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Agronomic and Economic Implications of Cover Crop Inclusion within Varying Nitrogen Management Strategies in Central Illinois

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AGRONOMIC AND ECONOMIC IMPLICATIONS OF COVER CROP INCLUSION WITHIN VARYING NITROGEN MANAGEMENT STRATEGIES IN CENTRAL ILLINOIS

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This thesis contains a comprehensive analysis of research investigating the impacts of nitrogen application timing and cover crops on the biomass production, nitrogen uptake, and cash crop grain yield in subsequent cash crops. Also contained within this thesis is a cost benefit analysis for the implementation of cover crops within varying nitrogen management systems, which assigns value to the environmental benefits of cover crops and determines their potential to recover the implementation costs associated with cover crops.

KEYWORDS: Cover Crops; Cost Recovery; Nitrogen Management; Cover Crop Economics, Environmental Benefits; Corn-Soybean Rotation; Fertilizer Timing; Nitrogen; Mineralization; Corn Yield; Soybean Yield; Crop Growth Stage; Nitrogen Uptake; Biomass Production; Illinois Nutrient Loss Reduction Strategy; Cost Benefit Analysis;

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IN CENTRAL ILLINOIS

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R.T.R.

CONTENTS

FIGURES

CHAPTER I: INTRODUCTION AND BACKGROUND

It has been estimated that greater than 1.57 million metric tons of nitrogen are delivered to the Gulf of Mexico on an annual basis, of which agricultural leaching of nitrogen (loss of nitrogen from the soil profile) accounts for approximately 65% (Alexander et al., 2000, Rabalais et al., 2002; Robertson and Saad et al., 2013). The link between Midwestern agriculture and the hypoxic zone in the Gulf of Mexico has become increasingly clear, with relatively poor nitrogen use efficiency (ratio of crop nitrogen uptake to applied nitrogen fertilizer) of 60% or less across the Midwestern region demonstrating the need for alternative nutrient management strategies to be developed (Chichester et al., 1978; Dinnes et al., 2002; Goolsby et al., 2001). In response to the Gulf Hypoxic Zone Action Plan released by the Environmental Protection Agency (EPA) in 2008, the Illinois EPA developed the Illinois Nutrient Reduction Strategy which contained a goal of reducing total nutrient transfer from Illinois water ways to the Mississippi River by 45% (IEPA, 2015). In order to achieve this goal, the efficacy of all nutrient management strategies employed across the state must be improved.

The use of split nitrogen applications (50% or greater of total N applied in spring) has been identified as one of the best in-field practices in order to achieve the goal set forth in the Illinois Nutrient Loss Reduction Strategy (IEPA, 2015). Making the change from fall to spring applied nitrogen has been shown to reduce agricultural leaching by as much as 17%, increase corn nitrogen uptake by 3-8%, and increase corn grain yields by as much as 7% (Randall et al., 2003; Vetsch and Randall, 2004; Strock et al., 2004; Randall and Vetsch, 2005). However, even with the demonstrated agronomic and environmental benefits of spring applied nitrogen over fall applied nitrogen, surveys suggest that within some Midwestern regions 46% - 75% of producers still apply some nitrogen in the fall (Smiciklas et al,. 2008; Bierman et al,. 2011; O'Rourke and Winter 2010; Lemke et al,. 2011). Therefore, a need exists for the development of strategies to increase the efficacy of fall dominated nitrogen management systems.

Cover crops (CC), also identified as one of the best in-field practices by the ILNLRS, represent the best management practice (BMP) with the lowest annual cost per hectare when compared to constructed wetlands and two-stage ditches; but, over 50 years, CC represent the lest cost-effective BMP in terms of cost per kilogram of N removed from surface water sources (Roley et al., 2016). However, CC represent an in-field practice that require only short-term commitments from producers, as they are planted and removed each year. Unlike constructed wetlands and two-stage ditches which require up to 5% of the land for which they are implemented to be removed from production, CC represent an effective BMP which requires zero land to be removed from production; and thus, may be a more attractive option to producers looking to implement environmentally friendly practices into their operations (Roley et al., 2016; D'Ambrosio et al., 2015; Christianson and Helmers, 2011).

CC have demonstrated the potential to absorb nitrogen from the soil profile and assimilate it into their organic structure, thus preventing the nitrogen from being lost from the agricultural field to the environment via leaching, denitrification, or volatilization. CC used in a fall nitrogen management system have demonstrated the ability to stabilize 66-91% of fall applied nitrogen and can potentially reduce the amount of nitrate leaching within a fall application management strategy (Lacey and Armstrong, 2014). They also have proven environmental benefits of erosion control, improving soil tilth, increasing soil organic matter, and increased water-holding capacity, they also have the potential to be used as a nutrient management tool in order to increase overall soil fertility (Danso et al., 1991; Odell et al., 1984; Hartwig and Ammon, 2002; Ditsch et al., 1991; Kaspar and Singer, 2011; IEPA, 2015).

There has been a vast amount of research concerning the impact of CC on grain yields of the subsequent cash crop in which the vast majority found the yields to be equal or greater than those from non-CC fields; however, others have found grain yields following CC to be equal or slightly less attributing the decreases to poor crop establishment or potential soil property differences, and possible cereal rye allelopathic effects (Deppe 2016; O'Reilly et al., 2011, 2012; Frye et al., 1985; Sainju et al., 2003; Belfry et al., 2016; Miguez and Bollero 2005; Reese et al., 2014; Ketterings et al., 2015; Moore et al., 2014; olson et al., 2010; Pantoja et al., 2015; Raimbault et al., 1990, 1991; Johnson et al., 1998). While much research exists concerning grain yields following CC, there is a dearth of knowledge surrounding the effect of CC on nitrogen uptake of the subsequent cash crop. Consequently, there is a need for research examining cash crop N uptake by growth stage following CC, to determine if specific critical growth stages impacted by CC can be identified.

The Conservation Technology Information Center conducted a survey to gauge producer perspective towards CC revealed increased soil health and organic matter, reduced soil compaction, reduced soil erosion, nitrogen scavenging, and being a source of nitrogen as the top motivators towards CC adoption (CTIC, 2016). However, surveys also reveal that the top barriers to CC adoption amongst producers include the costs of planting and managing the CC, the cost of the CC seed itself, and the lack of measurable economic returns following implementation (CTIC, 2015). A lack of measurable economic returns being identified as a top barrier to CC adoption is a concern, as most farm operations operate with the primary objective of profit maximization. There has been little research conducted concerning the value of measureable environmental benefits of CC. With profit maximization the primary objective of many producers, there is a great need for research to be conducted on the valuation of CC environmental benefits and how they relate to the recovery of CC implementation costs.

With CC recognized as one of the best and most cost effective in-field practices in helping reduce the impact of agriculture on the hypoxic zone in the Gulf of Mexico, it is important to begin breaking down the barriers to widespread adoption of the practice (ILNLRS, 2015). While the environmental benefits of CC as a method of improving water quality and soil health should be considered by producers and policy makers, cost and logistical obstacles must be accounted for before widespread implementation of CC can occur (Strock et al,. 2004). Therefore, there is a need for research concerning the valuation of CC environmental benefits and how they relate to the recovery of CC implementation costs.

Research Hypotheses

1. Fall and spring nitrogen management treatments with cover crops will have greater cash crop biomass production and nitrogen uptake at all growth stages versus the fall and spring nitrogen management treatments without cover crops
2. Fall and spring nitrogen management treatments with cover crops will have greater cash crop grain yields versus the fall and spring nitrogen management treatments without cover crops
3. The environmental benefits associated with cover crop will offset 100% of cover crop implementation costs in both the fall and spring dominated nitrogen management treatments.

Research Objectives

1. Investigate the effects of nitrogen application timing and cover crops on biomass production, nitrogen uptake, and grain yield of the subsequent cash crop.
2. Quantify and assign value to cover crop environmental benefits, and determine the potential for the value of cover crop environmental benefits to offset the costs of cover crop implementation.

CHAPTER II: LITERATURE REVIEW

Nitrogen Management

General

Nitrogen is an essential element for the sustainability of any life form, and is the nutrient taken up in the largest proportion by plants. Nitrogen is essential in the formation of compounds such as DNA, RNA, chlorophyll, amino acids, proteins, and enzymes in plants; but is often considered the most limiting factor in the production of corn and other non-leguminous crops. Generally crops considered to be non-leguminous require the addition of nitrogen fertilizer in either organic or inorganic form in order to achieve the yields expected in modern day agriculture. However, nitrogen is also the nutrient most susceptible to environmental loss via the process of leaching.

After application, nitrogen is susceptible to varying biological processes within the soil including leaching, denitrification, volatilization, and immobilization due to microbial activity; all of which result in a loss of available nitrogen within the profile. Therefore, different nitrogen management strategies will influence the amount of plant available nitrogen in different ways. The potential for nitrogen loss via these biological processes increases as the time between application and planting increases. This is true for applied nitrogen as well as residual nitrogen (Bock et al., 1991, Durieux et al., 1995).

When nitrogen is applied, whether as organic fertilizer such as manure or inorganic fertilizer such as anhydrous ammonia, it undergoes several biological processes within the soil. One such biological process is known as nitrification, the conversion of ammonium (NH_4^+) the positively charged ionic form of nitrogen to the negatively charged ionic form of nitrogen nitrate

(NO_3^-). Soil particles also carry a negative charge due to their clay and organic matter content. Therefore, the negatively charged nitrate ions are repelled by the negatively charged soil particles making nitrate free to move within soil profile. The downward movement of nitrate through the soil profile is known as leaching.

In fields with subsurface drainage the downward movement of the nitrogen is intercepted by the drainage line, and the nitrate is removed from the field and delivered to a surface water source. The introduction of nitrate from agricultural fields to surface waters, along with surface runoff of nitrogen and atmospheric deposition account for up to 81% of the annual nitrate load in the hypoxic zone located on the Gulf of Mexico (alexander et al., 2000).

This nitrate loading effect can be linked to the intensification of row crop production within the Midwest. The two major components behind the intensification of Midwest agriculture are the increased availability of inorganic nitrogen fertilizers following World War II and the establishment of the Haber-Bosch process, as well as the growth in use of artificial subsurface drainage covering approximately 20.8×10^6 Midwest hectares by 1987 (practice that removes excess water from soil subsurface quickly and effectively) (Dinnes et al., 2002). This is especially true in the case of a continuous corn rotation, which has continuously been identified as the largest source of nitrate leaching to surface water sources through subsurface drainage due to the need for added nitrogen fertilizer each crop year (Kanwar et al., 1993). This has led to the development of adaptive management strategies to help improve conventional nitrogen management practices.

Conventional Management

Nitrogen management is: “managing the amount, source, placement, form and timing of application of nitrogen to the soil” as defined by the NRCS (Natural Resources Conservation

Service), a division of the USDA (United States Department of Agriculture) (USDA-NRCS, 2006). Current nitrogen practices within the Midwest are generally inefficient, resulting in an increased potential for water source contamination (Kanwar et al., 1993, Randall et al., 1997). Traditionally, nitrogen fertilizer rates for the production of corn were based on 60% nitrogen use efficiency rates, however this percentage can be drastically altered by suboptimal weather conditions (Chinchester et al., 1978). A broad definition of nitrogen use efficiency as set forth by the NRCS is: “the ratio of crop nitrogen uptake to available soil nitrogen (N) which would include applied fertilizer N plus residual mineral N in the soil” (USDA-NRCS, 2007). This means that the greater the nitrogen uptake to available soil nitrogen ratio, the more efficient the use of nitrogen. The key for producers is to obtain optimal crop yields while using minimal nitrogen inputs. High nitrogen use efficiency results in reduced amounts of nitrogen remaining in the soil profile after crop removal, which is subject to leaching or denitrification processes resulting in a loss of nutrients from the agronomic rooting depth of the soil profile (USDA-NRCS, 2007).

The relatively low nitrogen use efficiency in current nitrogen practices has led to the development of certain strategies aimed at increasing nitrogen use efficiency. The primary strategies for increasing nitrogen use efficiency are by following Best Management Practices (BMPs) as set forth by the NRCS, The Fertilizer Institute (TFI) and other state agencies such as the Illinois Council on Best Management practice (ICBMP), specifically focusing on the use of the 4R Nutrient Stewardship strategy for nitrogen Management. The 4R Nutrient Stewardship strategy for the management of nitrogen focuses on using the right fertilizer source, the right fertilizer rate, the right application timing, and the right application placement in order to increase environmental protection, increase production and overall operational profitability, as well as improved sustainability (Johnson, 2011). The 4R strategies as defined by Bruulsema et al., (2013) are as follows:

- Rate: matching nitrogen application rates with crop requirements while accounting for all other N sources, irrigation water, atmospheric deposition and residual N from previous crops
- Timing: Applying Nitrogen fertilizers as close to maximum crop uptake as possible, rather than applying before the crop is planted (ex: fall application)
- Placement: placing and keeping nutrients, via injection or incorporation into the soil, where the crop can get to them, nitrogen use efficiency is maximized, and the potential for leaching and volatilization is reduced.
- Source: matching the right fertilizer product with soil properties and crop needs

Timing

Fall Application

Fall and spring application of nitrogen are the two primary application timings within which producers work to apply their nitrogen fertilizers sources. It has been demonstrated that nitrate losses through subsurface drainage can be reduced by as much as 13%-17% and overall leachate can be reduced by 11-13% with the use of spring application methods for nitrogen fertilizer (Randall et al., 2003, Strock et al., 2004). However, it has been shown that 46-55% of farmers' nitrogen fertilizer applications occur in the fall within some Midwest regions (Smiciklas et al,. 2008; Bierman et al,. 2011). In fact, 48-52% of farmers in the central Illinois region apply their nitrogen fertilizer in the fall (Smiciklas et al,. 2008; O'Rourke et al., 2010). Furthermore, up to 75% of farmers applied their nitrogen fertilizer in the fall within some Illinois watersheds (Lemke et al,. 2011). However, Smiciklas's study also showed that regardless of application timing or inhibitor use nitrate levels leaving subsurface drainage lines were well above the Environmental Protection Agency (EPA) standard of 10 ppm for drinking water. In fact, fields that received zero application of nitrogen exhibited nitrate levels in excess of the EPA standard for drinking water. Though this study again demonstrated a reduction in subsurface nitrate runoff for spring application of nitrogen as compared to a fall application system (Smiciklas et al., 2008).

Fall application of nitrogen fertilizer has the potential for greater input losses as compared to spring application of nitrogen due to the increased amount of time between the application and critical crop uptake stages. However, fall application of nitrogen is generally perceived to be more economically feasible due to lower nitrogen prices as well as requiring less equipment to complete the application thus making fall application a preferred method by producers and also the fertilizer industry (Smiciklas et al., 2008; Illinois agronomy handbook). Logistical advantages also exist with the use of fall nitrogen application such as saving time in the spring to allow for early planting, better distribution of labor and equipment, and generally better soil conditions due to reduced compaction of the seed bed (Vetsch et al., 2004; Fernández et al., 2009). If producers choose to use the fall application method of nitrogen the preferred nitrogen source is anhydrous ammonia injected into soils at temperature below 50°F. Anhydrous ammonia is preferred because it nitrifies at a slower rate than other sources, and urea containing fertilizers should be avoided as they are not as effective as fall-applied anhydrous ammonia or spring-applied urea (Nafziger et al., 2013; Fernández et al., 2009). Several considerations should be taken into account when contemplating the fall application of nitrogen including: soil temperature, soil moisture, nitrogen source, and whether or not a nitrification inhibitor should be used (Nafziger et al., 2013).

Although the recommended soil temperature for the application of fall nitrogen is 50°F due to the drastic reduction of nitrifying microbial activity, the biological process continues until temperature are below 32°F. In fact, in cases of late fall and early spring nitrogen application most of the applied N is converted to nitrate by corn planting due to nitrification during the period of time when soil temperatures are between 32°F and the mid-40s (Fernández et al., 2009). Use of a nitrification inhibitor will slow the nitrification process that converts ammonium to nitrate (Nafziger et al., 2013). A nitrification inhibitor is a nitrogen fertilizer amendment which inhibits the activity of the nitrosomonas bacterium within the soil. Nitrosomonas is the bacterium which converts ammonium into nitrite, the first step of the two step nitrification process.

Spring Application

While spring application of nitrogen may not always be a viable option, dependent upon weather conditions affecting the workability of a field, there are demonstrated benefits from the use of a spring nitrogen management system. It has been shown that nitrate losses through subsurface drainage can be reduced by as much as 13%-17% and overall leachate can be reduced by 11-13% with the use of spring application methods for nitrogen fertilizer (Randall et al., 2003, Strock et al., 2004). This reduction in nitrate leaching may be due to the timing of the application being closer to critical crop uptake stages. Greater yields as compared to fall nitrogen management systems have also been demonstrated with the use of a spring nitrogen management system (Vetsch and Randall, 2004, Welch et al., 1971). Two methods of spring application exist: pre-emergence and post-emergence application. Post-emergence side-dress application of nitrogen is the most optimal application method as it delivers the nitrogen to the plant at the time of critical growth, however pre-emergence is still preferred over any fall application. Some deterrent to the use of a spring nitrogen management system include cost, availability of equipment and nitrogen sources, as well as the delegation of time away from other in-field activities. Also, producers often worry about causing irreversible yield damage caused by delays in application timing due to weather (Scharf et al., 2002, Fernández et al., 2009). As with all processes in agriculture, nitrogen application is very weather dependent and application timing may change from year to year.

Cover Crops

History

Records indicate that early civilizations such as Mesopotamia, Greece, Egypt, and Rome farmed their lands so intensively that the soils became depleted of nutrients due to poor soil stewardship (Paine et al. 1993). Leaving a field fallow, or bare, has until recently been the most common method for dealing with declining soil productivity. In fact, fallowing is the earliest recorded attempt at the restoration of soil fertility, and is still used amongst some indigenous farmers (Paine et al., 1993). However, in 500 BC China introduced the idea of green manure, defined as: "plant material incorporated with the soil while green or soon after maturity, for improving the soil" (SSSA, 2015, Pieters et al., 1927). In 1927, Adrian Pieters released a book titled *Green Manuring Principles and Practice* in which he categorized green manure into four general categories based on how the crop fits into a producer's rotation.

- Main Crop- green manure grown during the regular growing season in place of any other crop on poor soils incapable of growing other crops
- Catch Crop- green manure planted after the main crop in hope of capturing residual soil nutrients

- Winter Cover Crop-planted in fall and serves to cover the soil during winter to protect from erosion
- Companion Crop- a species planted with main crop or during final cultivation and allowed to grow between crop rows as well as after crop harvest, now known as “living mulch”

The concept of green manure amongst European and American producers was generally not accepted until several studies were published during the 19th century demonstrating benefits for the use of green manure (Paine et al., 1993).

The adoption of these practices brought about the introduction of modern day cover crops (CC) such as cereal rye, annual rye, daikon radish, crimson clover, triticale, and hairy vetch. Traditionally, CC were defined as crops grown to protect soil from erosion and loss of plant nutrients, while green manures were crops grown with the purpose of improving soil productivity (Pieters et al., 1927, Reeves et al., 1994, SSSA, 2015). However, in modern agriculture we generally use the term CC as an inclusive term, where the two are interchangeable, as we reap the benefits of both definitions from the introduction of CC into a rotation.

Benefits

Several potential benefits can be seen within varying cropping systems following the introduction of a CC into the crop rotation. CC have many potential benefits, though they are primarily grown for their ability to reduce soil erosion. Soil erosion as defined by the Soil Science Society of America is the detachment and movement of soil or rock by water, wind, ice, or gravity (SSSA, 2015). The process of erosion can affect the productivity of an agricultural field by removing the fertile top soil. Splash erosion is defined as: “the detachment and airborne movement of small soil particles caused by the impact of raindrops on the soil” (SSSA, 2015). CC provide vegetative cover to cushion the force of falling raindrops as well as reduce the rate of runoff which increases infiltration rates, effectively reducing splash and erosive surface runoff (Hartwig et al., 2002, Mermut et al., 1997).

Erosion control is not the only benefit from the introduction of CC into a rotation. Along with erosion control, the introduction of a CC into a crop rotation may potentially provide and conserve nitrogen for grain crops, reduce weed pressure, and increase soil organic matter (Hartwig et al., 2002). Soil organic matter is: “the organic fraction of the soil exclusively comprised of undecayed plant and animal residue” and is essential to soil health (SSSA 2015). Approximately 100 years ago the average soil organic matter of the U.S. Corn belt was about 12%, but after years of intensive row crop agriculture the average soil organic matter of those soils is less than 6% and in many cases is even lower. These soils would greatly benefit from the addition of organic matter, and CC provide the potential to increase soil organic matter and in turn benefit many other soil properties (Odell et al., 1984). CC may also improve soil structure, water-holding capacity, and help reduce the chance of environmental pollution from nitrogen fertilizers (Danso et al., 1991).

In recent decades one heavily researched topic is the ability of CC to be used as a nutrient management tool in order to increase overall soil fertility. Of the 17 elements essential to crop growth and development, nitrogen is at the forefront of this research.

Integration of Cover Crops

Following the harvest of cash crops, producers can plant fast-growing annual cereal crops, known as catch crops, for the purposes of scavenging residual nitrogen from the soil profile in an attempt to optimize their nitrogen management strategy (Ditsch et al., 1991; Hartwig and Ammon, 2002; Pieters et al., 1927). Residual nitrogen from the fertilization of a previous cash crop is absorbed by these CC and assimilated into their structure, preventing the nitrogen from being lost via leaching, denitrification, or volatilization (Hartwig and Ammon, 2002; Kaspar and Singer, 2011). Following winterkill or chemical termination, the CC residues begin to breakdown and decay releasing the nitrogen held within the biomass back into the soil. Along with providing protective ground cover and reducing environmental losses of nitrogen, the CC residues have the capability of providing the following cash crop with enough required nitrogen to produce a high yielding crop (Danso et al., 1991).

Use of CC within a fall nitrogen management system also has demonstrated benefits. It has been shown that CC have the ability to stabilize 66-91% of fall applied nitrogen and can potentially reduce the amount of nitrate leaching within a fall application management strategy (Lacey et al,. 2014). The ability of CC to absorb and assimilate residual plant-available nitrogen from the soil following the harvest of a cash crop not only reduces the potential for nitrate leaching, but may also eliminate many of the environmental problems associated with excess nitrogen in agricultural systems (Danso et al., 1991; Hartwig and Ammon, 2002; Kaspar and Singer, 2011).

The long running concern of establishing a CC stand has been a deterrent to many producers concerning the introduction of a CC into their rotation. It has been shown that the probability of favorable conditions for the establishment of a CC stand is 1 in 4 years (25%) in parts of southwestern Minnesota (strock et al,. 2004). However, new methods of CC planting have been established which would allow for producers to interseed CC into corn densities of up to 75,000 plants ha^{-1}, while maintaining corn grain yields and allowing for enough biomass growth for the subsequent spring. This information could be used in low-input farming systems as a method of reducing nitrogen fertilizer inputs (Baributsa et al,. 2008).

Environmental Benefits of Cover Crops

Another question often raised by producers when discussing CC is the return of nitrogen taken up by the CC being available to the following cash crop. There is no simple answer to this question, however in order to better understand the return of nitrogen from the biomass of the CC, one must understand the process of mineralization. The process of mineralization is the conversion of organically bound nitrogen found within the CC biomass, back into the plant available inorganic forms of nitrogen. This is a two-step process, the first of which is known as amminization where the organically bound nitrogen is converted into an amine with the form of $R\text{-}NH_2$, where R- is used as a general term for any connected substituent. The second step of the process is known as ammonification where the previously converted amine is further converted into the positively charged plant available form of nitrogen, ammonium (NH_4^{+1}). This process is primarily driven by microbial activity based on the ratio of carbon to nitrogen (C:N ratio) within the residues. Microbes within the soil require a C:N ratio of 24:1 for optimal residue decomposition. This mean that for every 24 carbon atoms within the residue, the microbes require only one nitrogen atom to decompose them. However, if the C:N ratio of the residue exceeds 24:1 then a process known as immobilization occurs. Immobilization is the process by which microbes pull nitrogen from the soil solution to obtain a 24:1 C:N ratio with the residue to allow for optimal decomposition. Once decomposition is complete the nitrogen is returned back to the soil solution. To our knowledge little work has been done on the determination of mineralization rates following the termination of a CC, especially amongst varying nutrient management and tillage systems.

Since the 1950s annual nitrate deposition from the Mississippi River to the Gulf of Mexico has nearly tripled (Goolsby et al., 1999). Upwards of 1.57 million metric tons of nitrogen is released annually into the Gulf of Mexico. Agricultural leaching, runoff, and atmospheric deposition have been estimated to account for up to 81% of the annual nitrogen load delivered to the Gulf of Mexico from the Mississippi River (Alexander et al., 2000). CC have been shown to reduce subsurface drainage discharge by as much as 11% and to reduce nitrate nitrogen loss through subsurface drainage by as much as 13% as compared to agricultural fields without CC (Strock et al,. 2004). A reduction in the load of nitrates, from the use of CC, entering surface waters via subsurface drainage lines may have the potential to reduce the nitrate load reaching the Gulf of Mexico, which in turn may reduce the overall size of the Hypoxic Zone.

In 2008 the United States Environmental Protection Agency implemented the Gulf Hypoxia Action Plan which requires the 12 states within the Mississippi River Basin to develop individual state strategies for the reduction of nitrogen and phosphorous carried in rivers within the state and to the Gulf of Mexico and in 2011 set forth a framework by which the strategies should be constructed (ILNLRS, 2015). Illinois has set forth a strategy which comprehensively describes best management practices for reducing nutrient loading in water sources with the goal of reducing the phosphorous load in water sources by 25 percent and the nitrogen load by 15 percent. Along with addressing water quality issues in Illinois' rivers, lakes and streams, the ultimate goal of the Illinois Nutrient Loss Reduction Strategy is to reduce the total nutrient losses to the Mississippi River by 45 percent (ILNLRS, 2015).

Cover Crop Adoption

National CC hectares increased from 48,393 hectares in 2010 to 151,157 hectares in 2015 corresponding to a 312% increase in national CC hectares over a period of just five years (CTIC, 2015). A survey conducted by the Conservation Technology Information Center in 2016 aimed at gauging producer perspective towards CC revealed that the top motivators amongst producers for the adoption of CC include increased soil health and organic matter, reduced soil compaction, reduced soil erosion, nitrogen scavenging, and being a source of nitrogen (CTIC, 2016). However, a survey conducted by the same group suggests that there are still several barriers to the widespread adoption of CC. The survey revealed that the top barriers to CC adoption amongst producers are the costs of planting and managing the CC, the cost of the CC seed itself, and the lack of measurable economic returns following implementation (CTIC, 2015). There has been little research conducted concerning the value of measureable environmental benefits of CC. A lack of measurable economic returns being identified as a top barrier to CC adoption is a concern, as most farm operations operate with the primary objective of profit maximization. However, there has been little research conducted concerning the value of measureable environmental benefits of CC. With profit maximization the primary objective of many producers, there is a great need for research to be conducted on developing methods for the valuation of CC environmental benefits which allow for increased economic returns following the use of CC.

In response to the Gulf Hypoxic Zone Action Plan release in 2008 by the Environmental protection Agency (EPA), the Illinois EPA developed the Illinois Nutrient Loss Reduction Strategy which outlined several management practices, in-field practices, and edge-of-field practices that could be implemented to reduce nutrient loading to the Mississippi River. The use of CC on all tiled and non-tiled acres in the state of Illinois was identified as one of the most cost effective and easily implemented in-field practices that could help achieve the ILNLRS goal of reducing total nutrient loading from Illinois waterways to the Mississippi River by 45% (IEPA, 2015). Over a four year period from 2011 to 2015, total CC acres across the state of Illinois increased by 187% from 600,000 acres to 1,120,000 acres. The 187% statewide increase was a result of non-tiled acres planted with CC increasing by 166% from 380,000 acres to 630,000 acres, while tiled acres planted with CC increased by 223% from 220,000 acre to 490,000 acres. Illinois producers that planted CC in 2015 identified erosion control, nitrogen and phosphorus preservation, control of weeds and pests, and improved soil quality as their top motivations for planting CC (USDA-NASS, 2016). While the agronomic and environmental benefits may sway some producers towards the adoption of CC, the additional input costs and the recovery of those costs must considered by producers, and policy makers, before widespread adoption of CC without governmental economic assistance can occur. Therefore, research must be conducted that is aimed at quantifying the environmental benefits of CC, placing value to them, and determining their role in the recovery of the initial CC implementation costs.

Economics of Cover Crops

While the benefits of CC as a method of improving water quality should be considered by producers and policy makers, cost and logistical obstacles must be accounted for before widespread implementation of CC can occur (Strock et al,. 2004). The economic component of implementing CC is of concern to producers, as it has neither been proven nor disproven as to whether there is an economic incentive for implementing CC into crop rotations and nutrient management strategies. Based on most operations' primary objective of profit maximization, a producer who considers implementing a CC into their rotation will only do so if the revenue from the cash crop after planting and managing the CC is greater than or equal to the cost of implementing the CC (Morton et al,. 2006).

Currently, there are a couple spreadsheet based economic models commercially available for producers to use in determining the profitability of implementing CC into the operations. In general, these models use a cost benefit analysis to determine the profitability of CC implementation costs based upon yield changes in the following cash crop (USDA-NRCS, 2014). Other factors accounted for amongst these models include erosion control, nutrient credits from CC, and reduced pesticide application. However, there are some drawbacks to these commercially available tools. First, the general recommendation is to use nutrient credits from leguminous CC species only, and they do not account for nitrogen scavenged and assimilated into the biomass of grass or brassica CC species. Second, these nutrient credits are often valued by the amount change in a producer's fertilizer application plan; however, many producers do not adjust fertilizer application rates following CC. Lastly, the method recommended for estimating erosion reduction is to use the downloadable RUSLE2 program available through the United States Department of Agriculture Natural Resources Conservation Service; however, this program is relatively non-user friendly to first time users, and requires time and effort to understand and comprehend the methods used in running the program. These tools certainly have value as a method of allowing producers to predict their profitability following CC use; but, research needs to be conducted into the valuation of all CC environmental benefits and their use in supplementing the value of crop grain yield impacts. The incorporation of the value of these environmental benefits into commercially available cost benefit models could allow producers to better predict economic returns following the use of CC.

Pratt et al., (2014) conducted a study across 24 Indiana farms in which they examined the ability of CC environmental benefits to recover the cost of CC implementation. A combination of four agronomic and environmental benefits were used in the cost benefit analysis including increased soil organic matter, reduced soil compaction, reduced soil erosion, and added nutrient content. However, much like the commercially available tools, the study conducted by Pratt et al., (2014) does have its weak points. First, they did not measure yield increases or decreases, but rather assumed increases in soil organic matter were correlated to increased grain yield; however, this is not always the fact as evidenced by Ismail et al., (1994) who observed nine continuous years of declining corn grain yields despite increasing soil organic matter content. Second, as with the commercially available tools, added nutrient content was primarily accounted for only from leguminous CC species with only small values being associated with scavenged N from brassica and annual grass crops. Again, these nutrient credits were valued based upon the assumption that producers would reduce their fertilizer application rates by the assumed nutrient credit of the CC. Despite the drawbacks of this study, Pratt et al., (2014) determined that the that the on-site net benefit of CC ranged from a net loss of \$11.09 ha^{-1} to a net benefit of \$87.32 ha^{-1}.

Pratt et al., (2014) took their study a step further by examining and estimating the net economic benefit to producers following the removal of corn stover for the purposes of bioenergy production as a method of supplementing the value of CC agronomic benefits on the recovery of CC implementation costs. Through the introduction of a new source of revenue through the sale of corn stover for bioenergy production, they were able to increase the total net benefits of the cropping system containing CC to a range of net losses of \$3.78 to net benefits of \$249.52 dependent upon stover prices. Although the removal of corn stover as a method of cost recovery increased the overall net benefits of the CC system, if this practice is not already incorporated into a producers operation it may require the purchase of additional equipment or hiring of extra labor which could lead to additional annual costs exceeding that of the CC.

One major component missing from all discussed models is the inclusion of a value for the amount of nutrients lost through subsurface drainage in a field without CC as compared to a field with CC. Through the determination of nutrient efficiency in a CC field via analysis of subsurface drainage leachate, the potential for reducing nutrient inputs as a result of increased nutrient efficiency is possible. While CC have demonstrated the potential to provide various environmental benefits within cropping systems, there is a dearth of knowledge regarding the value of these environmental benefits in relation to the costs of including CC in a cropping system and research is still necessary to determine whether there is an economic incentive behind the implementation of CC.

References

"Conservation Practice Standard: Nutrient Management" (2006). United State Department of Agriculture Natural Resources Conservation Service. Web. 25 Mar. 2015.

"Cover Crop Survey Report." (2015). n. pag. *COVER CROP SURVEY*. Conservation Technology Information Center/ Sustainable Agriculture Research and Education. Web. 17 March 2017.

"Cover Crop Survey Report." (2016). n. pag. *COVER CROP SURVEY*. Conservation Technology Information Center/ Sustainable Agriculture Research and Education. Web. 17 March 2017.

"Cover Crops Tool: An Economic Decision Support Tool." (2014). *Cover Crops Tool Fact Sheet*. United States Department of Agriculture Natural Resources Conservation Service. Web. 17 March 2017.

"Illinois Nutrient Loss Reduction Strategy." (2015). *Illinois Nutrient Loss Reduction Strategy*. Illinois Environmental Protection Agency. Web. 25 Mar. 2015.

"Nitrogen Efficiency and Management" (2007). United State Department of Agriculture Natural Resources Conservation Service. Web. 25 Mar. 2015.

"Nutrient Loss Survey Results" (2016). United State Department of Agriculture National Agricultural Statistics Service Illinois Field Office. Web. 19 Mar. 2017.

Alexander, R.A., R. B. Smith, G. E. and Schwarz. (2000). Effect of stream channel size on the delivery of nitrogen to the Gulf of Mexico: *Nature*. v. 403. p. 758-761.

Baributsa, D., E. Foster, K. Thelen, A. Kravchenko, D. Mutch, and M. Ngouajio. (2008). Corn and cover crop response to corn density in an interseeding system. *Agronomy Journal*, *100*(4), 981-987.

Belfry, K. D., and L. L. Van Eerd. (2016). Establishment and Impact of Cover Crops Intersown into Corn. *Crop Sci*. 56:1245-1256. doi:10.2135/cropsci2015.06.0351

Bierman, M.P., C. Rosen, R. Venterea, and J. Lamb. (2012). Survey of N fertilizer use on corn in Minnesota. *Agric. Syst*. 109:43–52.

Bock, B. R., and G. W. Hergert. (1991). Fertilizer Nitrogen Management In *Managing Nitrogen for Groundwater Quality and Farm Profitability*. p. 139–164. doi:10.2136/1991.managingnitrogen.c7 Soil Science Society of America

Bruulsema, T. W., P. E. Fixen, and E. Sulewski. (2013). *4R Plant Nutrition: a manual for improving the management of plant nutrition, North American Version*. Norcross, GA: International Plant Nutrition Institute

Chichester, F. W., and S. J. Smith. (1978). Disposition of 15N-Labeled Fertilizer Nitrate Applied During Corn Culture in Field Lysimeters. *J. Environ. Qual*. 7:227-233. doi:10.2134/jeq1978.00472425000700020015x

Christianson, Laura E., and Matthew Justin Helmers. (2011) *Woodchip Bioreactors for Nitrate in Agricultural Drainage*. Agriculture and Environment Extension Publications. Book 85.

D'Ambrosio, J. L., A.D. Ward, and J. D. Witter. (2015). Evaluating Geomorphic Change in Constructed Two-Stage Ditches. JAWRA *Journal of the American Water Resources Association*, 51(4), 910-922.

Danso, S. K., C. Labandera, D. Pastorini, and S. Curbelo. (1991). Herbage yield and nitrogen fixation in a triple species mixed sward of white clover, lotus and fescue. *Soil Biol. Biochem*. 23:65–70.

Deppe, William Travis. (2016). *Winter Cover Crops Impact on the Distribution of Soil Inorganic Nitrogen and Subsequent Crop Uptake and Yield Following Fall Applied Anhydrous Ammonium*. Theses and Dissertations. Paper 493.

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/agronj2002.0153

Ditsch, D. C., M. M. Alley, K. R. Kelley, and Y. Z. Lei. (1993). Effectiveness of winter rye for accumulating residual fertilizer N following corn. *Journal of soil and water conservation 48*(2), 125-132.

Durieux, Robert P., Hugh J. Brown, E. J. Stewart, J. Q. Zhao, William E. Jokela, Frederick R. Magdoff. (1995). Implications of Nitrogen Management Strategies for Nitrate Leaching Potential: Roles of Nitrogen Source and Fertilizer Recommendation System. *Agron. J* 87:884–887. doi:10.2134/agronj1995.00021962008700050017x

Fernández, Fabián G., Emerson D. Nafziger, Stephen A. Ebelhar, Robert G. Hoeft. (2009). Managing Nitrogen. In *Illinois Agronomy Handbook: 24th Edition* (pp. 113-132). Urbana, IL: University of Illinois at Urbana-Champaign, College of Agriculture, Cooperative Extension Service.

Frye, W.W., W.G. Smith, and R.J. Williams. (1985). Economics of winter cover crops as a source of nitrogen for no-till corn. *J. Soil Water Conserv*. 40:246–249.

Goolsby, D.A., W. A. Battaglin, G. B. Lawrence, R. S. Artz, B. T. Aulenbach, R. P. Hooper, D. R. Keeney, and G. J. Stensland. (1999). Flux and sources of nutrients in the Mississippi-Atchafalaya River Basin--topic 3 report for the integrated assessment on hypoxia in the Gulf of Mexico: Silver Spring, Md. NOAA Coastal Ocean Office. *NOAA Coastal Ocean Program Decision Analysis Series*. No. 17 pp 130+.

Goolsby, Donald A., Battaglin, William A., Aulenbach, Brent T., Hooper, Richard P. (2001). Nitrogen Input to the Gulf of Mexico. *joenq* 30:329–336. doi:10.2134/jeq2001.302329x

Hartwig, N. L., & H.U. Ammon. (2002). Cover crops and living mulches. *Weed science*, 50(6), 688-699.

Ismail, I., R. L. Blevins, and W. W. Frye. (1994). Long-Term No-tillage Effects on Soil Properties and Continuous Corn Yields. *Soil Sci. Soc. Am. J*. 58:193-198. doi:10.2136/sssaj1994.03615995005800010028x

Johnson, Jason. (2011). *4Rs Right for Nutrient Management*. United State Department of Agriculture Natural Resources Conservation Service. Web. 12 Mar. 2015.

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

Kanwar, R.S., D.E. Stolenberg, R. Pfeiffer, D.L. Karlen, T.S. Colvin, and W.W. Simpkins. (1993). Transport of nitrate and pesticides to shallow groundwater systems as affected by tillage and crop rotation practices. p. 270–273. In *Proc. Natl. Conf. on Agric. Res.to Protect Water Quality.*

Kaspar, T.C., and J W. Singer. (2011). The Use of Cover Crops to Manage Soil, In *Soil Management: Building a Stable Base for Agriculture*. p. 321–337. doi:10.2136/2011.soilmanagement.c21 Soil Science Society of America

Ketterings, Q. M., S. N. Swink, S. W. Duiker, K. J. Czymmek, D. B. Beegle, and W. J. Cox. (2015). Integrating Cover Crops for Nitrogen Management in Corn Systems on Northeastern U.S. Dairies. *Agron. J.* 107:1365-1376. doi:10.2134/agronj14.0385

Koch, B., R. Khosla, W. Frasier, D. Westfall, and D. Inman. (2004). Economic feasibility of variable-rate nitrogen application utilizing site-specific management zones. *Agronomy Journal*, *96*(6), 1572-1580.

Lacey and Armstrong.(2014). In Field Measurements of Nitrogen Mineralization Following Fall Applications of N and the termination of Winter cover crops. *Air, Soil and Water Research* 2014:7 53 – 59 doi:10.4137/ASWR.S13861.

Lemke, A., K. Kirkham, T. Lindenbaum, M. Herbert, T. Tear, W. Perry, and J. Herkert. (2011). Evaluating agricultural best management practices in tile-drained subwatersheds of the Mackinaw River, Illinois. *J. Environ. Qual.* 40:1215–1228.

Mermut, A. R., S. H. Luk, M. J. M. Römkens, and J. W. A. Poesen. (1997). Soil loss by splash and wash during rainfall from two loess soils. *Geoderma*, *75*(3), 203-214., Vol. 50, No. 6, pp. 688-699

Miguez, F. E., and G. A. Bollero. (2005). Review of Corn Yield Response under Winter Cover Cropping Systems Using Meta-Analytic Methods. *Crop Sci*. 45:2318-2329. doi:10.2135/cropsci2005.0014

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

Morton, T. A., J. S. Bergtold, and A. J. Price. (2006). *The Economics of Cover Crop Biomass for Corn and Cotton.* USDA-ARS, National Soil Dynamics Laboratory. Auburn, AL.

Nafziger, Emerson. "Issues with Nitrogen Fertilizer: Fall 2013." *Pest Management and Crop Development Information for Illinois* (2013): n. pag. U of I Extension. Web. 08 Feb 2015.

O'Reilly, K.A., J.D. Lauzon, R.J. Vyn, and L.L. VanEerd. (2012). Nitrogen cycling, profit margins and sweet corn yield under fall cover crop systems. *Can. J. Soil Sci*. 92:353–365. doi:10.4141/cjss2011-065

O'Rourke, P.D., and Randy J. Winter. (2010). The Practice of Fall Applied Nitrogen: Economic Implications to Illinois. *Paper presented at: Illinois Fertilizer Conference*. Peoria, Illinois.

Odell, R. T., S. W. Melsted, and W. M. Walker. (1984). Changes in Organic Carbon and Nitrogen of Morrow Plot Soils Under Different Treatments, 1904-1973. *Soil Science*, 137(3), 160-171.

Olson, K.R., S.A. Ebelhar, and J.M. Lang. (2010). Cover crop effects on crop yields and soil organic carbon content. *Soil Sci*. 175:89–98. doi:10.1097 SS.0b013e3181cf7959

O'Reilly, Kelsey A., Darren E. Robinson, Richard J. Vyn, and Laura L. Van Eerd. (2011). Weed Populations, Sweet Corn Yield, and Economics Following Fall Cover Crops. *Weed Technology*: July-September, Vol. 25, No. 3, pp. 374-384

Paine, L.K., and H. Harrison. (1993). Review: The historical roots of living mulch and related practices. *Hortic. Tech*. 3:137-143

Pantoja, J. L., K. P. Woli, J. E. Sawyer, and D. W. Barker. (2015). Corn Nitrogen Fertilization Requirement and Corn–Soybean Productivity with a Rye Cover Crop. *Soil Sci. Soc. Am. J.* 79:1482-1495. doi:10.2136/sssaj2015.02.0084

Pieters, A. J.. (1927). *Green Manuring: Principles and Practice*. New York, NY: John Wiley & Sons, Inc.

Pratt, M. R., W. E. Tyner, D. J. Muth, and E. J. Kladivko. (2014). Synergies between cover crops and corn stover removal. *Agricultural Systems*, 130, 67-76.

Rabalais, N.N., R.E. Turner, and W.J. Wiseman. (2002). Gulf of Mexico hypoxia, A.K.A. "The Dead Zone". *Annu. Rev. Ecol. Syst*. 33:235-263.

Raimbault, B. A., T. J. Vyn, and M. Tollenaar. (1990). Corn Response to Rye Cover Crop Management and Spring Tillage Systems. *Agron. J*. 82:1088-1093. doi:10.2134/agronj1990.00021962008200060012x

Raimbult, B. A., T. J. Vyn, and M. Tollenaar. (1991). Corn Response to Rye Cover Crop, Tillage Methods, and Planter Options. *Agron. J.* 83:287-290. doi:10.2134/agronj1991.00021962008300020005x

Randall, G. W., and J. A. Vetsch. (2005). Corn Production on a Subsurface-Drained Mollisol as Affected by Fall versus Spring Application of Nitrogen and Nitrapyrin. *Agron. J*. 97:472-478. doi:10.2134/agronj2005.0472

Randall, G. W., T. K. Iragavarapu, and B. R. Bock. (1997). Nitrogen Application Methods and Timing for Corn after Soybean in a Ridge-Tillage System. *Jpa.* 10:300–307.doi:10.2134/jpa1997.0300

Randall, G., J. Vetsch, and J. Huffman. (2003). Corn Production on a Subsurface –Drained Mollisol as affected by time of nitrogen application and nitrapyrin. *Agronomy Journal.* 95:1213-1219.

Randall, G., J. Vetsch, and J. Huffman. (2003). Nitrate losses in subsurface drainage from a corn-soybean rotation as affected by time of nitrogen application and use of nitrapyrin. *Journal of Environmental Quality*, 32(5), 1764-1772.

Reese, C. L., D. E. Clay, S. A. Clay, A. D. Bich, A. C. Kennedy, S. A. Hansen, and J. Moriles. (2014). Winter Cover Crops Impact on Corn Production in Semiarid Regions. *Agron. J.* 106:1479-1488. doi:10.2134/agronj13.0540

Reeves, D. W. (1994). Cover crops and rotations. In: *J.L. Hatfield and B.A. Stewart (eds.) Crops Residue Management: Advances in Soil Science*. pp 125-172. Boca Raton, FL: Lewis Publishers.

Robertson, Dale M., and David A. Saad. (2013). SPARROW Models Used to Understand Nutrient Sources in the Mississippi/Atchafalaya River Basin. *joenq* 42:1422–1440. doi:10.2134/jeq2013.02.0066

Roley, S. S., Tank, J. L., Tyndall, J. C., & Witter, J. D. (2016). How cost-effective are cover crops, wetlands, and two-stage ditches for nitrogen removal in the Mississippi River Basin?. *Water Resources and Economics*, 15, 43-56.

Scharf, Peter C., William J. Wiebold, and John A. Lory. (2002). Corn Yield Response to Nitrogen Fertilizer Timing and Deficiency Level *Agron. J*. 94:435–441. doi:10.2134/agronj2002.4350

Smiciklas, K.D., A.S. Moore, and J.C. Adams. (2008). Fertilizer nitrogen practices and nitrate levels in surface water within an Illinois watershed. *J. Agron. Educ*. 37:14-19

Soil Science Society of America. (2015). *Glossary of soil science terms.* SSSA, Madison, Wis.

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. Environ. Qual.* 33:1010-1016. doi:10.2134/jeq2004.1010

Vetsch, J.A., and G.W. Randall. (2004). Corn production as affected by nitrogen application timing and tillage. *Agron. J.* 96:502-509

Welch, L. F., D. L. Mulvaney, M. G. Oldham, L. V. Boone, J. W. Pendleton. (1971). Corn Yields with Fall, Spring, and Sidedress Nitrogen *Agron. J.* 63:119–123. doi:10.2134/agronj1971.00021962006300010037x

CHAPTER III: COVER CROP AND NITROGEN TIMING IMPACT ON CORN AND SOYBEAN BIOMASS PRODUCTION, NITROGEN UPTAKE, AND GRAIN YIELD

Abstract

The coupling of cover crops (CC), along with spring application of nitrogen has shown improved nitrogen efficiency in corn production systems. However, studies have shown that only 50% of central Illinois farmers practice spring application of nitrogen (N). Therefore, the overarching objective of this research was to evaluate the impacts of N application timing and CC inclusion on subsequent cash crop biomass production, N uptake, and grain yield. The experimental site was located at the Illinois State University Nitrogen Management Research Field Station, east of Lexington, IL. The treatments consisted of fall and spring dominated N application systems, with and without CC. All treatments received a total N application of 224 kg N ha^{-1} from a combination of diammonium phosphate and anhydrous ammonia prior to corn, while zero N fertilizer was applied to any of the treatments prior to soybeans. CC above ground biomass was collected once in the fall prior to daikon radish winter termination and once in the spring prior to cereal rye chemical termination to assess aboveground biomass production and N uptake. Two years of sampling demonstrated the ability of CC to produce an average aboveground biomass of 1,165 kg ha^{-1} and sequester an average of 42.5 kg N ha^{-1} prior to chemical termination in the spring. It was determined that winter CC did increase corn biomass production and N uptake during vegetative growth; however, corn biomass production and total N uptake at physiological maturity was not significantly different amongst any of the treatments. There was no significant impact on corn grain yield observed amongst the two N application timings, with or without CC. The coupled effect of CC and N application timing did not

significantly impact corn yield in the fall dominated N application; however, there was a significant (df=4 F=339.97 P< 0.0001) 7% reduction in corn grain yield following the introduction of CC in the spring dominated N application system. There was no impact on soybean yield amongst treatments. These data demonstrates the potential for CC to be introduced into existing nitrogen management systems common to the Midwest, while maintaining close to equal crop productivity levels.

Introduction

It has been estimated that agricultural leaching of nitrogen (loss of nitrogen from the soil profile) accounts for approximately 65% of the greater than 1.57 million metric tons of nitrogen delivered annually to the Gulf of Mexico, resulting in the world's second largest hypoxic zone (Alexander et al., 2000, Rabalais et al., 2002; Robertson and Saad et al., 2013). Relatively poor nitrogen use efficiencies (the ratio of crop nitrogen uptake to applied nitrogen fertilizer) of 60% or less across the Midwest have demonstrated the need for alternative nutrient management strategies, as the connection between the hypoxic zone in the Gulf of Mexico and Midwestern agriculture has become increasingly clear (Chichester et al., 1978; Dinnes et al., 2002; Goolsby et al., 2001). In an effort to mitigate nutrients carried by rivers to the Gulf of Mexico, the Gulf Hypoxic Zone Action Plan was released by the Environmental Protection Agency (EPA) in 2008. This action plan required each of the 12 states in the Mississippi River Basin to develop individual strategies for mitigating nutrient transfer to the Gulf, and in response the Illinois EPA developed the Illinois Nutrient Loss Reduction Strategy stating an overall goal of reducing total nutrient transfer to the Mississippi River by 45% (IEPA, 2015). The use of CC, as well as, making a change to split applications of nitrogen in which 50% or greater of the total N application occurs in the spring have been identified as two of the best in-field practices to help achieve the 45% total reduction in nutrient transfer from Illinois rivers to the Gulf of Mexico (IEPA, 2015).

Fall and spring applications of nitrogen are the two primary timings which producers use to apply their nitrogen fertilizers sources. Switching nitrogen applications from fall to spring has reduced nitrogen leaching by up to 17%, thus reducing the overall nutrient transfer from agricultural fields to surface waters (Randall et al., 2003, Strock et al., 2004). Previous studies have determined that total plant N uptake for corn can increase by 3 – 8% and corn grain yields can increase by as much as 7% when nitrogen applications are moved from the fall to the spring (Randall et al., 2003; Vetsch and Randall, 2004; Randall and Vetsch, 2005). However, even with demonstrated environmental benefits of spring N applications, surveys suggest that 46-75% of farmers make fall nitrogen applications within some Midwestern regions (Smiciklas et al,. 2008; Bierman et al,. 2011; O'Rourke and Winter 2010; Lemke et al,. 2011). Thus, there is a need to develop strategies to improve the efficacy of fall nitrogen applications.

CC have demonstrated the potential to absorb nitrogen from the soil profile and assimilate it into their organic structure, thus reducing the potential for nitrogen to be lost from agricultural fields to the environment via leaching, denitrification, or volatilization (Ditsch et al., 1991; Hartwig and Ammon 2002; Kaspar and Singer 201l). Fast growing annual cereal crops can be planted following cash crop harvest for the purposes of scavenging residual, naturally mineralized, and applied fertilizer nitrogen from the soil profile. CC used in a fall nitrogen management system have demonstrated the ability to stabilize 66-91% of fall applied nitrogen and can potentially reduce the amount of nitrate leaching within a fall application management strategy (Lacey et al,. 2014).

There has been a vast amount of research conducted on the impact of CC on yields of the following cash crops, in which the overwhelming results were that cash crop yields following winter CC we equal to or greater than yields observed on non-CC fields (Deppe 2016; O'Reilly et al., 2011, 2012; Frye et al., 1985; Sainju et al., 2003; Belfry et al., 2016; Miguez and Bollero 2005; Reese et al., 2014; Ketterings et al., 2015). However, in comparison to the previous studies that demonstrated neutral or positive impacts of CC on cash crop yields, others have determined that the impact of CC on cash crop yields is either neutral or negative with decreases attributed to poor crash crop establishment and potential soil property differences, as well as, possible cereal rye allelopathic effects (Moore et al., 2014; olson et al., 2010; Deppe 2016; Pantoja et al., 2015; Raimbault et al., 1990, 1991; Johnson et al., 1998). While there is much research concerning crop yields following CC, there is a dearth of knowledge surrounding the impacts of CC on N uptake throughout the cash crop growing season. Consequently, there is a need for research examining cash crop N uptake by growth stage following CC, to determine if specific critical growth stages impacted by CC can be identified.

The potential for reducing environmental impacts of agriculture has been demonstrated for both spring nitrogen application systems and CC; however, it is important to understand how these practices will influence overall productivity of traditional Midwestern cropping systems. Therefore, the objectives of this study were I) determine the impact of nitrogen application timing on cash crop biomass production, nitrogen uptake, and grain yield, II) determine the impact of CC on cash crop biomass production, nitrogen uptake, and grain yield and III) determine the combined effect of nitrogen application timing and CC on cash crop biomass production, nitrogen uptake, and grain yield.

Materials and Methods

This study was conducted in Lexington, Illinois at the Illinois State University Nitrogen Management Research Farm, also known as the Tile Drainage Site (TDS). The predominant soil types found within the approximately 10 hectare (25 acre) field are Drummer and El Paso silty clay loams, as well as Hartsburg silty clay loam, all of which are poorly drained Mollisols containing a slope of 0-2%. The cropping history for the Nitrogen Management Research Farm includes an 8 year rotation of strip-tilled corn (*Zea mays L.*) and no-till soybeans (*Glycine max L.*), which are harvested and sold for grain. This experiment was a continuation of these practices. The site was divided into fifteen individually tile drained plots (1.6 acre, 0.648 ha), each possessing its own controlled drainage structure and tile water monitoring systems. The N management strategies were to apply a total rate of 224 kg N ha^{-1} across various N application timings. The N rate for this study was the suggested MRTN (Maximum Return to Nitrogen) value of 224 kg N ha^{-1} for the central Illinois region as calculated by the Iowa State University N rate calculator. The plots were arranged in a complete randomized block design with three replications of each experimental treatment (Figure 1). The experimental treatments for this site included:

- Fall Dominated (68% fall, 32% spring) N application system without CC (FN)
- Fall Dominated (68% fall, 32% spring) N application system with CC (daikon radish (*Raphanus sativus L.*) and cereal rye (*Secale cereal L.*) blend) (FCC)
- Spring Dominated (18% fall, 82% spring) N application System without CC (SN)
- Spring Dominated (18% fall, 82% spring) N application system with CC (daikon radish (*Raphanus sativus L.*) and cereal rye (*Secale cereal L.*) blend). (SCC)

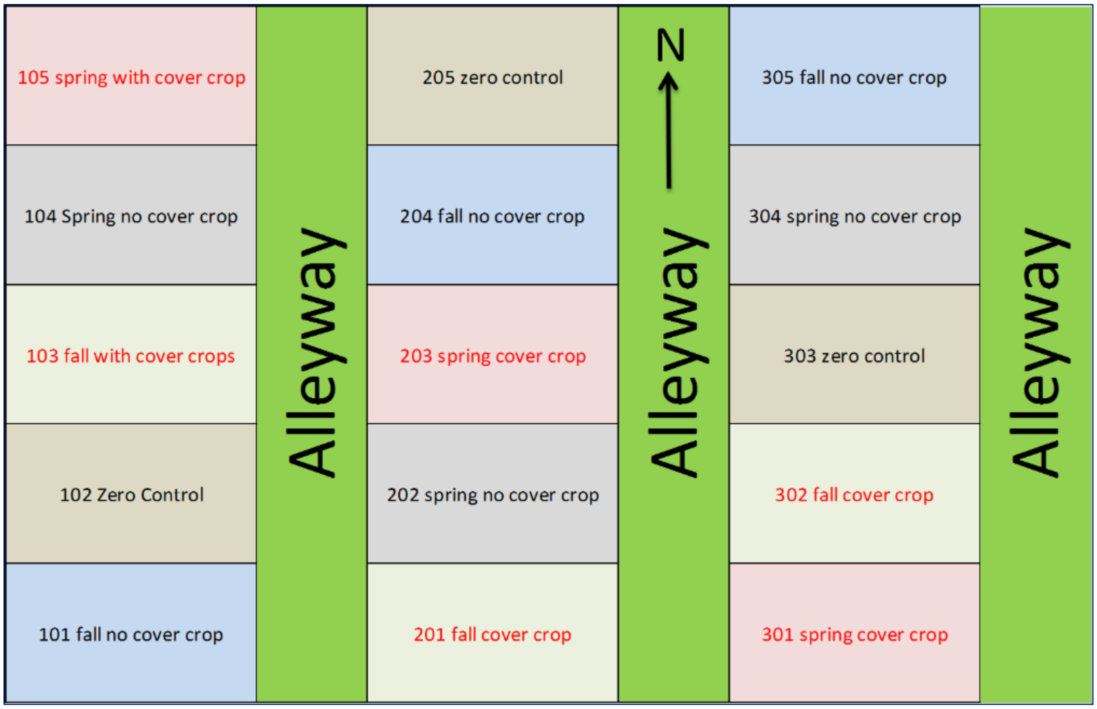

Figure 1- Illinois State University Nitrogen Management Research Field Station Plot Layout.

Cultural Practices

All in field practices and applications were designed to follow major agricultural practices used within the Midwest. Following popular cultural practices from the region allows the researchers to better communicate with producers on the logistics of the experiment, as well as demonstrate the ability to adapt and potentially improve current practices. Year-to-year decisions based on weather conditions were made in regards to application dates, although applications were made within the same period of time each year. The farmer from which the site is rented provided all equipment for the completion of general farming practices (planting, harvesting, pesticide application, mowing, etc.) at TDS.

All treatments at the site received a total of 224 kg N ha^{-1} during the corn phase of the corn and soybean rotation. The N sources used to reach this application rate were anhydrous ammonia (AA) and diammonium phosphate (DAP). The fall portion (68%) of the fall dominated N management system was a result of 40 kg N ha^{-1} from DAP and 112 kg N ha^{-1} as AA. The fall portion (18%) of the spring dominated N management system was a result of 40 kg N ha^{-1} from DAP. All fall AA was applied with a nitrogen inhibitor (N-Serve), and application occurred only once soil temperatures fell below 10°C. The remaining N was applied to the plots in the spring following corn planting as a side-dress AA application near the V6 growth stage. The spring portion (32%) of the fall dominated N management system was a result of 72 kg N ha^{-1} as AA. The spring portion (82%) of the spring dominated N management system was a result of 184 kg N ha^{-1} as AA. Spring AA did not include a nitrogen inhibitor.

Corn and soybeans were planted in 76.2 cm rows using a John Deere 1770NT 24 row planter pulled by a John Deere 8360R. Corn was planted at a rate of 86,485 seeds per hectare on April 30, 2015. Soybeans were planted at a rate of 308,875 seeds per hectare on May 7, 2016. Weather conditions in 2015 allowed the corn stand to establish without problems. However, weather conditions in the early part of the 2016 growing season caused poor emergence and resulted in an average population of approximately 214,977 soybean plants per hectare. Due to this reduction in stand, a replant at a rate of 135,905 seeds per hectare occurred on May 25, 2016. After a population check the replant stand was found to be at approximately 133,434 plants per hectare, which resulted in an average of 348,411 plants per hectare. Harvest was carried out using a John Deere S670 combine with a John Deere 608C 8 row head for corn, and a John Deere 635FD 35 foot flex draper head for soybeans. The CC (CC) were interseeded at a rate of 84 kg ha^{-1} into the standing crops using a Hagie STS12 modified with an air seeding box (figure

2) between late August and early September. The CC chosen were a 92% cereal rye and 8% daikon radish blend. This blend was selected because it provides ground cover in both fall/winter and spring, as well as opportunities for continual N scavenging from fall through spring. The daikon radish provides rapid fall N uptake and biomass production, while the cereal rye grows slower in the fall with some N uptake. Daikon radish generally winterkills, however, cereal rye is winter hardy and flourishes in the spring with rapid N uptake and biomass production.

Figure 2. Hagie STS12 modified with an air seeding box used to plant cover crops.

Throughout the duration of the study, the daikon radish self-terminated through vegetative desiccation in mid-to-late December following several days of subfreezing weather conditions. The cereal rye, however, is a winter hardy species that was chemically terminated at least 2 weeks prior to the planting of the cash crop. Along with the chemical termination of the CC, the research plots received varying pesticide applications dependent upon the main crop and weather conditions. All applications, other than fungicides which were commercially flown on, were applied by the farmer with a John Deere 4730 spray rig with a 90 foot boom. In 2015, the CC was terminated two weeks prior to corn planting on April 14 using Roundup Powermax (active ingredient: glyphosate) at a rate of 2.34 liters per hectare. A pre-emergence herbicide application occurred on April 17 at a rate of 4.1 liters per hectare of Lexar (active ingredients: S-metolachlor, atrazine, mesotrione) and 0.88 liters per hectare of 2, 4-Dichlorophenoxyacetic acid. A post-emergence application of 1.75 liters per hectare of Roundup Powermax took place on May 23. The final application of 2015 occurred on July 23 when 0.73 liters per hectare of Headline Amp fungicide (active ingredients: pyraclostrobin, metconazole) was applied. All 2015 applications occurred across all plots. In 2016 the CC were terminated three weeks prior to soybean planting on April 16 with an application of 2.34 liters per hectare of Roundup Powermax. While the termination application occurred across all plots in 2015, only the CC plots were sprayed during the termination application in 2016. A pre-emergence/burndown application occurred across all plots on April 18 at a rate of 0.29 liters per hectare of Authority XL (active ingredients: sulfentrazone, chlorimuron ethyl), 1.75 liters per hectare of Roundup Powermax, and 0.88 liters per hectare of 2, 4-dichlorophenoxyacetic acid. A final post-emergence herbicide application of 2.34 liters per hectare of Roundup PowerMax, 0.22 liters per hectare of Fusilade (active ingredient: fluazifop-p-butyl), and 1.0 kilograms per hectare of ammonium sulfate occurred on June 20.

Cover Crop Sampling

CC sampling occurred in both the fall and spring in order to document both above ground growth, as well as, CC nitrogen uptake. Within each treatment, four 0.6858 m^2 quadrants were randomly chosen and the above ground CC biomass was collected in order to create a representative sample for each treatment. This sampling technique is a modified version of Dean and Weil's method developed in 2009 (Dean and Weil, 2009). Samples were collected from all plots containing CC; no samples were collected from the control or zero control plots. The CC biomass samples were oven dried at 60 °C and ground to pass through a 1-mm sieve. The dry weight of each biomass sample was determined and used to calculate both total CC biomass, as well as total CC nitrogen uptake. The dried and ground above ground CC biomass was then analyzed for percent total nitrogen using a 0.1000 g sample via the use of a LECO FP-528 dry combustion instrument. The percent total nitrogen was then multiplied by total CC biomass in order to determine total CC nitrogen uptake (kg ha^{-1}).

Cash Crop Sampling

Cash crop samples were taken at critical growth stages within the growing season as determined by previous studies involving plant nutrient uptake. The critical growth stages to be sampled for corn include vegetative stage 6 (V6), V12, VT (tasseling), and reproductive stage 6 (R6, physiological maturity). The critical growth stages to be sampled for soybeans include vegetative stage 4 (V4), reproductive stage 2 (R2, full flowering), R4 (full pod), and R8 (physiological maturity). During the collection of each cash crop plant sample, population densities were calculated for corn by counting the plants within a 5.3086 m length two times, and for soybeans by counting the plants within a 1.8288 m length three times, and extrapolated out to determine plants per acre. Within each corn density check two whole plants (from soil surface to top of plant) were collected and within each soybean density check three whole plants (from soil surface to top of plant) were collected. The collected plants were combined into one representative sample, and analyzed for nitrogen content. Plants collected during the R6 corn sampling were divided into sample subsets including grain, cob, lower stalk, and remaining plant biomass. Plants collected during the R8 soybean sampling were divided into sample subsets including grain, pod, and remaining plant biomass. The cash crop plant samples were oven dried at 60 °C and ground to pass through a 1-mm sieve. The dry weight of each plant sample was determined and used to calculate both total cash crop biomass, as well as total cash crop nitrogen uptake. The dried and ground cash crop plant samples were analyzed for total percent nitrogen using a 0.1000 g sample via the use of a LECO FP-528 dry combustion instrument. The total percent nitrogen was then multiplied by total cash crop biomass in order to determine total cash crop nitrogen uptake (kg ha^{-1}).

Grain Yield Sampling

Cash crop grain yield and moisture data was analyzed following the completion of each year’s harvest. Grain yields were calculated via weights collected from a weigh wagon following the harvest of an area with a known length and width. These weights were used to determine cash crop grain yield on a per hectare basis (bu ha^{-1}). Grain samples from each plot were collected and dried in an oven at 100°C in order to determine the grains moisture content at harvest.

Statistical Analysis

The experimental design for the analysis of biomass production, grain yield, and nutrient uptake was a complete randomized block. SAS 9.4 was used to analyze the data with block and CC treatment (CC trt) as the independent variables (one-way random analysis of variance). These variables were tested using [block x CC trt] as the error term. A α-level equal to 0.05 was used to determine significant value. Following the two-way analysis of variance, a Ryan's test was used to determine significant differences between treatments.

Results and Discussion

Weather Conditions

Ambient air temperature and precipitation data was collected for the duration of the study to better understand the effect of various climatic conditions on CC and cash crop growth and nitrogen sequestration. Noticeably different climatic conditions between the two seasons allowed for the observation of CC and cash crop performance within two distinctly different crop management systems. For the time period associated with the 2014 CC – 2015 corn season (September 2014 – August 2015), the average ambient air temperature and total precipitation were less than the 30-year regional average. However, the time period associated with the 2015 CC – 2016 soybean season (September 2015 – August 2016) average ambient air temperature and total precipitation was greater than the 30-year regional average.

Specifically, the 2014 CC season (September 2014 – April 2015), recorded temperatures of 1.1, 4.3, 6.1, and 1.9°C below the 30-year average in September, November, February, and March, respectively. There was 401.1mm of total precipitation recorded during the 2014 CC season, which was considerably lower than the 30-year average of 571.6mm for the same time period. Specifically, November – April ranged 17.6 - 40.9mm below the 30-year average for total precipitation. Conversely, average ambient air temperatures recorded in September, November, December, February, and March during the 2015 CC season (September 2015 – April 2016) measured 1.5, 2.1, 6.0, 1.8, and 3.4°C warmer than the 30-year average ambient air temperature, respectively. Total precipitation for the 2015 CC season was in general lower than the 30-year average except for the months of November, December and March which observed 21.9mm, 91mm, and 11.4mm greater total precipitation than the 30-year average, respectively.

The average ambient air temperatures during the 2015 corn season (May 2015 – September 2015) were similar to the 30-year regional average, averaging just 0.2°C cooler. Measurably higher total precipitation was recorded during the 2015 corn season when compared to the 30-year average; specifically, record rainfall occurred in June 2015 resulting in 179.1mm total precipitation compared to the 30-year regional average of 100.5mm. The average ambient air temperatures during the 2016 soybean season (May 2016 – September 2016) were similar to the 30-year regional average, with May and July average 0.5 and 0.7°C cooler and June and September averaging 1.0 and 0.3°C warmer than the 30-year regional average. The 2016 soybean season had 515.7mm of total precipitation, which is 114.6mm greater than the 30-year average of 401.1mm. Specifically, July and August (soybean reproductive period) observed measurably higher total precipitation, resulting in 58.7mm and 59.2mm greater than the 30-year average, respectively.

Cover crop Biomass Production and Nitrogen Uptake

The CC grown in the fall of 2014 through the spring of 2015 was prior to a corn cash crop, thus the CC was given the opportunity to interact with nitrogen fertilizer applied in the fall for the corn crop, along with residual and mineralized nitrogen from the previous year. Biomass production and nitrogen content were measured both in the fall prior to daikon radish winter desiccation and the spring prior to chemical termination of the cereal rye. The fall CC sampling of the cereal rye and daikon radish CC mixture grown in the FCC and SCC treatments resulted in a total of 332.2 kg ha^{-1} and 265.2 kg ha^{-1} dry aboveground biomass and a total nitrogen content of 12.34 kg N ha^{-1} and 10.95 kg N ha^{-1}, respectively. A study conducted in Finland regarding crop responses to temperature and precipitation, determined that winter cereal rye growth increases with early season increases in precipitation and warmer than average temperatures throughout the growing season (Peltonen-Saino et al., 2010). The results of that study, coupled with the collected weather data from this study that indicates a cool, dry winter portion of the CC season, could explain the low CC biomass and N uptake results observed among the treatments at the fall CC sampling date during the 2014 CC season. Below average ambient air temperatures and precipitation during the winter of 2014 caused early desiccation of the daikon radish in the CC mixtures; however, the winter-hardy cereal rye survived the cool and dry winter weather conditions and flourished in the spring of 2015. The spring sampling of the cereal rye biomass revealed significantly greater (df=3 F=5.16 P=0.0424) dry biomass production of 1,179.6 kg ha^{-1} and 1,033.7 kg ha^{-1} and measurably greater total nitrogen content of 61.47 kg N ha^{-1} and 45.58 kg N ha^{-1} for the FCC and SCC treatments, respectively, when compared to the fall CC biomass samplings from the same treatments.

CC incorporated into the FCC treatment compared to those in the SCC treatment, resulted in greater biomass production and N uptake at both the fall and spring biomass samplings. This can likely be attributed to the incorporation of fall applied anhydrous ammonia and fall diammonium phosphate (DAP) into the FCC treatments, allowing for CC interaction with not only residual and naturally mineralized N, but also a large pool of inorganic N from fertilizer. Conversely, the SCC treatments only received DAP inorganic fertilizer prior to spring chemical termination of the cereal rye, thus the pool of inorganic N from fertilizer available for CC interaction was much smaller. While the FCC treatment resulted in higher biomass production and N uptake at the fall and spring sampling dates, both the FCC and SCC treatments significantly increased biomass production (df=3 F=5.16 P=0.0424) and measurably increased N uptake at the spring sampling date compared to the fall sampling date. This difference can be attributed to the ability of cereal rye to withstand harsh winter conditions and thrive following the spring warming period. The cereal rye may also be interacting with soil N that is mineralized from the residue of daikon radish, which could also contribute to the vigorous cereal rye growth experienced in the spring. These results help solidify the idea that planting a mixture of CC species that provides both fall and spring growth aids in reducing the vulnerability of nitrate N to leave the soil profile.

The fall 2015 through spring 2016 CC was grown preceding a soybean cash crop for which no inorganic fertilizer was applied; thus, the CC was only provided the opportunity to interact with residual nitrogen from the previous year, as well as, naturally mineralized nitrogen. The fall sampling of the cereal rye and daikon radish biomass from the FCC and SCC treatments resulted in 1,375.4 kg ha^{-1} and 1,459.1 kg ha^{-1} of accumulated dry biomass and a total nitrogen content of 54.86 kg N ha^{-1} and 63.86 kg N ha^{-1}, respectively. The weather results for the 2015 CC season revealed a warmer and wetter than average winter period of the CC growing season. Coinciding with results from Peltonen-Saino et al., (2010), warm and wet conditions during CC growth promotes better performance from winter cereal crops such as the cereal rye found in the CC mixture used in this study. Significantly greater biomass production (df=3 F=5.16 P=0.0424) in the fall of 2015 compared to the fall of 2014 could be a result of measurably warmer ambient air temperatures during the winter months of 2015, allowing for a longer daikon radish growing period prior to desiccation. The remaining cereal rye biomass in the FCC and SCC treatments sampled prior to chemical termination in the spring resulted in 1,072.7 kg ha^{-1} and 1,373.8 kg ha^{-1} of accumulated dry biomass and noticeably lower total nitrogen content of 29.05 kg N ha^{-1} and 33.72 kg N ha^{-1} with respect to the fall CC sampling from the same treatments. The examination of short-term weather data during the 2014 and 2015 CC growing seasons demonstrated that air temperature and precipitation have a greater influence on annual CC growth compared to other variables such as nitrogen management or previous cash crop.

In the 2014 CC growing season the FCC treatment had higher biomass production and N uptake than the SCC treatment at both the fall and spring sampling dates. Conversely, the 2015 CC growing season saw opposite results with the SCC treatment recording higher biomass production and N uptake at both the fall and spring sampling dates. This reversal of roles can likely be attributed to a larger portion of the applied inorganic N fertilizer for corn growth in the SCC treatments being applied in mid-June as side dressed anhydrous ammonia compared to the majority of applied inorganic N fertilizer for the FCC treatment being applied the previous fall. Thus, there was likely a larger pool of residual N within the SCC treatment, allowing for greater N uptake and biomass growth compared to the FCC treatment. Following two years of experimentation, it is estimated that species dependent biomass production and nitrogen uptake may be dependent upon climatic conditions. It was observed that daikon radish growth flourishes in warm fall and winter conditions which allows for a longer duration of growth prior to winter termination, whereas cereal rye growth is maximized in moderate-to-cool fall and winter conditions followed by warm spring weather. This observation again demonstrates the security of planting a mixture of CC species that provide both fall and spring growth to guard against unknown climatic conditions.

Differences in average ambient air temperature and total precipitation between the two CC growing seasons had measureable impacts on fall biomass production and N sequestration, as well as, the date of daikon radish winter termination. Winter termination of the daikon radish occurred in mid-to-late November during the 2014 CC season compared to an early January winter termination date in the 2015 CC season. This equates to approximately 1-1.5 months of extra growth for the daikon radish in the 2015 CC growing season relative to the 2014 CC growing season, which can be attributed to the considerably warmer ambient air temperatures and higher precipitation totals of the 2015 CC season compared to the 2014 CC growing season. Below average ambient air temperature and total precipitation during the 2014 CC growing season resulted in 76 and 82% less biomass production with 80 and 76% less N uptake in the FCC and SCC treatments compared to the 2015 CC growing season, respectively. While the 2014 CC performed relatively poorly in the fall, the cereal rye flourished during the spring warming period resulting in substantial biomass production and N uptake. In terms of biomass production, the 2014 CC and the 2015 CC performed relatively equally at the spring sampling date. While the 2014 CC increased its total N uptake from the fall sampling to the spring sampling, the 2015 CC saw a reduction in total N uptake between the fall and spring sampling dates. Many factors may have contributed to the reduction in N uptake seen in the spring sampling of the 2015 CC compared to the fall sampling of the 2015 CC and the spring sampling of the 2014 CC. The first consideration is that warmer and wetter than average climatic conditions allowed for longer growth of the daikon radish in the fall prior to winter termination, and thus greater uptake by the daikon radish within the CC mixture. The later termination date of the daikon radish, allowed less time for possible mineralization of N from the daikon radish to occur while the cereal rye was still growing, and therefore less possible transfer of N from the daikon radish biomass to the cereal rye biomass. The second factor to consider when investigating the difference in N uptake between the fall and spring samplings for the 2015 CC is that it was grown prior to a soybean cash crop. Soybeans do not require inorganic N fertilizer to achieve optimal yields. Thus, the total inorganic N within the soil profile available for the 2015 CC may have been reduced, and the CC was left to interact with just residual and naturally mineralized N. The vigorous fall growth of both the daikon radish and cereal rye, promoted by the warm and wet weather conditions, resulted in rapid uptake of N by both species. However, warm and wet environmental conditions are also ideal conditions to promote the loss of N from the soil via leaching and denitrification. Therefore, the late winter termination of daikon radish coupled with high leaching and denitrification potential, resulted in a depleted pool of inorganic nitrogen available within the soil profile. This, along with a lack of added inorganic N fertilizer during a soybean cash crop year to replenish the pool of N within the soil, resulted in a substantial decrease between the fall and spring samplings of the 2015 CC.

Previous research in the area of CC being used as a nitrogen management tool used to interact and stabilize soil inorganic N has primarily been focused on the interaction of CC with residual and naturally mineralized N within spring applied N management systems (Sainju et al., 2007; Weinert et al., 2002; O'Reilly et al., 2012; McCracken et al., 1994). The cereal rye component of our CC mixture was able to sequester 30-46 kg N ha^{-1} over the two years of study, despite distinctly different climatic conditions across two different cropping management systems. These results demonstrate the ability of the cereal rye CC to absorb 100% of N applied in the fall from DAP within our spring dominated N application system. These results align with previously published works from Dean and Weil (2009) which demonstrated the ability of cereal rye to absorb 37-83 kg N ha^{-1} when incorporated into spring N application systems in Maryland.

Kasper et al., (2007) determined cereal rye incorporated into spring N application systems in Iowa had the capacity to absorb 9-76 kg N ha^{-1}. Though the majority of CC research has been performed in spring applied N systems, Adeli et al., (2011) investigated the impacts of CC inclusion in a fall applied broiler litter system, while research from Illinois State University looked at the interaction of CC in a fall applied anhydrous ammonia N application system (Lacey and Armstrong, 2014, 2015; Deppe, 2016). Adeli et al., (2011) demonstrated that cereal rye CC have the capability to absorb 10.8 - 64 kg N ha^{-1} within a fall applied broiler litter system, while the work conducted at Illinois State University demonstrated the ability of cereal rye within a cereal rye and daikon radish to absorb 32-128 kg N ha^{-1}, corresponding to an 18-64% absorption of fall applied anhydrous ammonia (Lacey and Armstrong, 2014, 2015; Deppe, 2016). In comparison, the cereal rye incorporated into our fall dominated N application system was able to absorb 61.47 kg N ha^{-1} in the corn year which corresponds to 40% of the 152 kg N ha^{-1} applied in the fall as DAP and anhydrous ammonia, while the cereal rye was able to sequester just 29.05 kg N ha^{-1} in the soybean year when zero fertilizer was applied.

Cash Crop Biomass Production and Nitrogen Uptake

In the 2014-2015 season, the cash crop grown was corn, which was sampled at various critical growth stages throughout the season. No significant differences in biomass production were observed amongst any of the treatments at any of the sampled growth stages. There were no significant differences in crop nitrogen uptake at V6, VT, R6, or any of the R6 subsamples (plant matter, cob, and grain); however, significant differences were observed between the SN and SCC treatments at V12.

At growth stage V6, the spring sidedress application of nitrogen had not yet been applied. Therefore, the fall dominated N management treatments, which received a large portion of its total applied inorganic N fertilizer in the fall, had potential for a greater amount of total inorganic N within the soil profile than the spring dominated nitrogen management treatments. While not significant, a decrease in both N uptake and crop biomass production was observed when the predominant portion of applied N fertilizer was moved from the fall to the spring. The move from a fall dominated to a spring dominated N application system resulted in a 24% reduction in total biomass production with the FN and SN treatments producing 661.47 kg ha^{-1} and 502.66 kg ha^{-1} of biomass, respectively. A 41% decrease in total nitrogen uptake was also observed following the change from a fall dominated to spring dominated N application system, with a total N uptake of 22.64 kg N ha^{-1} and 13.25 kg N ha^{-1} for the FN and SN treatments, respectively. These results indicate that a fall dominated N application system promotes more vigorous early season biomass production and N uptake. The introduction of a CC into the fall dominated N application system resulted in a 3% decrease in crop biomass production and a 1% increase in total N uptake relative to the FN treatment, with the FCC recording a total biomass production of 641.57 kg ha^{-1} and total N uptake of 22.93 kg N ha^{-1}. The SCC treatment had a total crop biomass production of 504.43 kg ha^{-1} and total N uptake of 14.13 kg N ha^{-1}, corresponding to a 0.4 and 6% increase relative to the SN treatment, respectively. In comparison, Deppe (2016) observed a 27% decrease in corn N uptake at V6 when a cereal rye and daikon radish mixture was introduced into a fall applied anhydrous ammonia N application system in central Illinois. While the increase was small, it may be attributed to differing levels of residual N within the soil profile or early mineralized N from the CC biomass. The percent N uptake at V6 relative to total N content at physiological maturity varied according to treatment but measured at 10, 12, 5, and 8% for the FN, FCC, SN, and SCC treatments, respectively. When the factors of N application timing and CC were coupled, it was observed that the FCC treatment resulted in 21% greater crop biomass production and 38% greater total N uptake at growth stage V6 relative to the SCC treatment. This is likely due to a larger pool of inorganic N, including applied, residual, and mineralized N, being available in the fall dominated N management treatments than the spring dominated N management treatments

At the V12 growth stage, while not significant, the movement from a fall dominated to a spring dominated N application system resulted in a 15% decrease in crop biomass production with the FN and SN treatments measuring 6671.07 kg ha^{-1} and 5661.27 kg ha^{-1}, respectively. The same change in N application timing resulted in total N uptake of 126.03 kg N ha^{-1} and 110.70 kg N ha^{-1} for the FN and SN treatments, which corresponds to a 12% decrease in total N uptake. These results indicate that a fall dominated N application system promotes higher biomass production and N uptake through the V12 growth stage, even following a spring sidedress application of nitrogen fertilizer. The introduction of CC into the fall dominated N application system resulted in 17% greater crop biomass production with the FCC and FN treatments measuring 8079.11 kg ha^{-1} and 6671.07 kg ha^{-1}, respectively. The FCC treatment also increased total N uptake by 20% absorbing 30.81 kg N ha^{-1} more at the V12 growth stage relative to the FN treatment, measuring 156.84 kg N ha^{-1} and 126.03 kg N ha^{-1}, respectively. The introduction of CC into the spring dominated N application resulted in a 19% increase in crop biomass production measuring 7023.56 kg ha^{-1} and 5661.27 kg ha^{-1} for the SCC and SN treatments. There was a significant increase ($df=4$ $F=31.33$ $P<0.0001$) in N uptake of 30% in the corn at V12 between the SCC and SN treatments, measuring 157.05 kg N ha^{-1} and 110.70 kg N ha^{-1}, respectively. These results indicate that the introduction of a CC into a cropping system, regardless of N application timing, promotes greater biomass production and total N uptake through the V12 growth stage. Worth noting is that the FCC treatment also resulted in 30%

greater crop biomass production and 29% greater N uptake at corn stage V12 when compared to the SN treatment. When the factors of N application timing and CC were coupled, it was observed that the FCC treatment resulted in 13% greater crop biomass production and less than 1% lower total N uptake relative to the SCC treatment at growth stage V12. These results indicate that a fall dominated N application system with CC has the potential to outperform a spring dominated N application system with or without CC, in terms of crop biomass production and total N uptake through corn growth stage V12. The percent N uptake at V12 relative to total N content at physiological maturity varied according to treatment but measured at 55, 85, 43, and 84% for the FN, FCC, SN, and SCC treatments, respectively.

At growth stage VT, the FN treatment resulted in measurably less biomass production and total N uptake relative to the SN treatment. Total crop biomass measured 5767.07 kg ha^{-1} and 6965.95 kg ha^{-1} and total N uptake was 108.50 kg N ha^{-1} and 151.20 kg N ha^{-1} for the FN and SN treatments, respectively. These results indicate that the change from fall dominated to spring dominated N application promotes greater crop biomass production and total N uptake by the time the corn plant reaches the VT growth stage. The introduction of CC into the fall dominated N application system resulted in 14% greater crop biomass production with measured values of 5767.07 kg ha^{-1} and 6713.75 kg ha^{-1} for the FN and FCC treatments, respectively. There was no significant difference in total N uptake between the FCC and FN treatments, however there again was noticeably greater uptake in the CC treatment compared to the non-CC treatment with corresponding N uptake of 124.80 kg N ha^{-1} and 108.50 kg N ha^{-1}. There was a 15% decrease in crop biomass production following the introduction of CC into the spring dominated N application system, with recorded crop biomass production of 6965.95 kg ha^{-1} and 5884.68 kg ha^{-1} for the SN and SCC treatments. While the difference in corn N uptake at growth stage VT was not significant between the SCC and SN treatments, there was a noticeably greater amount of corn N uptake in the SN treatment compared to the SCC treatment, measuring 151.20 kg N ha^{-1} and 134.50 kg N ha^{-1}, respectively. These results indicate that introducing CC into a fall dominated N application system has the potential to result in increased crop biomass production and total N uptake at the VT growth stage. However, the results also demonstrate that the introduction of CC into spring dominated N application systems could result in reduced crop biomass production and total N uptake at corn growth VT. When comparing the CC treatments from each N application system, it was observed that the FCC treatments resulted in 12% great crop biomass production relative to the SCC treatment; however, measured total N uptake for the FCC treatment was 8% lower than that of the SCC treatment. The percent N uptake at V6 relative to total N content at physiological maturity varied according to treatment but measured at 47, 68, 58, and 72% for the FN, FCC, SN, and SCC treatments, respectively. These results align with Bender et al., (2013) who found that approximately two thirds of the total N uptake at physiological maturity is acquired by the VT/R1 growth stage. It is important to note that at the VT growth stage the crop biomass production and total N uptake decreased relative to the V12 sampling for three of the four measured treatments. These decreases could be a partial result of sampling methodology, and the differences could potentially have been accounted for with more extensive sampling of the treatments. There has been work done that determined corn N uptake decreases during the transition period from vegetative to reproductive growth, and thus the possibility exists that the decrease in total N content between V12 and VT could be explained by a dilution effect as crop N uptake slows, but crop biomass production continues (Karlen et al., 1987; Dharmakeerthi et al., 2006). In a study conducted at Oklahoma State University, Holtz

(2005) demonstrated corn biomass and N uptake decreases between growth stages V12 and VT within three separate N application rates.

Within the growth stage R6 samples and the subdivided plant matter, cob, and grain samples, there were no significant differences between any of the treatments in either crop biomass production or total N uptake. While no significant differences were observed, there were notable biological trends that existed within all samplings for both crop biomass production and total N uptake. In terms of biomass production, the FN treatment recorded higher crop biomass production for the R6 plant matter subsample relative to the SN treatment. All other R6 samples recorded greater crop biomass production in the SN treatments compared to the FN treatment. Total N uptake recorded for each the R6 subsets was greater in the SN treatment relative to the FN treatment. Previous studies have determined that total plant N uptake for corn can increase by 3 – 8% when nitrogen applications are moved from the fall to the spring (Randall et al., 2003; Vetsch and Randall, 2004; Randall and Vetsch, 2005). This could be due to a greater amount of nitrogen being added to the system through a sidedress application of anhydrous ammonia in the SN treatment compared to the FN treatment. Within each of the R6 samples, the FN treatment outperformed the FCC treatment in terms of both crop biomass production and total N uptake. The SN treatment recorded greater crop biomass production and total N uptake at all R6 samples relative to the SCC treatment. This indicates that the introduction of CC into both fall dominated and spring dominated N applications has the potential to reduce crop biomass production and total N uptake during the reproductive phase of crop growth. These results contradict findings by Deppe (2016) who found that crop nitrogen uptake increased by as much as 25% in fall N application systems containing a cereal rye and daikon radish CC, relative to the same N application without a CC. The reduction in N uptake between the non-CC treatments and the CC treatments may be attributable to the heavy precipitation that occurred in June and July. The precipitation could have caused a flush of nitrogen from the soil profile resulting in lower total inorganic nitrogen available for plant growth. While the hope is that the N contained in the CC biomass will undergo mineralization and become available for cash crop uptake, there is a possibility that immobilization of soil N occurred in order to help facilitate CC biomass mineralization. Thus, the result of this process would be a higher pool of inorganic N within the soil profile in the non-CC treatments relative to the CC treatments, ultimately resulting in greater potential for cash crop N uptake within the non-CC treatment during the reproductive growth stages of the cash crop. The SCC treatment resulted in total crop biomass production at each of the R6 samples except for the plant matter subsample, relative to the FCC treatment. The same trend was observed for total N uptake amongst the R6 samples when comparing the SCC treatment to the FCC treatment.

In the 2015 – 2016 season the cash crop grown was soybeans, and zero inorganic N fertilizer was applied to any of the treatments. The soybean crop resulted in zero significant differences in either crop biomass production or total N uptake amongst any of the treatments at the sampled growth stages V4, R2, R4, and R8, nor the subdivided R8 plant matter and R8 grain samples.

At soybean vegetative growth stage 4, there was a 4% increase in crop biomass production in the SN treatment relative to the FN treatment, with recorded biomass production of 570.12 kg ha^{-1} and 545.37 kg ha^{-1}, respectively. There was also a 5% increase in total N uptake within the SN treatment relative to the FN treatment, with corresponding total N uptakes of 26.43 kg N ha^{-1} and 25.23 kg N ha^{-1}. These results indicate that a soybean crop grown following a corn crop with a spring dominated N application has the potential to promote great crop biomass production and total N uptake than a soybean crop grown following a corn crop with a fall dominated N application. When comparing the CC and non-CC treatments within their respective N application timings at growth stage V4, there was a general trend of increased crop biomass production and total N uptake in the non-CC treatments relative to the CC treatments. Within the treatments that received a fall dominated N application the previous year, the FN treatment resulted in 16% greater crop biomass production relative to the FCC treatment measuring 545.37 kg ha^{-1} and 457.98 kg ha^{-1}, respectively. The FN treatment also recorded 14% greater total N uptake relative to the FCC treatment, with corresponding total N uptakes of 25.23 kg N ha^{-1} and 21.80 kg N ha^{-1}. Within the treatments that received a spring dominated N application the previous year, the SN treatment resulted in 17% greater crop biomass production than the SCC treatment, with 570.12 kg ha^{-1} and 470.41 kg ha^{-1} of crop biomass production, respectively. The non-CC treatment also outperformed the CC treatment in terms of total N uptake, with a 14% increase from 22.60 kg N ha^{-1} in the SCC treatment to 26.43 kg N ha^{-1} in the SN treatment. These results indicate that the incorporation of a CC prior to a soybean cash crop, regardless of N application timing, has the potential to decrease crop biomass production and total N uptake in the subsequent soybean crop at the V4 growth stage. When comparing the two CC treatments, the SCC resulted in 3% greater crop biomass production and 4% greater total N uptake at growth stage V4 relative to the FCC treatment.

Sampling at soybean growth stage R2 revealed that the soybeans grown in the FN treatment resulted in 6% greater crop biomass production and 2% greater total N uptake when compared those in the SN treatment. The measured crop biomass production was equal to 3809.51 kg ha^{-1} and 3571.29 kg ha^{-1} and the total N uptake was 158.98 kg N ha^{-1} and 155.27 kg N ha^{-1} for the FN and SN treatments, respectively. The introduction of CC into the fall dominated N application system prior to soybean growth resulted in 24% great crop biomass production from 3809.51 kg ha^{-1} in the FN treatment to 5029.13 kg ha^{-1} in the FCC treatment. There was also 27% greater total N uptake in the FCC treatment compared to the FN treatment, measuring 217.93 kg N ha^{-1} and 158.98 kg N ha^{-1}, respectively. Within the spring dominated N application system, the crop biomass production measured 3571.29 kg ha^{-1} and 4486.32 kg ha^{-1} for the SN and SCC treatments, respectively. This corresponds to a 20% increase in crop biomass production following the introduction of CC prior to soybean growth within the spring dominated N application system. There was an 18% increase observed in total N uptake between the SN and SCC treatments which measured 155.27 kg N ha^{-1} and 189.00 kg N ha^{-1}, respectively. These results indicate that the introduction of CC prior to soybean growth, regardless of N application timing for the previous corn crop, has the potential to increase both crop biomass production and total N uptake at soybean growth stage R2. There was 11% greater crop biomass production and 13% great total N uptake observed in the soybeans grown in the FCC treatment when compared to those from the SCC treatment.

The results from the soybean sampling at growth stage R4 revealed that the SN treatment had 1% greater crop biomass production compared to the FN treatment, with 6033.56 kg ha^{-1} and 5951.55 kg ha^{-1} of accumulated biomass, respectively. The total N uptake for the SN treatment was 269.83 kg N ha^{-1} while the FN treatment had 254.68 kg N ha^{-1}, corresponding to 6% greater total N uptake in the SN treatment compared to the FN treatment. The FCC treatment resulted in 4% greater crop biomass production than the FN treatment with accumulated crop biomass production of 6172.68 kg ha^{-1} and 5951.55 kg ha^{-1}, respectively. The FCC treatment had a total N uptake of 277.59 kg N ha^{-1} which was 8% higher than the FN treatment which had a total N uptake of 254.68 kg N ha^{-1}. The SCC treatment also observed a 2 % increase in crop biomass production and a 5% increase in total N uptake relative to the SN treatment. Corresponding crop biomass production and total N uptake for the SCC and SN treatments were 6184.86 kg ha^{-1} and 6033.56 kg ha^{-1}, and 284.30 kg N ha^{-1} and 269.83 kg N ha^{-1}, respectively. These results indicate the potential for increased biomass production and total N uptake in soybeans grown in cropping systems following a CC compared to cropping systems that do not include a CC, regardless of previous N application timing. When comparing the crop biomass production and total N uptake for the FCC and SCC treatments, it was observed that the SCC treatment had <1% greater crop biomass production and 2% greater total N uptake relative to the FCC treatment.

At the R8 growth stage total crop biomass production and total N uptake was measured, along with plant matter biomass production and N uptake and grain biomass production and N uptake. There was 1% greater total biomass production, with 4% greater plant matter biomass production and 1% less grain biomass production in the SN treatment compared to the FN treatment. Total N uptake was 2% greater in the SN treatment compared to the FN treatment, with 13% greater grain N uptake and >1% increase in plant matter N uptake. A 2% increase in total crop biomass production was observed between the FCC and FN treatments, measuring 7871.13 kg ha^{-1} and 7732.65 kg ha^{-1}, respectively. Plant matter biomass production increased by 5% in the FCC treatment relative to the FN treatment, while grain biomass production decreased by less than 1%. Total N uptake increased by 1% from 350.66 kg N ha^{-1} in the FN treatment to 355.99 kg N ha^{-1} in the FCC treatment. This increase was a result of 16% great plant matter N uptake in the FCC treatment compared to the FN treatment; however, the FCC treatment resulted in a <1% decrease in grain N uptake compared to the FN treatment. Total crop biomass production was 4% greater in the SN treatment compared to the SCC treatment, with a 1% increase in plant matter biomass production and 6% increase in grain biomass production. Total

N uptake measured 356.33 kg N ha^{-1} in the SN treatment and 336.51 kg N ha^{-1} in the SCC treatment, corresponding to 6% greater total N uptake in the SN treatment compared to the SCC treatment. This increase was a result of 7% greater plant matter N uptake and 5% greater grain N uptake in the SN treatment compared to the SCC treatment. When comparing the two CC treatments, the FCC treatment compared to the SCC treatment resulted in 2%, 6%, and 4% greater R8 plant biomass, R8 grain biomass, and R8 total biomass production, respectively. The FCC treatment also had 11% greater plant matter N uptake, 5% greater grain N uptake and 5% greater total N uptake relative to the SCC treatment.

Cash Crop Grain Yield

For corn crop grown during the 2014 – 2015 season, while not significant, the SN treatment resulted in 3% greater yield relative to the FN treatment, measuring 13.19 Mg ha^{-1} and 12.76 Mg ha^{-1}, respectively. This indicates that spring dominated N application systems have the potential to increase corn grain yields relative to fall dominated N application systems. Previous studies have concluded that changing N applications from the fall to the spring can result in as much as 7% increases in corn grain yield (Randall et al., 2003; Vetsch and Randall, 2004; Randall and Vetsch, 2005). There was no significant difference observed when comparing the FCC treatment to the FN treatment, with yields of 12.74 Mg ha^{-1} and 12.76 Mg ha^{-1}, respectively; however, there was a significant (df=4 F=339.97 $P<0.0001$) 7% decrease in yield between the SN and SCC treatments with corresponding yields of 13.19 Mg ha^{-1} and 12.28 Mg ha^{-1}. These results indicate that the introduction of CC into fall or spring dominated N application systems have the potential to result in neutral or negative impacts on corn grain yields. There has been a vast amount of research conducted on the impact of CC on yields of the following cash crops, in which the overwhelming results were that cash crop yields following winter CC we equal to or greater than yields observed on non-CC fields (Deppe 2016; O'Reilly et al., 2011, 2012; Frye et al., 1985; Sainju et al., 2003; Belfry et al., 2016; Miguez and Bollero 2005; Reese et al., 2014; Ketterings et al., 2015). However, in comparison to the previous studies that demonstrated neutral or positive impacts of CC on cash crop yields, others have determined that the impact of CC on cash crop yields is either neutral or negative with decreases attributed to poor CC establishment and potential soil property differences, as well as, possible cereal rye allelopathic effects (Moore et al., 2014; Olson et al., 2010; Deppe 2016; Pantoja et al., 2015; Raimbault et al., 1990, 1991; Johnson et al., 1998). While not significant, there was a 4% difference in grain yield when comparing the FCC and SCC treatments, with corresponding yields of 12.74 Mg ha^{-1} and 12.28 Mg ha^{-1}.

A study conducted in Lincoln, Nebraska determined that corn grain yields decreased with higher than average temperatures in the months of June and July and increased precipitation between March, April, and May; however, corn yield showed increases with higher than average precipitation in august and early-September (Wilhelm and Wortmann, 2004). Coinciding with the study from Nebraska, Thompson (1986) determined that highest corn yields are associated with average June temperatures and below average temperatures in July and August, as well as, average pre-to-early season rainfall and increased precipitation in July and August. Muchow et al., (1990) determined that high corn yield is associated with low temperature and high solar radiation, concluding that biomass accumulation is directly proportional to radiation interception, and that grain yield is directly proportional to biomass production. The climatic data collected during this study revealed temperatures lower than the 30-year regional average during the months of June and July, and increased precipitation during July and August relative to the 30-year regional average; however, pre-to-early season precipitation for the months of March, April, and May resulted in 47.9 mm less than the 30-year regional average. These results indicate that, besides lower than average pre-to-early season precipitation, climatic conditions during the 2015 corn season were ideal for high corn grain yields. Close to ideal conditions for corn grain yields also indicates that any substantial differences in corn grain yield amongst treatments is likely due to factors other than climatic conditions.

The 2016 soybean cash crop resulted in zero significant differences for crop yield amongst any of the treatments. Despite the lack of significant differences in crop yield, there was a notable biological trends in the soybean yield reminiscent of those observed in the soybean plant biomass and N uptake results. The SN treatment which yielded 4.07 Mg ha^{-1} resulted in 3% greater grain yield compared to the FN treatment which had a measured yield of 3.96 Mg ha^{-1}. The introduction of CC prior to soybean growth resulted in decreased yields for both the fall and spring dominated N application systems. The FN treatments recorded 5% greater yields than the FCC treatments, with measured grains yields of 3.96 Mg ha^{-1} and 3.77 Mg ha^{-1}, respectively. The SN treatment had a measured grain yield of 4.07 Mg ha^{-1} corresponding to a 4% increase over the SCC treatment which measured 3.90 Mg ha^{-1}. When exploring the coupled effect of CC and N application timing, it was observed that the SCC treatment resulted in 3% greater grain yields relative to the FCC treatment.

Wilhelm and Wortmann (2004), as well as, Yamoah (1998) determined that soybean yields decrease with increased late-summer temperatures, especially in July and August. Generally, the rate at which soybeans develop increases as temperature increases; however, increased rates of development lead to shorter durations at various growth stages such as pod elongation and seed fill (Hodges and French, 1985; Sinclair et al., 1991). Increased temperatures decreasing the time the soybean plant spends at critical growth stages such as pod elongation and seed fill, is another indicator of potential climatic impacts on soybean production. Generally water stress is most pronounced in soybeans during the pod fill stage following full bloom, and increased water stress during flowering can induce shorter flowering periods with some of the flowers being aborted resulting in fewer flowers, pods, and seeds (Doss et al., 1974; Sionit and Dramer, 1977). This climatic data indicates that the 2016 soybean crop was grown is close to ideal conditions to achieve optimal yields.

Conclusion

The results of this study indicate that CC performance in terms of aboveground biomass production and N uptake capacity can be affected by variations in weather conditions. Cool and dry environmental conditions result in poor daikon radish growth, while warm and wet conditions promote increased daikon radish aboveground biomass production and N sequestration. We demonstrated the capacity of CC to sequester and secure 29-61 kg N ha^{-1} within its aboveground biomass. However, there is a dearth of knowledge relating to the release of this nitrogen from the CC biomass, and whether it aligns with times of critical N requirements for the following cash crop. Therefore, research correlating N mineralization from CC biomass to critical growth stages of cash crops is required for both fall and spring N application systems. Additionally, research investigating the uptake and release of phosphorus (P) and potassium (K) by CC, and how this relates to cash crop P and K uptake and resultant grain yields should be conducted.

This research also demonstrated that introducing winter CC into a corn-soybean rotation in central Illinois resulted in a neutral to negative impacts on resulting cash crop yields. CC have been indicated as a practice which could help to reduce agricultures' over all environmental footprint. However, most farm operations operate with the primary objective of profit maximization. Implementing a practice into a current management system that increases overall costs to the producer, yet results in equal or lesser overall revenue production, could be observed as a deterrent to adoption. This indicates that further research should be conducted on improving CC management strategies in order to improve on current cash crop productivity levels; thus, giving producers an economic incentive to adapt this environmentally smart practice.

References

Illinois Environmental Protection Agency. (2015). *Illinois Nutrient Loss Reduction Strategy*. Web. 25 Mar. 2015.

Adeli, A., H. Twolde, J. Jenkins, and D. Rowe. (2011). Cover Crop Use for managing broiler litter applied in the fall. *Agronomy Journal.* 103:200-210.

Alexander, R.A., R. B. Smith, G. E. and Schwarz. (2000). Effect of stream channel size on the delivery of nitrogen to the Gulf of Mexico: *Nature*. v. 403. p. 758-761.

Belfry, K. D., and L. L. Van Eerd. (2016). Establishment and Impact of Cover Crops Intersown into Corn. *Crop Sci.* 56:1245-1256. doi:10.2135/cropsci2015.06.0351

Bender, R. R., J. W. Haegele, M. L. Ruffo, and F. E. Below. (2013). Modern corn hybrids' nutrient uptake patterns. *Better crops*, 97(1), 7-10.

Bierman, M.P., C. Rosen, R. Venterea, and J. Lamb. (2012). Survey of N fertilizer use on corn in Minnesota. *Agric. Syst*. 109:43–52.

Chichester, F. W., and S. J. Smith. (1978). Disposition of 15N-Labeled Fertilizer Nitrate Applied During Corn Culture in Field Lysimeters. *J. Environ. Qual*. 7:227-233. doi:10.2134/jeq1978.00472425000700020015x

Dean, J., and R. Weil. (2009). Brassica Cover Crops for Nitrogen Retention in the Mid-Atlantic Coastal Plain. *Journal of Environmental Quality*. 38:520-528.

Deppe, William Travis. (2016). *Winter Cover Crops Impact on the Distribution of Soil Inorganic Nitrogen and Subsequent Crop Uptake and Yield Following Fall Applied Anhydrous Ammonium.* Theses and Dissertations. Paper 493.

Dharmakeerthi, R. S., B. D. Kay, and E. G. Beauchamp. (2006). Spatial variability of in-season nitrogen uptake by corn across a variable landscape as affected by management. *Agronomy Journal*, 98(2), 255-264.

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/agronj2002.0153

Ditsch, D. C., M. M. Alley, K. R. Kelley, and Y. Z. Lei. (1993). Effectiveness of winter rye for accumulating residual fertilizer N following corn. *Journal of soil and water conservation 48*(2), 125-132.

Doss, B. D., R. W. Pearson, and H. T. Rogers. (1974). Effect of soil water stress at various growth stages on soybean yield. *Agronomy journal*, 66(2), 297-299.

Frye, W.W., W.G. Smith, and R.J. Williams. (1985). Economics of winter cover crops as a source of nitrogen for no-till corn. *J. Soil Water Conserv.* 40:246–249.

Goolsby, Donald A., Battaglin, William A., Aulenbach, Brent T., Hooper, Richard P. (2001). Nitrogen Input to the Gulf of Mexico. *joenq* 30:329–336. doi:10.2134/jeq2001.302329x

Hartwig, N. L., & H.U. Ammon. (2002). Cover crops and living mulches. *Weed science,* 50(6), 688-699.

Hodges, T., and V. French. (1985). Soyphen: soybean growth stages modeled from temperature, daylength, and water availability. *Agronomy Journal*, 77(3), 500-505.

Holtz, S. L. (2007). *Above-ground Nitrogen Accumulation as a Function of Time in Corn and Winter Wheat.* ProQuest.

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

Karlen, D. L., E. J. Sadler, and C. R. Camp. (1987). Dry matter, nitrogen, phosphorus, and potassium accumulation rates by corn on Norfolk loamy sand. *Agronomy Journal,* 79(4), 649-656.

Kaspar, T.C., and J W. Singer. (2011). The Use of Cover Crops to Manage Soil, In *Soil Management: Building a Stable Base for Agriculture*. p. 321–337. doi:10.2136/2011.soilmanagement.c21 Soil Science Society of America

Kaspar, T.C., D.B. Jaynes, T.B. Parkin, and T.B. Moorman. (2007). Rye Cover Crop and Gamagrass Strip Effects on NO3 Concentration and Load in Tile Drainage. *J. Environ. Qual.* 36:1503-1511. doi:10.2134/jeq2006.0468

Ketterings, Q. M., S. N. Swink, S. W. Duiker, K. J. Czymmek, D. B. Beegle, and W. J. Cox. (2015). Integrating Cover Crops for Nitrogen Management in Corn Systems on Northeastern U.S. Dairies. *Agron. J.* 107:1365-1376. doi:10.2134/agronj14.0385

Lacey and Armstrong. (2014). In Field Measurements of Nitrogen Mineralization Following Fall Applications of N and the termination of Winter cover crops. *Air, Soil and Water Research* 2014:7 53 – 59 doi:10.4137/ASWR.S13861.

Lacey, C., and S. Armstrong. (2015). The Efficacy of Winter Cover Crops to Stabilize Soil Inorganic Nitrogen after Fall-Applied Anhydrous Ammonia. *J. Environ. Qual.* 44:442-448. doi:10.2134/jeq2013.12.0529

Lemke, A., K. Kirkham, T. Lindenbaum, M. Herbert, T. Tear, W. Perry, and J. Herkert. (2011). Evaluating agricultural best management practices in tile-drained subwatersheds of the Mackinaw River, Illinois. *J. Environ. Qual.* 40:1215–1228.

McCracken, D., M. Smith, J. Grove, C. MacKown, and R. Blevins. (1994). Nitrate Leaching as Influenced by Cover Cropping and Nitrogen Source. *Soil Science Society of America Journal.* 58:1476-1483.

Miguez, F. E., and G. A. Bollero. (2005). Review of Corn Yield Response under Winter Cover Cropping Systems Using Meta-Analytic Methods. *Crop Sci.* 45:2318-2329. doi:10.2135/cropsci2005.0014

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

Muchow, R. C., T. R. Sinclair, and J. M. Bennett. (1990). Temperature and solar radiation effects on potential maize yield across locations. *Agronomy journal*, 82(2), 338-343.

O'Reilly, K.A., J.D. Lauzon, R.J. Vyn, and L.L. VanEerd. (2012). Nitrogen cycling, profit margins and sweet corn yield under fall cover crop systems. *Can. J. Soil Sci*. 92:353–365. doi:10.4141/cjss2011-065

O'Rourke, P.D., and Randy J. Winter. (2010). The Practice of Fall Applied Nitrogen: Economic Implications to Illinois. *Paper presented at: Illinois Fertilizer Conference*. Peoria, Illinois.

Olson, K.R., S.A. Ebelhar, and J.M. Lang. (2010). Cover crop effects on crop yields and soil organic carbon content. *Soil Sci.* 175:89–98. doi:10.1097 SS.0b013e3181cf7959

O'Reilly, Kelsey A., Darren E. Robinson, Richard J. Vyn, and Laura L. Van Eerd. (2011). Weed Populations, Sweet Corn Yield, and Economics Following Fall Cover Crops. *Weed Technology*: July-September, Vol. 25, No. 3, pp. 374-384

Pantoja, J. L., K. P. Woli, J. E. Sawyer, and D. W. Barker. (2015). Corn Nitrogen Fertilization Requirement and Corn–Soybean Productivity with a Rye Cover Crop. *Soil Sci. Soc. Am. J.* 79:1482-1495. doi:10.2136/sssaj2015.02.0084

Peltonen-Sainio, P., L. Jauhiainen, and K. Hakala. (2011). Crop responses to temperature and precipitation according to long-term multi-location trials at high-latitude conditions. *The Journal of Agricultural Science*, 149(01), 49-62.

Rabalais, N.N., R.E. Turner, and W.J. Wiseman. (2002). Gulf of Mexico hypoxia, A.K.A. "The Dead Zone". *Annu. Rev. Ecol. Syst*. 33:235-263.

Raimbault, B. A., T. J. Vyn, and M. Tollenaar. (1990). Corn Response to Rye Cover Crop Management and Spring Tillage Systems. *Agron. J.* 82:1088-1093. doi:10.2134/agronj1990.00021962008200060012x

Raimbult, B. A., T. J. Vyn, and M. Tollenaar. (1991). Corn Response to Rye Cover Crop, Tillage Methods, and Planter Options. *Agron. J.* 83:287-290. doi:10.2134/agronj1991.00021962008300020005x

Randall, G. W., and J. A. Vetsch. (2005). Corn Production on a Subsurface-Drained Mollisol as Affected by Fall versus Spring Application of Nitrogen and Nitrapyrin. *Agron. J.* 97:472-478. doi:10.2134/agronj2005.0472

Randall, G., J. Vetsch, and J. Huffman. (2003). Corn Production on a Subsurface –Drained Mollisol as affected by time of nitrogen application and nitrapyrin. *Agronomy Journal*. 95:1213-1219.

Reese, C. L., D. E. Clay, S. A. Clay, A. D. Bich, A. C. Kennedy, S. A. Hansen, and J. Moriles. (2014). Winter Cover Crops Impact on Corn Production in Semiarid Regions. *Agron. J*. 106:1479-1488. doi:10.2134/agronj13.0540

Ribaudo, Marc, Michael Livingston, and James Williamson. (2012). *Nitrogen Management on U.S. Corn Acres, 2001-10, EB-20*. U.S. Dept. of Agriculture, Economic Research Service, November 2012.

Robertson, Dale M., and David A. Saad. (2013). SPARROW Models Used to Understand Nutrient Sources in the Mississippi/Atchafalaya River Basin. *joenq* 42:1422–1440. doi:10.2134/jeq2013.02.0066

Sainju, U. M., B. P. Singh, W. F. Whitehead, and S. Wang. (2007). Accumulation and Crop Uptake of Soil Mineral Nitrogen as Influenced by Tillage, Cover Crops, and Nitrogen Fertilization. *Agron. J.* 99:682-691. doi:10.2134/agronj2006.0177

Frye, W.W., W.G. Smith, and R.J. Williams. (1985). Economics of winter cover crops as a source of nitrogen for no-till corn. *J. Soil Water Conserv.* 40:246–249.

Sinclair, T. R., S. Kitani, K. Hinson, J. Bruniard, and T. Horie. (1991). Soybean flowering date: linear and logistic models based on temperature and photoperiod. *Crop Science*, 31(3), 786-790.

Sionit, N., and P. J. Kramer. (1977). Effect of water stress during different stages of growth of soybean. *Agronomy Journal*, 69(2), 274-278.

Smiciklas, K.D., A.S. Moore, and J.C. Adams. (2008). Fertilizer nitrogen practices and nitrate levels in surface water within an Illinois watershed. *J. Agron. Educ*. 37:14-19

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. Environ. Qual.* 33:1010-1016. doi:10.2134/jeq2004.1010

Thompson, L. M. (1986). Climatic change, weather variability, and corn production. *Agronomy Journal*, 78(4), 649-653.

Vetsch, J.A., and G.W. Randall. (2004). Corn production as affected by nitrogen application timing and tillage. *Agron. J.* 96:502-509

Weinert, T. L., W. L. Pan, M. R. Moneymaker, G. S. Santo, and R. G. Stevens. (2002). Nitrogen Recycling by Nonleguminous Winter Cover Crops to Reduce Leaching in Potato Rotations. Departmental Paper no. 0109-07. Project 0203. . *Agron. J*. 94:365-372. doi:10.2134/agronj2002.3650.

Wilhelm, W. W., and C. S. Wortmann. (2004). Tillage and rotation interactions for corn and soybean grain yield as affected by precipitation and air temperature. *Agronomy Journal*, 96(2), 425-432.

Yamoah, C. F., C. A. Francis, G. E. Varvel, and W. J. Waltman. (1998). Weather and Management Impact on Crop Yield Variability in Rotations. *J. Prod. Agric*. 11:219-225. doi:10.2134/jpa1998.0219

CHAPTER IV: COST ANALYSIS OF COVER CROP INCLUSION AND ENVIRONMENTAL BENEFITS: A CENTRAL ILLINOIS ON FARM CASE STUDY

Abstract

The use of cover crops (CC) in row crop agricultural systems has been shown to provide numerous environmental benefits along with increasing overall soil health. While the environmental benefits of CC are well known, the costs associated with CC inclusion must be accounted for before widespread adoption of CC can occur. Therefore, the objective of this study is to quantify the environmental benefits observed from CC and determine the potential of those benefits to offset the input costs of CC implementation. This experiment used data collected between CC planting in 2014 and cash crop harvest in 2016 from an associated study conducted at the Illinois State University Nitrogen Management Research Field Station, in Lexington, IL. Experimental treatments were fall dominated (70% fall, 30% spring) Nitrogen (N) application with and without CC and a spring dominated (20% fall, 80% spring) N application with and without CC. The chosen CC for the study was a 92% cereal rye (*Secale cereal L.*) and 8% daikon radish (*Raphanus sativus L.*) blend, and data were collected for both strip-till corn (*Zea mays L.*) and no-till soybeans (*Glycine max L.*). Different from existing attempts to model the economic value of CC, this model includes input variables that quantify the reduction of N loss through tile drainage and the return of N from CC residue after termination. Based upon data that places an economic value on reductions in subsurface drainage nitrogen loading, nitrogen mineralization, and erosion reductions due to CC there was an average calculated recovery of approximately 60% of the costs associated with implementing CC into the cropping systems. The average composition of recovered costs was 34% from reductions in nitrogen loading to subsurface

drainage, 57% from the net mineralization of nitrogen from the CC biomass, and 9% from the estimated reduction in erosion. The results of this study have the potential to provide a more comprehensive assessment of CC value that will help producers make informed nitrogen and CC management decisions.

Introduction

Between the years of 2010 and 2015, there was a national increase of 312% in total CC hectares, from 48,393 hectares to 151,157 hectares (CTIC, 2015). This increase comes at a time when the connection between agriculture and the hypoxic zone in the Gulf of Mexico has become increasingly clear. It has been estimated that Agricultural leaching of nitrogen (loss of nitrogen from the soil profile) accounts for approximately 65% of the greater than 1.57 million metric tons of nitrogen delivered annually to the Gulf of Mexico (Alexander et al., 2000; Robertson and Saad et al., 2013). CC have been identified by the Illinois Nutrient Loss Reduction Strategy as key in-field practice to help mitigate the losses of nitrogen from agricultural fields (ILNLRS 2015). CC have proven environmental benefits of erosion control, improving soil tilth, increasing soil organic matter, and increased water-holding capacity, they also have the potential to be used as a nutrient management tool in order to increase overall soil fertility (Danso et al., 1991; Odell et al., 1984; Hartwig et al., 2002). In fact, a survey conducted to gauge producer perspective towards CC revealed increased soil health and organic matter, reduced soil compaction, reduced soil erosion, nitrogen scavenging, and being a source of nitrogen were identified as the top motivations towards CC adoption (CTIC, 2016). While the ability of CC to be used as a method of improving water quality and soil health should be considered by producers and policy makers, the cost and logistical obstacles associated with CC must be accounted for before widespread implementation can occur (Strock et al,. 2004).

A Conservation Technology Information Center survey revealed that the top barriers to CC adoption amongst producers are the costs of planting and managing the CC, the cost of the CC seed itself, and the lack of measurable economic returns following implementation (CTIC, 2015). A lack of measurable economic returns being identified as a top barrier to CC adoption is a concern, as most farm operations operate with the primary objective of profit maximization. To our knowledge, there has been a lack of research concerning the value of measureable CC environmental benefits. With profit maximization the primary objective of many producers, there is a great need for research to be conducted on the valuation of CC environmental benefits and how they relate to the recovery of CC implementation costs.

With CC being recognized as one of the most effective in-field practices in helping reduce the impact of agriculture on the hypoxic zone in the Gulf of Mexico, it is important to begin breaking down the barrier of economic risk and benefit if widespread adoption of the practice is going to occur. Previous attempts at estimating the economic risk and benefits of CC have generally included assigning value to agronomic factors such as changes in soil organic matter, erosion, compaction and added nutrients (Pratt et al., 2014; USDA-NRCS, 2014). Previous studies have only accounted for added nutrients from leguminous CC species and do not account for the return of scavenged nutrients from the CC biomass of grass or brassica species. Other methods of determining CC cost recovery include the removal of crop stover to be sold for the purposes of bioenergy production, in an effort to offset the input costs associated with CC (Pratt et al., 2014).

CC represent the best management practice (BMP) with the lowest annual cost per hectare when compared to constructed wetlands and two-stage ditches; but, over 50 years, CC represent the lest cost-effective BMP in terms of cost per kilogram of N removed from surface water sources (Roley et al., 2016). Of all the practices mentioned in the ILNLRS, CC represent the only practice with potential to not only reduce nitrogen losses, but recycle nitrogen to the cropping system. This would allow producers to utilize nitrogen that would have otherwise been lost to the atmosphere through denitrification with constructed wetlands, woodchip bioreactors or two-stage ditches. While constructed wetlands, woodchip bioreactors, and two-stage ditches are efficient practices at reducing the nitrogen load to surface waterways, they represent a long-term commitment which requires up to 5% of the land for which they are implemented to be removed from production. CC represent an in-field practice that require only short-term commitments from producers, as they are planted and removed each year and require zero land to be removed from production(Roley et al., 2016; D'Ambrosio et al., 2015; Christianson and Helmers, 2011). Thus, CC may be a more attractive option over other BMPs for producers looking to implement environmentally friendly practices into their operations.

While CC have demonstrated the potential to provide various environmental benefits within cropping systems, there is a dearth of knowledge regarding the value of these environmental benefits in relation to the costs of including CC in a cropping system. Therefore, the objectives of this study are I) to determine and assign an economic value to the perceived environmental benefits of cover crops, and II) determine the potential of the environmental benefits of cover crops to recover the costs of cover crop implementation.

Materials and Methods

This study was conducted in Lexington, Illinois at the Illinois State University Nitrogen Management Research Farm, also known as the Tile Drainage Site (TDS). The predominant soil types found within the approximately 10 hectare (25 acre) field are Drummer and El Paso silty clay loams, as well as Hartsburg silty clay loam, all of which are poorly drained Mollisols containing a slope of 0-2%. The cropping history for the Nitrogen Management Research Farm includes an 8 year rotation of strip-tilled corn (*Zea mays L.*) and no-till soybeans (*Glycine max L.*), which are harvested and sold for grain. This experiment was a continuation of these practices. The site was divided into fifteen individually tile drained plots (1.6 acre, 0.648 ha), each possessing its own controlled drainage structure and tile water monitoring systems. The N management strategies were to apply a total rate of 224 kg N ha^{-1} across various N application timings. The N rate for this study was the suggested MRTN (Maximum Return to Nitrogen) value of 224 kg N ha^{-1} for the central Illinois region as calculated by the Iowa State University N rate calculator. The plots were arranged in a complete randomized block design with three replications of each experimental treatment. The experimental treatments for this site included:

- Fall Dominated (68% fall, 32% spring) N application system without CC (FN)
- Fall Dominated (68% fall, 32% spring) N application system with CC (daikon radish (*Raphanus sativus L.*) and cereal rye (*Secale cereal L.*) blend) (FCC)
- Spring Dominated (18% fall, 82% spring) N application System without CC (SN)
- Spring Dominated (18% fall, 82% spring) N application system with CC (daikon radish (*Raphanus sativus L.*) and cereal rye (*Secale cereal L.*) blend). (SCC)

All valuations set forth in this study have been converted to year January 2014 dollars using the consumer price index inflation calculator available through the Bureau of Labor Statistics, which uses the consumer price index for all urban consumers (CPI-U) as its basis for calculation.

Cover Crop Costs

Variables that contribute to CC establishment costs include seed cost, seeding rate and seed application cost. Data relating to the cost of CC seed was obtained from the seed distributor, while the seed application cost was obtained from receipts relating to the application of the CC seed. CC for this study were interseeded into standing cash crops at the manufacturer suggested broadcast rate of 84 kg ha^{-1} using a Hagie STS12 modified with an air seeding box. CC establishment costs were calculated by obtaining the price per kilogram of seed and multiplying by the seeding rate, then adding the cost of seed application (equation 1).

Equation 1.

$$Establishment\ Cost\ \$\ ha^{-1} = (seed\ cost\ \$\ kg^{-1} \times seeding\ rate\ kg\ ha^{-1}) + application\ cost\ \$\ ha^{-1}$$

Three factors were considered when calculating the cost of terminating the CC including: the cost of herbicide, application rate of herbicide, and application cost of the herbicide. Data relating to the termination of CC including cost of herbicide, application rate, and application cost was obtained from the collaborating farmer. To calculate the total termination costs, the herbicide cost per liter multiplied by the herbicide rate in liters per hectare was added to the application cost per hectare (equation 2).

Equation 2.

$$Termination\ Cost\ \$\ ha^{-1} = (herbicide\ cost\ \$\ L^{-1} \times herbicide\ rate\ L\ ha^{-1}) + application\ cost\ \$\ ha^{-1}$$

While the direct costs of establishment and termination must be accounted for when calculating the total costs of CC implementation, the indirect costs incurred through the impact on cash crop yields following the CC must also be considered. To calculate the impact of CC on cash crop yields, the observed yields from the FN and SN treatments were subtracted from the observed yields of the FCC and SCC treatments, respectively. This was then multiplied by the price per mega gram of grain in order to determine a value for the difference in cash crop yield following CC inclusion (equation 3). The price for grain was obtained from the collaborating farmer on a per bushel basis, and converted to price per mega gram. A positive result indicates that the use of CC increased cash crop yield, while a negative results indicates that the CC decreased cash crop yields.

Equation 3.

$$Yield\ Cost\ \$\ ha^{-1} = (CC\ treatment\ Mg\ ha^{-1} - Non_{CC}Treatment\ Mg\ ha^{-1}) \times price\ per\ megagram\ \$$$

In order to determine the total cost of including CC into a crop rotation the three components that contribute to the cost of CC implementation must be considered. To do so, the cost per hectare for establishment, termination, and yield changes were added together to calculate the total CC cost per hectare (equation 4).

Equation 4.

$$Total\ CC\ Cost\ \$\ ha^{-1} = establishment\ costs\ \$\ ha^{-1} + Termination\ costs\ \$\ ha^{-1} \pm yield\ cost\ \$\ ha^{-1}$$

Nitrogen Valuation

CC benefits were measured using the as-applied value per kilogram of inorganic nitrogen fertilizer; however, fall-applied diammonium phosphate, fall-applied anhydrous ammonia with nitrification inhibitor (FAA), and spring-applied anhydrous ammonia (SAA) were all used at varying rates as inorganic sources of nitrogen. Therefore, the per-kilogram value of nitrogen for each of the three nitrogen sources had to be calculated before the per-kilogram value of nitrogen for the total application could be determined. In order to calculate the value per kilogram of nitrogen for each nitrogen source, the price per metric ton (1,000 kg) of fertilizer was divided by the kilograms of nitrogen in one metric ton of the fertilizer source. The price per U.S. ton for each of the three fertilizer sources was obtained from the collaborating farmer and converted to price per metric ton. The kilograms of nitrogen per metric ton of inorganic fertilizer is calculated by multiplying the percent nitrogen in the fertilizer source by 1,000 kilograms (equation 5).

Equation 5.

$$\$\ kg^{-1}\ N\ from\ (N\ Source) = \frac{price\ per\ metric\ ton\ of\ fertilizer\ source}{\%\ N\ in\ fertilizer\ source\ \times 1{,}000\ kilograms}$$

After determining the value per kilogram from each nitrogen source, it is necessary to determine the total value of each fertilizer source applied on a per hectare basis to each treatment. To do this, the value per kilogram of nitrogen from each fertilizer source was multiplied by the application rate of each fertilizer source for each of the treatments (equation 6).

Equation 6.

$$\$\ ha^{-1}\ (N\ Source) = \$\ kg^{-1} N\ from\ (N\ Source) \times Application\ Rate\ of\ (N\ Source)$$

To determine the total value per kilogram of applied nitrogen within each treatment, the \$ ha^{-1} for each N source and the additional application costs associated with fall and spring anhydrous ammonia are summed and then divided by the total kilograms of nitrogen applied to the treatment.

Equation 7.

$$\$\ kg^{-1}\ Applied\ N = \frac{\$\ ha^{-1}\ DAP + \$\ ha^{-1}\ FAA + \$\ ha^{-1}\ SAA + \$\ ha^{-1}\ SAA\ App. + \$\ ha^{-1}\ FAA\ App.}{Total\ kg\ N\ applied\ per\ hectare}$$

Subsurface Drainage Nitrogen Loading

The subsurface drainage system at this site was monitored over the same time period as this case study during a companion study investigating the efficacy of CC to impact the nutrient load leaving agricultural fields through artificial drainage systems (Ruffatti, 2016). The time period used to examine the impact of CC on subsurface drainage nitrogen loading was from the planting of one CC to the planting of the next CC (generally, September through August), defined as a CC year (Ruffatti, 2016). Teledyne Isco 6712 automated water sampling units were used to tap into the individual subsurface drainage systems for each experimental plot in order to collect leachate samples following rainfall events. These samples were filtered and submitted for colorimetric analysis using a Lachat flow injection analysis instrument to determine nitrate and ammonia concentrations. Using these concentrations, the total load in kilograms per hectare of nitrogen leaving the field was determined for each plot. In order to determine the environmental benefit of CC, the total load of the CC treatments were subtracted from the non-CC treatments, thus determining the overall reduction in nitrogen loading to subsurface drainage systems due to the inclusion of CC into a crop rotation (equation 8).

Equation 8.

$$N\ Loading\ Reduction\ kg\ N\ ha^{-1} = Total\ load\ without\ CC\ kg\ N\ ha^{-1} - Total\ load\ with\ CC\ kg\ N\ ha^{-1}$$

While understanding the environmental impact of CC on subsurface drainage nutrient loading is of utmost importance, the objective of this portion of the study was to determine the economic value of this environmental impact. To do so, a value must be placed on the nitrogen being retained in the field due to CC relative to the non-CC treatments. Using the assumption that nitrogen leaving the field through the subsurface drainage system is nitrogen that was applied as inorganic fertilizer, the value per kilogram of applied nitrogen for each experimental treatment is assigned. Therefore, the total economic value of the observed reduction in nitrogen loading due to CC is equal to the reduction in nitrogen load in kilograms per hectare between the non-CC and CC treatments multiplied by the value per kilogram of applied nitrogen for each treatment (equation 9).

Equation 9.

$$Value\ of\ N\ loading\ reduction\ \$\ ha^{-1} = Reduction\ in\ N\ loading\ kg\ ha^{-1} \times \$\ kg^{-1}\ applied\ N$$

Cover Crop Nitrogen Uptake and Return

CC sampling occurred in both the fall prior to daikon radish winter termination and the spring prior to chemical termination of the cereal rye in order to document aboveground biomass production and nitrogen uptake for each CC species. Within each treatment, two one-meter-square quadrants were randomly chosen and the above ground CC biomass was collected in order to create a representative sample for each treatment. This sampling technique is a modified version of Dean and Weil's method developed in 2009 (Dean and Weil, 2009). Samples were collected from all plots containing CC. The CC biomass samples were oven dried at 60 °C to determine the dry weight of each sample and used to calculate total aboveground biomass production. To be used in determining nitrogen return from the CC, 100 g of dried biomass was retained, while the remaining dry biomass was ground to pass through a 1-mm sieve. The dried and ground aboveground CC biomass was analyzed for percent total nitrogen using a dry combustion instrument. The percent total nitrogen was then multiplied by total CC biomass in order to determine total CC nitrogen uptake (kg ha^{-1}).

The retained unground CC biomass was used in the completion of a litter bag study in order to track the return of absorbed nitrogen from the CC residue to the soil profile. The 100 grams of biomass was evenly distributed between 10 mesh litter bags which were then placed randomly throughout the corresponding plots from which the biomass originated. The litterbags were sampled throughout the season and submitted for dry combustion analysis in order to track the release of nitrogen from the CC biomass. This allowed for the determination of mineralization factors for the CC species, which in turn allows us to determine N return from the CC to the soil profile on a per hectare basis.

Gross mineralization is the calculation of all nitrogen returned from the CC biomass on a per hectare basis. To attain this value, the total kg N ha^{-1} for each CC species (cereal rye (CR) and daikon radish (DR)) are multiplied by their respective mineralization factors (minF) and then summed (equation 10).

Equation 10.

$$Gross\ Mineralization\ kg\ N\ ha^{-1} = (CR\ kg\ N\ ha^{-1} \times CR\ minF) + (DR\ kg\ N\ ha^{-1} \times DR\ minF)$$

It is important to ensure that N mineralized from the CC residue is only accounted for once, and thus the reduction in N loading through the subsurface drainage system must be subtracted from the value calculated for gross mineralization, as it is assumed that the N loading reduction is a result of CC N uptake. For the purposes of this study, this value will be referred to as net mineralization (equation 11).

Equation 11.

$$Net\ Mineralization\ kg\ N\ ha^{-1} = Gross\ Mineralization\ kg\ N\ ha^{-1} - N\ Loading\ Reduction\ kg\ N\ ha^{-1}$$

To place value to the mineralized nitrogen from the CC biomass, the net mineralization of nitrogen in kilograms of N per hectare is multiplied by the value per kilogram of applied nitrogen for each respective treatment (equation 12).

Equation 12.

$$Value\ of\ net\ mineralization\ \$\ ha^{-1} = Net\ mineralization\ kg\ N\ ha^{-1} \times \$\ kg^{-1}\ applied\ N$$

RUSLE2 Erosion Estimation

Erosion was estimated using the downloadable RUSLE2 program available through the natural resources conservation service website. A custom crop rotation was built using the rotation builder tool within the program to match that used by the farmer at our experimental site. CC were built into the rotation by following the guidelines within the RUSLE2 CC training manual. The program estimates erosion reduction by comparing a crop rotation with CC to a crop rotation without CC. The results of the RUSLE2 program give the estimated erosion reduction for a corn-soybean crop rotation with CC before each cash crop. Therefore, the estimated erosion reduction must be divided by two to determine the annual estimated erosion reduction from the use of CC (equation 13).

Equation 13.

$$tonnes\ of\ soil\ ha^{-1}yr^{-1} = \frac{erosion\ no\ CC\ tonnes\ ha^{-1}2yr^{-1} - erosion\ with\ CC\ tonnes\ ha^{-1}2yr^{-1}}{2yr}$$

The value per tonne of eroded soil was determined using a method developed in a United States Department of Agriculture Economic Research Service (USDA-ERS) study conducted by Hansen and Ribaudo (2008). The study determined a method for valuing a tonne of soil based upon its on-site and off-site cost and takes into account wind and water erosion and changes in soil productivity. The USDA-ERS also provides a database with the on-site and off-site costs of soil erosion for each county in the United States. The value per tonne of eroded soil used in this study was obtained by using the county specific values for the on-site and off-site costs of soil erosion and placing them into the equation on page two of the publication by Hansen and Ribaudo (2008). To obtain the total value of the estimated erosion reduction from the use of CC, the average annual erosion reduction was multiplied by the value per tonne of eroded soil obtained from the USDA-ERS (equation 14).

Equation 14.

$$Value\ of\ erosion\ reduction\ \$\ ha^{-1}yr^{-1} = erosion\ reduction\ tonnes\ soil\ ha^{-1}yr^{-1} \times \$\ tonne\ soil^{-1}$$

Cover Crop Cost Recovery

CC cost recovery is calculated by accounting for all costs associated with implementing CC, and the economic value of all environmental benefits associated with the CC. This value is expressed as a percentage and is calculated by summing the total values per hectare for N loading reduction (NLR), net CC N mineralization (NNM), and erosion reduction (ER), and dividing by the total CC costs per hectare. This is then multiplied by 100 to obtain a percentage (equation 15).

Equation 15.

$$\%\ CC\ Cost\ Recovery = \frac{NLR\ \$\ ha^{-1} + NNM\ \$\ ha^{-1} + ER\ \$\ ha^{-1}}{Total\ Cover\ Crop\ Costs\ \$\ ha^{-1}} \times 100$$

Results

Cover Crop Implementation Costs

In the 2014 CC – 2015 cash crop season, the price per kilogram of seed for our CC mixture was $1.04, and it was seeded at a rate of 84 kilograms per hectare. The total cost for CC seed was $87.36 per hectare. The cost to apply the seed using a Hagie STS12 highboy interseeder was $29.65 per hectare. When the seed cost was added to the application cost, the result was a total establishment cost of $117.01 per hectare (Table B-1). Termination was a result of glyphosate being applied at a rate of 2.34 liters per hectare at a cost of $6.85 per liter, resulting in a total chemical cost of $16.03 per hectare. There was an application cost for the glyphosate of $12.36 per hectare. Therefore, the total termination cost, accounting for the chemical cost and application cost, for this year was equal to $28.39 per hectare (Table B-2). Total CC costs differentiated only in the observed yield drag of the cash crop that followed the CC. The FCC treatment yielded 0.02 Mg less than the FN treatment, while the SCC treatment yielded 0.91 Mg less than the SN treatment (Table B-3). At a value of \$156.89 Mg^{-1}, this equates to an additional cost of $3.14 and $142.77 for the FCC and SCC treatments, respectively (Table B-4). When accounting for all of the components associated with implementing CC, the calculated total CC costs for the FCC and SCC treatments were \$148.54 ha^{-1} and \$288.17 ha^{-1}, respectively (Table B-5).

In the 2015 CC – 2016 cash crop season, the cost for the CC seed remained $1.04 and was again seeded at a rate of 84 kg ha^{-1}, resulting in a total CC seed cost of \$87.36 ha^{-1}. The cost for interseeding with the Hagie STS12 was slightly lower at \$29.61 ha^{-1}. The total calculated establishment costs for the year were \$116.97 ha^{-1} (Table B-1). Glyphosate was used to terminate the CC at a rate of 2.34 liters per hectare at a cost of $6.12 per liter, resulting in a total chemical cost of \$14.32 per hectare. The cost for chemical application was \$12.35 per hectare. When adding the chemical cost to the chemical application cost, the total calculated termination cost was equal to \$26.67 per hectare (Table B-2). Observed yield drags resulted in additional costs associated with implementing CC. The FCC and SCC treatments resulted in 0.19 and 0.17 Mg lower yield when compared to the FN and SN treatments, respectively (Table B-3). Valued at \$344.31 Mg^{-1}, the additional costs associated with implementing CC was equal to \$65.42 and \$58.53 for the FCC and SCC treatments, respectively (Table B-4). Accounting for establishment, termination, and yield change costs, the total cost of implementing CC for this year was equal to \$209.06 ha^{-1} and \$202.17 ha^{-1} for the FCC and SCC treatments, respectively (Table B-5).

Nitrogen Valuation

Fall diammonium phosphate (DAP) was purchased at a cost of \$639.12 per metric ton including application. Since one metric ton is equivalent to 1,000 kilograms and DAP is comprised of 18% nitrogen, this allows us to determine that one metric ton of DAP contains 180 kilograms of nitrogen. Thus, the price per kilogram of N for DAP is equal to \$639.12 $tonne^{-1}$ DAP divided by 180 kg N in DAP, or \$3.55 kg^{-1} N from DAP. Fall anhydrous ammonia with a nitrification inhibitor was purchased at a cost of \$960.77 per metric ton. Anhydrous ammonia is an inorganic fertilizer containing 82% nitrogen, therefore one metric ton of anhydrous ammonia contains 820 kilograms of nitrogen. Accounting for the N content in the fertilizer source the price per kilogram of nitrogen from the fall anhydrous ammonia is equivalent to \$960.77 per metric ton divided by 820 kilograms of N per metric ton, or \$1.17 kg^{-1} N from fall anhydrous ammonia. Spring anhydrous ammonia was purchased at a cost of \$845.82 per metric ton, therefore the price per kilogram of nitrogen from spring anhydrous ammonia is equal to the price per metric ton of fertilizer divided by the N content of the fertilizer which is equal to 820 kg N per metric ton. The calculated price per kilogram of nitrogen for spring anhydrous ammonia was \$1.03 kg^{-1} N (Table B-6).

In order to determine the total value of fertilizer per hectare, the value per kilogram of each fertilizer source was multiplied by the application rate of each source for each treatment. The fall dominated nitrogen management treatment received 40 kg N ha^{-1} from DAP at a cost of \$3.55 kg^{-1} N DAP, for a total DAP cost per hectare of \$142.00 ha^{-1}. Fall anhydrous ammonia was applied to this treatment at a rate of 112 kg N ha^{-1} from fall anhydrous ammonia at a cost of \$1.17 kg^{-1} N, for a total fall anhydrous ammonia cost of \$131.04 ha^{-1}. In the spring, a second anhydrous ammonia application occurred at a rate of 72 kg N ha^{-1} valued at \$1.03 kg^{-1} N, equaling a total cost for spring anhydrous ammonia of \$74.16 ha^{-1}. The fall nitrogen management treatment resulted in a calculated total value of fertilizer of \$347.20 ha^{-1} (Table B-7).

The spring nitrogen management treatments received 40 kg N ha^{-1} from DAP. Valued at \$3.55 kg^{-1} N, there was a total DAP cost of \$142.00 ha^{-1}. The spring nitrogen management treatments received 0 kg N ha^{-1} from fall anhydrous ammonia, however the toolbar which doubles as a strip tillage implement was still run through the plots, and thus the cost of operating the equipment in the plots was still considered. Spring anhydrous ammonia accounted for 184 kg N ha^{-1} of the total N application for the spring nitrogen management treatments. Valued at \$1.03 kg^{-1} N, there was a total cost for spring anhydrous ammonia of \$189.52 ha^{-1}. Accounting for all applications of N there was a calculated total cost for N fertilizer of \$331.32 ha^{-1} within the spring nitrogen management treatments (Table B-9).

Associated with the application of anhydrous ammonia in both the fall and spring is the cost connected to the equipment used in the application of the fertilizer. The cost associated with operating the tractor to pull the application toolbar including fuel and labor is equal to \$30.15 ha^{-}

^{1}. Since the toolbar was pulled through all plots during both the fall and spring anhydrous ammonia application, the application cost must be accounted for twice. Therefore, an additional \$60.30 ha^{-1} application was added to the total value of fertilizer per hectare.

In both the fall and spring dominated nitrogen management treatments, there was a total of 224 kg N ha^{-1} applied. To calculate the total value per kilogram of applied nitrogen the total value of fertilizer is added to the anhydrous ammonia application equipment cost, then divided by the total kilograms of nitrogen applied. The value per kilogram of applied nitrogen in the fall nitrogen management system is equal to \$347.20 ha^{-1} for applied nitrogen plus \$60.30 ha^{-1} for anhydrous ammonia equipment operation divided by the total 224 kg N ha^{-1} applied. The calculated total value per kilogram of applied nitrogen in the fall nitrogen management treatments is \$1.82 kg^{-1} N (Table B-8). The spring nitrogen management treatments had a total value for applied fertilizer of \$331.32 ha^{-1}. Added to the anhydrous ammonia application equipment cost of \$60.30 ha^{-1}, the spring nitrogen management treatments had a total N fertilizer cost of \$391.62 ha^{-1}. Dividing the total cost for fertilizer per hectare by the total application rate of 224 kg N ha^{-1}, resulted in a value of \$1.75 kg^{-1} N for the spring nitrogen management treatments (Table B-10).

Economic Value of Cover Crop Environmental Benefits

In both years of this study, the introduction of CC into both the FN and SN management systems resulted in reduced nitrogen loading in the subsurface drainage system relative to the non-CC plots of the same management system. In the 2014 CC – 2015 cash crop season, the FN treatment lost 54.09 kg N ha^{-1} through the subsurface drainage system, while the FCC treatment lost 39.29 kg N ha^{-1}. This equated to a 14.80 kg N ha^{-1} reduction in subsurface drainage N loading due to the use of CC (Table B-11). With a value of \$1.82 kg^{-1} placed on nitrogen applied to the fall dominated nitrogen management system, the reduction in N loading due to CC resulted in a total economic value of \$26.94 ha^{-1} associated with the FCC treatment (Table B-12). In the same season, the SCC treatment lost 38.62 kg N ha^{-1} compared to the SN treatment that lost a total of 44.58 kg N ha^{-1}. This reduction in N loading through the subsurface drainage system in the spring dominated nitrogen management system due to CC was equivalent to 5.96 kg N ha^{-1} (Table B-11). A value of \$1.75 kg^{-1} was placed on nitrogen applied to the spring dominated nitrogen management system, thus the observed reduction in N loading due to CC within this treatment resulted in a total economic value of \$10.43 ha^{-1} (Table B-12).

In the 2015 CC – 2016 cash crop season, much like the previous year, substantial reductions in nitrogen loading through the subsurface drainage system were observed in both the fall and spring dominated nitrogen management systems. There was a total reduction in N loading through subsurface drainage of 26.91 kg N ha^{-1} between the FN and FCC treatments, which had measured losses of 47.67 kg N ha^{-1} and 20.76 kg N ha^{-1}, respectively (Table B-11). That reduction, valued at the \$1.82 kg^{-1} for N applied to the fall dominated nitrogen management treatment, resulted in a total economic value of \$48.98 ha^{-1} (Table B-12). There was an observed loss of 72.26 kg N ha^{-1} through the drainage system in the SN treatment compared to just 26.01 kg N ha^{-1} in the SCC treatment, resulting in a 46.25 kg N ha^{-1} reduction in N loading due to the addition of CC into the crop rotation (Table B-11). Valued at \$1.75 kg^{-1}, the reduction in N loading within the spring dominated nitrogen management system, represents a total economic value of \$80.94 ha^{-1} (Table B-12).

According three sites years of study, it was determined that on average 100% of the N within the daikon radish biomass and 95% of the N within the cereal rye biomass is mineralized prior to cash crop physiological maturity. The high percentage of mineralized nitrogen from the cereal rye biomass could be explained by the low observed C:N ratio of the biomass. The cereal rye in this study was chemically terminated prior to stem elongation, when the C:N ratio begins to rapidly increase, resulting in a C:N ratios ranging from 13:1 to 17:1. Nitrogen Mineralization is promoted when C:N ratios are 24:1 or less; thus, the low C:N ratios observed in our cereal rye biomass explain the high percentage of nitrogen mineralization from the biomass. When calculating total N return from the CC the spring cereal rye N uptake is multiplied by a mineralization factor of 0.95 and then the fall daikon radish N uptake multiplied by a mineralization factor of 1 is added. It is important to ensure that N mineralized from the CC residue is only accounted for once, and thus the reduction in N loading through the subsurface drainage system must be subtracted from the value calculated for total N return, as it is assumed that the reduction is a result of CC N uptake.

In the 2014 CC – 2015 cash crop season, the fall CC sampling revealed a total N content in the daikon radish of 5.72 kg N ha^{-1} and 5.37 kg N ha^{-1} for the FCC and SCC treatments, respectively. The cereal rye biomass sampled in the spring prior to chemical termination from the FCC and SCC treatments had sequestered 61.47 kg N ha^{-1} and 45.58 kg N ha^{-1}, respectively. After multiplying the N uptake for each species from the FCC treatment by its respective mineralization factor, it was determined that a gross mineralization of 64.12 kg N ha^{-1} from the CC in the FCC treatment had occurred (Table B-13). In order to ensure that the N being returned to the soil profile from the CC biomass is only accounted for once, we must determine a net mineralization value by subtracting the N loading reduction from the gross mineralization value for each of the respective treatments. In the case of the FCC treatment, this is 64.12 kg N ha^{-1} minus 14.80 kg N ha^{-1}, which equates to a net mineralization of CC biomass N of 49.32 kg N ha^{-1}. The mineralized N from the FCC treatment valued at \$1.82 kg^{-1} of N applied to the fall dominated nitrogen management treatments, equates to a total economic value of \$89.76 ha^{-1} (Table B-14). The SCC treatment was determined to have a gross mineralization of 48.67 kg N ha^{-1} after accounting for the correct mineralization factor of each CC species (Table B-13). A calculated net mineralization of 42.71 kg N ha^{-1} for the SCC treatment was determined after subtracting the N loading reduction of 5.96 kg N ha^{-1} from the treatments calculated gross mineralization. Valued at \$1.75 kg^{-1} of applied N for the spring dominated nitrogen management treatment, the calculated net mineralization for the SCC treatment is equivalent to a total economic value of \$74.74 ha^{-1} (Table B-14).

The fall CC sampling for the 2015 CC – 2016 cash crop season revealed a daikon radish N content for the FCC and SCC treatments of 32.17 kg N ha^{-1} and 36.40 kg N ha^{-1}, respectively. Following the sampling of the CC prior to spring chemical termination, it was determined that the cereal rye biomass had a total N content of 29.05 kg N ha^{-1} and 33.72 kg N ha^{-1} for the FCC and SCC treatments, respectively. After accounting for the correct mineralization factor of each CC species, it was determined that the FCC treatment had a gross N mineralization of 59.77 kg N ha^{-1} (Table B-13). Accounting for the observed N loading reduction for the FCC treatment of 26.91 kg N ha^{-1}, a net N mineralization of 32.86 kg N ha^{-1} was calculated for the FCC treatment. Valued at \$1.82 kg^{-1} of N applied to the fall dominated nitrogen management treatment, the net mineralized CC N within the FCC treatment was equivalent to an economic value of \$59.80 ha^{-1} (Table B-14). Gross N mineralization for the SCC treatment, after accounting for each species N content and corresponding mineralization factor, was determined to be 68.43 kg N ha^{-1} (Table B-13). However, taking into account the N loading reduction of 46.25 kg N ha^{-1} for the SCC treatment, the calculated net N mineralization for the SCC treatment was revealed to be 22.18 kg N ha^{-1}. The calculated net mineralization, valued at \$1.75 kg^{-1} of N applied to the spring dominated nitrogen management treatments, equates to a total economic value of \$38.82 ha^{-1} (Table B-14).

The calculated average erosion for our site as determined by the RUSLE2 program was 1.46 metric tons per hectare per year for the non-CC treatments and 0.25 metric tons per hectare per year for the treatments including CC. This is equivalent to a total reduction of 1.21 metric tons per hectare per year due to the inclusion of CC (Table B-15). Using data from the USDA ERS it was determined that the value per metric ton of soil was equal to \$9.20 per metric ton. The calculated value for the reduction in erosion due to CC inclusion was equal to \$11.13 per hectare per year (Table B-16).

Cover Crop Cost Recovery

In the 2014 CC – 2015 corn year, the total costs incurred for implementing CC was \$148.54 ha^{-1} and \$288.17 ha^{-1} for the FCC and SCC treatments, respectively. The total economic value of the measurable environmental benefits of CC for the FCC and SCC treatments were equal to \$127.83 ha^{-1} and \$96.30 ha^{-1} (Table B-17). The value of the environmental benefits resulted in 86.1 and 33.4% recovery of the CC implementation cost for the FCC and SCC treatments, respectively (Table B-18). Within the FCC treatment, N loading reductions accounted for 21.1% of the total recovered cost, net mineralization represented 70.2% of the total recovered costs, and erosion reductions corresponded to 8.7% of the recovered costs of CC implementation. The composition of recovered costs within the SCC treatment was 10.8% from N loading reductions, 77.6% from CC N mineralization, and 11.6% from erosion reduction (Table B-19).

The total cost of implementing CC into the crop rotation for the 2015 CC – 2016 soybean year were \$209.06 ha^{-1} and \$202.17 ha^{-1} for the FCC and SCC treatments, respectively. The environmental benefits observed from the CC resulted in a total economic value for the FCC and SCC treatments of \$119.91 ha^{-1} and \$130.89 ha^{-1}, respectively (Table B-18). The resulting recovery of CC implementation cost due to the value of observed environmental benefits is equal to 57.4 and 64.7% for the FCC and SCC treatments, respectively (Table B-21). Nitrogen loading reductions accounted for 40.8% of the total recovered costs of CC implementation in the FCC treatment, while net CC mineralization and erosion reduction corresponded to 49.9 and 9.3% of the total recovered costs, respectively. In the SCC treatment, nitrogen loading reductions composed 61.8% of the total recovered costs of CC implementation, with net CC mineralization representing 29.7% and erosion reduction equaling 8.5% of the total recovered costs (Table B-22).

Discussion

With CC being recognized as one of the most effective in-field adaptive management practices to reduce the impact of agriculture on the hypoxic zone in the Gulf of Mexico, it is important to begin breaking down the barriers to widespread adoption of the practice (ILNLRS, 2014). Producers understand the various environmental benefits that CC can provide and have identified these benefits as key motivators for CC adoption. However, these same producers acknowledged that the costs associated with CC adoption, along with no measureable economic return are key deterrents to adoption of this environmentally smart practice (CTIC 2015, 2016). Our study found that there are short-term recovery variables associated with CC conservation and release of N that have the potential to increase the annual value of CC to producers.

We determined that the total CC costs for this study ranged from \$148.54 ha^{-1} to \$288.17 ha^{-1}; however, the high variability in in total CC costs can be explained by the variability in yield reductions of the cash crop the CC inclusion. When removing the costs associated with changes in yield, the total costs associated with CC establishment and termination ranged from \$143.64 ha^{-1} to \$145.40 ha^{-1}. We also determined that the total value of benefits from a combination of erosion reduction, mineralization of CC N, and subsurface drainage N loading reduction ranged from \$96.30 ha^{-1} to \$130.89 ha^{-1}.

The net benefit of CC at our site ranged from a net loss of \$20.71 ha^{-1} to a net loss of \$191.87 ha^{-1}. The largest portion of these losses were a result of yield decreases in the cash crop following the CC. If the yields are assumed to remain constant between the CC and non-CC treatments resulting in a yield change cost of zero, the percent CC cost recovery ranges from 66.2% to 91.1%. In this situation, the net benefits of CC range from a net loss of \$12.75 ha^{-1} to a net loss of \$49.10 ha^{-1} (Table B-20; Table B-23).

A study conducted by Pratt et al. (2014) across 24 farms in Indiana focused on estimating the costs and benefits of CC. They also examined the removal of corn stover for bioenergy production as a method of supplementing the value of CC agronomic benefits for CC cost recovery. This study valued four categories of agronomic benefits associated with CC I) added nutrient content, II) increased soil organic matter, III) reduced soil compaction, and IV) reduced soil erosion. They also estimated the net economic benefit to producers following the removal of corn stover for the purposes of bioenergy production as a method of CC implementation cost recovery.

Conversely, this study attempted to examine the costs and benefits of CC through a blend of agronomic and environmental factors. This study and the study conducted by pratt et al. (2014) both took into account added nutrients from the CC and changes in soil erosion. However, unlike the study conducted by Pratt et al. which used average values for CC N additions provided through the Midwest Cover Crop Council, this study measured of the actual uptake and return of nitrogen from the biomass of the CC in our mixture. Also unlike the Pratt et al. study which assumed that the producers' fertilization would be adjusted by the assumed nutrient credit of the CC mix, we assumed that producers would maintain their current fertilization practices and that N mineralized from CC biomass was essentially treated as another N application. This study did not account for changes in soil compaction or soil organic matter, but rather focused on the environmental impact CC have on N loading through subsurface drainage systems. The model used in this study also accounted for changes in cash crop yields following CC.

Pratt et al. (2014) determined that total CC costs ranged from \$81.76 ha^{-1} to \$172.50 ha^{-1} with the variability being accounted for by the seed cost and seeding rates of the different CC species used. Comparatively, the total CC costs when yield change costs were removed ranging from \$143.64 ha^{-1} to \$145.40 ha^{-1} were in the middle of the range observed by Pratt et al., (Pratt et al., 2014). In the study conducted by Pratt et al. (2014), total on-site agronomic benefits of CC were found to range from \$91.45 ha^{-1} to 192.07 ha^{-1}. They found that agronomic benefits were highly influenced by the estimated added and scavenged nitrogen, and determined that agronomic benefits ranged from \$74.72 ha^{-1} to \$134.62 ha^{-1} with the valuation of the N credit removed. The results of our study which determined the value of CC environmental benefits to range from \$96.30 ha^{-1} to \$130.89 ha^{-1} are very comparable to the results from Pratt et al., (2014) whether they accounted for the nitrogen credit or not.

Following a cost benefit analysis, Pratt et al. (2014) determined that the on-site net benefit of CC ranged from a net loss of \$11.09 ha^{-1} to a net benefit of \$87.32 ha^{-1}. They further determined that a producer could remove greater amounts of crop stover to be sold for the purposes of bioenergy production when using covers crops, and net-benefits can range from a net loss of \$3.78 ha^{-1} to a net benefit of \$249.52 ha^{-1} dependent upon stover price. In comparison, the results of the cost benefit analysis conducted in this study demonstrate that the environmental benefits of CC cannot offset 100% of the CC implementation costs and result in net economic losses. Pratt et al., (2014) used increased soil organic matter as a measure of increased cash crop grain yields, thus only accounted for increases in yield. Whereas, this study used actual cash crop grain yields and accounted for decreased grain yields as an additional cost, which could explain the discrepancy in net CC benefits between the two studies.

The Net losses observed over the duration of our study could potentially be corrected through several methods. First, changes as a result of CC use in factors such as soil organic matter, soil compaction, surface and subsurface phosphorus losses, and losses of nitrogen through denitrification could be valued and accounted for in the model as CC benefits. Second, seeding rates could be adjusted and thus the overall establishment costs would be reduced as a result of reduced seed costs. Lastly, nutrient management strategies could be developed that keep overall operational costs consistent, but lead to increased cash crop yields following CC.

The greatest impact of this research could be on future policy regarding subsidies provided to producers who implement BMPs, such as CC, woodchip bioreactors, and two-stage ditches, into their operations. Currently, cost sharing programs, such as the environmental quality incentives program, exist that help alleviate the added costs incurred by producers who implement CC. However, the question that exists is how much of the cost of CC needs to be subsidized in order to incentivize producers to implement this environmentally friendly practice. The continuation of this study culminating in a long-term average representing the cost recovery of CC implementation could potentially guide policy makers through decision making processes concerning CC subsidies.

Conclusion

The economic value of CC environmental benefits as revealed through the results of this study could help justify the inclusion of CC into existing crop rotations. The economic value of erosion reduction, nitrogen mineralization, and reduced subsurface nitrogen loading can account for 33.4 – 86.1% of the costs to implement CC. We determined that an average of just 61% of the initial CC costs can be recovered by placing economic value to the observed environmental benefits of CC. However, there is a potential for this percentage to substantially increase with the evolution of cropping and management strategies for rotations that include CC. Results also indicate that a large proportion of initial CC costs is a result of yield losses observed in the subsequent cash crop. Therefore, additional research should be conducted on nutrient management strategies aimed at maintaining or increasing cash crop yields following a CC.

The average composition of recovered costs was 34% from reductions in nitrogen loading to subsurface drainage, 57% from the net mineralization of nitrogen from the CC biomass, and 9% from the estimated reduction in erosion. The high proportion of recovered costs coming from CC biomass mineralization indicates that further research should be conducted on determining the nitrogen content of grass CC through a method that producers could easily adopt into their practices. This would allow for producers to better estimate the nitrogen contribution of grass CC within a cropping system.

References

"Cover Crop Survey Report." (2015). n. pag. *COVER CROP SURVEY*. Conservation Technology Information Center/ Sustainable Agriculture Research and Education. Web. 17 March 2017.

"Cover Crop Survey Report." (2016). n. pag. *COVER CROP SURVEY*. Conservation Technology Information Center/ Sustainable Agriculture Research and Education. Web. 17 March 2017.

"Cover Crops Tool: An Economic Decision Support Tool." (2014). *Cover Crops Tool Fact Sheet*. United States Department of Agriculture Natural Resources Conservation Service. Web. 17 March 2017.

"Illinois Nutrient Loss Reduction Strategy." (2015). *Illinois Nutrient Loss Reduction Strategy*. Illinois Environmental Protection Agency. Web. 25 Mar. 2015.

Alexander, R. A., R. B. Smith., and G. E. Schwarz. (2000), Effect of stream channel size on the delivery of nitrogen to the Gulf of Mexico: *Nature*, v. 403. p. 758-761.

Christianson, Laura E., and Matthew Justin Helmers. (2011). *Woodchip Bioreactors for Nitrate in Agricultural Drainage*. Ames, IA: Iowa State University Extension. Web. 27 February 2017.

D'Ambrosio, J. L., A.D. Ward, and J. D. Witter. (2015). Evaluating Geomorphic Change in Constructed Two-Stage Ditches. JAWRA *Journal of the American Water Resources Association*, 51(4), 910-922.

Danso, S. K., C. Labandera, D. Pastorini, and S. Curbelo. (1991). Herbage yield and nitrogen fixation in a triple species mixed sward of white clover, lotus and fescue. *Soil Biol. Biochem.* 23:65–70.

Dean, J., and R. Weil. (2009). Brassica Cover Crops for Nitrogen Retention in the Mid-Atlantic Coastal Plain. *Journal of Environmental Quality*. 38:520-528.

Fageria, N. K., V. C. Baligar, and B.A. Bailey. (2005). Role of cover crops in improving soil and row crop productivity. *Communications in soil science and plant analysis*, 36(19-20), 2733-2757.

Hansen, L., and M. Ribaudo. (2008). *Economic measures of soil conservation benefits*. USDA, September.

Hartwig, N. L., and H. U. Ammon. (2002). Cover crops and living mulches. *Weed science*, 50(6), 688-699.

Odell, R. T., S. W. Melsted, and W. M. Walker. (1984). Changes in Organic Carbon and Nitrogen of Morrow Plot Soils Under Different Treatments, 1904-1973. *Soil Science*, 137(3), 160-171.

Pratt, M. R., W. E. Tyner, D. J. Muth, and E. J. Kladivko. (2014). Synergies between cover crops and corn stover removal. *Agricultural Systems*, 130, 67-76.

Robertson, Dale M., and David A. Saad. (2013). SPARROW Models Used to Understand Nutrient Sources in the Mississippi/Atchafalaya River Basin *joenq*. 42:1422–1440. doi:10.2134/jeq2013.02.0066

Roley, S. S., Tank, J. L., Tyndall, J. C., & Witter, J. D. (2016). How cost-effective are cover crops, wetlands, and two-stage ditches for nitrogen removal in the Mississippi River Basin?. *Water Resources and Economics*, 15, 43-56.

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. Environ. Qual.* 33:1010-1016. doi:10.2134/jeq2004.1010

CHAPTER V: CONCLUSION

The examination of short-term weather data collected during the 2014 and 2015 cover crop (CC) growing seasons demonstrates that air temperature and precipitation have a greater influence on annual CC growth compared to other variables such as nitrogen management or previous cash crop. Differences in average ambient air temperature and total precipitation between the two CC growing seasons had measureable impacts on fall biomass production and N sequestration, as well as, the date of daikon radish winter termination. The 2014 CC season recorded lower than average ambient air temperatures and total precipitation, while the 2015 CC season had greater than average ambient air temperatures and total precipitation. Winter termination of the daikon radish occurred in mid-to-late November during the 2014 CC season compared to an early January winter termination date in the 2015 CC season. This equates to approximately 1-1.5 months of extra growth for the daikon radish in the 2015 CC growing season relative to the 2014 CC growing season, which can be attributed to the considerably warmer ambient air temperatures and higher precipitation totals of the 2015 CC season compared to the 2014 CC growing season. Below average ambient air temperature and total precipitation during the 2014 CC growing season resulted in 76 and 82% less biomass production with 80 and 76% less N uptake in the FCC and SCC treatments compared to the 2015 CC growing season, respectively.

The introduction of a CC into both the fall and spring dominated nitrogen management systems resulted in greater corn biomass production and nitrogen uptake through the V12 growth stage; however, at physiological maturity the treatments with CC resulted in less total biomass and nitrogen uptake than the treatments without CC. Corn grain yields were not significantly affected when CC were introduced into the fall dominated nitrogen management system; however, within the spring dominated nitrogen management system there was demonstrated potential for significantly decreased corn grain yields following the introduction of CC. In the soybean phase of the crop rotation, increased biomass production and nitrogen uptake was observed through soybean growth stage R2 when CC were present. However, the introduction of CC did not significantly impact crop biomass production or nitrogen at any growth, and no significant differences were observed in soybean grain yields amongst any of the experimental treatments.

The results of the cost benefit analysis conducted over the two years of this study suggest that environmental CC benefits of subsurface drainage nitrogen load reductions, net nitrogen mineralization, and erosion reduction can recover 33.4% to 86.1% of CC implementation costs. While the results across all treatments over two years indicate an average of just 61% of the initial CC costs being recovered by placing economic value to the observed environmental benefits of CC, there is a potential for this percentage to substantially increase with the evolution of cropping and management strategies for rotations that include CC. Results of the cost benefit analysis demonstrated that a substantial portion of the total costs associated with CC were attributed to losses in revenue due to decreases in grain yield in the cash crop following CC. Therefore, research aimed at maintaining or increasing cash crop grain yields following CC should be conducted.

Results of the cost benefit analysis revealed that net nitrogen mineralization provided the largest contribution towards the recovery of CC implementation costs, followed by subsurface drainage nitrogen loading reductions, with erosion reduction accounting for the smallest portion of recovered costs. With such a high proportion of CC cost recovery coming from the net mineralization of nitrogen from the biomass of CC, there is a need for research aimed at determining the timing of nitrogen release from the CC biomass and its availability to the following cash crop. There is also a need for research aimed at developing producer friendly methods of determining the nitrogen content of all CC species which could be easily adapted into existing operations. This would allow for producers to better estimate the contribution of nitrogen from CC to the cropping system, and potentially adjust their applied nitrogen rates.

Currently, the state of Illinois does not regulate the use of CC or the timing and rate of nitrogen fertilizer applications; however, this could easily change if the goals set forth in the Illinois Nutrient Reduction Strategy (ILNLRS) are not met in a timely manner. Illinois, along with many other states, offers cost sharing programs to producers who choose to implement best management practices into their farming operations. These cost sharing options could help alleviate some of the implementation costs associated with best management practices but may not cover the whole costs. However, the results of this study could provide producers, and policy makers alike, the knowledge that valuing CC environmental benefits could help offset implementation costs not covered through governmental cost sharing programs. While studies have shown that the use of CC and split applications of nitrogen (50% or greater applied nitrogen in the spring) can help achieve the nutrient loading reduction set forth in the ILNLRS, it will take evidence of an economic benefit before producers will voluntarily change their farming practices without a form of economic assistance.

APPENDIX A: TABLES AND FIGURES FOR CHAPTER III

Table A-1

Average Monthly Ambient Air Temperatures Years 2014, 2015, 2016

	Average Ambient Air Temperature (°C)			
Year	2014	2015	2016	30-Year Average
January	-8.9	**-4.6**	**-3.6**	-3.8
February	-9.0	**-8.3**	**-0.4**	-2.1
March	-0.4	**2.5**	**7.7**	4.3
April	10.5	**11.4**	**10.5**	10.9
May	17.1	**18.0**	**16.6**	17.1
June	22.3	**21.5**	**23.2**	22.2
July	20.7	**22.3**	**23.2**	23.9
August	23.0	**21.2**	**23.2**	22.9
September	**17.7**	**20.3**	20.5	18.8
October	**11.3**	**12.2**	14.6	12.0
November	**0.6**	**7.0**	7.3	4.9
December	**-0.1**	**4.2**	-2.4	-1.8

Note: Average monthly ambient air temperatures for the years of 2014, 2015, and 2016. Values in bold represent the time period of this study.

Table A-2

Total Monthly Precipitation Years 2014, 2015, 2016

	Total Precipitation (mm)			
Year	2014	2015	2016	30-Year Average
January	22.4	**39.9**	**15.7**	57.5
February	19.6	**13.7**	**19.1**	51.8
March	42.2	**22.4**	**74.7**	63.3
April	59.4	**60.2**	**67.1**	90.7
May	64.8	**131.6**	**102.9**	108.1
June	188.7	**179.1**	**102.4**	100.5
July	86.6	**139.2**	**157.0**	98.3
August	57.4	**104.1**	**153.4**	94.2
September	**98.8**	**69.1**	78.5	83.4
October	**104.1**	**45.7**	42.9	86.1
November	**41.9**	**100.1**	66.0	78.2
December	**20.1**	**151.6**	21.6	60.6

Note: Total monthly precipitation for the years of 2014, 2015, and 2016. Values in bold represent the time period of this study.

Table A-3

Cover Crop Biomass Production ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	1	0.99	0.3590
Block	2	0.05	0.9518
Date	3	129.17	<0.0001
Treatment*Date	3	5.16	0.0424
Treatment*Block	2	3.84	0.0842
Block*Date	6	12.74	0.0034
Error	6		

Note: ANOVA table depicts the response variable (cover crop biomass production) and probability values for each source of variation

Table A-4

Cover Crop Nitrogen Uptake ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	1	0.02	0.8808
Block	2	0.10	0.9080
Date	3	22.82	0.0011
Treatment*Date	3	2.99	0.1178
Treatment*Block	2	2.25	0.1867
Block*Date	6	3.83	0.0635
Error	6		

Note: ANOVA table depicts the response variable (cover crop nitrogen uptake) and probability values for each source of variation

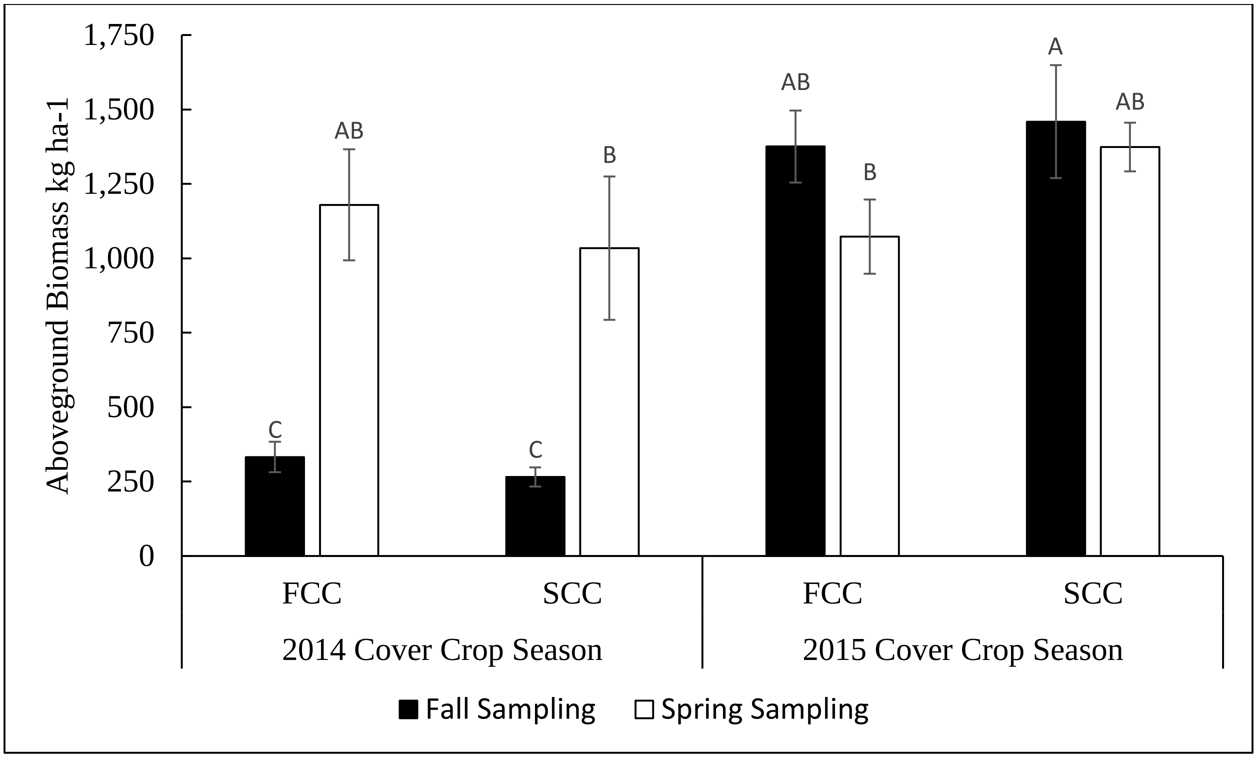

Figure A-1. Cover crop biomass production (kg ha^{-1}) by experimental treatment at both the fall and spring sampling dates for both cover crop seasons. Different letters indicate significant differences between treatments across all sampling dates at an alpha level of 0.05 according to a least square means tukey comparison lines test. Error bars represent standard error.

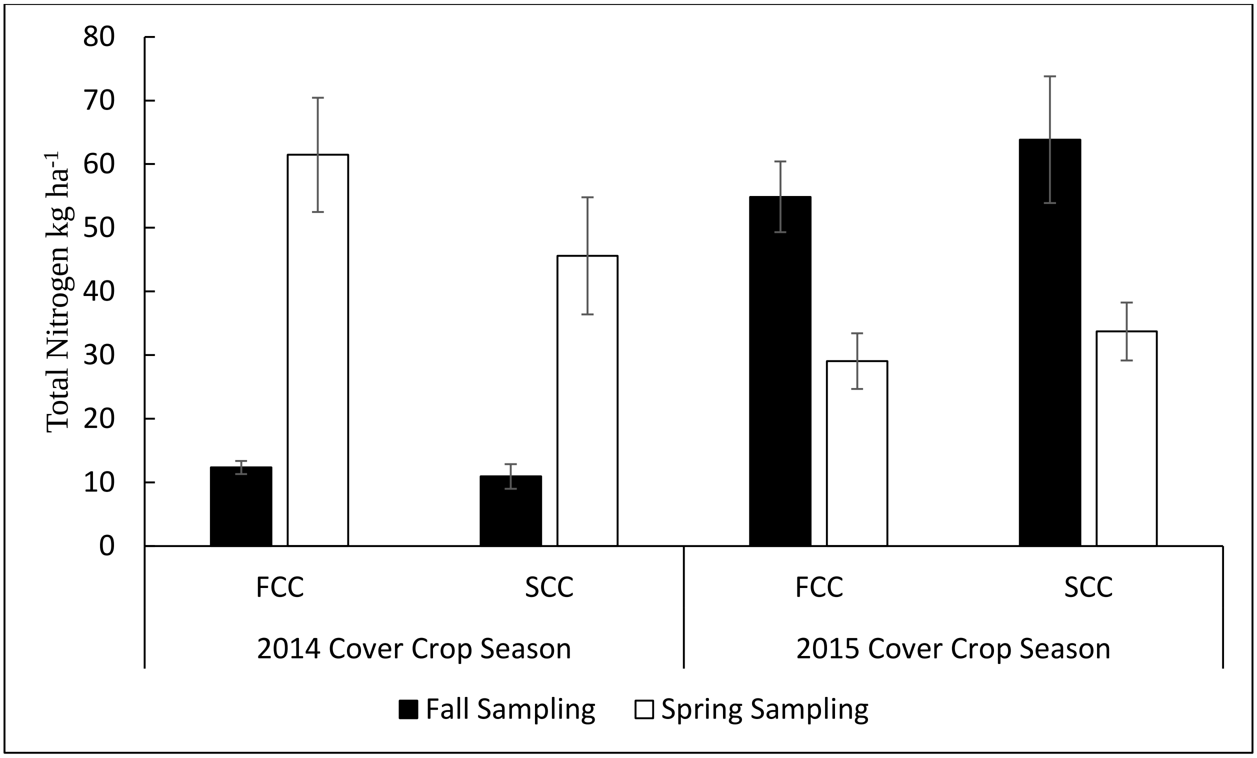

Figure A-2. Cover crop nitrogen uptake (kg N ha^{-1}) by experimental treatment at both the fall and spring sampling dates for both cover crop seasons. Error bars represent standard error.

Table A-5

Corn Growth stage V6 Biomass ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	0.67	0.6292
Block	2	1.04	0.3973
Error	8		

Note: ANOVA table depicts the response variable (corn growth stage V6 biomass) and probability values for each source of variation.

Table A-6

Corn Growth Stage V12 Biomass ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	2.23	0.1848
Block	2	0.26	0.7795
Error	8		

Note: ANOVA table depicts the response variable (corn growth stage V12 biomass) and probability values for each source of variation.

Table A-7

Corn Growth Stage VT Biomass ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	1.36	0.3284
Block	2	4.66	0.0456
Error	8		

Note: ANOVA table depicts the response variable (corn growth stage VT biomass) and probability values for each source of variation.

Table A-8

Corn Growth Stage R6 Biomass ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	2.58	0.1179
Block	2	2.11	0.1831
Error	8		

Note: ANOVA table depicts the response variable (corn growth stage R6 biomass) and probability values for each source of variation.

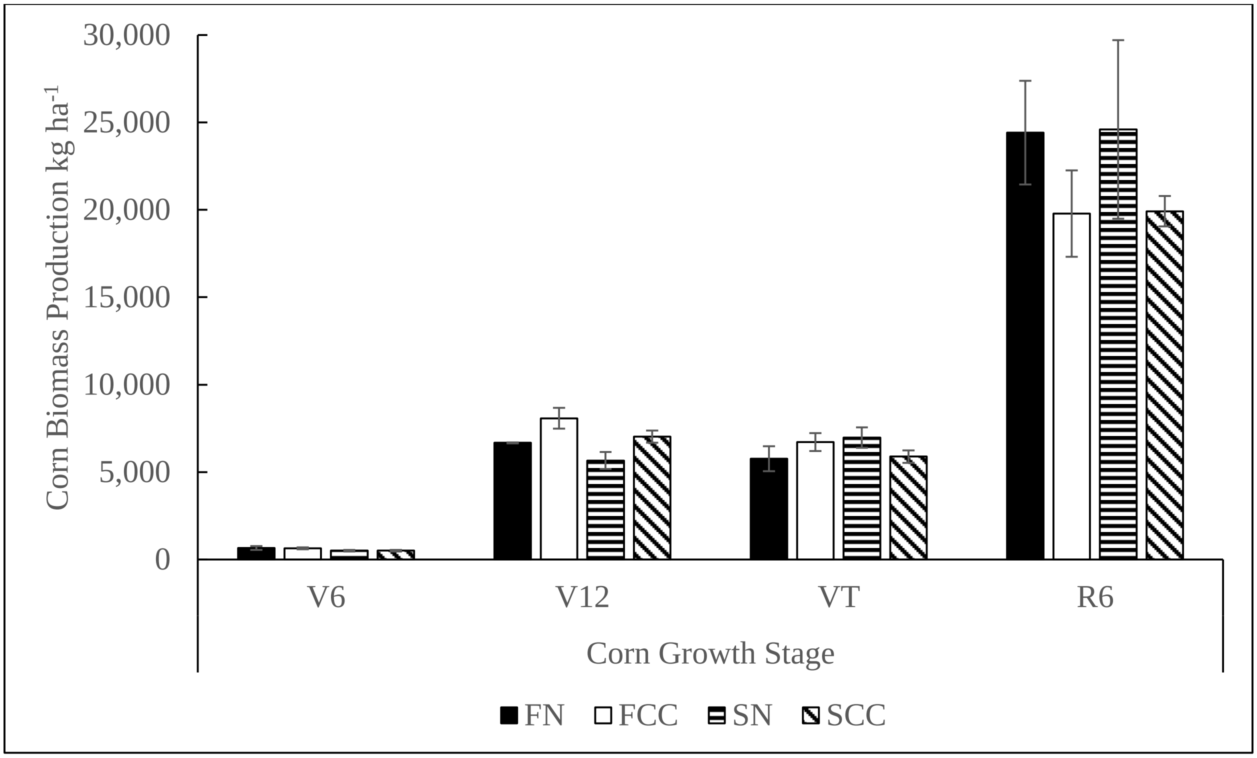

Figure A-3. Corn biomass production (kg ha^{-1}) by crop growth stage collected during the 2015 corn season. The error bars represent the standard error.

Table A-9

Corn Growth Stage R6 Plant Matter Biomass ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	1.70	0.2423
Block	2	1.90	0.2110
Error	8		

Note: ANOVA table depicts the response variable (corn growth stage R6 plant matter biomass) and probability values for each source of variation.

Table A-10

Corn Growth Stage R6 Cob Biomass ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	2.20	0.1594
Block	2	1.57	0.2663
Error	8		

Note: ANOVA table depicts the response variable (corn growth stage R6 cob biomass) and probability values for each source of variation.

Table A-11

Corn Growth Stage R6 Grain Biomass ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	3.27	0.0721
Block	2	2.19	0.1742
Error	8		

Note: ANOVA table depicts the response variable (corn growth stage R6 grain biomass) and probability values for each source of variation.

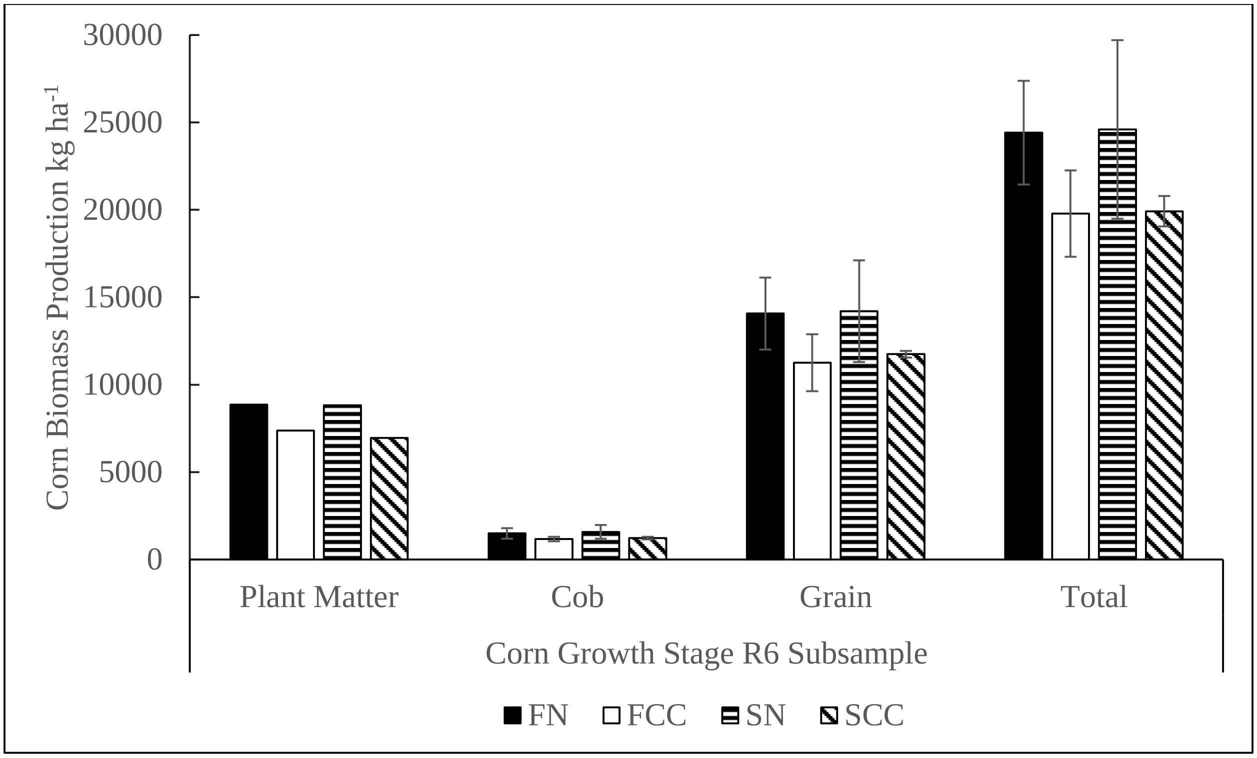

Figure A-4. Corn Biomass Production (kg ha^{-1}) for the growth stage R6 subsamples collected during the 2015 corn season. The error bars represent standard error.

Table A-12

Corn Growth Stage V6 Nitrogen Uptake ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	2.07	0.1775
Block	2	0.58	0.5838
Error	8		

Note: ANOVA table depicts the response variable (corn growth stage V6 Nitrogen Uptake) and probability values for each source of variation.

Table A-13

Corn Growth Stage V12 Nitrogen Uptake ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	31.33	<0.0001
Block	2	2.39	0.1573
Error	8		

Note: ANOVA table depicts the response variable (corn growth stage V12 Nitrogen Uptake) and probability values for each source of variation.

Table A-14

Corn Growth Stage VT Nitrogen Uptake ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	1.71	0.2632
Block	2	3.01	0.1241
Error	8		

Note: ANOVA table depicts the response variable (corn growth stage VT Nitrogen Uptake) and probability values for each source of variation.

Table A-15

Corn Growth Stage R6 Nitrogen Uptake ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	2.53	0.1226
Block	2	1.42	0.2974
Error	8		

Note: ANOVA table depicts the response variable (corn growth stage R6 Nitrogen Uptake) and probability values for each source of variation.

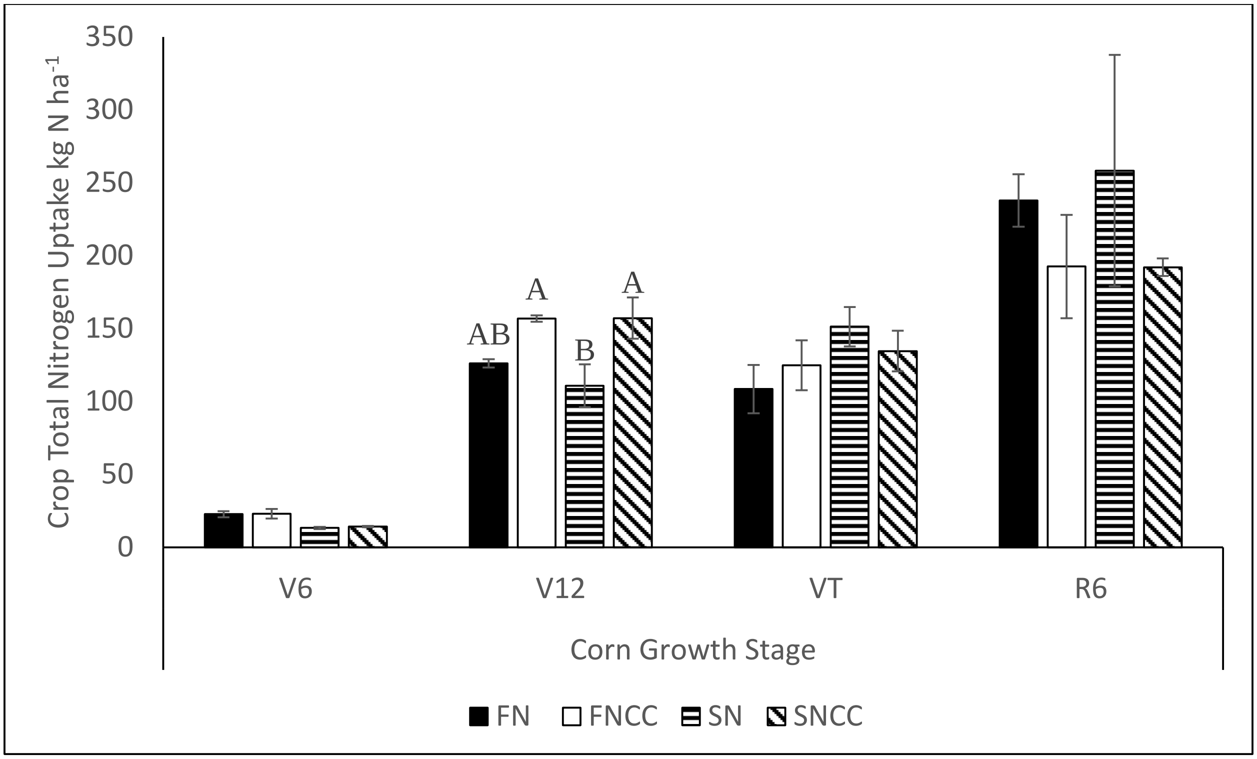

Figure A-5. Corn nitrogen uptake (kg N ha^{-1}) by growth stage collected during the 2015 corn season. Different letters indicate significant differences between treatments within a growth stage at an alpha level of 0.05 according to Ryan's multiple comparisons test. Error bars represent standard error.

Table A-16

Corn Growth Stage R6 Plant Matter Nitrogen Uptake ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	1.73	0.2367
Block	2	1.29	0.3281
Error	8		

Note: ANOVA table depicts the response variable (corn growth stage R6 plant matter Nitrogen Uptake) and probability values for each source of variation.

Table A-17

Corn Growth Stage R6 Plant Cob Nitrogen Uptake ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	3.03	0.0853
Block	2	0.41	0.6764
Error	8		

Note: ANOVA table depicts the response variable (corn growth stage R6 Cob Nitrogen Uptake) and probability values for each source of variation.

Table A-18

Corn Growth Stage R6 Grain Nitrogen Uptake ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	2.69	0.1090
Block	2	1.56	0.2672
Error	8		

Note: ANOVA table depicts the response variable (corn growth stage R6 Grain Nitrogen Uptake) and probability values for each source of variation.

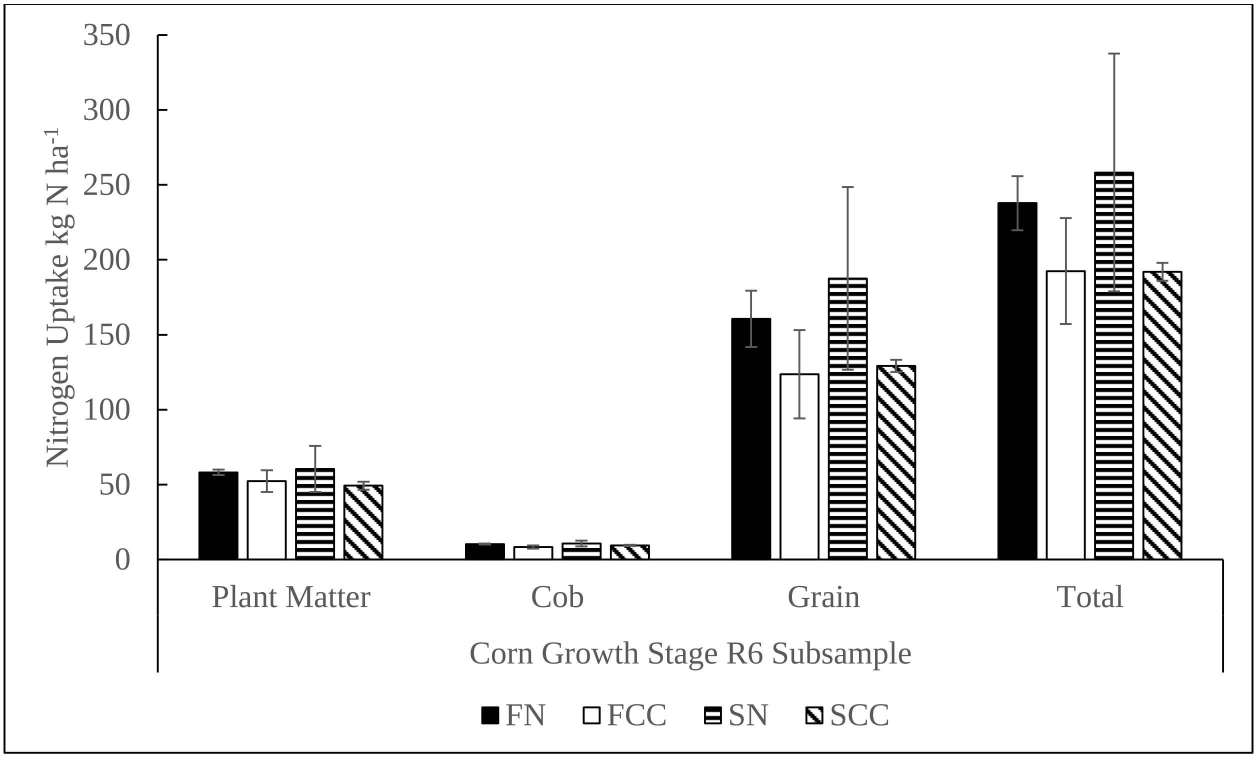

Figure A-6. Corn nitrogen uptake (kg N ha^{-1}) for the growth stage R6 subsamples collected during the 2015 corn season. Error bars represent standard error.

Figure A-19

Soybean Growth Stage V4 Biomass ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	1.61	0.2848
Block	2	0.54	0.6013
Error	8		

Note: ANOVA table depicts the response variable (soybean growth stage V4 biomass) and probability values for each source of variation.

Figure A-20

Soybean Growth Stage R2 Biomass ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	0.36	0.8378
Block	2	0.16	0.8558
Error	8		

Note: ANOVA table depicts the response variable (soybean growth stage R2 biomass) and probability values for each source of variation.

Figure A-21

Soybean Growth Stage R4 Biomass ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	1.00	0.4206
Block	2	1.44	0.2923
Error	8		

Note: ANOVA table depicts the response variable (soybean growth stage R4 biomass) and probability values for each source of variation.

Table A-22

Soybean Growth Stage R8 Biomass ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	0.06	0.9927
Block	2	4.34	0.0528
Error	8		

Note: ANOVA table depicts the response variable (soybean growth stage R8 biomass) and probability values for each source of variation.

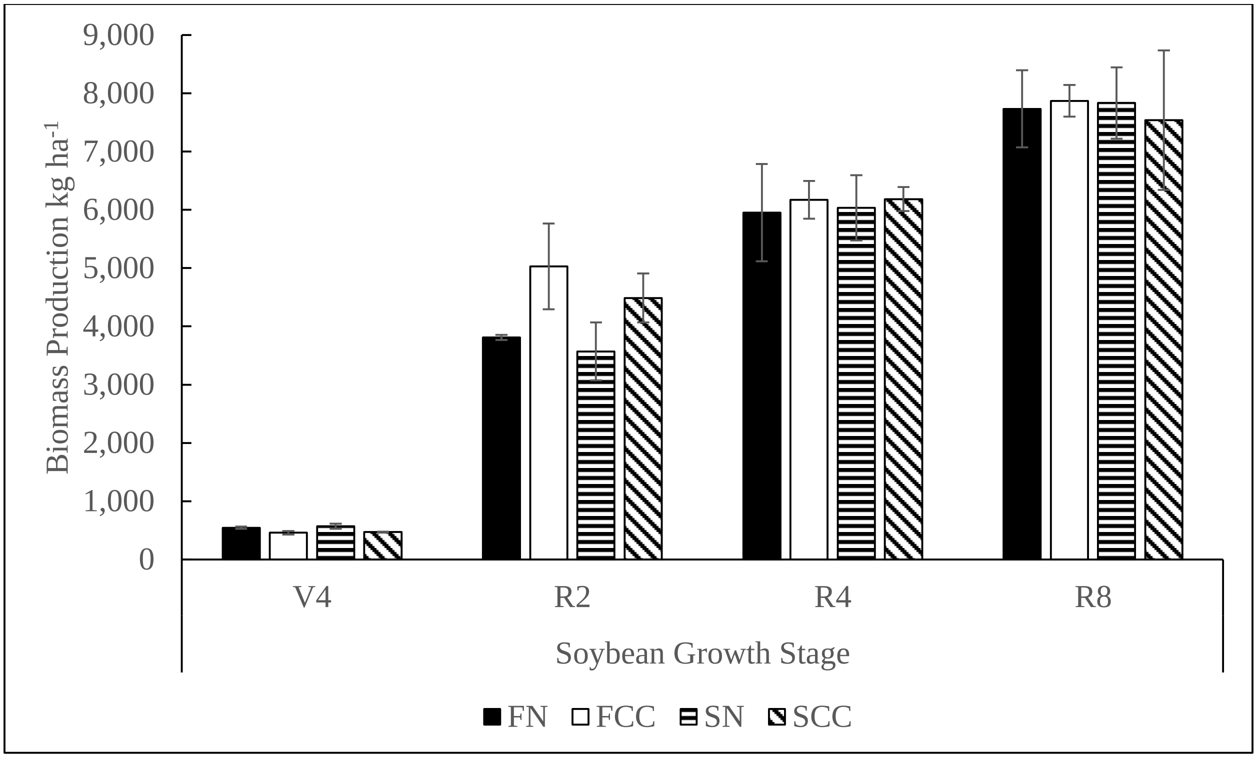

Figure A-7. Soybean biomass production (kg ha^{-1}) by crop growth stage collected during the 2016 soybean season. Error bars represent the standard error.

Table A-23

Soybean Growth Stage R8 Plant Matter Biomass ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	0.03	0.9976
Block	2	4.68	0.0452
Error	8		

Note: ANOVA table depicts the response variable (soybean growth stage R8 plant matter biomass) and probability values for each source of variation.

Table A-24

Soybean Growth Stage R8 Grain Biomass ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	0.18	0.9399
Block	2	3.71	0.0725
Error	8		

Note: ANOVA table depicts the response variable (soybean growth stage R8 grain biomass) and probability values for each source of variation.

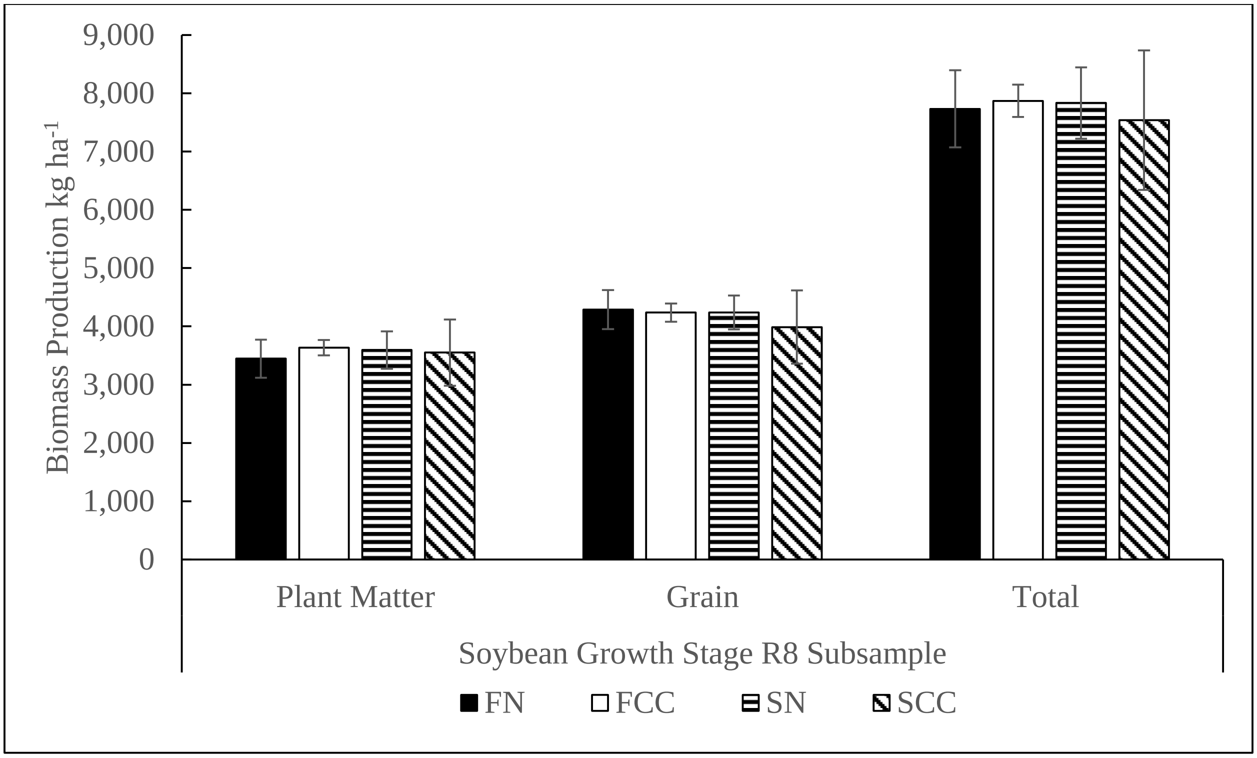

Figure A-8. Soybean biomass production (kg ha^{-1}) for the growth stage R8 subsamples collected during the 2016 soybean season. Error bars represent standard error.

Table A-25

Soybean Growth Stage V4 Nitrogen Uptake ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	0.76	0.5820
Block	2	0.37	0.7005
Error	8		

Note: ANOVA table depicts the response variable (soybean growth stage V4 nitrogen uptake) and probability values for each source of variation.

Table A-26

Soybean Growth Stage R2 Nitrogen Uptake ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	0.25	0.9036
Block	2	0.06	0.9416
Error	8		

Note: ANOVA table depicts the response variable (soybean growth stage R2 nitrogen uptake) and probability values for each source of variation.

Table A-27

Soybean Growth Stage R4 Nitrogen Uptake ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	0.92	0.4832
Block	2	1.26	0.3351
Error	8		

Note: ANOVA table depicts the response variable (soybean growth stage R4 nitrogen uptake) and probability values for each source of variation.

Table A-28

Soybean Growth Stage R8 Nitrogen Uptake ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	0.10	0.9804
Block	2	1.95	0.2047
Error	8		

Note: ANOVA table depicts the response variable (soybean growth stage R8 nitrogen uptake) and probability values for each source of variation.

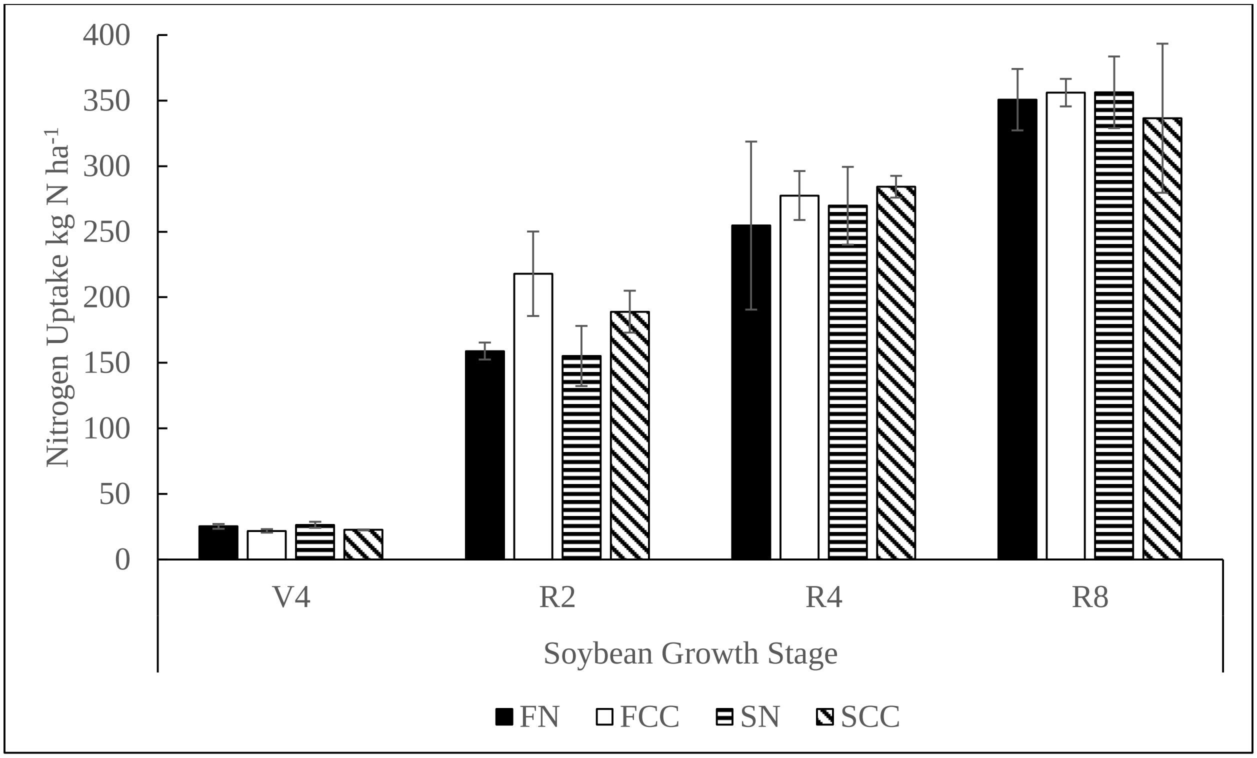

Figure A-9. Soybean nitrogen uptake (kg N ha^{-1}) by crop growth stage collected during the 2016 soybean season. Error bars represent the standard error.

Table A-29

Soybean Growth Stage R8 Plant Matter Nitrogen Uptake ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	0.15	0.9587
Block	2	2.43	0.1501
Error	8		

Note: ANOVA table depicts the response variable (soybean growth stage R8 plant matter nitrogen uptake) and probability values for each source of variation.

Table A-30

Soybean Growth Stage R8 Grain Nitrogen Uptake ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	0.11	0.9756
Block	2	1.78	0.2287
Error	8		

Note: ANOVA table depicts the response variable (soybean growth stage R8 grain nitrogen uptake) and probability values for each source of variation.

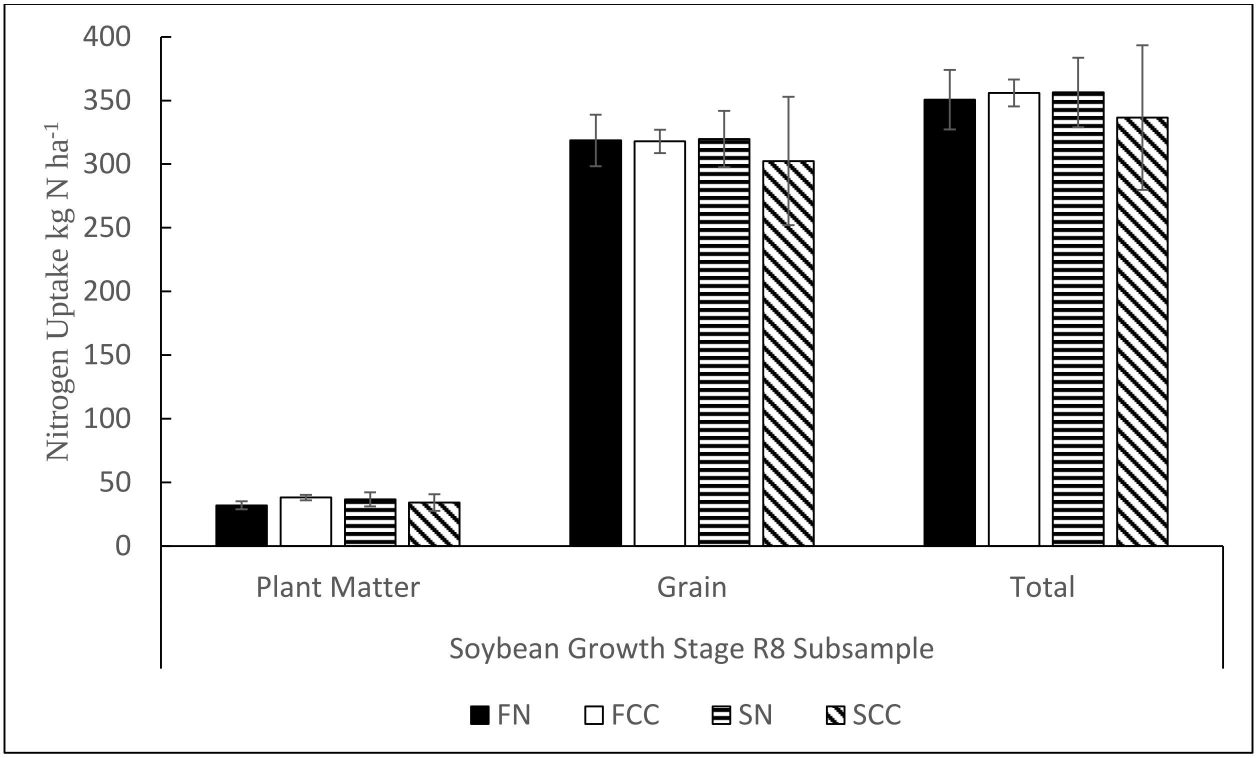

Figure A-10. Soybean nitrogen uptake (kg N ha^{-1}) for the growth stage R8 subsamples collected during the 2016 soybean season. Error bars represent standard error.

Table A-31

Corn Grain Yield ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	339.97	<0.0001
Block	2	1.80	0.2263
Error	8		

Note: ANOVA table depicts the response variable (corn grain yield) and probability values for each source of variation.

Table A-32

Soybean Grain Yield ANOVA Table

Source of Variation	DF	F Value	Pr > F
Treatment	4	1.42	0.3125
Block	2	4.63	0.0463
Error	8		

Note: ANOVA table depicts the response variable (soybean grain yield) and probability values for each source of variation.

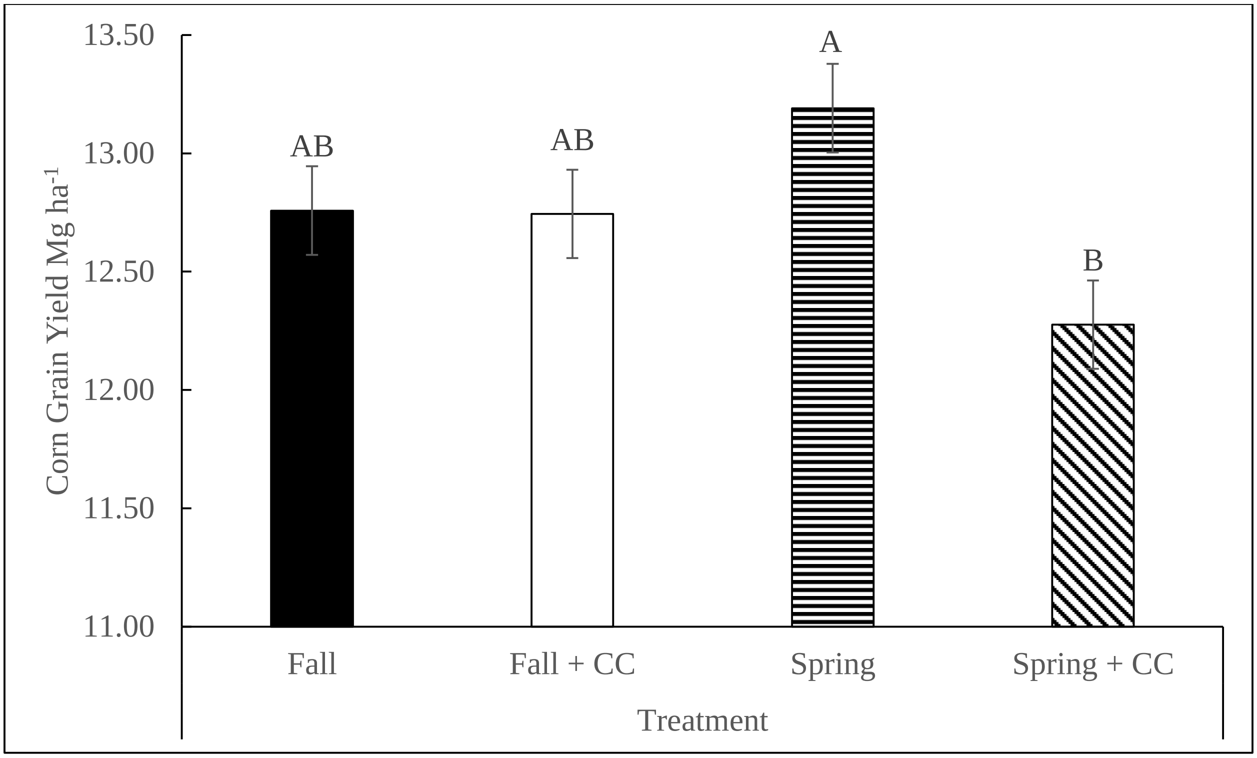

Figure A-11. Corn Grain Yield (Mg ha^{-1}) for each treatment collected during the 2015 corn season. Different letters indicate significant differences between treatments within a growth stage at an alpha level of 0.05 according to Ryan's multiple comparisons test. Error bars represent standard error.

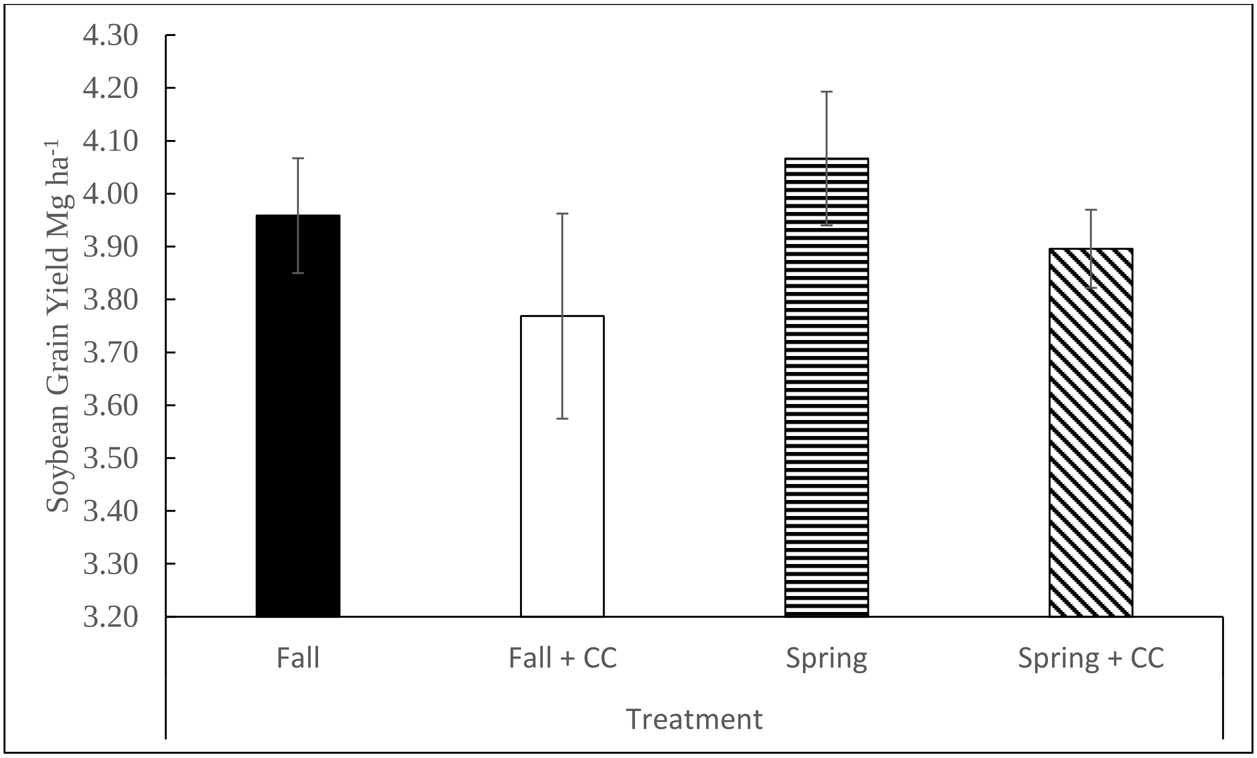

Figure A-12. Soyean Grain Yield (Mg ha^{-1}) for each treatment collected during the 2016 Soybean season. Error bars represent standard error.

APPENDIX B: TABLES AND FIGURES FOR CHAPTER IV

Table B-1

Cover Crop Establishment Costs

	2014 Cover Crop Season	2015 Cover Crop Season
Seed Cost ($ kg^{-1})	1.04	1.04
Seeding Rate (kg ha^{-1})	84	84
Seed Application Cost ($ ha^{-1})	29.65	29.61
Total Establishment Cost ($ ha^{-1})	117.01	116.97

Note: This table represents the breakdown of cover crop establishment costs for the cover crops planted in both 2014 and 2015.

Table B-2

Cover Crop Termination Costs

	2014 Cover Crop Season	2015 Cover Crop Season
Chemical Cost ($ L^{-1})	6.86	6.12
Chemical Application Rate (L ha^{-1})	2.34	2.34
Chemical Application Cost ($ ha^{-1})	12.36	12.35
Total Termination Costs ($ ha^{-1})	28.39	26.67

Note: This table represents the breakdown of cover crop termination costs for the cover crops planted in both 2014 and 2015.

Table B-3

Cover Crop Impact on Cash Crop Grain Yield

Treatment	2015 Corn (Mg ha^{-1})	Difference (Mg ha^{-1})	2016 Soybean (Mg ha^{-1})	Difference (Mg ha^{-1})
FN	12.76	-0.02	3.96	-0.19
FCC	12.74		3.77	
SN	13.19	-0.91	4.07	-0.17
SCC	12.28		3.90	

Note: This table represents the difference in grain yield between the non-cover crop treatments and the cover crop treatments for both the 2015 corn and 2016 soybeans.

Table B-4

Cost of Cash Crop Grain Yield Change Following Cover Crops

	2014 Cover Crop Season		2015 Cover Crop Season	
	FCC	SCC	FCC	SCC
Yield Impact (Mg ha^{-1})	-0.02	-0.91	-0.19	-0.17
Yield Value (\$ Mg^{-1})	156.89	156.89	344.31	344.31
Total Yield Impact Cost (\$ ha^{-1})	3.14	142.77	65.42	58.53

Note: This table represents the value of observed yield changes between the non-cover crop and cover crop treatments. If the yield change is negative the value is added to the total cover crop costs. If the yield change is positive, the value is subtracted from the total cover crop costs.

Table B-5

Total Cover Crop Costs

	2014 Cover Crop Season		2015 Cover Crop Season	
	FCC	SCC	FCC	SCC
Total Establishment Cost ($ ha^{-1})	117.01	117.01	116.97	116.97
Total Termination Cost ($ ha^{-1})	28.39	28.39	26.67	26.67
Total Yield Impact Cost ($ ha^{-1})	3.14	142.77	65.42	58.53
Total Cover Crop Cost ($ ha^{-1})	148.54	288.17	209.06	202.17

Note: This table represents the total cover crop costs for both the fall and spring dominated nitrogen management systems for both years of the study. The composition of total cover crop costs is also represented.

Table B-6

Valuation of Nitrogen from each Nitrogen Source

Fertilizer Source	$ Tonne^{-1} Fertilizer	kg N Tonne^{-1} Fertilizer	$ kg^{-1} N
Fall Diammonium Phosphate	639.12	180	3.55
Fall Anhydrous Ammonia	960.77	820	1.17
Spring Anhydrous Ammonia	845.82	820	1.03

Note: This table represents the value per kilogram of nitrogen from each of the three separate sources used in this study.

Table B-7

Fall Dominated Nitrogen Management System Fertilizer Application Rates and Total Cost

	$ kg^{-1} N	kg N ha^{-1}	$ ha^{-1}
Fall Diammonium Phosphate	3.55	40	142.00
Fall Anhydrous Ammonia	1.17	112	131.04
Spring Anhydrous Ammonia	1.03	72	74.16
Total		224	347.20

Note: This table represents the applications rates and total value of nitrogen applied from each of the three nitrogen sources within the fall dominated nitrogen management system. Also represented is the total value of applied nitrogen for the fall dominated nitrogen management system.

Table B-8

Value per Kilogram of Nitrogen Applied to Fall Dominated Nitrogen Management System

Value of Applied Fertilizer ($ ha^{-1})	347.20
Spring Anhydrous Ammonia Application ($ ha^{-1})	30.15
Fall Anhydrous Ammonia Application ($ ha^{-1})	30.15
Total Nitrogen Applied (kg N ha^{-1})	224
Value of Nitrogen Applied ($ kg^{-1} N)	1.82

Note: This table represents the average value per kilogram of nitrogen applied within the fall dominated nitrogen management system.

Table B-9

Spring Dominated Nitrogen Management System Fertilizer Application Rates and Total Cost

	$ kg^{-1} N	kg N ha^{-1}	$ ha^{-1}
Fall Diammonium Phosphate	3.55	40	142.00
Fall Anhydrous Ammonia	1.17	0	0.00
Spring Anhydrous Ammonia	1.03	184	189.52
Total		224	331.32

Note: This table represents the applications rates and total value of nitrogen applied from each of the three nitrogen sources within the spring dominated nitrogen management system. Also represented is the total value of applied nitrogen for the fall dominated nitrogen management system.

Table B-10

Value per Kilogram of Nitrogen Applied to Spring Dominated Nitrogen Management System

Value of Applied Fertilizer ($ ha^{-1})	331.32
Spring Anhydrous Ammonia Application ($ ha^{-1})	30.15
Fall Anhydrous Ammonia Application ($ ha^{-1})	30.15
Total Nitrogen Applied (kg N ha^{-1})	224
Value of Nitrogen Applied ($ kg^{-1} N)	1.75

Note: This table represents the average value per kilogram of nitrogen applied within the spring dominated nitrogen management system.

Table B-11

Subsurface Drainage System Nitrogen Loading Reduction

	2014 Cover Crop – 2015 Corn Season		2015 cover crop – 2016 Soybean Season	
Treatment	Total N Load (kg N ha^{-1})	Difference (kg N ha^{-1})	Total N Load (kg N ha^{-1})	Difference (kg N ha^{-1})
FN	54.09	14.80	47.67	26.91
FCC	39.29		20.76	
SN	44.58	5.96	72.26	46.25
SCC	38.62		26.01	

Note: This table represents the change in subsurface drainage nitrogen loading between the non-cover crop and cover crop treatments for both years of the study.

Table B-12

Subsurface Drainage System Nitrogen Loading Reduction Valuation

	2014 Cover Crop – 2015 Corn Season			2015 Cover Crop – 2016 Soybean Season		
Treatment	N Load Reduction (kg N ha^{-1})	\$ kg^{-1} N	Total N Load Reduction (\$ ha^{-1})	N Load Reduction (kg N ha^{-1})	\$ kg^{-1} N	Total N Load Reduction (\$ ha^{-1})
FCC	14.80	1.82	26.94	26.91	1.82	48.98
SCC	5.96	1.75	10.43	46.25	1.75	80.94

Note: This table represents the value of subsurface drainage nitrogen loading reductions between the non-cover crop and cover crop treatments for both years of the study

Table B-13

Gross Cover Crop Nitrogen Mineralization

Treatment	Daikon Radish N Content (kg N ha^{-1})	Mineralization Factor	Cereal Rye N Content (kg N ha^{-1})	Mineralization Factor	Gross N Mineralization (kg N ha^{-1})
			2014 Cover Crop – 2015 Corn Season		
FCC	5.72	1.00	61.47	0.95	61.42
SCC	5.37	1.00	45.58	0.95	48.67
			2015 Cover Crop – 2016 Soybean Season		
FCC	32.17	1.00	29.05	0.95	59.77
SCC	36.40	1.00	33.72	0.95	68.43

Note: This table represents the nitrogen content of daikon radish and cereal rye within each nitrogen management system across both years of the study. Mineralization factors used to calculate gross mineralization were obtained through three site years of a cover crop litter bag study.

Table B-14

Net Cover Crop Nitrogen Mineralization and Valuation

Treatment	Gross N Mineralization (kg N ha^{-1})	Subsurface N Load Reduction (kg N ha^{-1})	Net Mineralization (kg N ha^{-1})	\$ kg^{-1} N	Total Net N Mineralization Benefit (\$ ha^{-1})
			2014 Cover Crop – 2015 Corn Season		
FCC	61.42	14.80	49.32	1.82	89.76
SCC	48.67	5.96	42.71	1.75	74.74
			2015 Cover Crop – 2016 Soybean Season		
FCC	59.77	26.91	32.86	1.82	59.80
SCC	68.43	46.25	22.18	1.75	38.82

Note: This table represents the total benefit of net nitrogen mineralization within both experimental treatments across both years of the study. Net nitrogen mineralization is calculated by subtracting subsurface nitrogen load reductions from gross nitrogen mineralization.

Table B-15

Erosion Reduction Estimation from RUSLE2 Program

Treatment	2 Year Erosion Estimation (Tonnes ha^{-1})	2 Year Erosion Reduction (Tonnes ha^{-1})	Annual Erosion Reduction (Tonnes ha^{-1} yr^{-1})
FN	2.92	2.42	1.21
FCC	0.50		
SN	2.92	2.42	1.21
SCC	0.50		

Note: This table represents the annual estimated erosion reduction between the non-cover crop and cover crop treatments as calculated by the RUSLE2 program.

Table B-16

Erosion Reduction Estimation Valuation

Treatment	Annual Erosion Reduction (Tonnes ha^{-1} yr^{-1})	Value of Soil ($ $Tonne^{-1}$)	Total Reduction Value ($ ha^{-1} yr^{-1})
FCC	1.21	9.20	11.13
SCC	1.21	9.20	11.13

Note: This table represents that total benefit of the annual estimated erosion reduction. The value per tonne of soil was obtained from the United States Department of Agriculture Economic Research Service.

Table B-17

Total Cover Crop Benefit Value

Treatment	Subsurface N Load Reduction ($ ha^{-1})	Net N Mineralization ($ ha^{-1})	Erosion Reduction ($ ha^{-1})	Total Cover Crop Benefits ($ ha^{-1})
2014 Cover Crop – 2015 Corn Season				
FCC	26.94	89.76	11.13	127.83
SCC	10.43	74.74	11.13	96.30
2015 Cover Crop – 2016 Soybean Season				
FCC	48.98	59.80	11.13	119.91
SCC	80.94	38.82	11.13	130.89

Note: This table represents the total benefits of cover crops obtained by adding the total benefits of subsurface drainage nitrogen loading reduction, net nitrogen mineralization, and erosion reduction.

Table B-18

Cover Crop Cost Recovery 2014 Cover Crop – 2015 Corn Season With Actual Yield

2014 Cover Crop – 2015 Corn Season				
Variable	FCC		SCC	
Total Establishment Cost ($ ha^{-1})	117.01		117.01	
Total Termination Cost ($ ha^{-1})	28.39		28.39	
Total Yield Impact Cost ($ ha^{-1})	3.14		142.77	
Total Cover Crop Cost ($ ha^{-1})		148.54		288.17
Subsurface N Load Reduction ($ ha^{-1})	26.94		10.43	
Net N Mineralization ($ ha^{-1})	89.76		74.74	
Erosion Reduction ($ ha^{-1})	11.13		11.13	
Total Cover Crop Benefits ($ ha^{-1})		127.83		96.30
Net Cover Crop Benefit ($ ha^{-1})	-20.71		-191.87	
Percent Cover Crop Cost Recovery	86.1		33.4	

Note: This table represents the net benefit of cover crop inclusion and percent cover crop cost recovery for both experimental treatments within the 2014 cover crop – 2015 corn season. Net benefits are calculated by subtracting total cover crop costs from total cover crop benefits. Percent cover crop cost recovery is calculated by dividing total cover crop benefits by total cover crop costs.

Table B-19

2014 Cover Crop – 2015 Corn Season Total Cover Crop Cost Recovery Composition

2014 Cover Crop – 2015 Corn Season		
Variable	FCC	SCC
Total Percent Cover Crop Cost Recovery	86.1	33.4
Percent Coverage From Subsurface N Load Reduction	21.1	10.8
Percent Coverage From Net N Mineralization	70.2	77.6
Percent Coverage From Erosion Reduction	8.7	11.6

Note: This table represents the composition of recovered costs as percentages of the total recovered costs for both experimental treatments within the 2014 cover crop – 2015 corn season.

Table B-20

Cover Crop Cost Recovery 2014 Cover Crop – 2015 Corn Season With Constant Yield

2014 Cover Crop – 2015 Corn Season				
Variable	FCC		SCC	
Total Establishment Cost ($ ha^{-1})	117.01		117.01	
Total Termination Cost ($ ha^{-1})	28.39		28.39	
Total Yield Impact Cost ($ ha^{-1})	0.00		0.00	
Total Cover Crop Cost ($ ha^{-1})		145.40		145.40
Subsurface N Load Reduction ($ ha^{-1})	26.94		10.43	
Net N Mineralization ($ ha^{-1})	89.76		74.74	
Erosion Reduction ($ ha^{-1})	11.13		11.13	
Total Cover Crop Benefits ($ ha^{-1})		127.83		96.30
Net Cover Crop Benefit ($ ha^{-1})	-17.57		-49.10	
Percent Cover Crop Cost Recovery	87.9		66.2	

Note: This table represents the net benefit of cover crop inclusion and percent cover crop cost recovery assuming constant grain yields for both experimental treatments within the 2014 cover crop – 2015 corn season. Net benefits are calculated by subtracting total cover crop costs from total cover crop benefits. Percent cover crop cost recovery is calculated by dividing total cover crop benefits by total cover crop costs.

Table B-21

Cover Crop Cost Recovery 2015 Cover Crop – 2016 Soybean Season With Actual Yield

2015 Cover Crop – 2016 Soybean Season				
Variable	FCC		SCC	
Total Establishment Cost ($ ha^{-1})	116.97		116.97	
Total Termination Cost ($ ha^{-1})	26.67		26.67	
Total Yield Impact Cost ($ ha^{-1})	65.42		58.53	
Total Cover Crop Cost ($ ha^{-1})		209.06		202.17
Subsurface N Load Reduction ($ ha^{-1})	48.98		80.94	
Net N Mineralization ($ ha^{-1})	59.80		38.82	
Erosion Reduction ($ ha^{-1})	11.13		11.13	
Total Cover Crop Benefits ($ ha^{-1})		119.91		130.89
Net Cover Crop Benefit ($ ha^{-1})	-89.15		-71.28	
Percent Cover Crop Cost Recovery	57.4		64.7	

Note: This table represents the net benefit of cover crop inclusion and percent cover crop cost recovery for both experimental treatments within the 2015 cover crop – 2016 soybean season. Net benefits are calculated by subtracting total cover crop costs from total cover crop benefits. Percent cover crop cost recovery is calculated by dividing total cover crop benefits by total cover crop costs.

Table B-22

2015 Cover Crop – 2016 Soybean Season Total Cover Crop Cost Recovery Composition

2015 Cover Crop – 2015 Soybean Season		
Variable	FCC	SCC
Total Percent Cover Crop Cost Recovery	57.4	64.7
Percent Coverage From Subsurface N Load Reduction	40.8	61.8
Percent Coverage From Net N Mineralization	49.9	29.7
Percent Coverage From Erosion Reduction	9.3	8.5

Note: This table represents the composition of recovered costs as percentages of the total recovered costs for both experimental treatments within the 201 cover crop – 2016 soybean season.

Table B-23

Cover Crop Cost Recovery 2014 Cover Crop – 2015 Corn Season With Constant Yield

2015 Cover Crop – 2016 Soybean Season				
Variable	FCC		SCC	
Total Establishment Cost ($ ha^{-1})	116.97		116.97	
Total Termination Cost ($ ha^{-1})	26.67		26.67	
Total Yield Impact Cost ($ ha^{-1})	0.00		0.00	
Total Cover Crop Cost ($ ha^{-1})		143.64		143.64
Subsurface N Load Reduction ($ ha^{-1})	48.98		80.94	
Net N Mineralization ($ ha^{-1})	59.80		38.82	
Erosion Reduction ($ ha^{-1})	11.13		11.13	
Total Cover Crop Benefits ($ ha^{-1})		119.91		130.89
Net Cover Crop Benefit ($ ha^{-1})	-23.73		-12.75	
Percent Cover Crop Cost Recovery	83.5		91.1	

Note: This table represents the net benefit of cover crop inclusion and percent cover crop cost recovery assuming constant grain yields for both experimental treatments within the 2015 cover crop – 2016 soybean season. Net benefits are calculated by subtracting total cover crop costs from total cover crop benefits. Percent cover crop cost recovery is calculated by dividing total cover crop benefits by total cover crop costs.