	77	11650	0	1430	448310	130	72	3650
Mihi	39920	160	76	11410	0	1380	407060	120	72	3570
Red clover	38230	160	75	10820	0	1440	420510	130	72	3490
MFA 2249	39360	160	76	11530	0	1400	410650	130	72	3560
Winter rye	38510	180	75	11040	0	2240	439340	130	72	3480
EcoTill	40060	170	76	11300	0	1500	425890	130	72	3510
Bayou	39920	170	77	11310	0	1540	423200	130	74	3480
Bounty	40490	160	75	11650	80	1990	431270	130	72	3600
Assist	39500	160	75	11360	0	1770	406160	120	72	3660
Bounty 60% + Dixie 40%	39500	160	77	11620	150	1530	452790	130	72	3650
Bounty 60% + Multicut 40%	38790	180	76	10950	110	1320	380160	130	74	3580
Bounty 60% + Mihi 40%	40770	170	76	11310	20	980	404370	130	72	3540
Nontreated	37800	160	76	11120	0	1980	416030	120	74	3560
LSD (*P*=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[†]Weed species present: Common chickweed [*Stellaria media* (L.) Vill.], dandelion (*Taraxacum officinale* F.H. Wigg.), field pennycress (*Thlaspi arvense* L.), henbit (*Lamium amplexicaule* L.), marestail [*Conyza canadensis* (L.) Cronquist] purple deadnettle (*Lamium purpureum* L.), shepherd's purse [*Capsella bursa-pastoris* (L.) Medik].
[‡]Least significant difference at *P* = 0.05. NS = not significant.

Table 2.9. Plant population, moisture, test weight, and yield for corn overseeded with a cover crop at V10 and subsequent soybean crop response, cover crop, and weed dry weight assessed between spring 2016 and fall 2018.

	Corn				Biomass			Soybean				
	Plant		Test		Cover crop			Plant		Test	Yield	
Cultivar	population	Moisture	weight	Yield	2017	2018	Weed[†]	population	Moisture	weight	2017	2018
	plants ha^{-1}	g kg^{-1}	kg hL^{-1}	kg ha^{-1}	------- kg ha^{-1} -------			plants ha^{-1}	g kg^{-1}	kg hL^{-1}	-- kg ha^{-1} --	
Dixie	48570	190	77	13380	0	0	680	71	71	71	5520	2680
Multicut	45040	180	77	13380	0	0	1050	74	74	71	4830	2960
Mihi	47190	190	77	13350	0	0	710	72	72	70	4880	2890
Red clover	47800	180	77	13470	0	0	690	71	71	71	5060	2720
MFA 2249	51340	180	77	13380	390	0	580	72	72	70	5100	2860
Winter rye	48730	180	77	13660	50	170	550	73	73	70	4770	2830
EcoTill	47030	180	77	13720	0	0	640	71	71	71	5030	2670
Bayou	50880	180	77	13680	0	0	860	71	71	71	5140	2790
Bounty	46420	170	77	13860	630	40	660	72	72	70	4880	2870
Assist	47340	170	77	13320	210	0	1020	72	72	71	5150	2760
Bounty 60% + Dixie 40%	47650	170	77	13850	920	0	540	72	72	72	5010	2820
Bounty 60% + Multicut 40%	45350	170	77	13720	480	0	880	71	71	72	4940	2800
Bounty 60% + Mihi 40%	47190	170	77	13750	530	0	710	73	73	71	5030	2920
Nontreated	44580	170	77	13190	0	0	950	72	72	71	5030	2760
LSD (*P*=0.05)	NS	NS	NS	NS	--- 340 ---		NS	NS	NS	NS	---- 280 ----	

[†]Weed species present: Common chickweed [*Stellaria media* (L.) Vill.], dandelion (*Taraxacum officinale* F.H. Wigg.), field pennycress (*Thlaspi arvense* L.), henbit (*Lamium amplexicaule* L.), marestail [*Conyza canadensis* (L.) Cronquist] purple deadnettle (*Lamium purpureum* L.), shepherd's purse [*Capsella bursa-pastoris* (L.) Medik].

[‡]Least significant difference at *P* = 0.05. NS = not significant.

Table 2.10. Plant population, moisture, test weight, and yield for corn overseeded with a cover crop at VT and subsequent soybean crop response, cover crop, and weed dry weight assessed between spring 2016 and fall 2018.

	Corn					Biomass			Soybean			
	Plant		Test	Yield		Cover crop			Plant		Test	
Cultivar	population	Moisture	weight	2016	2017	2017	2018	Weed†	population	Moisture	weight	Yield
	plants ha^{-1}	g kg^{-1}	kg hL^{-1}	--- kg ha^{-1} ---		--- kg ha^{-1}---		kg ha^{-1}	plants ha^{-1}	g kg^{-1}	kg hL^{-1}	kg ha^{-1}
Dixie	42990	130	60	13910	12930	0	0	1740	356600	120	55	3510
Multicut	43150	130	60	13860	12910	0	0	1790	315610	110	55	3670
Mihi	44990	130	60	13420	13010	0	0	2050	291830	120	54	3720
Red clover	43990	130	60	14000	12260	0	0	2580	384260	110	55	3700
MFA 2249	43990	130	60	14090	12400	0	0	2070	343270	120	54	3680
Winter rye	43990	130	60	13560	13560	0	0	1810	335080	110	54	3630
EcoTill	44990	130	60	14210	12610	0	0	2140	302290	120	55	3700
Bayou	41320	130	60	13740	13310	0	0	2080	328930	120	55	3610
Bounty	41320	130	60	13530	12570	480	0	1880	325850	130	54	3460
Assist	42990	130	60	13730	13290	20	0	1480	356600	110	55	3600
Bounty 60% + Dixie 40%	43820	140	60	13410	13120	160	0	1610	32160	120	56	3720
Bounty 60% + Multicut 40%	42990	130	60	13600	13240	110	0	2100	351470	120	56	3670
Bounty 60% + Mihi 40%	41320	130	60	13840	13100	260	0	2340	380160	120	55	3690
Nontreated	45320	120	60	14080	13020	0	0	2010	357620	120	55	3600
LSD (*P*=0.05)	2460	NS	NS	------ 680 ------		----160 ----		NS	NS	NS	NS	NS

†Weed species present: Common chickweed [*Stellaria media* (L.) Vill.], dandelion (*Taraxacum officinale* F.H. Wigg.), field pennycress (*Thlaspi arvense* L.), henbit (*Lamium amplexicaule* L.), marestail [*Conyza canadensis* (L.) Cronquist] purple deadnettle (*Lamium purpureum* L.), shepherd's purse [*Capsella bursa-pastoris* (L.) Medik].
‡Least significant difference at *P* = 0.05. NS = not significant.

Table 2.11. Plant population, moisture, test weight, and yield for soybean overseeded with a cover crop at R6 and subsequent corn crop response, cover crop, and weed dry weight assessed between spring 2016 and fall 2018.

	Soybean				Biomass				Corn					
					Cover crop		Weed[†]		Plant population				Yield	
Cultivar	Plant population	Moisture	Test weight	Yield	2017	2018	2017	2018	2017	2018	Moisture	Test weight	2017	2018
	plants ha^{-1}	g kg^{-1}	kg hL^{-1}	kg ha^{-1}	----------- kg ha^{-1} -----------				plants ha^{-1}		g kg^{-1}	kg hL^{-1}	---- kg ha^{-1} ----	
Dixie	391820	120	75	4100	10	0	350	90	90380	81810	160	76	14740	5990
Multicut	420510	120	75	3890	0	0	260	20	83920	80730	170	76	13550	5820
Mihi	406160	120	75	4010	0	0	250	20	91450	85040	170	77	13900	6480
Red clover	385540	120	75	3840	0	0	130	30	72090	83960	160	76	13910	5870
MFA 2249	380160	120	75	4020	3310	160	0	90	50570	82880	170	76	10230	3290
Winter rye	364020	120	75	4140	2730	100	0	0	54870	90420	180	76	11720	5930
EcoTill	416920	120	75	4090	570	0	260	10	86074	85040	190	76	13580	6030
Bayou	408850	120	75	4080	0	0	210	0	88230	83960	180	76	13870	6190
Bounty	395400	120	75	4030	3130	420	0	0	74240	86110	160	76	14050	6460
Assist	362230	120	75	4100	2680	600	0	0	67780	90420	160	76	12660	6130
Bounty 60% + Dixie 40%	404370	120	75	4050	2960	120	0	90	57030	77500	170	76	13060	6330
Bounty 60% + Multicut 40%	390030	110	75	3930	2750	240	0	0	76390	89340	180	80	11950	6450
Bounty 60% + Mihi 40%	415130	120	75	3970	2510	550	70	130	59180	85035	170	77	11950	6220
Nontreated	415130	120	75	4070	0	0	50	0	88230	82880	170	77	13820	6720
MFA 2249 + EcoTill + PurpleTop	377470	120	76	3970	3020	150	10	10	61330	80730	180	76	12020	6640
LSD (*P*=0.05)	NS	NS	NS	NS	---- 660 ----		---- 140 ----		---- 16910 ----		17	NS	------- 1640 -------	

[†]Weed species present: Common chickweed [*Stellaria media* (L.) Vill.], dandelion (*Taraxacum officinale* F.H. Wigg.), field pennycress (*Thlaspi arvense* L.), henbit (*Lamium amplexicaule* L.), marestail [*Conyza canadensis* (L.) Cronquist] purple deadnettle (*Lamium purpureum* L.), shepherd's purse [*Capsella bursa-pastoris* (L.) Medik].

[‡]Least significant difference at *P* = 0.05. NS = not significant.

REFERENCES

Abdin, O.A., B.E. Coulman, D.C. Cloutier, M.A. Faris, and D.L. Smith. 1997. Establishment, development and yield of forage legumes and grasses as cover crops in grain corn in eastern Canada. J. Agron. Crop Sci. 179:19-27. doi: 10.1111/j.1439-037X.1997.tb01143.x.

Abendroth, L.J., R.W. Elmore, M.J. Boyer, and S.K. Marlay. 2011. Corn growth and development. PMR 1009. Iowa State Univ. Ext., Ames, Iowa. pp. 1-50.

Barnes, J.P., and A.R. Putnam. 1983. Rye residues contribute weed suppression in no-tillage cropping systems. J. Chem. Ecol. 9:1045-1057. doi: 10.1007/BF00982210.

Baskin, C.C., and J.M. Baskin. 1988. Germination ecophysiology of herbaceous plant species in a temperate region. Am. J. Bot. 75:286-305. doi: 10.2307/2443896

BASF Corporation. 2017a. Sharpen® powered by Kixor® herbicide label. BASF Corporation, Research Triangle Park, North Carolina. pp. 1-31.

BASF Corporation. 2017b. Zidua herbicide label. BASF Corporation, Research Triangle Park, North Carolina. pp. 1-20.

BASF Corporation. 2018. Verdict® powered by Kixor® herbicide label. BASF Corporation, Research Triangle Park, North Carolina. pp. 1-21.

Bastiaans, L., R. Paolini, and D.T. Baumann. 2002. Integrated Crop Management: Opportunities and limitations for prevention of weed problems. http://proxy.mul.missouri.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=edsnar&AN=edsnar.oai.library.wur.nl.wurpubs.122608&site=eds-live&scope=site> (accessed 26 Jun. 2018).

Baumann, D.T., L. Bastiaans, and M.J. Kropff. 2001. Competition and crop performance in a leek–celery intercropping system. Crop Sci. 41:764-774. doi:10.2135/cropsci2001.413764x

Belfry, K.D., and L.L. Van Erd. 2016. Establishment and impact of cover crops intersown into corn. Crop Sci. 56:1245-1256. doi: 10.2135/cropsci2015.06.0351

Bertin, C., X. Yang, and L.A. Weston. 2003. The role of root exudates and allelochemicals in the rhizosphere. Plant and Soil. 256:67-83. doi: 10.1023/A:1026290508166

Bowman, G., C. Shirley, and C. Cramer. 2007. Managing cover crops profitably. 3rd ed. Sustainable Agric. Network Handb. Ser. Book 9. Sustainable Agric. Network, Natl. Agric. Library, Beltsville, Maryland.

Brandsæter, L.O., and J. Netland. 1999. Winter annual legumes for use as cover crops in row crops in northern regions 39:1369-1379. doi: 10.2135/cropsci1999.3951369x.

Campiglia, E.R., and E.R. Mancinelli. 2015. Cover crops and mulches incluence weed management and weed flora composition in strip-tilled tomato (*Solanum lycopersicum*). Weed Res. 55:416-425. doi: 10.1111/wre.12156

Curell, C. 2012. Overseeding cover crops, Michigan State University Extension, East Lansing, MI. pp. 1.

Curran, W.S., R.J. Hoover, S.B. Mirsky, G.W. Roth, M.R. Ryan, V.J. Ackroyd, J.M. Wallace, M.A. Dempsey, and C.J. Pelzer. 2018. Evaluation of cover crops drill interseeded across the Mid-Atlantic region. Agron. J. 110:435-443. doi:10.2134/agronj2017.07.0395 den Hollander, N.G., L. Bastiaans, and M.J. Kropff. 2007. Clover as a cover crop for weed suppression in an intercropping design: II. Competitive ability of several clover species. European J. of Agron. 26:104-112. doi: 10.1016/j.eja.2006.08.005.

Duiker, S.W. 2014. Establishment and termination dates affect fall-established cover crops. Agron. J. 106:670-678. doi: 10.2134/agronj2013.0246.

Fehr, W.R., and C.E. Caviness. 1977. Stages of soybean development. Ext. Pub. 80. Iowa State Univ. Ext., Ames, Iowa. pp. 3-13.

Frye, W.W., R.L. Blevins, M.S. Smith, S.J. Corak, and J.J. Varco. 1988. Role of annual legume cover crops in efficient use of water and nitrogen. ASA Special Pub. Cropping Strategies for Efficient Use of Water and Nitrogen. 51: 129-154. doi:10.2134/asaspecpub51.c8

Gummerson, R.J. 1986. The effect of constant temperatures and osmotic potentials on the germination of sugar beet. J. Exp Bot. 37:729-741. doi: 10.1093/jxb/37.6.729

Johnson, T.J., T.C. Kaspar, K.A. Kohler, S.J. Corak, and S.D. Logsdon. 1998. Oat and rye overseed into soybean as fall cover crops in the upper midwest. J. Soil Water Conserv. 53:276-279.

Kunz, C., D.J. Sturm, D. Varnholt, F. Walker, and R. Gerhards. 2016. Allelopathic effects and weed suppressive ability of cover crops. Plant, Soil, and Environment 62:60-66. doi: 10.17221/612/2015-PSE

Li, Y., V.G. Allen, J. Chen, F. Hou, C.P. Brown, and P. Green. 2013. Allelopathic influence of a wheat or rye cover crop on growth and yield of no-till cotton. Agron. J. 105:1581-1587. doi: 10.2134/agronj2013.0065.

Licht, M., and T.C. Kaspar. 2015. Tips and considerations for getting started with cover crops. Integrated Crop Manage. News Pub 823. Iowa State Univ. Ext., Ames, Iowa. pp. 1.

Meisinger, J. J., W.L. Hargrove, R. L. Mikkelsen, J.R. Williams, and V.W. Benson. 1991. Effects of cover crops on groundwater quality. In: W.L. Hargrove, editor, Cover Crops for Clean Water. Proceedings of an International Conference, West Tennessee Experiment Station. Jackson, Tennessee. 1-11 Apr. 1991. Soil and Water Conserv. Soc. Ankeny, Iowa pp. 57-68.

Michigan State University Extension. Getting started & management, Cover Crops, Michigan State University Extension. www.canr.msu.edu/cover_crops/getting_started_and_management/planting (accessed 26 Jun 2018).

Monsanto Company. 2017. Roundup Powermax® herbicide label. Monsanto Company, St. Louis, Missouri. pp. 1-22.

Mutch, D. 2013. Incorporating cover crops into corn systems. Michigan State Univ. Ext. Michigan State Univ. http://canr.msu.edu/news/incorporating_cover-_crops_into_corn_systems (accessed 26 Jun 2018).

Myers, R., C. Ellis, R. Hoormann, T. Reinbott, N. Kitchen, and J. Reisner. 2015. Cover crops in Missouri: Putting them to work on your farm. Ext. Pub. G4161. Univ. of Missouri Ext., Columbia, Missouri. pp. 1-6.

Noland, R.L., M.S. Wells, C.C. Sheaffer, J.M. Baker, K.L. Martinson, and J.A. Coulter. 2018. Establishment and function of cover crops interseeded into corn. Crop Sci. 58:863-873. doi: 10.2135/cropsci2017.06.0375.

NRCS. 2010. Aerial seeding of cover crops. Agronomy #36. USDA, Des Moines, IA. pp. 5.

NRCS. 2014. NRCS Cover crop termination guidelines. Version 3. USDA, Beltsville, Maryland. pp. 1-3.

Phatak, S.C. 1992. An integrated sustainable vegetable production system. HortScience 27:738-741.

Redfearn, D., and J. McMechan. 2018. Timing of cover crop termination and related factors. University of Nebraska-Lincoln. https://cropwatch.unl.edu/2018/timing-cover-crop-termination-and-related-factors (accessed 12 Nov. 2018).

Ryan, M.R., S.B. Mirsky, D.A. Mortensen, J.R. Teasdale, and W.S. Curran. 2011. Potential synergistic effects of cereal rye biomass and soybean planting density on weed suppression. Weed Sci. 59:238-246. doi: 10.1614/WS-D-10-00110.1.

Singer, J.W. 2008. Corn belt assessment of cover crop management and preferences. Agron. J. 100:1670-1672. doi: 10.2134/agronj2008.0151

Strock, J.S., P.M. Porter, and M.P. Russelle. 2004. Cover cropping to reduce nitrate loss through subsurface drainage in the northern US Corn belt. J. Environm. Qual. 33:1010-1016.

Sturm, D.J., C. Kunz, and R. Gerhards. 2016. Inhibitory effects of cover crop mulch on germination and growth of *Stellaria media* (L.) vill., *Chenopodium album L.*, and *Matricaria chamomilla* L. Crop Protection 90:125-131. doi: 10.1016/j.cropro.2016.08.032

Syngenta Crop Protection. 2013. AAtrex 4L herbicide label. Syngenta Crop Protection, LLC, Greensboro, North Carolina. pp. 1-24.

Syngenta Crop Protection. 2015. Halex GT herbicide label. Syngenta Crop Protection, LLC, Greensboro, North Carolina. pp. 1-20.

Teasdale, J.R. 1996. Contribution of cover crops to weed management in sustainable agricultural systems. J. Prod. Agric. 9:475-479. doi:10.2134/jpa1996.0475

Teasdale, J.R. 1998. Influence of corn (*Zea mays*) population and row spacing on corn and velvetleaf (*Abutilon theophrasti*) yield. Weed Sci. 46:447-453.

Teasdale, J.R., C.E. Beste, and W.E. Potts. 1991. Response of weeds to tillage and cover crop residue. Weed Sci. 39:195-199.

Tribouillois, H., C. Dürr, D. Demilly, and M.H. Wagner, E. Justes. 2016. Determination of germination response to temperature and water potential for a wide range of cover crop species and related functional groups. PLoS ONE 11:1-16. doi: 10.1371/journal.pone.0161185.

Weir, T.L., S. Park, and J.M. Vivanco. 2004. Biochemical and physiological mechanisms mediated by allelochemicals. Plant Biology 7:472-479. doi: 10.1016/j.pbi.2004.05.007

Wells, M.S., S.C. Reberg-Horton, and S.B. Mirsky. 2016. Planting date impacts on soil water management, plant growth, and weeds in cover-crop-based no-till corn production. Agron. J. 108:162-170. doi: 10.2134/agronj2014.0524.

Wilson, M.L., D.L. Allan, and J.M. Baker. 2014. Aerially seeding cover crops in the northern US corn belt: Limitations, future research needs, and alternative practices. J. Soil Water Conserv. 69:67A-72A. doi: 10.2489/jswc.69.3.67A

Wilson, M.L., J.M. Baker, and D.L. Allan. 2013. Factors affecting successful establishment of aerially seeded winter rye. Agron. J. 105:1868-1877. doi: 10.2134/agronj2013.0133.

CHAPTER 3
IMPACT OF COVER CROPS ON NUTRIENT LOSS AND CROP YIELDS IN A TERRACE TILE FIELD IN UPSTATE MISSOURI

ABSTRACT

Further research on effective conservation practices in highly erodible soils of Missouri is needed. A field trial was established at the University of Missouri Grace Greenley near Novelty, Missouri with two treatments [1) cover crop (CC) and 2) no cover crop (NTC)] and three replications in 2016. Six parallel terraces were installed on 36.5 m spacings each consisting of an individual tile outlet to evaluate the water quality impacts of cover crops in a terraced field. Soybean [*Glycine max* (L.) Merr] was planted in 2016 and a cost-effective cover crop blend was overseeded at R6. Corn (*Zea* mays) was planted in 2017 and a post-harvest winter rye cover crop was drill-seeded into corn stubble. Soil health parameters were evaluated at project initiation and completion. Water grab samples were taken during storm events. Flow meters and data loggers were utilized to document flow events for each tile outlet and determine total suspended (TSS), NO_3-N and total P (TP) loss and loading throughout the year. Yield, spring CC + weed biomass, and soil parameters were evaluated at four landscape positions (summit, shoulder, channel, backslope) within each plot. Cover crop treatment reduced grain yield in 12% in 2016 and 6% 2017 and increased yield 4% in 2018. Grain yield was greatest on shoulder landscape positions and lowest in the channel position in all years. In 2017, corn yield was ranked NTC SH >NTC BS = CC SH >CC BS >CC FS = NTC FS >NTC CH >CC CH. Corn yield for the NTC was 6130 to 9580 kg ha^{-1} and 5450 to 9140 kg ha^{-1} for CC. No treatment by LP interaction was detected in soybean in 2016 or 2018. Combined over years (2016 and 2018), no treatment effects were detected for soil health. Year by

landscape position interactions were present for Mg, K, total organic C, and clay content. Each of these parameters were the same among LP before terrace construction, and at least one of the LP's differed following terrace construction. Cover crops reduced TSS 363 to 4713 g ha^{-1}, TP 2 to 90 g ha^{-1}, and NO_3-N mean loading 446 to 3407 g ha^{-1}in all seasons as well as event mean discharge. In the 2018 CC season, CC reduced mean nutrient concentrations of TP and NO_3-N by 0.0063 mg L^{-1} and 4.16 mg L^{-1}, respectively. Cover crops reduced cumulative water discharge 325 to 722 m^3 ha^{-1} in all three cropping seasons evaluated. Cumulative TSS and cumulative NO_3-N were reduced by CC in two cropping seasons. Cover crops did not affect cumulative TP loss. Cover crops were an effective tool for reducing drainage water discharge and nutrient loss in a tile terrace field.

INTRODUCTION

The Midwestern United States is the prime farmland for row crop production. Beginning in the late 1800's, installation of artificial drainage in poorly drained prairie soils expedited an increase in the intensity of row crop production on fields formerly limited to pasture and grazing. Additionally, the increased availability of N fertilizers encouraged row crop production in Midwest (Dinnes et al., 2002; Hewes and Frandson, 1952). Tile drainage allowed field work when conditions were typically too wet (Smith et al., 2015). Missouri ranks 7^{th} in the US for the area of tiled land at 357,790 hectares (National Agricultural Statistics Service, 2012). Though these artificial drainage systems are a key component to modern Midwestern agricultural systems (Tomer et al., 2003), they have been reported to have negative effects on ecosystems downstream (Royer et al., 2006; Sabotyagov et al., 2014). Agricultural watershed nitrogen (N) loss has been evaluated for over 70 years; however, interest has increased over the last 30 years (Hatfield et al., 2009). Ecosystem nutrient introduction can occur through fertilizer, animal manure, atmospheric deposition, soil, and industrial discharge movement. Excessive nutrients in aquatic ecosystems can lead to depletion of dissolved oxygen in the water column and at the interface of sediment and water resulting in hypoxia (Environmental Protection Agency, 2007). Pollution of N and phosphorous (P) from agricultural non-point sources contributes largely to the eutrophication of surface water resources (Carpenter et al., 1998; Sharpley et al., 2003).

Nutrient loss and erosion of farm ground negatively affects yield and farm finances (Aryal et al., 2018). Loss of nutrients, which typically occurs during high flow events (Tomer et al., 2003; Vanni et al., 2001), have been linked to the development of the hypoxic zone in the Gulf of Mexico (Royer et al., 2006; Sabotyagov et al., 2014). Conservation practices are implemented to mitigate this loss. Agricultural land use and nutrient concentrations in nearby bodies of water have been heavily investigated (Hatfield et al., 2009). Nutrient loss in the Mississippi River Basin is reflected in the Gulf of Mexico. Corn and soybean production account for 25% and 52% of P and N transport into the Gulf of Mexico respectively, while 37% of the P transport originated from animal manure applied to rangeland and pasture (Alexander et al., 2008). Zhu et al. (2012) cited N and P as large contributors of agricultural non-point nutrient losses which were due to excessive and improper fertilization, manure applications, and a lack of management strategies. Evaluating agricultural system's impact on water quality is essential to protecting ecosystems, especially when multiple conservation practices are implemented.

Historically, N was believed to be the limiting factor in aquatic ecosystems. However, Maloney et al. (1972) reported that P was the limiting nutrient in ecosystems and a primary cause of freshwater eutrophication. Phosphorous can enter surface water resources through subsurface flow or surface runoff. The quantity of P transportation through tile drains is influenced by field management, soil characteristics, drainage system design, and climate (King et al., 2015b). A Canadian study examining event-based, seasonal variability of drainage tile P contribution within a basin reported that 42% of basin runoff was a result of tile drains which occurred primarily during periods of fallow between crops. Furthermore, P loading from subsurface drainage tile water flow was greater during storm periods and was most prevalent during winter snowmelt/thaw events (Macrae et al., 2007). Focus on N pollution into water systems has increased in recent years. Prior to the adoption of the Haber-Bosch process, N fertilizer applied to agriculture fields were derived from biological sources. Following World War II, biological fertilizers increasingly were substituted with manufactured N (Dinnes et al., 2002). Smil (1999) reported that nearly half of the N applied annually for global agricultural purposes is now derived from synthetic fertilizers. The mean global recovery rate of N into crop biomass is only 50% (Smil, 1999). Nitrogen loss primarily occurs through denitrification and nitrate-N leaching NO_3^--N (Sawyer, 2015).

The Midwestern United States is home to over 4 million hectares of claypan soils (Buckley et al., 2010). Claypan soils have a very slowly permeable abrupt subsoil layer that has a much higher clay content than above soil layers (SSSA, 2006) and have low fertility and water availability, are poorly drained, have shallow rooting depths, and need intensive N management (Ghidey and Alberts, 1998; Sweeny, 2017). These properties present management challenges and crop response to management often yields different results when compared to a soil with no claypan. The claypan soils in the Salt River Basin of Northeast Missouri are noted to be highly erodible (Lerch et al., 2008). Geist et al. (2013) reported that in the last century, Missouri has lost over half of its topsoil. Soil loss is costly and nearly irreversible. In Northern Missouri, 2.5 cm of soil loss from farm ground in a corn-soybean rotation translated into a \$35.60 ha^{-1} annual loss at 2013 prices (Geist et al., 2013). Though claypan soils present many challenges, Missouri researchers have been investigating methods for increasing yields and reducing inputs in claypan soils since the mid-1930’s (Jones and Beasley, 1943). Because soils of northern Missouri may be low yielding (Lerch et al., 2008) and commodity prices are relatively low, it is exceptionally important that conservation efforts are thoroughly investigated before implementing and that they do not negatively affect farmers net income.

Missouri’s climate, topography, typical rotations, and soil drainage make farmland exceptionally susceptible to excessive soil erosion (Geist et al., 2013). Thousands of cropland acres in Missouri have been terraced to reduce surface water runoff and erosion. In Northeast Missouri where moderate, poorly drained, shallow, sloping soils are in corn and soybean production, thousands of hectares of terraces have been constructed to protect farmland during heavy rains. Terraces are defined as “earthen embankments constructed on the contour or across a slope to intercept [surface water] runoff” (Centner et al., 1999). During the construction of terraces, topsoil is removed, terraces are built, and then topsoil is replaced. Terraces mitigate soil loss in multiple ways. Water flow velocity increases as it flows down slopes. Terraces interrupt this flow of surface water which reduces soil transport (Geist et al., 2013). Additionally, terraces capture water in a channel and divert it from a field through waterways or pipe outlets known as tile drains (Schottman and White, 1993). In parallel tile outlet terraces (PTO), water that accumulates behind a terraced ridge discharges through a surface inlet and may be equipped with a constrictor to reduce the discharge rate to allow suspended soil sediment to settle out of the solution (Wheaton and Monke, 1981). Parallel terraces increase farming efficiency. They eliminate grass waterways, improve fieldwork maneuverability, and increase hectares in production (Dickey et al., 1985).

Water runoff and soil loss in the claypan region of the Midwest is relatively large during seedbed preparation and crop protection application which raises concerns for contamination of watersheds (Ghidey and Alberts, 1998). Loss of soil, water, and nutrients from agricultural fields is a concern not only for environmental purposes, but also human health (Aryal et al., 2018). Reducing erosion is critical to the long-term productivity of soils as it causes both in-and-out-of-field damages through soil transport and deposition that can be reduced through implementation of conservation practices such as terraces (Baker et al., 2006).

Terraces are a useful tool in reducing widespread erosion, but erosion may occur within terraces. Rill erosion within a terraced system may be effectively managed with the addition of cover crops (CC) in these landscapes (Johnson, 2008). Cropping systems with the inclusion of a CC have reported to improve soil health, prevent erosion, reduce compaction, assist in weed control, and may increase commodity yields over time (Myers et al., 2015). Villamil et al. (2005) reported that compared to corn-soybean rotations without a CC, rotations with a CC had reduced bulk density and penetration resistance. These properties were attributed to increased plant residue and soil organic matter. In a study on agricultural water management, Her et al. (2017) reported CC's reduced total sediment, N, and P loss from a field, but sometimes increased the loss of soluble nutrients. Cereal rye (*Secale cereal*) planted as a CC reduced sediment and nutrient loads immediately following planting, absorbed soluble nutrients from soils, and protected the soil surface from raindrop energy with a leaf canopy; however, investigators suggested that when the CC was terminated N mineralizing from CC organic matter residue could increase loads of soluble N lost from the field (Her et al., 2017). Cartwright (2016) reported that long-term CC use can lead to increased farm profitability through improved soil health.

The best management practices for reducing nitrate-N (NO_3-N) loss from agricultural fields included temporal strategies such as coupling N application with periods of large crop demand and avoiding N application during periods of large precipitation and soil water transport, along with cropping system management strategies such as utilizing soil test results, diversifying crop rotations, reducing tillage, implementing a CC and use of nitrification inhibitors (Dinnes et al., 2002; Havlin et al., 2014; Tonitto et al., 2006). Of these strategies, CC's are a highly investigated method for reduction of NO_3-N. Strock et al. (2004) reported that cereal rye CC to reduced NO_3-N loss from subsurface drainage discharge in four years. However, the small success rate was attributed to unsuitable CC establishment conditions and small NO_3-N leaching potential (Strock et al., 2004). Havlin et al. (2014) reported that a cereal rye CC in a corn-soybean rotation with subsurface tile drainage reduced drainage 11% and NO_3-N loss was reduced 13%. In a meta-analysis, Tonitto et al. (2006) reported that a non-legume CC reduced nitrate leaching 40-70% compared to a fallow field and that N uptake of the CC averaged 20-60 kg N ha^{-1}.

Cooler northern climates can present CC establishment challenges (Wilson et al., 2014). Strock et al. (2004) reported challenges in winter cereal establishment in the upper Midwest following harvest in a corn-soybean rotation. Singer (2008) had difficulties establishing legume and broadleaf CC's late in the season. To combat temperature challenges and promote greater fall growth, researchers suggested broadcast seeding a CC into a standing crop (Frye et al., 1988). Intercropping for more efficient cropping systems has been conducted historically (Scott et al., 1987; Triplett, 1962), and has become more prevalent in recent years due to increasing focus on conservation practices (Belfry and Van Erd, 2016; Curran et al., 2018; Nelson et al., 2011; Sandler et al., 2015b).

A crucial first step to establishing a CC is selecting a species that is compatible with local climatic conditions at planting (den Hollander et al., 2007; Tribouillois et al., 2016). Selection of CC species should be regionally dependent (Duiker, 2014). Seed size is another important factor to evaluate during selection as smaller seeds may float during aerial application (Wilson et al., 2014). Producers should further consider benefits associated with different CC species. For example, CC type is important determining weed suppression (Wells et al., 2016) and the effects of spring termination which can impact the subsequent rotational crop (Johnson et al., 1998). Cover crop seeding timing recommendations vary with latitudes and have been evaluated in many ways. Licht and Kaspar (2015) advised producers in central Iowa to overseed a CC between August 15 and September 15, and should be mindful of rotational crop maturity, rainfall patterns, and calendar date. In the Mid-Atlantic, Curran et al. (2018) reported decreased corn grain yield when CC's were interseeded into standing corn at V2-V3 but experienced no yield impact when interseeded at or after V4. Geist et al. (2013) suggested that Central Missouri farmers seed rye around Oct. 1 when leaf coverage of the standing crop had decreased by 20-25%; however, Michigan State University Extension recommended overseeding CC's into standing corn at V6 or near a side-dress fertilizer application (Curell, 2012). Weather conditions must be considered before overseeding a CC. Several studies have emphasized the necessity of a precipitation event following overseeding (Curell, 2012; Licht and Kaspar, 2015; Wilson et al., 2013).

Nutrient and sediment losses can be reduced through implementing conservation practices for soil loss reduction and water conservation improvement (Aryal et al., 2018). Previous research has evaluated several CC systems in northern Missouri (Sandler et al., 2015a; Sandler et al., 2015b), but no known research has evaluated the effects of a CC in a terrace-tile field following construction. Integrating CC's with the installation of terraces should synergistically reduce nutrient and sediment loss from agricultural landscapes. Integrating best management practices for CC establishment with erosion management systems should further reduce nutrient and soil loss from agricultural fields. In-field management to control sediment and nutrient loss (especially N and P) should be more cost-effective than the edge of a field or water treatment management systems as it would reduce input costs of farmers the following season. The objective of this research was to evaluate the effect of inclusion of a CC in a corn-soybean rotation on crop production, soil health, and nutrient loss in a terrace-tile field on an upstate Missouri claypan soil.

MATERIALS AND METHODS

Field Location and Management

A field trial was initiated in the spring of 2016 at the University of Missouri Grace Greenley Farm of the Greenley Research Center near Novelty, Missouri (39° 57' 27.94"N, 92° 10' 38.88"W). The site had not been in row crop production for over 25 years. Parallel terraces were installed according to NRCS conservation practice standards 600 and 620 (NRCS, 2010; NRCS 2013) with a 36.5 m spacing in the spring 2016 with individual outlets for each terrace (Fig. 3.1). The underground tile outlet system (UGO) utilized a 11-cm orifice to allow terraces to drain in similar amounts of time and to prevent pressure build-up within UGO tile lines (NRCS, 2013). Tile lines were non-perforated from the inlet riser to the outlet. Six of the seven terraces were utilized for experimental purposes and were referred as Tile-2 to Tile-7 (Fig. 3.2). Each terrace was drained individually using six separate non-perforated tile lines (15 cm diameter) to evaluate the effect of the CC system on drainage and water quality parameters. Crops were managed for high yielding systems for the duration of this project (2016 to 2018) to maximize the efficacy of CC's and crop yields.

The experiment included two treatments 1) CC and 2) no CC (control) with three replications. Soybean was planted in 38 cm wide rows at 444,600 seeds ha^{-1} in 2016 (Case IH 1245 Early Riser, Racine, WI). Cover crop treatments were aerially overseeded into standing soybean (Woods Flying Service, Memphis, MO) at the R6 soybean growth stage (Fehr and Caviness, 1977) with a blend of 'MFA 2449' wheat (*Triticum aestivum* L.) at 49.1 kg ha^{-1}, 'EcoTill' radish (*Raphanus raphanistrum* subsp. Sativus) at 4.9 kg ha^{-1}, and 'PurpleTop' turnip (*Brassica rapa* subsp. rapa) at 2.5 kg ha^{-1} which took into consideration the cost-effectiveness (\$86.45 ha^{-1}) of the treatment (Table 3.1). In 2017, corn was no-till planted in 76 cm rows (Case IH 1245 Early Riser, Racine, WI). Post-harvest cereal rye CC (variety not stated) was drill seeded (Great Plains, Salina, KS) at 79.8 kg ha^{-1} (\$77.81 ha^{-1}) into corn stubble (Table 3.2).

Landscape Position Classification

The topographic position index (TPI) tool in ArcGIS (v10.6) was used to identify topographic positions. Digital elevation model (DEM) with a raster resolution of 2.2 by 1.3 m was generated from elevation data collected from a Veris (Tualatin, OR) electrical conductivity tool. The model used for delineating topographic positions is a direct adaption of the slope position classification model by Evans et al. (2016) which delineates four topographic positions (e.g., shoulder, backslope, footslope, and channel). The TPI in the slope position classification model is the difference of a cell elevation (e) in the DEM from the mean elevation (*m*e) of a user-specified area surrounding e. A radius of 6.1 m was used to determine the TPI and a TPI raster was outputted from the DEM. A radius of 6.1 m was chosen so that microscale topographic variation within each field could be omitted.

Plant Biomass

Cover crop and weed aboveground biomass were harvested to evaluate biomass production. A 0.09 m^2 quadrat was randomly placed in 10 of the four locations within each landscape position (shoulder, backslope, footslope, and channel) of each terrace and biomass was collected from within the quadrat. Samples were dried, separated by species, and weighed. Biomass data were collected in the spring of 2017 the day of planting (17 Apr.), and the spring of 2018 (4 May) prior to planting soybean.

Grain Yield

The primary crop was harvested, and grain yield and moisture were determined in 2016, 2017, and 2018 using a Case IH 5140 or 6140 (Case IH, Racine, WI). Grain yield moisture was adjusted to 150 kg ha^{-1} and 130 kg ha^{-1} for corn and soybean, respectively. The combine was equipped with a yield monitor to determine yield. Coordinates including latitude and longitude for yield data points were recorded simultaneously by a GPS (AFS 162, Trimble Inc., Sunnyvale, CA) receiver on the combine. Unrealistic yield data points that were likely caused by significant positional errors or operating errors such as abrupt changes of speed, partial swath entering the combine, and combine stops and starts-were removed from the data set before the statistical analysis (Sudduth et al., 2012). Data were tested for normality and outliers were removed (Table 3.5). After removing outliers, developed yield data sets having latitude and longitude were imported to ArcGIS (v10.6) for extraction of landscape positions and yield features for 2016, 2017, and 2018 that matched each yield point collected by the combine.

Soil Quality

Soil quality parameters were evaluated at project initiation prior to terrace construction (Table 3.3) and were evaluated again in the spring of 2018. Soil samples taken prior to terrace construction were sampled where prospective terrace channels and shoulders were located. Soil samples to a depth of 20 cm following terrace construction were collected at four landscape positions created during construction and composited for the landscape position (Fig. 3.1 and 3.2). Following sampling guidelines from the MU Soil Health Assessment Center (University of Missouri), four rings were placed on the soil surface and used to collect soil samples for each landscape position were collected from each landscape and submitted to the MU Soil Health Assessment Center to evaluate soil health indicators as outlined in the Missouri Department of Natural Resources/Soil Water Conservation District CC cost-share program (NRCS, 2016). These soil health indicators included simplified particle size analysis, active carbon, total organic carbon (TOC), potentially mineralizable N (PMN), water stable aggregates (WSA), pH (salt and water), effective CEC plus exchangeable bases, plant available P, and bulk density. Methods for these parameters can be found in Table 3.4. Additional soil samples were collected to a 15 cm depth from individual plots prior to construction and each spring after terrace construction to evaluate the effect of cropping systems on soil chemical properties (MU Soil and Plant Testing Laboratory) (Nathan et al., 2012).

Water

A trapezoidal flume (large, 60-degree) was integrated into the tile flow path of each tile line approximately 7.6 m from the tile discharge site. A flow meter was connected to each flume and programmed for flume specifications (Sigma 950 flow meter, Hach Company, Loveland, CO). Flow meters analyzed the stage (depth) of water in the flumes by using an internal air compressor and a bubble line submerged into the stream flow of the flume. Flow meters utilize this data to calculate the discharge from each tile line by using Manning's equation (LMNO Engineering, 2014). Tile flow measurements were recorded every ten minutes.

Additionally, grab samples were collected from the tile outlets during or shortly after each precipitation or flow event in 2017 and 2018. Tile drainage water samples were stored in a refrigerator (5°C) within 1 hour of collection until they were analyzed. Samples of subsurface tile drainage water were analyzed for NO_3-N, total P (TP), and total suspended solids (TSS) for each individual tile outlet by the MU Soil and Plant Testing Laboratory. To determine the concentration of TSS, 100 mL of water from each sample was filtered (1.5 µm, 934-AH; Whatman Glass Microfiber, GE Healthcare Bio-Sciences, Pittsburgh, PA). Solids retained on the filter were used to calculate the concentration of TSS in each sample. Prior to being analyzed for NO_3-N concentration, water samples were filtered (1.5 µm, 934-AH; Whatman Glass Microfiber, GE Healthcare Bio-Sciences, Pittsburgh, PA). Samples were then immediately analyzed for NO_3-N concentration (QuickChem, 10-107-04-1-F, Lachat Instruments, Milwaukee, WI) using an automated ion analyzer (Quick Chem 8000, Lachat Instruments, Milwaukee, WI). In addition, TP was also analyzed.

Nutrient loads were calculated based on storm events. Storm events were separated from the flow data based on the duration of the rainfall events. Grab samples of water were interpolated for stage data collected by flow meters between the start and end of rainfall events. Stage data readings below 1.9 cm were not taken into consideration for load calculations due to large percent error of the trapezoidal flume. Water and nutrient data were divided into CC and cash crop seasons. The 2016-2017 CC season spanned from project initiation to CC termination and corn planting in April. The 2017 corn season began at planting and was completed following harvest in the fall of 2017. The 2017-2018 CC season began when post-harvest cereal rye CC was drill-seeded and was completed in the spring of 2018 at soybean planting (Table 3.2).

STATISTICAL ANALYSIS

Prior to analysis, all variables were tested for normality using the UNIVARIATE procedure in SAS version 9.4 (SAS Institute, 2014). Based on Shapiro-Wilk and

Kolmogorov-Smirnov tests used for determining the normality of data, soil health parameters (PMN), analytes for water quality load data, and discharge were log transformed. Water concentration data were log transformed for TSS and NO_3-N for the spring 2017 CC, and fall 2017 corn season, and the spring 2018 CC season. Total P concentrations were log transformed in spring 2018 CC season. The values were back-transformed to a normal distribution for the presentation of results. All data were analyzed using mixed models in the GLIMMIX procedure of SAS (SAS Institute, 2014). Cover crop treatment and landscape position were treated as fixed factors whereas the replication of the terraces was treated as a random factor. For analyzing yield data, georeferenced coordinates of each yield data point were added to a random statement with an exponential spatial covariance structure type=SP(EXP(c-list) that compensated for the spatial autocorrelation of the yield data. To analyze water quality data, a repeated measure statement was added in the mixed model for the stormwater collection events. The repeated measure statement had an exponential spatial or temporal covariance structure type=SP(EXP(c-list) which was selected based on the lowest Akaike's Information Criteria (AIC) (Littell et al., 2007). The T-grouping of least square means was used for the comparison of the means at alpha = 0.10.

RESULTS AND DISCUSSION

Grain Yield

Soybean and corn grain yield for 2016 and 2017 were larger for the non-treated control (NTC) compared to CC (Tables 3.5 and 3.6). Shoulder, backslope, and footslope landscape positions had 550 to 1680 kg ha^{-1} greater corn grain yields for the NTC compared to CC (Table 3.6). In all years, differences in grain yield occurred between landscape positions when data were combined over landscape positions. In 2016 and 2017, the shoulder position on the terraces had the highest grain yield followed by backslope, footslope, and channel positions. In 2018, shoulder and backslope landscape positions had the greatest grain yield followed by footslope and channel positions (Table 3.6). Similarly, Johnson et al. (1998) reported reduced corn yields following soybean overseeded with a rye and oat CC blend. However, other studies have reported that a CC had no effect on the subsequent cash crop yields (Curran and Roth, 2013). Myers et al. (2015) reported that CCs may increase commodity yields over time, but these benefits may not be immediately detected. Terraces are recognized for their ability to reduce surface water runoff, increase field water availability, and improve field maneuverability (Dickey et al., 1985; Geist et al., 2013; Wheaton and Monke, 1981); however, no literature has shown significantly increased yields in the first 5-10 years following terrace construction (Schottman and White, 1993). Terrace construction created an artificial A horizon on the shoulder and backslope landscape positions encouraging enhanced plant growth (SSSA, 2018). Data analyzed in this study only evaluated one year of rotational crop data for corn and two years for soybean and the CC effect on the cash crop may have not yet been established. Others have reported that the long-term use of CCs may benefit crop productivity (Myers et al., 2015).

Biomass

A significant treatment effect was observed for the CC + weed biomass in 2017 and 2018 (Table 3.7). In 2017, plots that received a CC treatment had 1790 kg ha^{-1} of biomass compared to NTC that had 650 kg ha^{-1} (Tables 3.7 and 3.8). In 2018 CC had 1,980 kg ha^{-1} more biomass than the NTC (Tables 3.7 and 3.8). This was expected as these plots were seeded with a CC. When combined across treatments and evaluated for the landscape position, the footslope position had the greatest biomass accumulation followed by the shoulder, backslope, and channel, in both years (Table 3.8). In 2017, the shoulder biomass was similar to the footslope and backslope biomass. Backslope biomass was similar to channel biomass (Table 3.8). In 2018, the shoulder biomass was similar to the footslope biomass and backslope biomass. Combined across landscape positions, CC biomass was greater in the CC treatment than in the NTC (Fig. 3.3). A study in Nebraska comparing various CC species and blends of species reported that spring biomass of cereal rye was greatest compared to CC blends and legume CCs in both early and late planted plots (Koehler-Cole et al., 2016). Kemp and Lyutse (2011) reported that CC's produced 4,490-6,740 kg ha^{-1} of biomass in an average year and up to 11,230 kg ha^{-1} of biomass in an optimal year during good growing conditions.

Soil Health

Treatment effects were detected for soil exchangable Na, potentially mineralizable nitrogen (PMN), and bulk density soil health parameters in 2018 (Tables 3.9 and 3.10). Landscape position effects were detected following terrace construction for Ca, Mg, Na, K, pH $CaCl_2$, pH H_2O, Active C, total organic carbon (TOC), Bray 1 P, and bulk density (Tables 3.9 and 3.10). No interaction was present between treatment and landscape position. Cartwright (2016) found the long-term use of CCs can lead to improvements in soil physical and biological properties that can improve overall soil health. No research has been conducted on soil health impacts following terrace construction. However, our results show that terrace construction and the creation of landscape positions has a significant impact on soil health. When terraces were constructed, upper layers of soil were pushed back. Lower layers of soil were used for the construction of the terraces. The upper layers were then put back on top of the terraces. We believe terrace construction may have created an unnatural A horizon on the shoulder position which encouraged plant growth and increased microbial activity (SSSA, 2018). In an evaluation of Missouri soils at various landscape positions, Young and Hammer (2000) reported ridge and shoulder properties to be similar, but they were but different from backslope positions. Backslope positions were reported to have lesser TOC, pH, base saturation, and less silt. This was not observed in our study as terraces were manmade. Young and Hammer (2000) also concluded that water differences created by slope and stratigraphic conditions often cause soil variability. After large rain events, wetter conditions near subsurface tile inlets in terrace channels was visually observed. The effect of landscape position on impact on soil health properties and a lack of treatment by landscape position effect on soil health properties (Tables 3.3 and 3.10) suggest that terrace construction's impact on soil health and differences in soil water between landscape positions (a result of terrace construction) are likely greater contributing factors to differences in soil health than the impact of implementing a CC. Over time, the cover crop may reverse the effects created by this construction.

Water and Nutrients

Cover crops reduced cumulative TSS (7 kg ha^{-1} to 43 kg ha^{-1}) and NO_3-N (5 kg ha^{-1} to 32 kg ha^{-1}) loss compared to the NTC in the 2016-2017 CC season and 2017 corn season (Fig. 3.4). Cover crops reduced cumulative discharge in all seasons 325 m^3 ha^{-1} to 722 m^3 ha^{-1} (Fig.3.4). In a similar rotation, Strock et al. (2004) reported an 11% reduction in subsurface drainage discharge. Cover crops reduced event mean loads of TSS (363 g

ha^{-1} to 4713 g ha^{-1}), TP (2 g ha^{-1} to 90 g ha^{-1}), and NO_3-N (446 g ha^{-1} to 3407 g ha^{-1}) in all seasons (Table 3.11). Further, CC's reduced event mean discharge 40 m^3 ha^{-1} to 81 m^3 ha^{-1} when compared to the NTC (Table 3.11). In the 2018 CC season, CC reduced mean nutrient concentrations of TP and NO_3-N by 0.0063 mg L^{-1} and 4.16 mg L^{-1}, respectively (Table 3.12). In the 2017 corn season, CC's reduced mean NO_3-N concentration of drainage water 8 mg L^{-1} (Table 3.12). In the 2017-2018 CC season, CC TSS mean nutrient concentration was 1.16 mg L^{-1} greater than the NTC (Table 3.12). Similarly, Her et al. (2017) reported that CCs reduced TSS, N, and P loss from fields in the Midwest. Increased mean TSS concentration during the spring 2018 CC season was possibly due to increased soil disturbance when drill-seeding the cereal rye CC. However, reduced event mean discharge during the same season, and smaller TSS loading (Table 3.11) indicates that though planting the CC caused soil disturbance, less loss occurred with a CC than in the NTC.

Previous research has reported that when used separately, terraces and CCs assisted in conserving soil moisture (Al-Kaisi, 2001; Basche and DeLonge, 2017). Abel (2013) reported that CCs terminated earlier had water content like fallow ground at planting, and earlier terminated CCs would likely have less impact on rotational crop growth and yield. Our research demonstrates that terraced plots with a CC had reduced water discharge compared to terraced plots without a CC. This indicates that there was a synergistic effect combining the conservation practices of terracing and cover cropping.

During the 2017-2018 CC season, cereal rye CC did not affect cumulative NO_3-N loss; however, only one CC season of cereal rye was evaluated. In a study examining NO_3-N loss from subsurface drainage discharge, cereal rye was found to be an effective tool reducing NO_3-N loss one in four years. Its low success rate was attributed to years with small potential for nitrate leaching as well as unsuitable environmental conditions for establishment (Strock et al., 2004). No significant reduction of cumulative TP was observed during the study period. Cover crops reduced cumulative TSS loss by 77% and 61% during the 2016-2017 CC and 2017 corn seasons, respectively. Similarly, studies have reported a 40-96% reduction in erosion with CC use (Blanco-Canqui et al., 2015; Martens, 2001; Myers et al., 2015).

Unlike CCs, terraces are a long-term and permanent conservation practice. Therefore, the impact of landscape positions on yield is an important factor for producers when considering the impacts of terrace construction on yield variability. As the soil profile reestablishes following construction over time, the influence of landscape position on grain yield will not be as great. Along with a reduced influence on yield, plots containing a CC may have different soil health over time compared to NTC terraces. In 2016 and 2017, CC's reduced corn and soybean yield. In 2018, use of CCs in a tile-terraced field reduced nutrient loss and water discharge without affecting cash crop yields. In 2018, a synergistic effect between conservation practices (CCs and terraces) was observed. In 2018, northeast Missouri experienced severe-exceptional drought conditions (National Drought Monitor 2018). Larger yields in 2018 were attributed to CC's water conservation properties. In 2016 and 2017, treatment and landscape position had equal impacts on yield. In 2018, yield was impacted more by landscape position than by CC. Combined over treatments, the channel landscape position in 2016, 2017, and 2018 had the smallest grain yield and the least weed + CC biomass. The 2016 soybean crop was not planted following a CC due to project initiation. In 2017 and 2018, rotational crops were planted after a CC. Combined across treatments in both 2017 and 2018, grain yield was ranked (largest to smallest) shoulder, backslope, footslope, and channel while CC biomass was ranked footslope, shoulder, backslope, and channel, respectively. As yield and biomass were ranked in dissimilar orders, we assume that the amount of biomass did not directly impact yield in these years. In all seasons evaluated, CC's reduced tile drainage and CC's reduced both TSS and NO_3-N in 66% of the seasons. Further research is needed to investigate if the long-term economic effect of CC's on nutrient and field water loss is more cost-effective than the economic effect of a CC on rotation crop grain yield.

CONCLUSION

Cover crops are a possible conservation practice for farmers with terraced fields. In some seasons, CC's reduced cumulative nutrient loss (TSS 61-76%, NO_3-N 60-78%) and in all seasons, CC's reduced cumulative drainage water discharge (37-75%). In two out of three years, CCs reduced rotational grain yield 6% for corn in 2017 and 12% for soybean in 2016. Cover crops increased soybean yield 4% in 2018, the third year after terrace construction. In 2017, corn yield was ranked NTC SH >NTC BS = CC SH >CC BS >CC FS = NTC FS >NTC CH >CC CH. In 2017, corn yield for the NTC was 6130 to 9580 kg ha^{-1} and 5450 to 9140 kg ha^{-1} for CC. No treatment by LP interaction was detected in soybean in 2016 or 2018. Farmers that are interested in constructing terraces should consider the impact that the construction of terraces and the effect of landscape positions has on rotational crop grain yield. Detectable differences in rotational crop grain yield may lessen between landscape positions within terraces over time; however, water accumulation in the channel may need additional management to maintain the benefits of the CC and cash crop yield. Further research needs to be done to examine the economic impact of implementing CC’s on this terraced field with surface inlets.

Figure 3.1. Design of the six parallel terraces constructed in 2016. Plots 101, 202, and 301 received a cover crop treatment. Plots 102, 201, and 302 are non-treated controls. Landscape positions are delineated within each terrace.

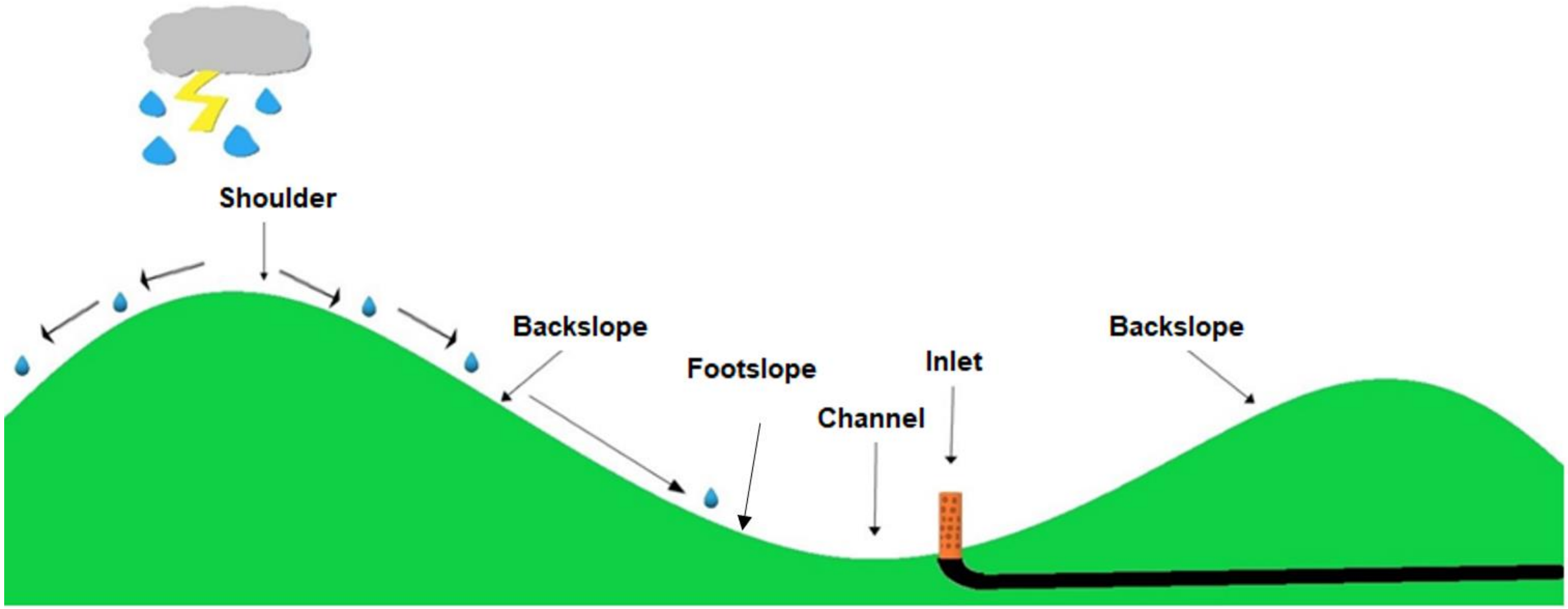

Figure 3.2. Soil and biomass samples were taken at shoulder, backslope, footslope, and channel positions in terraced field. Arrows illustrate terrace construction's effect on water flow.

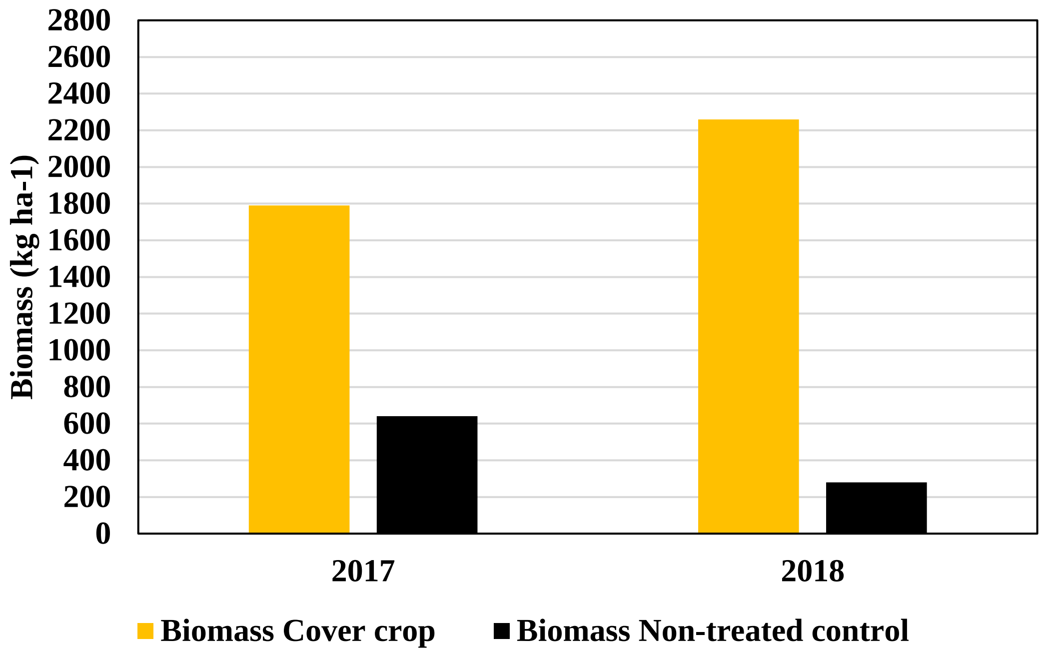

Figure 3.3. Aboveground cover crop plus weed biomass in 2017 and 2018. Biomass was collected the day of planting (17 Apr. 2017 and 4 May 2018). Bars followed by the same letter within a year are not statistically different (α = 0.10).

.

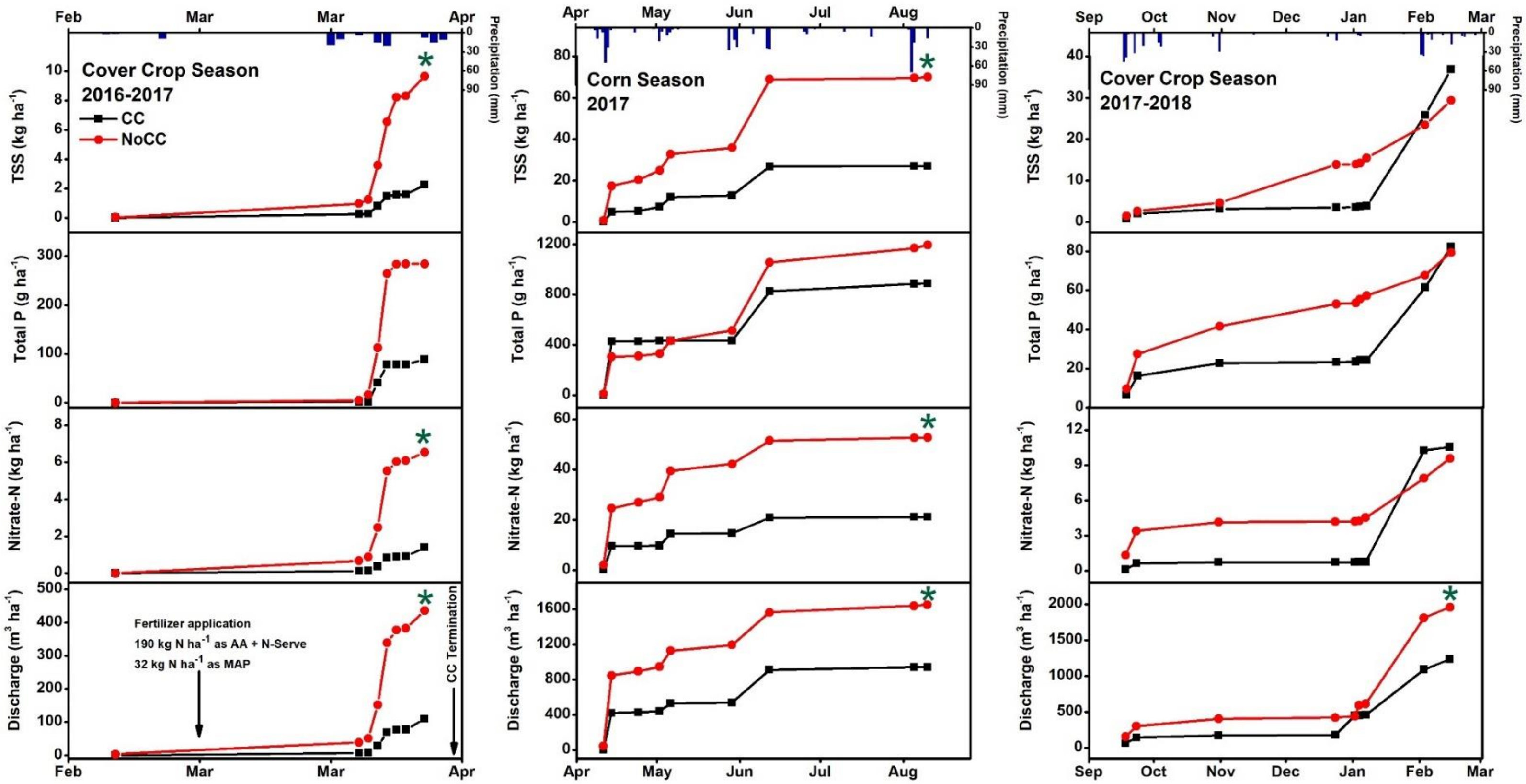

Figure 3.4. Precipitation, cumulative nutrient loss, and water discharge in the cover crop (CC) and non-treated control (NTC). Parameters were observed during cover crop and rotational crop (corn) cropping seasons. Asterisks indicate significant differences between treatment means (α = 0.10).

Table 3.1. Main, cover, and rotational crop management in 2016, 2017, and 2018.

Cover crop	2016 Soybean		2017 Corn		2018 Soybean	
		Cover crop cultivar		Cover crop cultivar		Cover crop cultivar
Species	Winter wheat Radish Turnip	MFA2449 EcoTill PurpleTop	Winter rye	VNS	Winter wheat Radish Turnip	MFA2449 EcoTill PurpleTop
Rate (kg ha^{-1})	49:5:3		80		49:5:3	
Seeding timing	Soybean R6		Post-harvest		Soybean R6	
Seeding method	Aerial overseeded		Drill seeded		Aerial overseeded	
Seeding date	8 Sep. 2016		2 Oct. 2017		15 Aug. 2018	

Table 3.2. Crop rotations and cover crop treatments from 2016 to 2018. Cover crops were overseeded into standing soybean at R6 (Aug.-Sep.) in 2016 and 2018 while soybean was harvested in October. A cereal rye cover crop was drill-seeded following corn harvest in 2017. Intermediate shading (Sep. and Oct.) indicates a period of soybean and cover crop cohabitation.

	2016										2017														2018											
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Treatment																																				
CC						Soybean					CC Blend					Corn						Cereal Rye CC							Soybean					CC	Blend	
NTC						Soybean										Corn													Soybean							

†Abbreviations: CC, cover crop; NTC, non-treated control; and Letters indicate each month of the year.

Table 3.3. Mean soil health parameters evaluated in the spring of 2016 prior to terrace construction and the spring of 2018 determined by cover crop (non-treated control, NTC; and cover crop, CC) treatment main effects, landscape position (LP) main effects, and year main effects. Within a column and within a given factor, means followed by the same letter are not statistically different ($\alpha = 0.1$).

Treatment[†]	LP	Year	Ca	Mg	Na	K	CEC	pH $CaCl_2$	pH H_2O	Active C
			---------------- cmol kg^{-1} ----------------							mg C kg^{-1}
NTC			14	2.3	0.07	0.4	18	5.7	6.1	420
CC			14	2.4	0.08	0.4	19	5.7	6.1	430
	Shoulder		14	2.3b	0.05b	0.3b	19	5.9a	6.3a	440
	Channel		13	2.5a	0.1a	0.4a	19	5.6b	6.0b	420
		2016	16a	2.4	0.06	0.3b	20a	5.9a	6.3a	540a
		2018	12b	2.4	0.08	0.4a	17b	5.6b	6.0b	320b
NTC		2016	16	2.3	0.03b	0.4	20	5.9	6.3	530
CC		2016	16	2.5	0.08ab	0.3	20	5.9	6.3	550
NTC		2018	11	2.4	0.1a	0.4	17	5.6	6.0	320
CC		2018	12	2.4	0.07ab	0.5	18	5.6	6.0	320
	Shoulder	2016	16	2.4ab	0.05	0.3b	20	6.0	6.4	540
	Channel	2016	15	2.4ab	0.07	0.4b	20	5.8	6.2	530
	Shoulder	2018	12	2.2b	0.05	0.3b	17	5.7	6.2	330
	Channel	2018	11	2.6a	0.12	0.5a	18	5.5	5.8	310

			TOC	Clay	Silt	Sand	WSA	PMN	Bray 1 P
			-------------------- g kg^{-1} --------------------					-------- mg kg^{-1}--------	
NTC			20	230	600	160a	410	80	16
CC			21	240	630	130b	410	90	17
	Shoulder		21	230b	620	150	430	80	14b
	Channel		20	240a	610	140	400	90	19a
		2016	27a	210b	670a	120b	570a	130a	15
		2018	14b	260a	570b	170a	240b	40b	18
NTC		2016	27	210b	660	130	590	130	15
CC		2016	27	220b	680	100	580	130	14
NTC		2018	14	260a	550	190	230	30	17
CC		2018	15	260a	580	160	250	40	19
	Shoulder	2016	27a	210c	660	120	610	130	14
	Channel	2016	27a	220c	680	110	570	140	16
	Shoulder	2018	15b	240b	580	170	250	40	14
	Channel	2018	13c	270a	550	180	230	40	23

[†]Abbreviations: Active C, active carbon; CC, cover crop; CEC, cation exchange capacity; NTC, non-treated control, PMN, potentially mineralizable nitrogen; TOC, total organic carbon; WSA, water stable aggregates.

Table 3.4. Soil health pa methods used by University of Missouri Soil Health Assessment Center. Soil health parameters were evaluated following guidelines outlined in the Missouri DNR/SWCD cover crop cost-share program. Soil health was evaluated prior to terrace construction in 2016, and in the spring of 2018.

Soil Health Parameter†	Method	Reference
Particle size	Modified pipette method	NRCS (2004)
Active Carbon	1. Potassium permanganate added to 5-g of soil 2. Sample shaken (two min) then allowed to stand undisturbed (5-10 min) 3. portion of the sample is diluted with reverse osmosis water 4. absorbance read (550 nm) with a spectrophotometer	Weil et al. (2003)
Exchangeable Bases	1. Bases extracted from soil using 1 M NH_4Cl 2. Atomic adsorption spectrophotometer used to analyze base concentrations 3. Extracted soil flushed with C_2H_6O 4. Extracted soil analyzed with FOSS Kjeltec™ 8200 automatic distillation apparatus to analyze for ammonium thereby determining the cation exchange capacity	NCRS (2004)
TOC	Leco C-144	
PMN	1. Place 20 g of soil into a 125-mL extraction bottle 2. Add 25 mL of distilled water to the bottle and stir. Add another 25 mL to rinse sides of the bottle 3. Create an air tight seal over the mouth of the bottle 4. Incubate sample at 40°C for 7 days 5. Remove sample from the incubator and add 50 mL of 2 M KCl. Replace plastic covers 6. Shake sample. Place sample on a mechanical shaker for 1 hour before filtering through Whatman No. 42 paper into acid rinsed filter vials 7. Determine the NH_4-N content using a spectrophotometer	Anderson et al. (2010)
Water stable aggregates	1. Soil dispersed on 0.5 -mm sieve 2. Sample submerged in RO water overnight 3. Sample agitated	NRCS (2004)
pH_w	1. Soil sample mixed with RO water (1:1 w:v). 2. Samples stand 1 hour and occasionally stirred. 3. Sample stirred 30 seconds and pH measured with the pH-reference electrode (Brinkmann Instruments, Inc., Westbury, NY)	NRCS (2004)
pH_s	Procedures 1-3 for determining pH_w are performed and 0.02 *M* $CaCl_2$ (same volume as water) is added.	NRCS (2004)
CEC	1. Exchange sites saturated with NH_4^+. 2. soil washed free of excess saturated salt 3. NH_4^+ displaced and quantified	Holmgren et al. (1977)

Table 3.4. Continued

Bulk density	1. Soil Sample was taken with Humbolt H-4203DT.3 bulk density ring (4 subsamples) (Humbolt Mfg Company Elgin, IL). 2. A subsample of soil placed into a pre-tared moisture tin. Moisture and weight of subsample is recorded. 3. Sub-sample oven-dried overnight and mass recorded the following day. The remainder of the sample is set out to air dry. 4. Moist: dry mass ratio used to convert the entire sample moist mass to dry mass. 5. The oven-dried portion is ground and sieved to retrieve coarse fragments (> 2 mm in diameter). Coarse fragments are weighed and recorded. The oven-dried soil is discarded. 6. After drying remaining sample, coarse fragments are removed, weighed, and recorded as with the oven-dry sample. 7. Tare weights and course fragment mass subtracted from oven dry sample. Oven-dry mass of 4 rings is divided by the internal volume of 4 sample rings.	
Bray I P	1. 25 mL of Bray P-1 extracting solution + 2.5-g soil sample shaken for 15 min. 2. Sample centrifuged until free of soil mineral particles. Clear extracts are collected. 3. 2-mL of collected solution is diluted with 8-mL of ascorbic acid molybdate solution. 4. The absorbance of solution is read using a spectrophotometer (882 nm)	Bray and Kurtz (1945)

†Abbreviations: min, minutes; RO, reverse osmosis.

Table 3.5. Probability values (p-values) and numerator degrees of freedom (df) associated with the sources of variation in the statistical analysis of corn and soybean grain yields in 2016, 2017, and 2018.

Source of Variation	df	Soybean 2016	Corn 2017	Soybean 2018
			p-values	
Treatment	1	<0.001	<0.001	0.0184
Landscape Position	3	<0.001	<0.001	<0.0001
L x T[†]	3	0.1174	<0.001	0.7583

[†]Abbreviations: P, landscape position; T, treatment.

Table 3.6. Mean values of grain yield in cover crop (CC) terraces and non-treated control (NTC) terraces determined by treatment main effects, landscape position main effects, and interactions (2016-2018). Within a column, means followed by the same letter are not statistically different (α = 0.1).

Treatment†	Landscape Position	Soybean fall 2016[‡]	Corn fall 2017[§]	Soybean fall 2018[‡]
		---------------------------	kg ha^{-1}	---------------------------
NTC		4910a	8030a	3500b
CC		4304b	7530b	3630a
	Shoulder	5230a	9330a	3820a
	Backslope	4962b	8700b	3560a
	Footslope	4630c	7260c	3420b
	Channel	3550d	5760d	3270c
NTC	Shoulder	5432	9580a	3755
	Backslope	5365	9200b	3688
	Footslope	5029	7200d	3286
	Channel	3822	6130e	3420
CC	Shoulder	5029	9140b	3822
	Backslope	4627	8200c	3822
	Footslope	4292	7320d	3353
	Channel	3286	5450f	3487

[†]Abbreviations: CC, cover crop; NTC, non-treated control.
[‡]Cover crops were overseeded into standing soybean at R6 in 2016 and 2018. Soybean was harvested in October.
[§]Cover crop was drill-seeded after corn harvest.

Table 3.7. Probability values (p-values) and numerator degrees of freedom (df) associated with the sources of variation in the statistical analysis of aboveground cover crop (CC) and weed biomass.

		Aboveground Biomass CC + weeds	
Source of Variation†	df	2017	2018‡
		p-values	p-values
Treatment	1	<0.0001	<0.0001
Landscape position	3	0.0240	0.0012
T x LP	3	0.4899	0.0012
Collection	1	<0.0001	NA
C x T	1	0.0009	NA
C x LP	3	0.3020	NA
C x T x LP	3	0.8498	NA

†Source of variation: treatment (T) landscape position (LP), collection (C).
‡Abbreviations: NA, not available.

Table 3.8. Mean values of aboveground biomass (kg ha^{-1}) of cover crop (CC) plus weeds in CC terraces and weeds in non-treated control (NTC) terraces determined by treatment, landscape position, and collection timing. Within a column, means followed by the same letter are not statistically different ($\alpha = 0.1$).

Treatment	Landscape Position	Aboveground Biomass CC + weeds	
		2017	2018
		-------- kg ha^{-1} --------	
NTC		640b	280b
CC		1790a	2260a
	Shoulder	1340ab	1410ab
	Backslope	1040bc	1270b
	Footslope	1660a	1680a
	Channel	810c	720c

†Abbreviations: NA, not available.

Table 3.9. Probability values (p-values) and numerator degrees of freedom (df) associated with the sources of variation in the statistical analysis of soil health data in 2018.

Source of Variation[†]	df	Ca	Mg	Na	K	CEC	pH $CaCl_2$	pH H_2O	Active C
Treatment	1	0.1392	0.5510	0.0653	0.6351	0.1490	0.5749	0.3063	0.8549
Landscape position	3	0.0269	0.0104	0.0299	0.0070	0.3802	0.0262	0.0503	0.0004
T x LP[‡]	3	0.8310	0.2560	1.0000	0.4136	0.4917	0.6877	0.9307	0.5007
		TOC	Clay	Silt	Sand	WSA	PMN	Bray 1 P	Bulk Density (BD)
Treatment	1	0.1215	0.8251	0.2497	0.1587	0.1587	0.0639	0.6937	0.0188
Landscape position	3	0.0094	0.0086	0.2733	0.7084	0.7084	0.1198	0.0171	0.0298
T x LP	3	0.9845	0.1748	0.8591	0.9437	0.9437	0.7258	0.3899	0.2398

[†]Source of variation: treatment (T), landscape position (LP)

[‡]Abbreviations: PMN, potentially mineralizable nitrogen; TOC, total organic carbon; WSA, water stable aggregates.

Table 3.10. Mean soil health parameters evaluated in the spring of 2018 determined by cover crop (non-treated control, NTC; and cover crop, CC) treatment main effects and landscape position main effects. Within a column and within a given factor, means followed by the same letter are not statistically different (α = 0.1).

Treatment	Landscape Position	Ca	Mg	Na	K	CEC	pH $CaCl_2$	pH H_2O	Active C
		------------- cmol kg^{-1} -------------							mg C kg^{-1}
NTC		12	2.3	0.08a	0.4	18	5.7	6.0	350
CC		12	2.4	0.05b	0.4	18	5.7	6.1	350
	Shoulder	12b	2.3c	0.05b	0.3b	17	5.7a	6.2a	340bc
	Backslope	12b	2.4ab	0.05b	0.4b	18	5.7a	6.2ab	350b
	Footslope	13a	2.2bc	0.05b	0.4b	19	5.9a	6.3a	420a
	Channel	12b	2.63a	0.12a	0.5a	18	5.5b	5.8b	310c
Treatment	Landscape position	TOC	Clay	Silt	Sand	WSA	PMN	Bray 1 P	Bulk Density
		----------------- g kg^{-1} -----------------					mg kg^{-1}		g cm$^{3 -1}$
NTC		14	250	560	190	220	37b	16	1.29a
CC		15	250	580	160	260	45a	17	1.26b
	Shoulder	15ab	240b	580	170	230	39b	14b	1.30a
	Backslope	15bc	260b	560	190	260	39b	14b	1.28a
	Footslope	17a	240b	590	160	250	51a	15b	1.28a
	Channel	13c	270a	550	180	230	35b	23a	1.23b

Table 3.11. Event mean load values and p-values of nutrient loads including total suspended solids (TSS), total phosphorous (TP) and nitrate-N (NO3-N) cover crop (CC) and non-treated control (NTC) treatments. Within a column and within a given factor, means followed by the same letter are not statistically different ($\alpha = 0.1$).

	Cover Crop Season† Feb. 2017 to Mar. 2017				Corn‡ Apr. 2017 to Sep. 2017				Cover Crop Season§ Oct. 2017 to Mar. 2018			
Treatment	TSS	TP	NO_3-N	Event Mean Discharge	TSS†	TP	NO_3-N	Event Mean Discharge	TSS†	TP	NO_3-N	Event Mean Discharge
	----------g ha^{-1}----------			$m^3\ ha^{-1}$	----------g ha^{-1}----------			$m^3\ ha^{-1}$	----------g ha^{-1}----------			$m^3\ ha^{-1}$
CC	268b	6b	162b	13b	3070b	103b	2450b	105b	5384b	11b	1625b	137b
NTC	1267a	69a	849a	53a	7783a	190a	5857a	183a	5747a	13a	2071a	218a
p-value	<0.0001	0.0075	0.0003	<0.0001	0.0021	0.0142	0.0011	0.0124	0.0784	0.0457	0.0016	0.0066

†Event mean loads of 8 storm events

‡Event mean loads of 9 storm events

§Event mean loads of 9 storm events

Table 3.12. Mean values and p-values of the nutrient concentration of drainage water including total suspended solids (TSS), total phosphorous (TP) and nitrate-N (NO3-N) for cover crop (CC) and non-treated control (NTC) treatments. Within a column and within a given factor, means followed by the same letter are not statistically different (α = 0.1).

	Cover Crop Season† Feb. 2017 to Mar. 2017			Corn‡ Apr. 2017 to Sep. 2017			Cover Crop Season§ Oct. 2017 to Mar. 2018		
Treatment	TSS	TP	NO_3-N	TSS†	TP	NO_3-N	TSS†	TP	NO_3-N
	----------mg L^{-1}----------			----------mg L^{-1}----------			----------mg L^{-1}----------		
CC	24.24	0.8103	13.06	63.55	1.0041	21.67b	71.59a	0.1727b	5.85b
NTC	24.45	0.7887	12.31	53.03	1.0858	30.30a	70.43b	0.1790a	10.01a
p-value	0.7433	0.9093	0.3240	0.8233	0.6506	0.0270	0.0490	0.0796	0.0005

†Event mean concentrations of 8 storm events

‡Event mean concentrations of 9 storm events

§Event mean concentrations of 9 storm events

REFERENCES

Abel, D.S. 2013. Cover crop effects on soil moisture and water quality. Department of Agronomy, Kansas State University, Manhattan, Kansas. pp. 23-98.

Al-Kaisi, M. 2001. Install and maintain terraces for conservation. Ext. Pub. IC-486(16). Iowa State Univ. Ext, Ames, Iowa.

Alexander, R.B., R.A. Smith, G.E. Schwarz, E.W. Boyer, J.V. Nolan, and J.W. Brakebill. 2008. Differences in phosphorus and nitrogen delivery to the Gulf of Mexico from the Mississippi River Basin. Environ. Sci. Technol. 42:822-830. doi: 10.1021/es0716103.

Anderson, N.P., J.M. Hart, N.W. Christensen, M.E. Mellbye, and M.D. Flowers. 2010. Using the nitrogen mineralization soil test to predict spring fertilizer N rate for soft white winter wheat grown in western Oregon. Ext. Pub. EM 9020. Oregon State Univ. Ext. Service, Corvallis, Oregon. pp. 1-5

Aryal, N., R. M.L., N. Straitt, T.G. Teague, J. Bouldin, and S. Dabney. 2018. Impact of cover crop and season on nutrients and sediment in runoff water measured at the edge of fields in the Mississippi Delta of Arkansas. J. Soil Water Conserv. 73:24-34. doi: 10.2489/jswc.73.1.24.

Baker, J.L., M.J. Helmers, and J.M. Laflen. 2006. Water management practices: Rain-fed cropland. In: M. Schnepf and C. Craig, editors, Environmental benefits of conservation on cropland: The status of our knowledge. Soil and Water Conservation Society, Ankeny, Iowa. pp. 89-130.

Barnes, J.P., and A.R. Putnam. 1983. Rye residues contribute weed suppression in no-tillage cropping systems. J. Chem. Ecol. 9:1045-1057. doi: 10.1007/BF00982210.

Basche, A., and M. DeLonge. 2017. The impact of continuous living cover on soil hydrologic properties: A meta-analysis. Soil Sci. Am. J. 81:1179-1190. doi:10.2136/sssaj2017.03.0077

Belfry, K.D., and L.L. Van Erd. 2016. Establishment and impact of cover crops intersown into corn. Crop Sci. 56:1245-1256.

Blanco-Canqui, H., T.M. Shaver, J.L. Lindquist, C.A. Shapiro, R.W. Elmore, C.A. Francis, and G.W. Hergert. 2015. Cover crops and ecosystem services: Insights from studies in temperate soils. Agron. J. 107:2449-2474. doi: 10.2134/agronj15.0086.

Bray, R.H., and L.T. Kurtz. 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Sci. So. Am. J. 59:39-45.

Buckley, M.E., G.J. Kluitenberg, D.W. Sweeny, K.W. Kelley, and L.R. Stone. 2010. Effect of tillage on the hydrology of a claypan soil in Kansas. Soil Sci. Soc. Am. J. 74:2109-1119.

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley, and V.H. Smith. 1998. Nonpoint pollution of surface waters with phosphorous and nitrogen. Ecol. Appl. 8:559-568.

Cartwright, L. 2016. Adding cover crops and reducing tillage in a corn-corn-wheat double crop soybean furrow irrigated rotation. Missouri Cover Crop Economics Case Study 4. USDA, Columbia, Missouri. pp. 1-2.

Centner, T.J., J.E. Houston, A.G. Keeler, and C. Fuchs. 1999. The adoption of best management practices to reduce agricultural water contamination. Limnologica 29:366-373. doi: 10.1016/S0075-9511(99)80029-2.

Curell, C. 2012. Overseeding cover crops. Michigan State Univ. Ext. http://canr.msu.edu/news/ov erseeding_cover_crops (accessed 25 Jun. 2018).

Curran, W.S., R.J. Hoover, S.B. Mirsky, G.W. Roth, M.R. Ryan, V.J. Ackroyd, J.M. Wallace, M.A. Dempsey, and C.J. Pelzer. 2018. Evaluation of cover crops drill interseeded across the Mid-Atlantic region. Agron. J. 110:435-443.

Curran, W.S., and G.W. Roth. 2013. Cover crop interseeder: Impacts on corn yield. Penn State Univ. Ext. https://extension.psu.edu/cover-crop-interseeder-impacts-on-corn-yield (accessed 12 May 2018).

den Hollander, N.G., L. Bastiaans, and M.J. Kropff. 2007. Clover as a cover crop for weed suppression in an intercropping design: II. Competitive ability of several clover species. European J. of Agron. 26:104-112. doi: 10.1016/j.eja.2006.08.005.

Dickey, E.C., T. Hamer, D. Hay, and P.J. Jasa. 1985. Terrace systems for Nebraska. Ext. Pub. G85-750. Univ. of Nebraska Ext., Lincoln, Nebraska. pp. 1-6.

Dinnes, D.L., D.L. Karlen, D.B. Jaynes, T.C. Kaspar, J.L. Hatfield, T.S. Colvin, and C.A. Cambardella. 2002. Nitrogen management strategies to reduce nitrate leaching in tile-drained Midwestern soils. Agron. J. 94:153-171. doi: 10.2134/agronj2002.1530.

Duiker, S.W. 2014. Establishment and termination dates affect fall-established cover crops. Agron. J. 106:670-678. doi: 10.2134/agronj2013.0246.

Environmental Protection Agency. 2007. Hypoxia in the northern Gulf of Mexico: An update by the EPA science advisory board. EPA-SAB-08-003. Science Advisory Board, Washington D.C. pp. 69-70.

Frye, W.W., R.L. Blevins, M.S. Smith, S.J. Corak, and J.J. Varco. 1988. Role of annual legume cover crops in efficient use of water and nitrogen. ASA Special Pub. Cropping Strategies for Efficient Use of Water and Nitrogen. 51:129-154. doi:10.2134/asaspecpub51.c8

Geist, L., P. Scharf, B. Myers, and P. Guinan. 2013. Topsoil lost to rainfall costs farmers money erosion of topsoil can permanently reduce farmland productivity. News from Univ. of Missouri Ext. Univ. of Missouri Ext., Columbia, Missouri.

Ghidey, F., and E.E. Alberts. 1998. Runoff and soil losses as affected by corn and soybean tillage systems. J. Soil Water Conserv. 53:64-70.

Hatfield, J.L., L.D. McMullen, and C.S. Jones. 2009. Nitrate-nitrogen patterns in the Raccoon River basin related to agricultural practices. J. Soil Water Conserv. 64:190-199. doi: 10.2489/jswc.64.3.190

Her, Y., I. Chaubey, J. Frankenberger,and J. Jeong. 2017. Implications of spatial and temporal variations in effects of conservation practices on water management strategies. Agric. Water Manag. 180:252-266. doi: 10.1016/j.agwat.2016.07.004.

Hewes, L., and P.E. Frandson. 1952. Occupying the wet prairie: The role of artificial drainage in Story County, Iowa. Annals of the Assoc. of American Geographers. 42:24-50. doi: 10.2307/2561045

Holmgren, G.G.S., R.L. Juve, and R.C. Geschwender. 1977. A mechanically controlled variable rate leaching device. Soil Sci. Soc. Am. J. 41:1207-1208.

Johnson, J. 2008. Terraces popular in protecting Muchakinock Creek. NRCS Conservation Showcase. USDA, Des Moines, IA. pp 1-3.
Johnson, T.J., T.C. Kaspar, K.A. Kohler, S.J. Corak, and S.D. Logsdon. 1998. Oat and rye overseed into soybean as fall cover crops in the upper Midwest. J. Soil Water Conserv. 53:276-279.
Jones, M.M., and R.P. Beasley. 1943. Corn tillage studies on rolling putnam silt loam Columbia, Missouri. Bull 475. Univ. of Missouri Agric. Exp. Stn., Univ. of Missouri, Columbia, Missouri.
Kemp, L., and S. Lyutse. 2011. Executive summary. In: C. Salazar, editor, Second harvest: Bioenergy from cover crop biomass. Natural Resources Defense Council, New York, New York. pp. 4-7.
King, K.W., M.R. Williams, and N.R. Fausey. 2015a. Contributions of systematic tile drainage to watershed-scale phosphorous transport. J. Environ. Qual. 44:486-494. doi: 10.2134/jeq2014.04.0149
King, K.W., M.R. Williams, M.L. Macrae, N.R. Fausey, J. Frankenberger, D.R. Smith, P.J.A. Kleinman, and L.C. Brown. 2015b. Phosphorous transport in agricultural subsurface drainage: A review. J. Environ. Qual. 44:467-485.
Koehler-Cole, K., R.W. Elmore, H. Blanco-Canqui, C.A. Francis, D. Heeren, S. Irmak, C. Proctor, C.A. Shapiro, T. Shaver, and M. Stockton. 2016. Biomass production of winter annual cover crops in corn and soybean. Univ. of Nebraska. http://cropwatch.unl.edu/201 6/spring-biomass-production-winter-annual-cover-crops-corn-and-soybean (accessed 17 Jun., 2018).
Lerch, R.N., E.J. Sadler, N.R. Kitchen, K.A. Sudduth, R.J. Kremer, D.B. Myers, C. Baffaut, S.H. Anderson, and C.H. Lin. 2008. Overview of the Mark Twain Lake/Salt River Basin conservation effects assessment project. J. Soil Water Conserv. 63:345-359. doi: 10.2489/jswc.63.6.345
Licht, M., and T.C. Kaspar. 2015. Tips and considerations for getting started with cover crops. Integrated Crop Manage. News Pub 823. Iowa State Univ. Ext., Ames, Iowa. pp. 1.
Littell, R.C., G.A. Milliken, W.W. Stroup, R.D. Wolfinger, and O. Schabenberger. 2007. SAS for mixed models. SAS Institute.
Macrae, M.L., M.C. English, S.L. Schiff, and M. Stone. 2007. Intra-annual variability in the contribution of tile drains to basin discharge and phosphorus export in a first-order agricultural catchment. Agric. Water Manage. 92:171-182. doi: 10.1016/j.agwat.2007.05.015
Maloney, T.E., W.E. Miller, and T. Shiroyama. 1972. Algal responses to nutrient additions in natural waters. I. Laboratory assays. In: G.E. Likens, editor, Nutrients and Eutrophication. Spec. Symp. Vol. 1. Am. Soc. Limnol. Oceanogr., Allen Press, Lawrence, Kansas.
Martens, D.A. 2001. Nitrogen cycling under different soil management properties. Adv. Agron. 70:143-191. doi: 10.1016/S0065-2113(01)70005-3
Massey, R.E. 2016. Custom rates for farm services in Missouri. Ext. Pub. G302. Univ. of Missouri Ext., Columbia, Missouri. pp. 1-6.

Mutch, D. 2013. Incorporating cover crops into corn systems. Michigan State Univ. Ext. Michigan State Univ. http://canr.msu.edu/news/incorporating_cover¬-_crops_into_corn_systems. (accessed 26 Jun 2018).
Myers, R., C. Ellis, R. Hoormann, T. Reinbott, N. Kitchen, and J. Reisner. 2015. Cover crops in Missouri: Putting them to work on your farm. Ext. Pub. G4161. Univ. of Missouri Ext., Columbia, MO. pp. 1-6.
Nathan, M., J.A. Stecker, and Y. Sun. 2012. Soil testing in Missouri, A Guide for Conducting Soil Tests in Missouri, Division of Plant Sciences, College of Agriculture, Food, and Natural Resources, Columbia, Missouri.
National Agricultural Statistics Service. 2012. Quick Stats. United States Dept. of Agriculture. https://quickstats.nass.usda.gov. (accessed 4 May 2017).
United States Drought Monitor. 2015. U.S. drought monitor map archive. Available at http://droughtmonitor.unl.edu/MapsAndData/MapArchive.aspx (accessed 5 June 2015). Lincoln, NE: National Drought Mitigation Center.
Nelson, K.A., W.G. Johnson, J.D. Wait, and R. Smoot. 2006. Winter-annual weed management in corn (*Zea mays*) and soybean (*Glycine max*) and the impact on soybean cyst nematode (*Heterodera glycines*) egg population densities. Weed Sci. 20:965-970.
Nelson, K.A., R.E. Massey, and B.A. Burdick. 2011. Harvest aid application timing affects wheat and relay intercropped soybean. Agron. J. 103:851-855. doi: 10.2134/agronj2010.0384.
NRCS. 2004. Soil survey laboratory methods manual. 4th ed. In: R. Burt, editor. USDA, Lincoln, Nebraska. pp. 163, 181, 188, 231, 379.
NRCS. 2010. Conservation practice standard: underground outlet code 600. National Handbook of Conservation Practices. 600-1-600-4.
NRCS. 2013. Conservation practice standard: underground outlet code 620. National Handbook of Conservation Practices. 620-1-620-4.
NRCS. 2013. Terrace inlets: Why orifices are important. USDA. pp. 1.
NRCS. 2016. Sheet and rill/gully erosion resource concern. N340 Cover crop. 34-37.
Royer, T.V., M.B. David, and L.E. Gentry. 2006. Timing of riverine export of nitrate and phosphorus from agricultural watersheds in Illinois: Implications for reducing nutrient loading to the Mississippi River. Environ. Sci. Technol. 40:4126-4131. doi: 10.1021/es052573n
Sabotyagov, S.S., T.D. Campbell, M. White, J.G. Arnold, J. Atwood, M.L. Norfleet, C.L. Kling P.W. Gassman, A. Valcu, R. J., R.E. Turner, and N.N. Rabalais. 2014. Cost-effective targeting of conservation investments to reduce the northern Gulf of Mexico hypoxic zone. Proc. Natl. Acad. Sci. USA. 111:18530-18535.
Sandler, L.N., K.A. Nelson, and C.J. Dudenhoeffer. 2015a. Radish planting date and nitrogen rate for cover crop production and the impact on corn yields in upstate missouri. Journal of Agric. Sci. 7:1-13. doi: 10.5539/jas.v7n6p1.
Sandler, L.N., K.A. Nelson, C.J. Dudenhoeffer, R.J. Miles, and P.P. Motavalli. 2015b. Effect of radish overseeded planting date on interseeded soybean and corn yield. Crop Forage Turfgrass Manage. 1:1-10. doi: 10.2134/CFTM2015.0119.
SARE-CTIC. 2016. Cover crop survey: 2015-2016 annual report. Conserv. Technol. Inf. Ctr., Sust. Agric. Res. Educ., Am. Seed Trade Assoc.

https://www.sare.org/Learning-Center/Topic-Rooms/Cover-Crops/Cover-Crop-Surveys (accessed 28 Aug. 2017).
Sawyer, J. 2015. Nitrogen loss. Iowa State Univ. Ext. https://crops.extension.iastate.edu/cropnews/2015/12/nitrogen-loss. (accessed 11 Sep. 2017).
Schindler, D.W., R.E. Hecky, D.L. Findlay, M.P. Stainton, B.R. Parker, M.J. Paterson, K.G. Beaty, M. Lyng, and S.E.M. Kasian. 2008. Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment. Proc. Natl. Acad. Sci. USA. 105:11254-11258. doi: 10.1073/pnas.0805108105.
Schnitkey, G., J. Coppess, and N. Paulson. 2016. Costs and benefits of cover crops: An example with cereal rye. Farmdoc Daily 6. Dept. of Agric. and Comsumer Econ., Univ. of Illiniois, Urbana-Champaign, Illinois.
Schnitkey, G., and D. Lattz. 2017. Machinery cost estimates for 2017. Farmdoc Daily 7. Dept. of Agric. and Comsumer Econ., Univ. of Illiniois, Urbana-Champaign, Illinois.
Schottman, R.W., and J. White. 1993. Choosing terrace systems. Ext. Pub. G1500. Univ. of Missouri Ext., Columbia Missouri. pp. 1-4.
Scott, T.W., J. Mt. Pleasant, R.F. Burt, and D.J. Otis. 1987. Contributions of ground cover, dry matter, and nitrogen from intercrops and cover crops in a corn polyculture system. Agron. J. 79:792-798. doi: 10.2134/agronj1987.00021962007900050007x.
See, C. 2017. NRCS cover crop cost share program in Knox County, Missouri, In: R.L. Adler (interviewer), NRCS.
Sharpley, A.N., T. Daniel, T. Sims, J. Lemunyon, R. Stevens, and R. Parry. 2003. Agricultural phosphorus and eutrophication. 2nd ed. USDA-Agricultural Research Serice ARS-49. U.S. Gov. Print. Office, Washington, D.C.
Singer, J.W. 2008. Corn belt assessment of cover crop management and preferences. Agron. J. 100:1670-1672. doi: 10.2134/agronj2008.0151
Smil, V. 1999. Nitrogen in crop production: An account of global flows. Global Biogeochemical Cycles 13:647-662. doi: 10.1029/1999GB900015
Smith, D.R., K.W. King, L. Johnson, W. Francesconi, P. Richards, D. Baker, and A.N. Sharpley. 2015. Surface runoff and tile drainage transport of phosphorus in the Midwestern United States. J. Environ. Qual. 44:495-502. doi: 10.2134/jeq2014.04.0176
SSSA. 2008. Glossary of soil science terms 2008. In: Glossary of soil science terms, SSSA, Madison, Wisconsin pp. 1-82. doi:10.2136/2008.glossarysoilscienceterms
SSSA. 2018. Soil horizons. SSSA. https://www.soils4teachers.org/soil-horizons (accessed 1 Oct. 2018).
Strock, J.S., P.M. Porter, and M.P. Russelle. 2004. Cover cropping to reduce nitrate loss through subsurface drainage in the northern U.S. Corn belt. J. Environm. Qual. 33:1010-1016.
Sudduth, Kenneth A., S.T. Drummond, and D.B. Myers. 2012. Yield editor 2.0: software for automated removal of yield map errors. Dallas, Texas, July 29-August 1, 2012. American Society of Agricultural and Biological Engineers, 2012. pp. 1-14.

Sweeney, D.W. 2017. Does 20 years of tillage and N fertilization influence properties of a claypan soil in the eastern Great Plains? Agric. Environ. Lett. 2:170025. doi:10.2134/ael2017.08.0025

Teasdale, J.R., C.E. Beste, and W.E. Potts. 1991. Response of weeds to tillage and cover crop residue. Weed Sci. 39:195-199.

Tomer, M.D., D.W. Meek, D.B. Jaynes, and J.L. Hatfield. 2003. Evaluation of nitrate nitrogen fluxes from a tile-drained watershed in central Iowa. J. Environ. Qual. 2:642-653. doi:10.2134/jeq2003.6420

Tonitto, C., M.B. David, and L.E. Drinkwater. 2006. Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics. Agriculture, Ecosystems & Environment 112:58-72. doi:10.1016/j.agee.2005.07.003.

Tribouillois, H., C. Dürr, D. Demilly, M.-H. Wagner, and E. Justes. 2016. Determination of germination response to temperature and water potential for a wide range of cover crop species and related functional groups. PLoS ONE 11:1-16. doi: 10.1371/journal.pone.0161185.

Triplett, G.B. 1962. Intercrops in corn and soybean cropping systems. Agron. J. 54:106-109. doi: 10.2134/agronj1962.00021962005400020004x.

Vanni, M.J., W.H. Renwick, J.L. Headworth, J.D. Auch, and M.H. Schaus. 2001. Dissolved and particulate nutrient fl x from three adjacent agricultural watersheds: A five-year study. Biogeochemistry. 54:85-114.

Villamil, M.B., G.A. Bollero, R.G. Darmody, F.W. Simmons, and D.G. Bullock. 2005. No-till corn/soybean systems including winter cover crops: Effects on soil properties. Soil Sci. Soc. Am. J.:1936-1944. doi:10.2136/sssaj2005.0350

Weil, R.R., R.I. Kandikar, M.A. Stine, J.B. Gruver, and S.E. Samson-Liebig. 2003. Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use. Am. J. Alternative Agric. 18:3-17. doi: 10.1079/AJAA200228

Wells, M.S., S.C. Reberg-Horton, and S.B. Mirsky. 2016. Planting date impacts on soil water management, plant growth, and weeds in cover-crop-based no-till corn production. Agron. J. 108:162-170. doi: 10.2134/agronj2014.0524.

Wheaton, R.Z., and E.J. Monke. 1981. Terracing as a `best management practice' for controlling erosion and protecting water quality. Ext. Pub. AE-114. Purdue Univ., West Lafayette, Indiana. pp. 1.

Wilson, M.L., D.L. Allan, and J.M. Baker. 2014. Aerially seeding cover crops in the northern US corn belt: Limitations, future research needs, and alternative practices. J. Soil Water Conserv. 69:67A-72A. doi: 10.2489/jswc.69.3.67A

Wilson, M.L., J.M. Baker, and D.L. Allan. 2013. Factors affecting successful establishment of aerially seeded winter rye. Agron. J. 105:1868-1877. doi: 10.2134/agronj2013.0133.

Young, F.J., and R.D. Hammer. 2000. Soil–landform relationships on a loess-mantled upland landscape in Missouri. Soil Sci. Am. J. 64:1443-1454. doi: 10.2136/sssaj2000.6441443x.

Zhu, Q., J.P. Schmidt, and R.B. Bryant. 2012. Hot moments and hot spots of nutrient losses from a mixed land use watershed. J. Hydrol. 414:393-404. doi: /10.1016/j.jhydrol.2011.11.011

CHAPTER 4
LONG-TERM REDUCED TILLAGE AND NO-TILL CROPPING SYSTEMS AFFECT CROP YIELDS, SOYBEAN CYST NEMATODE, AND CLAYPAN SOIL PROPERTIES

ABSTRACT

There has been an increase in the implementation of conservation practices on highly erodible soils of Missouri. When combining use of cover crops with conservation tillage, cover crops may improve productivity of degraded soils. The objectives of this research were to evaluate the effect of long-term no-till and reduced tillage cropping systems on yields, soil chemical properties, soybean cyst nematode (*Heterodera glycines*) egg population densities, and economics. This research was initiated in 1994 near Novelty, MO. Treatments included a corn (*Zea mays* L.)-soybean [*Glycine max* (L.) Merr.]-wheat (*Triticum aestivum* L.) rotation with three tillage/cropping systems: 1) no-till corn-soybean-wheat with double crop soybean (NT DCS), 2) no-till corn-soybean-wheat with frost-seeded red clover (*Trifolium pretense*) cover crop (NT FSC), and 3) reduced-till corn-soybean-wheat (RT). Each crop and cropping system was represented each year in nine large plots (9.1 by 90 m). The reduced tillage treatment included fall chisel plowing before corn and soybean followed by a finishing tool in the spring, while a finishing tool is utilized prior to planting wheat. Soil was sampled to a 15 cm depth to evaluate soil chemical properties (1994, 2002-2016) and soybean cyst nematode (SCN) egg population densities (2002-2016). Significant differences in corn yields occurred in 1995-96, 2000, 2009-10, and 2015-16 with the highest yielding treatments in five RT, one NT DCS, and one RT=NT DCS. Significant differences in soybean yield occurred in 2000, 2002, and 2006 with the highest yielding cropping system being two NT DCS and one RT system. Significant differences in wheat yield occurred in 2008, 2009, 2011, and

2014 with four RT systems being the highest yielding. Combined over years, SCN egg population densities were lowest using the NT FSC cropping system. Differences in soil chemical properties occurred between cropping systems when combined over years. Soil test pHs, P, and K were ranked RT=NT DCS>NT FSC, RT>NT DCS=NT FSC, and RT>NT FSC>NT DCS, respectively. Greatest levels of soil organic matter occurred in 2003, 2005, 2008, and 2010, in NT FSC. Input costs were greatest in RT and NT DCS cropping systems; however, net income was greatest in NT DCS. The highest net returns were observed with NT DCS ($568 ha^{-1}). Producers should match cropping systems with individual management goals specific to each rotational crop.

INTRODUCTION

Beneficial ecosystem functions in managing the biotic component of soil quality are important for decomposition and nutrient cycling, detoxification of soil toxins, water storage, and suppression of pathogenic organisms (Doran and Zeiss, 2000). Conservation programs over the years for managing soil health have included abiotic and simple biotic soil indicators of soil health. Tillage systems can affect crop production, biotic factors of soils, and chemical properties, but the impact of long-term cropping systems on monoculture and the cost-effectiveness of these systems are essential to affect farmer decisions.

Early humans devised primitive tools for scratching and digging in the soil between 5000 to 3000 B.C. which facilitated the transfer to on current conventional agriculture systems from hunting and gathering (Lal, 2009). Since that time, tillage has been used to promote mineralization of soil organic matter (SOM), manage weeds, loosen compacted soil, and develop a seedbed that aids mechanical planting and seed-to-soil contact (Ofori, 1993; Ryan et al., 2011). Like other conservation practices, there are both assets and liabilities surrounding reduced tillage (RT) or no tillage (NT) cropping systems. Crop residue management, rotation practices, and changes in tillage programs all prompt major alterations in soil microbial properties (Govaerts et al., 2007) and influence the timing and amount of nutrient cycling (Martens, 2001). Slight deviations in cultural farming practices can have significant long-term results; therefore, long-term experiments are necessary to quantify practice effects under fluctuating weather conditions (Varvel, 2006).

Soil productivity is affected by tillage systems which can subsequently impact soil properties (Martens, 2001). Before the 1960's, multiple tillage operations each season reaching soil depths of 18-20 cm were a commonplace and affected weed growth, soil crusting, crop establishment, surface water runoff, and compaction (Whitaker et al., 1966). Research on reduced and NT cropping systems have intensified with increased focus on the importance of soil conservation. Research in Austria reported short-term tillage altered soil physical properties through the incorporation of crop residues as well as mineral and organic fertilizers which influence nutrient availability (Neugschwandtner et al., 2014). Stecker (1993) reported immobilization of surface applied N was an indirect result of increased crop residue in no-till production systems. These effects of intensive tillage amass over time leading to compaction, degradation of SOM, loss of soil physical properties, and development of a hardpan (Al-Kaisi and Hanna, 2004) which have a negative effect on plant growth and crop production. No-till planting systems conserve moisture; reduce erosion, labor, fuel use, and crusting; increase soil firmness at harvest, SOM and tilth (Buchholz et al., 1993). However, a producer moving from a conventional tilled corn (*Zea mays* L.) system to a no-till system can expect costs per hectare to increase in herbicides and interest on operating capital, but there are cost reductions in repairs, fuel, labor, equipment, taxes, insurance, depreciation, and interest (Massey, 1997).

Since 1934, Missouri researchers have been investigating methods for increasing yields and reducing inputs in claypan soils (Jones and Beasley, 1943). Research has shown adoption of NT practices may produce smaller crop yields (Toliver et al., 2012), but yields similar or greater than conventional tillage have also been reported (Al-Kaisi and Kwaw-Mensah, 2007; Al-Kaisi and Licht, 2004). Implementing conservation tillage practices have decreased erosion, improved water quality, enhanced crop available water, and increased soil quality (Martens, 2001). Decreasing erosion increases soil productivity in the long-term (Pimentel et al., 1995). No-till systems have resulted in greater soil moisture levels and smaller soil temperatures (Linden et al., 2000; Toliver et al., 2012). However, an increase in annual rainfall has also increased the probability for reduced NT yields (Toliver et al., 2012). Researchers have attributed these conditions to cause reductions in plant emergence and delayed plant growth (Licht and Al-Kaisi, 2005). When comparing NT to tillage, yield was affected differently by soil, crop, and climate factors (Toliver et al., 2012). In an analysis comparing 442 tillage studies from 92 locations in the United States, Toliver et al. (2012) reported that the probability of having smaller NT corn yields (compared to tillage) increased the longer NT was used, and the probability of increased yield of soybean in NT increased with the length of time using NT. Similarly, Linden et al. (2000) reported reduced corn yields over time with NT. Toliver et al. (2012) attributed yield reductions in NT corn from increased weed, insects, and disease from increased residue, but could also be due to management factors such as nitrogen rates, sources, timing, and/or placement.

Claypan soils compose over 4 million hectares of the Midwest (Buckley et al., 2010) and are characterized by their very slowly permeable abrupt subsoil layer having a much greater clay content than the overlying soil material (SSSA, 2008). Previous research on claypan soils has shown that response to crop management practices is often different from soils with no claypan. Claypan soils have small fertility and water availability, are poorly drained, have shallow rooting depths, and need N management (Ghidey and Alberts, 1998; Sweeny, 2017). During seedbed preparation and when crop protection chemicals are applied, water runoff and soil loss from the claypan region of the Midwest are relatively high raising concern for contamination of watersheds (Ghidey and Alberts, 1998). A long-term study on a claypan soil in Missouri found that no-till systems increased runoff 14 to 20% compared to tillage systems that caused soil disturbance (Ghidey and Alberts, 1998).

A 20-year study on a claypan soil in Southwestern Kansas reported conventional and reduced tillage treatments had no significant effect on soil pH in the top 15 cm or on extractable P or K in the surface to 7.5 cm depth compared to initial tests. However, no-till had significantly lower levels of P, K, and SOM at a 7.5-15 cm depth (Sweeney, 2017). Neugschwandtner et al. (2014) reported similar results in Austria in a silty loam soil. However, a study in Kentucky reported potassium stratification in long-term no-till cropping systems enhanced corn potassium uptake, in comparison to plow tillage (Blevins et al., 1986). In addition to nutrient stratification, no-till's effect on field conditions at planting may be problematic. Soils that are untilled or covered in residue often dry and warm up more slowly (Buchholz et al., 1993). No-till systems have cooler soil temperatures (Al-Darby and Lowery, 1987) and excess moisture during the spring may be the reason cereal grains produced on poorly drained soils are lesser yielding when compared with tilled soils (DeFeliece et al., 2006).

Composing approximately 58% of the mass of soil organic matter (SOM), soil organic carbon (SOC) is often used to estimate SOM (Griffin, 2017). As SOM decomposes, plant nutrients are mineralized (Martens, 2001). Soil organic matter also provides physical benefits such as increased water holding capacity and improved infiltration along with biological benefits which can lead to disease and pest suppression (Fenton et al., 2008). An eight-year study in Southern Illinois reported SOC levels (0-75 cm) in no-till plots with and without a cover crop remained similar; therefore, the cover crop system did not sequester significant levels of SOC (Olson et al., 2010). In a separate twelve-year study in southern Illinois, Olson et al. (2014) reported chisel plow treatments decreased SOC (0-75 cm) in both cover crop and non-cover crop treatments. In moldboard plow treatments, significant losses of SOC occurred in surface soil layers (0-15 cm) in cover crop and non-cover crop treatments. Overall, moldboard plow treatments had a numerical loss of SOC in comparison to SOC at project initiation (0-75 cm). In an 18-year study in Nebraska, Varvel (2006) reported increased levels of SOC (449 kg ha^{-1}) in the top 30-cm of soil in rotational cropping systems for the first eight years. An increase in tillage depth from 10-15 cm to 15 to 20 cm in the subsequent 10 years resulted in a loss of SOC. In long-term research, crop rotations with increased complexity, especially those including a perennial legume, were found to increase SOC levels (Russell et al., 2005; Varvel, 2006; Wilts et al., 2004). The University of Missouri

Soil Health Assessment Center currently recommends decreasing tillage, decreasing periods of bare soil, and implementing a cover crop to increase total (soil) organic carbon (Soil Health Assessment Center, 2016).

Cover crops have been reported to reduce winter annual weeds (Barnes and Putnam, 1983; Myers et al., 2015; Teasdale et al., 1991) and could affect other pests such as soybean cyst nematode (SCN). Soybean cyst nematode causes an estimated $1.5 billion in losses yearly in the US alone (Wrather and Mitchum, 2006). Therefore, SCN management is a vital consideration when evaluating tillage and cover crop systems. In short-term experiments in upstate Missouri, the effects of cover crops and fall applied weed control programs on SCN over a two-year and two-location experiment (Nelson et al., 2006) showed limited effects on cyst nematode egg counts. Greenhouse experiments have illustrated that winter annual weeds including henbit (*Lamium amplexicaule* L.), shepherd's purse [*Capsella bursa-pastoris* (L.) Medik], field pennycress (*Thlaspi arvesne* L.), and purple deadnettle (*Lamium purpureum* L.) were hosts for SCN (Creech et al., 2007; Venkatesh et al., 2000). Although SCN has been reported to complete a reproductive life cycle on purple deadnettle in field conditions, the cold environmental conditions typical of winter annual weeds growing conditions is unfavorable for SCN reproduction (Creech and Johnson, 2006; Creech et al., 2005; Hill and Schmitt, 1989). Furthermore, Creech et al. (2008) found the removal of winter annual weeds had insignificant impacts on SCN egg densities when suggested that a greenhouse setting lacked environmental factors relevant in the field that may limit SCN to reproduction. However, Mock et al. (2007) reported removal of winter annual weeds prior to planting during warm spring weather conditions may provide SCN juveniles time to develop on these winter annuals and time needed to complete a reproductive life cycle.

Long-term research helps understand the effects of cropping systems on production, soils, and pest management strategies. No research on claypan soils has integrated the effects of no-till cropping systems to reduced tillage. Management of tillage and fertilization by producers is economically driven by regional agronomic systems (Sweeney, 2017). Many of these evaluations are short-term with limited evaluations of long-term cropping systems. Conservation efforts are only effective and sustainable if they can be implemented at the farm level and align with individual farmers economic goals (Ongley, 1996). Epplin et al. (2005) points out that farm size plays a role in production cost of conventional compared to NT systems. Input and operating costs must be compared with potential differences in yield and crop market value before adopting conservation systems. Reduced or NT systems saved trips across the field (Chase and Duffy, 1991; Zentner et al., 2002), and reduced fuel consumption, machinery repair, and labor costs (Johnson et al., 1986). Cost-share programs assist farmers to implement conservation practices; however, government cost-sharing requires estimating benefits and cost-effectiveness of a conservation practice before it is adopted (Zhou et al., 2009). Thus, a compromise between return on investment (ROI) and environmental quality is affected by cost-sharing conservation efforts between government agencies (Zhou et al., 2009) as well as commodity prices adopting a practice. Though reduced yields are reported with the implementation of NT, Toliver et al. (2012) predicts that corn and soybean yields would only be reduced by 4.37 and 2.33%, respectively.

Conservation efforts can increase (i.e. constructing terraces, installing tile, etc.) or decrease (i.e. reduction of tillage saves fuel, time on equipment, cost of owning tillage tools, etc.) input costs with a long-term goal to increase yields and production over time, but their impact on crop yield is site-specific (Griffith and Wollenhaupt, 1994). Since yield is not the only factor that contributes to a producer's economic success (Uri, 2000), it is essential to perform an economic analysis that coincides with long term-research. The object of this research was to evaluate the effect of long-term cropping systems management on crop yield, input costs, revenue, net income, soil chemical properties, and soybean cyst nematode egg population densities.

MATERIALS AND METHODS

A long-term cropping systems site was established in 1994 at the University of Missouri Greenley Memorial Research Center near Novelty (40° 01' 8.56"N, 92° 11' 21.20"W). The study was a split-plot design with three rotational crops as the main plot and three cropping systems as the sub-plot with four replications. This site included a corn-soybean-wheat rotation with three tillage/cropping systems [1) no-till corn-soybean-wheat with double crop soybean following wheat (NT DCS), 2) no-till corn-soybean-wheat with frost-seeded red clover (cover crop) into wheat (NT FSC), and 3) reduced-till corn-soybean-wheat (RT)]. Each of the crops and cropping systems were represented each year in nine large plots (9.1 x 91 m). The management year was defined by any management action that was implemented to affect the crop harvested in the year yields were determined. Management for each crop is described in Tables 4.1 to 4.3. Although specific dates were occasionally not recorded, fall tillage occurred each year and spring tillage usually occurred prior to planting in the reduced till treatment.

The main soil type at the site was a Kilwinning silt loam (fine, smectitic, mesic Vertic Epiaqualfs). Soil samples (composite of 10 sub-samples) were collected from the main plots prior to the establishment of the site in 1994 (Table 4.4) and in the spring (Table 4.5) in early to mid-March to a 15-cm depth using a stainless steel push probe before planting to evaluate the effects of cropping systems (sub-plots) on soil chemical properties (2002-2017) analyzed using standard methods of the University of Missouri Soil and Plant Testing Laboratory (Nathan et al., 2012). Soil samples were also analyzed for SCN egg population densities (2002-2015) (Table 4.6) and HG type (2004, 2015, and 2017) using the University of Missouri SCN Diagnostics standard procedures (Mitchum et al., 2007; Niblack et al., 2002).

Manual precipitation observations were recorded on-site (National Weather Service rain gauge) and daily temperature observations were made from a cooperative weather station approximately 32.2 km away (National Weather Service cooperative station, Steffenville, MO) from project initiation to 1 Sep. 1994. Precipitation and temperature data were collected on-site for the duration of the study from 1 Sep. 1994-present using an automated weather station (Campbell Scientific Inc., Logan, UT) and is summarized in Tables 7 and 8.

Corn was planted in the spring using a John Deere 7000 planter (Moline, IL). Soybean was planted in 38-cm rows using a John Deere 7200 or in 19-cm rows using a Great Plains Solid Stand 10 no-till drill (Salina, KS). Winter wheat (*Triticum aestivum* L.) was drill seeded in 19-cm rows the fall using a Great Plains no-till drill and was harvested in the summer of the following calendar year. Double-crop soybean was planted in the summer immediately following wheat harvest, typically using a Great

Plains no-till drill or a John Deere 7000 planter and harvested in the fall. Frost-seeded clover was broadcast seeded into wheat stubble in Feb.-Mar. depending on the weather conditions using a hand or four-wheeler mounted spreader. The reduced tillage treatment included fall chisel plowing (International Harvester, Racine, WI) before corn and/or soybean followed by a field cultivator (John Deere 1000), tandem disk harrow (John Deere, Moline, IL), or finishing tool (Tilloll 875, Landoll Corp., Marysville, KS) in the spring, while a field cultivator, tandem disk, vertical tillage (335 VT, Case IH, Racine, WI), or finishing tool was utilized prior to planting wheat. In select years, rotational crop stubble was shredded using a rotary mower (John Deere 709, Moline, IL) prior to chisel plowing to prevent residue from plugging the chisel plow.

Each year, hybrid and cultivar selections were reviewed, and selection of high yielding hybrids or cultivars were made to align with typical practices of local producers. Weeds were managed using appropriate combinations of burndown herbicides (NT FSC, NT DCS), crop-specific selective herbicides as pre-emergence applications (NT FSC, NT DCS), and post-emergence herbicide applications in all treatments (not presented). Burndown herbicides such as glyphosate, paraquat, and 2,4-D alone or in combination were used for no-till. The cost-effectiveness of the cropping systems was evaluated using historical inputs (Massey, 2016; Plain and White, 2012; Plain et al., 1997; Plain et al., 2000; Plain et al., 2003; Plain et al., 2006; Plain et al., 2009) and yields from the 24-years of research to date. Grain yields (Table 4.9) and moisture (Table 4.10) were determined and adjusted to 150 g kg^{-1} for corn, 130 g kg^{-1} for soybean, and 130 g kg^{-1} for wheat prior to analysis. An R50 Gleaner (Duluth, GA), Gleaner K2 (Duluth, GA), Massey 10

(Massey Ferguson, Duluth, GA), or a Wintersteiger Delta (Salt Lake City, UT) were used to harvest crops.

Data from the 22-years of research were analyzed using Proc UNIVARIATE and GLM models using SAS (SAS Institute, 2013). Box plots were used to illustrate the variability of cropping systems. The box represents 50% of the data and the whiskers represent 95% of the data. Means were separated using Fisher's Protected LSD (P=0.05 or P=0.1) and letters above box plots indicate significant differences among treatments. Similar letters indicate no significant differences between means.

RESULTS AND DISCUSSION

Wheat Grain Yield

Significant differences in wheat grain yield means among cropping systems occurred four times from 1994 to 2016 (Table 4.9). Reduced tillage cropping system wheat yield was similar or 692 to 1492 kg ha^{-1} greater than NT FSC and/or NT DCS in 2008, 2009, 2011, and 2014. A long-term study in Italy reported average grain yield of durum wheat (*Triticum durum* Desf.) and soybean were 390 kg ha^{-1} and 480 kg ha^{-1} lower in NT systems when compared conventional tillage, respectively (Mazzoncini et al., 2008). Conversely, a separate study in Italy reported greater wheat yield (>1 Mg ha^{-1}) in NT systems compared to conventional tillage and RT when water stress was present (Amato et al., 2013). In water adequate conditions, wheat grain yield was over 0.05 Mg ha^{-1} higher in conventional tillage systems when compared to NT systems (Amato et al., 2013). The observed effects on wheat may be due to the use of improved cultivators in recent years compared to cultivators used early in this research. Mean wheat yields were greatest in the RT system (3900 kg ha^{-1}) when combined over years (Fig. 4.1). No-till system wheat yields were similar and lower than RT wheat yield by 180 kg ha^{-1} and 170 kg ha^{-1} in the NT DCS and NT FSC systems, respectively. In 2011, wheat harvested from the NT DCS system had greater moisture than the RT and NT FSC systems by 9 and 11 g kg^{-1}, respectively (Table 4.10).

Corn Grain Yield

Significant differences in corn grain yield means among cropping systems occurred seven times between 1994 and 2016 (Table 4.9). Reduced tillage corn yield was 1588 to 5021 kg ha^{-1} greater than frost-seeded clover (NT FCS) in 1995, 1996, 2000, 2009, 2015, and 2016. RT corn yield was also 252-2780 kg ha^{-1} greater than no-till double crop soybean (NT DCS) in 1995, 1996, 2000, 2009, and 2015. In 2016, NT DCS and FSC had identical yields. NT DCS corn yield was 1337-3779 kg ha^{-1} greater than NT FSC in 1996, 2010, 2015-16. In 2010, NT DCS corn grain yield was 1786 and 2776 kg ha^{-1} higher than FSC and RT yields. When data were combined over years (1994-2016), grain yield response to cropping systems indicated no differences between NT DCS and RT (Fig. 4.1). However, RT yield was greater by 401 to 562 kg $ha^{-1}$when compared to NT systems. Corn yield was categorized as low (<5 Mg ha^{-1}), medium (5-10 Mg ha^{-1}), high (10-15 Mg ha^{-1}), and very high (15-20 Mg ha^{-1}) yielding (Long et al., 2017) (Table 4.13). Reduced tillage had the largest yields when compared with NT cropping systems in years with medium (1995, 1996, 2000, 2009, and 2015) and high (2016) corn grain yields (Table 4.9). No-till corn with double-crop soybean had the highest yields in low (2010), medium (1996 and 2013) and high (2016) yielding years. Similarly, Yost et al. (2016) reported corn produced on a claypan soil in Missouri to have increased resiliency to a variety of environmental conditions caused by unsteady and extreme climate conditions when produced in cropping systems with extended rotations and cover crops such as hairy vetch (*Vicia villosa* R.), cereal rye (*Secale cereal* L.), and red clover.

In 1995 and 1996, large spring rainfall (Table 4.7) caused corn to be planted later into the season than residual herbicide may have provided protection (Johnson et al., 1996). Burndown herbicides were used at lower than labeled rates in environmental conditions prone to herbicide volatility to desiccate red clover (Albaugh LLC, 1993; Monsanto Company, 2017) in formulations that may not have been optimally effective, perhaps allowing cover crop survival (Delvalle, 2014). Poor desiccation may have allowed the cover crop to accumulate additional biomass which may have contributed to nutrient competition with the rotational crop. Reduced yields can also be attributed increased weed, insects, and disease from increased residue in NT systems (Toliver et al., 2012) and early in this research due to the absence of Bt (*Bacillus thuringiensis* B.) corn hybrids.

In 2000, Knox County, MO experienced a severe drought from mid-April to mid-June (National Drought Mitigation Center, 2018). Above average rainfall in June (V6-V10 corn) decreased the drought classification and by the week of 11 Jul. no drought conditions were present. Lipiec et al. (2006) noted greater infiltration rates throughout the growing season in soils tilled to 20 cm in contrast with NT soils. Reduced tillage treatments had an improved root system and were able to access soil water more effectively during drought conditions. Tillage practices that maintain surface crop residue, such as reduced tillage systems and no-till increase SOM and promote infiltration and storage of water (Meijer et al., 2014). Reduced tillage plots may have experienced greater water infiltration and could have greater root growth. No-till plots likely experienced saturated soil conditions through June, during a growth period when corn root growth is expected to be most rapid (Archontoulis et al., 2017). July-September rainfall was below average and temperatures in August and September were above average. Greater yields in NT FSC cropping systems when compared to NT DCS can be attributed to residue management when double-crop soybean were harvested which may have allowed soils to dry out quicker. The combined processed wheat stubble and soybean plants during harvest and left a smooth soil surface with an even distribution of residue that could break down easier. In years of predicted high spring moisture, Unger and Vigil (1998) suggest allowing cover crop growth to persist as long as possible to enhance soil water extraction and bank water for the subsequent growing season. Yost et al. (2016) reported corn produced on claypan soils had increased resiliency to a variety of environmental conditions caused by unsteady and extreme climate when produced in systems with extended rotations and cover crops.

In 2009, high monthly rainfall from March to August in 2009 and heavy winds (74 km h^{-1}) nine days after pollination (Abendroth et al., 2011) could have resulted in root lodging (visual observation). After pollination, root lodging may be more likely than stem lodging, particularly if rooting depth is limited (Ransom, 2016). Excess soil moisture reduces root growth and development (Nielsen and Colville). Wetter soils in NT DCS and NT FSC could have encouraged root lodging and could have reduced yields. However, Bitzer (1983) notes that NT corn at these populations has a lower likelihood of lodging than RT while Nielsen and Colville reported that stands above 59,000 plants ha^{-1} promoted plant competition for nutrients and increased occurrence of stalk lodging.

In 2010 (small yielding) and 2015 (medium yielding), cool temperatures decreased for an extended period between planting and emergence (12-15 days) due to slow accumulation of growing degree days (Abendroth et al., 2009). After planting and before plant emergence in 2010, a series of rainfall events caused soil to remain saturated. Clover cover crop residue may have retained soil moisture and further prevented soil warming. Significantly lower stand establishment was observed in 2010 (Table 4.11) in FSC which could have been due to waterlogging (Kaur et al., 2017). In cotton (Rickerl et al., 1988) and sorghum (Dabney et al., 1996), increased seedling disease was the main reason for decreased growth following legume cover crops. Surface and sub-surface growth inhibition effects have been reported from surface residues (Dabney et al., 1996). Following above average monthly rainfall in April through June, more than three times the average rainfall occurred in July. Excess water reduces root growth, increasing susceptibility to lodging (Ransom, 2016). There was 188 cm of precipitation between July 18 and 20. Although lodging data were not recorded, several studies have reported differences among tillage systems. In a South African study, NT cropping systems experienced less lodging (root or stem) than conventional or reduced tillage systems (Lang et al., 1986) and NT systems were more likely to experience stem lodging than root lodging. However, a study in China reported greater stem lodging damage under NT conditions compared to conventional tillage; however, this did not affect yield, nor the ratio of yield to a 4-year undamaged yield (Aizhen et al., 2017).

Unlike 2010, no stand reduction was observed in 2015 (Table 4.11). On July 16, 82.4 km h^{-1} winds were observed. Corn was approximately at the R1 stage of development. Corn planted in FSC cropping systems could have be at an earlier growth stage than the NT DCS and RT systems if the clover cover crop created cooler or wetter soil conditions that delayed corn emergence. Frost-seeded clover cropping systems could have experienced damage at lower nodes resulting in a larger yield reduction than RT or NT DCS (Ransom, 2016). As discussed above, RT and NT DCS may have better standability than FSC cover crops which may have a greater incidence of disease. Combined over all years, grain yield for RT and NT DCS cropping systems were equal but were 401 to 562 kg ha^{-1} greater than grain yield for NT FSC (Fig. 4.1).

Soybean Grain Yield

Significant differences in soybean grain yield means among cropping systems occurred three times between 1994-2016 with DCS being the highest yielding in 2000 and 2002 (Table 4.9). In 2006, RT and DCS were the greatest yielding cropping systems (Table 4.9). No-till DC soybean system yield was greater than NT FSC and RT by 135 kg and 202 kg ha^{-1} and 336 and 605 kg ha^{-1} in 2000 and 2002, respectively. However, RT and NT FSC soybean yields were 202 to 538 kg ha^{-1} greater than DCS soybean yield in 2006. Average grain yield from 1994-2016 indicated no difference between NT DCS (3174 kg ha^{-1}) and NT FSC (3203 kg ha^{-1}) (Fig. 4.1). Both NT systems yielded 91 to 120 kg ha^{-1} greater than RT. Soybean yield data were categorized as low, medium, or high yielding (Table 4.13) environments (Long et al., 2017; Staggenborg et al., 1996; Wang, 2017). No-till DC soybean had significantly greater yields than RT and FSC in both high (2000 and 2006) and low (2002) yielding years (Staggenborg et al., 1996) demonstrating production resiliency.

In 2006, soybean experienced abnormally dry to moderate drought conditions from planting to harvest (The National Drought Mitigation Center, 2018). Tilled soils may have larger water infiltration rates (Lipiec et al., 2006). Reduced tillage cropping systems may have experienced greater water infiltration and improved water storage and greater yields. On a claypan soil in Missouri, Yost et al. (2016) reported yield advantages of conservation cropping systems were greater in soybean than in corn. Similarly, Edwards et al. (1988) also reported increased soybean yield with conservation tillage practices when examining tillage and crop rotations.

Soybean Cyst Nematode

Evaluated prior to planting corn, greatest SCN egg population densities occurred once (P=0.05) in 2011 in the NT DCS cropping system (Table 4.6). Egg population densities in all years and cropping systems evaluated were categorized as low (<5,000 eggs/250 cm^3) (Tylka). No significant interaction between treatments and years (n=12) was detected; therefore, data were combined over years. Soybean cyst nematode egg population densities (Fig. 4.2) were greatest in RT and NT DCS and lowest in NT FSC cover crop prior to planting soybean. Egg population density decreased 25-93% in corn-soybean rotations with reduced tillage intensity in Indiana (Westphal et al., 2009), northeast Alabama (Edwards et al., 1988), and Kentucky (Hershman and Bachi, 1995), but there was no effect of tillage in Minnesota (Chen et al., 2001).

In more than 95% of currently available SCN resistant soybean varieties, the resistance source is PI 88788 (HG type test indicator line #2) (Tylka and Mullaney, 2015). Soybean cyst nematode HG tests performed in 2004, 2015, and 2017, were Type 1.2.5.7, 1.2.4, and 1.2, respectively. In years that a SCN resistant soybean variety was planted, it is unlikely that it protected the crop against SCN; however, a longer rotation period with NT FSC maintained low (<100 eggs/250 cm^3) egg population densities.

Soil chemical properties

At the initiation of this experiment, no significant differences in soil chemical properties were observed (Table 4.4). When data were combined over years (1994, 2002-2016), significant differences in soil test pHs, P, and K occurred between cropping systems (P=0.05) (Table 4.5). Soil pH_s was 0.07 units greater in RT and NT DCS compared to NT FSC. Decomposition of SOM and nitrification of ammonia-based fertilizers produces H^+ (Havlin et al., 2014) which decreases soil pH. Rengel (2003) reported H^+ production from red clover to be 128-180 cmol kg shoot^{-1}. Increased organic matter in NT FCS plots had lower soil pH when compared to RT or NT DCS. Soil test K was greater in RT than NT FSC and NT DCS, and greater in NT FSC than in NT DCS. There was greater K removal in the grain of the DC soybeans which probably reduced soil test K. The reduced tillage cropping system had greater levels of soil P than NT FSC or NT DCS. Similarly, in a long-term NT study in Maryland, reported increased plant available P in the cover crop treatment when compared to winter fallow treatments (Grove et al., 2007). Conversely, a long-term study in Austria reported higher levels of P in upper soil layers (0-10 cm) in NT and conservation tillage systems compared to moldboard plow systems while NT and shallow conservation tillage had lower P than deep tillage at 30-40 cm depths (Neugschwandtner et al., 2014). Furthermore, the study reported K in top 10-cm of soil to be greatest in NT cropping systems. Grove et al. (2007) reported higher levels of both P and K in the top 15 cm of soil in NT systems compared with a fall chisel plow and disk system which was counter to our results.

In soybean, P and K removal is higher than corn (Table 4.15) (Nathan et al., 2006). In the NT DCS cropping system, soybean was planted twice in a three-year rotation whereas in RT and NT FSC soybean was planted only once. Therefore, lesser levels of these nutrients are expected in NT DCS if nutrient management was static across all cropping systems. Fertilizer was managed similarly among similar crops (Tables 4.1-4.3) however, different cropping systems may have had different removal rates. When combined over years (1994-2016), NT DCS and NT FSC soybean yields were significantly higher when compared with RT systems (Fig. 4.1). Increased planting frequency of soybean and highest soybean yield over time resulted in smaller soil test levels of nutrients.

Significant differences in soil organic matter (P=0.05) occurred in 2003, 2005, 2008, and 2009 (Fig 4.3). In 2003, 2008, and 2010, NT FSC and NT DCS was 0.75 to 3.0 g kg^{-1} greater than RT. In 2005, NT FSC was 6.25 and 6.75 kg ha^{-1} greater than RT and NT DCS, respectively (Table 4.14). Several other studies have reported cropping systems including a cover crop had increased SOM (Buchholz et al., 1993; Bowman et al., 2007 ; Soil Health Assessment Center, 2016). It is likely that larger SOM levels in the NT DCS system were a result of four crops in three years when compared to RT which experienced three crops in three years. A long-term study in Nebraska reported that more than one point-in-time measurement was necessary to measure SOC when multiple variables are used (Varvel, 2006)**.**

Economics

Yield data were unable to adequately analyze the profitability of the DC soybean system. However, all data were combined over years and main effects for individual cropping systems were presented (Fig. 4.5). Significant differences in net income among cropping systems occurred eleven times in corn, six times in soybean, and eighteen times in wheat (Table 4.16). For corn, there were seven years NT DCS had the greatest net return, while RT and NT FSC had the greatest net income three and one time, respectively. For soybean, the greatest net income system was NT DCS for four years and NT FSC for two years. No-till double crop soybean had the highest net returns for wheat cropping systems 18 years. Double crop soybean input costs and profits are reflected in wheat net income. The NT DCS system had the highest net income system the most frequently for each rotational crop. Combined across rotational crops of the same tillage treatment, net income of NT DCS was significantly greatest five times (Fig. 4.4). Net returns were ranked NT DCS>NT FSC=RT when combined over years and crops. Limited long-term research has been done evaluating the impact of tillage on net returns in a corn-soybean-wheat rotation. A 10-year tillage study in Montana comparing five tillage treatments also reported greatest net economic returns (\$19.04 ha^{-1}) in a NT system (Aase and Schaefer, 1996). However, this monoculture study examined only continuous spring wheat and was performed under different environmental conditions (Aase and Schaefer, 1996).

CONCLUSIONS

Long-term cropping systems are important to understand economic, ecological, and production relations. Combined over years, wheat and corn had the significantly greatest yields in the RT cropping system, 7850 kg ha^{-1} and 3990 kg ha^{-1}, respectively. Soybean was highest yielding in the NT FSC system (3200 kg ha^{-1}). The no-till double crop soybean cropping system was the most profitable of the three systems and had a mean net income of \$567 ha^{-1}, \$145 ha^{-1} and 165 ha^{-1} greater than FSC and RT respectively. The NT FSC had the highest levels of organic matter prior to planting corn for four years (29.25 to 37.75 g kg^{-1}). Combined over 14 years of data (2002-2016), soybean cyst nematode egg population densities were least in the NT FSC prior to planting corn, soybean, and wheat. No system yielded the most desirable outcomes for all factors evaluated. The highest yielding system did not always correlate with highest net incomes. Producers should select cropping systems based on individual management goals.

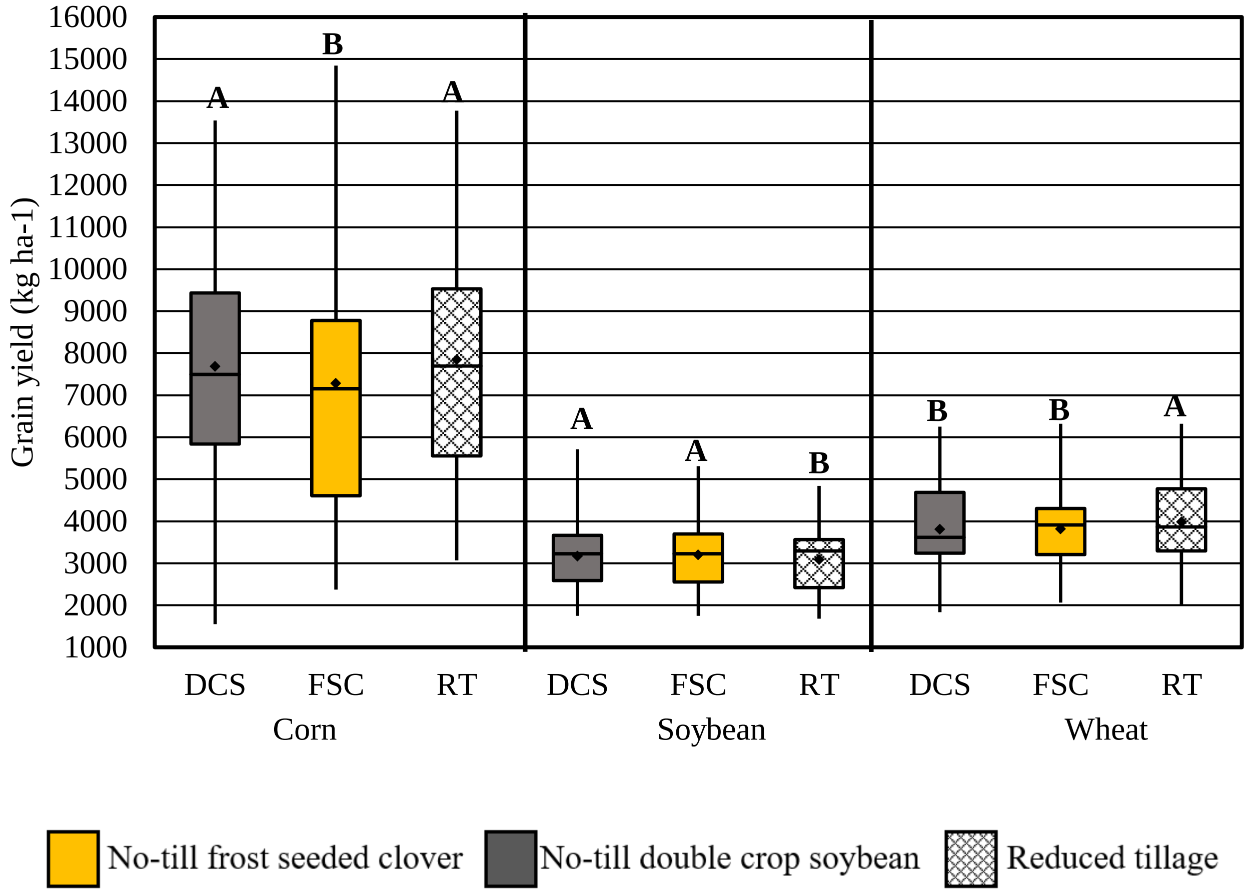

Figure 4.1. Box plots of the grain yield response to cropping systems (no-till double crop soybean, no-till frost seeded clover, and reduced-tillage) combined over years from 1994-2016. Letters above boxes indicate significant differences in yield between cropping system means (P=0.05).

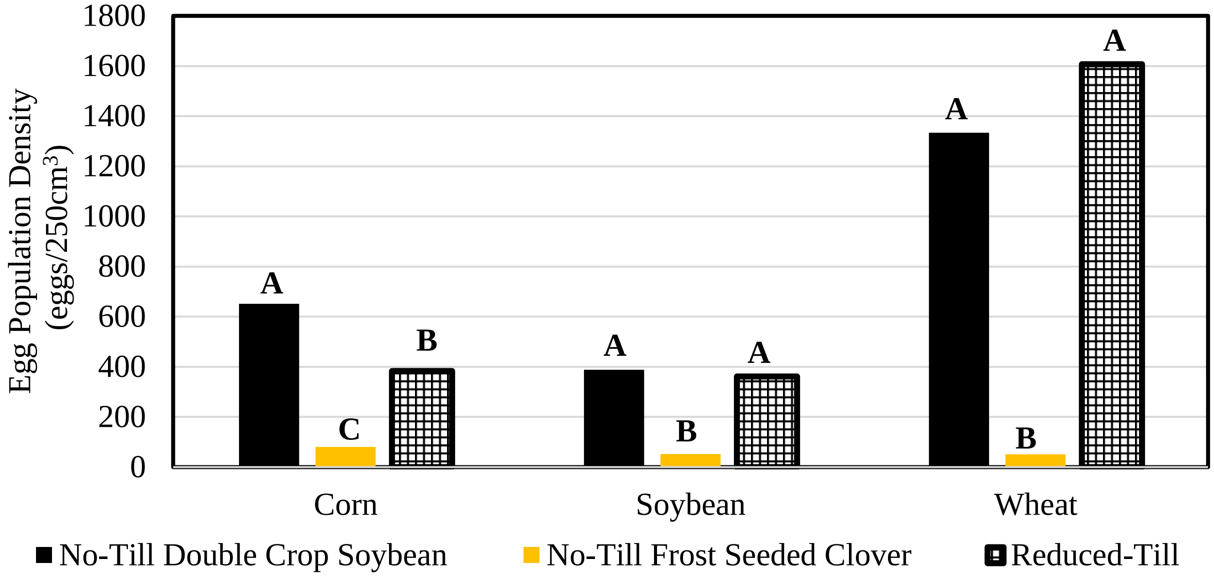

Figure 4.2. Soybean cyst nematode egg population densities prior to planting corn, soybean, or wheat for NT DCS, NT FSC, and RT cropping systems. Data were combined over years (2002-2016) in the absence of a significant interaction within years. Lettered bars represent significant differences among cropping systems (P=0.1). Comparisons within a crop are valid.

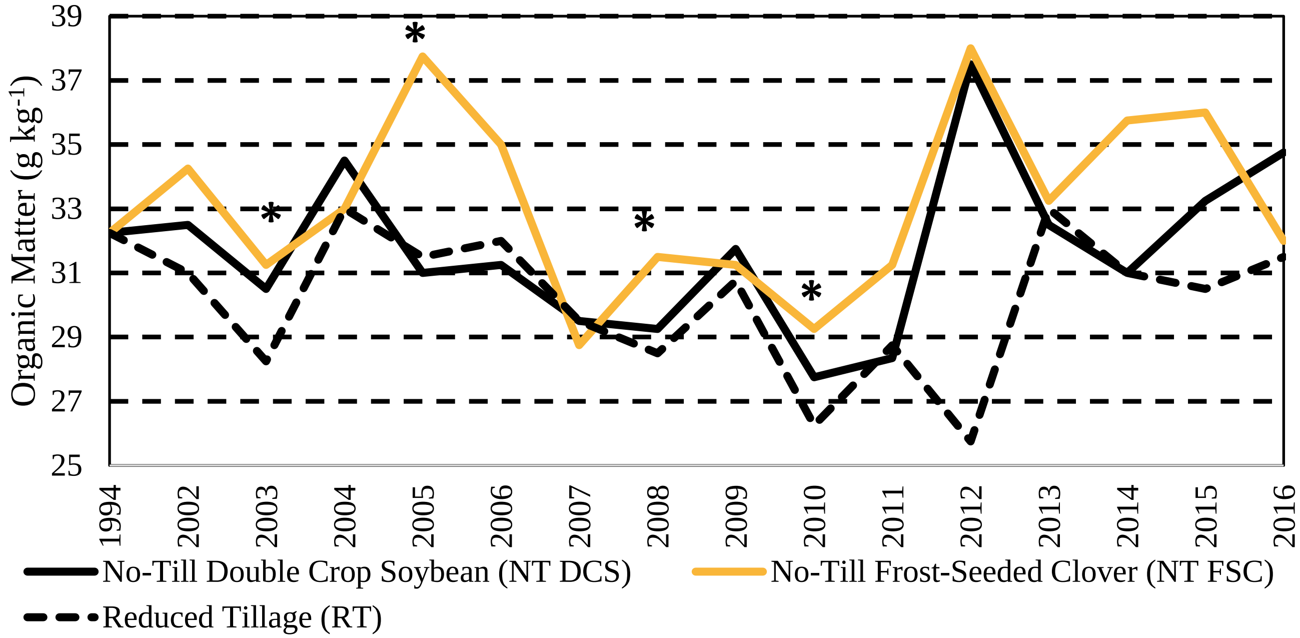

Figure 4.3. Differences in soil organic matter (SOM) measured prior to corn (1994, 2002-2016) for NT DCS, NT FSC, and RT cropping systems. Asterisks represent significant differences in SOM levels among cropping systems (P=0.05).

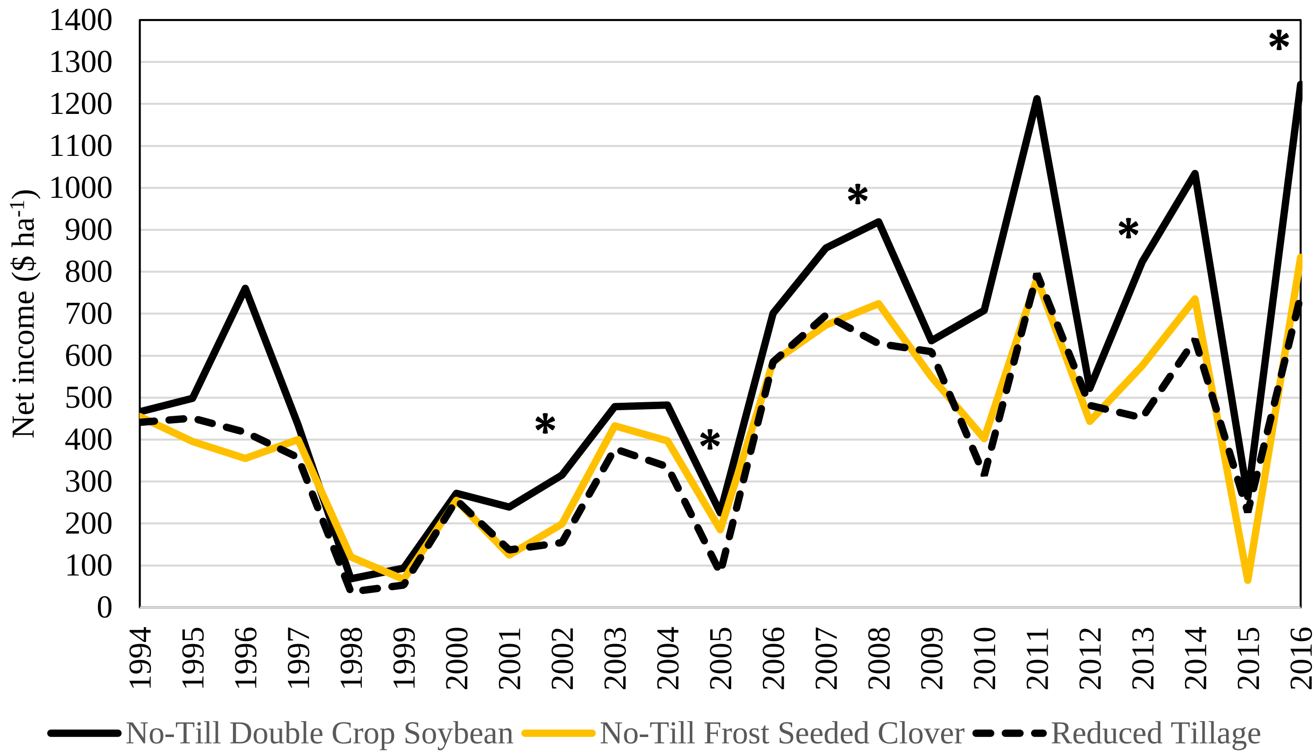

Figure 4.4. Net income combined across rotational crops from 1994-2016. Asterisks represent significant differences in net incomes among cropping systems (P=0.05).

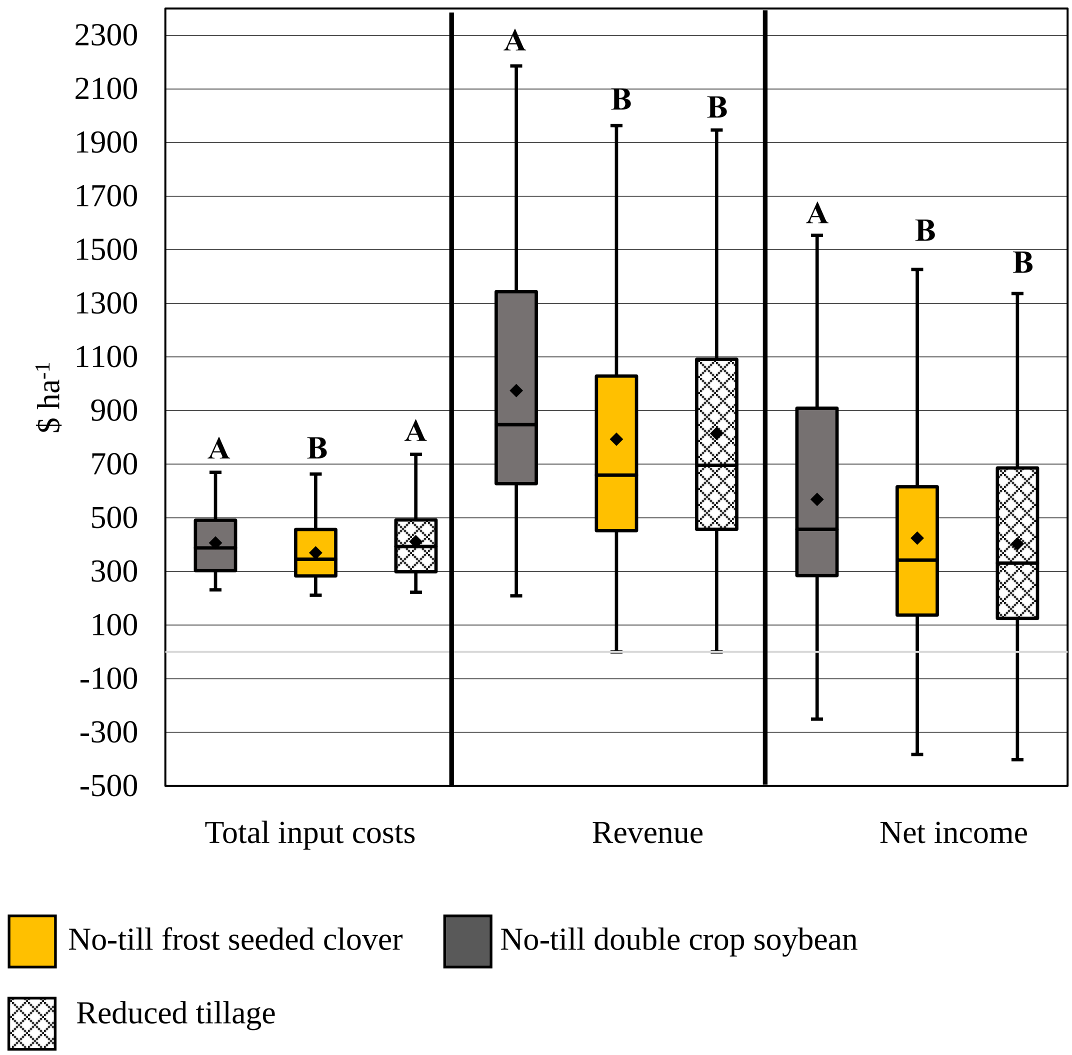

Figure 4.5. Box plots of the total input cost, revenue, and net income response to cropping systems (no-till double crop soybean, no-till frost seeded clover, and reduced-tillage) combined over years from 1994-2016 in dollars ha^{-1}. Letters above boxes indicate significant differences in dollars ha-1 between cropping system means (P=0.05).

Table 4.1. Crop management of corn main and sub-plots from 1994 to 2017.

Year	Tillage	Tillage date	Planting date	Hybrid	Seeding rate	Fertilizer Rate	Fertilizer date	Harvest date
					seeds ha^{-1}	kg ha^{-1}		
1994†	CP D	Fall 93 Spring 94	25 Apr.	P3417IR	59,305	NA	NA	NR
1995	CP, D	25 Apr. 95	7 Jun.	P3394	66,965	NA	NA	NR
1996	CP D	27 Sep. 95 19 Oct. 95	4 Jun.	P3394	66,718	NA	NA	NR
1997	CP D	15 Nov. 96 10 May 97	12 May	P3335	67,954	NA	NA	NR
1998	CP, D	9 Oct. 97	NR	NR	NR	NA	NA	NR
1999	CP D	Fall 98 Spring 99	26 May	P33026	68,695	NA	NA	NR
2000	CP D	Fall 99 Spring 00	2 May	P34B23	64,742	NA	NA	NR
2001	CP D	Fall 00 Spring 01	29 Apr.	BX65RR	66,718	180-56-112	4 May 01	18 Oct.
2002	CP D	2 Nov. 01 5 Apr. 02	4 Jun.	P33R77	65,236	NA	NA	15 Oct.
2003	CP D	Fall 02 Spring 03	23 May	DK60-19	71,660	NA	NA	3 Oct.
2004	D 2x	23 Oct. 03	14 Apr.	DK60-19	NR	21-56-112 170-0-0	15 Nov. 03 NA	3 Oct.
2005	FC	5 Apr. 05	5 Apr.	DK60-18	76,108	NA	NA	12 Sep.
2006	CP D	Fall 05 Spring 06	18 Apr.	DK60-18	NR	NA	NA	15 Sep.
2007	TO	11 May 07	20 May	DK60-18	NR	NA	NA	27 Sep.
2008	CP TO TO	12 Oct. 07 14 Jun. 08 17 Jun. 08	17 Jun.	DK63-42 P35K03 DK61-73	71,660	202-101-135	17 Jun. 08	21 Nov.
2009	TO 2x	21 May 09	21 May	DK61-69	NR	180-0-0 112-0-0	20 May 09 19 Jun. 09	12 Nov.
2010	CP D	Fall 09 Spring 10	3 May	DK62-54	76,108	0-202-170	13 May 10	4 Oct.
2011	CP	11 Oct. 10	11 Apr.	DK62-54	76,108	202-0-0	1 Apr. 11	15 Sep.
2012	CP TO	11 Oct. 11 12 Apr. 12	26 Apr.	DK62-54	79,074	NA	NA	24 Sep.
2013	CP D	Fall 12 Spring 13	16 May	DK63-25	74,132	NA	NA	2 Oct.
2014	CP D	23 Oct. 13 Spring 14	8 May	DK62-97	74,132	NA	NA	8 Oct.
2015	CP, D	10 Nov. 14 Spring 15	Apr. 23	DK62-97	76,108	NA	NA	24 Sep.
2016	CP VT 2x	3 Nov. 15 13 Apr. 16	15 Apr.	DK62-97	79,074	15-73-17 190-0-0	15 Feb. 16 15 Mar. 16	27 Sep.
2017	CP VT	20 Oct. 16 18 Apr. 17	18 Apr.	DK62-97	81,545	202-0-0	9 Mar. 2016	21 Sep.

†Abbreviations: CP, chisel plow; D, disk; FC, field cultivate; NA, not available; NR, not recorded; TO, Tilloll; VT, vertical till

Table 4.2. Crop management of soybean main and sub-plots from 1994 to 2017.

Year	Tillage	Tillage date	Planting date	Cultivar	Plant method	Row spacing	Seeding rate	Harvest date
						cm	plants ha^{-1}	
1994†	CP D	Fall 93 Spring 94	17 May	P9493	Drill	19	741,315	NR
1995	CP CP, D	4 Nov. 94 25 Apr. 95	20 Jun.	AG3431	Drill	19	494,210	NR
1996	CP D	17 Nov. 95 19 Jun. 96	19 Jun.	NK39-11 Saline	Drill	19	494,210	NR
1997	CP D	15 Nov. 96 4 Nov. 96	17 May	Maverick	Drill	19	555,986	NR
1998	CP, D	9 Oct. 97	NR	NR	Drill	19	NR	NR
1999	CP D	Fall 98 Spring 99	NR	NR	Drill	19	NR	NR
2000	CP D	Fall 99 Spring 00	NR	NR	Drill	19	NR	NR
2001	CP D	Fall 00 Spring 01	13 Jun.	AG3701	Drill	19	494,210	21 Oct.
2002	CP D	2 Nov. 01	NR	NR	Drill	19	NR	1 Oct.
2003	CP D	Fall 02 Spring 03	23 May	P94B13	Planter	38	444,789	NR
2004	CP D	Fall 03 Spring 04	4 Jun.	DK38-52 P93B15	Planter	38	345,947	9 Nov.
2005	FC	5 Apr. 05	23 May	NR	Planter	38	NR	NR
2006	TO	21 Feb. 06	17 May	NR	NR	NR	NR	NR
2007	CP D	Fall 06 Spring 07	NR	NR	NR	NR	NR	9 Oct.
2008	CP TO	12 Oct. 07 17 Jun. 08	17 Jun.	P93M61	NR	NR	444,789	28 Nov.
2009	TO 2x	29-May-09	22 May	AG3905	Drill	19	.	20 Oct.
2010	CP D	Fall 09 Spring 10	21 May	AG35391	Planter	38	420,079	5 Oct.
2011	CP TO	11 Oct 10 13 Apr. 11	2 May	AG3803	Planter	38	395,368	NR
2012	CP TO	11 Oct. 11 12 Apr. 12	26 Apr.	NK34-N33	Planter	38	395,368	4 Oct.
2013	CP D	Fall 12 Spring 13	13 Jun.	NK534-N33	Planter	38	395,368	5 Oct.
2014	CP TO	23 Oct. 13 21 May 14	21 May	AG3731	Planter	38	444,789	22 Oct.
2015	CP TO	10 Nov. 14 3 Jun. 15	3 Jun.	AG3832	Planter	38	444,789	19 Oct.
2016	CP TO	6 Oct. 15 25 Apr. 16	25 Apr.	AG3832	Drill	19	420,079	14 Oct.
2017	CP VT	20 Oct. 16 18 Apr. 17	24 Apr.	AG38X6	Drill	19	444,789	2 Oct.

†Abbreviations: CP, chisel plow; D, disk; FC, field cultivate; NR, not recorded; TO, Tilloll; VT, vertical till

Table 4.3. Crop management of wheat main and sub-plots from 1994 to 2017.

	Wheat										Double crop soybean					
Year	Tillage	Tillage date	Plant date	Variety	Rate	Fertilizer rate	Fertilizer date	FSC date	FSC rate	Harvest date	Plant date	Plant method	Row Spacing	Variety	Seeding rate	Harvest date
					kg ha^{-1}				kg ha^{-1}				cm		seeds ha^{-1}	
1994[†]	NA	NA	NA	NA	NA	NA	NA	----[‡]	9	----	10 Jul.	Drill	19	Linford	741,000	----
1995	D	19 Oct. 95	3 Oct. 94	P2548	978	NA	NA	Feb.-Mar.	9	----	12 Jul.	Drill	19	Linford	596,337	----
1996	D	Fall	19 Oct. 95	P2552	133	NA	NA	26 Feb.	10	----	----	Drill	19	----	----	----
1997	D	Fall	18 Oct. 96	Ernie	112	NA	NA	7 Mar.	9	----	11 Jul.	Drill	19	Saline	741,000	30 Oct.
1998	D	Fall	7 Oct. 97	Ernie	104	NA	NA	Feb.-Mar.	9	----	----	Drill	19	----	----	----
1999	D	Fall	----	----	----	NA	NA	Feb.-Mar.	9	----	----	Drill	19	----	----	----
2000	D	Fall	----	----	----	NA	NA	Feb.-Mar.	9	----	----	Drill	19	----	----	----
2001	D	20 Oct. 00	20 Oct. 00	P25R26	126	45-56-67 67-0-0	20 Oct. 00 27 Mar. 01	9 Mar.	22	1 Jul.	----	Drill	19	----	----	30 Oct.
2002	D	Fall	22 Oct. 01	Ernie	168	56-0-0	20 Oct. 01	Feb.-Mar.	9	1 Jul.	3 Jul.	Drill	19	AG3701	----	----
2003	D, H	12 Oct. 02	22 Oct. 02	Ernie	168	45-0-0 50-0-0	12 Oct. 02 10 Mar. 03	17 Feb.	13	3 Jul.	9 Jul.	Drill	19	AG3701	494,000	21 Nov.
2004	D	Fall	23 Oct. 03	Ernie	168	45-56-67	31 Oct. 03	18 Mar.	9	26 Jun.	26 Jun.	Drill	19	DK38-52	494,000	9 Nov.
2005	D	Fall	10 Nov. 04	P25R37	157	NA	NA	8 Mar.	11	29 Jun.	1 Jul.	Drill	19	DK38-52	----	7 Nov.
2006	D	7 Nov. 05	10 Oct. 05	Ernie	135	NA	NA	1 Mar.	11	29 Jun.	29 Jun.	Drill	19	DK38-52	----	----
2007	TO TO	5 Oct. 06 6 Oct. 06	6 Oct. 06	----	168	NA	NA	16 Mar.	9	27 Jun.	27 Jun.	Drill	19	K382RR	----	30 Oct.
2008	TO TO	10 Oct. 07	10 Oct. 07	P25R56	----	45-67-135 67-0-0	9 Oct. 07 11 Mar. 08	12 Mar.	9	3 Jul.	7 Jul.	Drill	19	P93M61	444,600	5 Nov.
2009	TO TO	30 Oct. 08	1 Nov. 08	P25R56	----	NA	NA	----	9	6 Jul.	6 Jul.	Drill	19	P94Y01	----	9 Nov.
2010		Fall	9 Nov. 09 6 Apr. 10	P25R37 Oats	----	NA	NA	19 Mar.	9	----	1 Jul.	Drill	19	AG3539	----	20 Oct.
2011	TO 2x	7 Oct. 10	8 Oct. 10	Ernie	----	112-56-112	19 Mar. 11	9 Mar.	9	30 Jun.	1 Jul.	Drill	19	AG3731	----	27 Oct.
2012	TO	3 Oct. 11	3 Oct. 11	MFA2525	112	NA	NA	Feb.-Mar.	9	15 Jun.	20 Jun.	Drill	19	AG3730	444,600	4 Oct.
2013	TO	10 Oct. 12	11 Oct. 12	MFA2525	112	112-67-135	22 Mar. 13	Feb.-Mar.	9	2 Jul.	28 Jun.	Drill	19	AG3730	----	28 Oct.
2014	TO	11 Oct. 13	11 Oct. 13	MFA2525	112	26-123-135	11 Oct. 13	Feb.-Mar.	9	7 Jul.	10 Jul.	Planter	38	NKS39-U2	543,400	3 Nov.
2015	TO 2x	21 Oct. 14	22 Oct. 14	MFA2525	135	NA	NA	Feb.-Mar.	9	15 Jul.	16 Jul.	Planter	38	AG3832	444,600	19 Oct.
2016	TO	21 Oct. 15	21 Oct. 15	MFA2525	----	15-73-17	15 Feb. 16	11 Feb.	7	24 Jun.	----	----	----	----	----	13 Oct.

[†]Abbreviations: D, disk; FSC, frost seeded clover; NA, not available; H, harrow; TO, Tilloll.

[‡]Data were not collected

Table 4.4. Baseline soil test values for corn, soybean, and wheat at project initiation (1994).

Soil properties	Corn	Soybean	Wheat	LSD (P=0.05)
pHs (0.01 M $CaCl_2$)	7.1±0.1	7.1±0.2	7.0±0.1	NS
Bray 1-P (kg ha^{-1})	45±11.1	54±9.1	42±2.9	NS
K (kg ha^{-1})	264±50.8	320±38.2	276±8.9	NS
Ca (kg ha^{-1})	5604±208	5798±587	5610±259	NS
Mg (kg ha^{-1})	326±42	349±63	342±12	NS
CEC (cmol kg^{-1})	14.0±0.7	14.7±1.7	14.2±0.6	NS

Table 4.5. Soil test values for reduced tillage, cover crop, and double crop soybean cropping systems (1994, 2002-2016). Data (2002-2016) were combined over years due to the absence of a significant interaction between years.

Soil properties	Reduced tillage	Frost-seeded clover	Double-crop soybean	LSD (*P=0.05*)	Tillage system P>F	Tillage*year P>F
pHs (0.01 M $CaCl_2$)	6.6a	6.5b	6.6a	0.04	0.0013	0.9994
Bray 1-P (kg ha^{-1})	65a	54b	51b	4	<.0001	0.8850
K (kg ha^{-1})	348a	321b	283c	12	<.0001	0.2005
Ca (kg ha^{-1})	5380	5300	5400	NS	0.2130	0.9765
Mg (kg ha^{-1})	460	460	450	NS	0.5542	0.9230
CEC (cmol kg^{-1})	15	15	15	NS	0.8925	0.9589

Table 4.6. Soybean cyst nematode (SCN) egg population densities prior to planting for no-till double crop soybean (NT DCS), no-till frost seeded clover (NT FSC), and reduced tillage (RT) cropping systems (*P*=0.1).

	SCN egg population densities			
Year	NT DCS	NT FSC	RT	LSD
	---------- eggs/250 cm^3 ----------			*P*=0.1
2002	0	0	0	NS
2003	0	0	31	NS
2004	0	0	0	NS
2005	0	69	69	NS
2006	138	138	378	NS
2007	1685	125	66	NS
2008	.	.	.	NS
2009	35	97	35	NS
2010	731	0	0	NS
2011	2253	103	1657	2077
2012	103	69	28	NS
2013	947	47	563	NS
2014	1716	422	1166	NS
2015	797	47	985	NS

Table 4.7. Monthly and cumulative rainfall data for individual years and 22-year average for the experiment from 1994-2016.

Year	Monthly Rainfall												Cumulative rainfall
	------------------------------ cm ------------------------------												
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	
1994	0.86	6.10	1.19	16.18	6.17	5.72	6.53	13.94	6.71	6.12	11.38	5.41	86.31
1995	4.60	2.79	2.69	12.65	27.69	8.46	15.44	13.64	10.52	2.06	4.47	1.14	106.15
1996	2.90	0.56	9.19	4.01	28.50	7.62	4.57	20.45	6.65	3.94	4.45	0.74	93.57
1997	1.27	12.04	4.93	14.96	14.20	6.78	7.24	6.93	5.82	9.32	4.95	3.63	92.08
1998	4.67	6.50	12.62	11.48	13.11	20.32	13.72	3.07	9.93	24.18	12.07	4.72	136.40
1999	7.09	3.56	3.78	16.43	10.85	5.72	1.14	4.37	18.01	1.30	0.71	4.88	77.83
2000	1.09	7.24	4.39	5.26	6.35	19.25	5.74	9.98	7.65	6.12	4.78	0.86	78.71
2001	6.45	11.07	6.02	7.06	20.96	12.80	6.93	6.68	12.52	9.27	2.16	2.41	104.34
2002	1.65	5.28	2.44	15.90	27.94	5.03	8.76	6.81	2.57	7.47	0.61	1.47	85.93
2003	0.74	2.24	3.23	16.00	9.32	8.23	8.31	15.65	15.88	5.26	7.67	10.29	102.79
2004	0.86	1.07	7.39	7.80	11.99	8.36	6.71	20.60	2.49	16.56	7.21	2.44	93.47
2005	6.96	5.46	3.07	6.86	5.59	14.45	5.69	8.15	7.01	8.51	3.35	2.31	77.42
2006	5.36	0.23	7.19	6.22	6.53	8.97	8.18	17.17	1.68	5.99	5.38	6.40	79.30
2007	2.11	6.81	12.37	10.59	14.12	7.16	4.72	9.17	6.76	8.64	2.01	4.80	89.26
2008	1.98	9.91	7.82	11.63	11.23	25.65	27.18	10.77	20.12	7.72	3.89	5.92	143.81
2009	0.03	4.19	13.16	12.14	17.02	14.50	10.77	16.74	8.59	22.45	6.50	4.37	130.45
2010	4.27	2.26	5.26	14.55	15.98	16.33	32.64	4.50	24.21	2.08	3.61	2.54	128.22
2011	0.81	2.97	3.51	11.00	13.36	19.15	5.03	5.77	1.52	3.71	14.00	7.49	88.32
2012	1.12	5.44	5.94	11.91	6.32	5.66	1.85	7.59	9.04	8.26	3.73	5.28	72.16
2013	4.70	5.79	5.41	19.35	26.09	9.19	4.83	0.00	7.87	12.12	3.18	1.78	100.30
2014	0.89	2.36	2.24	10.57	2.62	22.48	5.11	16.38	17.53	11.10	2.59	2.67	96.52
2015	2.54	2.03	2.77	7.14	11.91	32.16	25.70	10.64	3.51	5.18	14.61	10.97	129.16
2016	1.68	2.08	4.83	6.65	10.82	3.78	11.63	20.65	4.52	5.18	3.91	2.97	78.71
Mean	2.81	4.69	5.72	11.15	13.85	12.51	9.93	10.85	9.18	8.37	5.53	4.15	98.75

Table 4.8. Monthly temperature data for individual years and 22-year average for the experiment from 1994-2016.

	Average temperature (ºC)											
Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
1994	-5.94	-1.56	6.56	12.94	17.11	23.94	23.83	23.83	18.61	13.28	6.94	1.56
1995	-4.50	-0.67	6.11	9.83	15.06	22.00	24.78	25.72	16.72	34.72	2.78	-1.61
1996	-4.83	-0.39	1.39	9.94	16.61	22.22	23.22	23.06	17.22	12.56	1.78	-1.72
1997	-5.94	0.50	6.33	8.89	14.50	22.06	24.50	22.89	19.67	13.06	3.56	-0.56
1998	-0.44	4.06	3.56	11.11	20.00	21.83	24.61	24.67	21.83	13.50	7.50	0.78
1999	-4.06	3.67	4.39	12.50	17.44	22.00	26.78	23.33	18.33	12.83	9.28	0.67
2000	-1.79	4.02	7.78	11.41	19.03	21.17	23.83	24.73	19.31	14.28	2.36	-8.58
2001	-3.42	-1.88	2.56	15.26	17.69	21.67	25.73	24.84	17.92	11.93	10.09	1.93
2002	0.37	1.53	3.03	12.04	15.51	23.64	25.53	23.68	20.57	9.88	3.84	0.85
2003	-4.98	-3.22	4.77	12.25	16.13	20.55	24.51	24.54	17.08	12.91	6.84	0.69
2004	-4.60	-1.51	6.92	12.69	18.66	20.73	22.56	19.89	19.39	12.72	6.81	0.05
2005	-2.78	2.06	4.47	12.98	16.71	23.34	25.09	24.04	20.93	12.60	6.63	-2.83
2006	2.68	-1.10	5.58	14.54	17.04	22.10	25.55	23.74	17.28	10.44	6.48	1.81
2007	-2.17	-4.82	9.18	9.99	19.20	22.24	23.56	25.65	20.18	14.45	5.35	-2.43
2008	-3.26	-4.04	3.95	9.96	15.50	22.01	23.67	21.96	18.15	12.09	4.63	-3.63
2009	-5.00	0.33	6.11	10.62	16.89	22.21	21.42	21.21	17.69	9.16	8.34	-2.55
2010	-6.78	-5.46	5.90	14.88	16.82	23.79	25.17	24.65	18.77	13.45	5.84	-3.41
2011	-6.42	-2.17	5.51	11.82	16.52	22.50	27.01	24.02	16.99	13.32	6.81	1.81
2012	-0.25	1.82	12.81	13.01	19.89	23.50	27.88	23.56	17.72	10.94	5.81	1.27
2013	-2.02	-1.42	1.07	9.81	16.47	21.71	23.28	23.52	20.66	12.01	3.69	-3.72
2014	-6.43	-7.15	1.97	11.14	17.72	22.54	21.58	23.04	17.74	12.15	1.72	0.64
2015	-2.69	-6.45	5.53	13.14	17.31	22.27	23.86	22.16	21.04	12.94	7.89	3.92
2016	-3.09	1.13	8.56	12.27	16.37	24.48	23.89	23.29	20.67	15.34	8.68	-2.38
Mean	-3.41	-0.99	5.39	11.87	17.14	22.37	24.43	23.57	18.89	13.50	5.81	-0.76
Standard deviation	2.43	3.19	2.69	1.72	1.45	1.00	1.59	1.36	1.54	4.84	2.40	2.73

Table 4.9. Corn, soybean, and wheat grain yield response of no-till double crop soybean (NT DCS), no-till frost seeded clover (NT FSC), and reduced tillage (RT) cropping systems from 1994-2016.

	Corn				Soybean				Wheat			
Year	NT DCS	NT FSC	RT	LSD (*P*=0.05)	NT DCS	NT FSC	RT	LSD (*P*=0.05)	NT DCS	FSC	RT	LSD (*P*=0.05)
	---------------- Mg ha^{-1} ----------------				---------------- Mg ha^{-1} ----------------				---------------- Mg ha^{-1} ----------------			
1994	8.2	8.5	8.2	NS	3.50	3.50	3.56	NS	----	----	----	NA[‡]
1995	5.9	5.2	7.5	1.1	2.89	3.03	2.82	NS	3.24	3.21	3.08	NS
1996	9.8	8.5	10.1	1.22	----	----	----	----	1.84	2.06	2.01	NS
1997	7.0	7.2	7.1	NS	2.76	3.03	2.69	NS	5.49	5.41	5.53	NS
1998	3.1	3.2	3.4	NS	2.49	2.62	2.62	NS	2.68	2.42	2.24	NS
1999	3.4	3.1	3.1	NS	1.75	1.82	1.88	NS	5.45	5.45	5.65	NS
2000	7.5	8.4	10.3	1.75	3.50	3.36	3.29	0.10	4.91	5.04	4.77	NS
2001	4.0	3.3	4.6	NS	3.90	3.76	3.83	NS	4.21	4.30	4.17	NS
2002	5.7	6.0	5.5	NS	2.82	2.49	2.22	0.36	3.49	3.60	3.87	NS
2003	9.1	9.1	9.0	NS	3.29	3.43	3.36	NS	3.84	4.09	4.05	NS
2004	13.5	14.8	13.8	NS	3.23	3.23	3.36	NS	3.50	3.56	3.76	NS
2005	6.3	6.1	5.6	NS	2.69	2.89	2.62	NS	4.20	4.03	3.29	NS
2006	12.0	12.6	12.9	NS	4.10	3.76	4.30	0.37	3.52	3.91	3.62	NS
2007	9.4	7.6	8.8	NS	3.63	3.70	3.56	NS	2.48	2.23	2.57	NS
2008	9.5	9.0	6.9	NS	2.96	3.09	2.96	NS	3.62	4.09	5.11	1.07
2009	6.2	6.5	9.0	1.22	4.24	4.44	4.17	NS	2.29	2.51	3.32	0.62
2010	5.8	4.0	3.5	1.70	3.23	3.63	3.56	NS	----	----	----	NA
2011	6.6	5.8	6.2	NS	3.70	3.70	3.56	NS	1.99	2.11	2.68	0.38
2012	1.6	2.4	3.1	NS	1.82	1.95	1.75	NS	4.69	3.96	4.75	NS
2013	8.6	8.6	7.7	NS	1.82	1.75	1.68	NS	3.50	3.54	3.52	NS
2014	13.4	13.6	12.9	NS	5.04	5.04	4.84	NS	4.84	4.37	5.45	0.57
2015	7.5	3.8	8.8	1.98	1.95	1.88	1.82	NS	4.03	3.90	3.97	NS
2016	12.6	10.2	12.6	1.68	5.71	5.31	4.24	NS	6.25	6.32	6.32	NS

[†]Data were not collected

[‡]Abbreviations: LSD, least significant difference; NA, not applicable; NS, non-significant

Table 4.10. Corn, soybean, and wheat grain moisture response of no-till double crop soybean (NT DCS), no-till frost seeded clover (NT FSC), and reduced tillage (RT) cropping systems from 1994-2016.

	Corn				Soybean				Wheat			
Year	NT DCS	NT FSC	RT	LSD (P= 0.05)	NT DCS	NT FSC	RT	LSD (P= 0.05)	NT DCS	NT FSC	RT	LSD (P= 0.05)
	------------------- g kg^{-1} -------------------				------------------- g kg^{-1} -------------------				------------------- g kg^{-1} -------------------			
1994†	176	177	173	NS	125	124	125	NS	----‡	----	----	NA
1995	227	225	222	NS	90	90	90	NS	103	103	103	NS
1996	220	230	210	11	----	----	----	NA	149	154	146	NS
1997	177	173	166	NS	89	89	89	NS	116	114	115	NS
1998	309	309	309	NS	153	153	153	NS	134	134	134	NS
1999	180	180	180	NS	97	97	97	NS	----	----	----	NA
2000	165	161	163	NS	100	100	100	NS	133	133	133	NS
2001	175	177	167	6	141	140	141	NS	167	181	158	NS
2002	172	171	169	NS	106	100	104	NS	147	147	162	NS
2003	199	200	184	NS	127	127	128	NS	218	220	220	NS
2004	174	175	173	NS	116	118	119	NS	122	112	118	NS
2005	182	195	171	6	143	140	145	NS	158	164	199	NS
2006	200	201	200	NS	113	112	100	7	145	145	146	NS
2007	182	193	181	6	130	131	130	NS	150	149	150	NS
2008	257	263	264	NS	119	118	118	NS	164	168	168	NS
2009	199	207	207	NS	173	179	158	NS	156	163	161	NS
2010	267	313	299	20	111	116	114	4	0	0	0	NA
2011	203	200	189	NS	136	133	135	NS	135	124	126	7
2012	150	150	150	NS	160	143	143	NS	124	119	127	NS
2013	195	198	204	NS	111	116	114	3	132	133	134	NS
2014	199	202	195	NS	112	113	113	NS	147	158	148	NS
2015	155	208	152	NS	107	104	90	NS	139	138	140	NS
2016	135	132	135	NS	156	157	156	NS	151	156	158	NS

†Abbreviations: LSD, least significant difference; NA, not applicable; NS, non-significant.
‡Data were not collected.

Table 4.11. Corn plant population response to no-till double crop soybean (NT DCS), no-till frost seeded clover (FSC), and reduced tillage (RT) cropping systems from 1994-2016.

	NT DCS	NT FSC	RT	LSD (P=0.05)
Year	------------------------------ plants ha^{-1} ------------------------------			
1994	41326	43278	37385	NS†
1995	64257	61246	62243	2180
1996	61490	59631	62861	NS
1997	58958	56752	57640	NS
1998	----‡	----	----	NA
1999	----	----	----	NA
2000	54348	57573	58112	NS
2001	22875	29959	45119	NS
2002	63292	68458	60278	3782
2003	66736	64163	66790	NS
2004	65314	64218	65698	NS
2005	32766	32074	49624	9544
2006	60039	50829	56073	NS
2007	65314	64218	65698	NS
2008	58191	57807	57773	NS
2009	70324	68710	66377	NS
2010	65122	37404	69427	14396
2011	----	----	----	NA
2012	54761	56901	62083	NS
2013	----	----	----	NA
2014	56167	55445	54326	NS
2015	59365	50775	52297	NS
2016	----	----	----	NA

†Abbreviations: LSD, least significant difference; NA, not applicable; NS, non-significant.

‡Data were not collected.

Table 4.12. Soybean plant population response to no-till double-crop soybean (NT DCS), no-till frost-seeded clover (NT FSC), and reduced tillage (RT) cropping systems from 1994-2016. Data were combined over years due to the absence of a significant interaction between years.

NT DCS	NT FSC	RT	LSD (*P*=0.05)†
------------------------------ plants ha^{-1} ------------------------------			
28,6088	29,0665	29,4792	NS

†Abbreviations: LSD, least significant difference; Ns, not significant

Table 4.13. Crop yield categories for corn, soybean, and wheat.

Yield category	Corn	Soybean	Wheat
	Mg ha^{-1}	--------------- kg ha^{-1}	---------------
Low	< 5	< 2,695	NA†
Medium	5-10	2,695-3,370	NA
High	10-15	>3,370	9,000-10,000
Very High	15-20	NA	NA
	Long et al. (2017)	Staggenborg et al. (1996)	Wang (2017)

†Abbreviations: NA, not available

Table 4.14. Differences in soil organic matter (SOM) measured prior to corn (1994, 2002-16) no-till double crop soybean (NT DCS), no-till frost seeded clover (NT FSC), and reduced tillage (RT) cropping systems (P=0.05).

	Soil organic matter			
Year	NT DCS†	NT FSC	RT	LSD (*P*=0.05)
	------------------------------ g kg^{-1} ------------------------------			
1994	32.3	32.3	32.3	NS
2002	32.5	34.3	31.0	NS
2003	30.5	31.3	28.3	2.29
2004	34.5	33.0	33.0	NS
2005	31.0	37.8	31.5	5.80
2006	31.3	35.0	32.0	NS
2007	29.5	28.8	29.5	NS
2008	29.3	31.5	28.5	2.36
2009	31.8	31.3	30.8	NS
2010	27.8	29.3	26.3	1.99
2011	28.4	31.3	28.8	NS
2012	37.5	38.0	35.8	NS
2013	32.5	33.3	33.0	NS
2014	31.0	35.8	32.3	NS
2015	33.3	36.0	30.5	NS
2016	34.8	31.5	32.0	NS

†Abbreviations: LSD, least significant difference; NS, non-significant.

Table 4.15. University of Missouri P2O5 and K2O removal rates for corn, soybean, and wheat (Nathan et al., 2006).

	P_2O_5	K_2O
Crop	g of nutrient kg grain^{-1}	
Corn	8.02	5.35
Soybean	13.97	23.95
Wheat	9.98	4.99

Table 4.16. Corn, soybean, and wheat net income response to no-till double crop soybean (NT DCS), no-till frost seeded clover (NT FSC), and reduced tillage (RT) cropping systems from 1994-2016.

Year	Corn					Soybean					Wheat				
	NT DCS	NT FSC	RT	LSD	Pr>F	NT DCS	NT FSC	RT	LSD	Pr>F	NT DCS	NT FSC	RT	LSD	Pr>F
	---------------- $ ha^{-1} ----------------			*P*=0.05		------------ $ ha^{-1}------------			*P*=0.05		------------ $ ha^{-1}------------			*P*=0.05	
1994	470	452	444	64	0.4727	463	457	446	30	0.4547	-	-	-	-	-
1995	549	451	736	145	0.0080	486	531	443	128	0.3126	460	203	173	30	<0.0001
1996	761	612	757	128	0.0477	-	-	-	-	-	-	98	78	86	0.5035
1997	398	402	363	92	0.5520	405	457	341	130	0.1732	672	369	368	108	0.0109
1998	-8	-8	-22	67	0.8003	213	232	185	74	0.3554	123	-38	-66	60	0.0005
1999	17	-14	-48	50	0.0530	64	67	41	42	0.3355	201	168	166	56	0.3061
2000	246	300	384	113	0.0625	325	307	258	17	0.0002	245	159	126	43	0.0013
2001	19	-36	32	76	0.1483	341	313	306	66	0.4436	358	97	73	106	0.0010
2002	245	261	193	48	0.0321	295	218	138	71	0.0051	407	117	132	57	<0.0001
2003	506	497	445	81	0.2220	611	651	568	138	0.3972	319	151	121	80	0.0019
2004	664	751	622	182	0.2860	345	345	313	169	0.8723	439	95	71	98	0.0002
2005	131	110	21	77	0.0281	230	262	153	62	0.0134	315	184	71	122	0.0080
2006	1001	1056	1047	124	0.5404	621	541	610	77	0.0876	482	158	99	105	0.0002
2007	1159	869	1011	189	0.0267	1029	1041	933	172	0.3118	381	108	145	160	0.0116
2008	1091	986	628	391	0.0610	686	737	643	109	0.1854	980	448	615	202	0.0018
2009	420	456	717	159	0.0073	1086	1167	992	234	0.2638	401	26	120	84	<0.0001
2010	789	433	272	339	0.0247	994	1158	1075	207	0.2306	-	-	-	-	-
2011	1150	962	995	290	0.3096	1275	1264	1157	84	0.0245	-	125	234	99	0.0404
2012	-39	191	313	418	0.1948	515	573	407	151	0.0876	1089	567	726	294	0.0125
2013	966	963	733	191	0.0390	377	368	265	121	0.1119	1128	396	358	151	<0.0001
2014	1214	1299	1074	158	0.090	1300	1303	1170	68	0.0047	558	-325	-328	130	<0.0001
2015	493	-20	586	268	0.0031	139	117	25	174	0.3064	159	97	71	92	0.1339
2016	1021	736	943	206	0.0359	1488	1347	900	446	0.0415	1231	420	386	197	<0.0001

REFERENCES

Aase, J.K., and G.M. Schaefer. 1996. Economics of tillage practices and spring wheat and barley crop sequence in the Northern Great Plains. J. Soil and Water Cons. 51:167-170.

Abel, D.S. 2013. Cover crop effects on soil moisture and water quality. Department of Agronomy, Kansas State University, Manhattan, Kansas. P. 23-98.

Abendroth, L.J., R.W. Elmore, M.J. Boyer, and S.K. Marlay. 2011. Corn growth and development. PMR 1009. Iowa State Univ. Ext., Ames, Iowa.

Abendroth, L.J., S.K. Marlay, and R.W. Elmore. 2009. Unpublished emergence data measurements collected from three Iowa State University Research trials. Iowa State Univ., Ames, Iowa.

Aizhen, L., Z. Zhengli, N.B. McLaughlin, Y. Xueming, Z. Xiaoping, C. Xuewen, S. Bingjie, and Z. Yan. 2017. Lodging in corn varies with tillage and crop rotation: A case study after Typhoon Bolaven pummeling over the black soil Zeon in northeast China. Pakistan Journal of Agricultural Sciences 54:539-545. doi: 10.21162/PAKJAS/17.4156.

Al-Darby, A.M., and B. Lowery. 1987. Seed zone soil temperature and early corn growth with three conservation tillage systems. Soil Sci. Soc. Am. J. 51:768-774.

Al-Kaisi, M., and M. Hanna. 2004. Frequent tillage and its impact on soil quality. Ext. Pub. IC-492(13). Iowa State Univ. Ext. Pub., Ames, Iowa.

Al-Kaisi, M., and D. Kwaw-Mensah. 2007. Effect of tillage and nitrogen rate on corn yield and nitrogen and phosphorus uptake in a corn-soybean rotation. Agron. J. 99:1548-1558.

Al-Kaisi, M., and M.A. Licht. 2004. Effect of strip tillage on corn nitrogen uptake and residual soil nitrate accumulation compared with no-tillage and chisel plow. Agron. J. 96:1164-1171.

Albaugh LLC. 1993. 2,4-D LV4 herbicide label.

Amato, G., P. Ruisi, A.S. Frenda, G. Di Miceli, S. Saia, A. Plaia, and D. Giambalvo. 2013. Long-term tillage and crop sequence effects on wheat grain yield and quality. Agron. J. 105:1317-1327. doi: 10.2134/agronj2013.0019.

Archontoulis, S., M. Licht, and R. Antonio-Ordonez. 2017. How fast and deep do corn roots grow in Iowa?, ICM News, Iowa State University Extension, Ames, Iowa.

Barnes, J.P., and A.R. Putnam. 1983. Rye residues contribute weed suppression in no-tillage cropping systems. J. of Chemical Ecology 9:1045-1057. DOI: 10.1007/BF00982210.

Bitzer, M.J. 1983. No-till corn. Agriculture and Natural Resources Pub. 13. University of Kentucky UKnowledge. Lexington, Kentucky.

Blevins, R.L., J.H. Grove, and B.K. Kitur. 1986. Nutrient uptake of corn grown using moldboard plow or no-tillage soil management. Commun. Soil Sci. Plant Anal. 17:401-417.

Bowman, G., C. Shirley, and C. Cramer. 2007. Managing cover crops profitably. 3rd ed. Sustainable Agric. Network Handb. Ser. Book 9. Sustainable Agric. Network, Natl. Agric. Library, Beltsville, Maryland.

Buchholz, D.D., E. Palm, G. Thomas, and D.L. Pfost. 1993. No-till planting systems. Ext. Pub. G4080. Univ. of Missouri Ext., Columbia, Missouri.

Buckley, M.E., G.J. Kluitenberg, D.W. Sweeney, K.W. Kelley, and L.R. Stone. 2010. Effect of tillage on the hydrology of a claypan soil in Kansas. Soil Sci. Soc. Am. J. 74:2109-1119.

Chase, C.A., and M.D. Duffy. 1991. An economic analysis of the Nashua tillage study: 1978-1987. J. Prod. Agric. 4:91-98.

Chen, S.Y., W.C. Stienstra, W.E. Lueschen, and T.R. Hoverstad. 2001. Response of *Heterodera glycines* and soybean cultivar to tillage and row spacing. Plant Disease 85:311-316. doi: 10.1094/PDIS.2001.85.3.311.

Creech, J.E., J. Faghihi, V.R. Ferris, A. Westphal, and W.G. Johnson. 2007. Influence of intraspecific henbit (*Lamium amplexicaule*) and purple deadnettle (*Lamium purpureum*) competition on soybean cyst nematode reproduction. Weed Sci. 55:665-670.

Creech, J.E., and W.G. Johnson. 2006. Survey of broadleaf winter weeds in Indiana production fields infested with soybean cyst nematode (*Heterodera glycines*). Weed Technol. 20:1066-1075. doi: 10.1614/WT-05-161.1.

Creech J.E., W.G. Johnson, J. Faghihi, V.R. Ferris, A. Westphal. 2005. First report of soybean cyst nematode reproduction on purple deadnettle under field conditions Plant Management Network.

Creech, J.E., A. Westphal, V.R. Ferris, J. Faghihi, T.J. Vyn, J.B. Santini, and W.G. Johnson. 2008. Influence of winter annual weed management and crop rotation on soybean cyst nematode (*Heterodera glycines*) and winter annual weeds. Weed Sci. 56:103-111.

Dabney, S.M., J.D. Schreiber, C.S. Rothrock, and J.R. Johnson. 1996. Cover crops affect seedling growth. Agron. J. 88:961-970.

DeFeliece, M.S., P.R. Carter, and S.B. Mitchell. 2006. Influence of tillage on corn and soybean field in the United States and Canada. Crop Manage 5.

Delvalle, T. 2014 Amines or esters; which should you use? PennState Univ. Ext. Pub., University Park, Pennsylvania.

Edwards, J.H., D.L. Thurlow, and J.T. Eason. 1988. Influence of tillage and crop rotation on yields of corn, soybean, and wheat. Agron. J. 80:76-80. doi: 10.2134/agronj1988.00021962008000010018x.

Epplin, F.M., C.J. Stock, D.D. Kletke, and T.F. Peeper. 2005. Cost of conventional tillage and no-till continuous wheat production for four farm sizes. J. of the ASFMRA. 8:69-76.

Fenton, M., C. Albers, and Q. Ketterings. 2008. Soil organic matter. Ext. Pub. 41. Cornell Univ. Coop. Ext., Ithaca, New York.

Govaerts, B., M. Fuentes, M. Mezzalama, J.M. Nicol, J. Deckers, J.D. Etchevers, B. Figueroa-Sandoval, and K.D. Sayre. 2007. Infiltration, soil moisture, root rot and nematode populations after 12 years of different tillage, residue and crop rotation managements. Soil Tillage Res. 94:209-219. doi:10.1016/j.still.2006.07.013.

Griffin, E. 2017. What is soil organic carbon? Government of Western Australia. http://www.agr ic.wa.gov.au/measuring-and-assessing-soils/what-soil-organic-carbon (accessed 20 Oct 2018).

Griffith D.R., N.C. Wollenhaupt. (1994) Crop residue management strategies for the midwest Lewis Publishers, Boca Raton, FL.

Grove, J.H., R.C. Ward, and R.R. Weil. 2007. Nutrient stratification in no-till soils. Leading Edge 6:374-381.
Havlin, J.L., S.L. Tisdale, W.L. Nelson, and J.D. Beaton. 2014. Soil fertility and fertilizers: An introduction to nutrient management. 8th ed. Prentice Hall, Upper Saddle River, New Jersey.
Hershman, D.E., and P.R. Bachi. 1995. Effect of wheat residue and tillage on *Heterodera glycines* and yield of double crop soybean in Kentucky. Plant disease 79:631-633.
Hill, N.S., and D.P. Schmitt. 1989. Influence of temperature and soybean phenology on dormancy induction of *Heterodera glycines*. J Nematol 21:361-9.
Johnson, O.S., J.R. Williams, R.E. Gwin, and C.L. Mikeshell. 1986. Economic analysis of reduced-tillage wheat and grain sorghum rotations in western Kansas. Bull. 650. Kansas State Univ. Ext., Manhattan, Kansas.
Johnson, W.G., A. Kendig, and F. Fishel. 1996. Atrazine: Best management practices and alternatives in missouri. Ext. Pub. G4851. Univ. of Missouri Ext., Columbia, Missouri.
Jones, M.M., and R.P. Beasley. 1943. Corn tillage studies on rolling putnam silt loam Columbia, Missouri. Bull 475. Univ. of Missouri Agric. Exp. Stn., Univ. of Missouri, Columbia, Missouri.
Kaur, G., B.A. Zurweller, K.A. Nelson, P.P. Motavalli, and C.J. Dudenhoeffer. 2017. Soil waterlogging and nirtogen fertilizer management effects on corn and soybean yield. Agron. J. 109:97-106. doi:10.2134/agronj2016.07.0411
Lal, R. 2009. The plow and agricultural sustainability. J. of Sustain. Agric. 33:66-84.
Lang, P.M., J.B. Mallet, and W.A.J. Berry. 1986. The effect of tillage system on lodging in maize resulting from a severe rainstorm. South African Journal of Plant and Soil 3:165-170. doi: 10.1080/02571862.1986.10634215
Licht, M.A., and M. Al-Kaisi. 2005. Strip-tillage effect on seedbed soil temperature and other soil physical properties. Soil Tillage Res. 80:233-249.
Linden, D.R., C.E. Clapp, and R.H. Dowdy. 2000. Long-term corn grain and stover yields as a function of tillage and residue removal in east central Minnesota. Soil Tillage Res. 56:167-174.
Lipiec, J., J. Kuś, A. Słowińska-Jurkiewicz, and A. Nosalewicz. 2006. Soil porosity and water infiltration as influenced by tillage methods. Soil Tillage Res. 89:210-220. doi: 10.1016/j.still.2005.07.012.
Long, N.V., Y. Assefa, R. Schwalbert, and I.A. Ciampitti. 2017. Maize yield and planting date relationship: A synthesis-analysis for us high-yielding contest-winner and field research data. Frontiers in Plant Science 8:2106. doi: 10.3389/fpls.2017.02106.
Martens, D.A. 2001. Nitrogen cycling under different soil management properties. Advances in Agronomy 70:143-191.
Massey, R.E. 1997. No-tillage and conservation tillage: Economic considerations. Ext. Pub. G355. Univ. of Missouri Ext., Columbia, Missouri.
Massey, R.E. 2016. Custom rates for farm services in Missouri. Ext. Pub. G302. Univ. of Missouri Ext., Columbia, Missouri.
Mazzoncini, M., C. Di Bene, A. Coli, D. Antichi, M. Petri, and E. Bonari. 2008. Rainfed wheat and soybean productivity in a long-term tillage experiment in central Italy. Agron. J. 100:1418-1429. doi: 10.2134/agronj2007.0173.

Meijer, A., J.L. Heitman, and J.G. White. 2014. Soil management can maximize water availability. Ext. Pub. AG-439-77. NC State Ext., Raleigh, North Carolina.

Mitchum M.G., J.A. Wrather, R.D. Heinz, J.G. Shannon, G. Danekas. 2007. Variability in distribution and virulence phenotypes of heterodera glycines in missouri during 2005. Plant Dis. 91:1473-1476.

Mock, V.A., J.E. Creech, B. Johnson, J. Faghihi, V.R. Ferris, A. Westphal, and K. Bradley. 2007. Winter annual weeds and soybean cyst nematode management. Purdue Univ. Ext. Pub., West Layfette, Indiana.

Monsanto Company. 2017. Roundup Powermax herbicide label.

Myers, R., C. Ellis, R. Hoormann, T. Reinbott, N. Kitchen, and J. Reisner. 2015. Cover crops in Missouri: Putting them to work on your farm. Ext. Pub. G4161. Univ. of Missouri Ext., Columbia, Missouri. pp. 1-6.

National Drought Mitigation Center. 2018. United States drought monitor. University of Nebraska- Lincoln, Lincoln, Nebraska.

Nathan, M., J.A. Stecker, and Y. Sun. 2012. Soil testing in Missouri, A Guide for Conducting Soil Tests in Missouri, Division of Plant Sciences, College of Agriculture, Food, and Natural Resources, Columbia, Missouri.

Nathan, M.V., Y. Sun, and D. Dunn. 2006. Nutrient removal values for major agronomic crops in Missouri. University of Missouri, Columbia, Missouri.

Nelson, K.A., W.G. Johnson, J.D. Wait, and R. Smoot. 2006. Winter-annual weed management in corn (*Zea mays*) and soybean (G*lycine max*) and the impact on soybean cyst nematode (*Heterodera glycines*) egg population densities. Weed Sci. 20:965-970.

Neugschwandtner, R.W., P. Liebhard, H.P. Paul, and H. Wangentristl. 2014. Soil chemical properties as affected by tillage and crop rotation in a long-term field experiment. Plant Soil Envt. J. 60:57-62. doi: http://agriculturejournals.cz/publicFiles/114057.pdf.

Niblack, T.L., P.R. Arelli, G.R. Noel, C.H. Opperman, J.H. Orf, D.P. Schmitt, J.G. Shannon, and G.I. Tylka. 2002. A revised classification scheme for genetically diverse populations of *Heterodera glycines*. J. Nematol. 34:279-288.

Nielsen, B., and D. Colville. Stalk lodging in corn: Guidelines for preventive management. Ext. Pub. AY-262. Purdue University, West Layfayette, Indiana.

Ofori, C.S. 1993. The challenge of tillage development in African agriculture. In: Soil Tillage in Africa: Needs and challenges. FAO soil Bulletin 69, Rome. Chapter 7: 77- 82.

Olson, K.R., S.A. Ebelhar, and J.M. Lang. 2010. Cover crop effects on crop yields and soil organic carbon content. Soil Sci. Soc. Am. J. 175:89-98.

Olson, K.R., S.A. Ebelhar, and J.M. Lang. 2014. Long-term effects of cover crops on crop yields, soil organic carbon stocks and sequestration. J. Soil Sci. 4:284-292.

Ongley, E.D. 1996. Introduction to agricultrual water pollution. In: J.G. Kamphuis. Control of water pollution from agriculture. FAO, Rome, Italy. p. 1-18

Pimentel, D., C. Harvey, P. Resosudarmo, K. Sinclair, D. Kurz, M. McNair, S. Crist, L. Shpritz, L. Fitton, R. Saffouri, and R. Blair. 1995. Environmental and economic costs of soil erosion and conservation benefits. Science 267:1117-1123.

Plain, R., and J. White. 2012. Custom rates for farm services in Missouri. Ext. Pub. G302. Univ. of Missouri Ext., Columbia, Missouri.

Plain, R., J. White, and J. Travlos. 1997. Custom rates for farm services in Missouri. Ext. Pub. G302. Univ. of Missouri Ext., Columbia, Missouri.

Plain, R., J. White, and J. Travlos. 2000. Custom rates for farm services in missouri. Ext. Pub. G302. Univ. of Missouri Ext., Columbia, Missouri.

Plain, R., J. White, and J. Travlos. 2003. Custom rates for farm services in missouri. Ext. Pub. G302. Univ. of Missouri Ext., Columbia, Missouri.

Plain, R., J. White, and J. Travlos. 2006. Custom rates for farm services in Missouri. Ext. Pub. G302. Univ. of Missouri Ext., Columbia, Missouri.

Plain, R., J. White, and J. Travlos. 2009. Custom rates for farm services in Missouri. Ext. Pub. G302. Univ. of Missouri Ext., Columbia, Missouri.

Ransom, J. 2016. Green snap in corn, Crop & Pest Report, North Dakota State University, North Dakota.

Rengel, Z. 2003. Role of plant cation/anion uptake ration in soil acidification. In: Z. Rengel. Handbook of soil acidity. New York, New York, Marcel Dekker. p. 58-82.

Rickerl, D.H., W.B. Gordon, E.A. Curle, and J.T. Touchton. 1988. Winter legume and tillage effects on cotton growth and soil ecology. Soil Tillage Res. 11:63-71.

Russell, A.E., D.A. Laird, T.B. Parkin, and A.P. Mallarino. 2005. Impact of nitrogen fertilization and cropping system on carbon sequestration in midwestern mollisols. Soil Sci. Soc. Am. J. 69:413-422.

Ryan, M.R., S.B. Mirsky, D.A. Mortensen, J.R. Teasdale, and W.S. Curran. 2011. Potential synergistic effects of cereal rye biomass and soybean planting density on weed suppression. Weed Sci. 59:238-246. doi: 10.1614/WS-D-10-00110.1.

Soil Health Assessment Center. 2016. Soil health assessment results report, University of Missouri-Columbia, Columbia, Missouri.

SSSA. 2008. Glossary of soil science terms 2008. In: Glossary of soil science terms, SSSA, Madison, Wisconsin p. 1-82. doi:10.2136/2008.glossarysoilscienceterms

Staggenborg, S.A., D.L. Devlin, D.L. Fjell, J.P. Shroyer, W.B. Gordon, B.H. Marsh, and L.D. Maddux. 1996. Soybean response to row spacing and seeding rates in northeast kansas. Ext. Pub. 112. Kansas State Univ. Ext., Manhattan, Kansas.

Stecker, J.A. 1993. Nitrogen management for no-tillage systems in Missouri. Ext. Pub. G9175. Univ. of Missouri Ext., Columbia, Missouri.

Sweeney, D.W. 2017. Does 20 years of tillage and N fertilization influence properties of a claypan soil in the eastern Great Plains? Agric. Environ. Lett. 2:170025. doi:10.2134/ael2017.08.0025

Teasdale, J.R., C.E. Beste, W.E. Potts. 1991. Response of weeds to tillage and cover crop residue. Weed Sci. 39:195-199.

Toliver, D.K., J.A. Larson, R.K. Roberts, B.C. English, D.G. De La Torre Ugarte, and T.O. West. 2012. Effects of no-till on yields as influenced by crop and environmental factors. Agron. J. 104:530-541. doi: 10.2134/agronj2011.0291.

Tylka G.I. Management of SCN. Iowa State University. www.plantpath.iastate.edu/scn/management-scn (accesed Jul. 15 2018).

Tylka, G.L., and M.P. Mullaney. 2015. Soybean cyst nematode-resistant soybeans for Iowa. Ext. Pub. 1649. Iowa State Univ. Ext., Ames, Iowa.

Unger, P.W., and M.F. Vigil. 1998. Cover crop effects on soil water relationships. J. Soil Water Conserv. 53:200-207.

Uri, N.D. 2000. An evaluation of the economic benefits and costs of conservation tillage. Environmental Geology 39:238-248.
Varve,l G.E. 2006. Soil organic carbon changes in diversified rotations of the western corn belt. Soil Sci. Soc. Am. J. 70:426-433.
Venkatesh, R., S.K. Harrison, and R.M. Riedel. 2000. Weed hosts of soybean cyst nematode (*Heterodera glycines*) in Ohio. Weed Technol. 14:156-160.
Wang, D. 2017. Water use efficiency and optimal supplemental irrigation in a high yield wheat field. Field Crops Res. 213:213-220. doi: 10.1016/j.fcr.2017.08.012.
Wells, M.S., S.C. Reberg-Horton, and S.B. Mirsky. 2016. Planting date impacts on soil water management, plant growth, and weeds in cover-crop-based no-till corn production. Agron. J. 108:162-170. doi: 10.2134/agronj2014.0524.
Westphal, A., L.J. Xing, R. Pillsbury, and T.J. Vyn. 2009. Effect of tillage intensity on population densities of *Heterodera glycines* in intensive soybean production systems. Field Crops Res. 113:218-226. doi: 10.1016/j.fcr.2009.05.009.
Whitaker, F.D., J.S. McKibben, and M.M. Jones. 1966. Reduced tillage in corn production. Bull. 852. Univ. of Missouri Ext., Columbia, Missouri.
Wilts, A.R., D.C. Reicosky, R.R. Allmaras, and C.E. Clapp. 2004. Long-term corn residue effects: Harvest alternatives, soil carbon turnover, and root-derived carbon. Soil Sci. Soc. Am. J. 68:1342-1351.
Wortman, S.E., C.A. Francis, M.L. Bernards, R.A. Drijber, and J.L. Lindquist. 2012. Optimizing cover crop benefits with diverse mixtures and an alternative termination method. Agron. J. 104:1425-1435. doi: 10.2134/agronj2012.0185.
Wrather, J.A., M.G. Mitchum. 2006. Soybean cyst nematode: Diagnosis and management. Ext. Pub. G4450. Univ. of Missouri Ext., Columbia, Missouri.
Yost, M.A., N.R. Kitchen, K.A. Sudduth, E.J. Sadler, C. Baffaut, M.R. Volkmann, and S.T. Drummond. 2016. Long-term impacts of cropping systems and landscape positions on claypan-soil grain crop production. Agron. J. 108:713-725. doi: 10.2134/agronj2015.0413.
Zentner, R.P., D.D. Wall, C.N. Nagy, E.G. Smith, D.L. Young, P.R. Miller, C.A. Campbell, B.G. McConkey, S.A. Brandt, G.P. Lafond, A.M. Johnston, and D.A. Derksen. 2002. Economics of crop diversification and soil tillage opportunities in the Canadian prairies. Agron. J. 94:216-230. doi: 10.2134/agronj2002.2160.
Zhou, X., M.J. Helmers, M. Al-Kaisi, and H.M. Hanna. 2009. Cost-effectiveness and cost-benefit analysis of conservation management practices for sediment reduction in an Iowa agricultural watershed. J. Soil Water Conserv. 64:314-323. doi: 10.2489/jswc.64.5.314.
Zhu, J.C., C.J. Gantzer, S.H. Anderson, P.R. Beuselinck, and E.E. Alberts. 1991. Water use evaluation of winter cover crops for no till soybeans. J. Soil Water Conserv. 46:446-449.

.

CHAPTER 5
OVERALL CONCLUSION

This research evaluated the effects of short and long-term conservation practices on grain yield, moisture, test weight, plant populations, soil chemical and soil health properties, nutrient loss, drainage discharge, nutrient concentrations, cover crop (CC) and weed biomass, crop rotations, and farm economics on claypan soils in upstate Missouri. As interest in conservation agriculture increases, it is essential to continue to analyze conservation practices to further understanding of implementation of best management practices.

Overseeding cover crops into standing corn and soybean

Four separate experiments were established in the spring of 2016 and 2017 ended in the fall of 2017 and 2018, respectively. Experiments were arranged in a randomized complete block design with 13 overseeded CC treatments in corn (*Zea mays* L.) and 14 overseeded CC treatments in soybean [*Glycine max* (L.) Merr.] with three to four replications to evaluate the effects of overseeding a cc into a standing crop. Corn was overseeded at V5, V10, and VT while soybean was overseeded at R6.

Plant population, moisture, grain test weight, and crop yield of the main and rotational (soybean) crops were not affected when CC's were overseeded into standing corn at the V5 growth stage. Biomass of CC's and weeds were not affected by the overseeding treatments.

Standing corn was not affected when a CC was overseeded at V10. Cover crop biomass was greater than the NTC in 2017, but was similar to the NTC in 2018. MFA 2249, Bounty, Bounty/Dixie, Bounty/Multicut, and Bounty/Mihi CC biomass was 390 kg ha^{-1} to 920 kg ha^{-1} greater than the NTC. In 2018, no CC treatments produced biomass greater than NTC. Lack of rain within seven days of overseeding and dry conditions in the fall of 2017 likely affected CC growth and germination. Soybean yield was increased 490 kg ha^{-1} by Dixie in 2017 following corn overseeded with a CC at V10, but it did not affect soybean yield in 2018.

When corn was overseeded with at CC at VT, red clover reduced corn yield 760 kg ha^{-1} compared to the NTC in 2018, but did not affect subsequent soybean crop. Yields otherwise were similar to the NTC in 201 and 201. Cover crops in this trial were overseeded using a hand spreader. It is possible that during the V5 and V10 overseeding timings, CC seed became trapped in the corn plant whereas this may not have occurred in the VT timing due to plant height differences. Bounty, Bounty/Dixie, and Bounty Mihi CC biomass values were greater than the non-treated control (NTC) in 2017, but no CC biomass was present in 2018. The subsequent soybean crop was not affected by overseeded CC treatments.

Soybean was not affected when overseeded with a CC at R6. In 2017, MFA 2259, winter rye, Bounty, Assist, Bounty/Dixie, Bounty/Multicut, and MFA 2249/EcoTill/PurpleTop varieties had 2510-3310 kg ha^{-1} greater CC biomass than the NTC. Subsequently, these CC treatments had CC biomass values similar to NTC. In 2017, Bounty/Mihi had greater CC biomass (2510 kg ha^{-1}) than the NTC, but did not reduce weed biomass. Neither CC nor weed biomass was significantly different from the non-treated control in 2018. MFA 2249, winter rye, Assist, Bounty/Dixie, Bounty/Mihi, and MFA 2249/EcoTill/PurpleTop overseeded into soybean at R6 reduced the subsequent corn crop plant population 20,450 to 37,660 plants ha^{-1}. In 2018, corn plant population was not affected by the previous CC. MFA 2249, winter rye, Bounty/Multicut, Bounty/Mihi, and MFA 2249/EcoTill/PurpleTop reduced corn grain yield in 2017 by 1800 kg ha^{-1} to 3590 kg ha^{-1}. A monoculture of MFA 2249 reduced corn grain yield 3430 kg ha^{-1} in 2018.

In general, grass species and grass species blends produced the greatest CC biomass and interfered with winter annual weeds. Subsequently, grass species also reduced corn yields when soybean was overseeded at R6. Wheat overseeded into soybean at R6 reduced subsequent corn crop yield in 2017 and 2018. A three species blend containing wheat (MFA 2249/EcoTill/PurpleTop) reduced subsequent corn yield in 2017. In 2016, this blend was overseeded into soybean at R6 in a tile-terrace field. Subsequent corn yield was reduced 500 kg ha^{-1}. Early burndown of wheat may be warranted for this CC to be consistent. Soybean overseeded with a CC at R6 reduced weed biomass in 2017. Clover species never produced biomass greater than the NTC in this research. Due to the lack of biomass and weed suppression properties, overseeding clover isn't recommended in upstate Missouri at the timings evaluated in this research. Excluding MFA 2249, CC's did not reduce subsequent cash crop yield in 2018. This suggests that lower CC biomass may reduce yield loss of rotational crops caused by CC's. Earlier springtime termination of CC's might prevent excessive biomass accumulation and detrimental effects on stand establishment and yield of the corn crop.

Cover crops in a tile-terrace field

In 2016, individually drained parallel terraces were constructed at the Grace Greenley Farm of the University of Missouri Greenley Research Center to evaluate the effects of CC's on nutrient loss, crop yields, CC biomass, and weed biomass in a tile-terrace field. Terrace construction disrupted the native soil profile and created artificial landscape positions (LP). Shoulder (SH), footslope (FS), channel (CH), and backslope (BS) LP's resulted within each terrace. The impact of LP following terrace construction was observed in crop yield, soil health, and CC + weed biomass.

When treatments were combined, the shoulder LP had the greatest soybean yield in 2016 and 2018, and the greatest corn yield in 2017 compared to BS, FS, and CH positions. The channel position had lowest yields in the same years. A treatment by LP interaction was detected for corn yields 2017. Yield was ranked NTC SH >NTC BS = CC SH >CC BS >CC FS = NTC FS >NTC CH >CC CH. Corn yield for the NTC was 6130 kg ha^{-1} to 9580 kg ha^{-1} and 5450 kg ha^{-1} to 9140 kg ha^{-1} for CC. No treatment by LP interaction was detected in soybean in 2016 or 2018.

Soil health properties were evaluated prior to terrace construction (2016) and again in the spring of 2018 (MU Soil Health Assessment Center). Prior to terrace construction, soil was sampled at the location of prospective shoulders and channels. In 2018, soil health was evaluated at SH, FS, CH, and BS positions. Prior to terrace construction, no detectable differences in soil health were present. Combined over treatments, year by LP interactions were detected for soil Mg, K, total organic carbon (TOC), and clay content. Soil test Mg was greatest (2.6 cmol kg^{-1}) in the CH and least in the SH (2.2 cmol kg^{-1}) in 2018. Prior to terrace construction, Mg was the same between LP (2.4 cmol kg^{-1}) and similar to both CH and SH soil test Mg levels following terrace construction. In 2016, SH and CH had similar levels of soil test K (0.3 cmol kg^{-1} and 0.4 cmol kg^{-1}, respectively). After terrace construction, CH soil test K was greater (0.5 cmol kg^{-1}) than SH (0.3 cmol kg^{-1}), which was similar to levels preceding construction.

Shoulder and CH position levels of TOC and clay were the same and greatest in 2016 (27 g kg^{-1}). In 2018, the CH position had the smallest TOC (13 g kg^{-1}) while the shoulder LP was ranked in the middle and had 15 g kg^{-1} of TOC. Following terrace construction, clay content was greatest in channel (270 g kg^{-1}) and smaller on the shoulder (240 g kg^{-1}). Clay content was smaller and similar in SH and CH positions prior to terrace construction (210 g kg^{-1} and 220 g kg^{-1}, respectively). All LP by treatment interactions (Mg, K, TOC, and clay) were similar prior to terrace construction. Therefore, differences in soil health parameters within LP's of terraces were a result of terrace construction.

Aboveground CC + weed biomass was greatest on FS position (1660 kg ha^{-1} to 1680 kg ha^{-1}) and lowest at the CH position (720 kg ha^{-1} to 810 kg ha^{-1}) in 2017 and 2018 when treatments were combined. In both years, SH CC + weed biomass was similar to FS and BS positions. Combined over treatments, CH was the lowest grain yielding LP and lowest CC + weed biomass position. Likewise, SH was the greatest yielding, or similar to the greatest yielding, LP for cash crop grain yield and CC + weed biomass. Following large rain events, CH positions were visually observed to have wetter soil conditions compared to SH, BS, and FS. The wetter conditions and the soil health properties discussed above may have resulted in areas of reduced plant growth or yield in the CH in 2016 and 2017. In 2018, the CH had the greatest clay content (270 g kg^{-1}), Mg (2.63 cmol kg^{-1}), Na (0.12 cmol kg^{-1}), K (0.5 cmol kg^{-1}) and Bray I P soil test levels (23 mg kg^{-1}), and had the least TOC (13 g kg^{-1}), potentially mineralizable nitrogen (35 mg kg^{-1}), bulk density (1.23 g cm^{3-1}), Ca (12 cmol kg^{-1}), pH $CaCl_2$ (5.5), pH H_2O (5.8), active C (310 mg C kg^{-1}). Therefore, smaller cash crop yield and CC + weed biomass in 2018 was attributed to soil health properties.

Increased grain yield and CC + weed biomass was observed possibly due to the creation of an unnatural A soil horizon on the SH position during terrace construction which provided greater plant growth and microbial activity. Over time, the CC may reverse some of the effects created by this construction.

Cover crops provided several benefits in a tile-terrace field. Cover crops increased soybean crop yield in 2018 by 130 kg ha^{-1} along with the water quality parameters evaluated in the rotational crop and CC season. Cover cops reduced event mean loads of total suspended solids (TSS) (363 g ha^{-1} to 4713 g ha^{-1}), total phosphorous (TP) (2 g ha^{-1} to 90 g ha^{-1}), and nitrate nitrogen (NO_3-N) (446 g ha^{-1} to 3407 g ha^{-1}) in all seasons. Compared to the NTC, CC's also reduced event mean discharge 40 to 81 m^3 ha^{-1} in each season. In the 2017 corn season, CC's reduced mean NO_3-N concentration of drainage water 8 mg L^{-1}. During the 2017-2017 CC season, CC's reduced mean concentrations of TP and NO_3-N in drainage water 0.0063 mg ha^{-1} and 4.16 mg ha^{-1}, respectively. During the 2016-2017 CC season and 2017 corn season, CC's reduced cumulative TSS (7 kg ha^{-1} to 43 kg ha^{-1}) and NO_3-N (5 kg ha^{-1} to 32 kg ha^{-1}) loss compared to the NTC. Cover crops reduced cumulative discharge 323 m^3 ha^{-1} to 722 m^3 ha^{-1}. Aboveground biomass of CC + weeds was evaluated in the spring in 2017 and 2018. In both years, CC had greater CC + weed biomass (1150 to 1980 kg ha^{-1}) than the NTC.

Though CC's provided water-nutrient, soil coverage, and yield benefits, CC's also presented opportunities for practice improvement. Cover crops reduced soybean yield 606 kg ha^{-1} in 2016 and corn yield 500 kg ha^{-1} in 2017. In 2018, northeast Missouri experienced a severe drought. The CC's may have conserved soil water thus increasing soybean yield (130 kg ha^{-1}). Though drought years cannot be predicted, this research demonstrates that in drought conditions, a cash crop following a drought had greater yields than a cash crop following an overwinter fallow. During the 2017-2018 CC season, CC's increased mean TSS concentration 1.16 mg L^{-1}. Though the 2017-2018 CC was planted using a low disturbance no-till drill (Solid Stand 10 No-Till Drill, Great Plains, Salina, KS), we believe that soil disturbance from CC planting may have increased mean TSS concentration while the winter fallow corn stalks in the NTC maintained soil protection and cover. No difference in mean TSS was detected in the 2016-2017 CC season when a CC blend was broadcast overseeded into standing soybean.

Long-term cropping systems study

A long-term cropping systems site was established in 1994 at the University of Missouri Greenley Memorial Research Center near Novelty. This site included a corn-soybean-wheat rotation with three tillage/cropping systems [1) no-till corn-soybean-wheat with double crop soybean following wheat (NT DCS), 2) no-till corn-soybean-wheat with frost-seeded red clover (cover crop) into wheat (NT FSC), and 3) reduced-till corn-soybean-wheat (RT)]. Each of the crops and cropping systems were represented each year. Combined over 22 years of data (1994-2016), corn grain yield was greatest in the reduced tillage system (7850 kg ha^{-1}) and similar to NT DCS yield (7680 kg ha^{-1}). In soybean, no-till systems were the highest yielding systems. Soybean grain yield was greatest in NT DCS (3170 kg ha^{-1}) and similar to NT FSC (3200 kg ha^{-1}). The reduced tillage system was the highest yielding wheat cropping system (3990 kg ha^{-1}).

Significant differences in corn grain yield means among cropping systems occurred seven times between 1994-2016. Reduced tillage was the highest yielding system five times (7530 kg ha^{-1} to 10275 kg ha^{-1}). In 2010, NT DCS was the greatest yielding corn cropping system (5000 kg ha^{-1}). Reduced tillage and NT DCS had equal and significantly greatest yields in 2016 (12550 kg ha^{-1}). Soybean grain yield differences occurred three times. In 2000 and 2002, NT DCS was the greatest yielding soybean cropping system (2820 kg ha^{-1} to 3500 kg ha^{-1}). In 2006, RT was the greatest yielding system (4300 kg ha^{-1}). Reduced tillage was the largest yielding cropping system for wheat four time (2680 kg ha^{-1} to 5450 kg ha^{-1}).

Combined over 14 years of data (2002 to 2016), soybean cyst nematode (SCN) egg population densities were smallest (0 to 422 eggs per 250 cm^3) in NT FSC prior to planting corn, soybean, and wheat. Prior to soybean and wheat planting, SCN egg population density was similar between NT DCS and RT. Before planting corn, NT DCS had greater egg population densities (2253 eggs per 250 cm^3) than RT and NT FSC (1657 and 103 eggs per 250 cm^3, respectively). Due to the race of the SCN population in this trial and the SCN resistant soybean varieties available, it is unlikely that planting an SCN resistant soybean variety protected the crop against SCN. Egg population densities remained below the action threshold throughout the study which indicated a corn-soybean-wheat rotation helped manage this pest.

Soil chemical properties and soil organic matter (SOM) were evaluated in 1994 and 2002-2016. The greatest levels of SOM occurred four times in 14 years. No-till DCS had 3 to 7 g kg^{-1} greater levels of soil organic matter in 2003, 2005, 2008, and 2010 compared to NT FSC and RT. By including a CC in the cropping system, SOM generally increased. Combined over years, soil pH_s was more acidic in the NT FSC. Decomposition of SOM produces H+ which probably reduced soil pH_s. Reduced tillage had the greatest Bray-I P (65 kg ha^{-1}) and soil test K (348 kg ha^{-1}) levels. Soil samples were taken to a 15 cm depth each spring prior to planting corn and soybean. Tillage mixed the soil layers and probably moved nutrients throughout the soil profile that would otherwise be immobile. Nutrient stratification in NT DCS and NT FSC deeper than the 15 cm sampled depth may have occurred due to a lack of tillage. The NT DCS cropping system experienced four cash crops in three years; therefore, larger crop nutrient removal occurred compared to NT FSC and RT resulting in lower levels of Bray-I P and soil test K.

Cropping system economics were analyzed for the 22-year study (1994-2016). Though double-crop soybean yield data from the NT DCS was not presented, input costs and net income reflect this additional crop. The greatest significant net income among cropping systems was observed five times which were all in NT DCS (\$91 ha^{-1} to \$505 ha^{-1}). Combined over years (1994-2016), total input costs for FSC were lowest (\$371 ha^{-1}). Input costs for RT (\$413 ha^{-1}) and NT DCS (\$408 ha^{-1}) were similar and highest. Overall net income was greatest (\$568 ha^{-1}) in NT DCS. No-till frost seeded clover and RT cropping systems were similar net incomes but were smaller (\$425 ha^{-1} and \$403 ha^{-1}, respectively) than NT FSC.

The greatest yielding cropping systems for corn were RT and NT DCS. The greatest soybean yields occurred in NT DCS and NT FSC. Finally, RT was the largest yielding wheat cropping system. In individual years, the system including a CC had the largest levels of SOM (29 to 38 g kg^{-1}) and combined over 14 years of data, had the smallest SCN egg population densities (0 to 280 eggs/250 cm^3). The NT DCS had the greatest net income of the evaluated cropping systems, but also had larger input costs than NT FSC. The greatest yielding cropping systems did not always have the greatest net incomes. No single cropping system had the greatest net benefits for all factors evaluated. Individual cropping systems produce unique results which can match individual producer management goals.

Overall

Cover crops increased SOM some years in long-term cropping systems. Cash crop yield was both increased and decreased depending on the CC that was used. Cover crops reduced SCN egg population densities, nutrient loss, and tile water discharge. In the 2017-18 CC season, drilling CC's increased mean TSS concentration in a tile terrace field. However, in the same season, CC's reduced cumulative and event mean drainage water discharge, event mean loads of TSS, TP, and NO_3-N, and TP and NO_3-N mean nutrient concentration. The drilled CC had greater CC biomass than NTC. In the same year when corn was overseeded at V5, V10, and VT and soybean was overseeded at R6, CC treatments did not produce greater biomass than NTC. There is a need to identify an effective CC that can be overseeded into soybean but does not negatively impact corn yields the following year.

No-till systems produced greater soybean yield, equal corn yield, and smaller wheat yields when compared to a RT system. The input costs of a RT system in a corn-soybean-wheat rotation was the same as the input costs for the NT DCS system which included four cash crops in three years. Though corn yields were equal and wheat yields were greater in a RT system, the additional cash crop in the NT DCS system plus residue management and lack of tillage costs allowed the NT DCS system to have a greater net income than the RT system. Switching to a reduced tillage system reduces equipment overhead and labor costs. No-till DCS system allowed conservation practice opportunities, reduced labor, crop rotation diversity, and increased net income. In a time of low commodity prices, balancing conservation, pest management, and production goals with the economic realities of farming is important for producers to consider.