2016

Evaluation of Tillage, Crop Rotation, and Cover Crop Impacts on Corn Nitrogen Requirements in Southeastern South Dakota

Sara Louise Berg
sara.berg@sdstate.edu

EVALUATION OF TILLAGE, CROP ROTATION, AND COVER CROP IMPACTS ON CORN NITROGEN REQUIREMENTS IN SOUTHEASTERN SOUTH DAKOTA

BY

SARA LOUISE BERG

A thesis submitted in partial fulfillment of the requirements for the

Master of Science

Major in Plant Science

South Dakota State University

2016

EVALUATION OF TILLAGE, CROP ROTATION, AND COVER CROP IMPACTS ON CORN NITROGEN REQUIREMENTS IN SOUTHEASTERN SOUTH DAKOTA

This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science in Plant Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Peter Sexton, Ph.D.
Thesis Advisor Date

David Wright, Ph.D.
Head, Department of Plant Science Date

Dean, Graduate School Date

This thesis is dedicated to the memory of my father, Charles E. Berg (Oct. 7, 1945- Sept. 12, 2007). He was a father, farmer, mechanic, welder, electrician, plumber, and inventor. From a very young age, he encouraged me to continue learning and to seek higher education. He instilled in me my love for agriculture and animals. With a great deal of patience and wisdom he taught me the value of hard work and how to enjoy the simple things in life.

ACKNOWLEDGEMENTS

Thank you to the South Dakota State University Southeast Research Farm and the South Dakota Agriculture Experiment Station for providing the necessary funding for this study to take place.

My family has always been supportive of my educational goals and understanding of the time commitments required. I am very thankful to each of you for the love and support you have provided during this long journey. A special thanks to my mom (Loretta), sister (Virginia), grandfather (Gerald), and aunt (Charlene). Thank you as well to Sean Bauder and his family for their love and encouragement throughout my graduate work; I am so blessed to have such wonderful, supportive people surrounding me!

Important data analysis was donated by very generous contributors, thank you to Dr. Ray Ward and Lance Gunderson at Ward labs for their contribution of Haney soil test analyses and to Dr. Shannon Osborne and Kurt Dagel for kindly donating plant tissue analyses.

I owe a very special thank you to Dr. Ron Gelderman, who recruited me to work for the SDSU Soil Fertility Project after college, and encouraged me to continue my education in plant science by seeking a master's degree. His guidance and genuine interest in the betterment of South Dakota agriculture is truly inspiring. Thank you for you encouragement and support!

I greatly appreciate the support and guidance of my advisor, Dr. Peter Sexton, who has led me through this project regardless of how difficult the circumstances, and never gave up. His faith in God, positive attitude, and eagerness to discover new ideas and techniques is contagious. Thank you for all of your time, support, and advice!

Thank you to Anthony Bly, who has guided me through my career with SDSU and has always been willing to help when needed or provide much welcomed advice. You are a fantastic colleague and I am so grateful for your mentorship!

Friendship is a highly valuable commodity; thank you to Claire Derdall for many late nights, bug bites, sun burns, and field work battle scars. But most importantly, thank you for a truly amazing friendship! Your hard work and willingness to have fun while on the job made the late nights all the more worthwhile!

My committee has been very helpful throughout the process of completing my graduate work and I am very thankful for the involvement of Dr. Christopher Graham, Dr. Shannon Osborne, and Dr. Charles Vollan in this process.

I am very appreciative of Dr. Christopher Saunders and Cami Fuglsby for sharing their expertise in statistical analysis and spending many hours helping with code writing and revising my work, thank you!

As the saying goes, “many hands make light work”. A special thank you goes to the following individuals whom, without their hard work, support, and involvement, this project would not have been possible: Brad Rops, Ruth Stevens, Doug Johnson, Garold Williamson, Kevin Henseler, Christine Morris, Darlene Buschenfeld, Jesse Hall, Cory Smith, Nick Hall, Jesse Cameron, Sheila Price, Dr. David Karki, Dr. Howard Woodard, and Jared Thompson.

Most importantly, I thank the Lord for His saving grace and guidance, and for providing me the skills and courage to make a positive difference in this world.

TABLE OF CONTENTS

ABBREVIATIONS

C	carbon
CT	conventional tillage
H^3A	Haney soil test extract
N	nitrogen
NT	no-till

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

EVALUATION OF TILLAGE, CROP ROTATION, AND COVER CROP IMPACTS ON CORN NITROGEN REQUIREMENTS IN SOUTHEASTERN SOUTH DAKOTA

SARA LOUISE BERG

2016

Nitrogen (N) is a vital factor of corn (*Zea mays*) production. Previous work in South Dakota has shown that there is uncertainty as to whether nitrogen requirements are the same for corn raised under no-till (NT) versus conventional till (CT) production systems. The objective of this study was to evaluate whether N requirements continue to be greater under long-term NT versus CT production systems in southeastern South Dakota, while also considering effects from cover crops and crop rotation. This was a two year study conducted at the SDSU Southeast Research Farm near Beresford, SD; it was superimposed on a long-term rotation and tillage study established in 1991. Treatments included applied N rates of 0, 40, 80, 120, 160, and 200 lbs N acre^{-1}. Rotations were: corn/soybean (*Glycine max*) and corn/soybean/small grain; the three-year rotation was split additionally by ‘cover crop’ and ‘no cover crop’ treatments. Parameters measured included: soil plant analysis development (SPAD) chlorophyll readings, normalized difference vegetation index (NDVI) readings, ear leaf N content, total plant N uptake, yield, test weight, moisture, and grain protein. In 2014 small plot results were quite variable due to 13.5” of rainfall in June; the 2015 growing season was mild, producing more representative yields. Both N rate and tillage showed significant impacts on yield in the 2014 and 2015 three-year rotation. In

2014, spring soil nitrate levels tended to be 50 lbs ac^{-1} less in the ‘cover crop’ verses ‘no cover crop’ treatments, but there were no significant yield differences between cover crop treatments. Nitrogen that was not available in the spring likely became available later when cover crop residue decomposed. No-till corn was generally more sensitive to N application in the 2015 two-year rotation than CT corn, however, optimum N rates were the same across tillage regimes. In this study, long-term NT soils did not consistently require more N than CT soils. More research needs to be conducted to further define N recommendations and the impact of cover crops and crop rotation on soil N credits.

INTRODUCTION AND LITERATURE REVIEW

Agriculture receives great public attention for many reasons including environmental concerns surrounding farm management practices. For example, the city of Des Moines, Iowa sued three Iowa counties (Buena Vista, Calhoun, and Sac) over water quality issues. The city claims the counties involved created drainage districts that allow nitrates to run from farm fields into rivers which serve as a major drinking water source for Des Moines (Eller, 2015). Situations like this are becoming more prevalent across the nation, raising many questions regarding the sustainability of our food production system. Soil resources are the basis of our food production system, key to food security, and very often overlooked. Improving our understanding of soils can improve crop growth, reduce environmental damages, and help others become more aware of the opportunities and resources soil can provide.

Many soil science studies in the past two decades have focused on tillage practices and their interaction with nitrogen (N) management (Halvorson et al. 2001; Salinas-Garcia et al. 1997; Viswakumar et al. 2008; Gordon et al., 1993). However, few studies have focused on long-term (more than 6 years) no-till (NT) practices and their relationship to N recommendations. To our knowledge, there is no information in the literature specific to South Dakota which evaluates corn (*Zea mays*) N requirements under long-term NT management.

According to the current South Dakota "Fertilizer Recommendations Guide" (2005), an additional 30 lbs ac^{-1} of N should be added to the recommended soil N fertilizer rate when NT or strip-till practices are used on corn. The guide states that reduced tillage practices cause slower breakdown and release of organic N, which requires higher N fertilizer application to compensate for this.

The objective of this study was to evaluate whether N requirements continue to be greater under long-term NT versus conventional till (CT) production systems, while also considering effects from cover crops and crop rotation in southeastern South Dakota.

This review will examine the N cycle, environmental effects it is involved with, the effects of tillage practices on soil structure and corn cropping systems, crop rotations, and the effects of tillage and crop rotation on soil organic carbon (C) and N. It will conclude by exploring the effects of cover crops on soil fertility, corn grain yield, and related parameters. Further research that should be explored relating to this topic will also be suggested.

N Cycle

The N cycle is a complex web of processes controlling how N is utilized, reused, and lost in our environment. It illustrates how N cycles interact in the soil, plants and atmosphere, and defines the transformations that occur during each phase. Each process is affected by plants, animals, atmosphere, and microorganisms in the system, which in turn affect rates of cycling or transformation (Havlin et al., 2004).

N is a primary factor limiting plant growth. Plants go about capturing N in many ways such as in association with mycorrhizal fungi, bacteria that fix N, direct absorption via roots, and leaf N absorption by foliar application (Bloom, 1997).

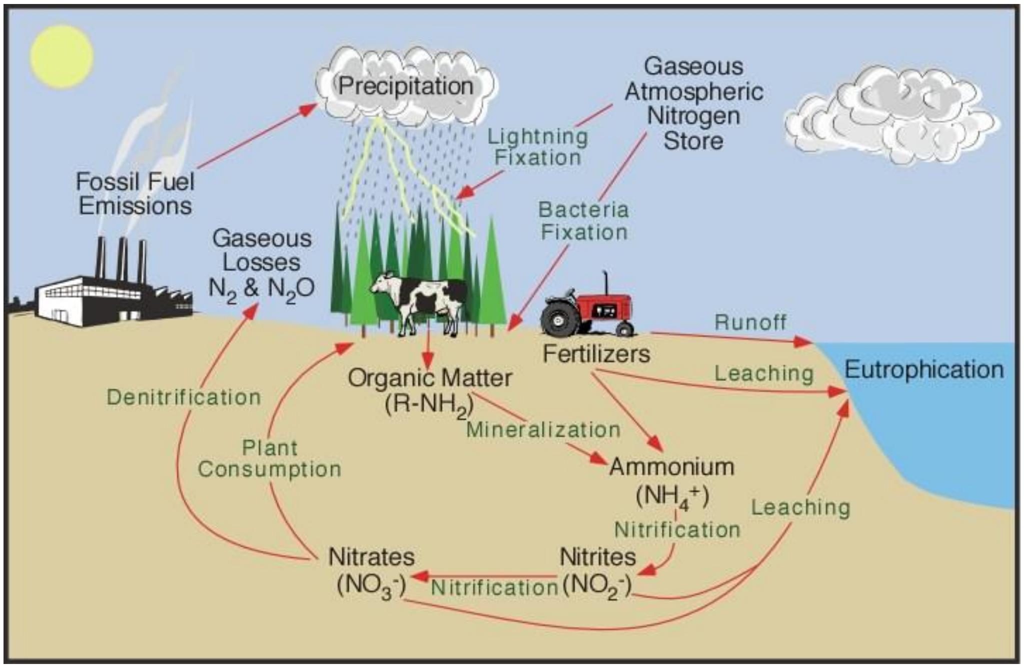

Figure 1. The N cycle taken from www.physicalgeography.net (Pidwirny, 2006).

The processes of the N cycle are organized as “N Gains”, “N Losses”, and “Cycling” (Fig. 1). Inputs may include: biological fixation, plant (and animal) residues or livestock manure, fertilizer application, and atmospheric deposition. Outputs may include: denitrification, volatilization, leaching, crop residue removal, and crop harvest. In addition to inputs and outputs, N cycling occurs; cycling examples are: nitrification, ammonification, or immobilization (Havlin et. al., 2004). These pools represent the movement of N between different forms in the soil.

As we advance in predicting N availability to crops, the basic principles of this cycle are addressed. Although we have not yet mastered these processes well enough to predict availability in a field setting due to the erratic environment around us, one can make insightful inferences regarding what will most likely happen to the N in the soil. Some N availability prediction factors include: weather events, application amount/timing, form of fertilizer applied, needs of the planted crop, previous crop information, and climate.

Mineralization

N mineralization is an integral component of understanding the previously described N cycle. Mineralization is commonly defined as the breakdown of organic matter to release ammonium. Stanford and Smith (1972) conducted early laboratory research on mineralization using soil samples from fields across many states. They found that an approximate estimate of N mineralization potential can be made from cumulative N mineralized, and this may reasonably be estimated after relatively few consecutive short-term study incubations. Their work also reinforces that the N mineralization potential of a soil is a definable quantity and can be expressed as such. Additionally, there are likenesses and differences among soils regarding sources of mineralizable N such as residue decomposition rates or C:N ratios, and microorganism activity (Stanford and Smith, 1972).

However, as technology and methodologies used to detect and better understand the processes of N advance, some early mineralization theories are being challenged. Schimel and Bennett (2004) specifically challenged the traditional idea that plants use only inorganic N, as well as the theory that plants are poor competitors for soil available N in comparison to microbes. Net mineralization is often discussed as an ‘index’ in many modern studies and the focus has been shifted to the idea that plants can compete with soil microbes and, at times, may outcompete them (Schimel and Bennett, 2004). The authors used a systems approach to view the process as a whole plant system and argued that although N mineralization is recognized as a key process in available N production, exoenzyme-depolymerization is the rate-limiting step in bioavailable N. However, the article impresses that this idea is just one of many innovations that need to be incorporated into a new ‘N cycling model’ (Schimel and Bennett, 2004).

As new innovations in soil fertility, and specifically, the N cycle come about, researchers work to compile ideas and question theories. The N cycle has been part of agriculture for thousands of years; however as humans, we work to understand its processes to this day.

Environmental Concerns

When considering all the factors involved in the cycle and mineralization potential of N, many possible issues arise concerning agriculture’s role in environmental protection regarding N fertilizers. Nitrogen is in the atmosphere, soil, and water; it is essential to all life. As the population of the world grows at increasing rates, more anthropogenic N inputs will occur within the N cycle (Follett and Hatfield, 2001). In fact, according to US Geological Survey (2015), in 2014, approximately 88% of apparent US domestic ammonia consumption was for fertilizer use. Farms across the country rely on N in multiple forms to grow quality food and fiber, but how often do we consider the negative effects that agriculture practices may have on our population and the ecosystem we live in? There are many N sources: point, non-point, agricultural, urban, organic, and inorganic. In addition to sources, the transformations and transport mechanisms previously mentioned should be considered within the N cycle: nitrification, denitrification, immobilization, mineralization, runoff, percolation, and groundwater transport (Follett and Hatfield, 2001).

By considering these mechanisms of transport, utilizing new technologies, maintaining efficient fertility management plans, and keeping our ecosystem in mind, the agriculture industry can help reduce N pollution issues. However, as we move forward with research and technology, we must be flexible enough to adjust our thinking and look at the issue from its source. New research is reflecting that various soil conservation and modern crop management practices are changing the N needs for many common row crops.

Tillage Systems

Tillage systems play an important role in many environmental aspects of agriculture. Conservation tillage, the practice of using minimal soil disturbance tillage tools or no tillage tools, protects resources by reducing soil erosion, thus guarding soil surfaces, increasing water infiltration, and reducing runoff (Janssen and Hill, 1994). Although befriending the environment is important, it is not a 'stand-alone' advantage of conservation tillage, there are many additional aspects to explore.

Soil conservation in the US Midwest is modernly viewed as a valuable concept that many farmers are putting into practice. Conservation tillage practices have increased in popularity as the US moves toward a more sustainable approach to agriculture. In South Dakota, NT adoption rates have increased since the early 2000s, however acceptance decreased from 2008-2010, as compared to 2004-2007 (Table 1) according to Clay et al. (2012). The study determined the decrease in NT adoption appears to be mainly due to wet growing seasons from 2008-2010 (as compared to 2004-2007) in which farmers had difficulty getting the spring seeding in.

Table 1. The influence region on the number of surveys collected, NT adoption, k_{soc} values (mineralization rate constant for Midwestern US surface soils), and bulk density in South Dakota (Clay et. al, 2012).

Region	Bulk density	2004–2007 Surveys	Planted corn	No-till adoption	k_{soc}	2008–2010 Surveys	Planted corn	No-tillage adoption	k_{soc}
	g cm^{-3}	no.	ha*1000	%	g soc/(g × yr)	no.	ha*1000	%	g soc/(g×year)
North-central	1.35	934	338	97	0.0117	796	346	69	0.0135
Central	1.31	2035	251	68	0.0135	941	229	57	0.0142
Northeast	1.29	3289	276	20	0.0165	2353	308	11	0.0171
East-central	1.24	6777	436	11	0.0171	12,479	447	5	0.0175
Southeast	1.25	3289	434	29	0.0160	1811	405	33	0.0157

Replacing moldboard plowing with conservation or NT practices is a “cultural” change that is driven by several factors including: markets, weather cycles, biological changes, agribusiness, and scientific advances (Coughenour and Chamala, 2000). In addition to these scientific factors, a willingness to change traditional farming practices plays a significant role in management decisions for many farmers. A change in several years of production management practices is not easily adopted on many farms, and advantages of such a change must often be personally proven before any action is taken.

NT proponents boast many advantages of the practice, one of which is a physical change in soil properties. Eliminating tillage can affect many soil physical properties, such as bulk density, soil strength, aggregation, porosity, and macro-pore development leading to improved water infiltration.

Research by Iqbal et al. (2013) found that tillage and N fertilization significantly affected bulk density, soil strength, and water infiltration under deep tillage practices resulting in a 4-9% decrease in bulk density compared to CT, minimum till, and NT. In addition, soil strength was found to be 2-3% higher in the control treatment (0 N) when compared to applied N treatments but no clear explanation of this effect was provided.

Overall, tillage and N fertilization had variable effects on bulk density, soil strength, total C and N accumulation, nitrate content, and corn yield. However, another study showed that bulk density was influenced by tillage up to 30 cm deep (with NT showing significantly higher bulk density values); nonetheless between 30 and 100 cm there were no significant tillage treatment differences among soil physical properties (Gál *et al.* 2007).

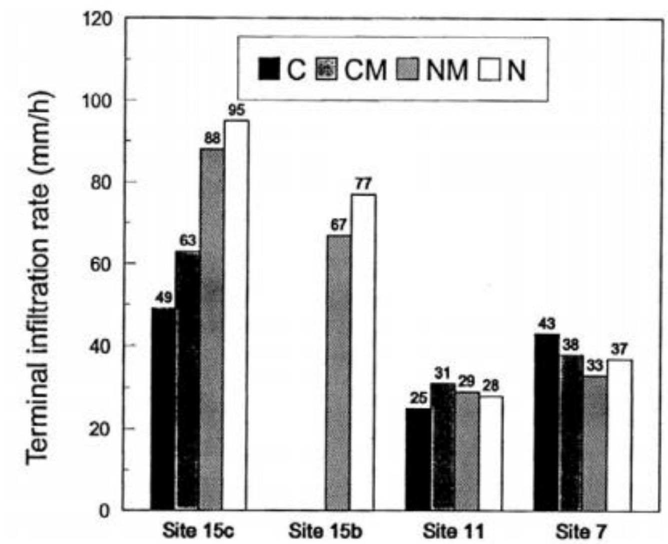

Figure 2. Average terminal infiltration rate under rainfall simulation of about 100 mm/hr at different sites (Savabi et al., 2008). C=conventional, CM=conventional plots with residue from the NT plots, NM= NT plots with residue removed, N=NT plots with residue. The mass of residue was 1.1, 0.4, 0.1, and 0.2, kg/m^{-2} respectively. The values represent the average of two plots.

Bulk density affects several soil properties, including infiltration. A study conducted in Indiana and Illinois on CT and NT farms sites with a corn/soybean (*Glycine max*) rotation used sprinkler rainfall simulation and ponded infiltrometer methods to study infiltration rate. Results showed the NT study areas with silt loam and silty clay loam soils had higher infiltration rates than those of CT farms (Fig. 2). This could be attributed to earthworm activity and high surface residue amounts compared to CT soils. However, on sandy loam soils, conventional sites had higher infiltration, and earthworm activity was found to be the same in both treatments. Therefore the study concluded that infiltration rates depend upon texture, and such infiltration is directly dependent upon earthworm activity as well as residue cover (Savabi et al., 2008).

Many studies have been conducted with mixed responses regarding the impact of tillage practices on the physical characteristics of soil. However, incorporating this factor into a more in-depth tillage study may result in further inferences.

In a 2015 publication, Pittelkow et al. suggests that "Conservation agriculture represents a set of three crop management principles: 1) direct planting of crops with minimum soil disturbance, 2) permanent soil cover by crop residue or cover crops, 3) crop rotations". The study indicates NT practices significantly boost yields (7.3%) in rain fed, dry-land environments with implementation of crop rotation and residue retention, but reduces yields (11.9%) when practiced alone. It attributes the yield benefits with all three principles combined to improved water infiltration and greater soil moisture conservation. The authors suggest NT has negative effects on yield (especially in its early [1-2] and late [10+] years of adoption), but when combined with the two listed additional management practices, these effects are minimized (Fig. 3). One suggested reason for the decrease in long-term NT yields is possible weed, pest, and disease pressure build up. In addition, Pittelkow et al. (2015) are of the opinion that yields decrease with NT in humid climates whether the other two mentioned crop management principles are applied or not.

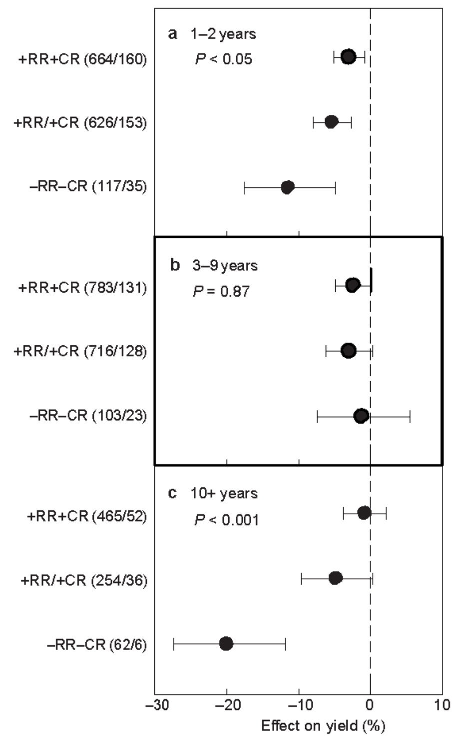

Figure 3. Comparison of yield in NT versus CT systems in relation to two other principles of conservation agriculture over time; the influence of (a) 1–2, (b) 3–9, and (c) 10+ years following no-till implementation (Pittelkow et al., 2015). RR=residue retention, CR=crop rotation.

When conservation tillage yield data is evaluated, one must remember that long-term NT soils may have very different soil characteristics than short-term NT soils. At Iowa State University, in Boone County, IA, a tillage effects study was conducted over 30 years, beginning in 1975 (Karlen et al., 2013). The study was broken into 3 phases: 1) establishment (1976-1980), 2) maintenance (1988-2002), and 3) recovery/intensification (2003-2006) (yield data from 1981-1987 was lost). In phase 2, moldboard plowing increased the average continuous corn grain yield by 0.8-1.7 Mg ha^{-1} when compared to other tillage systems. The moldboard plow system also had the highest average grain yield for rotated corn, but with small differences (0.35 Mg ha^{-1}) (Fig. 4). Rotation furthermore played an important role as it increased corn grain yields by 17% when compared to continuous corn systems. However, net returns to land, labor, and management for NT production were overall higher than tilled treatments as compared to intensive till treatments across several rotations even though yields may not directly reflect this (Karlen et al., 2013). In principle, this agrees with the Pittelkow et al. (2015) study that infers NT, when practiced alone, may decrease corn yields; however the Karlen et al. (2013) study takes modern farming's economic inputs into account and suggests yield as a sole indicator may not adequately correlate with economic advantages, ie: NT systems have lower input costs as a whole, meaning yield cannot be the only measured economic factor.

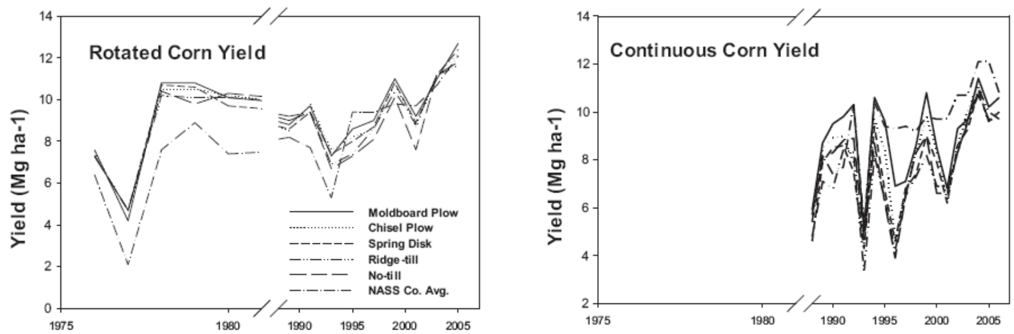

Figure 4. Crop yield response to long-term tillage treatments on glacial till soils in Central Iowa, U.S.A (Karlen et al., 2013).

In a study with tillage as the main plot and N rate as a subplot that took place in the semi-arid climate of Faisalabad, Pakistan, Iqbal et al. (2013) found that corn yields were higher with deep tillage and CT when compared to conservation tillage (minimum till and NT) systems. But the study suggested this may be attributed to the short-term reduction of compaction, higher porosity, and more uniform distribution of nutrients in the soil profile created by the tillage. In addition, in an Iowa study, Bakhsh and Kanwar (2007) found that chisel plow treatments with corn/soybean rotations yielded highest within tillage treatments (chisel plow and NT with: continuous corn, corn after soybean, and soybean after corn). Within these treatments, rotated corn had significantly higher grain yields overall than continuous corn treatments.

In Ohio, a study conducted using tillage as the main plot design (NT, early planted strip-till, normal planted strip-till, AerWay® tool tillage, zone deep-till, and disc-field cultivator) investigated N application timing and application methods on tillage treatments (Viswakumar et al., 2008). Nitrogen rates served as subplots to tillage treatments (UAN [28-0-0] applied near planting at 168 kg ha^{-1} N, N split applied between starter at a rate of 22.4 kg ha^{-1}, and side dressed at V4-V6 145.6 kg ha^{-1}). The researchers concluded that across N application methods, conventionally tilled soils resulted in higher corn grain yields than NT soils. This was partially attributed to moisture conditions and NT volatilization losses due to low precipitation after fertilizer application in one treatment year. Nitrogen mineralization differences may also cause such interaction, but are not described in detail. Under conservation tillage methods with low moisture after application, various N application procedures (listed above) showed greater impact on corn grain yields than did tillage methods. However, the following cropping year had sufficient rainfall after N application and no significant losses due to N application method were found. The authors suggested that a split N application is the best method under the tillage regimes used in this study when keeping N loss in mind.

Another important tillage factor that is often overlooked is the importance of its effects on the mycorrhizal system. A healthy mycorrhizal system has positive impacts on overall soil health and organic matter breakdown efficiency. According to Douds et al. (1995), reduced tillage increases the mycorrhizal colonization of plant roots. Mozafar et al. (2000) concluded that reduced tillage changed the colonization of roots in corn and wheat by mycorrhizal structures. Wortmann et al. (2008) concluded that mycorrhizae were very sensitive to tillage with little recovery back to their original long-term NT levels during the 2 seasons after one-time tillage took place. Although this one time tillage reduced the arbuscular biomarker by only 22% in the second year after tillage, this shows that NT soils are providing a healthy growing environment for mycorrhizal activity, and that tillage is destructive to that community.

Most of the discussed studies confer that CT systems may yield higher, or the same, as NT/conservation till systems. However, the long-term benefits and economic advantages of one system verses the other are disputed. Soil mycorrhizal activity and biology and their long-term effect on yield should also be taken into consideration when observing tillage systems and overall soil health. Further investigation of this topic leads us to evaluating the effects of conservation tillage practices when combined with other management strategies.

Crop Rotation

Improved soil structural stability, increased nutrient and crop water use efficiency, increased organic matter levels, and better weed control are all possible outcomes with certain crop rotation patterns (Riedell et al., 1998). In conjunction with environmental awareness, cover crop management, and overall sustainability, rotation can be a very fitting piece to NT systems and N use efficiency and management.

Long term experiments in the US Corn Belt have shown 10-17% greater yield in corn grown in rotation with another crop than when grown in a monoculture. In addition, one study noted that a beneficial effect of crop rotation on soil N and iron was observed early in the growing season (Reidell et al., 1998). Crop rotation plays a large role in nutrient efficiency and overall yield effect. Findings in Iowa show that crop rotation increased corn grain yield by 17% compared to a continuous corn monoculture in the previously mentioned Karlen et al. (2013) study.

Enhancing rotations by adding more complex crop sequences can also sequester an average of 14±11 gm^{-2} yr^{-1} C; however, this does not occur when moving from continuous corn to corn/soybean rotations. Following rotation enhancement, it may take as long as 40-60 years for soil organic C to reach a new equilibrium (West and Post, 2002).

Crop rotations are also an excellent method of reducing pesticide use by breaking pest cycles, specifically corn rootworm within corn crops. In fact, row crop rotation reduced insecticide use by over 40% on average, as compared to continuous corn systems in a 1993 USDA survey (Padgitt, 1993). In legume specific rotations, one advantage is the residual soil N potential, typically provided as an “N credit” for the following crop that is not present in continuous cropping systems.

In addition, Bakhsh and Kanwar (2007) report that in comparison, continuous corn treatments had about 200% higher NO_3-N leaching losses overall when compared with rotated corn and soybean treatments under CT or NT systems. This could be in part, due to the monoculture treatment receiving an N application each year at a high rate.

Tillage and Crop Rotation: *Soil Biological Indicators (C:N)*

West and Post (2002) studied the effects of tillage and crop rotation on soil organic C sequestration. A global database was used to conduct 67 long-term experiments. Conclusions showed that a change from CT to NT can increase C sequestration by 57±14 g C m^{-1} yr^{-1} with the exception of wheat crops. West and Post (2002) also reported that with a change from CT to NT, C sequestration rates should peak in 5-10 years with soil organic C reaching a new equilibrium in 10-15 years (Fig. 5). After such time, very little change is seen in C sequestration, which implies that previous to meeting an equilibrium, additional N fertilizer may need to be applied on NT soils relative to CT soils. After an equilibrium is met, additional N application should not be necessary for NT soils relative to CT soils.

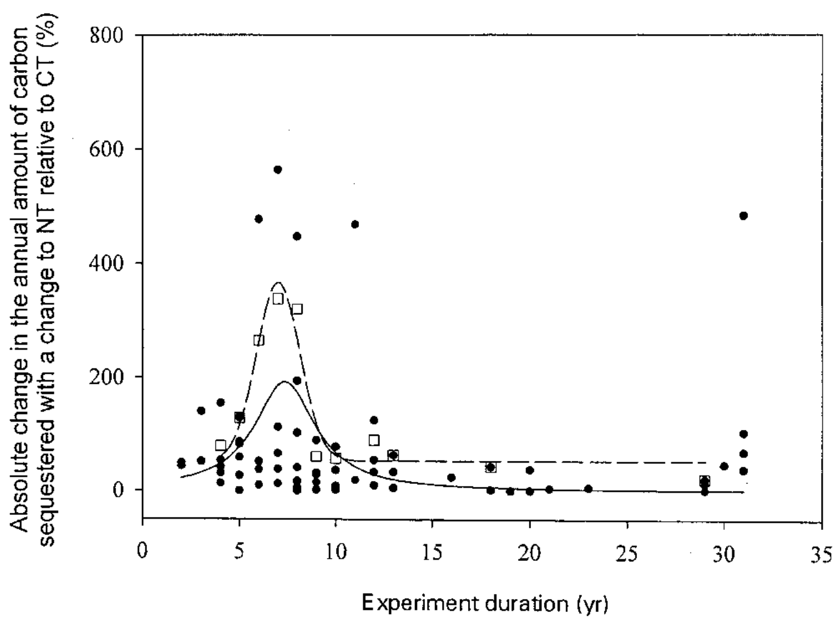

Figure 5. The percentage change in annual soil organic C (SOC) sequestration rates under NT, relative to CT (West and Post, 2002). Solid line represents data (solid circles) using a nonlinear regression equation. Dashed line represents the 75% quantile of mean values (open squares) using a nonlinear regression equation. A data point at year 8 and 1236% has been excluded from the graph, for easier visual interpretation, but was included in the analysis.

In a study that focused on C sequestration in South Dakota surface soils, researchers suggested gradual corn crop yields have increased and wide-scale adoption of reduced tillage and NT systems since homesteading times has caused C sequestration. They suggest that surface soils of the SD region have become a C sink (Clay et al., 2012). This could be of great advantage to agriculture producers and our ecosystem. Farming brings forth many soil health factors to consider; specifically, soil C and C:N ratios which serve as a crucial factor in corn production systems.

There are very few sources that specifically verify a change to a new soil equilibrium state after a change in tillage operation is made; therefore, further research needs to be conducted to determine when this happens, and how it changes the entire ecological management system.

Al-Kaisi et al. (2005) conducted a 7 year experiment to evaluate the effects of different tillage systems on soil organic C and soil organic N as well as residue C and N inputs, and corn and soybean yields. It appeared increases in soil organic C and soil organic N in the NT and strip till treatments, after three growing seasons, were due to a tillage treatment effect; therefore, the reduction in soil organic matter mineralization rates in conservation till treatments were most likely the cause (Al-Kaisi et al., 2005). This agrees with the work previously mentioned by Clay et al. (2012). Al-Kaisi et al. (2005) also found no significant difference in corn and soybean yields between NT and chisel plow treatments across a range of soil textures over the 7 years of the study, indicating that NT practices did not significantly have a negative or positive effect on corn and soybean yields. This does not agree with previously mentioned data from Pittelkow et al. (2005) who found yield reductions with NT relative to CT systems, however different management practices and growing conditions may be the cause of discrepancy between the two studies.

A 1990 long-term rotation and tillage study by Havlin et al. (1990) was established in Kansas. Established in 1974, 1975, and 1978, sites were designed with a continuous soybean treatment, a continuous sorghum treatment, and a soybean/sorghum treatment. Each rotation was situated on a NT and CT soil. One site housed a continuous corn, continuous soybean and a corn/soybean rotation, each on both CT and NT soils. The authors found a higher amount of organic matter left on the surface after harvest in NT sorghum plots as compared to continuous soybean plots after 10-12 years of observation; the increased organic matter led to an increase in organic C and N in the sorghum plots. Escalations in organic C and N with NT varied with rotation and soil texture throughout the study. For example, in the sorghum/soybean and continuous sorghum treatments under NT at one site, organic C was 5% and 14% higher and organic N was 7% and 10% higher than CT treatments, respectively. This phenomena was most significant at the surface layer, but was expected to move deeper into the soil profile with time (Havlin et al., 1990). With increased surface organic N, it could be expected that less-applied N fertilizer may be needed in long-term NT situations versus CT soils. The study points to rotation and soil texture playing comparatively as important of a role as tillage in soil organic C and N buildup.

In a similar study established in 1991, Ibrahim et al. (2015) explored tillage and rotation impacts on soil properties and nutrients near Beresford, SD. Rotations of corn/soybean, corn/soybean/wheat, and corn/soybean/wheat/alfalfa (*Medicago sativa*) were employed. This study found significantly higher soil organic matter concentrations in long-term NT soils as compared to CT soils at the same location, but crop rotation did not have an impact on soil organic matter. Much like other mentioned studies, they suggested that the lower concentrations of soil organic matter in CT soils were a result of tillage action which blends the soil at the surface layer, resulting in more aeration and oxidation and allowing for faster breakdown of soil organic matter. Moreover, crop rotation significantly affected nitrate concentrations in the soil, with the four year rotation of corn/soybean/wheat/alfalfa having the highest concentration followed by the corn/soybean/wheat rotation, and finally the corn/soybean rotation (Fig. 6). This tendency was accredited to the N-fixing abilities of the legumes in rotations providing a narrower C:N ratio, which caused faster organic matter decomposition. Nitrate concentrations under each tillage method were much more sensitive to application and significantly different in the NT system when compared to the CT system (Fig. 6). In the previously mentioned Iqbal et al. (2013) study, total N contents of NT soils within the two-year study increased and nitrate contents decreased.

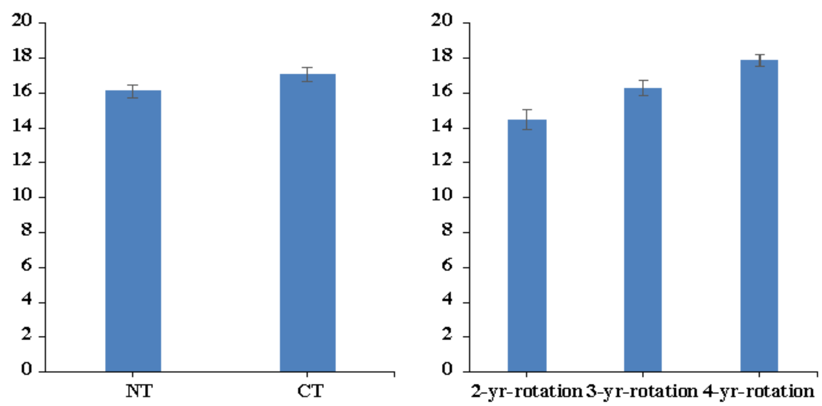

Figure 6. Soil nitrate (NO_3^-) as influenced by long-term tillage (A) and rotation systems (B) for the 0-15 cm depth (Ibrahim et al., 2015).

Many of the reviewed studies have found that an increase in organic C is found in NT soils when compared to deep tilled or CT soils. High organic C contents in the top 0 to 20 cm of NT soil is suspected to have resulted from crop residue decomposition and decreased contact with soil microorganisms due to sitting on the soil surface for a long period of time (Salinas-Garcia et al., 1997). Soil organic C values were greatest in cropping systems with little to no soil disturbance and least in more intensive tillage settings in a Nebraska study (Varvel, 2011). This research agrees with a Gelderman et al. (1998) study which, in regard to a 20 year NT Conservation Reserve Program (CRP) stand, stated “Apparently less net mineralization [more immobilization] is occurring with NT. This makes sense in that we have less physical disturbance of the soil and less oxygen being incorporated for the breakdown to occur.”

Conversely, intensive tillage systems incorporate crop residual materials deeper into the soil profile which could decrease organic C and total N contents at the soil surface. One might infer there is a higher organic C level and total N level at deeper depths in deep tilled soils. This can be attributed to inverted topsoil due to soil mixing/burying and an increased ability for N leaching due to amplified porosity (Sadej and Przekwas, 2008). Another study found that when sampled among different tillage treatments and soil profile depths on a long-term study in eastern Nebraska, total soil N tended to be highest in NT and disk-tilled systems when compared to chisel and plow tilled systems. A significant difference in soil organic C and soil N values among tillage systems and rotations were found at multiple depths. No-till systems with continuous corn rotations had the highest total N and soil organic C levels (Varvel et al. 2011).

Gál et al. (2007) implemented a study intended to “assess impacts of long-term (28 years) tillage and crop rotation on organic C and N content and depth distribution together with bulk density and pH” on Indiana soils. The study consisted of plow, chisel, ridge, and NT treatments compared to one another in continuous corn, corn/soybean, and continuous soybean rotations since the beginning of the trial in 1975. The research confirmed that NT treatments resulted in a large gain of organic C and total N at shallow depths (0-5, 5-15 cm). At intermediate depths NT treatments were about the same when compared to plow operations, and at 30-50 cm deep, substantial reductions in organic C and total N were seen in NT systems. At the 50-75 and 75-100 cm depth, both plow tillage and NT had about the same soil organic C concentrations (Table 2).

Table 2. Tillage treatment effects (averaged for two crop rotations) on organic C, total N concentration, C/N ratio, bulk density and pH at multiple depth increments to a 1 m sampling depth (Gál et al., 2007).

Depth (cm)	OC (g kg^{-1})		N (g kg^{-1})		C/N ratio		BD (g cm^{-3})		pH	
	NT	P	NT	P	NT	P	NT	P	NT	P
0–5	35.7**	23.9	2.8**	1.9	12.8	12.6	1.26**	1.13	7.05**	6.65
5–15	26.6*	24.1	2.1*	1.9	12.7	12.7	1.37**	1.16	5.94**	6.74
15–30	22.9	24.5	1.8	1.9	12.7	12.9	1.40**	1.16	5.39**	6.78
30–50	11.6*	15.2	1.0*	1.3	11.6	11.7	1.44	1.45	6.38	6.61
50–75	4.7	5.1	0.6	0.6	7.8	8.5	1.42	1.44	6.99	7.02
75–100	3.1*	3.5	0.4	0.3	7.8	11.7	1.55	1.50	7.51	7.48

NT, no-till; P, moldboard plow.
* Significant differences between two tillage systems at $\alpha = 0.05$.
** Significant differences between two tillage systems at $\alpha = 0.01$.

Many of the mentioned studies agree, inverted topsoil due to tillage can cause higher organic C levels at lower than expected soil depths. However, only a small number of studies have sampled past 30 cm to explore this concept, and do not address it as such.

Once out of reach of crop roots, nitrate has the potential to move downward to groundwater through percolation during wet spells (Gerwing et al., 2006). In addition to sequestration, N leaching within tillage systems is also an important issue to be taken into consideration. At a study located in Nashua Iowa, Bakhsh and Kanwar (2007) found that on average, chisel plow treatments had higher NO_3-N leaching losses (8 kg ha^{-1} N) than NT treatments when higher N application rates were used. Conversely, NT systems showed significantly higher NO_3-N leaching loss (9 kg ha^{-1} N) than chisel plowing under a corn/soybean rotation when lower N application rates were used. The study also concluded that NT systems had about a 92% higher tile flow volume compared with those from other tillage systems for five consecutive years of the study, creating seemingly greater leaching losses due to higher base flows. Higher flows were attributed to well-developed macropores, preferential flow paths, and less evaporation/greater infiltration due to crop reside in the NT soil profile as compared to CT systems.

Using conservation tillage as compared to CT improves soil N and soil organic C in various cropping systems, which indicates good potential for improved soil quality and increased sustainability (Varvel and Wilhelm, 2011).

Cover Crops

Some studies in the last decade have been devoted to finding new soil N management techniques and practices to improve soil quality. One practice gaining popularity is growing cover crops in conjunction with conservation tillage practices.

Current cover crop studies tend to focus on what cover crop species are best to plant with particular goals in mind and what risks are involved with such a decision. Cover crops can offer many 'services' to a cash crop such as: prevented soil erosion, increased yields, enhanced soil organic matter, reduced nitrate leaching, conserving water resources, reduced insect and pathogen damage, competition with weeds, fighting soil compaction and crusting, increasing aeration, and providing nutrients for plants and microbes according to the Rodale Institute (2011). But with each of these benefits, the producer takes a financial and production risk.

In 1994, a long-term no-till row crop rotation study was established with plots in three locations in Maryland (Steele et al., 2012). Many measurements were taken for organic C, bulk density, aggregate stability, water infiltration, and grain yield. Measurements over several years showed that on average, total above-ground dry plant biomass increased within the cropping system at each site due to the presence of winter annual cereal cover crops. Using winter cover crops in rotation with grain cash crops also showed significant effects on physical properties at one site more than others. At the coastal plains site, cover crops increased aggregate stability, but winter annual cereal cover crops only impacted soil physical properties during months after bulk density decreased. The study concluded that there was no consistent difference in labile soil C or total organic C observed between cover crop and control treatments (Steele et al., 2012).

A corn/soybean rotation study in Brazil (Nascente, 2013) concluded that cover crops (such as millet) in a NT system increased C and N concentrations in light soil organic matter fractions. Soil organic matter physical fraction measurement is a positive indicator of significant differences caused by soil management in organic matter dynamics within a short time period.

Cover crop research on NT soils is gaining in popularity at this time. As cover crops grow in acceptance, more research can and should be conducted. One should understand that there are many benefits and risks of using cover crops as a tool to improve soil health and physical properties in the US Midwest, but as seen above, results are not consistent and there is no over-arching understanding and conclusion of what exactly happens within soil physical properties when cover crops are used.

Conclusion

This review has provided a comprehensive overview of the effects of tillage system, crop rotation and cover crops on soil and plant systems with respect to soil fertility and health. We conclude the following:

1) Nitrogen is the #1 limiting nutrient for cereal grain production. However, excess N costs more money, which lowers returns, and has potentially negative impacts on the environment. Therefore, N management is important.
2) No-till increases soil organic matter and soil organic N, hence the need for more N fertilizer during conversion from CT to NT. However, eventually the NT system reaches a new equilibrium, meaning that extra N should no longer be required in long-term NT systems.
3) Current South Dakota NT fertilizer N recommendations for 30 lbs ac^{-1} additional N above the normal recommended rate for corn are based on short-term NT systems; no long-term NT data for South Dakota has been published.
4) The objective of this study was to evaluate whether N requirements continue to be greater under long-term NT versus CT production systems, while also considering effects from cover crops and crop rotation in southeastern South Dakota. Our basic hypothesis is that under longer term NT, soil organic N levels will reach a new equilibrium and extra applied N for optimizing corn yield will no longer be required. To test this hypothesis, we utilized a long-term tillage and rotation study at the Southeast Research Farm near Beresford, SD which has been in place since 1991. This allowed us to evaluate corn N response for CT and NT management in two and three-year rotations, and to evaluate the impact of a cover crop on the cropping system within the three-year rotation.

MATERIALS AND METHODS

This research project took place at the South Dakota State University (SDSU) Southeast Research Farm near Beresford, SD from the spring of 2014 through the fall of 2015. The research plots utilized for this study are part of a long-term rotation study block with 4 tillage treatments and 3 different crop rotations, established in 1991 (Fig. 7, 8). The block in which the study took place has 2, 3, and 4 year crop rotations. This study utilized the two and three-year crop rotations: corn/soybean, and corn/soybean/small grain, respectively; winter wheat (*Triticum aestivum*) served as the previous crop to the 2014 corn, and oat (*Avena sativa*) was planted previous to the 2015 corn. The trial took place on the corn phase of the rotation study block. The plots are located on an Egan-Trent silty clay loam soil, 0% to 2% slope (USDA, 2016). Annual rainfall in the area is 26.4 inches (SDSU, 2016), however the 2014 cropping season was unseasonably wet, dropping 13.06 inches of rain at the Beresford weather station (located at the SDSU Southeast Research Farm) in June (SDSU, 2014). All plants were measured and observed based upon the Iowa State University special report, “How a Corn Plant Develops” (Ritchie et al., 1997). The plots were set up with rotation as a main block, tillage was split across rotation, and N application was split across tillage blocks. Where evaluated, cover crop or planting date served as a strip across the three-year rotation and 2015 two-year rotation, respectively. Table 3 describes applied N fertilizer treatments and the overall plot set-up.

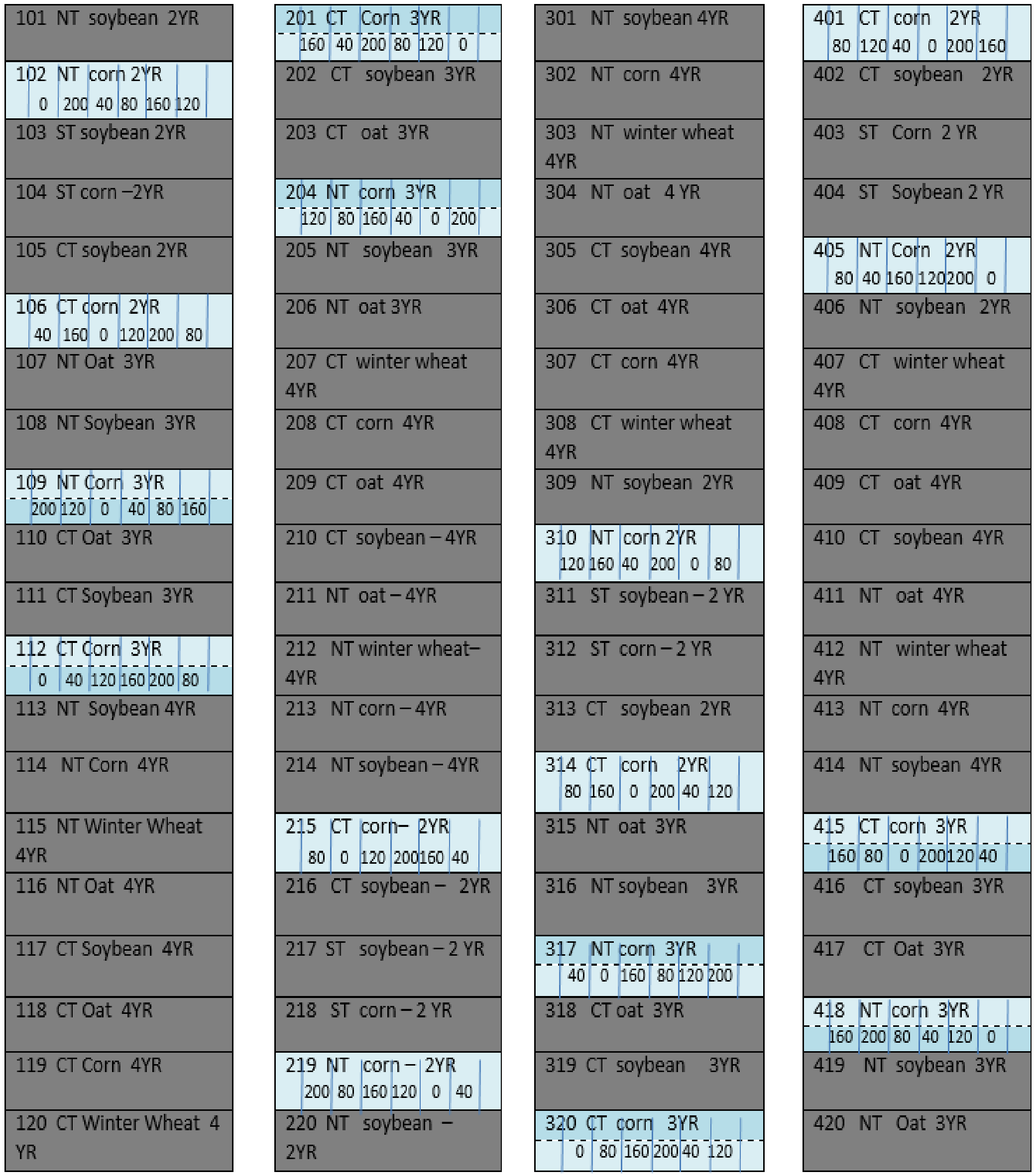

Figure 7. 2014 SDSU Southeast Research Farm rotation study plot layout at Beresford, SD. Plots in light shades were used for the 'Corn N Requirements' study. Tillage is indicated by 'CT' and 'NT'; crop rotation is indicated by '2YR' (2 year) or '3YR' (3 year). N rates are denoted in lb ac^{-1} by numbers within vertical boundary lines. '3YR' corn plots are split by two shades, the darker shading indicates where cover crops were present. Plots in dark, solid shading were not used for this study.

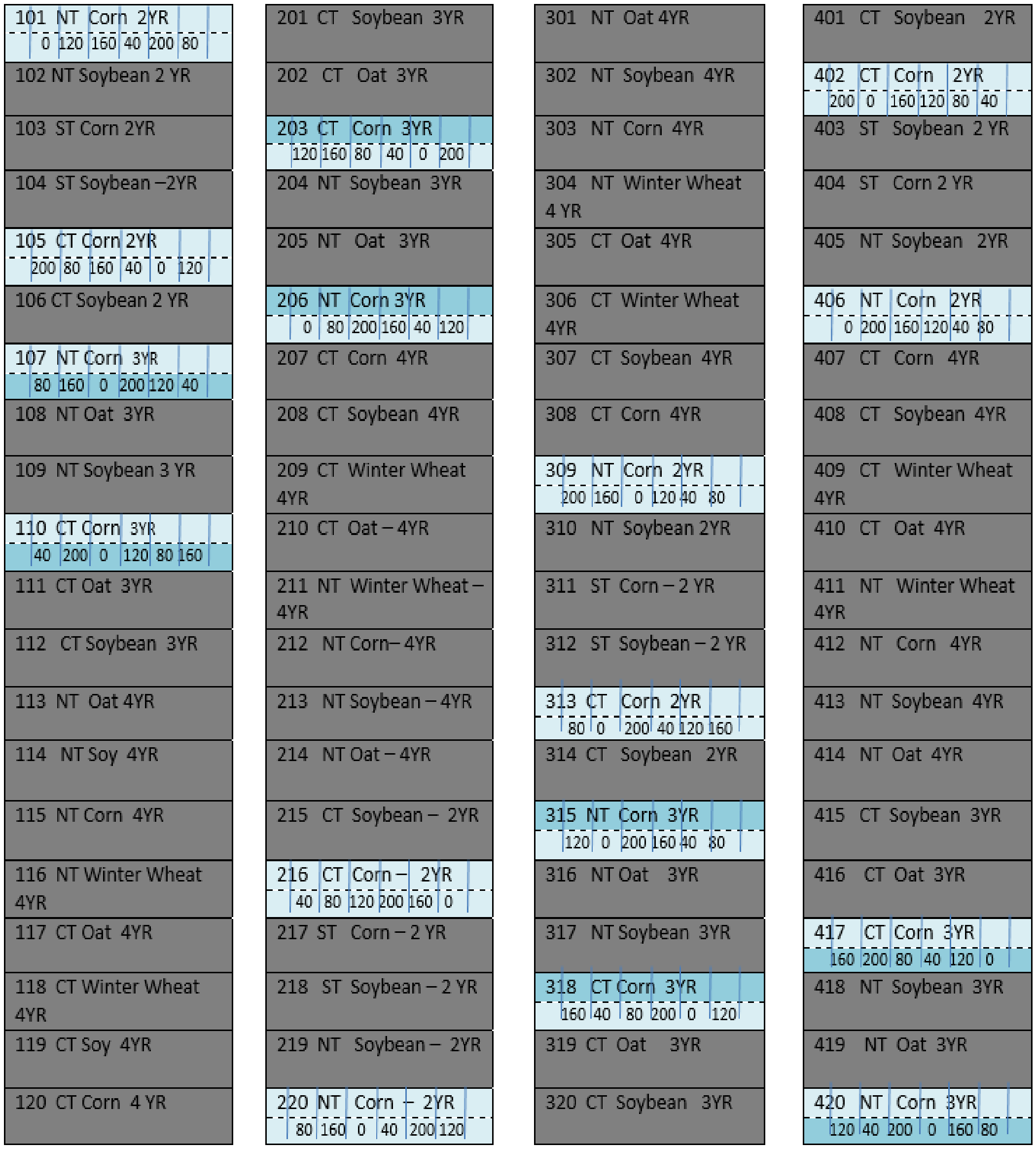

Figure 8. 2015 SDSU Southeast Research Farm rotation study plot layout at Beresford, SD. Plots in light shades were used for the 'Corn N Requirements' study. Tillage is indicated by 'CT', and 'NT'; crop rotation is indicated by '2YR' (2 year) or '3YR' (3 year). N rates are denoted in lb ac^{-1} by numbers within blue vertical boundary lines. '3YR' corn plots are split by two shades, the darker shading indicates where cover crops were present. '2YR' plots are marked with a horizontal line across the block, denoting a difference in planting date. Plots in dark, solid shading were not used for this study.

Table 3. Fertilizer treatments applied to corn in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in a 2 and 3 year rotation with and without tillage in 2014 and 2015.

----------------------2014----------------------					---------------------2015--------------------				
Rot.[1]	N Rate[2]	Till[3]	C. Crop[4]	Plant Date	Rot.	N Rate	Till	C. Crop	Plant Date
C/S	0	NT	NCC	16-May-14	C/S	0	NT	NCC	5-May-15 2-Jun-15
		CT					CT		5-May-15 2-Jun-15
C/S	40	NT	NCC	16-May-14	C/S	40	NT	NCC	5-May-15 2-Jun-15
		CT					CT		5-May-15 2-Jun-15
C/S	80	NT	NCC	16-May-14	C/S	80	NT	NCC	5-May-15 2-Jun-15
		CT					CT		5-May-15 2-Jun-15
C/S	120	NT	NCC	16-May-14	C/S	120	NT	NCC	5-May-15 2-Jun-15
		CT					CT		5-May-15 2-Jun-15
C/S	160	NT	NCC	16-May-14	C/S	160	NT	NCC	5-May-15 2-Jun-15
		CT					CT		5-May-15 2-Jun-15
C/S	200	NT	NCC	16-May-14	C/S	200	NT	NCC	5-May-15 2-Jun-15
		CT					CT		5-May-15 2-Jun-15
C/S/SG	0	NT	NCC CC	16-May-14	C/S/O	0	NT	NCC CC	2-Jun-15
		CT	NCC CC				CT	NCC CC	
C/S/SG	40	NT	NCC CC	16-May-14	C/S/O	40	NT	NCC CC	2-Jun-15
		CT	NCC CC				CT	NCC CC	
C/S/SG	80	NT	NCC CC	16-May-14	C/S/O	80	NT	NCC CC	2-Jun-15
		CT	NCC CC				CT	NCC CC	
C/S/SG	120	NT	NCC CC	16-May-14	C/S/O	120	NT	NCC CC	2-Jun-15
		CT	NCC CC				CT	NCC CC	
C/S/SG	160	NT	NCC CC	16-May-14	C/S/O	160	NT	NCC CC	2-Jun-15
		CT	NCC CC				CT	NCC CC	
C/S/SG	200	NT	NCC CC	16-May-14	C/S/O	200	NT	NCC CC	2-Jun-15
		CT	NCC CC				CT	NCC CC	

[1]'C/S' and 'C/S/SG' indicate corn/soybean and corn/soybean/small grain rotation, respectively. The C/S/SG rotation was switched from wheat to oat in 2013.
[2]Applied 4/10/14 and 4/15/15 as UAN using streamer bar application method.
[3]'CT' indicates conventional till since 1991, and 'NT' indicates no-till since 1991.
[4]'CC' and 'NCC' indicate 'cover crop' and 'no cover crop' respectively.

2014 Season

Tillage operations were managed using fall and spring tillage. Conventional till plots were tilled in the fall of 2013 on 11/20/13 with a chisel plow. Spring tillage was performed using a field cultivator on 4/30/14. No tillage operations took place on NT plots.

In the fall of 2013, a '+/-' cover crop treatment was imposed in the three-year rotation following winter wheat harvest. Each of these plots were split in two, with half being seeded to a broadleaf cover crop blend and half without a cover crop. The cover crop cocktail was planted on 8/20/13 in all 4 replications of the study (Fig. 7). The mixture consisted of 1.9 lbs ac^{1} radish (*Raphanus saivus*), 1.1 lbs ac^{-1} dwarf essex (*Brassica napus*), 0.3 lbs ac^{-1} turnip (*Brassica rapa subsp. rapa*), 3.9 lbs ac^{-1} pea (*Pisum sativum*), 2.8 lbs ac^{-1} lentil (*Lens culinaris*), 7 lbs ac^{-1} oat, 1.4 lbs ac^{-1} cowpea (*Vigna unguiculata*), 1.4 lbs ac^{-1} millet (*Pennisetum glaucum*), and 2.3 lbs ac^{-1} vetch (*Vicia*). This was the first time a cover crop had ever been planted in this block; cover crops were drilled with a NT drill (750, John Deere, Moline, IL). They were left to grow undisturbed and a sample was taken from each replication of above ground biomass in the fall to secure yield and nutrient data.

On 4/2/14, 133 lbs ac^{-1} of 0-0-60 granular fertilizer (80 lbs ac^{-1} K) was broadcast applied to all research plots to maintain basic soil fertility levels based upon soil tests per the South Dakota State University "Fertilizer Recommendations Guide" (Gerwing and Gelderman, 2005). Nitrogen rate treatments were applied on 4/10/15 across each tillage plot in the form of liquid UAN (urea-ammonium nitrate) with a streamer bar applicator

(20 inch nozzle spacing, 4 streamers per bar, 5 inches between streamers, Needham Ag Technologies, LLC., Calhoun, KY).

N rates applied were 0, 40, 80, 120, 160, and 200 lbs ac^{-1} and were randomly placed per each plot. Nitrogen sub plots in the two-year rotation were 45 ft by 60 ft, and in the three-year rotation, 45 ft by 30 ft. The difference in size is due to the split of ‘cover crop’ and ‘no cover crop’ treatments across each rate of the three-year rotation (Fig. 7). A 101 relative maturity day corn (‘P0193AM’, Pioneer, Johnston, IA) was planted ~2 inches deep on 5/16/14 at a rate of 32,300 seeds per acre.

Spring 2014 soil samples were taken from check plots (0 N rate plots) on 4/17/14. Two, 1.5 inch diameter cores were obtained per each plot using a hydraulic soil probe. Samples were split in the following depth increments: 0-6, 6-12, 12-24, 24-36, and 36-48 inches. The 0-6 inch depth was mixed and split in the field; half for moisture analysis and half for nitrate analysis. For moisture measurements, one half was sealed in a plastic bag and weighed for soil moisture, then soil was dried at 100°F for one week, and weighed again. Topsoil gravimetric moisture at the time of sampling was calculated using the difference between the wet and dry weights of these samples.

Soil samples for N analysis were air dried, ground using a flail grinder, passed through a US No. 10 (2 mm opening) sieve, and analyzed for initial NO_3-N and NH_4-N at Ward Labs in Kearney, NE. Nitrate N was found by means of a 2 M KCl extraction and cadmium reduction chemistry using a flow injection analyzer instrument (Lachat Quikchem flow injection analyzer, Lachat Instruments, INC., Milwaukee, WI). Procedures were followed according to Lachat Instruments, INC. (1992) and Kenney and Nelson (1982). Soil ammonium 2 M KCl values were found by the Salicylate Method using a flow injection analyzer instrument (Lachat Quikchem flow injection analyzer, Lachat Instruments, Inc.) according to Lachat Instruments, Inc. (1992), and Kenney and Nelson (1982).

Ward Labs also analyzed soil samples for soil health using the ‘Haney Test’. This method, entitled ‘Soil Health Tool Explanation ver. 4.0’ (SHT) involves using green chemistry for soil testing (Haney, unpublished data, 2012). According to Ward labs samples are: “weighed into two 50 ml Erlenmeyer flasks (4 g each) and one 50 ml plastic beaker (40 g) that is perforated to allow water infiltration. The 40 g soil sample is analyzed with a 24 hour incubation test at 25°C. This sample is wetted through capillary action by adding 25 ml of DI water to an 8 oz glass jar containing a Solvita® paddle and then capped. At the end of 24 hour incubation, the paddle is removed and placed in the Solvita® digital reader for CO_2-C analysis. The two 4 g samples are extracted with 40 ml of deionized water and 40 ml of H^3A extract. H^3A is a soil extract containing naturally occurring root exudates, lithium citrate, and two synthetic chelators; it has the capability to extract NH_4, NO_3, and P. The samples are shaken for 10 minutes, centrifuged for 5 minutes, and filtered through Whatman® 2V filter paper. The water and H^3A extracts are analyzed on a Lachat 8000 flow injection analyzer for NO_3-N, NH_4-N, and PO_4-P. The water extract is also analyzed on a Teledyne-Tekmar Torch C:N analyzer for water-extractable organic C and total N. The H^3A extract is analyzed on a Thermo Scientific ICP-OES instrument for Al, Fe, P, Ca, and K as well (Ward, 2016). This procedure has been developed from several different pieces of literature (Arnold et al., 2005; Franzluebbers et al., 1995a, 1995b, 1996a, 1996b, 1999a, 1999b, 2000, 2001; Franzluebbers and Haney 2006a, 2006b; Green et al., 2007; Haney et al., 1999, 2000, 2001a, 2001b, 2002a, 2002b, 2004, 2006a 2006b, 2008a, 2008b, 2008c, 2010a, 2010b; Haney and Franzluebbers, 2009; Haney and Haney, 2010; Harmel et al., 2004, 2005, 2006a, 2006b, 2009, 2010, 2011; Jin et al., 2011; Krutz et al., 2003; Lancaster et al., 2006, 2009).

Wireless HOBO® data logger temperature probes were placed just under the soil surface at a depth of approximately two inches in a two-year rotation CT and NT plot on May 28, 2014 (only two plots were used due to equipment limitation). Both sensors were moved to a three-year rotation CT and NT plot within the same replication as originally placed on 6/14/14 due to N application error on the originally placed plots. The probes were left in the soil until after plot harvest, at such time they were removed and read with HOBO® Logger data software.

Chlorophyll meter readings were taken when the corn crop reached the V6-V7 growth stage on 7/2/14 and 7/3/14 (replications were completed within one day). Calibrated soil plant analysis development (SPAD) meters (Model 502, Minolta, Chiyoda-ku, Tokyo, Japan) with data logging and software were used to obtain readings. SPAD meter readings were taken on the upper-most collared leaf, midway from tip to collar, and midway from midrib to the edge of the leaf. A total of eight readings were taken in each individual plot and averaged for a final meter value per each plot. At R1, a second set of chlorophyll meter readings were taken per the same protocol as described above on the ear leaf (first leaf opposite and below the top ear) on 7/25/14 for two-year rotation plots. The same procedure was repeated on the two-year rotation at the early R3 stage on 8/14/14.

A Greenseeker® (Model 505 Handheld optical sensor, NTech Industries, Sunnyvale, CA) crop sensing system was used at V6-V7 and R1 (in conjunction with SPAD meter readings) per each plot. A GreenSeeker® was mounted on a specially designed pole and connected to a hand-held computer system which captured and stored normalized difference vegetation index (NDVI) data from the unit. The unit was held approximately 3 ft directly above the canopy of the corn and was walked from one end of each plot to the other (with the planted row) at a constant speed. The average of all readings in each plot were recorded and used in final data analysis.

Stand counts were taken at V6-V7 on 7/3/14 by counting 2, 10-foot sections of corn row at random in each plot. Both counts were added together and used to calculate final stand values.

At R1 (initial pollen drop) on 7/30-7/31/14, 16 ear leaf samples were taken from each plot; 'ear leaf' refers to the first leaf below and opposite the top ear of the plant. A large number of samples were taken due to unexpected visual plot differences associated with extremely heavy rainfall events. Samples were dried at 140°F for one week. Oven-dry samples were ground using a lab mill and were passed through a 1 mm sieve. After grinding, samples were analyzed for total N using the Kjeldahl N method at the --SDSU Soil Testing Lab (Skroch et al., 1999).

At R6 (full plant maturity- 9/25/14), full plant biomass samples were taken from the 0 lbs ac^{-1} N and 160 lbs ac^{-1} N rate plots in every treatment strip. Ten feet of row was cut approximately 1-2 inches above ground level per each sampled plot using a sharpened corn knife; the number of plants cut was recorded. The entire sample was weighed fresh, then three representative stalks were sub sampled from the whole sample. The sub sample was shredded through a wood chipper, mixed well, and sub sampled again. The shredded sub sample was then weighed wet and placed in an oven at 140°F for 2 weeks. After being dried, the sample was weighed and ground using a lab mill and passed through a 1 mm sieve. Ground samples were analyzed using the same Kjeldahl digestion method described previously to determine total Kjeldahl N.

All plots were harvested using a 4-row Kincaid plot combine (Model 2065, Haven, KS) on 10/30/14. Eight rows of 40 foot in length in the two-year rotation plots, and 12 rows of the same length in the three-year rotation plots were harvested, and any missing plants due to biomass plant sampling were accounted for in yield calculations. Plot weight and moisture were measured by the combine weigh unit and moisture sensor. Test weight was measured on each sample using a grain moisture tester (Model SL95, Steinlite, Atchison, KS).

Grain oil, protein, and starch content were obtained by near-infrared analysis, through the use of a grain analyzer (Model Infratech®, Foss Tecator, Hillerød, Denmark); all values were adjusted to 15.5% grain moisture. Yield was calculated using plot weight at harvest, harvested area, plot moisture at harvest, and the standard 56 lbs bu^{-1} test weight. Yields were corrected to 15.5% moisture for standard comparison purposes.

Fall soil samples were taken on 11/12/14 and 11/13/14 following the same sampling procedure as spring soil samples, however moisture was not measured and samples were taken in 0, 80, 160, and 200 lbs ac^{-1} applied N plots only. The same drying and grinding procedure as described for spring samples was followed. Analysis for soil nitrate N and ammonium soil N took place at the South Dakota State University Soil Testing Lab using the Nitrate Ion-Sensitive Electrode method with an aluminum sulfate extract and the Soil Ammonium-N Digestion method on a rapid still, according to the Soil Testing Procedures at the South Dakota State Soil Testing and Plant Analysis Laboratory (Gelderman et al., 1995).

Due to application error, replication 1 was eliminated from data analyses in the 2014 field season, and was not included in the final results and discussion of this paper. In addition, 9 N sub-plots were eliminated from reporting due to experimental error or because plots were extreme outliers due to heavy June rainfall. Two additional N sub-plots were excluded from statistical analysis (but left on yield figures for the reader's interest) and considered anomalies due to uncertainties in extremely outlying yield values.

2015 Season

The 2015 cropping season parameters were designed to mimic the 2014 season, however, due to a planting error and seasonal weather differences, some parameters were measured or analyzed slightly differently. Tillage operations on CT plots were managed using fall and spring tillage. Plots were spring tilled using a disk on 4/22/15 followed by a field cultivator on 4/23/15.

In the fall of 2015, following oat harvest in three-year rotation plots, a cover crop cocktail was planted on 8/21/14 in the east or west half of harvested oat plots (depending upon replication) in all 4 replications of the study (Fig. 8). The mixture consisted of 2.1 lbs ac^{-1} radish, 1.3 lbs ac^{-1} dwarf essex, 0.3 lbs ac^{-1} turnip, 4.4 lbs ac^{-1} pea, 3.2 lbs ac^{-1} lentil, 4.8 lbs ac^{-1} oat, 1.6 lbs ac^{-1} cowpea, 1.6 lbs ac^{-1} millet, and 2.6 lbs ac^{-1} vetch. Cover crops were drilled with the same John Deere NT drill as in 2014. A sample was taken from each replication of above ground biomass in the fall to secure cover crop yield and nutrient data. In addition to the planted cover crop mix, a significant amount of volunteer oat germinated in the fall of 2014 across both halves of the plots, possibly effecting spring soil N levels.

On 3/24/15 150 lbs ac^{-1} of 11-52-0 granular fertilizer was broadcast applied to all research plots to maintain basic soil fertility levels per the South Dakota "Fertilizer Recommendations Guide" (Gerwing and Gelderman, 2005). Nitrogen was applied using UAN by the same methods as in 2014 on 4/15/15 at applied treatment rates of 0, 40, 80, 120, 160, and 200 lbs ac^{-1} and randomly assigned within each block. Nitrogen rate sub plots in the two-year rotation were 45 ft by 60 ft and in the three-year rotation, 45 ft by 30 ft due to a split strip of 'cover crop' and 'no cover crop' treatments across each N rate in the three-year rotation. A 111 relative maturity day corn ('P1151AM', Pioneer, Johnston, IA) was planted on 5/5/15 at 27,900 seeds ac^{-1} at approximately 2 inches deep. Due to poor planter down pressure, many seeds were not planted at appropriate depths in small grain stubble in the three-year rotation; on 5/27/15 a decision was made to re-seed these plots. All of the three-year rotation plots and the east half of each two-year plot (running from north to south across all treatments) were killed using foliar applied clethodim. Half of each plot in the two-year rotation treatment was retained for a planting date comparison as the initial stand in the two-year plots was good. Due to the re-planting, the two-year rotation plots became 45 ft by 30 ft per each planting date. On 6/2/15, a 91 day corn ('P9188AMX', Pioneer) was re-planted ~2 inch deep at 33,000 seeds ac^{-1}.

Soil samples were taken from check plots on 4/2/15. Two, 1.5 inch diameter cores were obtained per each plot, using the same hydraulic soil probe as in 2014. Samples were split in the following depth increments: 0-6, 6-12, 12-24, 24-36, and 36-48 inches. The 0-6 inch depth was mixed and split as in 2014 for moisture analysis.

Spring soil samples were air dried, ground with a flail grinder, passed through a US No. 10 (2 mm opening) sieve, and analyzed for initial NO_3-N and NH_4-N at Ward Labs in Kearney, NE. The same methods were followed as in 2014, using a flow injection analyzer instrument. The Haney Test was also run on all samples, following the same method as previously described in 2014.

Wireless HOBO® data logger temperature probes were placed just under the soil surface to a depth of approximately two inches on 5/6/15 in a two-year and three-year 160 N CT and NT plot without cover crops as well as a two and three-year 160 N CT and NT plot with cover crops. The probes were left in the soil until after plot harvest, at such time they were removed and read with HOBO® Logger data software. Due to a setting error, soil temperatures for the three-year rotation NT plots with cover crops were not recorded.

Chlorophyll meter readings were taken in late planted plots when the corn crop reached the V7-V8 growth stage on 7/11/15. On the same day a SPAD meter was used on the upper-most collared leaf, following the same procedure as in 2014. At R1, a second set of chlorophyll meter readings were taken per the same protocol as described in 2014 on the ear leaf on 7/21/15 in early planted plots and on 7/29 through 7/31/15 in late planted plots.

A Greenseeker® (Model HCS-100 Handheld Crop Sensor, Trimble, Sunnyvale, CA) crop sensing system was used at V7-V8 on late planted plots on 7/11/15 (in conjunction with SPAD meter readings). Readings were taken at R1 on 7/24/15 for early planted plots and from 7/29 to 7/31/15 for late planted plots. For R1 readings, the GreenSeeker® was mounted on a specially designed pole and the average reading from each plot was recorded as readings were taken. The unit was held approximately 3 ft directly above the canopy of the corn and was walked from one end of each plot to the other at a constant speed (with the planted row). The average of all readings in each plot was used for final data analysis. Greenseeker® models used in 2014 and 2015 were compared and a highly correlated linear relationship was found (r^2=0.98).

At R1 (initial pollen drop) on 7/27/15, 8 ear leaf samples were taken from each plot. Samples were dried at 140°F for one week. Oven-dry samples were ground using a lab mill; samples were passed through a 1 mm sieve. Samples were then ground finer using a UDY Corporation Cyclone Sample Mill with a 1 mm screen. After the second grinding procedure, plant tissue samples were analyzed for total N at the USDA ARS lab near Brookings, SD. Samples were analyzed following the 'LECO N in Soil and Plant Tissue' method on a LECO instrument (Model FP628, LECO, St. Joseph, MI), with some exceptions (LECO Corp., 2014, St. Joseph, MI). Exceptions include: the USDA ARS lab uses 0.2000 grams for standards and unknowns as other methods use this weight because it is specified for drift corrections, no EDTA checks are used due to the value being much higher than materials typically analyzed, and plants are burned for 192 seconds. A different lab was used as compared to 2014 due to limited time and financial constraints.

A data subset was selected at random from the 2015 ear leaf samples. The subset was submitted to the SDSU Soil Testing Lab and the Brookings USDA ARS lab for plant analysis. Samples were ground one time with the same lab mill as used in 2014 and passed through a 1 mm sieve for SDSU plant analysis to simulate 2014 sample preparation. Samples were then passed through the UDY mill with a 1 mm sieve that was mentioned previously and sent to the USDA ARS lab for analysis to simulate 2015 procedures. Each lab followed their respective methods as listed previously for 2014 (SDSU) and 2015 (USDA ARS). When methods were compared across the same subset, the reported r^2 value was 0.72. It is suspected that the difference in particle size between the two methods may have affected the comparison.

At R6 on 9/11/15 and 9/14/15, full plant biomass samples were taken from the 0 N and 160 N rate plots in every treatment strip (2 replications were completed on each date). Methods of sample collection and preparation were the same as executed in 2014. Ground samples were analyzed using the LECO instrument at the USDA ARS Lab following the same methods and procedures as listed for 2015 ear leaf tissue analysis (LECO Corp., 2014).

Again, a data subset was randomly selected from the 2015 plant biomass samples. Subset samples were ground twice in the same manner as all 2015 plant biomass samples. The same subset was sent to the SDSU and USDA ARS lab for plant NO_3-N analysis following the same methods as previously listed for plant biomass in 2014 and 2015, respectively. A comparison of the analyses, in order to compensate for differences in methods from 2014 to 2015, was performed. After comparing each method against the other, an r^2 value of 0.94 was reached.

Stand counts were taken just before harvest on 10/21/15 by counting 2, 10 ft sections of corn row at random per each plot. Both counts were added together and used to calculate final stand values.

All plots were harvested using the same 4-row Kincaid plot combine as used in 2014 on 10/22/15. Four rows of each plot were harvested, and any missing plants due to biomass plant sampling were accounted for in yield calculations. Plot weight and moisture were measured by the combine weigh unit and moisture sensor. Test weight of each grain sample was measured on a grain moisture tester (Model SL95, Steinlite).

Grain oil, protein, and starch content were obtained through near-infrared analysis by the use of a grain analyzer (Model Infratech®, Foss Tecator, Hillerød, Denmark); values were adjusted to 15.5% grain moisture.

Yield was calculated using plot weight at harvest, harvested area, plot moisture at harvest, and using the standard of 56 lbs bu^{-1} corn test weight. Yields were corrected to 15.5% moisture for standard comparison purposes.

Fall 2015 soil samples were taken following a different procedure than in the fall of 2014 due to high soil moisture conditions which made soil sampling unfeasible. In replication 1, 0 N and 160 N rate plots were sampled in the fall on 11/6/2015; no other viable samples could be taken at that time. In the early spring of 2016, all 0 N and 160 N plots were soil sampled on 4/11/2016; samples were split from 0-24 inches and 24-48 inches deep. A relationship between the fall samples taken from replication 1 and the early spring 2016 samples taken from the same replication was developed to provide an estimation of N lost over the winter season. After evaluating the data it was determined that no substantial gains or losses occurred over the winter, and samples taken in the spring of 2016 were considered final soil samples for the 2015 cropping season. The same drying and grinding procedure was followed for spring and fall soil samples. Analysis for nitrate N took place at the SDSU Soil Testing Lab using the Nitrate Ion-

Sensitive Electrode method with an aluminum sulfate extract, according to the Soil Testing Procedures at the South Dakota State Soil Testing and Plant Analysis Laboratory (Gelderman et al., 1995).

High snap and lodging losses were observed in plots that were situated near the south and west ends of replication strips with little or no protection from the wind throughout the 2015 season. This was viewed primarily as a treatment effect due to N deficiency or late planting and because these characteristics were not localized to these areas only. In addition, a deer path was found running through a two-year rotation NT sub-plot (plot 406) with 160 lbs ac^{-1} N applied, however no significant yield loss was recorded, therefore this plot was left in the analysis. One N sub-plot was removed from the 2015 analysis as an anomaly and was considered an extreme outlier, however this data point was left on yield figures for the reader's interest.

Statistical Analysis

Statistical analysis was performed using SAS software- version 9.3 (SAS Institute, Cary, NC), and RStudio software- version 0.99.491 (R Foundation, Kansas City, MO). The ANOVA analysis was performed on all dependent variables using SAS software following a strip strip strip or strip split plot design as appropriate data sets were analyzed. All effects were considered fixed. Linear plateau statistics were determined using R statistical software. However, due to a lack of convergence using a Gauss Markov Assumption in both R and SAS software, a Grid Search method was used in R and confirmed original Gauss Markov Assumptions. Both SAS and R software were run on an HP EliteBook laptop computer running an Intel core processor i4 vPro, with a Windows 7 operating system.

RESULTS AND DISCUSSION

The 2014 season was marked by an extremely wet, cool growing season with an unprecedented total June rainfall of 13.5 inches (Table 4, Fig. 9). It was recorded as the wettest month on record at the Southeast Research Farm. In many cases, results were affected as a consequence of the extreme rainfall; CT plots showed a trend for greater yield than NT plots in this season. We suspect there was an infiltration effect on NT soils, which allowed them to super saturate during the June 2014 rainfall event; CT soils however, most likely experienced more run off, possibly resulting in a yield advantage under these conditions. Visually, the NT plots appeared to take the heavy rainfall harder than did the CT plots. The average NT corn yield across this study in 2014 was 152 bu ac^{-1}, though, a nearby tile-drained study yielded approximately 212 bu ac^{-1} under NT management in this same season (Ahiablame et al., 2015). The 2014 data implies that additional N was needed for NT soils under extreme rainfall conditions at the SDSU Southeast Research Farm. However, in 2015 the same nearby drained field had an average soybean yield of 56 bu ac^{-1} as compared to soybeans within this study block which yielded 57 bu ac^{-1}. Therefore, we suspect moisture and drainage had a very large impact on yield results for this study in 2014. For the purpose of data presentation, results will be discussed per growing season.

By way of a synopsis, the two study years for this experiment (2014 and 2015) experienced exceptionally different weather patterns. In contrast to 2014, 2015 exemplified ideal growing conditions with above average but well-spaced rainfall during the growing season (Table 5, Fig. 10). The May (early) planted plots in the two-year rotation were the most representative data set in relation to on-farm production in this experiment. Under an average growing season in southeastern South Dakota, this data implies that long-term NT soils do not need an additional 30 lbs ac^{-1} (in 2015) of applied N above CT plots as suggested by the SDSU "Fertilizer Recommendations Guide" (Gerwing and Gelderman, 2005).

Table 4. 2014 Climate summary[1] from the SDSU Southeast Research Farm at Beresford, SD.

	Measured amount	% of normal
Annual Precipitation (inch)	27.55	109%
Growing Season Precip (Apr-Sep, inch)	23.59	125%
Jan-Mar	0.98	36%
Apr-Jun	17.14	167%
Jul-Sep	6.45	74%
Oct-Dec	2.98	82%
Annual Snow (inch); (Jan-Jun/Jul-Dec)	15.2/6.0	21.2 total
Growing Degree Units (GDU)	2985	98%
Minimum / Maximum Air Temp, °F	-21°F Feb 25 & Mar 3	91°F Jun 20
Last Spring Frost; 32° / 28° basis	May 17 - 29°F	May 16 - 24°F
First Fall Frost; 32° / 28° basis	Oct 3 - 31°F	Oct 10 - 28°F
Frost Free Period (days); 32° / 28° basis	142	147
Average Annual High / Low Temp, °F	57/33	0.470588235

[1]Adapted from 2014 Southeast Research Farm Annual Report.

Table 5. 2015 Climate summary[1] from the SDSU Southeast Research Farm at Beresford, SD.

	Measured amount	% of normal
Annual Precipitation (inch)	30.26	119%
Growing Season Precip (Apr-Sep, inch)	24.85	131%
Jan-Mar	0.87	32%
Apr-Jun	8.25	81%
Jul-Sep	16.6	189%
Oct-Dec	4.54	124%
Annual Snow (inch); (Jan-Jun/Jul-Dec)	9.9/34.3	44.2 total
Growing Degree Units (GDU); Apr - Oct	3175	104%
Minimum / Maximum Air Temp, °F	-16°F Feb 27	96°F Jun 9
Last Spring Frost; 32° / 28° basis	Apr 29 - 29°F	Apr 22 - 19°F
First Fall Frost; 32° / 28° basis	Oct 14 - 32°F	Oct 16 - 24°F
Frost Free Period (days); 32° / 28° basis	168	180
Average Annual High / Low	60/37	1.076923077
Evaporation / rainfall May–Sept (inch)	28.8	23.7

[1]Adapted from 2015 Southeast Research Farm Annual Report.

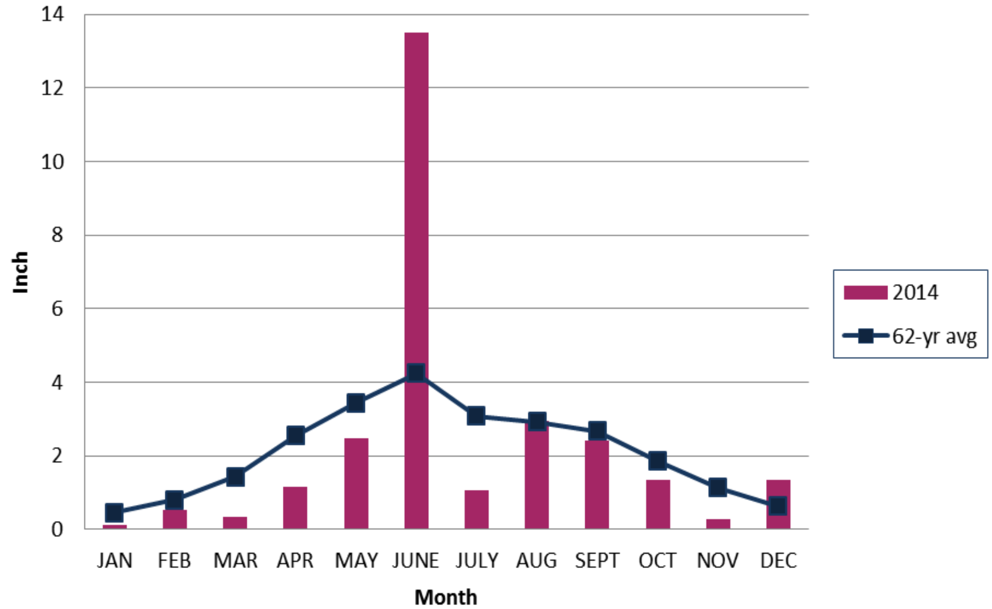

Figure 9. 2014 Monthly precipitation adapted from the 2014 Annual Report at the Southeast Research Farm at Beresford, SD.

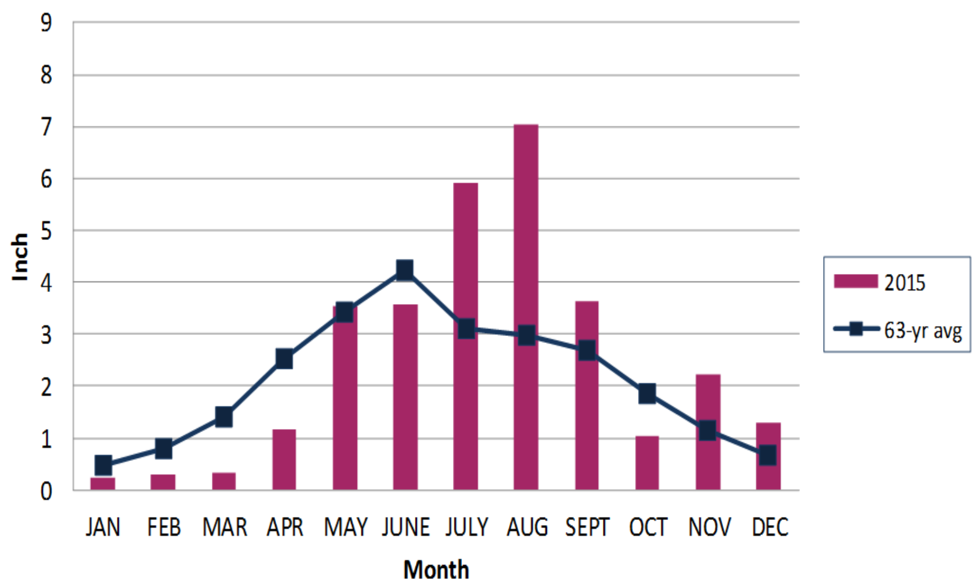

Figure 10. 2015 Monthly precipitation adapted from the 2015 Annual Report at the Southeast Research Farm at Beresford, SD.

2014 Growing Season

Initial spring soil tests showed varying levels of nitrate N present in the soils of the two-year (corn/soybean) and three-year (corn/soybean/winter wheat) rotation (Table 6). The most prominent characteristic however, appears between the three-year rotation 'cover crop' and 'no cover crop' treatments. We see a trend for approximately 50 lbs ac^{-1} less soil NO_3-N from 0 to 2' in the cover crop versus no cover crop plots on average. This difference is presumably attributed to nitrate N that the cover crop cocktail took up while growing the previous fall. This had no effect on the rate of fertilizer applied for the purposes of this study.

Data on soil organic matter, Haney N, and soil health indicators is also given in Table 6. Soil organic matter is slightly reduced in CT plots when compared to NT as one would expect due to loss of residue and erosion. The Haney N data was used to develop Haney soil N recommendations using 0 to 6 inch deep soil samples. The Haney N results indicate a 17 lbs ac^{-1} average difference in Haney soil N between cover crop treatments, a lesser difference than indicated by the 0 to 2 ft deep samples tested for NO_3-N, but a relative comparison. The Haney soil health values indicate slightly higher levels of soil health in three-year 'no cover crop' treatments than 'cover crop treatments', but do not specify a clear difference between CT and NT systems in the two-year rotation.

Table 6. Spring soil test N levels in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in a 2 and 3 year rotation with and without tillage in 2014 and 2015.

Year	Rotation[1]	Tillage[2]	Cover Crop[3]	NO_3-N	NH_4-N	OM	Haney N[4]	Haney SH[5]
				--lbs ac^{-1} (0-2')--		%	lbs ac^{-1} (0-6")	0-6"
2014	Corn/Soy	CT	--	42.3	23.7	4.5	48.0	11.7
		NT	--	56.2	31.1	4.6	58.0	11.7
	Corn/Soy/ WW	CT	CC	33.1	28.3	4.1	45.6	10.1
			NCC	85.9	22.8	4.4	62.1	12.3
		NT	CC	30.3	28.3	4.7	47.6	11.0
			NCC	80.9	30.2	4.7	65.1	12.2
2015	Corn/Soy	CT	--	54.1	62.9	4.7	54.5	17.4
		NT	--	37.8	66.7	4.8	38.5	14.4
	Corn/Soy/ Oat	CT	CC	22.0	57.9	4.6	33.7	13.2
			NCC	19.2	50.7	4.6	31.7	13.7
		NT	CC	18.5	58.4	4.9	32.2	12.6
			NCC	18.6	56.6	4.9	31.7	13.3

[1]'Corn/Soy', 'Corn/Soy/WW', and 'Corn/Soy/Oat' indicate the 2 and 3 year rotation in which the study took place.
[2]'CT' indicates conventional till since 1991, and 'NT' indicates no-till since 1991.
[3]'CC' and 'NCC' indicate 'cover crop' and 'no cover crop' respectively.
[4]'Haney N' indicates plant available soil N according to the Haney Method.
[5]'Haney SH' indicates index values of the Haney soil health test.

Table 7. SPAD, NDVI, and ear leaf N levels in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in a 2 and 3 year rotation with and without tillage in 2014 and 2015.

Rotation[1]	Tillage[2]	Cover Crop[3]	Plant Date[4]	App. N[5]	SPAD[6]	NDVI[7]	Ear Leaf N[8]	SPAD[9]	NDVI	Ear Leaf N
				lbs ac^{-1}	V6-V8	V6-V8	%	V6-V8	V6-V8	%
						--2014--			--2015--	
Corn/Soy	CT	--	early	0	41.00	0.62	2.48	n/a	n/a	2.37
				40	44.60	0.82	2.82	n/a	n/a	2.53
				80	44.60	0.75	3.07	n/a	n/a	2.62
				120	43.37	0.68	3.06	n/a	n/a	2.77
				160	53.40	0.76	3.41	n/a	n/a	2.84
				200	51.25	0.68	3.13	n/a	n/a	2.86
		--	late	0	--	--	--	56.45	0.79	2.58
				40	--	--	--	57.33	0.78	2.67
				80	--	--	--	56.73	0.78	2.68
				120	--	--	--	60.35	0.78	2.88
				160	--	--	--	58.75	0.79	2.78
				200	--	--	--	58.88	0.79	2.89
	NT	--	early	0	35.27	0.49	2.84	n/a	n/a	1.97
				40	36.93	0.55	2.70	n/a	n/a	2.31
				80	41.00	0.59	3.09	n/a	n/a	2.63
				120	45.30	0.63	3.03	n/a	n/a	2.70
				160	41.63	0.56	3.16	n/a	n/a	2.87
				200	43.13	0.62	3.21	n/a	n/a	2.78
		--	late	0	--	--	--	54.98	0.74	2.37
				40	--	--	--	57.90	0.76	2.61
				80	--	--	--	61.90	0.76	2.61
				120	--	--	--	59.53	0.76	2.75
				160	--	--	--	58.65	0.79	2.74
				200	--	--	--	59.53	0.78	2.85

Table 7 Continued.

Corn/Soy/ Sm. Grain	CT	CC	--	0	52.45	0.69	2.38	56.58	0.78	2.18
				40	40.00	0.63	3.02	56.88	0.79	2.43
				80	53.73	0.70	3.05	57.95	0.78	2.58
				120	51.13	0.67	2.95	59.08	0.80	2.69
				160	53.03	0.73	3.24	59.23	0.79	2.70
				200	54.90	0.71	3.49	58.85	0.79	2.68
		NCC	--	0	43.17	0.63	2.66	54.68	0.78	2.14
				40	43.57	0.61	3.25	59.13	0.79	2.41
				80	50.00	0.73	3.26	59.30	0.78	2.52
				120	48.03	0.67	3.30	58.95	0.80	2.75
				160	50.30	0.73	3.23	58.65	0.79	2.73
				200	49.17	0.74	3.23	58.95	0.79	2.63
	NT	CC	--	0	33.63	0.41	2.45	55.33	0.71	2.13
				40	34.75	0.44	3.02	56.63	0.72	2.36
				80	40.90	0.47	2.96	58.93	0.77	2.58
				120	43.37	0.50	3.04	57.95	0.75	2.74
				160	44.73	0.53	2.98	59.40	0.75	2.75
				200	43.70	0.52	3.04	59.35	0.73	2.86
		NCC	--	0	32.97	0.39	2.48	52.98	0.70	2.06
				40	40.70	0.57	2.79	57.30	0.73	2.33
				80	40.93	0.46	2.89	61.80	0.76	2.61
				120	42.43	0.46	3.02	58.40	0.75	2.74
				160	45.77	0.57	2.98	57.70	0.78	2.73
				200	41.50	0.52	3.00	56.93	0.76	2.71

Table 7 Continued.

Mean	CT			48.21	0.70	3.06	58.15	0.79	2.61
	NT			40.45	0.49	2.88	58.06	0.75	2.58
	2 yr		early+late	43.46	0.64	3.00	58.41	0.77	2.65
	3 yr			44.79	0.59	2.99	57.95	0.76	2.54
	15 2 yr		5-May-15	--	--	--	--	--	2.60
			2-Jun-15	--	--	--	58.41	0.77	2.70
	3 yr	CC		45.53	0.58	2.97	58.01	0.76	2.56
		NCC		44.04	0.59	3.01	57.90	0.77	2.53
St. Dev.	CT			4.76	0.06	0.30	1.41	0.01	0.21
	NT			4.33	0.06	0.21	2.23	0.02	0.24
	2 yr		early+late	5.14	0.10	0.25	1.88	0.02	0.15
	3 yr			6.24	0.11	0.28	1.84	0.03	0.23
	15 2 yr		5-May-15	--	--	--	--	--	0.27
			2-Jun-15	--	--	--	1.88	0.02	0.15
	3 yr	CC		7.44	0.12	0.30	1.36	0.03	0.23
		NCC		4.99	0.12	0.26	2.29	0.03	0.24

[1]'Corn/Soy' and 'Corn/Soy/Sm. Grain' indicate the 2 and 3 year rotation in which the study took place.
[2]'CT' indicates conventional till since 1991, and 'NT' indicates no-till since 1991.
[3]'CC' and 'NCC' indicate 'cover crop' and 'no cover crop' respectively.
[4]Plant Date: 'early' indicates a 5/5/15 planting date, 'late' indicates a 6/2/15 planting date due to planting error. All 2014 plots were planted on 5/16/14.
[5]Applied 4/10/14 and 4/15/15 as UAN using streamer bar application method.
[6]8 SPAD meter readings were taken per plot and averaged for an overall plot value.
[7]NDVI readings were obtained for each plot using a Greenseeker® instrument.
[8]In 2014, 16 ear leaf samples were taken per plot, 8 samples per plot were taken in 2015.
[9]2015 early planting V6 SPAD and Greenseeker® readings were not taken due to time restraints.

At different points throughout the growing season SPAD and NDVI readings were taken and along with ear leaf N concentration, provide indicators of crop N status; Table 7 summarizes this data. Plant chlorophyll and canopy cover were measured using a SPAD meter and hand-held Greenseeker® technology. As a general rule SPAD readings increased with N application, as one would expect with the exception of the three-year rotation CT cover crop plots. We see that CT plots in 2014, with a very wet June, tend to have higher SPAD readings at V6-V8 than did NT plots, indicating a greener leaf with more N in the plant at the time of reading. This difference appears to be lessened, or lost, by the R1 stage as there was no clear trend for ear leaf N in the two-year rotation data, nor was this trend observed in 2015. In addition, rotation and cover crop treatments appeared to have very little effect on SPAD readings.

Figures 11 and 12 describe SPAD meter readings as an indication of initial soil nitrate N plus applied N for the 2014 season. In Figure 11 it appears the SPAD readings rise with soil nitrate N plus applied N in the corn/soybean rotation with exception of two NT outliers. In fact, the NT and CT systems have a parallel slope 0.049, but CT plots had higher chlorophyll readings as a general rule in 2014. However, in the three-year rotation no clear increasing positive slope in ‘no cover crop’ treatment data was seen, possibly due to high initial soil nitrate N in these treatments. As indicated in Table 7, CT plots show a trend for higher SPAD readings as an apparent response to tillage in 2014, but some visual differences between cover crop treatments can be seen in Figure 12.

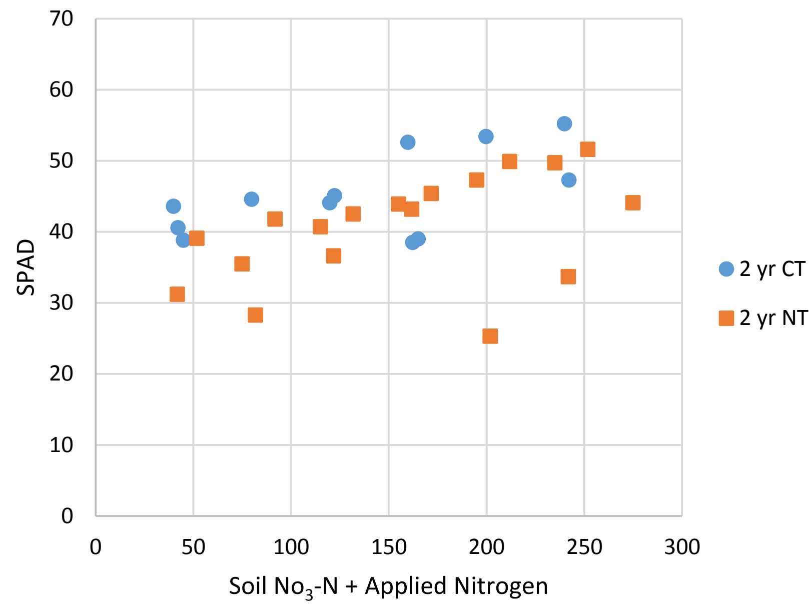

Figure 11. 2014- Soil N influence on SPAD meter readings at V6-V8 growth stage in a corn/soybean rotation (2 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems.

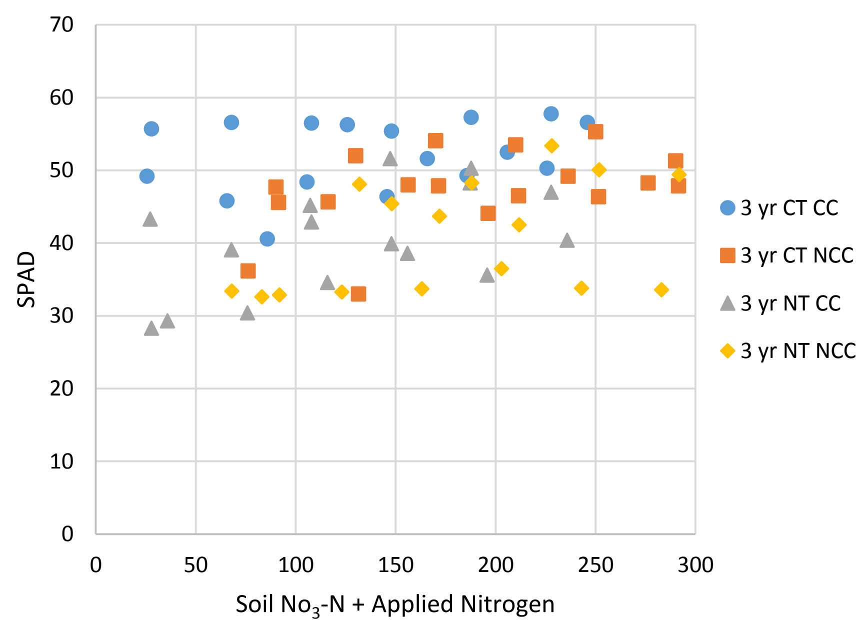

Figure 12. 2014- Soil N influence on SPAD meter readings at V6-V8 growth stage in a corn/soybean/winter wheat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crop (CC and NCC, respectively).

The 2014 NDVI readings were not exceptionally clear as N rates rose within a rotation by tillage plot (Table 7). However, the two and three-year NT plots, on average, tended to have lower NDVI readings, when compared to CT plots. At this point in growth development, NDVI readings indicated the NT plots tended to have less density within the green crop canopy than CT plots. The two-year rotation had a higher average NDVI canopy reading than the three-year rotation, but cover crops did not have a great effect on NDVI readings. In addition, Figures 13 and 14 do not show a clear pattern of NDVI reading vs. soil nitrate N plus applied N, indicating plants had the optimum amount of N uptake available at V6-V8 or NDVI readings displayed a large margin of error in this case.

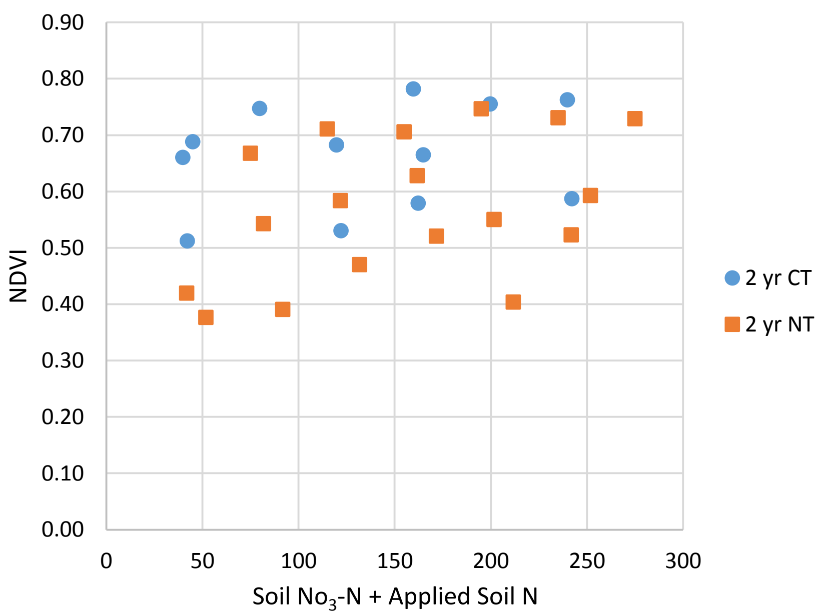

Figure 13. 2014- Soil N influence on NDVI readings at V6-V8 growth stage on a corn/soybean rotation (2 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems.

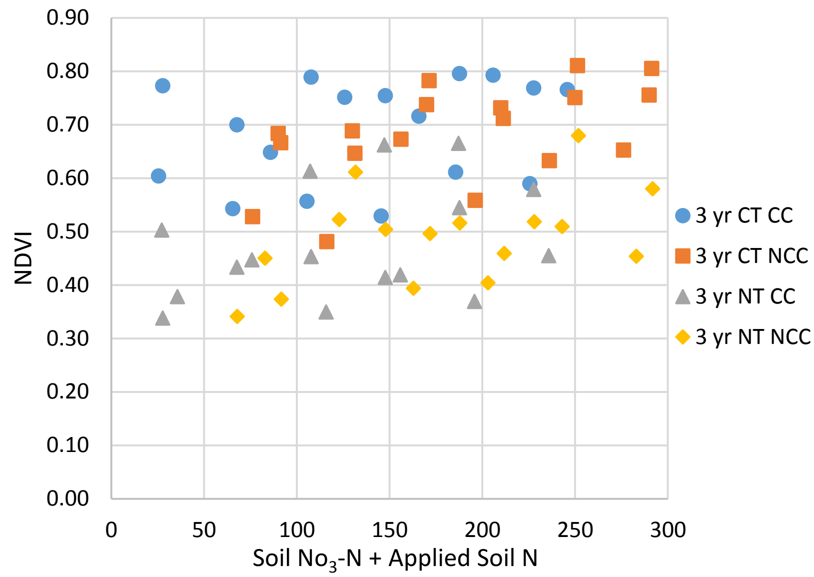

Figure 14. 2014- Soil N influence on NDVI readings at V6-V8 growth stage on a corn/soybean/winter wheat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crop (CC and NCC, respectively).

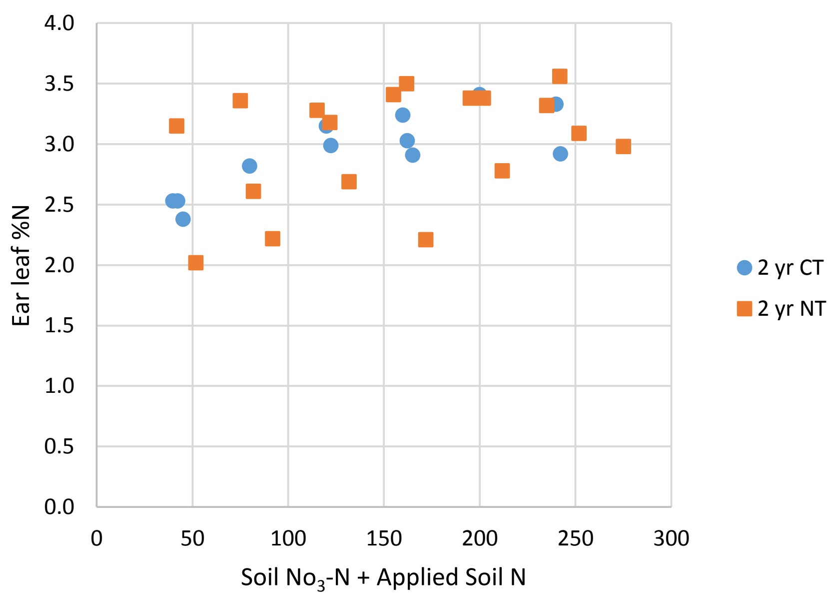

Figure 15. 2014- Soil N influence on percent corn ear leaf N at R1 growth stage in a corn/soybean rotation (2 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems.

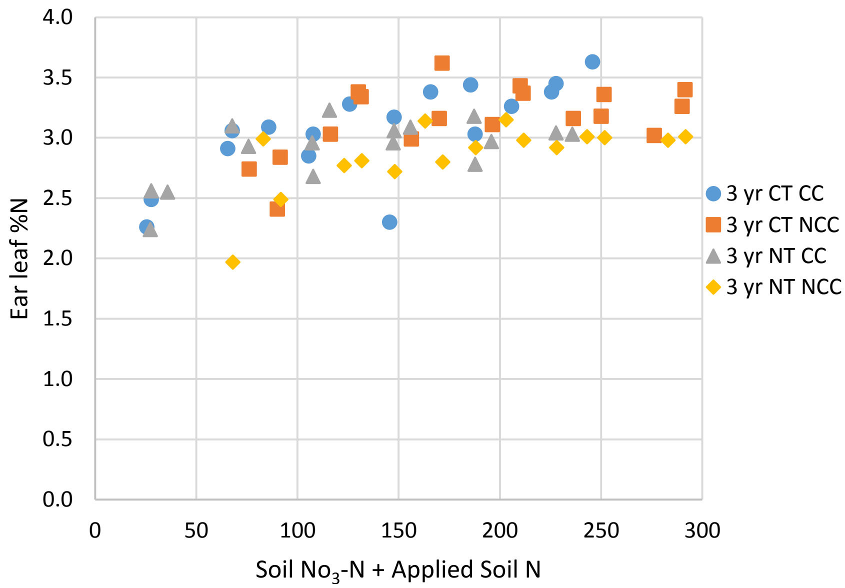

Figure 16. 2014- Soil N influence on percent corn ear leaf N at R1 growth stage in a corn/soybean/winter wheat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crops (CC and NCC, respectively).

Ear leaf N measurements at the R1 growth stage increased with applied N rate, as expected (Table 7). When soil nitrate N was added to applied N in Figure 15, the same was true; ear leaf N rose with increased available N. Conventional till treatments showed a trend for higher ear leaf N and on average, ear leaf N concentration was 3.06% in the CT plots versus 2.88% in the NT plots. Rotation and cover crop had little effect when comparing ear leaf N to applied N or soil plus applied N (Table 7, Fig. 15, Fig. 16). This mid-season N data provides an opportunity to monitor what is happening to N within the plant growing system and better interpret N effects on final yield results. The long-term goal of using this reflectance technology is to develop tools for monitoring N uptake and creating fertilizer side-dress application prescriptions.

Stand counts were taken mid-season in 2014, and averaged 33,311 plants ac^{-1} in the two-year rotation, and 32,210 plants ac^{-1} in the three-year rotation (Table 8). This was a typical stand rate for the region, and provided a reliable stand upon which to evaluate treatments. Biomass, shoot N, and yield information are also shown.

Plant biomass production and percent N were measured in the 0 and 160 lbs N ac^{-1} application plots at the R6 corn growth stage (Table 8). With the exception of the two-year CT treatments, data shows an average increase of 25% biomass production from 0 to 160 lbs applied N ac^{-1} in the two-year rotation and a 40% average increase in the three-year rotation. In two-year CT plots, two reps were eliminated due to excessive moisture, therefore only one value represents the entire treatment area making the reported standard deviation relatively high compared to other treatment means.

As expected, plant biomass N increases with applied N rate in all reported cases (Table 8). Overall, it appears there were no major biomass N differences between tillage, rotation, or cover crop treatments. Shoot N represents total biomass yield multiplied by percent N, therefore shoot N values reflect similar trends as the previously described biomass characteristics. Again, with the exception of the CT plots, the two-year rotation plots on average, increased from control (0 N) plots to the accepted regional optimum N rate (160 lbs ac^{-1} N) by 28% shoot N, and the three-year rotation increased 47% on average. CT tended to have higher shoot N due to high biomass yields in the CT system and the three-year rotation had slightly higher shoot N than the two-year rotation, on average in 2014.

Table 8. Plant stand, plant biomass, and grain yield in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in a 2 and 3 year rotation with and without tillage in 2014 and 2015. Data from 2014 is represented by only a few replications and should be viewed with caution.

Rotation[1]	Tillage[2]	Cover Crop[3]	Plant Date[4]	Applied N[5]	Stand[6]	Biomass[7]	Biomass N	Shoot N[8]	Yield	Stand	Biomass	Biomass N	Shoot N	Yield
				lbs ac^{-1}	plants ac^{-1}	lbs ac^{-1}	%	lbs ac^{-1}	bu ac^{-1}	plants ac^{-1}	lbs ac^{-1}	%	lbs ac^{-1}	bu ac^{-1}
					----------------------2014----------------------					----------------------2015----------------------				
Corn/Soy	CT	--	early	0	33106	16780	1.21	203	150	26426	12210	0.98	120	173
				40	32234				173	26136				186
				80	32670				171	25265				195
				120	34848				167	24829				212
				160	33106	11696	1.23	144	184	25265	20204	1.27	257	208
				200	35719				180	25700				211
		--	late	0	--	--	--	--	--	29839	16931	1.06	179	156
				40	--	--	--	--	--	28967				163
				80	--	--	--	--	--	28967				162
				120	--	--	--	--	--	28532				170
				160	--	--	--	--	--	30492	18044	1.25	226	169
				200	--	--	--	--	--	30056				165
	NT	--	early	0	33396	14606	1.16	170	134	23522	16022	0.89	142	145
				40	33977				135	24176				174
				80	33106				160	26136				184
				120	33106				167	23522				206
				160	34267	18287	1.19	217	161	24176	19488	1.24	242	210
				200	30202				163	25265				203
		--	late	0	--	--	--	--	--	29403	14909	1.03	153	126
				40	--	--	--	--	--	29621				151
				80	--	--	--	--	--	28096				164
				120	--	--	--	--	--	28314				162
				160	--	--	--	--	--	29403	16406	1.22	201	168
				200	--	--	--	--	--	31145				158

Table 8 Continued.

Corn/Soy/ Sm. Grain	CT	CC	--	0	34412	14908	1.12	166	133	34412	16014	0.94	151	132
				40	32525				157	32525				154
				80	30492				179	30492				170
				120	31654				179	31654				179
				160	30782	21309	1.29	274	182	30782	17829	1.21	216	179
				200	32815				184	32815				183
		NCC	--	0	31944	11997	1.23	148	153	31944	15113	0.89	135	125
				40	31654				168	31654				155
				80	32525				185	32525				168
				120	34558				178	34558				171
				160	30782	18728	1.28	240	188	30782	17728	1.19	211	179
				200	33106				190	33106				177
	NT	CC	--	0	31073	10831	1.25	135	115	31073	14393	0.86	124	116
				40	31363				141	31363				138
				80	32234				144	32234				157
				120	32815				167	32815				168
				160	33977	15874	1.29	205	169	33977	18045	1.24	223	169
				200	29621				162	29621				168
		NCC	--	0	33686	14088	1.26	178	124	29185	14521	0.90	131	106
				40	30056				154	29403				136
				80	32815				150	29839				163
				120	33396				164	29839				169
				160	32525	16039	1.22	196	170	30056	15935	1.25	198	169
				200	32234				165	28314				164
Mean	CT				32718	15903	1.23	196	172	31339	16943	1.09	186	164
	NT				32150	14208	1.25	178	152	30206	15701	1.08	172	153
	CT	NCC	‘15 late plant date	160-200 lbs ac^{-1} applied N	33178	15212	1.26	192	185	31109	17886	1.22	218	173
	NT				32307	17163	1.20	206	165	29730	16171	1.23	200	165
	2 yr				33311	15342	1.20	183	162	27757	16967	1.11	190	169
		CT	’15 early plant date		33614	14238	1.22	173	171	25604	16207	1.13	188	197
		NT			33009	16446	1.18	193	153	24466	17755	1.06	192	187

Table 8 Continued.

Mean	3 yr				32210	15472	1.24	193	162	31457	16197	1.06	174	158
		CT	CC + NCC		32271	16735	1.23	207	173	32271	16671	1.06	178	164
		NT			32150	14208	1.25	178	152	30643	15724	1.06	169	152
	'15 2 yr	5-May-15	5-May-15		--	--	--	--	--	25035	16981	1.10	190	192
		2-Jun-15	2-Jun-15		--	--	--	--	--	29403	16572	1.14	190	160
	3 yr	CC	CC		31980	15730	1.23	195	159	31980	16570	1.06	178	159
		NCC	NCC		32440	15213	1.25	190	166	30934	15825	1.06	169	157
St. Dev.	CT			160-200 lbs ac^{-1} applied N	1453	3793	0.06	53	15	1775	1168	0.15	37	16
	NT				1377	2418	0.03	31	18	1603	1398	0.18	41	20
	CT	NCC	'15 late plant date		2017	4972	0.04	68	4	1364	223	0.05	11	7
	NT				1666	1589	0.02	15	4	1186	333	0.02	2	5
	2 yr				1380	2862	0.03	33	16	2564	1610	0.15	40	21
		CT	'15 early plant date		2017	4972	0.04	68	4	1364	223	0.05	11	7
		NT			1666	1589	0.02	15	4	1186	333	0.02	2	5
	3 yr				1324	3402	0.06	47	20	1696	1501	0.17	42	21
		CT	CC + NCC		1328	4110	0.08	60	17	1328	1331	0.16	41	19
		NT			1377	2418	0.03	31	18	1674	1698	0.21	50	23
	'15 2 yr	5-May-15	5-May-15		--	--	--	--	--	1003	3668	0.19	69	21
		2-Jun-15	2-Jun-15		--	--	--	--	--	900	1303	0.12	31	12
	3 yr	CC	CC		1420	4314	0.08	60	22	1420	1714	0.19	49	21
		NCC	NCC		1239	2866	0.03	39	19	1843	1395	0.19	42	23

[1]'Corn/Soy' and 'Corn/Soy/Sm. Grain' indicate the 2 and 3 year rotation in which the study took place.
[2]'CT' indicates conventional till since 1991, and 'NT' indicates no-till since 1991.
[3]'CC' and 'NCC' indicate 'cover crop' and 'no cover crop' respectively.
[4]Plant Date: 'early' indicates a 5/5/15 planting date, 'late' indicates a 6/2/15 planting date due to planting error. All 2014 plots were planted on 5/16/14.
[5]Applied 4/10/14 and 4/15/15 as UAN using streamer bar application method.
[6]Stand counts were taken by counting 20' of plot row.
[7]Biomass data was collected on 10' of plot row in 0 and 160 N rate plots at full plant maturity.
[8]Shoot N was calculated by multiplying biomass yield by biomass %N.

As with shoot N, there was a trend for yield to be higher in the CT system than the NT system overall and within each rotation (Table 8). Aside from precipitation, this result could be influenced by yields in non-fertilized control plots. Higher yields in CT areas with no applied N than in NT areas with no applied N may have been due to higher levels of N mineralization from organic matter and C losses than in NT plots where residue was not disturbed. However, when comparing specifically across rates that are considered at or above the accepted regional optimum (160 and 200 lbs ac^{-1} applied N) yield change is comparable to that of the mean across all N rates, leading one to believe precipitation greatly affected this site-year's results. There was no observed average difference in yield between rotations across applied N rates in 2014. In addition, cover crop treatments showed no significant difference in yield.

The dominant feature of the 2014 growing season was the record-setting rainfall for the month of June. The long-term NT soils in this study have been established for over 20 years, and with such time, have a much-improved infiltration rate than that of concurrent CT plots. This is generally viewed as a positive attribute and assists moisture in reaching the plant root zone rather than sitting on the soil surface and running off before infiltration can occur. However, in 2014 June rainfall was 318% of normal; increased infiltration is presumed to have allowed NT areas to become super-saturated (Table 4). Neighboring CT areas experienced a great deal of runoff and did not appear to saturate to the great degree in which the enhanced infiltrated NT plots did. This presumably created less saturated growing conditions for CT plots as compared to NT plots, possibly allowing for more plant growth and N uptake.

Many factors have played a role in forming crop yields however, in 2014 one of the most prominent effects on yield data was environmental. Tillage treatments and minor elevation changes became very influential to data outcomes.

The ANOVA results in Table 9 reflect yield differences at a 5% level of significance. Tillage had a significant effect on the three-year rotation, but not the two-year rotation. One possible factor influencing this was the presence of winter annual weeds, such as cheatgrass (*Bromus tectorum*), in the three-year rotation NT plots. Without fall tillage, weeds can easily develop following a small grain crop. Winter annual weeds are not often found in corn/soybean rotations, so if they had a negative impact on the corn crop it would most likely occur in the three-year rotation NT plots. This is a situation that merits further research. Applied N is significant in both the two and three-year rotation, which is to be expected as N is a vital influential factor in corn production. In the three-year rotation, there is a 'cover crop by N' interaction. When data is sorted, both cover crop and no cover crop plots show tillage and N significance, which infers that cover crops did not cause great yield changes, but tillage and N did.

Table 9. ANOVA output for a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in a 2 and 3 year rotation with and without tillage in 2014 and 2015.

Source	Corn/Soy[1]		Corn/Soy/WW		Mean[2]		Corn/Soy		Corn/Soy/Oat		Mean	
	---2014---						---2015---					
Rot	--		--		ns		--		--		ns	
Till[3]	ns		0.0317		0.0356		ns		0.027		0.0274	
CC[4]	--		ns		--		--		ns		--	
Plant[5]	--		--		--		0.0006		--		--	
N[6]	0.0053		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001	
TillxRot	--		--		ns		--		--		ns	
TillxCC	--		ns		--		--		ns		--	
TillxPlant	--		--		--		ns		--		--	
RotxN	--		--		ns				--		<0.0001	
TillxN	ns		ns		ns		0.0206		ns		0.0364	
CCxN	--		0.0282		--		--		ns		--	
PlantxN	--		--		--		0.0020		--		--	
TillxRotxN	--		--		ns		--		--		ns	
TillxCCxN	--		ns		--		--		ns		--	
TillxPlantxN	--		--		--		ns		--		--	
			CC	NCC			Plant 1	Plant 2			2 yr	3 yr
Till	--	--	0.0416	0.0466	--	--	ns	ns	--	--	ns	ns
N	--	--	<0.0001	<0.0001	--	--	<0.0001	<0.0001	--	--	<0.0001	<0.0001
TillxN	--	--	ns	ns	--	--	ns	0.0487	--	--	0.0487	ns
							CT	NT				
Plant	--	--	--	--	--	--	0.0009	0.0014	--	--	--	--
N	--	--	--	--	--	--	<0.0001	<0.0001	--	--	--	--
PlantxN	--	--	--	--	--	--	0.0047	ns	--	--	--	--
											CT	NT
Rot	--	--	--	--	--	--	--	--	--	--	ns	ns
N	--	--	--	--	--	--	--	--	--	--	<0.0001	<0.0001
RotxN	--	--	--	--	--	--	--	--	--	--	0.0016	ns

[1]'Corn/Soy', 'Corn/Soy/WW', and 'Corn/Soy/Oat' indicate the 2 and 3 year rotation in which the study took place.
[2]'Mean' indicates the means of treatments across the Corn/Soy and Corn/Soy/Oat rotations.
[3]'Till' indicates tillage treatment type: CT or NT.
[4]'CC' indicates cover crop treatment, 'NCC' indicates no cover crop.
[5]'Plant' indicates planting date; in 2015, the 2 year rotation had a 5/5/15 (Plant 1) and 6/2/15 (Plant 2) planting date due to initial planting error.
[6]'N' indicates applied N treatment; treatments of 0, 40, 80, 120, 160, and 200 lbs ac^{-1} were applied to each plot as UAN in 2014 and 2015.

Table 10. Corn grain yield for different levels of applied N with and without a cover crop in a corn/soybean/small grain rotation from a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response with and without tillage in 2014 and 2015.

Year[2]	N rate[3]	----------------CT[1]----------------			---------------NT---------------		
	lbs ac^{-1}	CC[4,5]	NCC	Mean	CC	NCC	Mean
2014	0	133b	153c	--	115b	124c	--
	40	157c	168b	--	141c	154ab	--
	80	179a	185a	--	144c	150b	--
	120	179a	178ab	--	167a	164ab	--
	160	182a	187a	--	169a	170a	--
	200	184a	190a	--	162a	165ab	--
	mean	169	177	--	150	155	--
	CV	3.30	4.59	--	5.23	6.35	--
2015	0	132c	125c	128c	116c	106c	111c
	40	154b	155b	154b	138b	136b	137b
	80	170ab	168ab	169a	157a	163a	160a
	120	179a	171ab	175a	168a	169a	169a
	160	179a	179a	179a	169a	169a	169a
	200	183a	177a	180a	168a	164a	166a
	mean	166	163	164	153	151	152
	CV	7.62	8.02	7.63	6.63	5.68	5.94

[1]'CT' indicates conventional till since 1991, and 'NT' indicates no-till since 1991.
[2]CC treatment was not significant in 2015, individual treatment means are provided for reader information.
[3]Applied 4/10/14 and 4/15/15 as UAN using streamer bar application method.
[4]'CC' and 'NCC' indicate 'cover crop' and 'no cover crop' respectively.
[5]Fisher LSD tests are placed per column, in an effort to compare applied N treatments.

Table 9 shows no overall cover crop significance in the three-year rotation and cover crop interaction with tillage is similar across cover crop treatments. Seeing as initial soil N tended to be less in the 'cover crop' plots than 'no cover crop' plots but showed no significant yield difference between the two treatments in 2014, the N that was initially in cover crop residue at the beginning of the season presumably became available to the corn plants throughout the growing season. This resulted in no significant impact on yield (Table 9, Table 6). Further research on cover crop mixtures and N mineralization should be performed to explore this process.

N rate significantly impacted all treatments within this study, however, there was a ‘cover crop by N’ interaction in the 2014 three-year rotation (Table 9). Table 10 indicates that at zero applied N, cover crop treatment yields trended lower than plots without cover crops in the 2014 growing season, but appeared higher yielding in the 2015 growing season. Again, this may be due to an infiltration effect caused by excessive rainfall in 2014. Cover crop effects were non-significant at and above 80 lbs ac^{-1} applied N on all treatments at this site in both 2014 and 2015, with the exception of the 2014 NT plot yields which were not significantly different at or above 120 lbs ac^{-1} applied N.

Table 11 describes corn grain yield across rotation, tillage, and applied N treatments. Tillage and N were significant in the 2014 cropping year within this data set (Table 9). Yield differences between tillage treatments were not as one might have expected in a long-term NT setting, however, it is presumed extensive rainfall caused CT plots to have significantly higher yields than NT plots under such conditions. Rotation was not significant when comparing across corn/soy and corn/soy/small grain cropping systems, which may also be attributed to extensive rainfall concealing effects on yield.

In order to further examine characteristics of each rotation, data was analyzed by rotation. Table 12 depicts the corn/soybean rotation yields and statistics. In 2014, applied N was the only significant effect within the two-year rotation (Table 9). Conventional till yields showed no significant difference from 40 lbs ac^{-1} and above applied N, and in NT treatments all rates from 80 lbs ac^{-1} applied N and above showed no significant differences (Table 12). In the three-year rotation, plots with and without cover crops showed significance within both tillage treatments and applied N rates (Table 9). Again, we would expect N to have a significant impact on plant health and yield due to the range of rates applied, however the effects of tillage in the three-year rotation could be due to the presence of winter annual weeds, particularly cheatgrass, which was destroyed by fall tillage in CT plots, but was not controlled until planting in the NT plots. Yield effects between tillage treatments will be described in detail later in the text.

Table 11. Corn grain yield analyzed across rotation, tillage, and applied N in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in a 2 and 3 year rotation with and without tillage in 2014 and 2015 (late planted).

	N Rate[1]	---Corn/Soy[2,3]---		Corn/Soy/Sm.Grain[5]		------Mean------	
Year[6]	lbs ac^{-1}	CT[4]	NT	CT	NT	CT	NT
2014	0	150b	134b	153c	124d	152c	129c
	40	173ab	135b	168b	154abc	171b	145b
	80	171ab	160a	185a	150b	178ab	155a
	120	167ab	167a	178ab	164abc	173ab	166a
	160	184a	161a	187a	170ac	186a	166a
	200	180a	163a	190a	165abc	185a	164a
	mean	171	153	177	155	174	154
	CV	5.99	7.08	4.59	6.35	7.96	8.85
2015	0	156b	126b	125c	106c	--	--
	40	163ab	151a	155b	136b	--	--
	80	162ab	164a	168ab	163a	--	--
	120	170a	162a	171ab	169a	--	--
	160	169a	168a	179a	169a	--	--
	200	165ab	158a	177a	164a	--	--
	mean	164	155	163	151	--	--
	CV	3.87	8.04	8.02	5.68	--	--

[1]Applied 4/10/14 and 4/15/15 as UAN using streamer bar application method.
[2]'Corn/Soy' and 'Corn/Soy/Sm. Grain' indicate the 2 and 3 year rotation in which the study took place.
[3]Fisher LSD test are placed per column, in an effort to compare applied N treatments.
[4]'CT' indicates conventional till since 1991, and 'NT' indicates no-till since 1991.
[5]Data pooled for the 2015 3 year rotation is without cover crop and planted late on 6/2/15 as compared to 2014 plots that were planted 5/16/14.
[6]2014 corn was planted on 5/16/14; 2015 corn was planted on 6/2/15.

Table 12. Corn grain yield of May-planted corn compared across tillage systems in a corn/soybean rotation from a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response with and without tillage planted in May of 2014 and 2015.

N Rate[1]	CT[2,3]	NT	mean	CT	NT	mean
lbs ac^{-1}	---------------2014--------------			--------------2015--------------		
0	150b	134b	142b	173c	145d	159c
40	173ab	135b	154b	186bc	174c	180b
80	170ab	160a	165a	195b	184bc	190b
120	167ab	166a	167a	212a	206a	209a
160	183a	160a	172a	208a	210a	209a
200	180a	163a	172a	211a	203ab	207a
mean	171	153	162	198	187	192
CV	5.99	7.08	8.35	4.18	7.19	6.79
		-2014-	-2015-			
Pr > F	till	ns	ns			
	n	0.0053	<0.0001			
	till*n	ns	ns			

[1]Applied 4/10/14 and 4/15/15 as UAN using streamer bar application method.
[2]‘CT’ indicates conventional till since 1991, and ‘NT’ indicates no-till since 1991.
[3]Fisher LSD test are placed per column, in an effort to compare applied N treatments.

Table 13. Corn grain yield of treatments above optimum observed spring soil NO_3-N compared across rotation and tillage regime from a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in a 2 (2015, 5/5/15 planting date) and 3 year (2015, 6/2/15 planting date) rotation with and without tillage in 2014 and 2015.

Till	Corn/Soy[1,3]	Corn/Soy/ WW	Mean	Corn/Soy	Corn/Soy/ Oat[4]	Mean
	----------------2014-----------------			-----------------2015------------------		
CT[2]	181	189	185	210	178	194
NT	162	168	165	207	167	187
mean	172	179	176	208	173	191
CV	3.80	2.67	5.00	5.34	3.60	11.6
		-2014-	-2015-			
Pr > F	rot	ns	--			
	till	0.0001	ns			
	rot*till	ns	ns			

[1]'Corn/Soy', 'Corn/Soy/WW', and ‘Corn/Soy/Oat’ indicate the 2 and 3 year rotation in which the study took place.
[2]‘CT’ indicates conventional till since 1991, and ‘NT’ indicates no-till since 1991.
[3]Fisher LSD test are placed per column, in an effort to compare applied N treatments.
[4]Data pooled for the 2015 3 year rotation is without cover crop and planted late on 6/2/15 as compared to 2014 plots without cover crop that were planted 5/16/14.

Tillage is the only significant factor when applied N rates that produce at or above determined optimum yields in this study (160 lbs ac^{-1} and 200 lbs ac^{-1} applied N) are pooled (Table 13). This implies that when N is not a limiting factor of production, tillage systems can have a great effect on corn yield outcomes, when comparing a long-term NT system with a CT system in a very wet year. Conventional till plots yielded significantly higher than NT plots overall (12% increase) at or above determined optimum N rates. The average yield with optimum soil N across rotations and tillage treatments was 176 bu ac^{-1} in the 2014 cropping season.

As a part of this N study, two recommendation methods were put to the test and compared to the observed optimum N rate found by a linear plateau statistic (Fig. 17, Table 14). Based upon spring soil nitrate and ammonium tests, recommendations were calculated using the Haney method and the SDSU N recommendation method. Each method uses its own calculations to develop an N recommendation for the growing season. The Haney method uses H^3A nitrate, H^3A ammonium, and organic N release to calculate a plant available soil N value using a 0 to 6 inch soil sample depth. The SDSU method uses [yield goal * 1.2 (a set factor developed in 2005) less any credits given for soil nitrate N, manure, or previous legume crops].

In 2014, SDSU recommendations did not follow a direct trend with the observed optimum N rate and often suggested over application of N fertilizer (Fig. 17). This appears to be worse in areas where a fall cover crop was present or volunteer oats were involved. The Haney recommendations did not follow a clear pattern with the observed optimum either, as over-application of N was suggested in many treatments. This data may be confounded due to the unseasonably wet weather, which could have caused N to move and/or pool. Both methods provided a reasonable recommendation for the two-year rotation NT treatments, which had an observed optimum applied N rate of 102 lbs N ac^{-1}, whereas, SDSU suggested 100 lbs ac^{-1} and Haney, 105 lbs of N ac^{-1} (Table 14). In three-year NT plots the SDSU recommendations suggested over-application, especially in cover cropped areas, but Haney recommendations were slightly under the mark with 3 lbs ac^{-1} difference in cover cropped plots and 14 lbs ac^{-1} difference in NT plots with no cover crops. Neither method represented an inclusive ideal recommendation in this cropping year, however, conditions were abnormal. It appears that the Haney method captured some cover crop N credit, however, the SDSU recommendations did not account for cover crop N in the calculated methodology.

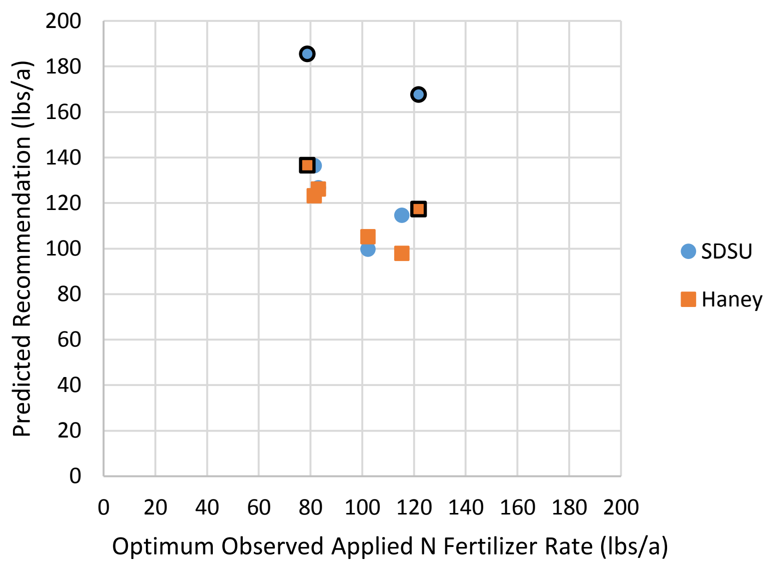

Figure 17. 2014- SDSU and Haney predicted N fertilizer recommendations (with no cover crop credit) vs. observed applied N fertilizer in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in a 2 and 3 year rotation with and without tillage. Note: outlined data points had a previous cover crop.

Table 14. Spring soil test results and N recommendations from a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in a 2 and 3 year rotation with and without tillage in 2014 and 2015.

Year	Rotation[1]	Tillage[2]	Cover Crop[3]	Plant Date	NO_3-N	NH_4-N	Haney N[4]	Legume Credit[5]	SDSU N Rec.[6]	Haney Rec.[7]	Obs. Opt. N Rate[8]
					-----lbs ac^{-1} (0-2')-----		lbs ac^{-1} (0-6")	----------------lbs ac^{-1}----------------			
2014	2 yr	CT	--	--	42.3	23.7	48.0	40.0	126.7	126.2	83.1
		NT	--	--	56.2	31.1	58.0	40.0	100.0	105.4	102.2
	3 yr	CT	CC	--	33.1	28.3	45.6		184.0	135.3	78.8
			NCC	--	85.9	22.8	62.1		136.3	123.1	81.4
		NT	CC	--	30.3	28.3	47.6		169.0	118.5	121.8
			NCC	--	80.9	30.2	65.1		118.9	101.5	115.3
2015	2 yr	CT	--	5-May-15	54.1	62.9	54.5	40.0	157.4	155.2	120.0
			--	2-Jun-15	54.1	62.9	54.5	40.0	105.7	112.0	59.9
		NT	--	5-May-15	37.8	66.7	38.5	40.0	170.0	168.0	121.1
			--	2-Jun-15	37.8	66.7	38.5	40.0	117.7	124.4	59.0
	3 yr	CT	CC	--	22.0	57.9	33.7		194.4	146.7	100.3
			NCC	--	19.2	50.7	31.7		191.9	144.3	89.2
		NT	CC	--	18.5	58.4	32.2		183.5	136.2	99.8
			NCC	--	18.6	56.6	31.7		182.6	136.0	85.6

[1]'2 yr' indicates a corn/soybean rotation, '3 yr' indicates a corn/soybean/small grain rotation.
[2]'CT' indicates conventional till since 1991, and 'NT' indicates no-till since 1991.
[3]'NCC' and 'CC' indicate 'no cover crop' and 'cover crop' respectively.
[4]'Haney N' indicates plant available soil N according to the Haney Method which adds soil H^3A nitrate, H^3A ammonium, and organic N release together to develop a 0-6" plant available soil N value.
[5]A 40 lbs ac^{-1} legume credit is recommended by the SDSU Soil Testing Lab when soybeans are grown as a previous crop.
[6]SDSU N recommendations are calculated by: (yield goal*1.2)-'0-2' soil test nitrate-legume credit. No cover crop credit is taken into account.
[7]Haney recommendations are calculated by: yield goal-Haney soil N calculation.
[8]Observed optimum N rate reflects the observed optimum N rate when plotted against yield using linear plateau statistics.

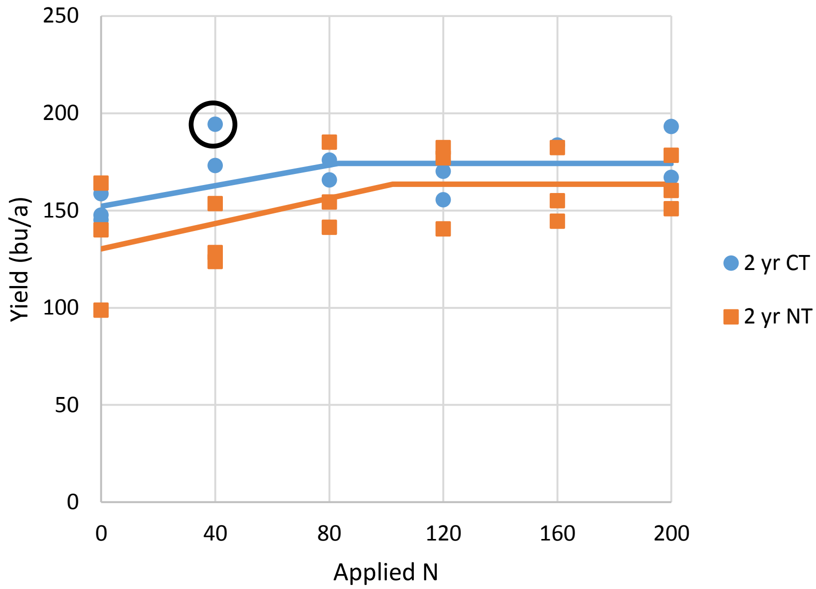

Figure 18. 2014- Corn grain yield vs. applied N on a corn/soybean rotation (2 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems. Note: circled data was treated as an outlier.

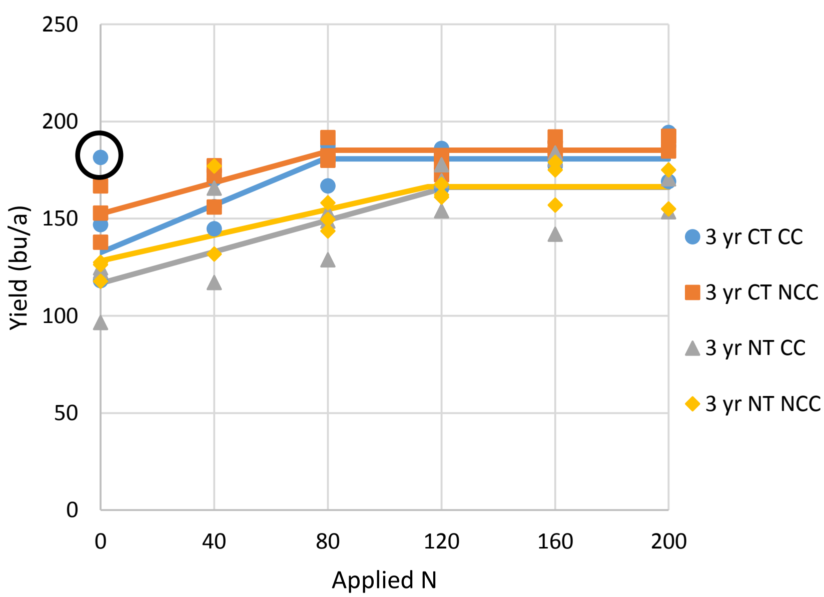

Figure 19. 2014- Corn grain yield vs. applied N on a corn/soybean/winter wheat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crop (CC and NCC, respectively). Note: circled data was treated as an outlier.

This study evaluated optimum N levels by fitting data to a linear plateau model (Fig. 18). In 2014, CT plots tended to yield significantly higher, on average, than NT plots (Table 9, Table 11). Within the two-year rotation, CT plots had an optimum applied N rate of 83 lbs ac^{-1} N, which resulted in a yield of 174 bu ac^{-1}. No-till plots in the same rotation had an optimum N rate of 102 lbs ac^{-1} applied N and the yield at such point was 163 bu ac^{-1} (Fig. 18). This leaves a 19 lbs ac^{-1} gap between CT and NT N needs to reach optimum levels in 2014. Precipitation is one explanation for such a gap in optimum N rate between tillage systems.

Figure 19 explains yield vs. applied N in a three-year rotation under CT and NT with and without a cover crop. Conventional till plots yielded significantly higher than no till plots in the 2014 three-year rotation. Cover crop treatments had very little effect on optimum N rate in either tillage system, which again leads one to believe that cover crop residue broke down throughout the season and released N back into the system, making it available to corn plants (Table 6). When comparing tillage treatments in the corn/soybean/small grain rotation, CT treatments had an average optimum N rate of 80 lbs N ac^{-1} and NT plots averaged 119 lbs N ac^{-1} as optimum, a difference of 38 lbs N ac^{-1} in 2014 (Fig. 19). This is a dissimilar result to the 2014 two-year rotation data. However, another interesting factor concerning these plots is the slope of the linear line which meets the plateau point.

In the three-year rotation, cover cropped plots appear to be more sensitive to N application regardless of tillage system, up until optimum N is reached (Fig. 19). In the two-year rotation, NT systems appeared to be more sensitive to N application with a slope of 0.33, as compared to CT plots which had a slope of 0.26. At this point, the data lends no firm conclusion as to whether this is a consistently occurring phenomena or an effect of the particular site and year.

When grain yield is compared to soil nitrate N plus applied N, slight differences are seen (Fig. 20). In the two-year rotation, optimum soil nitrate N plus applied N was 125 lbs ac^{-1} in the tilled plots and 155 lbs ac^{-1} in NT plots, leaving a 30 lbs ac^{-1} optimum N gap between the two tillage treatments at this location in 2014. This does follow a similar pattern as that of the yield vs. applied N data in Figure 18, however the N gap is greater between tillage regimes; when total plant available N is taken into consideration, this data suggests that NT required 30 lbs additional plant available N per acre in 2014 at this site. However, due to moisture conditions, the results of the 2015 growing season should be taken into consideration before firm conclusions are made.

In Figure 21, the three-year rotation is represented; once more cover crop has very little effect on NT plots, but it does appear to decrease the total optimum N rate in CT plots resulting in a 42 lbs ac^{-1} optimum N difference in applied plus soil nitrate N between cover crop treatments. No-till cover crop treatments differed by only 10 lbs ac^{-1} optimal N, but had nearly identical yields at the optimal N rate. However on average, NT plots yielded 19 bu ac^{-1} less than CT plots in 2014. In this case, NT plots were not able to reach the yield of CT plots with the same level of applied N or plant available N, which was optimized in both tillage systems. This could be a result of the specific year and location, considering conditions, and the 2015 cropping season should be taken into account.

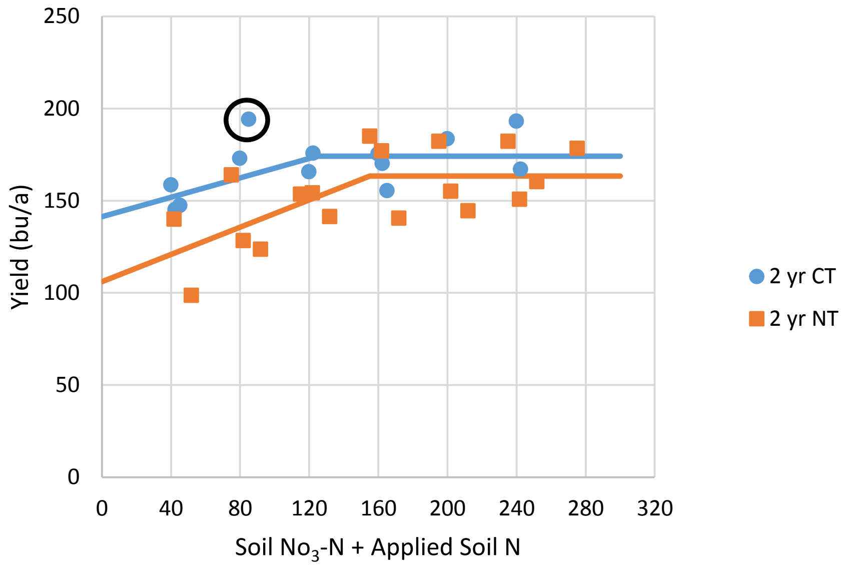

Figure 20. 2014- Corn grain yield vs. soil N on a corn/soybean rotation (2 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems. Note: circled data was treated as an outlier.

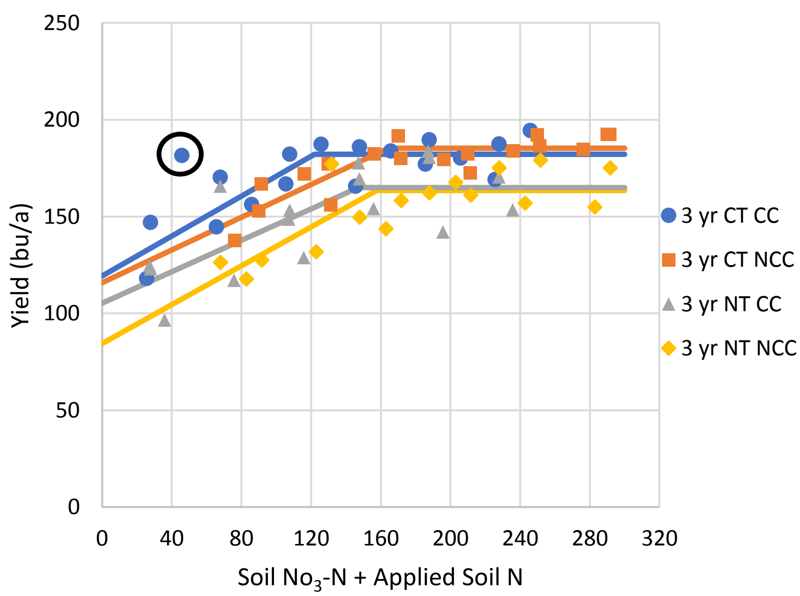

Figure 21. 2014- Corn grain yield vs. soil N on a corn/soybean/winter wheat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crop (CC and NCC, respectively). Note: circled data was treated as an outlier.

2015 Growing Season

The 2015 growing season was one of relatively ideal temperature and moisture for row crop production at the SDSU Southeast Research Farm. Early spring precipitation was slightly short, but as spring moved into summer, precipitation fell and crops grew under quite ideal conditions (Table 5). This weather pattern eliminated most extremes throughout the growing season that may have caused environmental stress-related variation in yield data.

In this season, due to planter errors affecting stands in the three-year rotation, half of each two-year rotation plot and all three-year rotation plots were re-planted on June 2, 2015. Due to this late planting date and fewer growing degree days, yields were decreased by about 35 bu ac^{-1} on average in these plots.

Spring 2015 soils in the corn/soybean crop rotation showed slight differences between the CT and NT plots with 54 lbs ac^{-1} and 38 lbs ac^{-1} NO_3-N from 0 to 2 feet deep, respectively (Table 6). The corn/soybean/small grain rotation appeared quite similar in soil nitrate N levels regardless of cover crop regime. One might expect cover crop plots to contain less N than plots that were not cover cropped, due to plant uptake throughout the fall growing season; but in this case no apparent difference was seen. This is suspected to have been caused by heavy volunteer oat pressure across the three-year rotation from the previous oat crop. Oat harvest lends to blowing light seed back on the field in order to increase harvested grain test weight. With many oat seeds laying on the soil surface, under ideal growing conditions, a great deal of volunteer oats grew. These oats most likely used available nitrate N, eliminating obvious cover crop effects for the

2015 season. In contrast, initial 2014 soil N levels tended to be different across cover crop plots, however the previous crop was winter wheat, which lent itself to much fewer volunteer plants.

Soil organic matter was similar across all treatments, as was the Haney N indicator, with the exception of the two-year rotation CT plots, which had about 16 lbs ac^{-1} more available N according to the Haney method than two-year NT plots (Table 6). It is possible that due to accelerated residue decomposition under CT, organic N release (ie: mineralization) may have been higher in this treatment, boosting the Haney N level as compared to NT systems. This difference was not observed in the three-year rotation, however the previously mentioned volunteer oat situation may have disguised such data. The Haney soil health index follows the same trend as the Haney N test, which indicates that the two-year rotation CT soils are considered the healthiest in this study, followed by the two-year rotation NT plots, and finally the three-year rotation (Table 6).

At V6-V8, SPAD readings were taken on each plot of the study. These chlorophyll readings indicated that as a general rule, as applied N fertilizer rates increased, so did leaf chlorophyll content (Table 7). As N rates reached a perceived applied optimum, SPAD readings increased in almost all cases, but tended to waver at or beyond the optimum. This most likely indicates that chlorophyll content was not changing greatly beyond such point. Figure 22 illustrates SPAD reading vs. soil nitrate N plus applied N, it shows a relatively flat slope for both CT and NT regimes (0.01 and 0.02, respectively), indicating that leaf chlorophyll content did not change greatly when all measured available N was taken into account. Figure 23 shows that in the three-year rotation, a clearer curve is apparent as soil plus applied N increases and begins to level off, meaning plant uptake was more consistent with applied N, up to an optimum point in the three-year rotation than in the two-year rotation. On average, CT and NT plots appeared to have similar chlorophyll readings across N rates; the same is true when comparing the two and three-year rotations. Within the three-year rotation, cover crops tended to have no effect on leaf chlorophyll content. When compared to the 2014 data, the only clear difference is that CT plots in 2014 tended to have higher chlorophyll readings than NT plots, most likely due to an infiltration effect with excessive rainfall (Table 7).

In addition to SPAD meter readings, NDVI index readings were obtained using a hand-held Greenseeker®. NDVI readings within the two-year rotation did not follow a clear trend. There appeared to be little change between CT N treatments and a tendency for a slight increase in readings as applied N rates rose in NT systems (Table 7). Figures 24 and 25 indicate no clear overall increase in NDVI reading with a rise in soil nitrate plus applied N in either rotation with the exception of a few outliers. This indicates canopy cover did not differ greatly between N plots, which could be due to substantial initial soil NO_3-N and NH_4-N test levels. The three-year rotation shows an increasing trend within treatments as applied N rate increases, but none of great consequence (Table 7).

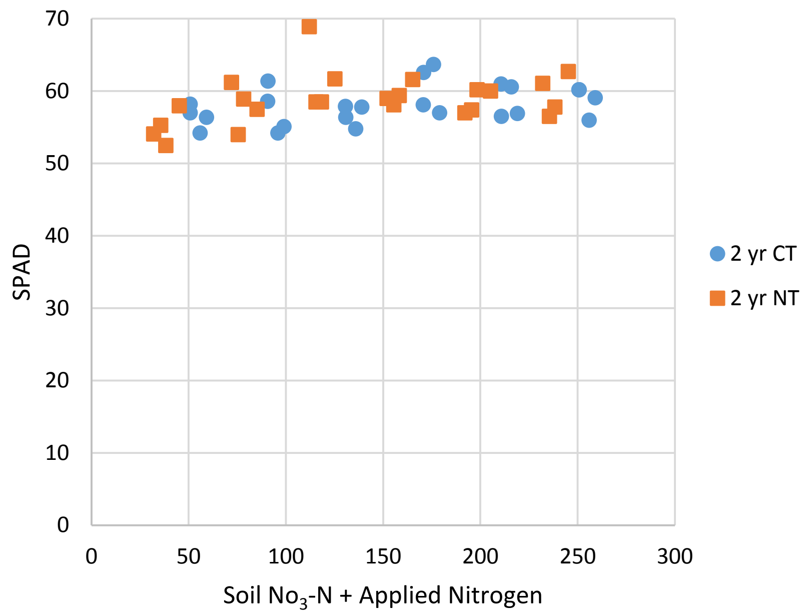

Figure 22. 2015- Soil N influence on SPAD meter readings at V6-V8 growth stage in a corn/soybean rotation (2 yr) planted on 6/2/15 in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and

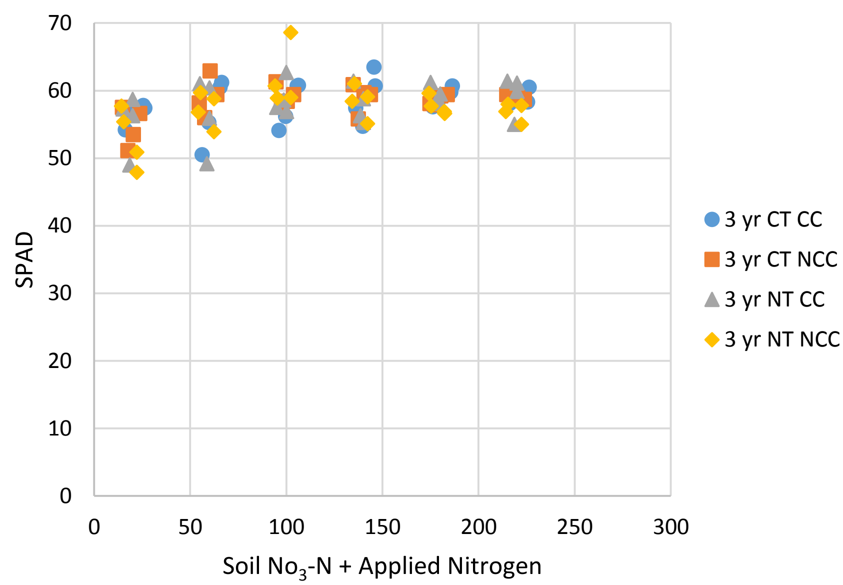

Figure 23. 2015- Soil N influence on SPAD meter readings at V6-V8 growth stage in a corn/soybean/oat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crop, (CC and NCC, respectively).

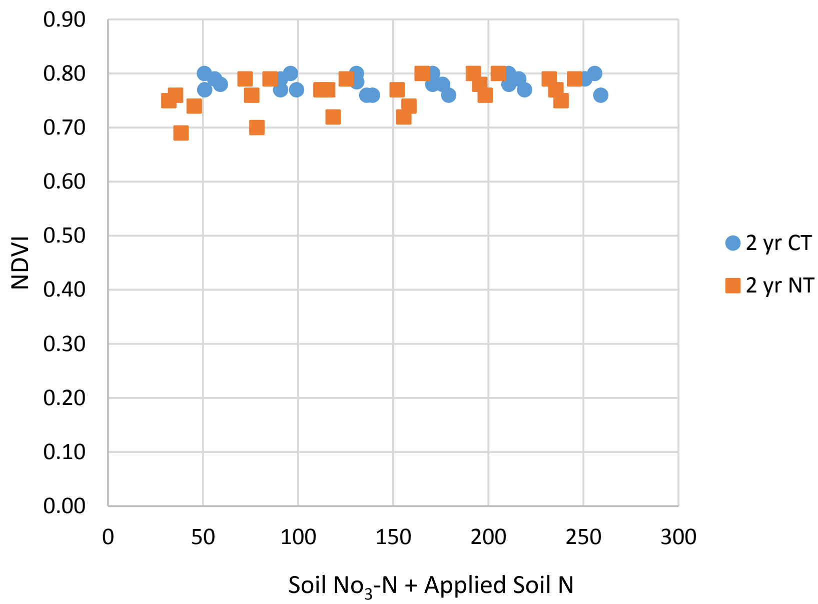

Figure 24. 2015- Soil N influence on NDVI readings at V6-V8 growth stage on a corn/soybean rotation (2 yr) planted on 6/2/15 in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems.

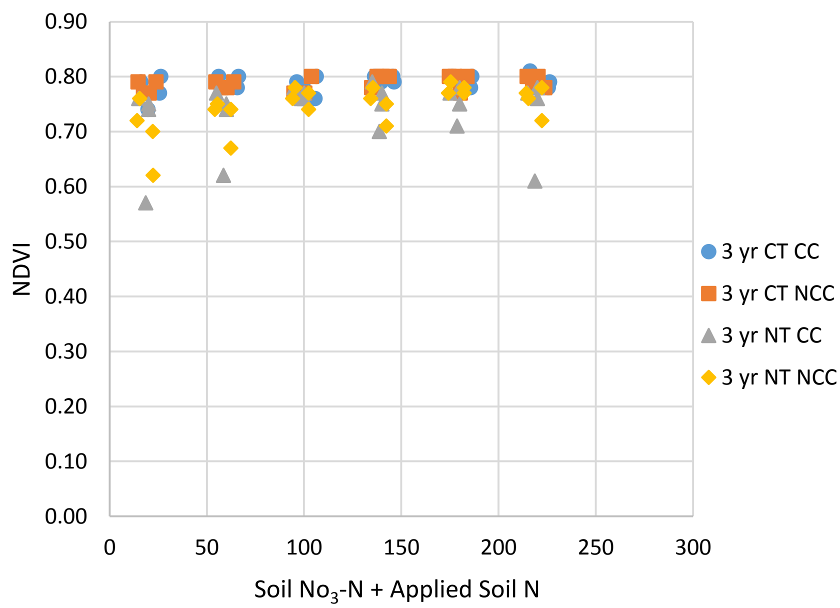

Figure 25. 2015- Soil N influence on NDVI readings at V6-V8 growth stage on a corn/soybean/oat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT, with and without cover crop (CC and NCC, respectively).

Table 7 also describes ear leaf N data, which is the most reliable method of plant N measurement compared within this data set. As with SPAD readings, ear leaf N within both rotations increased as applied N rate rose in general. Figures 26 and 27 also indicate this when comparing ear leaf N with soil nitrate plus applied N. Within the two-year rotation, planting date and tillage had little effect, but all data follows a globally increasing slope of 0.0026. The three-year rotation increases to an optimum point and visually levels off with a very similar global slope of 0.003. This is expected, as plants with more available N would assumedly obtain higher plant N concentration to a certain maximum degree. Ear leaf N shows no great differences across tillage treatments. But in 2014, CT treatments tended to be on average, 0.18% higher in ear leaf N than did NT treatments. In 2015 ear leaf N data, the two-year rotation is on average, 2.65% N and the three-year rotation, 2.54% N. In addition, late planted corn is only about 0.1% N higher in ear leaf N content than early planted corn, showing no apparent noteworthy difference. In this case, with consideration to ear leaf N content, it seems that SPAD readings were a reliable indicator of crop N status on a relative basis.

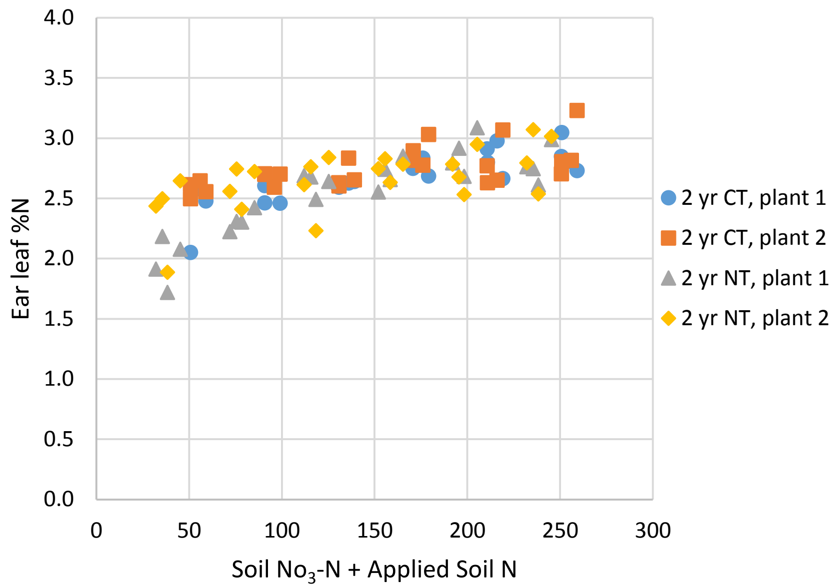

Figure 26. 2015- Soil N influence on percent corn ear leaf N at R1 growth stage in a corn/soybean rotation (2 yr) with an early (5/5/15- plant 1) and late (6/2/15- plant 2) planting date in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems.

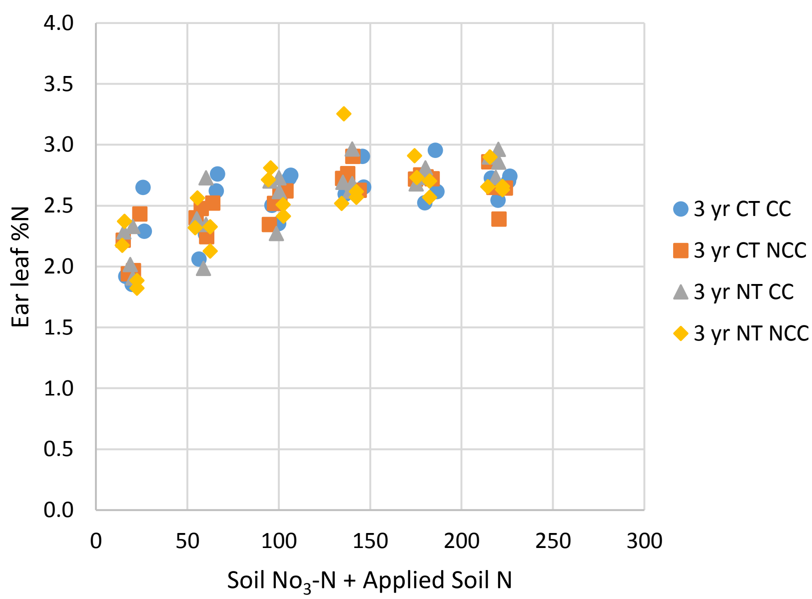

Figure 27. 2015- Soil N influence on percent corn ear leaf N at R1 growth stage in a corn/soybean/oat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crop (CC and NCC, respectively).

Plant stand is another important indicator of study soundness and yield. The 2015 two-year rotation early planting date had an average plant stand of 25,035 plants per acre (Table 8). Due to poor stands, especially in the three-year rotation, a second planting date was added to the two-year rotation, which averaged 29,403 plants per acre; after re-planting, the three-year rotation had an average plant stand of 31,457 plants per acre. Throughout the data analysis, planting dates are separated to compare tillage and rotation, as planting date had a large impact on yield.

Shoot N was calculated for the 2015 growing season, based upon plant biomass yield and percent N (Table 8). Shoot N tended to be slightly higher (5%) in CT plots than NT plots at optimum applied soil N levels. Planting date had very little impact on shoot N and treatments with cover crops showed a trend for increased shoot N by an average of 9% at the 160 lbs ac^{-1} applied N rate. Yield data follows the trend of shoot N content, which is to be expected as increased N content historically correlates with increased yield to an optimum extent. However, planting date had a 21% effect on yield with basically no effect on shoot N values, indicating that N was not the most limiting factor in yield production within these treatments.

Table 9 takes a closer look at what factors played the most important role in yield results. As expected, in the two-year rotation, planting date was highly significant as well as N application, which is to be expected. Also, ‘tillage by N’ and ‘planting date by N’ interactions were significant. When interactions were investigated, within CT there was a significant ‘plant by N’ interaction; within the late planting date only, there was a ‘tillage by N’ interaction. Therefore, within the late planted two-year rotation CT plots interacted with N, but there was no tillage by N interaction in early planted plots. The three-year rotation only indicated tillage and N significance with no significant interactions. This reflects data reviewed thus far and will be further examined in the following text. Because rotation shows no significance, values were averaged across the two and three-year rotation for late planted corn, resulting in tillage and N significance as well as a 'rotation by N' interaction and a 'tillage by rotation' interaction. Within the two-year rotation alone, a 'tillage by N' interaction was observed and a 'planting date by N' interaction occurred in CT plots.

Table 10 explains cover crop effects. In 2015, within the three-year rotation CT treatments, it is clear that yields increased as applied N rates increased, and tended to individually plateau at 120 to 160 lbs N ac^{-1}. Overall, yields did not significantly differ across cover crop treatments (Table 9). No-till plots were statistically similar at or above 80 lbs ac^{-1} applied N and displayed no significant difference between cover crop treatments (Table 10, Table 9). When both CT and NT plots are averaged across cover crop treatments, yields are not statistically different at applied N rates above 80 lbs ac^{-1}.

Yield was also analyzed across rotation, tillage and applied N in Table 11. Within the two-year rotation under late planting, the average yield across N rates for the CT plots appeared to be higher than NT plots by 9 bu ac^{-1}, but this was non-significant. It is also interesting that all yields from 40 to 200 lbs N ac^{-1} were statistically similar in NT and CT systems, meaning the crop did not respond to applied N beyond 40 lbs ac^{-1} at a statistically significant level in this component of the trial. In an average across N treatments, the three-year rotation CT plots yielded 12 bu ac^{-1} higher than NT plots and statistically plateaued at 80 lbs N ac^{-1} as did the NT plots.

A significant tillage effect was not expected in this study; one possible explanation for yield loss in the three-year rotation was the presence of winter annual weeds. The small grain allowed a window for winter annual weeds to develop in NT soils that typically would not have survived in a corn/soybean rotation, nor under CT systems. Under NT conditions, winter annuals (such as cheatgrass) may have caused an allelopathic effect on corn plants, resulting in slightly lower yields than CT plots. This is an inference based upon weed growth observations in the spring of 2015.

The 2015 two-year rotation data also has unique characteristics. Table 9 indicates a significant plant date factor. Table 15 indicates that on average, within CT plots, early planted plots (planted May 5, 2015) appeared to yield 34 bu ac^{-1} more than late planted plots (planted June 2, 2015). The NT system also tended to have a yield bump in early planted plots with a 32 bu ac^{-1} yield advantage above late planted plots. Late planting and the factors associated with it had a strong negative impact on yield. Because tillage effect was not statistically significant (Table 9), data was averaged across tillage treatments lending a 32 bu ac^{-1} yield advantage to early planted over late planted plots across tillage treatments. It is also interesting to note that early planted plot yields were statistically similar at 120 lbs ac^{-1} applied N, whereas late planted plots did not respond significantly beyond 40 lbs N ac^{-1} (Table 15).

Table 15. Corn grain yield compared across planting dates and tillage treatments in a corn/soybean rotation from a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response with and without tillage in 2015.

N Rate[1]	-----------CT[3,4]---------		-----------NT-----------		-------Mean-------	
lbs ac^{-1}	5-May-15[2]	2-Jun-15	5-May-15	2-Jun-15	5-May-15	2-Jun-15
0	173c	156b	145d	126b	159c	141b
40	186bc	163ab	174c	151a	180b	157a
80	195b	162ab	184bc	164a	190b	163a
120	212a	170a	206a	162a	209a	166a
160	208a	169a	210a	168a	209a	169a
200	211a	165ab	203ab	158a	207a	162a
mean	198	164	187	155	192	160
CV	4.18	3.87	7.19	8.05	6.79	8.02

[1]Applied 4/15/15 as UAN using streamer bar application method.
[2]Dates indicate planting date. A second planting date was added to this rotation in 2015 due to initial planting error.
[3]'CT' indicates conventional till since 1991, and 'NT' indicates no-till since 1991.
[4]Fisher LSD tests are placed per column, in an effort to compare applied N treatments.

The 2015 two-year rotation early planted plots provide clear data trends. Both tillage systems appear to plateau statistically at 120 lbs applied N ac^{-1} (Table 12). Tillage effects were non-significant and there was no significant tillage interaction between systems; only N was significant (Table 9). At low N rates early planted CT plots tended to show better yield than NT plots, however, at N rates greater than 120 lbs ac^{-1} yields were similar. A mean yield of 192 bu ac^{-1} was realized across tillage systems and N application rates, on average. This data indicates that N was the limiting factor in yield outcome and the optimum N rate does not tend to be different between tillage systems under a corn/soybean rotation. This data matches the focus of the original hypothesis of this study.

To examine what specifically happens between rotation and tillage systems when N is not limiting, Table 13 was created. When yield data from plots applied with 160 to 200 lbs ac^{-1} N is pooled, there is no significant difference between tillage treatments in 2015.

In an effort to compare different fertilizer recommendations to actual observed optimum N rates in this trial, both the SDSU and Haney fertilizer recommendations were developed and used, based upon spring soil nitrate test results. Table 14 defines the data used to create recommendations and compares each recommendation with the actual observed optimum. In 2015, it is clear that both recommendations suggest over applying N (Fig. 28). On average, SDSU recommendations were 48 lbs ac^{-1} and 94 lbs ac^{-1} over the observed optimum applied N rate in the two and three-year rotation, respectively. The Haney recommendations were on average 50 lbs ac^{-1} and 47 lbs ac^{-1} over the observed optimum in the two and three-year rotation as well (Table 14). However, the Haney data and select SDSU data do follow a consistent, positive trend with increasing optimum observed N. This indicates that neither recommendation was able to perfectly capture the total plant available N based upon biological or chemical soil properties in this case. One major gap appears to be accounting for cover crop N credits, which neither method seemed to do exceptionally well (Fig 28). Research such as this, may help establish more accurate N credits and estimates in various scenarios that would allow such recommendation methods to be updated or improved.

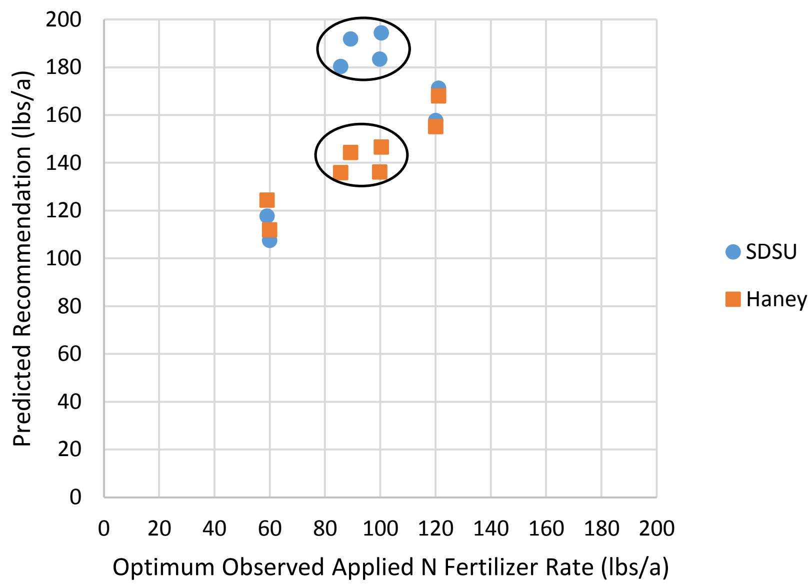

Figure 28. 2015- SDSU and Haney predicted N fertilizer recommendations (with no cover crop credit) vs. observed applied N fertilizer in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in a 2 and 3 year rotation with and without tillage. Note: circled data points had previous cover crop or volunteer oat crop.

Optimum N rates, as discussed previously were developed using a linear plateau model that allows one to estimate where the crops N needs were satisfied. In Figure 24, early and late planting dates are quite clear within the 2015 two-year rotation. In both cases, the optimum N rate for both CT and NT appeared nearly identical, meaning the optimum applied N fertilizer for each tillage system under these circumstances was seemingly the same. Early planting plots had an optimum N rate of 120 lbs N ac^{-1} in CT plots and 121 lbs ac^{-1} in NT plots. These rates coincided with yields of 210 bu ac^{-1} and 207 bu ac^{-1} for CT and NT, respectively. The 2015, early planted data is the best representation of typical southeastern SD on-farm conditions in this trial. Late planted plots broke at an optimum N rate of 60 lbs N ac^{-1} in CT plots and 59 lbs N ac^{-1} in NT plots, with yields of 167 and 163 bu ac^{-1}, correspondingly. It is also apparent that NT systems were more sensitive to N application than CT systems based upon the slope of the line which leads to the optimum N plateau point.

Figure 30 depicts the three-year rotation yield vs. applied N linear plateaus. Conventional till plots tended to yield higher at optimum N rates than NT plots on average, by 12 bu ac^{-1} (Table 10). Optimum N rate on CT plots was 100 lbs ac^{-1} and 89 lbs ac^{-1} for ‘cover crop’ and ‘no cover crop’ plots, respectively. Corresponding yields were 180 bu ac^{-1} and 176 bu ac^{-1}, meaning that 11 lbs of N ac^{-1} only altered yield 4 bu ac^{-1} on average (Fig. 30). No-till plots had similar optimum N rates of 100 lbs ac^{-1} in ‘cover crop’ plots and 86 lbs ac^{-1} in ‘no cover crop’ plots. No-till yields were 168 bu ac^{-1} at the optimum N rate for both ‘cover crop’ and ‘no cover crop’ plots. Although there was a 14 lbs ac^{-1} optimum N difference between cover crop treatments, yield was the same, which means the cover crop treatment may have needed slightly more N in this case.

Figures 31 and 32 provide insight regarding yield in comparison to soil nitrate N plus applied N. The 2015 two-year rotation very clearly describes planting date yield effects and optimum plant available N among tillage systems in 2015. Yield is not significantly different between tillage systems in the early planted rotation (Fig. 31). Optimum soil nitrate plus applied N rates was 163 bu ac^{-1} and 171 lbs ac^{-1} for NT and CT soils, accordingly, indicating that NT soils actually required less plant available N in this scenario. In late planted plots, NT had an optimum soil nitrate plus applied N rate of 93 lbs ac^{-1}, whereas CT required 172 lbs ac^{-1}. However, the CT system had very little response all in to N at this case. Again, (over both planting dates) NT plots showed more sensitively to available N in this scenario than CT plots.

The 2015 three-year rotation indicates a significant yield advantage for CT plots over NT plots of 11 bu ac^{-1} on average, perhaps due to lingering effects of winter annual weeds. Optimum soil nitrate plus applied N rates only differed by 5 lbs ac^{-1} between cover crop treatments (Fig. 32). No-till plots appear to have little yield difference at their optimum N rate of 94 lbs ac^{-1} for 'no cover crop' plots and 120 lbs ac^{-1} in 'cover crop' plots. Again, this indicates that the cover cropped plots tended to need slightly more available N to reach an optimum yield goal in this case.

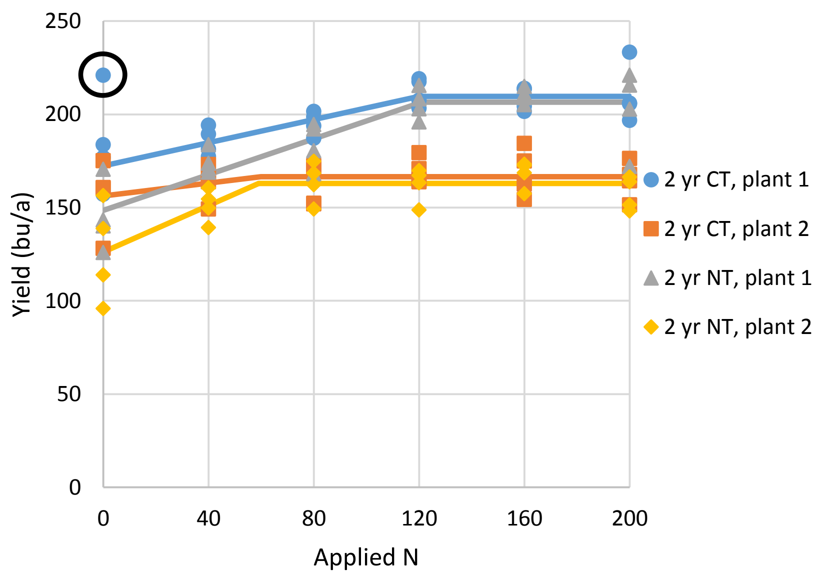

Figure 29. 2015- Corn grain yield vs. applied N on a corn/soybean rotation (2 yr) with an early (5/5/15- plant 1) and late (6/2/15- plant 2) planting date in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crop (CC and NCC, respectively). Note: circled data point was treated as an outlier.

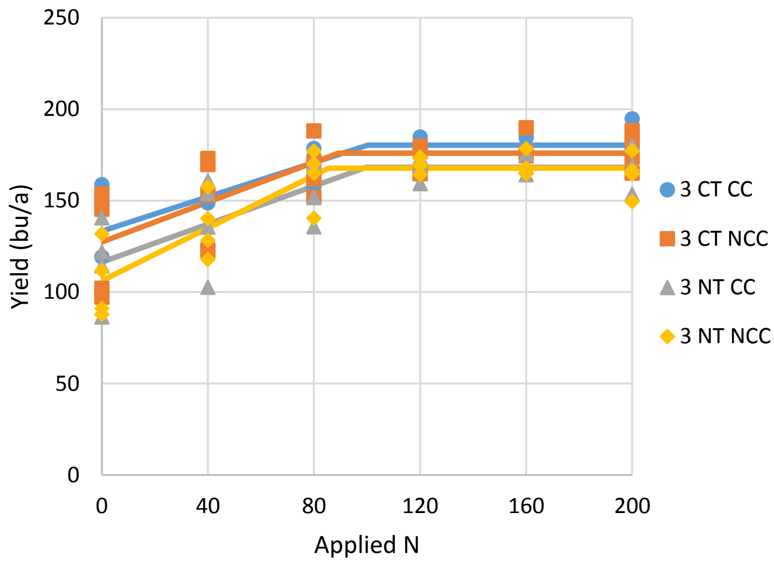

Figure 30. 2015- Corn grain yield vs. applied N on a corn/soybean/oat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crop (CC and NCC, respectively).

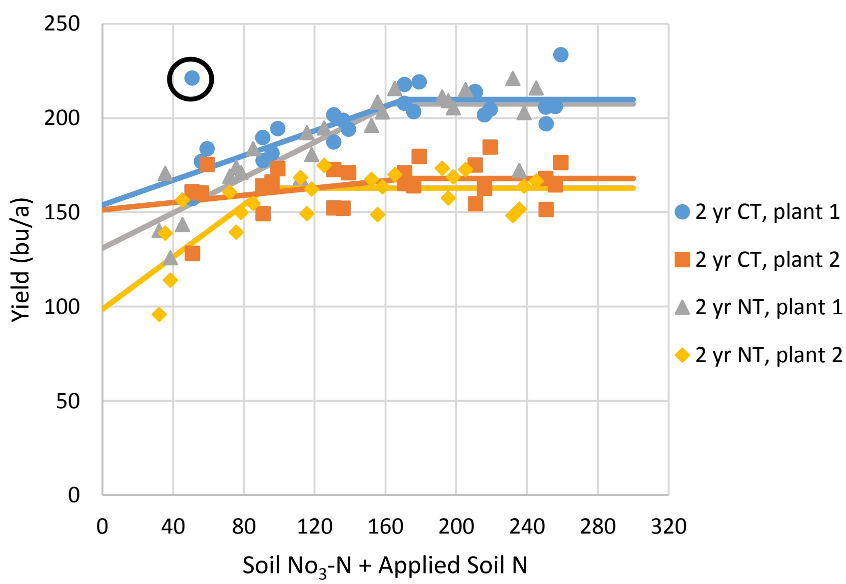

Figure 31. 2015- Corn grain yield vs. soil N on a corn/soybean rotation (2 yr) with 2 planting dates: early (5/5/15- plant 1) and late (6/2/15- plant 2) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems. Note: circled data point was treated as an outlier.

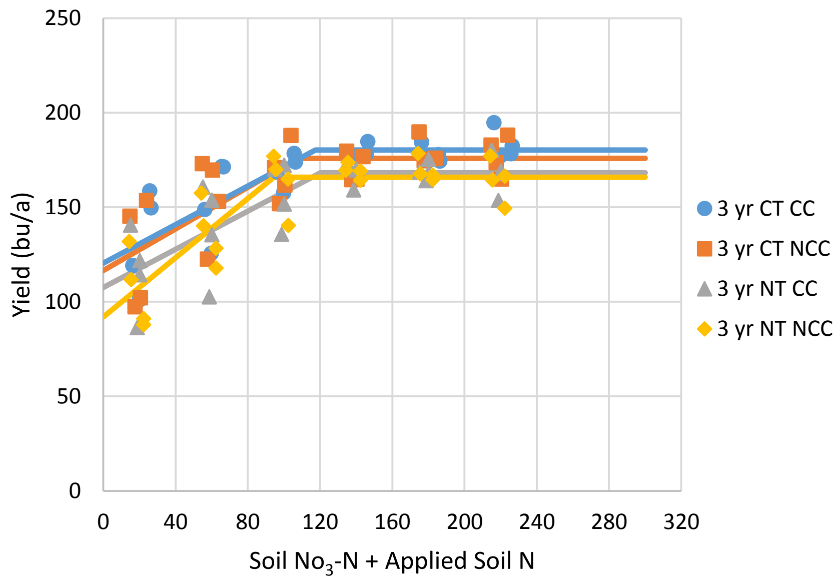

Figure 32. 2015- Corn grain yield vs. soil N on a corn/soybean/oat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crops (CC and NCC, respectively).

SUMMARY AND CONCLUSION

This two year study evaluated corn N response under CT and NT systems in a long-term study including two and three-year rotations and the use of cover crops. Record rainfall in June of 2014 strongly influenced the results for that season.

The corn/soybean rotation displayed a 19 lbs ac^{-1} applied optimum N gap between CT and NT plots, while the corn/soybean/small grain rotation had a 38 lbs ac^{-1} gap on average in 2014. We postulate that this may be a function of higher infiltration rates in the no-till plots leading to a prolonged period of saturated conditions. The two-year cropping system was more sensitive to N application in NT plots than in CT plots, meaning N management is especially important in NT systems. It appears that N taken up by fall 2013 cover crops was released throughout the 2014 growing season and made available to corn plants. This was confirmed by the lack of significant difference between 'no cover crop' and 'cover crop' treatment yields. Under extremely wet moisture conditions, N efficiency and uptake between tillage systems and rotations was not easily predictable.

In 2015, the growing season was much more 'typical' than in 2014 and did not include any record setting weather events; results were more representative of production environments in southeastern South Dakota. In the two-year rotation, optimum applied N rates between tillage systems appeared similar; yield differences between tillage regimes were insignificant. This implies that no extra N is needed on long-term NT soils as compared to CT soils under more 'typical' weather conditions in southeastern SD. Optimum applied N rates in CT and NT systems appeared similar in the three-year rotation as well, however CT plots yielded 12 bu ac^{-1} higher on average than did NT plots. We speculate that winter annual weed control is a factor that may need to be improved in an effort to avoid negative yield effects on NT corn crops following small grains, as the three-year rotation performed poorly under NT in this trial. Plots with and without cover crops did not yield significantly different within their respective tillage systems in 2015.

It is was postulated that volunteer oats may have taken up a fair amount of soil N in the fall of 2014, concealing cover crop effects on three-year rotation plots. The late planting date of half of the two-year rotation and all of the three-year rotation knocked back 2015 average yields.

As of June 15, 2016 corn grain bids in eastern South Dakota indicated an economic value of \$3.54 bu^{-1} to \$3.81 bu^{-1} (Bisel, 2016). For the purpose of simple calculations, an average of \$3.68 bu^{-1} will be used. The average national retail price of urea as of June 15, 2016, was \$0.177 lb^{-1} or \$0.38 lb^{-1} of N according to Knorr (2016). Therefore, when the plateau point is set at optimum, slopes leading to the optimum N level should be at or above 0.10 in order to be economical for the producer. For both 2014 and 2015, all measured ‘yield vs. applied N’ slopes in Figures 18, 19, 29, and 30 are above 0.10. Although the optimum rate varied depending on environment and yield potential, N application was economical in every tillage and rotation scenario tested in this study. No-till plots generally showed a sharper yield decline when N rates were below optimum, suggesting that proper N management is especially important in no-till systems.

Overall we conclude:

1) Under the conditions in this study which most closely approximated typical production environments in southeastern SD (ie: normal planting date, 2015 season), optimum N rates tended to be similar under both CT and NT management, suggesting that current South Dakota N recommendations calling for 30 lbs ac^{-1} additional N on corn grown in NT soils may need to be revisited.
2) Under extreme early-summer rainfall conditions, CT plots had lower optimum N rates than did NT plots. This analysis does not consider impacts such as greater erosion where there is a greater run-off effect associated with tillage.
3) A positive tillage effect was observed, particularly with late-planting, in the three-year rotation (corn following small grain). We postulate this was due to residual effects of winter annual weeds in NT plots. This suggests that effects of winter annual weeds on the following corn crop is an area that may need more research.
4) A preliminary comparison of current SDSU corn N recommendations and the Haney corn N recommendations versus observed optimum N rates indicates where cover crops draw down soil N, these tests tend to over predict corn N requirements. Therefore, predicting the effect of cover crops on corn N requirement, vis-à-vis soil nitrate testing, is another topic that is ripe for further research.

APPENDIX A- 2014

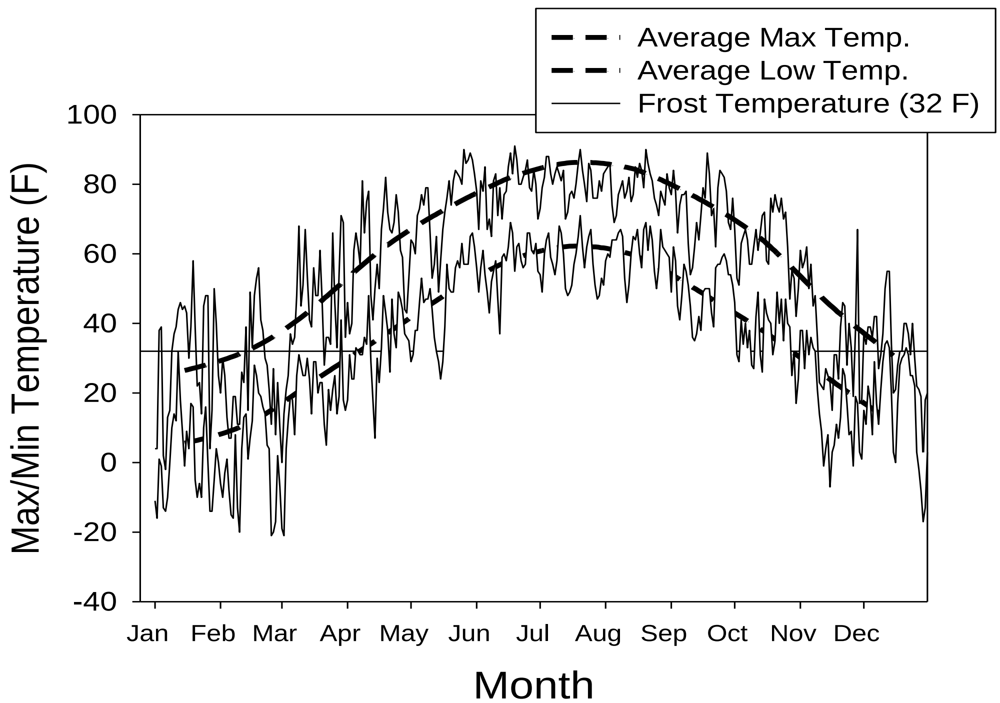

Figure A1. 2014 Monthly temperature (°F) adapted from the 2014 Annual Report at the Southeast Research Farm at Beresford, SD.

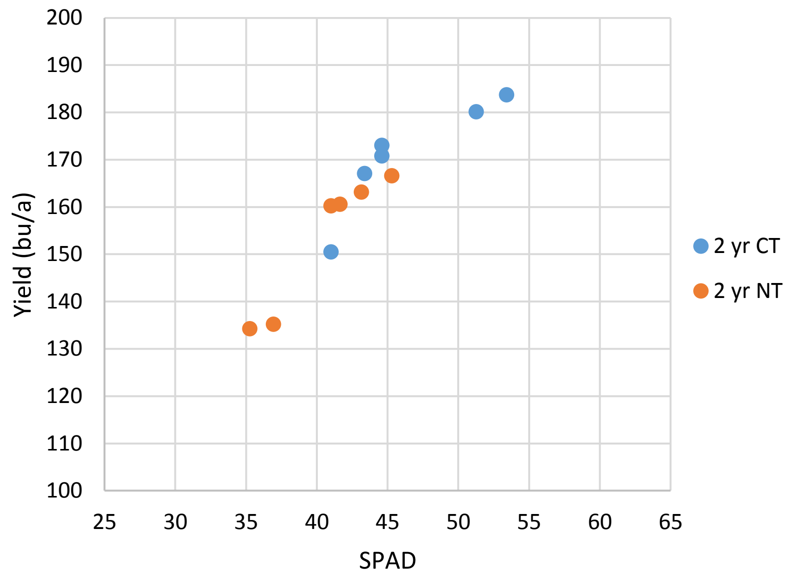

Figure A2. 2014- Corn grain yield vs. SPAD readings at V6-V8 growth stage in a corn/soybean rotation (2 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems.

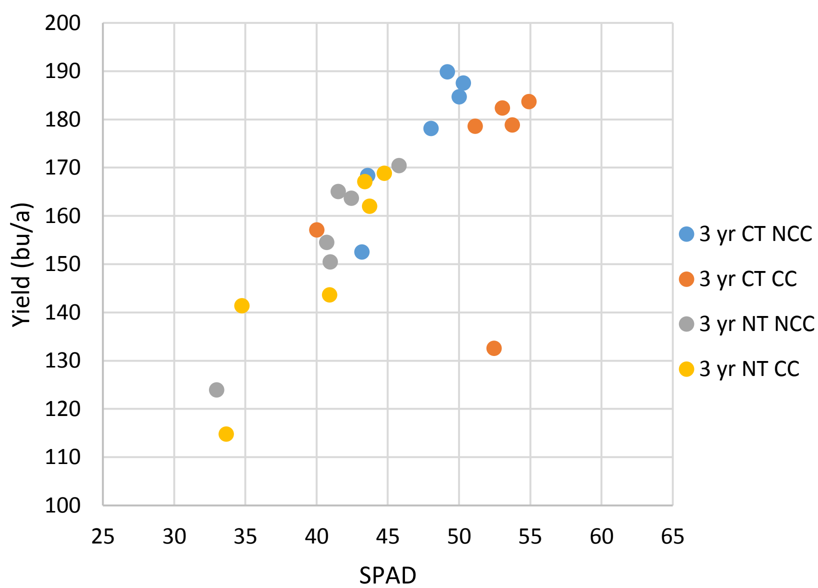

Figure A3. 2014- Corn grain yield vs. SPAD readings at V6-V8 growth stage in a corn/soybean/winter wheat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crops (CC and NCC, respectively).

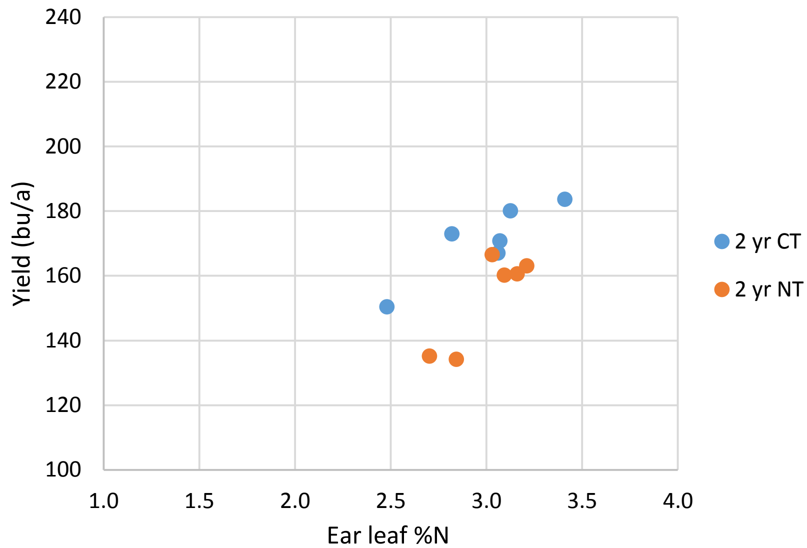

Figure A4. 2014- Corn grain yield vs. ear leaf N on a corn/soybean rotation (2 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems.

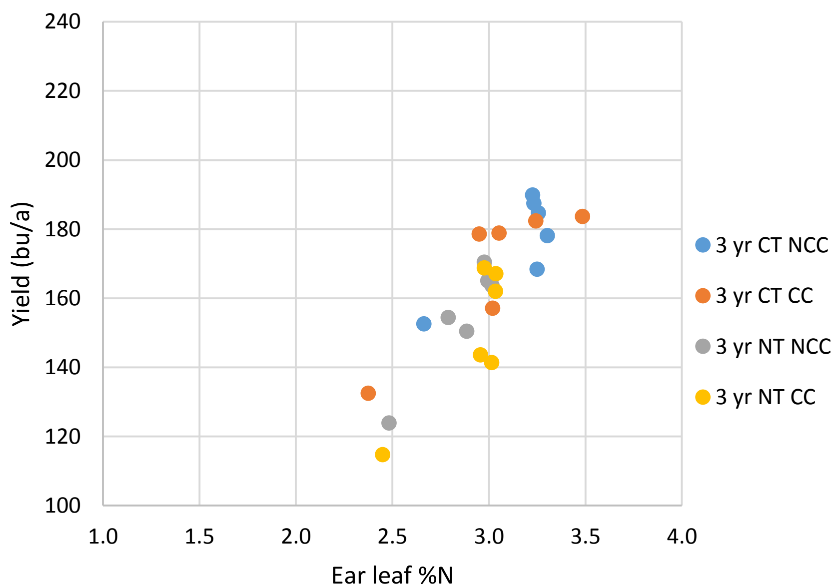

Figure A5. 2014- Corn grain yield vs. ear leaf N on a corn/soybean/winter wheat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crops (CC and NCC, respectively).

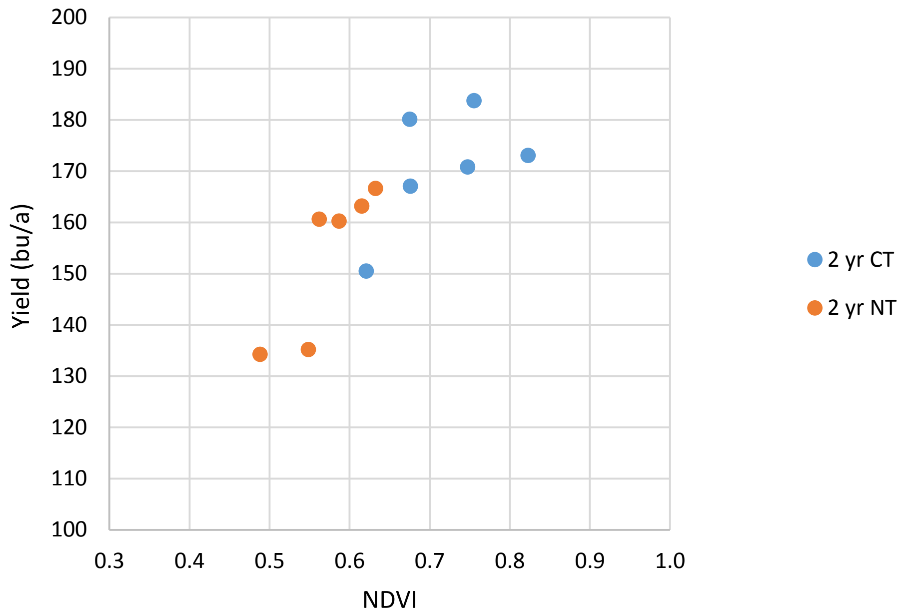

Figure A6. 2014- Corn grain yield vs. NDVI readings at the V6-V8 growth stage on a corn/soybean rotation (2 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems.

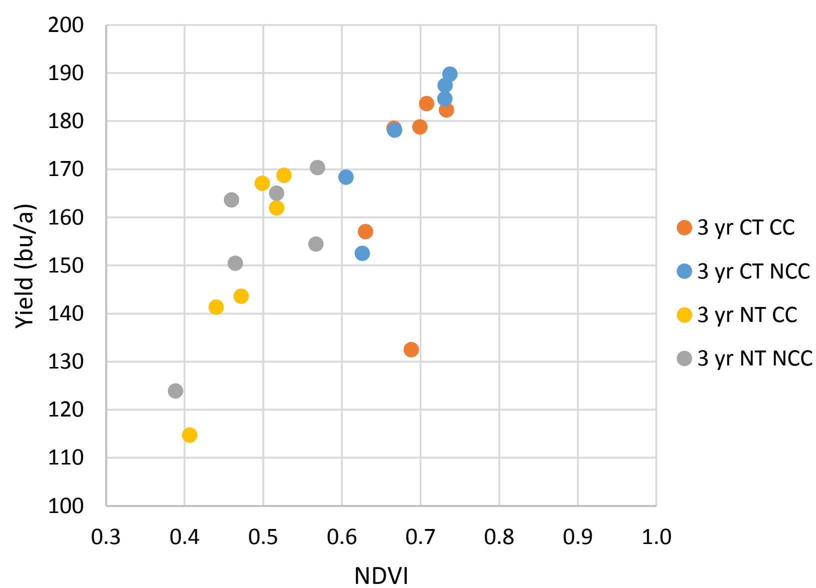

Figure A7. 2014- Corn grain yield vs. NDVI readings at the V6-V8 growth stage on a corn/soybean/winter wheat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crop (CC and NCC, respectively).

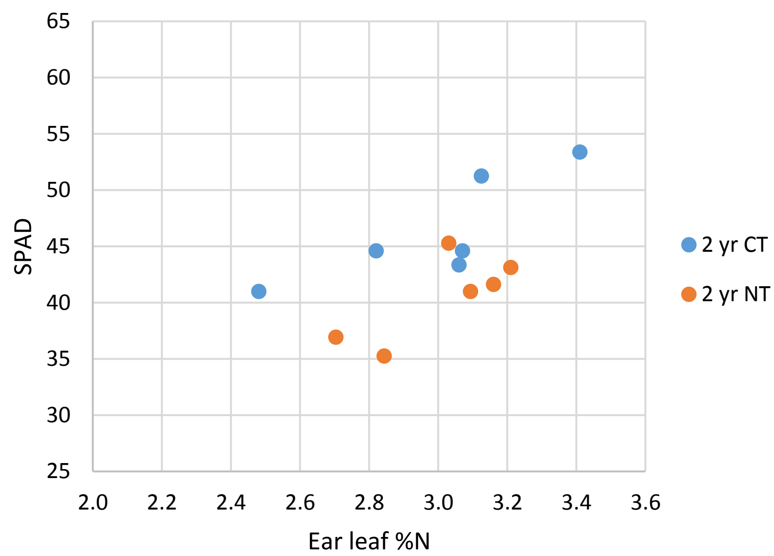

Figure A8. 2014- SPAD readings vs. ear leaf N at the V6-V8 growth stage on a corn/soybean rotation (2 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems.

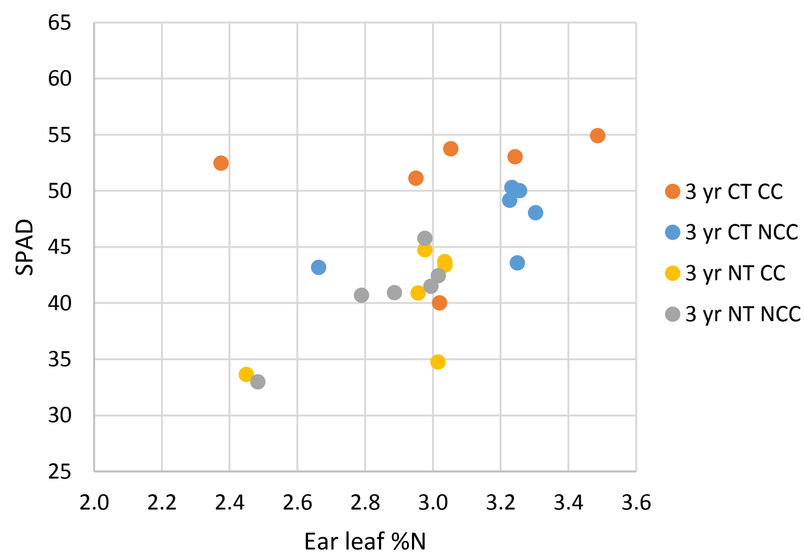

Figure A9. 2014- SPAD readings vs. ear leaf N at the V6-V8 growth stage on a corn/soybean/winter wheat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crop (CC and NCC, respectively).

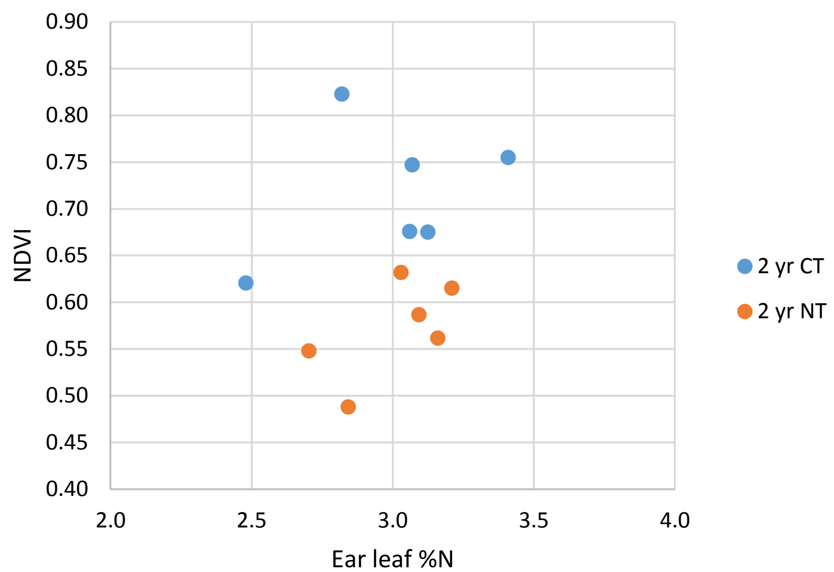

Figure A10. 2014- NDVI readings vs. ear leaf N at the V6-V8 growth stage on a corn/soybean rotation (2 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems.

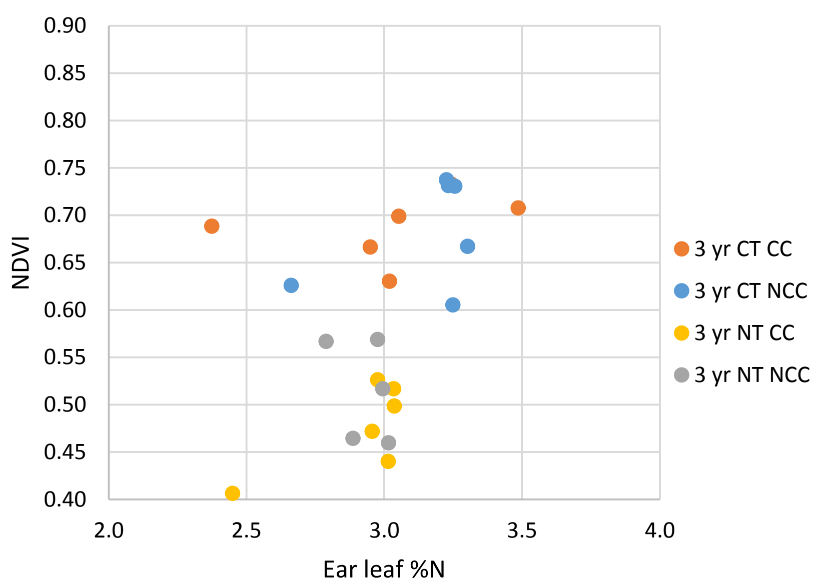

Figure A11. 2014- NDVI readings vs. ear leaf N at the V6-V8 growth stage on a corn/soybean/winter wheat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crop (CC and NCC, respectively).

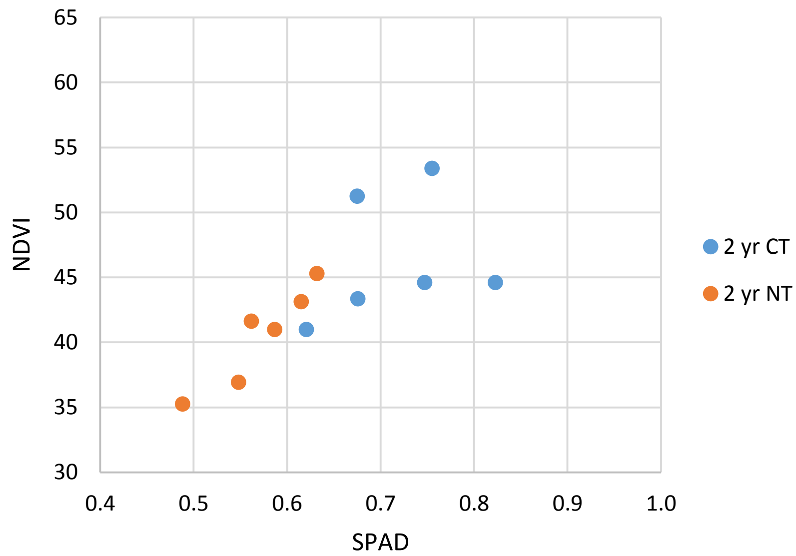

Figure A12. 2014- NDVI readings vs. SPAD readings at the V6-V8 growth stage on a corn/soybean rotation (2 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crop (CC and NCC, respectively).

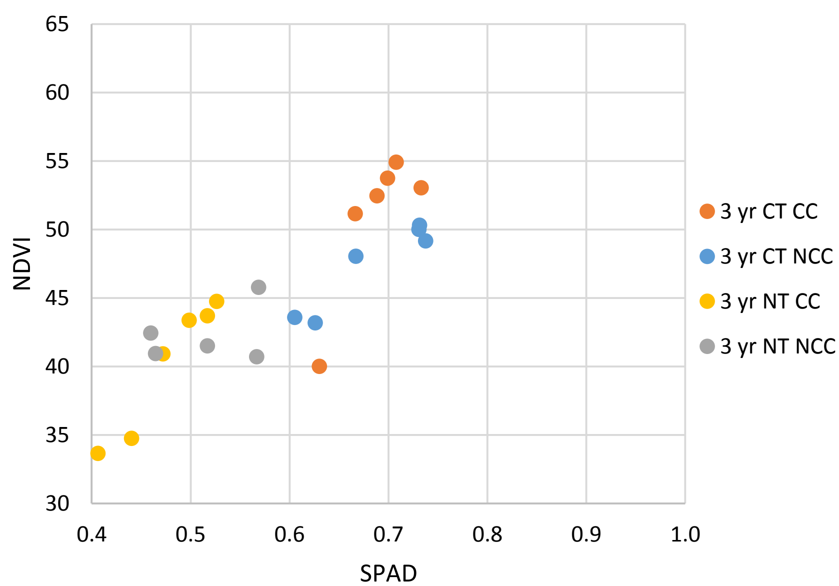

Figure A13. 2014- NDVI readings vs. SPAD readings at the V6-V8 growth stage on a corn/soybean/winter wheat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crop (CC and NCC, respectively).

Table A1. 2014 Fall soil test N levels in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in a 2 and 3 year rotation with and without tillage.

Rotation[1]	Tillage[2]	CC[3]	N[4]	NO_3-N	NH_4-N
				-----lbs ac^{-1}----- (0-2')	
Corn/Soy	CT	--	0	42.8	39.1
			80	31.4	55.3
			160	32.4	33.8
			200	93.8	48.1
	NT	--	0	44.4	42.5
			80	42.5	40.2
			160	69.1	43.9
			200	84.4	61.4
Corn/Soy/WW	CT	CC	0	22.8	38.0
			80	23.8	39.9
			160	25.1	33.3
			200	30.2	59.5
		NCC	0	18.0	29.3
			80	16.6	40.7
			160	37.7	33.3
			200	36.4	62.7
	NT	CC	0	22.8	34.3
			80	33.2	36.3
			160	50.1	35.8
			200	61.7	67.5
		NCC	0	25.5	30.7
			80	45.7	53.5
			160	56.0	22.6
			200	88.3	73.9

[1]'Corn/Soy' and 'Corn/Soy/WW' indicate the 2 and 3 year rotation in which the study took place.
[2]'CT' indicates conventional till since 1991, and 'NT' indicates no-till since 1991.
[3]'CC' and 'NCC' indicate 'cover crop' and 'no cover crop' respectively.
[4]'0, 80, 160, and 200' indicate pounds of N applied per acre for the given year.

Table A2. 2014 Fall soil test results in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in a 2 and 3 year rotation with and without tillage.

Rotation[1]	Tillage[2]	CC[3]	N[4]	Olsen-P ppm 0-6"	K ppm 0-6"	pH 0-6"	Salts 1:1 mmhos/cm 0-6"
Corn/Soy	CT	--	0	19.0	356.7	6.3	0.6
			80	12.1	294.5	5.7	0.9
			160	9.0	231.0	6.3	0.9
			200	17.0	284.0	6.6	1.0
	NT	--	0	34.1	278.7	6.3	0.6
			80	19.0	356.7	6.3	0.6
			160	18.0	261.0	5.8	0.4
			200	35.7	246.0	6.2	0.7
Corn/Soy/WW	CT	CC	0	19.8	311.5	5.9	0.5
			80	18.7	546.3	5.9	0.4
			160	15.4	281.0	6.1	0.5
			200	20.7	331.7	6.1	0.6
		NCC	0	21.1	331.0	6.0	0.5
			80	18.9	465.7	5.9	0.5
			160	22.3	272.3	5.8	0.5
			200	18.5	315.3	6.0	0.5
	NT	CC	0	20.2	272.3	5.9	0.6
			80	16.8	384.3	5.8	0.5
			160	25.8	224.3	5.7	0.4
			200	28.0	307.5	6.0	0.8
		NCC	0	26.4	294.0	5.9	0.4
			80	22.0	334.3	5.7	0.4
			160	27.7	256.0	5.8	0.4
			200	29.5	304.5	6.2	0.7

[1]'Corn/Soy' and 'Corn/Soy/WW' indicate the 2 and 3 year rotation in which the study took place.
[2]'CT' indicates conventional till since 1991, and 'NT' indicates no-till since 1991.
[3]'CC' and 'NCC' indicate 'cover crop' and 'no cover crop' respectively.
[4]'0, 80, 160, and 200' indicate pounds of N applied per acre for the given year.

Table A3. Corn grain characteristics in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in a 2 and 3 year rotation with and without tillage in 2014 and 2015.

Rotation[1]	Tillage[2]	Cover Crop[3]	Plant Date[4]	App. N[5]	Oil[6]	Protein	Starch	Test Weight[7]	Oil	Protein	Starch	Test Weight
				lbs ac^{-1}				lbs bu^{-1}				lbs bu^{-1}
					---------------2014---------------				---------------2015---------------			
Corn/Soy	CT	--	early	0	3.3	6.0	60.4	55.7	3.4	6.7	64.7	58.0
				40	3.2	6.4	60.3	56.8	3.4	7.0	64.5	58.2
				80	3.4	6.0	60.0	55.7	3.2	8.1	64.4	58.7
				120	3.2	6.3	60.5	54.6	3.3	8.1	64.4	59.0
				160	3.3	6.6	60.4	56.3	3.3	8.2	64.7	58.7
				200	3.1	6.4	59.9	55.3	3.2	8.2	64.0	58.7
		--	late	0	--	--	--	--	2.8	7.1	65.5	56.5
				40	--	--	--	--	3.0	7.4	65.5	56.7
				80	--	--	--	--	2.8	7.5	65.0	57.2
				120	--	--	--	--	2.8	7.6	65.0	56.6
				160	--	--	--	--	2.7	7.7	65.4	57.2
				200	--	--	--	--	2.7	7.7	65.4	56.7
	NT	--	early	0	3.3	5.8	60.0	55.9	3.3	6.1	65.5	57.3
				40	3.4	6.1	60.6	56.6	3.3	6.5	65.9	58.4
				80	3.3	6.2	60.2	56.4	3.2	7.0	65.2	58.2
				120	3.5	6.3	60.1	56.3	3.4	7.7	65.0	58.8
				160	3.5	6.3	60.1	55.9	3.3	8.4	64.5	58.3
				200	3.3	6.4	60.2	56.2	3.2	8.4	64.4	58.0
		--	late	0	--	--	--	--	2.9	6.5	65.8	56.0
				40	--	--	--	--	2.6	7.0	66.2	56.1
				80	--	--	--	--	2.7	7.2	65.0	56.2
				120	--	--	--	--	2.9	7.7	65.3	56.5
				160	--	--	--	--	2.7	7.5	65.7	56.4
				200	--	--	--	--	2.9	7.9	65.2	56.4

Table A3 Continued.

Corn/Soy/ Sm. Grain	CT	CC	--	0	3.6	5.7	60.1	55.1	2.7	5.7	66.2	55.5
				40	3.4	6.2	60.6	56.2	2.6	6.5	66.0	57.3
				80	3.6	6.8	59.8	56.1	3.0	7.1	65.4	57.0
				120	3.5	6.3	59.8	55.2	2.7	7.4	65.7	57.2
				160	3.4	6.6	59.9	56.2	2.8	7.5	64.7	56.5
				200	3.5	6.9	59.6	55.9	2.8	7.4	65.4	57.0
		NCC	--	0	3.5	5.9	60.0	56.1	2.9	6.0	66.2	55.4
				40	3.3	6.6	60.2	53.5	2.7	6.4	65.9	56.0
				80	3.5	6.5	59.5	55.6	2.8	6.9	65.3	56.7
				120	3.4	6.7	60.1	56.5	2.8	7.4	65.5	57.1
				160	3.5	6.9	59.9	55.9	2.8	7.5	65.3	56.8
				200	3.5	6.8	59.7	56.1	2.8	7.6	65.4	57.3
	NT	CC	--	0	3.7	5.5	60.1	54.6	2.8	5.9	66.0	55.4
				40	3.5	6.1	60.3	54.9	2.8	6.4	66.0	56.3
				80	3.5	5.8	60.0	55.6	2.8	6.7	65.9	56.3
				120	3.5	6.2	59.9	56.0	2.9	7.3	65.5	56.3
				160	3.5	6.4	60.0	55.8	3.0	7.5	65.1	57.2
				200	3.5	6.2	60.1	55.8	2.8	7.5	65.3	56.8
		NCC	--	0	3.4	5.8	59.9	55.0	2.8	5.8	66.6	54.8
				40	3.4	6.9	60.3	54.8	2.9	6.2	65.7	55.9
				80	3.6	6.1	60.0	55.2	2.8	6.8	65.6	56.1
				120	3.4	6.3	59.9	55.1	2.9	7.1	65.3	56.8
				160	3.4	6.4	60.2	55.3	2.8	7.4	65.4	56.6
				200	3.4	6.2	60.2	55.6	2.8	7.8	65.0	56.6

[1]'Corn/Soy' and 'Corn/Soy/Sm. Grain' indicate the 2 and 3 year rotation in which the study took place.
[2]'CT' indicates conventional till since 1991, and 'NT' indicates no-till since 1991.
[3]'CC' and 'NCC' indicate 'cover crop' and 'no cover crop' respectively.
[4]Plant Date: 'early' indicates a 5/5/15 planting date, 'late' indicates a 6/2/15 planting date due to planting error. All 2014 plots were planted on 5/16/14.
[5]Applied 4/10/14 and 4/15/15 as UAN using streamer bar application method.
[6]Oil, protein, and starch values were obtained using a grain analyzer and adjusted to 15.5% moisture.
[7]Test weight was obtained using a Steinlite grain moisture tester.

Table A4. Late season SPAD and NDVI readings in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in a 2 and 3 year rotation with and without tillage in 2014 and 2015.

Rotation[1]	Tillage[2]	Cover Crop[3]	Plant Date[4]	App. N[5]	SPAD[6]	SPAD	NDVI[7]	SPAD	NDVI
				lbs ac^{-1}	R1	R3	R1	R1	R1
					-----------2014-----------			-------2015--------	
Corn/Soy	CT	--	early	0	50.6	52.3	0.80	64.4	0.68
				40	55.1	59.1	0.82	59.7	0.66
				80	55.0	54.0	0.80	64.2	0.68
				120	55.1	57.0	0.79	65.9	0.66
				160	60.1	63.5	0.81	67.0	0.68
				200	63.9	61.0	0.79	66.9	0.65
		--	late	0	--	--	--	58.5	0.71
				40	--	--	--	58.6	0.69
				80	--	--	--	60.0	0.72
				120	--	--	--	59.8	0.72
				160	--	--	--	57.8	0.71
				200	--	--	--	58.5	0.71
	NT	--	early	0	48.2	50.8	0.77	55.9	0.58
				40	50.1	52.0	0.79	60.6	0.66
				80	55.0	56.9	0.80	63.9	0.65
				120	55.7	58.7	0.81	63.6	0.64
				160	57.4	57.6	0.79	67.2	0.67
				200	55.1	59.5	0.80	64.4	0.69
		--	late	0	--	--	--	56.8	0.76
				40	--	--	--	58.5	0.76
				80	--	--	--	60.0	0.76
				120	--	--	--	60.5	0.79
				160	--	--	--	59.8	0.78
				200	--	--	--	60.6	0.66

Table A4 Continued.

Corn/Soy/ Sm. Grain	CT	CC	--	0	--	--	--	54.4	0.68
				40	--	--	--	58.5	0.66
				80	--	--	--	58.3	0.70
				120	--	--	--	59.7	0.72
				160	--	--	--	59.1	0.71
				200	--	--	--	59.5	0.68
		NCC	--	0	--	--	--	53.3	0.68
				40	--	--	--	55.8	0.69
				80	--	--	--	57.8	0.68
				120	--	--	--	59.8	0.69
				160	--	--	--	58.7	0.69
				200	--	--	--	59.4	0.69
	NT	CC	--	0	--	--	--	51.8	0.69
				40	--	--	--	55.7	0.72
				80	--	--	--	58.5	0.69
				120	--	--	--	59.5	0.71
				160	--	--	--	60.2	0.73
				200	--	--	--	61.0	0.73
		NCC	--	0	--	--	--	49.9	0.70
				40	--	--	--	54.1	0.71
				80	--	--	--	58.3	0.69
				120	--	--	--	59.8	0.72
				160	--	--	--	60.7	0.72
				200	--	--	--	60.1	0.72

Table A4 Continued.

Mean	CT			56.63	57.82	0.80	61.78	0.69
	NT			53.58	55.92	0.79	60.98	0.70
	2 yr		early+late	55.11	56.87	0.80	63.64	0.66
	3 yr			--	--	--	57.66	0.70
	15 2 yr		5-May-15	--	--	--	63.64	0.66
			2-Jun-15	--	--	--	59.12	0.73
	3 yr	CC		--	--	--	58.02	0.70
		NCC		--	--	--	57.31	0.70
St. Dev.	CT			4.66	4.24	0.01	3.53	0.02
	NT			3.59	3.63	0.01	3.87	0.05
	2 yr		early+late	4.27	3.89	0.01	3.39	0.05
	3 yr			--	--	--	2.99	0.02
	15 2 yr		5-May-15	--	--	--	3.38	0.03
			2-Jun-15	--	--	--	1.17	0.04
	3 yr	CC		--	--	--	2.69	0.02
		NCC		--	--	--	3.34	0.02

[1]'Corn/Soy' and 'Corn/Soy/Sm. Grain' indicate the 2 and 3 year rotation in which the study took place.
[2]'CT' indicates conventional till since 1991, and 'NT' indicates no-till since 1991.
[3]'CC' and 'NCC' indicate 'cover crop' and 'no cover crop' respectively.
[4]Plant Date: 'early' indicates a 5/5/15 planting date, 'late' indicates a 6/2/15 planting date due to planting error. All 2014 plots were planted on 5/16/14.
[5]Applied 4/10/14 and 4/15/15 as UAN using streamer bar application method.
[6]8 SPAD meter readings were taken per plot and averaged for an overall plot value.
[7]NDVI readings were obtained for each plot using a Greenseeker® instrument.

APPENDIX B- 2015

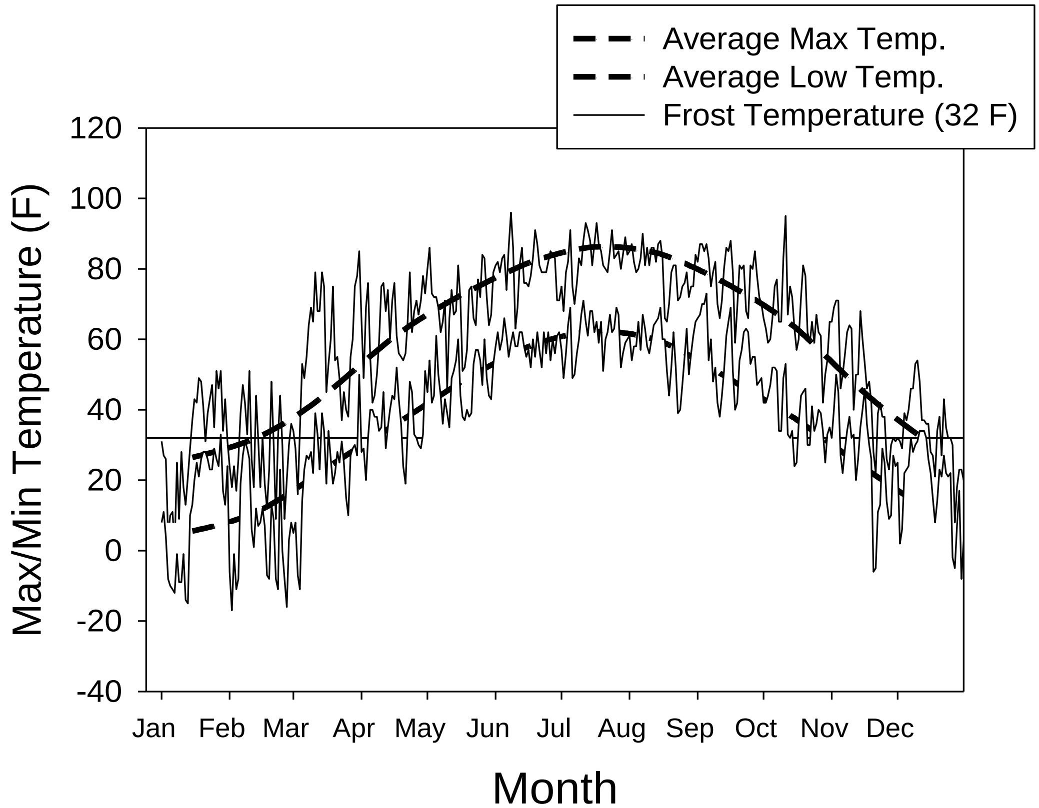

Figure B1. 2015 Monthly temperature (°F) adapted from the 2015 Annual Report at the Southeast Research Farm at Beresford, SD.

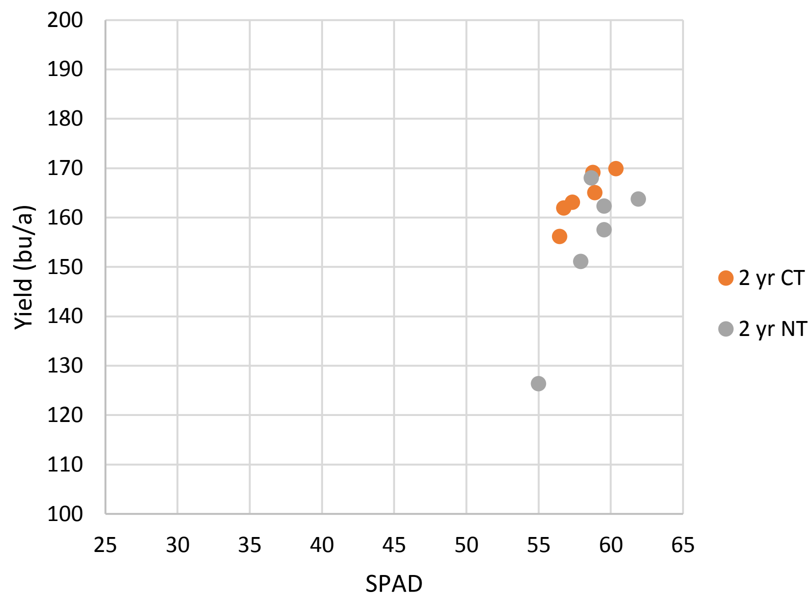

Figure B2. 2015- Corn grain yield vs. SPAD readings at V6-V8 growth stage in a corn/soybean rotation (2 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems.

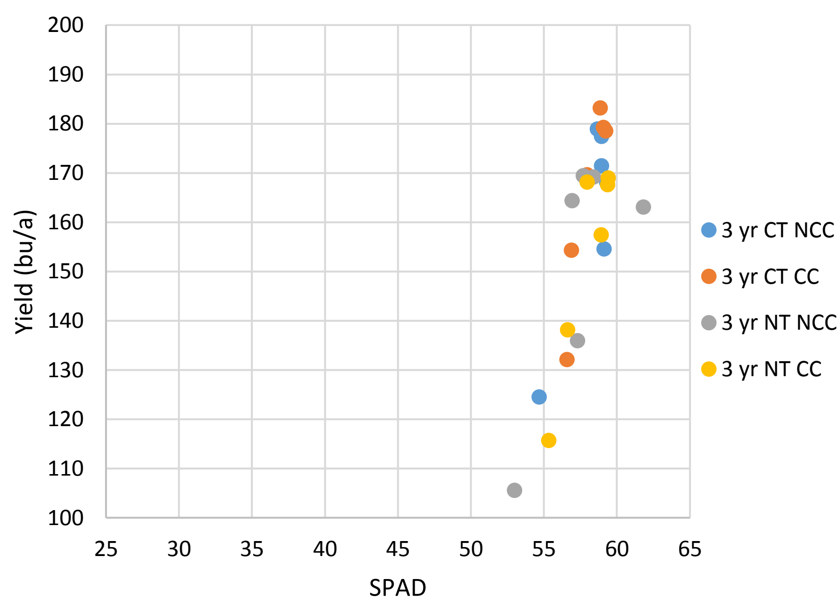

Figure B3. 2015- Corn grain yield vs. SPAD readings at V6-V8 growth stage in a corn/soybean/oat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crops (CC and NCC, respectively).

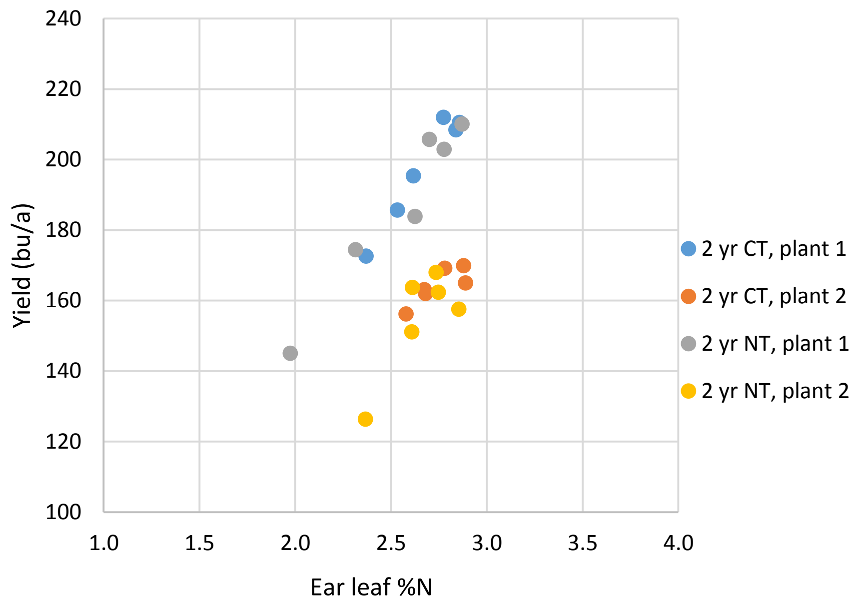

Figure B4. 2015- Corn grain yield vs. ear leaf N on a corn/soybean rotation (2 yr) with an early (5/5/15- plant 1) and late (6/5/15- plant 2) planting date in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems.

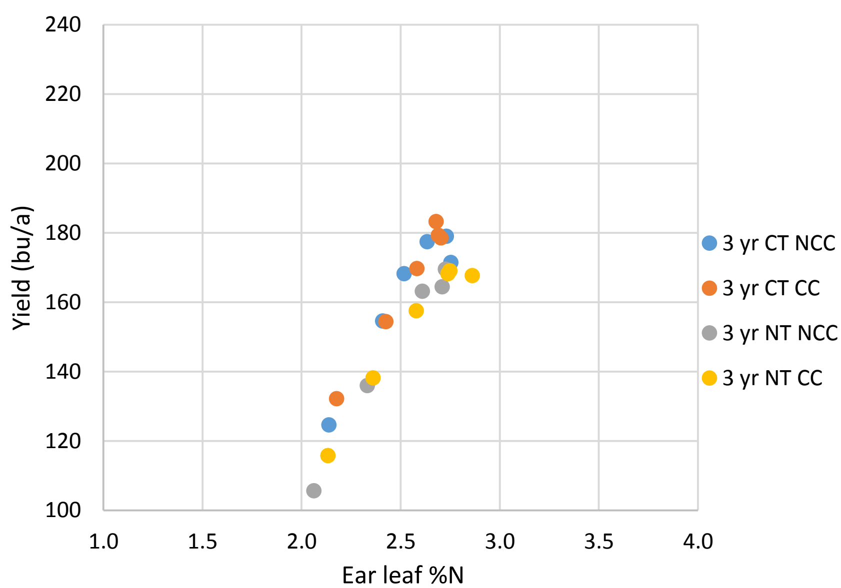

Figure B5. 2015- Corn grain yield vs. ear leaf N on a corn/soybean/oat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crops (CC and NCC, respectively).

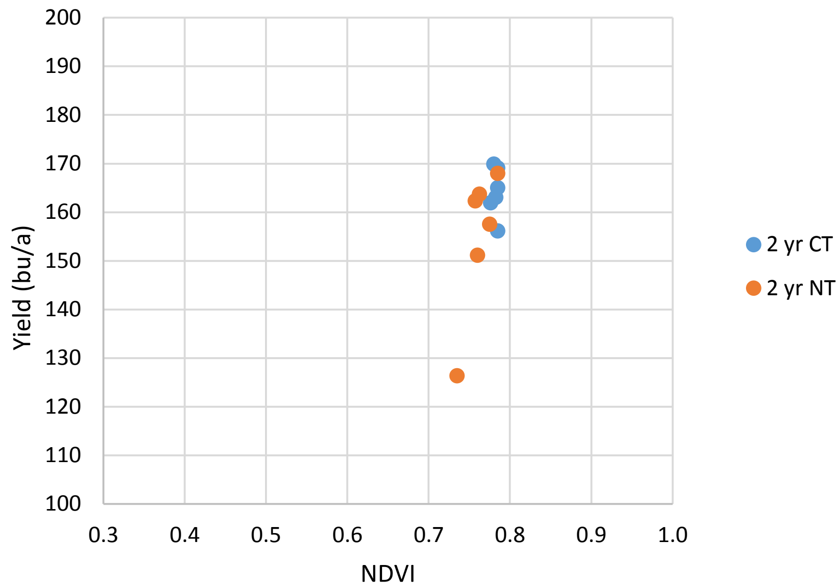

Figure B6. 2015- Corn grain yield vs. NDVI readings at the V6-V8 growth stage on a corn/soybean rotation (2 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems.

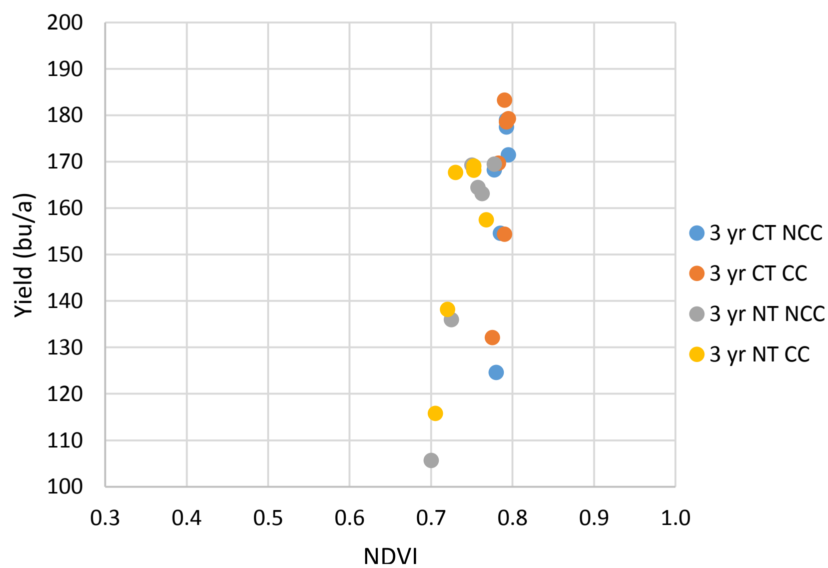

Figure B7. 2015- Corn grain yield vs. NDVI readings at the V6-V8 growth stage on a corn/soybean/oat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crop (CC and NCC, respectively).

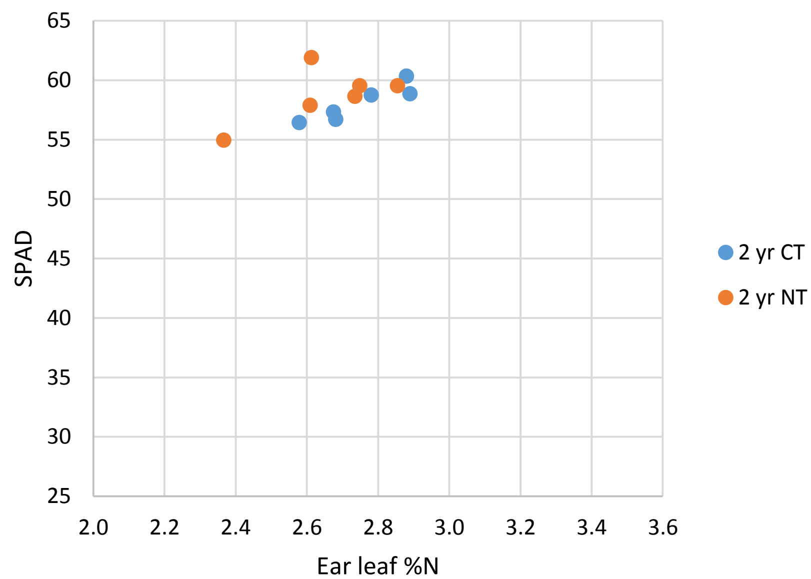

Figure B8. 2015- SPAD readings vs. ear leaf N at the V6-V8 growth stage on a corn/soybean rotation (2 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems.

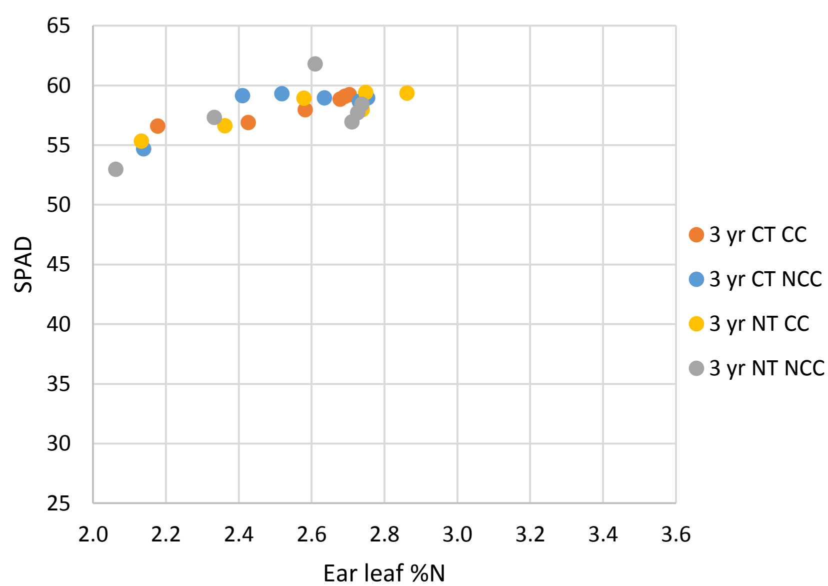

Figure B9. 2015- SPAD readings vs. ear leaf N at the V6-V8 growth stage on a corn/soybean/oat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crop (CC and NCC, respectively).

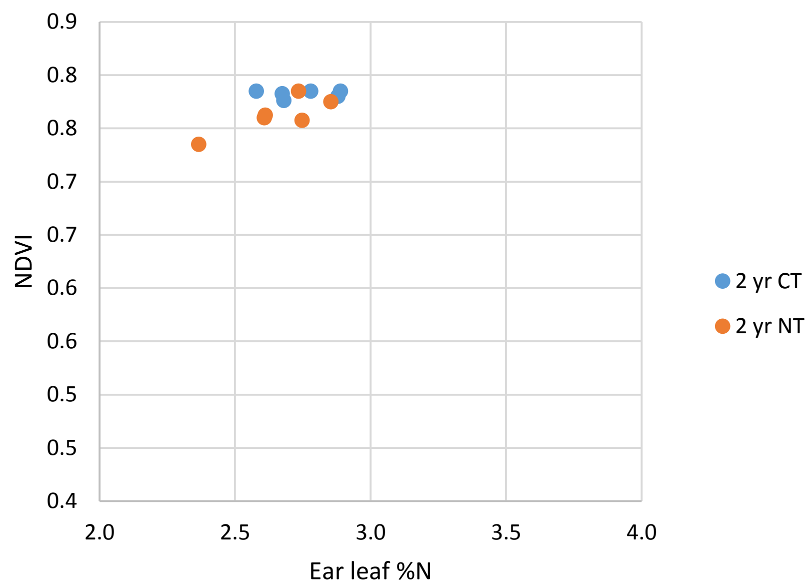

Figure B10. 2015- NDVI readings vs. ear leaf N at the V6-V8 growth stage on a corn/soybean rotation (2 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems.

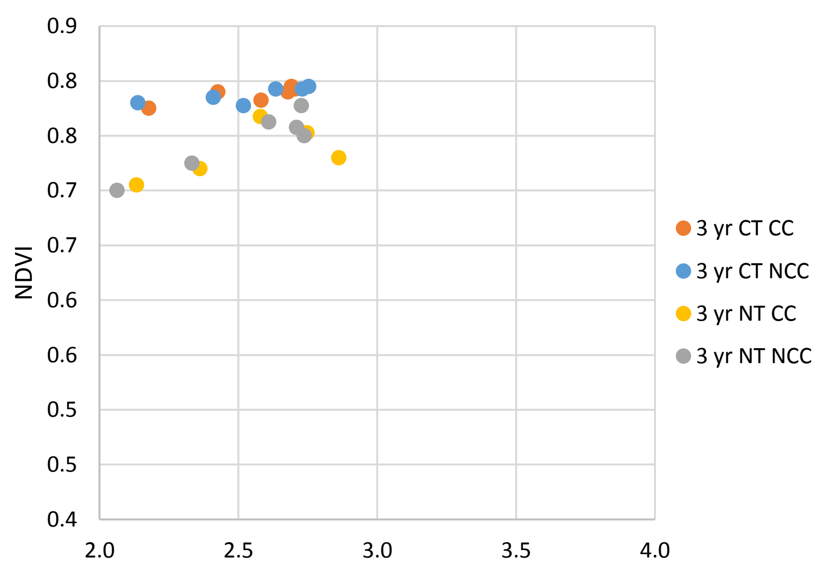

Figure B11. 2015- NDVI readings vs. ear leaf N at the V6-V8 growth stage on a corn/soybean/oat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in CT and NT systems, with and without cover crop (CC and NCC, respectively).

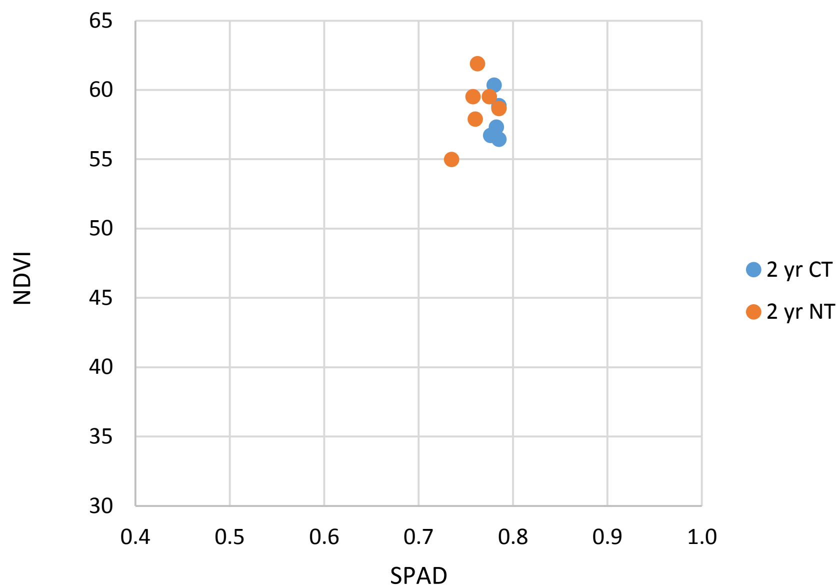

Figure B12. 2015- NDVI readings vs. SPAD readings the V6-V8 growth stage on a corn/soybean rotation (2 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in conventional till and no-till systems.

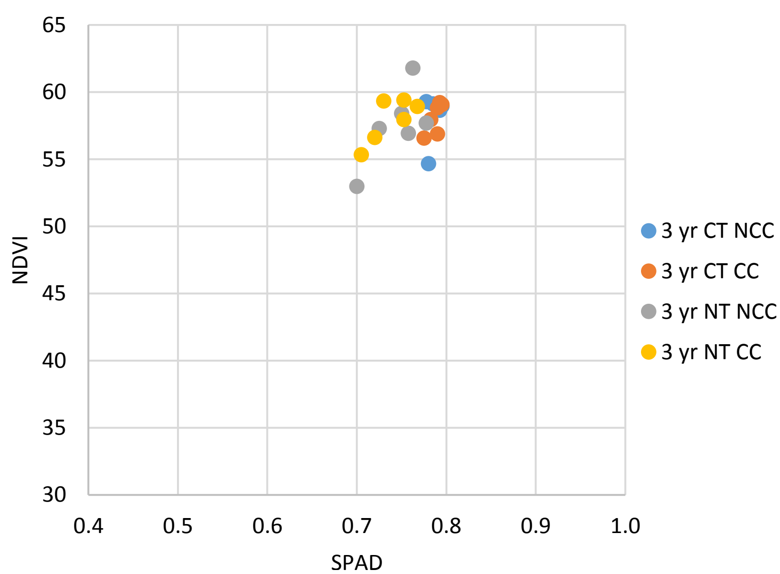

Figure B13. 2015- NDVI readings vs. SPAD readings at the V6-V8 growth stage on a corn/soybean/oat rotation (3 yr) in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in conventional till and no-till systems, with and without cover crop (CC and NCC, respectively).

Table B1. 2015 Fall[1] soil test N levels in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in a 2 and 3 year rotation with and without tillage.

Rotation[2]	Tillage[3]	CC[4,5]	Plant[6]	N[7]	NO_3-N lbs ac^{-1} (0-2')
Corn/Soy	CT	--	Early	0	20.8
				160	47.2
		--	Late	0	35.2
				160	115.2
	NT	--	Early	0	35.2
				160	37.6
		--	Late	0	34.4
				160	46.4
Corn/Soy/Oat	CT	CC	--	0	n/a
				160	n/a
		NCC	--	0	16.8
				160	29.6
	NT	CC	--	0	n/a
				160	n/a
		NCC	--	0	17.6
				160	53.2

[1]Fall samples were taken 4/2016 due to extremely wet fall 2015 conditions. A comparison was made to select fall samples and no significant difference was found.
[2]'Corn/Soy' and 'Corn/Soy/Oat' indicate the 2 and 3 year rotation in which the study took place.
[3]'CT' indicates conventional till since 1991, and 'NT' indicates no-till since 1991.
[4]'CC' and 'NCC' indicate 'cover crop' and 'no cover crop' respectively.
[5]'0 and 160 indicate pounds of N applied per acre for the given year.
[6]Plant Date: 'early' indicates a 5/5/15 planting date, 'late' indicates a 6/2/15 planting date due to planting error. All 2014 plots were planted on 5/16/14.
[7]Fall samples from the 3 yr CC plots were not taken due to experimental constraints.

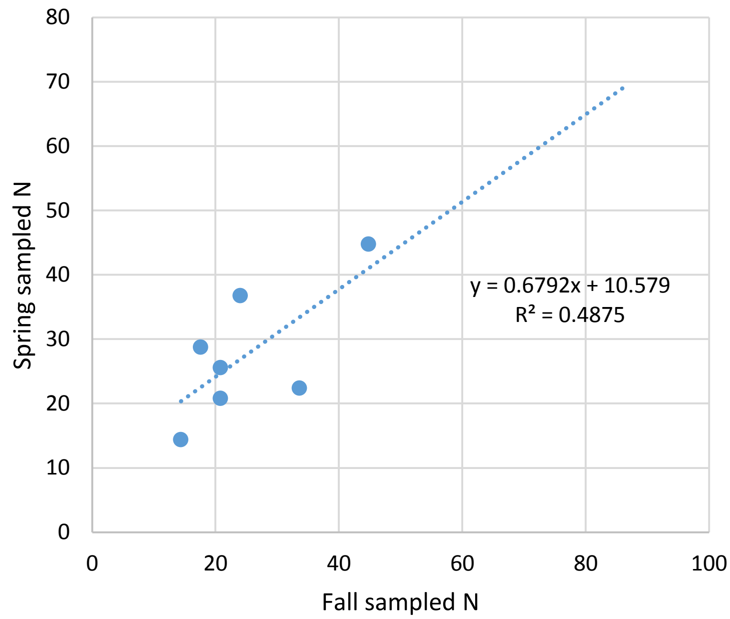

Figure B14. Comparison of early spring 2016 and late fall 2015 sampled soil NO_3-N results in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in conventional till and no-till systems.

Table B2. 2015 Fall[1] soil test results in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in a 2 and 3 year rotation with and without tillage.

Rotation[2]	Tillage[3]	CC[4,5]	Plant[6]	N[7]	Olsen-P ppm 0-6"	K ppm 0-6"	pH 0-6"	Salts 1:1 mmhos/cm 0-6"
Corn/Soy	CT	--	Early	0	3.9	201.0	6.9	1.6
				160	3.4	204.0	7.0	1.3
		--	Late	0	4.5	162.0	6.9	0.9
				160	4.5	164.0	7.1	0.7
	NT	--	Early	0	4.5	178.0	6.9	1.0
				160	6.3	165.0	7.0	0.7
		--	Late	0	7.6	187.0	7.0	1.1
				160	7.6	223.0	7.3	0.8
Corn/Soy/Oat	CT	CC	--	0	n/a	n/a	n/a	n/a
				160	n/a	n/a	n/a	n/a
		NCC	--	0	3.9	161.0	7.3	1.3
				160	5.7	156.0	7.2	1.5
	NT	CC	--	0	n/a	n/a	n/a	n/a
				160	n/a	n/a	n/a	n/a
		NCC	--	0	8.2	219.0	6.9	0.8
				160	8.2	191.0	7.0	0.8

[1]Fall samples were taken 4/2016 due to extremely wet fall 2015 conditions. A comparison was made to select fall samples and no significant difference was found.

[2]'Corn/Soy' and 'Corn/Soy/Oat' indicate the 2 and 3 year rotation in which the study took place.

[3]'CT' indicates conventional till since 1991, and 'NT' indicates no-till since 1991.

[4]'CC' and 'NCC' indicate 'cover crop' and 'no cover crop' respectively.

[5]'0 and 160 indicate pounds of N applied per acre for the given year.

[6]Plant Date: 'early' indicates a 5/5/15 planting date, 'late' indicates a 6/2/15 planting date due to planting error. All 2014 plots were planted on 5/16/14.

[7]Fall samples from the 3 yr CC plots were not taken due to experimental constraints.

APPENDIX C- Calibrations and Comparisons

Table C1. Cover crop yield and N content information from a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in a 2 and 3 year rotation with and without tillage in 2014 and 2015.

Fall Planted	Yield (lbs ac^{-1})[1]		%N
	----CT[2]----	----NT----	
2013	4995		3.60
2014	2308	1610	2.46

[1]Yield information from 2013 was pooled across tillage regimes.
[2]'CT' indicates conventional till since 1991, and 'NT' indicates no-till since 1991.

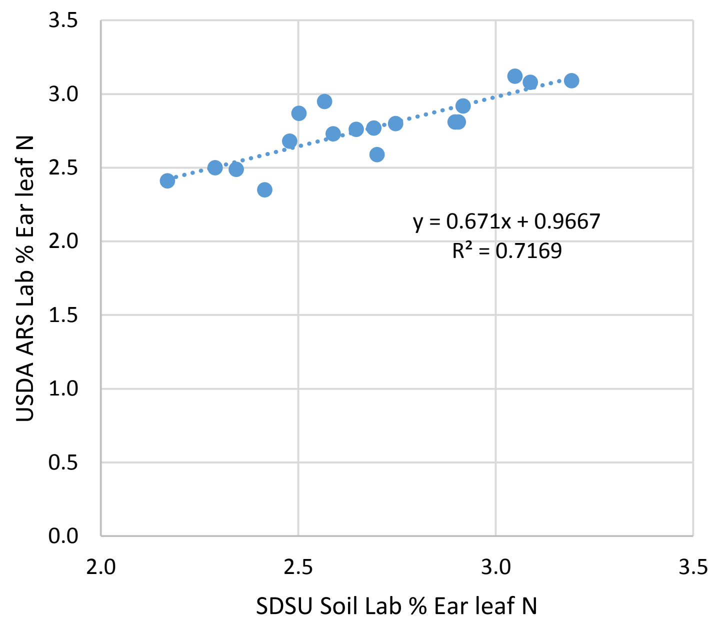

Figure C1. Comparison of USDA ARS lab vs. SDSU lab ear leaf N results in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in a 2 and 3 year rotation, with and without tillage in 2014 and 2015.

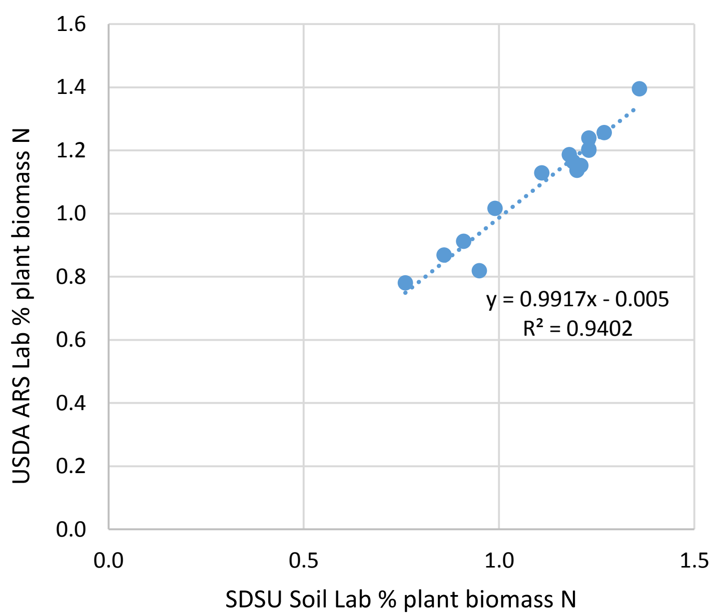

Figure C2. Comparison of USDA ARS lab vs. SDSU lab biomass N results in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in a 2 and 3 year rotation, with and without tillage in 2014 and 2015.

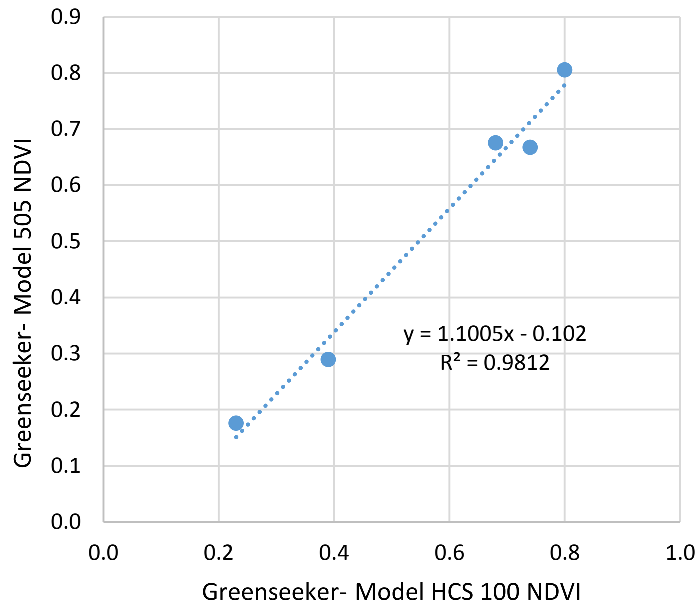

Figure C3. Comparison of two Greenseeker® models' NDVI readings in a field study conducted at the SDSU Southeast Research Farm at Beresford, SD for evaluating corn N response in a 2 and 3 year rotation, with and without tillage in 2014 and 2015.

APPENDIX D- Soil Temperature Data

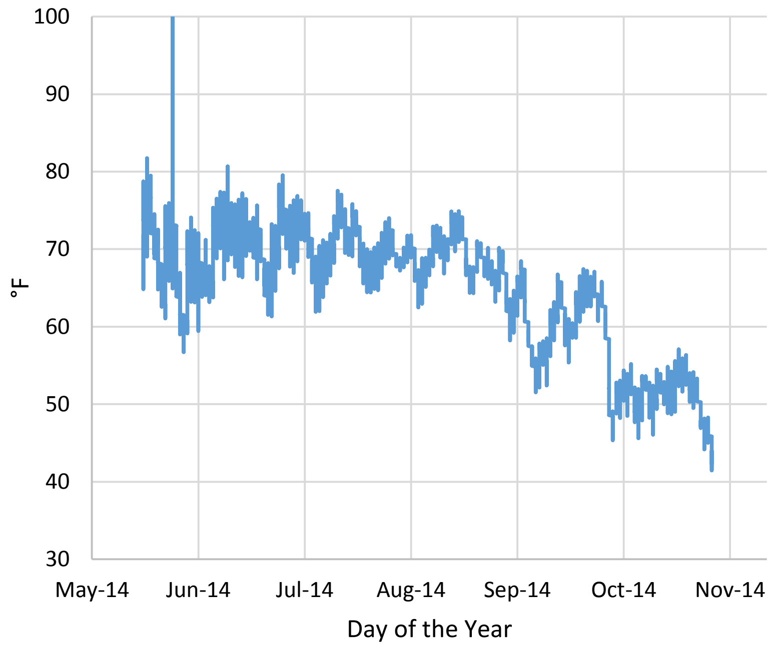

Figure D1. 2014 Corn/soybean rotation CT soil temperatures at 2" depth at the SDSU Southeast Research Farm at Beresford, SD.

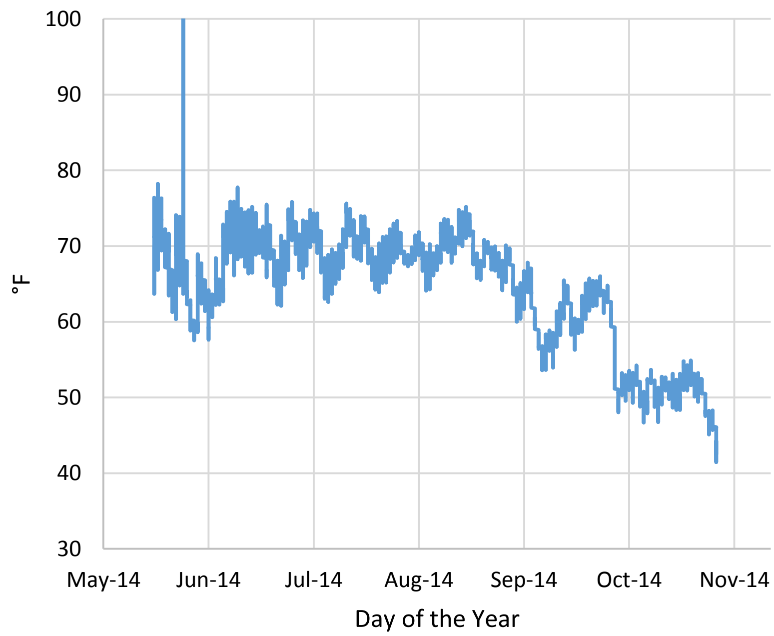

Figure D2. 2014 Corn/soybean rotation NT soil temperatures at 2" depth at the SDSU Southeast Research Farm at Beresford, SD.

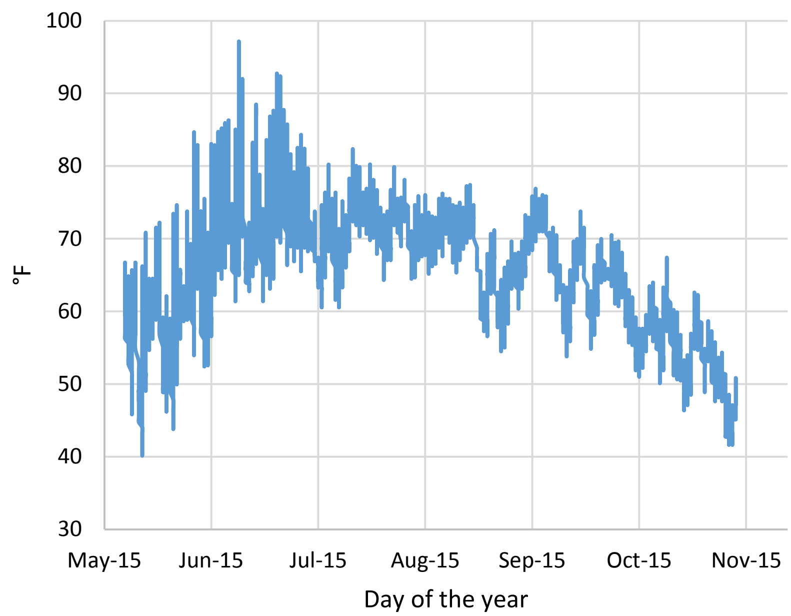

Figure D3. 2015 Corn/soybean rotation, CT soil temperatures at 2" depth at the SDSU Southeast Research Farm at Beresford, SD.

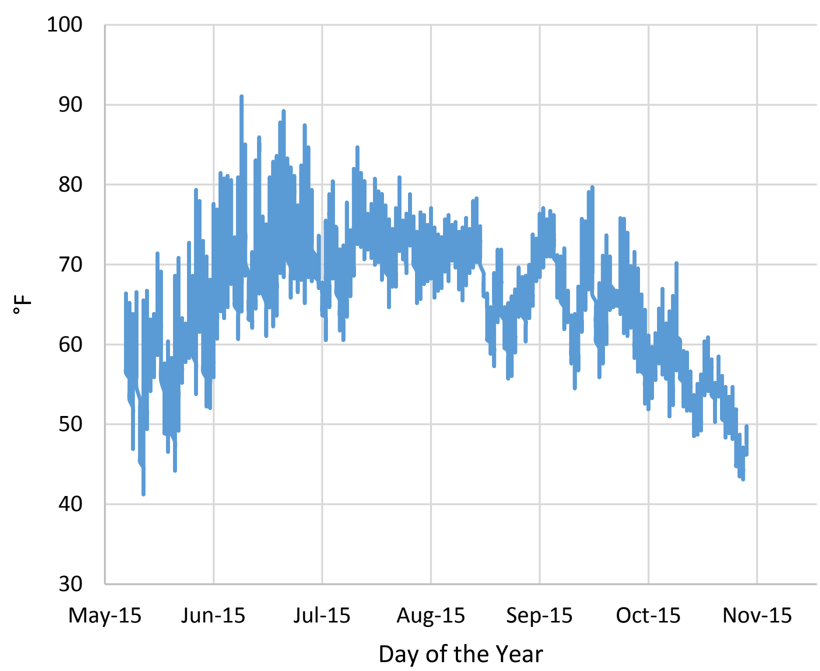

Figure D4. 2015 Corn/soybean rotation, NT soil temperatures at 2" depth at the SDSU Southeast Research Farm at Beresford, SD.

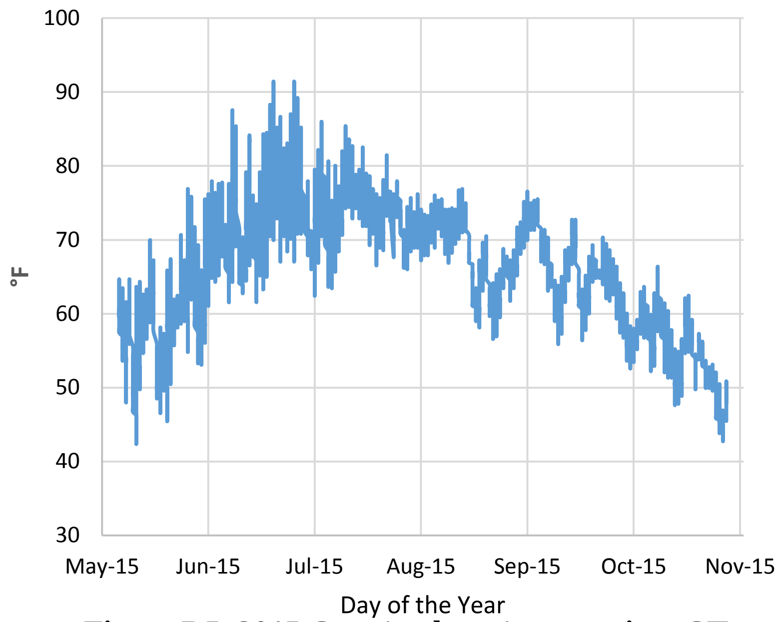

Figure D5. 2015 Corn/soybean/oat rotation, CT with cover crop soil temperatures at 2" depth at the SDSU Southeast Research Farm at Beresford, SD.

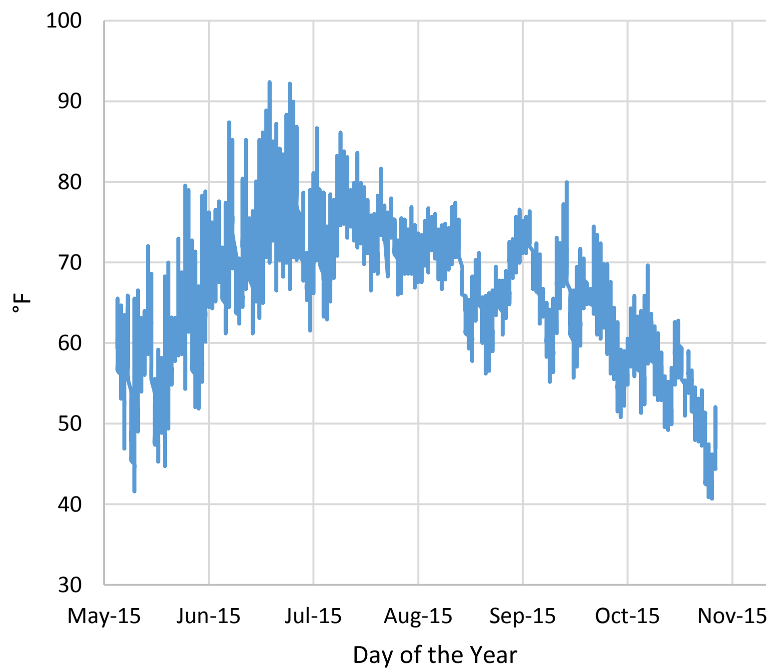

Figure D6. 2015 Corn/soybean/oat rotation, CT without cover crop soil temperatures at 2" depth at the SDSU Southeast Research Farm at Beresford, SD.

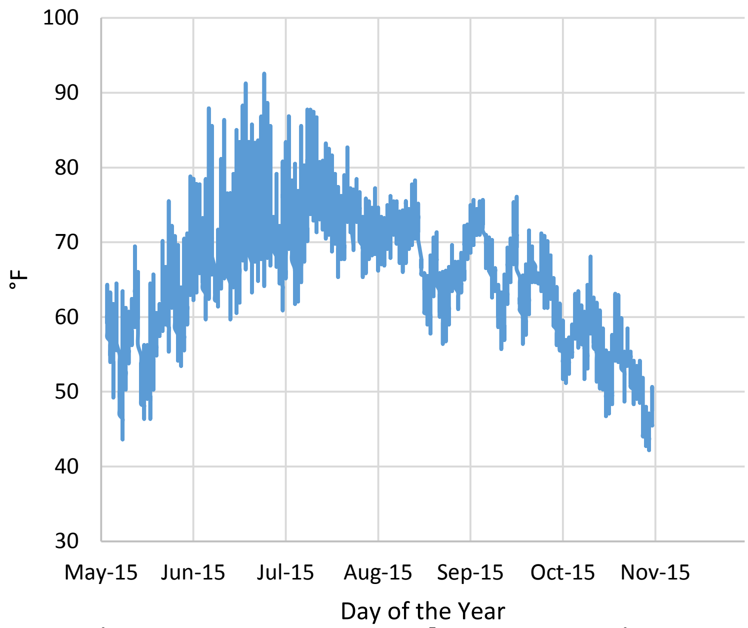

Figure D7. 2015 Corn/soybean/oat rotation, NT without cover crop soil temperatures at 2" depth at the SDSU Southeast Research Farm at Beresford, SD.

BIBLIOGRAPHY

Ahiablame, L., P. Sexton, C. Hay, T. Trooien, E. Cortus, and D. Todey. Drainage Management Strategies for Managing Water and Nutrients in South Dakota. In: Stevens, R., and P. Sexton, editors, 2015 Annual Progress Report. Southeast South Dakota Experiment Farm. SERF AR 1528. South Dakota Agricultural Experiment Station, South Dakota State University, Beresford, SD. p. 117-124.

Al-Kaisi, M.M., X. Yin, and M.A. Licht. 2005. Soil carbon and nitrogen changes as affected by tillage system and crop biomass in a corn-soybean rotation. Applied Soil Ecology 30: 174-191.

Arnold, J.G., R.L. Haney, C.H. Green, and R.D. Harmel. 2005. Phosphorus routine development for water quality modeling. Texas State Soil and Water Conservation Board. 20 pp. (Technical report).

Bakhsh, A., and R.S. Kanwar. 2007. Tillage and nitrogen application rates affect on corn and soybean yields and NO_3-N leaching losses. Trans. ASABE 50(4):1189-1198.

Bisel, R. 2016. Eastern South Dakota Grain Markets–Closing Elevator Bids. USDA-CO Department of Ag Market News Service, Greely, CO. https://www.ams.usda.gov/mnreports/sf_gr110.txt (accessed 16 June, 2015).

Bloom, A.J. 1997. Nitrogen as a Limiting Factor: Crop Acquisition of Ammonium and Nitrate. In L. E. Jackson, editor, Ecology in Agriculture. Academic Press, San Diego, CA. p. 145-164.

Clay, D.E., J. Chang, S.A. Clay, J. Stone, R.H. Gelderman, and G.C. Carlson, et al. 2012. Corn Yields and No-Tillage Affects Carbon Sequestration and Carbon Footprints. Agron. J. 104(3):763-770.

Coughenour, C.M., and S. Chamala. 2000. Conceptualizing System Innovation: Social Construction of Conservation Tillage and Cropping. In Conservation Tillage and Cropping Innovation: Constructing the new culture of agriculture. Iowa State University Press, Ames, IA. p. 15-44.

Douds, D.D., L. Galves, R.R. Janke, and P. Wagoner. 1995. Effect of tillage and farming system upon population and distribution of vesicular-arbuscular mycorrhizal fungi. Agric., Ecosyst. Environ. 52(2-3):111-118.

Eller, D. 2015. Des Moines water quality suit slated for trial in 2016. The Des Moines Register, Des Moines, IA.

Follett, R.F., and J.L. Hatfield. 2001. Nitrogen in the Environment: Sources, Problems, and Management. TheScientificWorld 1(S2):920-926.

Franzluebbers A.J., R.L. Haney. 2006a. Assessing soil quality in organic agriculture. Critical Issue Report 2006.2, The Organic Center, www.organic-center.org. (Technical Report).

Franzluebbers A.J., R.L. Haney. 2006b. Flush of CO2 as a soil biological quality indicator. p. 736-740. Proceedings of the 17th Conference of the International Soil Tillage Research Organization (CD-ROM), Kiel, Germany. 28 August-3 September.

Franzluebbers, A.J., R.L. Haney, and F.M. Hons. 1995a. Soil nitrogen mineralization potential for improved fertilizer recommendations and decreased nitrate contamination of groundwater. Texas Agricultural Experiment Station. (Texas Water Resources Institute); no. 171. V. 25: College Station, TX: Texas Water Resources Institute, Texas A&M University System. (Technical report).

Franzluebbers, A.J., R.L. Haney, and F.M. Hons. 1999a. Relationships of chloroform fumigation-incubation to soil organic matter pools. Soil Biology and Biochemistry 31:395-405.

Franzluebbers, A.J., R.L. Haney, C.A. Little, J.R. Salinas-Garcia, G.W. Evers, M.A. Sanderson, et al. 1995b. Managing soil nitrogen availability and potential nitrate leaching. Proceedings of the Water for Texas Conference: Setting the Research Agenda. 9 pp., (Technical report).

Franzluebbers, A.J., R.L. Haney, C.W. Honeycutt, H.H. Schomberg, and F.M. Hons. 2000. Flush of CO2 following rewetting of dried soil relates to active organic pools. Soil Science Society of America Journal 64:613-623.

Franzluebbers, A.J., R.L. Haney, C.W. Honeycutt, M.A. Arshad, H.H. Schomberg, and F.M. Hons. 2001. Climatic influences on active fractions of soil organic matter. Soil Biology and Biochemistry 33:1103-1111

Franzluebbers, A.J., R.L. Haney, F.M. Hons, and D.A. Zuberer. 1996a. Active fractions of organic matter in soils with different texture. Soil Biology and Biochemistry 28:1367-1372.

Franzluebbers, A.J., R.L. Haney, F.M. Hons, and D.A. Zuberer. 1996b. Determination of soil microbial biomass and nitrogen mineralization following rewetting of dried soil. Soil Science Society of America Journal 60:1133-1139.

Franzluebbers, A.J., R.L. Haney, F.M. Hons, and D.A. Zuberer. 1999b. Assessing biological soil quality with chloroform fumigation-incubation: Why subtract a control? Canadian Journal of Soil Science 79:521-528.

Gál, A., T.J. Vyn, E. Micheli, E.J. Kladivko, W.W. McFee. 2007. Soil carbon and nitrogen accumulation with long-term no-till versus moldboard plowing overestimated with tilled-zone sampling depths. Soil Tillage Res. 96(1-2):42-51.

Gelderman, R., S. Drymalski, C. Hoffman, S. Hanson, K. Skroch, and L.A. Anderson. 1995. Soil Testing Procedures, South Dakota State Soil Testing and Plant Analysis Laboratory. PSP 81. South Dakota State University Agricultural Exp. Stn., South Dakota State Univ., Brookings.

Gerwing, J., and R. Gelderman. 2005. Fertilizer Recommendation Guide. EC750. South Dakota State University Plant Science Dep., Brookings.

Gerwing, J., R. Gelderman, B. Berg, and A. Bly. 1999. 1999 Progress Report: Nitrogen management in a corn soybean rotation. South Dakota State University Soil/Water Research 99(4). http://www.sdstate.edu/ps/research/soil-fertility/reports/upload/99-04-N-Management-in-a-Corn-Soybean-Rotation.pdf (accessed 1 Jan. 2016).

Gordon, W.B., D.H. Rickerl, D.R. Sorensen, and P.K. Wieland. 1993. Tillage and nitrogen effects on growth, nitrogen content, and yield of corn. Commun. Soil Sci. Plant Anal. 24(5-6):421-441.

Green, C.H., J.G. Arnold, J.R. Williams, R.L. Haney, and R.D. Harmel. 2007. Soil and water assessment program hydrologic and water quality evaluation of poultry litter application to small-scale subwatersheds in Texas. Transactions of the ASABE 50(4):1199-1209.

Halvorson, A.D., B.J. Wienhold, and A.L. Black. 2000. Tillage and nitrogen fertilization influence grain and soil nitrogen in an annual cropping system. Agron. J. 93(4):836-841.

Haney E. B., R.L. Haney, L.R. Hossner, and G.N. White. 2006a. Neutralization Potential Determination of Siderite (FeCO3) Using Selected Oxidants Journal of Environmental Quality 35:871-879.

Haney, R.L. and A.J. Franzluebbers. 2009. CO2 Evolution: Response from arginine additions. Applied Soil Ecology 42:324-327.

Haney, R.L., A.J. Franzluebbers, and F.M. Hons. 2001a. A rapid procedure for prediction of nitrogen mineralization. Biology and Fertility of Soils 33:100-104.

Haney, R.L., A.J. Franzluebbers, E.B. Porter, F.M. Hons, and D.A. Zuberer. 2004. Soil carbon and nitrogen mineralization: Influence of drying temperature. Soil Science Society of America Journal 68:489-492. 2004.

Haney, R.L., A.J. Franzluebbers, F.M. Hons, and D.A. Zuberer. 1999. Soil carbon extracted with water or K2SO4: pH effect on determination of microbial biomass. Canadian Journal of Soil Science 79:529-533.

Haney, R.L., A.J. Franzluebbers, L.R. Hossner, F.M. Hons, and D.A. Zuberer. 2001b. Molar concentration of K2SO4 affects estimates of microbial biomass. Soil Biology and Biochemistry 33:1501-1507.

Haney, R.L., and E.B. Haney. 2010. A Simple Laboratory Method for Rewetting Dry Soil. Communications in Soil Science and Plant Analysis 41(12):1493-1501.

Haney, R.L., E.B. Haney, L.R. Hossner, and J.G. Arnold. 2006b. A new soil extractant for simultaneous phosphorus, ammonium, and nitrate analysis. Communications in Soil Science and Plant Analysis 37 (11-12):1511-1523.

Haney, R.L., E.B. Haney, L.R. Hossner, and J.G. Arnold. 2010a. Modifications to the new Soil Extractant H^3A–A Multi-Nutrient Extractant. Communications in Soil Science and Plant Analysis 41(12):1513-1523.

Haney, R.L., J.R. Kiniry, and M.W. Johnson. 2010b. Soil microbial activity under different grass species: underground impacts of biofuel cropping. Agriculture, Ecosystems and Environment 139:754-758.

Haney, R.L., L.R. Hossner, and E.B. Haney. 2008a. Soil Microbial Respiration as a Program to Assess Post Mine Reclamation. International Journal of Mining, Reclamation, and Environment 22(1):48–59.

Haney, R.L., S.A. Senseman, and F.M. Hons. 2002a. Effect of roundup ultra on soil microbial activity and biomass on selected soils. Journal of Environmental Quality 31:730-735.

Haney, R.L., S.A. Senseman, F.M. Hons, and D.A. Zuberer. 2000. Effect of glyphosate on soil microbial activity. Weed Science 48:89-93.

Haney, R.L., S.A. Senseman, L.J. Krutz, and F.M. Hons. 2002b. Soil carbon and nitrogen mineralization as affected by atrazine with and without glyphosate. Biology and Fertility of Soils 35:35-40.

Haney, R.L., W.F. Brinton, and E. Evans. 2008b. Soil CO2 respiration: Comparison of chemical titration, CO2 IRGA analysis and the Solvita gel system. Renewable Agriculture and Food Systems 23(0):1–6.

Haney, R.L., W.H. Brinton, and E. Evans. 2008c. Estimating Soil C, N, and P mineralization from short-term CO2 respiration. Communications in Soil Science and Plant Analysis 39:2706–2720.

Harmel, R.D., D.R. Smith, R.L. Haney, and M. Dozier. 2009. Nitrogen and phosphorus runoff from cropland and pasture fields fertilized with poultry litter. Journal of Soil and Water Conservation 64(6):400-412.

Harmel, R.D., H.A. Torbert III, P.B. Delaune, B.E. Haggard, and R.L. Haney, R.L. 2005. Field evaluation of three phosphorus indices on new application sites in Texas. Journal of Soil and Water Conservation Society 60(1):29-42.

Harmel, R.D., H.A. Torbert, B.E. Haggard, R.L. Haney, and M. Dozier. 2004. Water quality impacts of converting to poultry litter fertilization strategy. Journal of Environmental Quality 33(6):2229-2242.

Harmel, R.D., R.J. Cooper, R.M. Slade, R.L. Haney, and J.G. Arnold. 2006a. Cumulative uncertainty in measured streamflow and water quality data for small watersheds. Transactions of the ASABE 49(3):689-701.

Harmel, R.D., R.L. Haney, and D.R. Smith. 2011. Effects of Annual Turkey Litter Application on Surface Soil Quality of a Texas Blackland Vertisol. Soil Science 176(5):227-236.

Harmel, R.D., R.M. Slade, and R.L. Haney. 2010. Impact of Sampling Techniques on Measured Storm Water Quality Data for Small Streams. J. Environ. Qual. 39(5):1734-1742.

Harmel, R.D., S. Potter, P. Casebolt, K. Reckhow, C.H. Green, R.L. Haney. 2006b. Compilation of measured nutrient load data for agricultural land uses in the United States. Journal of the American Water Resources Assoc 42(5):1163-1178.

Havlin, J.L., D.E. Kissel, L.D. Maddux, M.M. Claassen, and J.H. Long. 1990. Crop Rotation and Tillage Effects on Soil Organic carbon and N. Soil Sci. Soc. Am. J. 54:448-452.

Havlin, J.L., J.D. Beaton, S. L. Tisdale, and W.L. Nelson. 2004. N. In 7th Ed. Soil Fertility and Fertilizers. Prentice Hall, Upper Saddle River, NJ. p. 97-100.

Ibrahim, M.A., A.H. Alhameid, S. Kumar, R. Chintala, P. Sexton, D.D. Malo, and T.E. Schumacher 2015. Long-Term Tillage and Crop Rotation Impact on a Northern Great Plains Mollisol. Adv. Crop Sci. Tech. 3(3):100-178.

Iqbal, M., A.G. Khan, A-ul. Hassan, and K.R. Islam. 2013. Tillage and Nitrogen Fertilization Impact on Irrigated Corn Yields, and Soil Chemical and Physical Properties Under Semiarid Climate. Journal of Sustainable Watershed Science & Management 1(3):90-98.

Janssen, C., and P. Hill. 1994. What is conservation tillage?. Conservation Tillage Series CT-1. https://www.extension.purdue.edu/extmedia/ct/ct-1.html (accessed 14 Jan. 2016).

Jin, V.L., M.V. Johnson, R.L. Haney, and J.G. Arnold. 2011. Potential carbon and nitrogen mineralization in soils from a perennial forage production system amended with class B biosolids. Agriculture, Ecosystems & Environment 141:461-465.

Karlen, D.L., J.L. Kovar, C.A. Cambardella, and T.S. Colvin. 2013. Thirty-year tillage effects on crop yield and soil fertility indicators. Soil Tillage Res. 130:24-41.

Kenney, D. R. and D. W. Nelson. 1982. N-Inorganic Forms. In R. L. Westerman, editor, Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties– Agronomy Monograph no. 9 (2nd Edition). ASA-SSSA, Madison, WI. P. 676-682.

Knorr, B. 2016. Weekly Fertilizer Review. Farm Futures. http://farmfutures.com/story-weekly-fertilizer-review-0-30765 (accessed 16 June, 2015).

Krutz, L.J., S.A. Senseman, and R.L. Haney. 2003. Effect of glyphosate on atrazine degradation. Biology and Fertility of Soils 38:115-118.

Lachat Instruments, INC. 1992. Nitrate in 2M KCl Soil Extracts. Quik Chem Method. 12-107-04-1-B. Lachat Instruments, INC., Milwaukee, WI.

Lancaster, S.H., R.L. Haney, S.A. Senseman, F.M. Hons, and J.M. Chandler. 2006. Soil microbial activity is affected by Roundup WeatherMax and pesticides applied to cotton (Gossypium hirsutum). Journal of Agricultural and Food Chemistry 54(19): 7221-7226.

Lancaster, S.H., R.L. Haney, R.L., S.A. Senseman, C.M. Kenerley, F.M. Hons, and J.M. Chandler. 2009. Microbial degradation of fluometuron is influenced by Roundup Weathermax. J. Agric. Food Chem. 56:8588-8593.

LECO Corporation. 2014. Nitrogen in Soil and Plant Tissue. Form No. 203-821-443. LECO Corporation, St. Joseph, MI.

Mozafar, A., T. Anken, R. Ruh, and E. Frossard. 2000. Tillage intensity, mycorrhizal and nonmycorrhizal fungi, and nutrient concentrations in maize, wheat, and canola. Agron. J. 92:1117-1124.

Nascente, AS., CAC. Crusciol, and T. Cobucci 2013. The no-tillage system and cover crops-alternatives to increase upland rice yields. Eur. J. Argron. 45:124-131.

Padgitt, M. 1993. AREI/Cropping Practices. United States Department of Agriculture. http://www.ers.usda.gov/media/871532/arei4-2.pdf (accessed 20 June 2016).

Pidwirny, M. 2006. The N Cycle. In Fundamentals of Physical Geography. 2nd ed. Michael Pidwirny, University of British Columbia Okanagan. http://www.physicalgeography.net/fundamentals/9s.html (accessed 5 Feb. 2016).

Pittelkow, C.M., X. Liang, B.A. Linquist, K.J. Groenigen, J. Lee, and M.E. Lundy, et al. 2015. Productivity limits and potentials of the principles of conservation agriculture. Nature 517:365-368.

Riedell, W.E., J.L. Pikul, and L. Carpenter-Boggs. 1998. Crop rotation improves soil fertility and plant mineral nutrition. South Dakota State University Soil/Water Research 98. https://www.sdstate.edu/ps/research/soil-fertility/reports/upload/98-x-Crop-Rotation-Improves-Soil-Fertility-and-Plant-Mineral-Nutrition.pdf (accessed 1 Jan 2016).

Ritchie, S.W., J.J. Hanway, and G.O. Benson. 1997. How a corn plant develops. Spec. Rep. 48. Cooperative Extension Service, Iowa State Univ. of Science and Technology, Ames, IA.

Rodale Institute. 2011. Cover Crops and No-till Management for Organic Systems. 20636. U.S. Dept. of Agriculture.

Sadej, W. and K. Przekwas. 2008. Fluctuations of nitrogen levels in soil profile under conditions of a long-term fertilization experiment. Plant and Soil Environment 54(5):197-203.

Salinas-Garcia J.R., J.E. Matocha, and F.M. Hans. 1997. Long term tillage and nitrogen fertilization effects on soil properties of an Alfisol under dry land corn/cotton production. Soil Tillage Res. 42(1):79-93.

Savabi, M.R., M.H. Golabi, A.A. Abou-Arab, and E.J. Kiadivko. 2008. Infiltration characteristics of No-till vs. Conventional Tillage in Indiana and Illinois farm fields. Journal of Environmental Hydrology 16:21.

Schimel, J.P., and J. Bennett. 2004. Nitrogen Mineralization: Challenges of a Changing Paradigm. Ecology 85(3):591–602.

Skroch, K., C. Hoffman, L. Mundt, and R.H. Gelderman. 1999. Plant Analysis Procedures, South Dakota State Soil Testing and Plant Analysis Laboratory. PSP 97. South Dakota State University Agricultural Exp. Stn., South Dakota State Univ., Brookings.

South Dakota State University. 2014. Daily Crop Water Use – Evapotranspiration (ET). South Dakota Climate and Weather. http://climate.sdstate.edu/awdn/et/et.asp?from=06%2F01%2F2014&to=06%2F30%2F2014&station=BES&Submit=Show+Data (accessed 31 March 2016).

South Dakota State University. 2016. Precipitation Normals (1981-2010). South Dakota Climate and Weather. http://climate.sdstate.edu/archives/data/precipnormals.asp (accessed 20 March 2016).

Stanford, G., and S.J. Smith. 1972. Nitrogen Mineralization Potentials of Soils. In: Soil Science Society of America Proceedings 36:465-472.

Steele, M.K., F.J. Coale, and R.L. Hill. 2012. Winter annual cover crop impacts on no-till soil physical properties and organic matter. Soil Sci. Soc. Am. J. 76:2164–2173.

Tueche, J.R., and S. Hauser. 2011. Maize (Zea mays L.) yield and soil physical properties as affected by the previous plantain cropping systems, tillage and nitrogen application. Soil Tillage Res. 115-116:88-93.

U.S. Geological Survey. 2015. Nitrogen (Fixed)-Ammonia. In: Mineral Commodity Summaries 2015. U.S. Geological Survey. 112-113. http://minerals.usgs.gov/minerals/pubs/mcs/2015/mcs2015.pdf (accessed 4 Feb. 2016).

United States Department of Agriculture, Natural Resource Conservation Service. 2016. Soil Map, Clay County, South Dakota (SD027). Web Soil Survey. http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx (accessed 16 January 2016).

Varvel, G.E., and W.W. Wilhelm. 2011. No-tillage increases soil profile carbon and nitrogen under long-term rainfed cropping systems. Soil Tillage Res. 114(1):28-36.

Viswakumar, A., R.W. Mullen, A. Sundermeier, and C.E. Dygert. 2008. Tillage and nitrogen application methodology impacts on corn grain yield. J. Plant Nutr. 31:1963–1974.

Ward laboratories, Inc. 2016. Haney/Soil health Test Information. Ward Laboratories, Inc. http://www.wr.ardlab.com/haney/haney_info.aspx (accessed 30 March 2016).

West, T.O., and W.M. Post. 2002. Soil organic carbon sequestration rates by tillage and crop rotation: a global data analysis. Soil Sci. Soc. Am. J. 66:1930–1946.

Wortmann, C.S., J.A. Quincke, R.A. Drijber, M. Mamo, and T. Franti. 2008. Soil microbial community change and recovery after one-time tillage of continuous NT. Agron. J. 100(5):1681-1686.