INVESTIGATION OF CORN YIELD IMPROVEMENT FOLLOWING CEREAL RYE USING STARTER NITROGEN FERTILIZER

by

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Dedicated to Great Grandpa Houston Schaffer, Grandpa Miller, and Grandpa Yocum.

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ABSTRACT

Cereal rye (CR), the most common and effective nitrogen (N) scavenging cover crop option in the Midwest, is often utilized in cropping systems to reduce nitrate loss for environmental benefits. To increase environmental efficiency in Midwest corn cropping systems, we must increase the overall adoption of CR. However, due to the yield reduction potential (6%) for corn planted after CR termination, CR is primarily recommended before soybean. To increase CR adoption, we must develop adaptive fertilizer management practices that achieve competitive grain yields relative to cropping systems where CR is not adopted. Therefore, the objectives of this study are to determine (1) the effect of CR and starter nitrogen rate on corn growth and nitrogen content. (2) the optimum starter nitrogen rate to achieve agronomic optimum corn yield following CR. (3) the impact of phosphorus (P) at starter on plant growth, nitrogen content, and yield with the inclusion of CR. For our study, five starter N rates were applied in a 5x5 cm band to both CR and non-CR plots, concentrations ranged from 0-84 kg N ha^{-1} in 28 kg N ha^{-1} intervals. Total N applied was the same for each treatment, relative to its location, and was split between starter N at planting and sidedress applied at growth stage V6 relatively. Although CR termination took place at least two weeks before planting, CR decreased corn grain yield at one of three locations by an average of 8%, nitrogen recovery efficiency (NRE) by 27%, and R6 total N content by 23%, relative to the conventional control (non-CR 0N), when no starter N was applied. At one of three locations, starter N rates of 56 kg N ha^{-1}, 56 kg N ha^{-1} plus 17 kg P ha^{-1}, and 84 kg N ha^{-1} increased corn grain yield, in CR plots, and 56 kg N ha^{-1} plus 17 kg P ha^{-1} increased corn grain yield in non-CR plots. Phosphorus increased corn grain N content at growth stage R6 in one of three locations and did not impact corn grain yield at all locations. We conclude that the inclusion of starter N at planting has the potential to

increase agronomic productivity in CR corn cropping systems in soil environments with a high capacity to mineralize soil N. However, further research is required to refine our starter N results to find an optimum starter N rate to apply before planting corn following CR.

CHAPTER 1. LITERATURE REVIEW

1.1 Environmental impact of nitrogen loss

1.1.1 Gulf of Mexico

Home to some of the world's most productive fisheries, the Gulf of Mexico accounts for about 16% of the total commercial fishery revenue in the United States and is worth approximately $850 million each year (National Marine Fisheries Service, 2016). Nutrients introduced into the Gulf of Mexico by the Mississippi River are disrupting this industry through eutrophication. Eutrophication occurs when water bodies, such as the Gulf of Mexico, are over-enriched with nutrients that lead to massive increases in phytoplankton growth, and once the influx of nutrient supply decreases phytoplankton start to decompose. This decomposition requires enough oxygen to cause a hypoxic phenomenon, where water has less than two parts per million of dissolved oxygen referred to as hypoxia, causing aquatic life to leave the area and in other cases die.

The principle nutrient directly related to creating this hypoxia zone in the Gulf of Mexico is nitrate (NO_3-N) (Burkart et al., 1999). Before 1972, the mean annual concentration of nitrate (NO_3-N) in the lower Mississippi River was approximately the same from 1905-1950s, but from 1956-1991 concentration doubled (Turner & Rabalais, 1991). This increase is strongly correlated with the increase in agricultural use of inorganic nitrogen fertilizer of 1 million mt yr^{-1} from the mid-1930s to 10 million mt yr^{-1} during the 1990s in the United States. Additionally, 42% of the total annual nitrogen applied takes place in states that are partially or completely located in the Mississippi watershed (Turner & Rabalais, 1991). With agricultural inputs as the main driver for the increase in nutrient flow to the Gulf of Mexico, we can attribute this increase in inorganic nitrogen fertilizer to the Haber-Bosch process.

1.1.2 Nitrogen Fertilizer

Between 1904 and 1908, Fritz Haber established equilibrium data for ammonia-hydrogen-nitrogen over a wide range of temperatures and pressures that lead to the ability to synthesize ammonia (NH_3N) by reacting hydrogen and atmospheric nitrogen. Badische Anilin-und Soda Fabrik (BASF) Corporation developed an iron-based catalyst that promoted this reaction of hydrogen and atmospheric N at temperatures below 540°C. BASF then went on to fund Fritz Haber's work and Carl Bosch, industrial chemist and engineer, to bring laboratory findings to small-scale production systems for testing, before commercialization (Russel et al., 1977). Nitrogen production for fertilizer in the United States, however, was not done on a large scale until World War II. During World War II, several nitrogen power plants were developed to supply munitions for the army. With this increase in production, synthesized nitrogen was able to sufficiently fill the agricultural market following World War II (Russel et al., 1977). With enough supply to meet demand, inorganic nitrogen fertilizer usage increased drastically due to the ease in application, storage, handling, and efficiency of these products.

Following World War II, synthetic N usage increased dramatically due to commercial product availability, rapid decline in soil organic matter, and changes in management (Tucker & Crowe, 1966). Organic matter in soils decreased due to half a century of cultivation that allowed excess nitrogen to mineralize from soil organic matter and before the 1950s released adequate nitrogen for crops. As a result, not much N was applied to maintain this nutrient level and erosion amplified soil organic matter lost. With the advances in mechanical technology agriculture management costs increased, while commercial N costs stayed relatively the same. Therefore farmers, to remain profitable would plant the most productive cash crops continuously such as corn and would rely more on synthetic fertilizers to supply crop needs.

The most common synthetic nitrogen fertilizers used today are urea, anhydrous ammonia, and urea ammonium nitrate solutions (UAN). Urea was first commercialized in 1920 and became the leading N fertilizer in the world by 1975 (Russel et al., 1977). Urea, 46% nitrogen, allows the handler to apply nitrogen to the soil as a solid and can be mixed with other granulated fertilizers. Typically, broadcasted urea left on the soil surface is vulnerable to ammonia volatilization. Therefore, without incorporation by tillage or rainfall shortly after application, nitrogen loss can be great.

Anhydrous ammonia, 82% nitrogen, is typically the most efficient nitrogen fertilizer source. Therefore, compared to other nitrogen sources less must be applied to meet the crop requirement, less product needs to be bought, and less time in the field overall. Application occurs as ground by knife injection, where anhydrous ammonia will attach to organic matter, clay particles, hydrogen ions, and soil water converting from ammonia (NH_3-N) to ammonium (NH_4-N). Approximately a three to four day conversion allows nitrogen in the NH_4-N form to be accessible by plants (Mengel et al., 2017). A disadvantage of using anhydrous ammonia is that other forms of fertilizer such as phosphorus or sulfur cannot be added to the mixture.

Made up of a mixture of urea, ammonium nitrate, and water, UAN, depending on how much percent is mixed by weight can contain 28, 30, or 32% nitrogen. Although not as efficient as the other two nitrogen products, anhydrous ammonia and urea, UAN has many advantages, as a solution UAN can be mixed with other fertilizers, herbicides, and fungicides. UAN can easily be applied in many different placements and timings. Having a solution pH of about 7, UAN is relatively harmless to crops unless UAN is applied in direct contact with the seed leading to moisture being drawn away from the seed or if ammonia is generated when applied to the soil, both of which can kill or stunt the cash crop (Mengel et al., 2017).

Agricultural inputs have contributed the most N to the Gulf of Mexico on a basin scale, since the 1900s. Therefore, the Mississippi River/Gulf of Mexico Hypoxia Task Force (HTF) in 2008 created a priority action plan asking major states located in the Mississippi River Basin Watershed to develop a Nutrient Reduction Strategy (NRS). The NRS specifically works to reduce the amount of excess nitrogen and phosphorus that enters the watershed and ultimately ends up in the Gulf of Mexico (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, 2008).

1.1.3 Nutrient Reduction Strategy

Twelve states located in the Mississippi River Basin Watershed have developed a NRS. Each strategy is particular to its respective state, but all follow a general framework of eight recommended elements for managing nitrogen and phosphorus pollution found in the 2011 EPA memo (Stoner, 2011). These elements include prioritizing watersheds based on supplying a substantial portion, ≥ 80%, of nitrogen and phosphorus loads, setting load reduction goals, annual reporting of implementation activities, biannual reporting of load reductions, etc. One of these elements is labeled Agricultural Areas, under which the EPA calls to develop watershed-scale plans that target the most effective practices where they are needed most. Specific plans include innovative approaches such as; targeted stewardship incentives and certainty agreements to accelerate the adoption of agricultural conservation practices (Stoner, 2011). Once states' identified priority areas, they began to identify the most effective practices to reduce nitrogen and phosphorus load to the water and more specifically nitrogen in the form of nitrate (NO_3-N). Some of the methods suggested include designated wetlands, bioreactors, no-till, reduced till, N reduction management practices, and cover crops. No-till, reduced till, N reduction management practices, and cover crops give us an interesting aspect because, they allow producers to integrate them into their current cropping system without compromising the cash crop. Therefore, promoting these conservation practices allows greater overall conservation adoption, relative to other conservation practices that restrict cash crop production. N reduction management practices often involve adequate N application during the time when the corn extracts the most N from the soil, such as moving fall N application to spring, and involves the 4R's, outlined in the NRS, these include the right timing, right rate, right source, and right placement of N fertilizers. However, Ruffatti et al., 2019 and others have shown that N reduction management and conservation tillage practices have only a small impact on soil water quality that is not enough to meet the EPA goals alone. So, to improve cropping systems to meet EPA goals coupling conservation tillage and N reduction management with cover crops is necessary. Cover crops are proven to reduce a larger amount of nitrogen load to the water, relative to conservation tillage and no-till. In fact, a cover crop such as cereal rye can reduce spring and fall nitrogen tile nitrate load by 40 and 47% (Ruffatti et al., 2019). For this reason, there has been a great push by states to increase the adoption of cover crops. In Indiana, the acreage of cover crops being implemented on corn and soybean ground has increased from 2% in 2011 to 8% in 2017 (Cover Crop and Tillage Transect Data, 2017).

1.2 Cover Crops

Cover crops are plants grown in a cropping system that are not harvested for profit, but are exclusively grown to protect the soil from erosion, unwanted plants, and loss of essential plant nutrients via the water cycle. Reportedly used over 200 years ago, cover crops were first known as green manures, where cover crops are grown on less productive land then left to reside and decease to benefit the next year's crop (Groff et al., 2015). Soon after World War II synthetic fertilizers and herbicides were introduced. Suppressing cover crop usage due to the affordability, simplicity, and effectiveness of these newly developed products. From then up until the 1990s, with the introduction of the Sustainable Agriculture and Research Education (SARE) program, cover crop usage was scarce. Now the SARE program allows farmers and researchers the ability to utilize funding to apply conservational ideas such as cover crops (Groff, 2015). Cover crops are utilized in cropping systems to help reduce eutrophication of surface waters and can be grown to capture nutrient loss when nitrogen and phosphorus loss is at its highest. Cereal rye being one of the best management practices for reducing soil nitrate loss (Motsinger et al., 2016) is highly promoted in soil and water conservation.

1.3 Cereal Rye

Cereal rye (Secale cereale L.) is the most widely grown cover crop in the Midwest United States (CTIC., 2017). This is in large part due to the ecosystem services that cereal rye has to offer and studies that prove cereal rye reduces nitrates lost through sub-surface tile drainage. Therefore, farmers are often incentivized to adopt cereal rye to support conservational goals. However, this is not the only reason cereal rye is the most popular cover crop, and cereal rye has many other intriguing ecosystem services. Including, the ability to enhance water penetration and retention, reduce soil erosion, build organic matter, and suppress weeds (Werle et al., 2017). Winter hardiness makes cereal rye the most popular with the widest planting window, greatest spring growth, and the ability to germinate at 34°F and grow at 38°F (Clark, 2008). Additionally, CR is relatively cheap to implement per acre and is easy to terminate, so why is cover crop implementation cover only 7% acreage before growing corn in Indiana (Cover Crop and Tillage Transect Data, 2017)? Perhaps the reasoning is that despite all the intriguing characteristics and benefits, cereal rye can negatively influence corn yield by an average of 6%.

1.4 Cereal Rye's Impact on Corn Yield

A system-level analysis lead by Martinez-Feria et al. (2016) identified that there is a 6% grain yield reduction on corn (Zea mays L.) following cereal rye when grown as a cover crop (Martinez-Feria et al., 2016; Pantoja et al., 2015). Therefore, what are the factors that contribute to the corn yield deficit caused by cereal rye? Perhaps it's cooler soil, poor seed to soil contact, nitrogen immobilization, less nitrogen in the soil, or harboring for disease. What aspects of the corn growth cycle are affected? Soil nitrogen, corn population, plant vigor, nitrogen content, maturation, nitrogen use efficiency, or a combination of the listed factors? Cereal rye creates an environment that decreases soil nitrogen, creates harboring for disease, and persuades nitrogen immobilization, all aspects that could potentially harm yield. Physical abilities that make cereal rye attractive as a cover crop also create an environment that could create a less attractive environment for corn. Such as a lower soil concentration of inorganic nitrogen caused by the cereal rye actively growing and taking up inorganic nitrogen that would otherwise be available to the corn plant, and once cereal rye is terminated, the added influx of carbon to the system can cause immobilization once decomposition occurs. Cereal rye's ability to overwinter may allow plant pathogens, such as Fusarium and Pythium, to overwinter by providing a food source, where usually most of these pathogens would die.

1.4.1 Soil Inorganic Nitrogen

Cereal rye has shown to reduce nitrate in the soil that is why it is utilized in fields to reduce nitrate water pollution, but this could mean less nitrogen available for the following corn crop. Cereal rye has shown to decrease nitrate in the soil an average of 28 kg N ha^{-1} to a two-foot depth (Sawyer et al., 2016), which corresponds to the percent nitrogen load reduction in another study where they found nitrate (NO_3-N) reduction to be 40-47% (Ruffatti et al., 2019). Less available inorganic N can also be caused by means of N immobilization brought on by degradation of CR residue.

1.4.2 Nitrogen Immobilization

Degradation of residue is a process where microorganisms use residue as a food source, convert compounds, and release these compounds back into the environment. During the decomposition of residue, nitrogen can be processed two ways either mineralized or immobilized. Mineralization is the conversion of organic nitrogen to inorganic nitrogen ammonia (NH_4+N) resulting in plant accessible nitrogen. Nitrogen immobilization is the conversion of inorganic nitrogen, NH_4+N or NO_3-N, to organic nitrogen causing nitrogen to be inaccessible by plants. Often nitrogen immobilization coincides with an increased level of microorganism activity. At approximately 39-53 days after CR termination, growth stage V6, is when soil microorganism activity spikes, which gives us the greatest chance for nitrogen immobilization (Nevins et al., 2018). Consequently, this happens around the same time as sidedress application and the greatest nitrogen content by corn takes place around growth stages V8-VT, this could be why, when a decrease in corn grain yield is caused by CR, we do not see a significant decrease in N content, caused by CR, until growth stage R6 (Otte, 2018). Whether microorganisms transform nitrogen by means of mineralizing or immobilizing it is dependent on the carbon to nitrogen (C:N) ratio (Weathers et al., 2012). Soil microbial biomass regulates its C:N ratio by utilizing carbon and nitrogen pools found in the organic form. With an 8:1 ratio soil microbes need to feed on residue with a high nitrogen content and low C:N ratio (Cleveland & Liptzin, 2007). Residue with a low C:N ratio provides microorganisms with enough nitrogen to help balance their C:N threshold leading to mineralization. High C:N ratios cause immobilization, with low amounts of nitrogen available microorganisms do not have the nitrogen needed to help maintain their threshold so they utilize inorganic nitrogen from other sources (Weathers et al., 2012). Cereal rye with an approximate C:N ratio of 24:1 can lead to immobilization due to the added influx of carbon (Kuo & Sainju, 1998). Further complications can arise within a no-till system, where previous crop residue have the potential to increase this C:N ratio that microorganisms decompose. Once immobilization occurs, corn's pool of plant available nitrogen begins to decrease and become inaccessible during early corn growth, slowing maturation of the corn and potentially leading to harmful effects on grain yield. Besides N immobilization, CR residue has the potential to harbor and increase pathogen populations in corn, leaving corn more susceptible to disease.

1.4.3 Harboring disease

When implementing cereal rye before corn in a cropping system there is always a risk for disease transfer since both species belong to the same family of grasses, *Poaceae*. Cereal rye's growth cycle typically involves being planted in the fall and then terminated in the spring prior to corn planting. This provides a food source for pathogens that would have originally passed on, now have overwintered and given their close phylogenetic similarity pathogens are expected to be shared between these two species (Gilbert et al., 2015). Acting as a "green bridge" by allowing pathogen populations to maintain or increase in size during the time they would typically decline and transfer these pathogens on to the following crop corn. In fact, Fusarium and Pythium have both been shown to infect corn and cereal rye. With cereal rye, having the capability of harboring elevated seedling pathogen densities when compared to a control (Bakker et al., 2016). When favorable conditions are present for pathogen infection cereal rye decreases corn yield for every treatment regardless of termination date (Acharya et al., 2017).

We must also keep in mind that the environment for favorable conditions for pathogen infection are also favorable conditions for nitrogen immobilization. Now that we have looked at the ways cereal rye can potentially decrease corn yield, what are some ways we can increase corn yield in a CR corn cropping system?

1.5 Adaptive Nitrogen Management to Increase Corn Yield in Cereal Rye Systems

In a corn cereal rye cropping system one adaptive management practice that is commonly agreed upon by many studies is that there should be a two-week interval between terminating cereal rye and planting corn (Wagger et al., 1989a; Crandall et al., 2005; Eckert et al., 1988). This helps by allowing adequate time for pathogen populations to decrease prior to planting (Acharya et al., 2017) and for cereal rye decomposition to commence. However, corn grain yield in CR plots has been observed to be less than grain yield in non-CR plots, even when delaying corn planting till two weeks after CR termination. Often when CR is observed to decrease corn grain yield, relative to non-CR, R6 total N content is also reduced. Therefore, to reduce the deficit in grain yield, total N application rate was investigated from 0 to 225 kg N ha^{-1} in 45 kg N ha^{-1} increments to identify if by exclusively increasing the total N application rate the deficit in corn N content between CR and non-CR plots could be eliminated (Pantoja et al., 2015). At all rates, Pantoja et al. (2005) observed corn in CR plots to consistently have less N content, at growth stage R6, compared to corn planted in non-CR plots. Additionally, after applying a greater rate in CR plots than what is required to reach the maximum N content in non-CR plots, corn in non-CR plots had consistently greater N content once maximum N content was reached, relative to corn N content in CR plots. When corn receives nitrogen solely at V6 in a CR corn cropping system, and termination of cereal rye takes place less than two weeks prior to planting can be detrimental to the corn plant. This results in poor soil and plant nitrogen status preceding

V6 nitrogen application that leads to reduced biomass, lower nitrogen content, and lower yields. However, when nitrogen at V6 was applied in combination with pre-plant or starter these harmful effects were not reflected (Crandall et al., 2005). Giving light to the potential benefits of applying starter in a corn cereal rye cropping system.

In a more recent study from Iowa, starter N was applied as urea in a 5x5 cm band at a rate of 34 kg N ha^{-1}, Sawyer et al. (2016) observed an average grain yield increase of 0.2 Mg ha^{-1} , in both CR and non-CR plots, across eight location years when applying starter N, relative to the control (Sawyer et al., 2016). These results further indicate there is some promise to improving CR corn cropping systems by applying starter N at planting, even though, the increase is consistent across both CR and non-CR plots. To further refine CR corn cropping systems research must analyze the effect of varying rates of starter N on both CR and non-CR plots, to optimize starter N in CR corn cropping systems.

Therefore, the objectives of this study are to (1) Investigate the effect of cereal rye and starter nitrogen rate on corn growth and nitrogen content. (2) Optimize starter nitrogen rate to achieve agronomic optimum corn yield following cereal rye. (3) Determine the impact of phosphorus at starter on plant growth, nitrogen content, and yield with the inclusion of cereal rye.

CHAPTER 2. INVESTIGATION OF CORN YIELD IMPROVEMENT FOLLOWING CEREAL RYE USING STARTER NITROGEN FERTILIZER

2.1 Introduction

Cover crops, ever since the implementation of the Nutrient Reduction Strategy (NRS), have been identified as one of the key methods to help reduce nitrate NO_3-N leaching into the Gulf of Mexico, from the Mississippi Watershed. Cover crops, although not the only method of reducing NO_3-N leaching, have the capability of being integrated into a farmer's current cropping system without compromising the land utilized to grow the cash crop. Cereal rye (CR), the most widely planted cover crop (CTIC., 2017), specifically can reduce spring and fall nitrogen load by 40 and 47% (Ruffatti et al., 2019). Therefore, CR is often recommended to farmers to grow to meet NRS goals. Since CR is easy to establish and grow, CR is implemented on a larger scale relative to other cover crops. However, CR grown before corn has been associated with corn yield reduction, on average approximately 6%, and as a result CR planted before corn is often avoided as it is hard for farmers to make these optimal N usage systems profitable (Martinez-Feria et al., 2016; Pantoja et al., 2015). With CR being one of the hardiest cover crops that is easy to establish, terminate, and implement in current cropping systems, we can improve the overall adoption of cover crops and NO_3-N reduction if we improve corn yield following CR.

When it comes to improving corn yield following CR many studies have investigated the time frame between CR termination and corn planting. The agreed upon time by many studies is there should be at least a two-week interval between CR termination and corn planting (Wagger, 1989b; Crandall et al., 2005; Eckert et al., 1988). This two-week interval is believed to help corn yield following CR because, it allows time for pathogen populations, held by the CR, to decrease prior to planting that would otherwise infect corn seedlings and decrease corn yield (Acharya et al., 2017). Another aspect of CR's impact on corn is its ability to cause a reduction in corn N content (Pantoja et al., 2015). Therefore, other studies have incorporated total N and timing of N in their research to attempt to eliminate this corn yield deficit, caused by CR. Total N application was investigated from 0 to 225 kg N ha^{-1} and found that the total N application rate for corn in a no-till corn soybean rotation should be the same with or without CR, because the agronomic optimum N rate (AONR), 180 kg N ha^{-1}, was observed to be the same in both non-CR and CR plots. Additionally, grain yield and R6 total N content were not improved when applying total N rates above the AONR, in both non-CR and CR plots, and corn grown in CR plots consistently yielded less and had less N content, relative to corn grown in non-CR plots (Pantoja et al., 2015). Crandall (2005) reported that when N was solely applied at V6 in a CR corn cropping system a termination time of less than two weeks prior to corn planting was detrimental to the corn plant. This then resulted in poor soil and corn nitrogen status preceding V6 nitrogen application that led to reduced biomass, lower nitrogen content, and lower corn yields. However, when nitrogen at V6 was applied in combination with pre-plant or starter fertilizer these harmful effects were avoided (Crandall et al., 2005), thus implying there may be potential benefits of applying starter fertilizer in a corn CR cropping system. Starter N has since been investigated to help reduce or eliminate the decrease in corn yield caused by CR, and this study has indicated that starter N could be used to offset negative effects of CR, when utilized as a cover crop before corn (Sawyer et al., 2016).

However, this study did not investigate an array of starter N rates to determine an optimum rate of starter N. It is important to identify if there is a corn yield response to starter N rate following CR, which could make the inclusion of CR into a corn cropping system more profitable to encourage widespread adoption of CR, and a significant reduction in nitrates loss in tile-drained landscapes.

Therefore, the objectives of this study were to (1) Determine the effect of cereal rye and starter nitrogen rate on corn growth and nitrogen content, (2) the optimum starter nitrogen rate to achieve agronomic optimum corn yield following cereal rye, and (3) the impact of including starter phosphorus on plant growth, nitrogen content, and yield with and without a cereal rye cover crop.

2.2 Materials and Methods

2.2.1 Location Descriptions

Field-scale trials were conducted during the 2018 growing season at the Southeast Purdue Agricultural Center (SEPAC) located in Butlerville, IN (two locations) and Northeast Purdue Agricultural Center (NEPAC) near Columbia City, IN. The predominant and secondary soil types for each location are listed in Table 1. Each location was made sure to have adequate phosphorus (P) and potassium concentrations prior to the 2018 corn growing season, excluding N, that met Tristate recommendations (Vitosh et al., 1995). The southeastern locations were arranged in a completely randomized experimental design, while our northeastern location was arranged as a randomized complete block design. There were twelve treatments at each location with six starter N rates applied to both CR and non-CR treatments (Table 1). Each treatment was replicated four times. Plots were twelve rows with 76.2 cm (30 in.) row spacing making 9.14 m (30 ft.) wide plots by at least 61 m (200 ft.) long.

2.2.2 Weather

Maximum and minimum temperatures and daily precipitation were recorded by automated weather stations at SEPAC and NEPAC. This data was obtained through the Indiana State Climate Office (ISCO) at https://climate.agry.purdue.edu/climate/data_archive.asp. Any data missing was replaced using Weather Underground https://www.wunderground.com/history. Data collected from these weather stations were then used to calculate Growing Degree Days by taking the maximum temperature for that day minus the minimum temperature in degrees Celsius divided by two and then subtract the answer by ten degrees Celsius. Max temperature calculated cannot exceed 30 °C and min temperature cannot be less than 10 °C. Data for the 30-year normal (1980-2010) was obtained from ISCO (Table 2).

2.2.3 Cereal Rye Management and Sampling

The crop rotation for each location was corn/soybean. At all locations, CR was planted after soybean harvest in the fall of 2017 using a no-till drill (Table 3). Chemical termination of the CR took place spring of 2018, at least two weeks prior to corn planting, using a combination of glyphosate $C_3H_8NO_5P$ (Round Up) and saflufenacil $C_{17}H_{17}ClF_4N_4O_5S$ (Sharpen). Weather at each location kept us from terminating each location exactly two weeks prior to planting. CR biomass was sampled at each location using two 0.25 m^2 representative areas per plot, the day before CR termination or at the most one week after CR termination. Cut directly above the soil surface, CR biomass was combined for a single 0.5 m^2 area representing each plot. Dried in a 60°C forced air drier until CR biomass weight was constant, and ground through a 1 mm sieve for Carbon (C) and N combustion analysis run on the Flash 2000 (Thermo Fisher Scientific Waltham, MA USA).

2.2.4 Soil sampling

Soil sampling occurred on the same date as planting, before planting, at all locations. Eight soil cores were taken with a 1.9 cm diameter soil probe to a 30 cm depth at equally distributed locations across each plot. Soil was air-dried and ground through a 2 mm sieve to prepare for total N and C combustion analysis with a Flash 2000 (Thermo Fisher Scientific Waltham, MA USA). Soil samples were analyzed for NH_4-N and NO_3-N with Seal Analyzer AQ2 (Seal Analytical Mequon, WI USA), by a colorimetric analysis procedure (Maynard et al., 1993). Briefly, 5 g of soil was weighed into a 50 ml centrifuge tube and 25 ml of a 2M KCl solution. Centrifuge tubes were shook for 30 minutes on a shaker at medium speed, and then centrifuged for 5 minutes each at 2400 rpm. The solution was filtered through 42 Whatman filter paper and frozen to await analysis (("Protocol for inorganic nitrogen extraction in soils (KCl method)", 2016)). Inorganic N results were then reported as kg N ha^{-1}, calculated by inputting bulk density from web soil survey and volume of soil in a hectare furrow slice down to a 30 cm depth (Table 6).

2.2.5 Corn Planting

Corn planting took place 14 to 26 days after CR termination (Table 4). Hybrids at each experiment were planted with maturity ratings that matched their geological area. Corn was no-till planted at a rate of 79,074 seeds ha^{-1} (32,000 seeds $acre^{-1}$). Planters at each location were equipped with row cleaners, coulters, and closing wheels. Planting at each location occurred in ideal soil conditions resulting in 93% or greater emergence by growth stage V2 (Table 7-12).

2.2.6 Nitrogen application

At all locations, treatments consisted of six starter N rates for both CR and no CR (non-CR) plots (Table 4). Starter was applied at planting utilizing a 5x5 cm band applicator attached to the planter. The six starter N rates ranged from 0 to 84 kg N ha^{-1} in increments of 28 kg N ha^{-1}. Each starter application included the addition of ammonium thio-sulfate (12-0-026S) at a rate of 5.6 kg S ha^{-1}, to eliminate sulfur (S) as a potential limiting factor. Phosphorus (P) was included in one starter treatment at a rate of 17 kg P ha^{-1} using ammonium polyphosphate (10-34-0), to determine the influence P on the aspects of corn growth measured. The rate of N applied at sidedress was calculated by taking the difference between starter N applied and total N applied. Total N applied was determined by the average Agronomic Optimum Nitrogen Rate (AONR) determined for each location (Camberato & Nielsen, 2019). Our sixth starter rate indicated by absolute zero (A.Zero) received no nutrient application during the growing season through starter or sidedress application. Additionally, all sidedress applications, excluding the "A.Zero" treatment, contained 11 kg S ha^{-1}. In the form of ammonium thio-sulfate (12-0-026S). Sidedress application dates are located in Table 3.

2.2.7 Corn Sampling

Corn population, above ground biomass, and growth stage were determined seven times during the growing season. The first five samplings were in weekly intervals during the vegetative growth stages of the corn plant, starting with growth stage V2. The last two samplings took place in reproductive stages R1-R2 and at growth stage R6 (physiological maturity). Corn plants were cut directly at the soil surface and the above ground biomass was gathered for later analysis. For each sampling, corn was sampled in three representative 1.39 m^2 locations within each plot, that changed at each sampling date, covering a total of 4.18 m^2. At each of these locations, all corn plants were recorded along a 1.82 m long pole to calculate population, and the first five plants at each location were removed for corn biomass, a total of fifteen plants were removed. Growth staging in each plot took place at one designated location, directly in the middle of each plot, along a 1.82 m length where every plant was recorded for total number of leaf collars and the fifth and tenth leaves were marked for staging after older leaf senescence and abscission. Total number of leaf collars was then averaged for each plot to have one representative growth stage for each plot. Corn plants used for growth staging did not change during the growing season. Destructive sampling took place outside of the middle six rows that would be harvested for yield estimation. Above-ground biomass was chopped and then dried in a 60°C forced air dryer to a consistent weight and then ground to pass through a 1 mm sieve prior to combustion analysis as described for CR. During the V2 growth stage, five seedlings were sampled from two arbitrary locations totaling ten seedlings per plot for disease identification. Each sampling was carefully dug up keeping roots intact, removing excess soil, and then placed in 1 gallon labeled Ziploc bags. Ziploc bags were placed in a cooler with ice, but the Ziploc bags were not placed in direct contact with ice. Seedlings were shipped overnight to the Robertson Lab at Iowa State University (Dr. Alison Robertson Ames, IA USA) to be quantified for *Pythium spp. and Fusarium spp.* roots colonization (Bakker et al., 2016). At R6, corn biomass was partitioned into stover (stalk and leaves) and grain. Corn stalks were cut into 8-inch segments beginning at 6 inches above the ground and processed the same as all plant material in addition to 8-inch stalk samples being shipped to United Soils Incorporation (USI) for stalk nitrate analysis. 8-inch stalk segment results were then added into stover analysis for biomass and N content, and reported as stover. Nitrogen recovery efficiency (NRE) was calculated at R6 by taking whole plant N content in fertilized plots (NUF) minus whole plant N content in our unfertilized A.Zero plots (NUC) divided by our total N rate applied (R) and multiplied by one hundred (NRE = ((NUF)-(NUC) / R) *100) (Kovacs et al., 2015). Corn grain harvest occurred after R6 maturity using commercial combines equipped with GPS-enabled grain yield monitors.

The middle six rows were harvested to avoid destructive sampling areas and obtain a full header pass. Prior to harvest, the yield monitor was calibrated using steps outlined in setup and calibration steps for the AgLeader Yield Monitor Manual (AgLeader Technology, 2018). The resulting yield data was cleaned in ArcGIS (Esri Redlands, CA USA) by removing at least 15.2 meters on the ends of each plot to remove potential error in carryover from plot to plot (Luck et al., 2015). At SE2 four plots were removed from the data set due to excessive weed pressure and standing water, documented by UAV aerial photos taken early and mid-season displaying crop stress in these plots. Grain moisture was determined using the harvest monitor data for grain moisture. Grain moisture was calibrated following the outlined steps in the AgLeader Yield Monitor Manual (AgLeader Technology, 2018).

2.2.7 Statistical Analysis

Data from the three trials were analyzed separately due to differences in experimental design and a variability between fields. Our southeastern locations, Location 1 and 2, were analyzed as a completely randomized experimental design, and Location 3, our northeastern location, as a randomized complete block design. All A.Zero treatments skewed the data to a point where transformations could not normalize the data so they were removed from the main statistical analysis, and later compared against one another using a t-test. The remaining data for each variable was considered normal and verified by the Shapiro-Wilk Normality Test. Therefore, no data transformations were used in our study. Measurements of CR growth and soil inorganic N were analyzed using a One-Way ANOVA utilized through R studio (R Core Team, 2017) in combination with the Agricolae package (Felipe, 2017). All other measurements; corn population, corn growth stage, N content, grain yield, NRE, stalk nitrate, and grain moisture were analyzed by single-degree-of-freedom contrasts using R studio (R Core Team, 2017) in combination with the Agricolae package (Felipe, 2017). Means were considered significantly different if the statistical analysis returned a P-value of ≤ 0.1. Single-degree-of-freedom contrasts were utilized to precisely answer our objectives and were necessary to identify the influence phosphorus had on measurements. With our single-degree-of-freedom contrasts we wanted to first answer three specific questions. 1. Did CR have an impact? 2. Did starter, in CR plots, influence results over the CR control? 3. Did starter, in non-CR plots, influence results over the non-CR control (conventional control)? We achieved this by contrasting CR control versus conventional control (1. Non-CR 0N vs. CR0N), contrasting the CR control versus each starter rate individually in CR plots, therefore no starter rates greater than 0N are compared to one another and each starter rate is only compared directly back to the control (2. CR 0N vs. CR28N, CR 0N vs. CR56N, CR 0N vs. CR56NP, CR 0N vs. CR84N), and contrasting the non-CR control versus each starter rate individually in non-CR plots. (3. Non-CR 0N vs. Non-CR28N, Non-CR 0N vs. Non-CR56N, Non-CR 0N vs. Non-CR56NP, Non-CR 0N vs. Non-CR84N). In addition to contrasting based on treatment we analyzed contrasts based on starter rate that included both CR and non-CR plots, and with these we were able to answer three more questions. 1. Did starter influence results, relative to the control? (0N vs. 28N, 56N) 2. Which specific starter rate had the greatest return? (28N, 56N vs. 84N) and (28N vs. 56N) 3. Did phosphorus have an impact? (56N vs. 56NP).

2.3 Results and Discussion

2.3.1 Location Characteristics

Total growing degree days (GDD) for the 2018 season at all locations was less than the 30-year average. Our southeastern locations (SE1 and SE2) had slightly more precipitation for the growing season, relative to the 30-year average, whereas our northeastern location (NE) had less precipitation for the 2018 growing season (Table 2). SE1 was observed to have the most precipitation between CR termination and corn planting (Table 3), compared to the other locations, this could cause CR decomposition to proceed slower than the other locations due to less oxygen being available in the soil. NE had the largest gap between corn planting and sidedress application of 38 days (Table 3). From this observation, we can presume that potentially starter N would have a greater impact at NE, relative to both SE1 and SE2. Table 2 contains the average monthly precipitation and GDD for each location. Table 3 helps to identify the differences in precipitation, GDD, and time between important dates; CR planting, CR termination, corn planting, sidedress application, and harvest.

2.3.2 Cereal rye Biomass, Nitrogen, and Carbon Content, and Carbon to Nitrogen ratio

Cereal rye biomass ranged from 1076 kg ha^{-1} (SE1) to 1454 kg ha^{-1} (NE), and CR N content ranged from 20 kg ha^{-1} (SE2) to 34 kg ha^{-1} (NE). The C:N ratio of the CR across all locations ranged from 17:1 (NE) to 21:1 (SE2). Cereal rye biomass, N content, and C content were not different between SE1 and SE2, and both were lower than NE. SE2 had the widest C:N ratio making SE2 susceptible N immobilization (Table 5).

The C:N ratio and N concentration of the CR residue are the best predictors for N mineralization (Quemada & Cabrera, 1995). Enwezor (1976), studied five C:N ratios, created by mixing different proportions of powdered straw and peas, that ranged from 9.8 to 44.4, observed that the critical C:N threshold for N immobilization occurs between 16.1 and 23.8. At C:N ratios higher than this range, N immobilization occurs and lower than this range, N mineralization occurs. When comparing a continuous corn rotation with a continuous corn with CR, as a cover crop rotation, CR reduced corn grain yield at two of six location years and the C:N ratios of the CR above ground biomass at these two locations were 11:1 and 22:1 (Martinez-Feria et al., 2016). All locations in our study had C:N ratios that were in this critical threshold and thus potentially created an N immobilizing soil environment, where N supply may have restricted corn growth.

2.3.3 Spring Soil NH_4-N, NO_3-N, and Total Inorganic Nitrogen Content

The CR decreased spring soil NH_4-N, and NO_3-N at all locations relative to non-CR (Table 6). At SE1, NO_3-N content was 28% lower in CR plots than in non-CR plots. NO_3-N content, in CR plots at SE2, was on average 42% less than NO_3-N content in non-CR plots. At NE, CR reduced NO_3-N content by an average of 9.3%, relative to non-CR (Table 6).

Organic matter (OM) observed at SE1 to a 30 cm depth was 1.51%, 1.3% at SE2, and 1.78% at NE. OM was not different between each location (Table 6).

A reduction in spring soil inorganic N is a common consequence of healthy CR growth and contributes to a reduction in soil NO_3-N loss via tile drainage (Ruffatti et al., 2019). Previous studies observed a 35 (Sawyer, 2016) and 46% (Krueger et al., 2011) decrease in spring soil NO_3-N content when utilizing CR as a cover crop. Another experiment, conducted in Illinois, observed greater soil NO_3-N content to a 30cm depth in fallow plots compared to CR plots at planting (Crandall et al., 2005). The question remains, can farmers manage this void of soil inorganic N in the spring just prior to corn planting using starter N fertilizer.

2.3.4 Two Spring Soil Nitrogen Environments

Based upon the previously stated results, we have characterized the spring soil N environment of each location as either CR N limiting or CR N non-limiting. SE1 and SE2 we considered to be in a CR N limiting environment, because the CR C:N ratio was in the potential N immobilizing range, CR had the least N content, and soil inorganic N found at these two locations had a large differential between CR and non-CR treatments, relative to NE. NE, we considered to be in a CR N non-limiting environment, because the CR N content was the greatest among locations, soil inorganic N gap between CR and non-CR plots was the lowest, and the CR C:N ratio was in the potentially N immobilizing range. The C:N ratio is not different among locations SE1 and NE, however, CR C:N ratios located in the potentially N immobilizing range does not guarantee that N immobilization will occur. SE2 was affected by poor drainage and caused large variability at this location. As a result, SE2 findings do not always resemble SE1 results.

2.3.5 Corn Population and Seedling disease

Corn plant population was unaffected by CR and starter N rate at all locations and growth stages sampled (Tables 7-12). This result agrees with those in a study conducted in Iowa that found no impact of CR on corn population, even when CR reduced corn yield (Sawyer et al., 2016). However, Kessavalou and Walters (1997) found CR decreased corn plant population by 6% in one of three location years, this decrease in corn plant population resulted in a 38% decrease in corn grain yield.

Cereal rye did not increase incidence of seedling disease, at the V2-V3 growth stage (data not shown). This finding suggested that CR did not act as a “green bridge” by allowing the previous season’s pathogen population to reside in residue and overwinter escalating pathogen population for the following year’s cash crop. Additionally, at all locations the starter fertilizer application of 84 kg N ha^{-1} decreased the incidence of Pythium clade B populations, at all locations (data not shown). A previous study suggested that with the increase in corn seedling pathogens there is a reduction in shoot growth and grain yield, and increasing the time interval between CR termination and corn planting to greater than ten days can decrease seedling disease incidence in corn plants (Acharya et al., 2017).

2.3.6 Corn Growth Stage

At SE1, corn development was not affected by CR growth when comparing the CR control (CR 0N) to the conventional control (non-CR 0N) at the vegetative growth stages V2-V11 (Table 13, Contrast 1). Corn growth stage in A.Zero treatments at 473 GDD was increased in non-CR A.Zero versus CR A.Zero (Table 13). Among the CR treatments, corn growth stage was greater for the 28N starter rate versus the “no starter” CR control at 379 and 473 GDD (Table 13, Contrast 2). Similarly, corn growth stage was significantly greater for the 56NP starter rate versus the “no starter” control at 627 GDD (Table 13, Contrast 4). No other effects of starter fertilizer were detected among the CR treatments. Corn growth stage among the non-CR treatments was significantly greater for the 56N starter rate at 298 and 473 GDD (Table 13, Contrast 7) and for the 28N, 56NP, and 84N starter rates versus the “no starter” control at 473 GDD (Table 13, Contrasts 6, 8, 9). Across both cover treatments a starter rate of 56N was not different from 56NP, at all GDD sampled (Table 14, Contrast 4).

At SE2, CR did not significantly impact corn development, when comparing the CR control against the conventional control (Table 15, Contrast 1). CR A.Zero and non-CR A.Zero were not different at all GDD (Table 15). In CR plots, corn growth stage was greater for starter N rate of 28N at 537 and 594 GDD, relative to the CR control (Table 15, Contrast 2). Similarly, a starter N rate of 56N increased corn growth stage at 371, 537, and 594 GDD, compared to the CR control (Table 15, Contrast 3). A starter N rate of 56NP increased corn growth stage, in CR plots, at 371 and 537 GDD, relative to the CR control (Table 15, Contrast 4). Additionally, in CR plots, a starter N rate of 84N increased corn growth stage at 371, 537, and 594 GDD, relative to the CR control (Table 15, Contrast 5). No other differences were found in CR plots due to starter N rate. Among non-CR plots, a starter N rate of 56N increased corn growth stage at 594 GDD, relative to the conventional control (Table 15, Contrast 7). A starter N rate of 56NP increased corn growth stage at 371 and 594 GDD, relative to the conventional control (Table 15, Contrast 8). Similarly, a starter N rate of 84N increased corn growth stage at 537 and 594 GDD, relative to the conventional control (Table 15, Contrast 9). No other differences were found in non-CR plots due to starter N rate. A starter N rate of 56N across all cover treatments was not different than a starter N rate of 56NP (Table 16, Contrast 4).

Cereal rye did not impact corn development, when comparing CR control (CR 0N) to the conventional control (non-CR 0N) at NE (Table 17, Contrast 1). Starter N $\geq$ 56 kg N ha^{-1}, including starter with P application, increased corn development, in CR plots, compared to the CR control (CR 0N) at 320, 411, and 468 GDD (Table 17, Contrast 3, 4, 5). No other differences were found in CR plots. An application rate of 56 kg N ha^{-1} and 17 kg P ha^{-1} at starter increased corn development at 320, 411, and 468 GDD (Table 17, Contrast 8), in non-CR plots, and 28 kg N ha^{-1} increased corn development at 411 GDD (Table 17, Contrast 2). Across both cover treatments starter N rate of 28N and 56N increased corn growth stage at 320, 411, and 468 GDD (Table 18, Contrast 1), relative to "no starter applied" (0N). A starter rate of 56NP increased corn growth stage, when compared to a starter rate of 56N, at 320 GDD (Table 18, Contrast 4).

According to a study from Ontario, Canada (Raimbault et al., 1990), CR delays corn silk emergence by five to seven days, reducing corn development in CR plots, relative to non-CR plots. In our study in contrast, we observed that CR did not reduce corn development at all locations.

Starter N $\geq$ 28 kg N ha^{-1} did not significantly reduce corn development at all locations, in both CR and non-CR plots, when compared to their respective controls (0N). Starter N has reportedly provided consistent early season growth response in corn across many different hybrids (Bermudez and Mallarino, 2002; Hornaday, 2017). A previous study, conducted in

Indiana, reflects our results that found little differences in corn development around growth stages V2-V3, when comparing 5x5 cm starter placement to the control, but differences became more apparent as the season progressed (Hornaday, 2017). Comparatively within our study, starter N did not significantly increase corn development at the last vegetative stage at one (SE1) of our three locations, even when a significant increase in corn development was observed at earlier growth stages. Potentially this could be a result of our southeastern location (SE1) receiving sidedress, at growth stage V4, at least one week prior to the other locations SE2 and NE at growth stage V7 relatively. Another study from Iowa, conducted on no-till management of eleven strip trials, observed an increase of 32% in early season corn development caused by starter when compared to no starter applied (Bermudez and Mallarino, 2002). In relation to the previous study above, we also found an increase in early season corn development with an application of starter N $\geq$ 28 kg N ha^{-1}, however, our percent increase averages to less than 10%, compared to 32%. Phosphorus at all locations had no consistent differences, when compared to the N only starter rate.

2.3.6 Corn Biomass

There was no impact of CR on corn biomass growth, where no starter was applied, at SE1 (Table 19, Contrast 1). In CR plots, starter rates of 28N and 84N increased corn biomass during growth stages V2-V7 (Table 19, Contrasts 2, 5). 56 kg N ha^{-1}, in CR plots, increased corn biomass during growth stages V2-V6 and R1-R6 (Table 19, Contrast 3). 56 kg N ha^{-1} with the addition of 17 kg P ha^{-1} increased corn biomass at growth stages V6 and R6, in CR plots (Table 19, Contrast 4). In non-CR plots a starter rate of 84 kg N ha^{-1} decreased corn biomass at growth stage V11 (Table 19, Contrast 9). Across both cover treatments (CR and non-CR), starter N rate increased corn biomass at growth stages V2-V7, relative to 0N and a starter rate of 28 kg N ha^{-1}

proved to increase corn biomass the most out of all starter N rates, at growth stage V2 (Table 20, Contrasts 1-3). When comparing 56N to 56NP (Table 20, Contrast 4) there was no difference in corn biomass, at all GDD sampled.

At SE2, no impact on corn biomass was observed due to CR, relative to CR 0N vs. non-CR 0N (Table 21, Contrast 1). Among CR plots, a starter rate of 56NP increased corn biomass, at growth stage V9, relative to the CR control (CR 0N) (Table 21, Contrast 4). No more differences were found in CR plots. In non-CR plots, at growth stage V7 and V9, corn biomass was increased with a starter application rate of 56 kg N ha^{-1}, relative to the conventional control (non-CR 0N) (Table 21, Contrast 7). Similarly, a starter rate of 84N increased corn biomass, at growth stage V9. Across both cover treatments, starter N application of 28N and 56N increased corn biomass, relative to the 0N, at growth stage V9 (Table 22, Contrast 1). Additionally, 56N was not different from 56NP (Table 22, Contrast 4).

Corn biomass at NE was not impacted by CR at all growth stages, when comparing CR 0N versus non-CR 0N (Table 23, Contrast 1). In CR plots, corn biomass was increased by starter N rates of 56N, 56NP, and 84N at growth stages V4, V7, and V8 (Table 23, Contrast 3, 4, 5). At growth stage V5, 56NP increased corn biomass in non-CR plots (Table 23, Contrast 8). In non-CR plots at growth stage V7 56NP and 84N increased corn biomass (Table 23, Contrast 8, 9). During the reproductive stages, R1-R6, starter rates of 56N and 56NP increased corn biomass, in CR plots (Table 23, Contrast 3, 4). Across all cover treatments, starter N application increased corn biomass at growth stages V4, V7, V8, and R1-R6 (Table 24, Contrast 1). A starter N rate of 56N was not different from 56NP (Table 24, Contrast 4).

Similar to our findings, a study conducted in Minnesota found that corn biomass at the end of the season was not different in CR plots, relative to non-CR plots (Kruegar et al., 2011).

Starter N application in a study from Nebraska found that starter application increases corn biomass at growth stage V6 to V8 three out of five location years, relative to no starter applied (Wortmann et al., 2006). Similarly, our study found that three out of three location years corn biomass was increased at growth stages V7-V9. Interestingly, Wortmann et al. (2006) observed that out of the three location years, where corn biomass was increased, two location years starter increased corn grain yield, relative to no starter applied. Contrast from our findings, a study from Minnesota observed that P increased corn biomass, at growth stages V4-V7, in four out of four location years (Kim et al., 2013).

2.3.6 Corn Nitrogen Content and NRE

At SE1, pre-sidedress application growth stage V2-V3, we observed that there was no impact of CR on corn N content, when comparing the CR control (CR 0N) to the conventional control (non-CR 0N) (Table 25, Contrast 1). Across both cover treatments, starter N rate of A.Zero in CR plots were not different from A.Zero treatments in non-CR plots (Table 25). Starter N rates of 28, 56, and 84 kg N ha^{-1} increased corn N content, in CR plots, when compared to the CR control pre-sidedress (Table 25, Contrast 2, 3, 5). No other differences were found in CR plots. In non-CR plots, only a starter N rate of 28 kg N ha^{-1} increased N content, relative to the conventional control (Table 25, Contrast 6). Post sidedress application, growth stages V6-R2, at growth stage V6 corn N content was decreased in the CR control, relative to the conventional control (Table 25, Contrast 1). At growth stage V6, all starter rates increased corn N content in CR plots relative to the CR control (Table 25, Contrast 2, 3, 4, 5), and at growth stage V7 only 84 kg N ha^{-1} increased corn N content (Table 25, Contrast 5). In non-CR plots, at growth stage V6, a starter application rate of 56 kg N ha^{-1} with the addition of 17 kg P ha^{-1} increased N content, when compared to the conventional control (Table 25, Contrast 8). At growth stage V7, a starter N rate of 28N, 56N, and 56NP increased N content versus the conventional control (Table 25, Contrast 6, 7, 8). At growth stage R1-R2, a starter rate of 56 kg N ha^{-1} decreased N content, when compared to the conventional control (Table 25, Contrast 7). At corn maturity, growth stage R6, CR decreased R6 total N content by 23.5%, compared to no CR, in no starter (0N) treatments (Table 25, Contrast 1). Starter N rate at maturity had no significant impact on corn N content in both CR and non-CR plots, when compared to their respective controls. A rate of 56N was not different from 56NP (Table 26, Contrast 4). In addition the A.Zero starter N rate was not different from the 0N starter N rate, before sidedress application, growth stage V5 (Table 26). This was evaluated because some N was present in the 0N starter N rate, when applying a sulfur rate, and not the A.Zero starter N rate. Therefore, the small amount of N in the starter N application did not affect corn N content, relative to the A.Zero treatment.

The corn nitrogen recovery efficiency (NRE) measured at the R6, maturity, was decreased in CR plots relative to non-CR plots by 27.5% (Table 31, Contrast 1), and starter N had no impact on NRE in CR and non-CR plots relative to their respective controls.

CR, at SE2, did not impact corn N content during pre-sidedress corn growth at growth stages V2-V7, when comparing the CR control (CR 0N) to the conventional control (non-CR 0N) (Table 27, Contrast 1). Across all cover treatments, A.Zero treatments were not different in CR plots compared to non-CR plots (Table 27). A starter application rate of 56 kg N ha^{-1} with 17 kg P ha^{-1} during pre-sidedress increased corn N content in CR plots at V7, when compared to the CR control (Table 27, Contrast 4). In non-CR plots at V7, starter N application rate of 56N, 56NP, and 84N increased corn N content, relative to the conventional control (Table 27, Contrast 7, 8, 9). Post-sidedress, growth stages V9-R2, CR did not significantly impact corn N content, when the CR control and conventional control were compared (Table 27, Contrast 1). Starter application rate of 56 kg N ha^{-1} and 17 kg P ha^{-1} during post-sidedress increased corn N content in CR plots at V9, when compared to the CR control (Table 27, Contrast 4). In non-CR plots, a starter N application of 56N, 56NP, and 84N increased corn N content at the V9 growth stage (Table 27, Contrast 7, 8, 9). At corn maturity, CR had no impact on corn N content when the CR control is compared with the conventional control (Table 27, Contrast 1). Starter N ≥ 28 kg N ha^{-1} also had no significant impact on corn N content in CR and non-CR plots, relative to their respective controls (Table 27, Contrasts 2-9). A starter rate of 56N was not different than a starter rate of 56NP at all growth stages, indicating P did not impact corn N content (Table 28, Contrast 4). A starter rate of 0N increased corn N content, relative to A.Zero starter N rates, indicating that the slight addition of N at starter increased corn N content at growth stage V7 (Table 28). NRE results were observed to reflect corn N content at maturity with no impact of CR or starter N ≥ 28 kg N ha^{-1} on corn NRE (Table 31, 32).

At NE, N content was not affected by CR during the pre-sidedress growth stages (V2-V7), when comparing the CR control (CR 0N) to the conventional control (non-CR 0N) (Table 29, Contrast 1). The A.Zero treatments were not different when comparing A.Zero in both CR and non-CR plots (Table 29). Pre-sidedress corn N content increased starter N of 28N, 56N, 56NP, and 84N in CR plots, when compared to the CR control (Table 29, Contrast 2-5). In non-CR plots, during the pre-sidedress time frame starter N ≥ 28 kg N ha^{-1} increased N content when compared to the conventional control (Table 29, Contrast 6-9). Post-sidedress, growth stages V8-R2, CR 0N did not affect corn N content, when compared to non-CR 0N (Table 29, Contrast 1). A starter N rate of 56 and 84 kg N ha^{-1} within CR plots increased corn N content at the V8 growth stage (Table 29, Contrast 3, 5). In non-CR plots, a starter rate of 84 kg N ha^{-1} increased corn N content at the reproductive growth stages R1-R2 (Table 29, Contrast 9). During corn maturity, CR did not impact corn N content, when comparing the CR control to the conventional control (Table 29, Contrast 1). Starter N application of 84 kg N ha^{-1}, in CR plots, increased corn N content, when compared to the CR control (Table 29, Contrast 5). Across both cover treatments, starter increased corn N content at growth stages V4, V7, V8, and R6 grain (Table 30, Contrast 1). Additionally, a starter N rate of 56NP decreased corn N content at V5, relative to a starter rate of 56N (Table 30, Contrast 4). Corn NRE at maturity was not different, when comparing the CR control against the conventional control (Table 31, Contrast 1). Starter N rate in CR and non-CR alike, when compared to their respective controls were not different (Table 31).

Corn N content was decreased by CR at R6 (maturity), relative to "no starter N applied", in the CR N limiting environment (SE1 and SE2) at one (SE1) of the three total locations. We attributed this decrease to greater precipitation observed between CR termination and corn planting, when compared to the other locations. Comparative to our results found at R6 N content, a study conducted in Maryland on corn in rotation with soybeans and CR, reported that CR decreases R6 corn N content by an average of 19% and the percentage is increased to 32% when CR termination took place only one week before corn planting. What is most interesting about their study is that corn N content was measured at growth stages V5, R2, and R6, and like our findings they saw no significant decrease in N content caused by CR until R6 (Otte et al., 2018). Similarly, another study conducted in Illinois measured R1 corn N content, and observed that corn planted in fallow plots returned the greatest N content in comparison to the CR plots (Crandall et al., 2005). Interestingly Crandall et al. (2005), found that the greatest corn N content at the R1 growth stage was observed in treatments that only received starter N, relative to N application at sidedress only and N application at both starter and sidedress.

An experiment, conducted in Indiana on no-till continuous corn, observed that starter applied in a 5x5 cm band consistently increased early season nitrogen concentrations at growth stage V6, during all seven location years, when compared to no starter applied (Hornaday, 2017). Comparatively our study shows inconsistency during early season corn growth, with only two out of three locations returning more than one significant response to starter N $\geq$ 28 kg N ha^{-1} within early vegetative stages (V2-V9).

Previously a study out of Minnesota, on starter banded 5x5 cm in corn, observed that starter P applied at planting increased ($P<0.01$) N content at early vegetative growth stages (V4-V7) at all four location-years within their study, however, increased N content by P never translated into improved yield (Kim et al., 2013). Comparatively we observed an increase in N content at early vegetative growth stages at two of three locations, when adding P to the starter solution, and similarly we observed that increased N content by P at early vegetative stages never translated into increased corn yield or total N content at maturity (R6).

NRE percentages at SE1 and SE2 was 80% on average, while NE resulted in an average NRE of 45%. Finding a lower percentage of NRE at our northeastern location was expected because the agronomic optimum N rate (AONR) is much larger, relative to the other locations. Our NRE results at SE1 are relatively high compared to other studies.

In a previous report, taken place in Iowa on a no-till corn-soybean rotation, CR has shown to reduce NRE in corn, relative to non-CR (Pantoja et al., 2015), which only relates to our results at SE1. Pantoja (2015) expressed that the difference between CR and non-CR plots relative to NRE gradually decreased as N application was increased, over six N application rates ranging from 0-225 kg N ha^{-1}. However even after a greater N application rate than the economic optimum nitrogen rate (EONR), corn NRE in CR plots does not equal or exceed corn NRE in non-CR plots.

2.3.7 Corn Stalk Nitrate

Stalk nitrate values, at SE1, were decreased by CR, when comparing the CR control (CR 0N) to the conventional control (non-CR 0N) (Table 33, Contrast 1). A starter rate of 56 kg N ha^{-1}, in CR plots, increased stalk nitrate by 97% (Table 33, Contrast 3). In non-CR plots, starter N $\geq$ 28 kg N ha^{-1} did not significantly impact corn stalk nitrate (Table 33, Contrast 6-9). Across both cover treatments (CR and non-CR), a starter N rate of 28N and 56N increased stalk nitrate values, relative to 0N (Table 34, Contrast 1). A starter rate of 56NP reduced stalk nitrate, relative to a starter rate of 56N (Table 34, Contrast 4).

Stalk nitrate concentrations were not different in the CR control (CR 0N), relative to the conventional control (non-CR 0N), at SE2 (Table 31, Contrast 1). In CR plots, we observed that starter N rates of 28N, 56NP, and 84N increased stalk nitrate concentration, when compared to the CR control (Table 31, Contrast 2, 4, 5). Starter N had no significant impact on stalk nitrate concentration in non-CR plots, relative to the conventional control (Table 31, Contrast 6-9). Across both cover treatments (CR and non-CR), a starter N rate of 28N and 56N decreased stalk nitrate values, relative to 0N (Table 32, Contrast 1). A starter rate of 56N and 56NP were not different (Table 32, Contrast 4).

Cereal rye, at NE, did not impact stalk nitrate concentration, when comparing the CR control to the conventional control (Table 31, Contrast 1). Starter N $\geq$ 28 kg N ha^{-1}, in both CR and non-CR plots, did not impact stalk nitrate concentration, when compared to their respective controls (Table 31). Across both CR and non-CR plots, a starter rate of 56NP increased stalk nitrate values, relative to a starter rate of 56N (Table 32, Contrast 4).

Corn stalk nitrate values in the CR N limiting environment were decreased with the presence of CR in “no starter” applied treatments, at SE1 only. Starter N increased stalk nitrate values at SE1 and decreased stalk nitrate values at SE2 in the CR N limiting environment. The CR N non-limiting environment had no differences in stalk nitrate values due to CR or starter N rate.

Most of the stalk nitrate values were within the 1000-2000 ppm range, indicating that most treatments received adequate N (Camberato and Nielsen, 2014). The remaining stalk nitrate values except for one treatment fell in the 251-1000 ppm range. In the 251-1000 ppm range, this indicates that the corn in these areas could have been N deficient up to 30 kg ha^{-1}. All stalk nitrate values were indicated to have optimal levels of nitrate, which means each location received adequate amounts of nitrogen, and CR at all locations did not impact stalk nitrate values.

2.3.8 Grain Yield

At SE1, CR A.Zero reduced corn yield, compared to non-CR A.Zero, by 71% (Table 35). Additionally, where no starter (0 kg N ha^{-1}) was applied, CR reduced corn yield by an average of 8%, compared to non-CR (Table 35, Contrast 1). Starter N $\geq$ 28 kg N ha^{-1} had no significant impact on corn yield in either CR or non-CR plots (Table 35). Grain yield was not different between starter N rates of 56N and 56NP (Table 36, Contrast 4).

Corn yield at SE2, was not different between A.Zero treatments in CR and non-CR plots (Table 35). Corn grain yield was not affected by CR or starter N $\geq$ 28 kg N ha^{-1} (Table 35, Contrast 1). Across all cover treatments, starter N rate had no effect on corn grain yield (Table 35). Between 56N and 56NP there were no differences in grain yield (Table 36, Contrast 4).

At NE, CR had no significant impact on corn grain yield when comparing the CR control to the conventional control (Table 35, Contrast 1). Additionally, there was no difference between A.Zero treatments in CR and non-CR plots (Table 35). In CR plots, a starter N rate of ≥ 56 kg N ha^{-1} resulted in an increase in corn yield, when compared to no starter applied (0N) (Table 35, Contrast 3, 4, 5). In non-CR plots a starter N rate of 56 kg N ha^{-1} with the addition of 17 kg P ha^{-1} resulted in an increase in corn grain yield of 8% (Table 35, Contrast 8). Starter rate of ≥ 56 kg N ha^{-1} at NE significantly increased corn grain yield and comparatively both SE1 and SE2 resulted in no significant impact of starter N when compared to no starter applied (0N). Across all cover treatments, starter N rate of 28N and 56N increased corn grain yield, relative to 0N (Table 36, Contrast 1). Starter N rate of 56N was not different from 56NP (Table 36, Contrast 4).

At corn maturity in the CR N limiting environment (SE1 and SE2), CR decreased corn N content (23%) (Table 25, Contrast 1) and corn grain yield (8%) (Table 35, Contrast 1), at SE1, when comparing the CR control to the conventional control. Corn N content in both the CR N limiting (SE1 and SE2) and non-limiting (NE) environment are increased with the application of starter N, however, starter N application in the CR N limiting environment does not increase corn N content during reproductive growth stages. In the CR N non-limiting environment, starter N application increases corn N content throughout both vegetative and reproductive growth stages. This increase in corn N content translated into increased yield, at NE. Across both environments, P had no impact on N content and corn grain yield, relative to the starter N rate of 56N. This resembled another study (Kim et al., 2013) that found P and N in combination, compared to N alone, increased early season corn growth and nutrient content, but only translated into improved grain yield at one of four locations.

Marcillo et al. (2017) utilized meta-analysis on data collected from 1965 to 2015 found that grass winter cover crops on average neither increased nor decreased corn grain yield. Although grass winter cover crops had a neutral effect on average for corn grain yield, they addressed that during some location years yield penalties still occur. Marcillo et al. (2017) suggests the decrease in yield to be a factor of reduced corn population and higher number of barren plants, caused by poor seed to soil contact, reduced soil temperatures, allelopathic effects inhibiting germination, or N content reduction. Eckert (1988) found a reduction in no-till corn yield following CR in 4 of 12 location years. Eckert (1988) attributed the corn yield reduction to a reduced corn population. In our study, no reduction in corn population occurred and we attributed loss in grain yield to reductions in N availability, caused by CR. Other studies have observed a yield reduction of 6% on corn following CR (Martinez-Feria et al., 2016; Pantoja et al. 2015). Yield loss in our study due to CR resulted in a 1.34 Mg ha^{-1} decrease in corn grain yield, while Pantoja et al. (2015) indicated that they observed a 0.75 Mg ha^{-1} difference in corn yield between non-CR and CR treatments. However, Pantoja et al. (2015) reported a loss in yield across all locations, and we only had a loss at one (SE1) of three locations. This may be due to the time between termination and planting, where we waited for at least two weeks before planting and in their study they waited 7-10 days. Eckert (1988) concludes that within a no-till corn cropping system CR is more likely to reduce than improve grain yields.

Previous studies also support our findings with starter N rate within CR. Sawyer (2016) found that applying 30 lbs N $acre^{-1}$ at starter significantly increased yields when compared to no starter applied within CR and non-CR treatments alike for an average yield improvement of 0.19 Mg ha^{-1}. Within our study we saw a significant increase in yield due to starter N at 33% of our locations whereas Sawyer (2016) reported 50%, relative to no starter N applied. Sawyer (2016) indicated that starter N increased corn yield in CR plots, but that they observed no significant interaction effects between starter N and cover.

2.3.9 Grain Moisture

At SE1, CR had no impact on grain moisture, when no starter was applied (0N) at harvest, relative to non-CR (Table 37, Contrast 1). In CR plots, a starter application rate of 84 kg N ha^{-1} decreased grain moisture, compared to the CR control (CR 0N) (Table 37, Contrast 5). Comparatively starter N $\geq$ 28 kg N ha^{-1} had no impact in non-CR plots, relative to the conventional control (non-CR 0N) (Table 37, Contrast 6-9). Grain moisture in both the starter N rate of 56N and 56NP were not different (Table 38, Contrast 4).

At SE2, grain moisture in the CR control was not significantly different than grain moisture in the conventional control (Table 37, Contrast 1). A starter N of 56N, 56NP, and 84N in CR plots did not impact grain moisture, when compared to the CR control (Table 37, Contrast 3, 4, 5). In non-CR plots, a starter N application of 56 kg N ha^{-1} and 56 kg N ha^{-1} with the addition of 17 kg P ha^{-1} decreased grain moisture, relative to the conventional control (Table 37, Contrast 7, 8). Across all cover treatments, starter N rate of 28N and 56N decreased corn grain moisture, relative to 0N (Table 38, Contrast 1). The presence of P in the starter N rate of 56N did not impact corn grain moisture (Table 38, Contrast 4).

NE results indicated that CR had no significant impact on grain moisture, when comparing the CR control to the conventional control (Table 37, Contrast 1). Starter N had no significant impact in CR plots, when compared to the CR control (Table 37). A starter N application of 28 kg N ha^{-1}, in non-CR plots, decreased grain moisture, relative to the conventional control (Table 37, Contrast 6). Grain moisture was not different between starter N rates of 56N and 56NP (Table 38, Contrast 4).

By analyzing grain moisture data gathered by the yield monitor, we can conclude that treatments with drier grain at harvest reached black layer, growth stage R6, sooner and therefore matured faster. Cereal rye in a previous study was shown to delay silk emergence in corn by 5 to 7 days under a no-till system (Raimbault et al., 1990). This is a clear indication of CR delaying corn maturity. and relatively we found that CR decreases grain moisture in the CR N limiting environment at SE1 by 1.8% and at SE2 starter N rates of 56N and 56NP decreased corn grain moisture. Whereas in the CR N non-limiting environment, CR did not impact grain moisture and starter N rate of only 28N decreased corn grain moisture in non-CR plots. Previous studies have found that starter N applied results in a faster maturity of the corn crop throughout the growing season and therefore a faster grain dry down time by maturity, when compared to no starter applied (Hornaday, 2017). Grain moisture on average is reduced by 3% (Vetsch & Randall, 2000) when applying starter N, relative to no starter applied. Contrastingly, Scharf (1999) observed no differences in corn grain moisture due to starter N being applied, even when significant differences were found in relative maturity and yield. Differences between Scharf (1999) and our study could be the way the grain moisture was sampled. Grain moisture in our study was measured through a combine yield monitor, whereas Scharf (1999) measured grain moisture using a portable moisture meter. Most likely when using a portable moisture meter fewer data points are taken per plot, relative to a grain monitor, making it less likely to detect differences. Additionally, the grain moisture differences range from 0-5% so the differences between treatments are small requiring more data points and reps to detect differences.

2.4 Conclusion

In this study we observed corn yield decrease behind CR, even when adequately terminating CR and delaying corn planting up to 4 weeks after CR termination. Due to no differences in corn population, disease, and corn development between CR and non-CR plots at all locations, we conclude that CR residue did not hamper corn planting by disrupting seed to soil contact or planting depth, damage corn health by harboring disease, or restrict vegetative corn development. Thus, corn yield loss due to CR adoption is most likely related to a reduction in soil inorganic N availability.

In CR N non-limiting environments, we found that the addition of starter N increased corn grain yield, NRE, and R6 total N content relative to the CR N limiting environment. In both environments, often there were early season increases in corn development and N content with the application of starter N. However, in the CR N non-limiting environment starter N rate increased early season corn N content and transferred into end of season increases of R6 corn N content and grain yield. Whereas in the CR N limiting environment early season increases did not develop into end of season increases.

The addition of P to the starter N treatment of 56N had no consistent effect across all measurements and locations. Additionally, any early season increases resulting from P addition did not translate into increases at corn growth stage R6 (maturity). Therefore, we conclude that adding P to starter N rate has no additional benefit, relative to starter N by itself, when applied into soils that had adequate P concentration, before planting.

Cereal rye, the most commonly grown and effective N scavenging cover crop in the Midwest, is often not grown before corn due to its ability to limit N availability. However, through our study we were able to confirm the positive impact starter N has on corn following CR adoption. Additionally, starter N applied in CR plots did not reduce corn grain yield at all locations, and at one of three locations an increase in corn grain yield in CR plots only resulted after applying at least 56 kg N ha^{-1} or greater. Prior to this study, there has been no attention given to the potential relationship between soil mineralization capacity and the response of corn to starter N application following CR termination. In our study, soils that had the highest potential to mineralize soil N from soil OM were indicated by the small difference between total spring soil inorganic N in CR and non-CR plots. In this environment, there was a positive response to starter N application in corn, resulting in increased corn N content and grain yield. In the latter environment, where the spring soil inorganic N difference was large, starter N application had no impact on R6 corn N content and grain yield.

Results from this study can be used to further adapt N management practices in CR corn cropping systems to become more agronomically efficient and appealing to farmers. Therefore, increasing the adoption of CR as a cover crop and consequently furthering the progression of enhanced water quality in agronomic systems.

Table 1. Predominant soil and secondary soil for each location. If no secondary soil is listed the predominant soil makes up ≥ 90% of the total area covered by the plots.

	Location		
	SE1	SE2	NE
	Predominant Soil		
Located	Butlerville, IN	Butlerville, IN	Columbia City, IN
Series	Avonburg	Cobbsfork	Boyer
Texture	SiL	SiL	SL
Slope %	0-2	0-1	1-6
Drainage	SP	P	W
% area covered	73	97	54
	Secondary Soil		
Series	Avonburg	-	Glynwood
Texture	SiL	-	L
Slope %	2-4	-	2-6
Drainage	SP	-	MW
% area covered	27		46

L- Loam
SiL- Silt Loam
SL- Sandy Loam
SP- Somewhat Poorly drained
P- Poorly drained
MW- Moderately Well drained
W- Well drained

Table 2. Precipitation in centimeters (cm) and growing degree days (GDD) in degrees Celsius were recorded for each month during the 2017-2018 CR and 2018 corn growing season. The difference between the 2018 growing season and the 30 year average is indicated in the difference column (2018 - 30 year average) = Difference.

			2018		30 Year Average		Difference	
Location	Season	Month	(cm) Precipitation	(°C) GDD	(cm) Precipitation	(°C) GDD	(cm) Precipitation	(°C) GDD
SE1 and SE2	CR	September	0.48	139	7.95	283	-7.47	-144
	CR	October	13.26	197	9.30	150	3.96	47
	CR	November	15.19	57	10.16	50	5.03	7
	CR	December	4.85	21	9.04	0	-4.19	21
	CR	January	6.27	14	7.67	0	-1.40	14
	CR	February	16.13	48	7.49	0	8.64	48
	CR	March	11.25	28	9.53	50	1.73	-22
	CR	April	10.95	97	11.38	142	-0.43	-45
	Corn	May	7.44	371	12.78	225	-5.33	146
	Corn	June	21.34	382	10.92	367	10.41	15
	Corn	July	5.08	328	11.48	425	-6.40	-97
	Corn	August	12.47	407	10.87	400	1.60	7
	Corn	September	3.35	227	7.95	283	-4.60	-56
	Corn	October	0.03	126	9.30	150	-9.27	-24
	Combined	Total	128.07	2442	126.52	2525	1.55	-83
NE	CR	October	0.48	125	7.62	100	-7.14	25
	CR	November	7.85	9	8.48	0	-0.64	9
	CR	December	0.43	9	6.88	0	-6.45	9
	CR	January	0.05	5	5.84	0	-5.79	5
	CR	February	5.89	17	5.38	0	0.51	17
	Corn	March	4.98	6	7.34	0	-2.36	6
	Corn	April	5.72	27	9.32	83	-3.61	-56
	Corn	May	8.41	143	10.92	167	-2.51	-24
	Corn	June	10.97	326	11.33	308	-0.36	18
	Corn	July	2.77	289	10.36	367	-7.59	-78
	Corn	August	21.34	375	9.75	342	11.58	33
	Corn	September	1.98	193	8.08	217	-6.10	-24
	Corn	October	4.04	130	7.62	100	-3.58	30
	Combined	Total	74.90	1654	108.94	1683	-34.04	-29

Table 3. The table below contains weather measurements with growing degree days (GDD) in degrees Celsius, precipitation, and days between CR planting, CR termination, corn planting, sidedress application, and corn grain harvest dates per location.

	Field Procedure			SE1					SE2					SE3				
Season	(1)		(2)	Date (1)	Date (2)	GDD(°C)	Precip.(cm)	Days	Date (1)	Date (2)	GDD(°C)	Precip.(cm)	Days	Date (1)	Date (2)	GDD(°C)	Precip.(cm)	Days
CR	CR. Planting	to	Termination	9/26/2017	4/13/2018	438	70.9	199	10/18/2017	5/3/2018	415	75.94	197	10/17/2017	5/2/2018	73	17.1	197
	Termination	to	C. Planting	4/13/2018	5/9/2018	144	8.5	26	5/3/2018	5/17/2018	159	2.8	14	5/2/2018	5/25/2018	47	2.16	23
Corn	C. Planting	to	Sidedress	5/9/2018	6/4/2018	352	8.5	26	5/17/2018	6/18/2018	415	17.9	32	5/25/2018	7/2/2018	452	12.8	38
	Sidedress	to	Harvest	6/4/2018	10/9/2018	1411	39.3	127	6/18/2018	10/9/2018	1235	29	113	7/2/2018	10/19/2018	957	30.2	109

CR. Planting- CR planting.
Termination- CR termination.
C. Planting- Corn planting.
Sidedress- Sidedress application at growth stage V4-V6.
Harvest- Corn grain harvest at corn maturity.

Table 4. Detailed analysis of treatment applications. Each N treatment listed below (6) was then applied to CR and non-CR plots creating a total of twelve treatments for each location. Treatments were then replicated 4 times. NE received a larger amount of total N, which is recommended by the agronomic optimum N rate (AONR) for that region.

Location	Treatment	Starter			Sidedress	
	CR and non-CR	kg N ha^{-1}	kg P ha^{-1}	kg S ha^{-1}	kg N ha^{-1}	kg S ha^{-1}
(SE1 and SE2)/(NE)	0N	0	0	5.6	(233)/(295)	11.2
	28N	28	0	5.6	(205)/(267)	11.2
	56N	56	0	5.6	(177)/(239)	11.2
	56NP	56	17	5.6	(177)/(239)	11.2
	84N	84	0	5.6	(149)/(211)	11.2
	A.Zero	0	0	0	0	0

Table 5. Measurements of cereal rye growth as indicated by total Biomass, Nitrogen (N) content, Carbon (C) content, and C:N ratio. Capital letters represent significance between locations for each measurement. P-value ≤ 0.05.

Location	Biomass		N		C		C:N ratio	
	-- kg ha^{-1} --							
SE1	1076	B	23	B	415	B	18	B
SE2	1083	B	20	B	414	B	21	A
NE	1454	A	34	A	563	A	17	B

Table 6. Soil inorganic nitrogen (N) and organic matter analysis to a 30 cm depth. Significance between cover is indicated by lowercase letters and significance by location is indicated by capital letters. (P-value ≤ 0.05). To calculate for kg ha^{-1} bulk density from each location was retrieved using web soil survey. Total refers to the addition of both NH_4-N and NO_3-N.

Location	Cover	NH_4-N			NO_3-N			Total			O.M.	
		----------	----------	----------	----------	kg ha^{-1}	----------	----------	----------	----------	%	
SE1	Non-CR	5.9	a	A	29.6	a	B	35.5	a	B	1.5	A
	CR	5.5	b		20.2	b		25.6	b			
SE2	Non-CR	5.1	a	A	48.0	a	A	53.1	a	A	1.3	A
	CR	3.7	b		27.0	b		30.8	b			
NE	Non-CR	5.9	a	A	17.3	a	C	23.3	a	C	1.8	A
	CR	5.4	b		15.8	b		21.1	b			

Table 7. SE1, average population (plants ha^{-1}) by growth stage and growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific treatment means. CR A.Zero vs. Non-CR A.Zero significance was analyzed using a t-test, and was not included in the contrast analysis as described in the materials and methods. Contrast significance is indicated by an asterisk "*" and level of significance is indicated below the table.

			Corn Population (plants ha^{-1})																				
	Contrasts		Growth Stage (Growing Degree Days)																				
	Treatment		V2 (202)			V3 (298)			V6 (379)			V7 (473)			V11 (627)			R1-R2 (810)			R6 (1524)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
CR 0N	vs.	Non-CR 0N		72955			78935			78935			72357			71161			74151			80729	
	vs.	CR 28N		74749			83719			83719			79533			78337			81327			80131	
	vs.	CR 56N	75347	75945		79533	80729		79533	80729		74749	78337		72955	75347		79533	83719		78337	80131	
	vs.	CR 56NP		76543			81327			81327			76543			75347			77141			76543	
	vs.	CR 84N		74749			75945			75945			76543			80131			77141			78935	
	vs.	Non-CR 28N		72357			77141			77141			86709	***		73553			75347			80131	
Non-CR 0N	vs.	Non-CR 56N	72955	72955		78935	83121		78935	83121		72357	72357		71161	78935	*	74151	77141		80729	81327	
	vs.	Non-CR 56NP		76543			77141			77141			79533			77141			76543			79533	
	vs.	Non-CR 84N		72357			80131			80131			77141			74749			81327	*		74151	
CR A.Zero	vs.	Non-CR A.Zero	74749	74749		79533	77739		77739	80729		77141	75347		77141	80729	*	78935	78935		79533	78935	
Coefficient of Variance C.V. (%)			6.2			6.5			6.5			8.1			8.4			6.4			7.7		
CR (C.V.%)	vs.	Non-CR (C.V.%)	5.3	7.0		6.4	6.7		6.4	6.7		6.5	9.4		7.3	9.3		6.8	6.0		9.0	6.1	

* P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 8. SE1 average population (plants ha^{-1}) by growth stage and growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific starter N rate means. Contrast significance is indicated by an asterisk “*” and level of significance is indicated below the table.

Contrasts			**Corn Population (plants ha^{-1})** Growth Stage (Growing Degree Days)																				
Starter Nitrogen Rates			V2 (202)			V3 (298)			V6 (379)			V7 (473)			V11 (627)			R1-R2 (810)			R6 (1524)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
0N	vs.	28N, 56N	74151	73992		79234	81178		79234	81178		73533	79234		72058	76543		76842	79384		79533	80430	
28N, 56N	vs.	84N	73992	73533		81178	78038		81178	78038		79234	76842		76543	77440		79384	79234		80430	76543	
28N	vs.	56N	73533	74450		80430	81925		80430	81925		83121	75347		75945	77141		78337	80430		80131	80729	
56N	vs.	56NP	74450	76543		81925	79234		81925	79234		75347	78038		77141	76244		80430	76842		80729	78038	

* P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 9. SE2, average population (plants ha^{-1}) by growth stage and growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific treatment means. CR A.Zero vs. Non-CR A.Zero significance was analyzed using a t-test, and was not included in the contrast analysis as described in the materials and methods. Contrast significance is indicated by an asterisk "*" and level of significance is indicated below the table.

			Corn Population (plants ha^{-1})																				
	Contrasts		Growth Stage (Growing Degree Days)																				
	Treatment		V2 (196)			V6 (278)			V7 (371)			V9 (537)			V11 (594)			R1-R2 (807)			R6 (1422)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
CR 0N	vs.	Non-CR 0N		77739			72955			80729			73553		75945	75945.3		73533	71161.3		75347	73553.3	
	vs.	CR 28N		80530			74949			75746			77341			78137.9			73353.9			75745.9	
	vs.	CR 56N	79533	81327		74151	75746		81327	78138		75945	78138			79732.6			78137.9			77340.6	
	vs.	CR 56NP		78337			76543			74749	*		74749			75347.3			72357.3			74749.3	
	vs.	CR 84N		77739			74151			78337			73553			74749.3			75347.3			75945.3	
	vs.	Non-CR 28N		83719			73354			72557	**		78935		75945.3	75745.9		71161.3	74151.3		73553.3	73353.9	
Non-CR 0N	vs.	Non-CR 56N	77739	78935		72955	74151		80729	79733		73553	76543			77340.6			75745.9			75745.9	
	vs.	Non-CR 56NP		78337			75347			77739			72357			72955.3			75347.3			73553.3	
	vs.	Non-CR 84N		76543			74151			78935			75945			74749.3			75945.3			69367.3	
CR A.Zero	vs.	Non-CR A.Zero	81327	78337		81327	83719		82523	81925		84317	85513		81925	87307		84317	86111		84317	86111	
Coefficient of Variance C.V. (%)			6.2			5.3			6.3			5.5			6.23			7.43			6.93		
CR (C.V.%)	vs.	Non-CR (C.V.%)	5.4	6.9		4.5	5.0		7.4	5.0		4.6	6.3		7	5.3		7.9	7		7.8	5.8	

* P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 10. SE2 average population (plants ha^{-1}) by growth stage and growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific starter N rate means. Contrast significance is indicated by an asterisk “*” and level of significance is indicated below the table.

			Corn Population (plants ha^{-1})																				
Contrasts			Growth Stage (Growing Degree Days)																				
Starter Nitrogen Rates			V2 (196)			V6 (278)			V7 (371)			V9 (537)			V11 (594)			R1-R2 (807)			R6 (1422)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
0N	vs.	28N, 56N	78636	81128		73533	74550		81028	76543		74749	77739		75945	77739		72357	73802		74450	75546	
28N, 56N	vs.	84N	81128	77141		74550	74151		76543	78636		77739	74749		77739	74749		73802	75646		75546	72656	
28N	vs.	56N	82124	80131		74151	74948		74151	78935		78137	77340		76941	78536		73752	73852		74549	76543	
56N	vs.	56NP	80131	78337		74948	75945		78935	76244		77340	73533		78536	74151		73852	73852		76543	74151	

* P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 11. NE, average population (plants ha^{-1}) by growth stage and growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific treatment means. CR A.Zero vs. Non-CR A.Zero significance was analyzed using a t-test, and was not included in the contrast analysis as described in the materials and methods. Contrast significance is indicated by an asterisk "*" and level of significance is indicated below the table.

			Corn Population (plants ha^{-1})																				
Contrasts			Growth Stage (Growing Degree Days)																				
Treatments			V2 (156)			V4 (228)			V5 (320)			V7 (411)			V8 (468)			R1-R2 (725)			R6 (1244)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
	vs.	Non-CR 0N		81925			80729			80131			80131			78337			74151			80729	
	vs.	CR 28N		82523			78337			77141			83121			82523			77141			86111	
CR 0N	vs.	CR 56N	80729	80729		81327	81925		78935	80729		80131	80131		80729	78337		79533	83121		81327	79533	
	vs.	CR 56NP		79533			80131			77141			81925			83121			80131			83719	
	vs.	CR 84N		81925			79533			77739			82523			82523			75347			82523	
	vs.	Non-CR 28N		80729			78935			78935			83121			79533			80131	*		80849	
Non-CR 0N	vs.	Non-CR 56N	81925	78337	*	80729	77739		80131	78337		80131	78935		78337	80729		74151	81327	**	80729	77739	
	vs.	Non-CR 56NP		78337	*		79533			81327			80131			81327			81925	**		78337	
	vs.	Non-CR 84N		80729			79533			78337			79533			82523	*		81925	**		83121	
CR A.Zero	vs.	Non-CR A.Zero	78337	76543		72357	75945		78337	74749		76543	76543		74749	72357		73553	74151		81925	81925	
Coefficient of Variance C.V. (%)			4.3			4.0			5.1			3.1			4.16			6.08			5.03		
CR (C.V.%)	vs.	Non-CR (C.V.%)	5.1	3.3		4.3	3.6		5.1	5.2		2.9	3.2		3.4	4.8		5.9	6.3		5.2	4.8	

* P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 12. NE average population (plants ha^{-1}) by growth stage and growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific starter N rate means. Contrast significance is indicated by an asterisk "*" and level of significance is indicated below the table.

			Corn Population (plants ha^{-1})																				
Contrasts			Growth Stage (Growing Degree Days)																				
Treatments			V2 (156)			V4 (228)			V5 (320)			V7 (411)			V8 (468)			R1-R2 (725)			R6 (1244)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
0N	vs.	28N, 56N	81327	80580		81028	79234		79533	78786		80131	81327		79533	80281		76842	80430		81028	80912	
28N, 56N	vs.	84N	80580	81327		79234	79533		78786	78038		81327	81028		80281	82523		80430	78636		80912	82822	
28N	vs.	56N	81626	79533		78636	79832		78038	79533		83121	79533		81028	79533		78636	82224		83187	78636	
56N	vs.	56NP	79533	78935		79832	79832		79533	79234		79533	81028		79533	82224		82224	81028		78636	80643	

* P-value $\leq$ 0.1
** P-value $\leq$ 0.5
*** P-value $\leq$ 0.01
**** P-value $\leq$ 0.001
sig. Significance level

Table 13. SE1 corn development by growth stage and growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific treatment means. CR A.Zero vs. Non-CR A.Zero significance was analyzed using a t-test, and was not included in the contrast analysis as described in the materials and methods. Contrast significance is indicated by an asterisk "*" and level of significance is indicated below the table.

Contrasts Treatment			**Corn Development by Growth Stage** Growth Stage (Growing Degree Days)															
			V2 (156)			V3 (228)			V6 (320)			V7 (411)			V11 (468)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
	vs.	Non-CR 0N		2.9			2.8			5.8			7.1			11.0	
	vs.	CR 28N		2.8			3.0			6.3	***		7.9	*		10.6	
CR 0N	vs.	CR 56N	2.9	2.9		2.9	2.9		5.8	5.9		7.4	7.7		11.0	11.4	
	vs.	CR 56NP		2.9			2.8			6.0			7.9	*		10.7	
	vs.	CR 84N		2.9			2.9			5.9			7.7			11.5	
	vs.	Non-CR 28N		2.9			2.9			5.9			7.5	*		11.6	
Non-CR 0N	vs.	Non-CR 56N	2.9	2.8		2.8	3.0	*	5.8	6.0		7.1	7.8	**	11.0	11.2	
	vs.	Non-CR 56NP		2.9			3.0			5.9			7.7	**		9.1	
	vs.	Non-CR 84N		2.9			2.9			5.8			7.9	***		10.2	
CR A.Zero	vs.	Non-CR A.Zero	2.8	2.9		2.9	2.9		5.8	5.9		6.7	7.6	*	9.7	10.8	
Coefficient of Variance C.V. (%)			4.3			4.6			3.6			4.8			17.9		

* P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 14. SE1 corn development measured by growth stage including growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific starter N rate means. Contrast significance is indicated by an asterisk "*" and level of significance is indicated below the table.

SE1			**Corn Development by Growth Stage**														
Contrasts			Growth Stage (Growing Degree Days)														
Starter Nitrogen Rate			V2 (156)			V3 (228)			V6 (320)			V7 (411)			V11 (468)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
0N	vs.	28N, 56N	2.9	2.8		2.9	2.9		5.8	6.0	**	7.2	7.7	*	11.0	11.2	
28N, 56N	vs.	84N	2.8	2.9		2.9	2.9		6.0	5.9		7.7	7.8		11.2	10.9	
28N	vs.	56N	2.9	2.8		2.9	2.9		6.1	5.9		7.7	7.7		11.1	11.3	
56N	vs.	56NP	2.8	2.9		2.9	2.9		5.9	6.0		7.7	7.8		11.3	9.9	

P-value ≤ 0.1
* P-value ≤ 0.5
** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 15. SE2 corn development by growth stage and growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific treatment means. CR A.Zero vs. Non-CR A.Zero significance was analyzed using a t-test, and was not included in the contrast analysis as described in the materials and methods. Contrast significance is indicated by an asterisk "*" and level of significance is indicated below the table.

SE2 Contrasts Treatment			Corn Development by growth stage — Growth Stage (Growing Degree Days)														
			V2 (196)			V6 (278)			V7 (371)			V9 (537)			V11 (594)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
	vs.	Non-CR 0N		2.9			6.0			6.9			9.2			10.9	
	vs.	CR 28N		3.0			6.0			7.2			9.3	**		11.5	*
CR 0N	vs.	CR 56N	2.9	3.0		5.9	6.0		6.8	7.4	**	8.8	9.7	****	10.8	11.7	**
	vs.	CR 56NP		3.0			5.7			7.3	*		9.3	**		11.4	
	vs.	CR 84N		3.0			5.9			7.3	*		9.5	***		11.5	*
	vs.	Non-CR 28N		3.0			6.0			7.1			9.6			11.2	
Non-CR 0N	vs.	Non-CR 56N	2.9	3.0		6.0	6.0		6.9	6.9		9.2	9.5		10.9	12.0	***
	vs.	Non-CR 56NP		2.9			6.0			7.4	*		9.5			11.6	*
	vs.	Non-CR 84N		3.0			5.9			7.1			9.6	*		11.7	**
CR A.Zero	vs.	Non-CR A.Zero	3.0	3.0		5.9	5.9		6.8	6.6		8.5	8.6		10.3	9.8	
Coefficient of Variance C.V. (%)			2.3			3.0			5.0			3.7			4.4		

*P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 16. SE2 corn development measured by growth stage including growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific starter N rate means. Contrast significance is indicated by an asterisk “*” and level of significance is indicated below the table.

SE2			**Corn Development by growth stage**														
Contrasts			Growth Stage (Growing Degree Days)														
Starter Nitrogen Rates			V2 (196)			V6 (278)			V7 (371)			V9 (537)			V11 (594)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
0N	vs.	28N, 56N	2.9	3.0	*	5.9	6.0		6.9	7.2	*	9.0	9.5	****	10.9	11.6	***
28N, 56N	vs.	84N	3.0	3.0		6.0	5.9		7.2	7.2		9.5	9.6		11.6	11.6	
28N	vs.	56N	3.0	3.0		6.0	6.0		7.1	7.2		9.4	9.6		11.3	11.9	*
56N	vs.	56NP	3.0	3.0		6.0	5.9		7.2	7.3		9.6	9.4		11.9	11.5	

P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 17. NE corn development by growth stage and growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific treatment means. CR A.Zero vs. Non-CR A.Zero significance was analyzed using a t-test, and was not included in the contrast analysis as described in the materials and methods. Contrast significance is indicated by an asterisk "*" and level of significance is indicated below the table.

NE			**Corn Development by growth stage**														
	Contrasts		Growth Stage (Growing Degree Days)														
	Treatments		V2 (156)			V4 (228)			V5 (320)			V7 (411)			V8 (468)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
	vs.	Non-CR 0N		2.6			3.9			5.3			6.8			8.3	
	vs.	CR 28N		2.5			4.0			5.6			6.8			8.5	
CR 0N	vs.	CR 56N	2.6	2.7		4.0	4.0		5.4	5.7	*	6.5	7.1	***	8.0	8.9	***
	vs.	CR 56NP		2.6			4.0			5.7	**		7.1	***		8.7	**
	vs.	CR 84N		2.5			3.9			5.7	*		7.1	***		8.7	**
	vs.	Non-CR 28N		2.6			3.9			5.5			7.0	***		8.4	
Non-CR 0N	vs.	Non-CR 56N	2.6	2.5		3.9	4.0		5.3	5.4		6.8	7.0		8.3	8.6	
	vs.	Non-CR 56NP		2.5			4.0			5.7	***		7.2	*		8.8	*
	vs.	Non-CR 84N		2.5			3.9			5.5			7.1			8.8	
CR A.Zero	vs.	Non-CR A.Zero	2.7	2.5		4.0	3.9		5.4	5.2		7.0	6.5		8.1	7.9	
Coefficient of Variance C.V. (%)			18.5			1.7			3.7			4.0			6.4		

*P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 18. NE corn development measured by growth stage including growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific starter N rate means. Contrast significance is indicated by an asterisk "*" and level of significance is indicated below the table.

NE			**Corn Development by growth stage**														
Contrasts			Growth Stage (Growing Degree Days)														
Treatments			V2 (156)			V4 (228)			V5 (320)			V7 (411)			V8 (468)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
0N	vs.	28N, 56N	2.6	2.6		3.9	4.0		5.4	5.5	*	6.7	7.0	**	8.2	8.6	**
28N, 56N	vs.	84N	2.6	2.5		4.0	3.9		5.5	5.6		7.0	7.1		8.6	8.7	
28N	vs.	56N	2.6	2.6		3.9	4.0		5.5	5.5		6.9	7.0		8.5	8.7	
56N	vs.	56NP	2.6	2.5		4.0	4.0		5.5	5.7	**	7.0	7.2		8.7	8.8	

*P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 19. SE1 corn biomass by growth stage and growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific treatment means. CR A.Zero vs. Non-CR A.Zero significance was analyzed using a t-test, and was not included in the contrast analysis as described in the materials and methods. Contrast significance is indicated by an asterisk "*" and level of significance is indicated below the table.

SE1			Corn Biomass (kg ha^{-1})																										
Contrasts			Growth Stage (Growing Degree Days)																										
Treatments			V2 (202)			V3 (298)			V6 (379)			V7 (473)			V11 (627)			R1-R2 (810)			Grain (1524)			Stover (1524)			R6 (1524)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
	vs.	Non-CR 0N		20			125			410			1119			4994			9181			16835			11229			28064	
	vs.	CR 28N		27	****		160	***		450	***		1467	**		4680			9191			15878			11511			27388	
CR 0N	vs.	CR 56N	18	21	*	114	155	***	294	451	***	1146	1343		4183	4235		8055	10007	*	15384	13916		11624	10150	**	27009	24066	*
	vs.	CR 56NP		20			120			380	*		1151			4323			8615			13493	*		10218	*		23711	*
	vs.	CR 84N		21	*		145	**		456	***		1430	**		4312			9219			15651			10344	*		25995	
	vs.	Non-CR 28N		26	***		154	**		438			1548	***		4438			9986			15699			10955			26654	
Non-CR 0N	vs.	Non-CR 56N	20	19		125	125		410	360		1119	1306		4994	4604		9181	9375		16835	17111		11229	12186		28064	29297	
	vs.	Non-CR 56NP		21			130			508			1298			5124			9668			15310			11019			26329	
	vs.	Non-CR 84N		18			129			403			1282			3726	**		9823			15394			10944			26339	
CR A.Zero	vs.	Non-CR A.Zero	18	20		119	117		416	432		982	1169		2624	3867	**	6401	7084		5088	5385		7172	7829	**	12260	13214	
Coefficient of Variance C.V. (%)			14			14			16			13			20			16			10			9			9		

*P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 20. SE1 corn biomass measured by growth stage including growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific starter N rate means. Contrast significance is indicated by an asterisk “*” and level of significance is indicated below the table.

SE1			**Corn Biomass (kg ha^{-1})**																										
Contrasts			Growing Degree Days (GDD)																										
Starter Nitrogen Rates			V2 (202)			V3 (298)			V6 (379)			V7 (473)			V11 (627)			R1-R2 (810)			Grain (1524)			Stover (1524)			R6 (1524)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
0N	vs.	28N, 56N	19	23	***	120	148	***	352	425	**	1132	1416	****	4589	4489		8618	9640		16110	15651		11427	11200		27536	26851	
28N, 56N	vs.	84N	23	20	***	148	137		425	429		1416	1356		4489	4019		9640	9521		15651	15523		11200	10644		26851	26167	
28N	vs.	56N	27	20	****	157	140	*	444	405		1508	1325	**	4559	4419		9588	9691		15788	15514		11233	11168		27021	26681	
56N	vs.	56NP	20	21		140	125		405	444		1325	1224		4419	4724		9691	9142		15514	14401		11168	10619		26681	25020	

*P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 21. SE2 corn biomass by growth stage and growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific treatment means. CR A.Zero vs. Non-CR A.Zero significance was analyzed using a t-test, and was not included in the contrast analysis as described in the materials and methods. Contrast significance is indicated by an asterisk "*" and level of significance is indicated below the table.

SE2			**Corn Biomass (kg ha^{-1})**																										
	Contrasts		Growth Stage (Growing Degree Days)																										
	Treatment		V2 (196)			V6 (278)			V7 (371)			V9 (537)			V11 (594)			R1-R2 (807)			Grain (1422)			Stover (1422)			R6 (1422)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
	vs.	Non-CR 0N	32	32			139			402			1369			3444			7560			12932			9477			22409	
	vs.	CR 28N	32	31			142			425			2071			3982			6257			11413			7883			19296	
CR 0N	vs.	CR 56N	32	34		146	162		408	460		1480	2038		3370	3566		7203	7187		13557	13236		9717	9286		23274	22522	
	vs.	CR 56NP	32	33			134			466			2301	**		4356			7161			13592			9423			23015	
	vs.	CR 84N	32	35			141			460			1789			4046			7138			13645			9548			23193	
	vs.	Non-CR 28N	32	35			138			386			1699			3706			6965			13028			8154			21183	
Non-CR 0N	vs.	Non-CR 56N	32	31		139	150		402	549	**	1369	2172	**	3444	4206		7560	8099		12932	13794		9477	9449		22409	23243	
	vs.	Non-CR 56NP	32	31			142			483			1785			4320			7561			12943			8979			21922	
	vs.	Non-CR 84N	32	28			128			486			2131	**		4358			7777			12063			8301			20364	
CR A.Zero	vs.	Non-CR A.Zero	31	35	*	127	122		393	326		1141	1165		2320	2628		3744	4126		2171	2762		5499	5461		7669	8223	
Coefficient of Variance C.V. (%)			14.8			16.5			19.0			27.5			25.0			16.4			15.4			15.4			14.8		

*P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 22. SE2 corn biomass measured by growth stage including growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific starter N rate means. Contrast significance is indicated by an asterisk "*" and level of significance is indicated below the table.

SE2			**Corn Biomass (kg ha^{-1})**																										
Contrasts			Growth Stage (Growing Degree Days)																										
Starter Nitrogen Rates			V2 (196)			V6 (278)			V7 (371)			V9 (537)			V11 (594)			R1-R2 (807)			Grain (1422)			Stover (1422)			R6 (1422)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
0N	vs.	28N, 56N	32	33		142	148		405	455		1425	1995	**	3407	3865		7381	7127		13245	12868		9597	8693		22841	21561	
28N, 56N	vs.	84N	33	31		148	134		455	473		1995	1960		3865	4202		7127	7458		12868	12854		8693	8924		21561	21778	
28N	vs.	56N	33	32		140	156		405	504	**	1885	2105		3844	3886		6611	7643		12221	13515		8019	9368	*	20239	22882	
56N	vs.	56NP	32	32		156	138		504	475		2105	2043		3886	4338		7643	7361		13515	13268		9368	9201		22882	22469	

*P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 23. NE corn biomass by growth stage and growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific treatment means. CR A.Zero vs. Non-CR A.Zero significance was analyzed using a t-test, and was not included in the contrast analysis as described in the materials and methods. Contrast significance is indicated by an asterisk "*" and level of significance is indicated below the table.

NE			Corn Biomass (kg ha^{-1})																										
Contrasts			Growth Stage (Growing Degree Days)																										
Treatments			V2 (156)			V4 (228)			V5 (320)			V7 (411)			V8 (468)			R1-R2 (725)			Grain (1244)			Stover (1244)			R6 (1244)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
	vs.	Non-CR 0N		12			45			328			939			1491			6696			12100			9608			21709	
	vs.	CR 28N		12			44			268			1719			1448			6948			11993			8521			20514	
CR 0N	vs.	CR 56N	12	13		38	54	***	336	407		1143	1864	*	1190	3099	***	6903	8873	**	12065	13966	*	7831	9466		19896	23432	**
	vs.	CR 56NP		12			54	***		429	*		1859	*		2288	*		9230	**		13951	*		8810			22760	*
	vs.	CR 84N		12			47	*		364			1798	*		2356	**		7944			13167			9271			22438	
	vs.	Non-CR 28N		14			52			340			1719	**		1929			8071			13690			8067			23913	
Non-CR 0N	vs.	Non-CR 56N	12	12		45	52		328	379		939	1471		1491	1989		6696	7580		12100	13252		9608	9233		21709	22484	
	vs.	Non-CR 56NP		14			51			386			1590	*		2117			8129			13128			9570			22698	
	vs.	Non-CR 84N		13			48			342			1664	**		2159			8221			13298			9382			22680	
CR A.Zero	vs.	Non-CR A.Zero	12	11		44	37		338	308		1191	953		1369	1356		6971	5326		5988	5999		2503	3142		8491	9141	
Coefficient of Variance C.V. (%)			14.5			18.8			19.9			31.6			35.2			15.9			10.9			22.7			10.9		

*P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 24. NE corn biomass measured by growth stage including growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific starter N rate means. Contrast significance is indicated by an asterisk "*" and level of significance is indicated below the table.

NE			**Corn Biomass (kg ha^{-1})**																										
Contrasts			Growth Stage (Growing Degree Days)																										
Starter Nitrogen Rates			V2 (156)			V4 (228)			V5 (320)			V7 (411)			V8 (468)			R1-R2 (725)			Grain (1244)			Stover (1244)			R6 (1244)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
0N	vs.	28N, 56N	12	13		42	50	***	332	349		1041	1693	***	1341	2116	**	6800	7868	*	12083	13272	*	8720	8809		20802	22586	*
28N, 56N	vs.	84N	13	13		50	48		349	353		1693	1731		2116	2258		7868	8083		13272	13233		8809	9327		22586	22559	
28N	vs.	56N	13	13		48	53		304	393	**	1719	1667		1689	2544	**	7510	8226		12936	13609		8268	9349		22213	22958	
56N	vs.	56NP	13	13		53	53		393	407		1667	1725		2544	2202		8226	8679		13609	13481		9349	9244		22958	22725	

*P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 25. SE1 corn N content by growth stage and growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific treatment means. CR A.Zero vs. Non-CR A.Zero significance was analyzed using a t-test, and was not included in the contrast analysis as described in the materials and methods. Contrast significance is indicated by an asterisk "*" and level of significance is indicated below the table.

SE1			Corn N content (kg N ha^{-1})																										
Contrasts			Growing Degree Days (GDD)																										
Treatments			V2 (202)			V3 (298)			V6 (379)			V7 (473)			V11 (627)			R1-R2 (810)			Grain (1524)			Stover (1524)			R6 (1524)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
	vs.	Non-CR 0N		1.2			6.6			16.5			33.6			142.8			310.0			217.7			121.9			339.6	***
	vs.	CR 28N		1.7	****		8.8	****		18.3	***		47.0			130.8			208.8			186.1			107.5	*		293.6	
CR 0N	vs.	CR 56N	1.0	1.3	*	6.0	8.6	***	11.7	18.2	***	36.6	43.7		116.9	110.6		171.2	199.5		175.9	162.2		84.0	92.3		259.9	254.5	
	vs.	CR 56NP		1.2			6.8			16.2	*		39.4			107.1			264.3			151.3			87.8			239.1	
	vs.	CR 84N		1.3	*		7.3			19.6	***		50.9	**		174.6			203.6			179.7			94.8			274.5	
	vs.	Non-CR 28N		1.7	***		8.6	**		18.6			46.9	*		169.6			228.4			191.7			109.7			301.4	
Non-CR 0N	vs.	Non-CR 56N	1.2	1.1		6.6	6.8		16.5	15.0		33.6	45.2	*	142.8	119.3		310.0	173.6	**	217.7	214.5		121.9	116.3		339.6	330.8	
	vs.	Non-CR 56NP		1.3			7.0			21.5	**		45.8	*		140.9			228.0			195.3			113.7			309.0	
	vs.	Non-CR 84N		1.1			7.4			17.1			40.6			105.3			319.0			199.5	**		107.4			306.9	
CR A.Zero	vs.	Non-CR A.Zero	1.1	1.2		6.1	6.3		13.9	14.8		27.3	30.8		50.8	69.8		91.7	80.6		45.0	48.1		44.9	47.4		89.9	95.5	
Coefficient of Variance C.V. (%)			16.7			14.6			19.2			21.5			42.1			39.4			13.5			16.1			13.3		

*P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 26. SE1 corn N content measured by growth stage including growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific starter N rate means. Contrast significance is indicated by an asterisk “*” and level of significance is indicated below the table.

SE1			**Corn N content (kg N ha^{-1})**																										
Contrasts			Growing Degree Days (GDD)																										
Starter Nitrogen Rates			V2 (202)			V3 (298)			V6 (379)			V7 (473)			V11 (627)			R1-R2 (810)			Grain (1524)			Stover (1524)			R6 (1524)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
0N	vs.	28N, 56N	1.1	1.5	****	6.3	8.2	***	14.1	17.5	**	35.1	45.7	**	129.9	132.6		240.6	202.6		196.8	188.6		102.9	106.5		299.7	295.1	
28N, 56N	vs.	84N	1.5	1.2	***	8.2	7.4	*	17.5	18.4		45.7	45.8		132.6	140.0		202.6	261.3		188.6	189.6		106.5	101.1		295.1	290.7	
28N	vs.	56N	1.7	1.2	****	8.7	7.7	*	18.5	16.6		46.9	44.5		150.2	114.9		218.6	186.6		188.9	188.3		108.6	104.3		297.5	292.6	
56N	vs.	56NP	1.2	1.3		7.7	6.9		16.6	18.8		44.5	42.6		114.9	124.0		186.6	246.1		188.3	173.3		104.3	100.7		292.6	274.1	
0N	vs.	A.Zero	1.1	1.1		6.3	6.2		-	-		-	-		-	-		-	-		-	-		-	-		-	-	

* P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 27. SE2 corn N content by growth stage and growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific treatment means. CR A.Zero vs. Non-CR A.Zero significance was analyzed using a t-test, and was not included in the contrast analysis as described in the materials and methods. Contrast significance is indicated by an asterisk "*" and level of significance is indicated below the table.

SE2			Corn N content (kg N ha^{-1})																										
Contrasts			Growth Stage (Growing Degree Days)																										
Treatments			V2 (196)			V6 (278)			V7 (371)			V9 (537)			V11 (594)			R1-R2 (807)			Grain (1422)			Stover (1422)			R6 (1422)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
	vs.	Non-CR 0N		1.6			5.1			10.0			35.0			81.7			181.6			151.5			94.8			246.2	
	vs.	CR 28N		1.5			5.4			12.3			53.4			93.0			157.3			118.9			59.6			178.5	
CR 0N	vs.	CR 56N	1.6	1.8		5.2	6.7		9.4	12.9		38.8	52.5		82.0	84.5		171.8	171.5		148.9	148.3		82.3	87.9		231.2	236.2	
	vs.	CR 56NP		1.7			5.6			13.8	*		63.1	*		99.4			178.5			154.6			81.9			236.5	
	vs.	CR 84N		1.8			5.9			13.1			48.7			84.5			164.6			151.3			92.2			243.5	
	vs.	Non-CR 28N		1.8			5.6			10.0			41.8			79.6			164.9			161.9			83.3			245.2	
Non-CR 0N	vs.	Non-CR 56N	1.6	1.6		5.1	6.3		10.0	16.4	**	35.0	60.9	*	81.7	100.6		181.6	182.8		151.5	155.0		94.8	91.9		246.2	246.9	
	vs.	Non-CR 56NP		1.7			5.9			14.0	*		43.9			110.2			176.8			143.0			79.1			222.2	
	vs.	Non-CR 84N		1.4			5.5			14.0	*		58.6	*		101.5			170.9			140.4			72.0			212.4	
CR A.Zero	vs.	Non-CR A.Zero	1.5	1.7		4.4	4.3		9.0	7.0		20.7	20.3		35.1	36.4		34.5	41.0		18.7	23.6		38.5	33.8		57.2	57.4	
Coefficient of Variance C.V. (%)			15.1			19.4			24.9			37.8			35.7			19.2			22.9			28.3			24.1		

*P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 28. SE2 corn N content measured by growth stage including growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific starter N rate means. Contrast significance is indicated by an asterisk "*" and level of significance is indicated below the table.

SE2			**Corn N content (kg N ha^{-1})**																										
Contrasts			Growth Stage (Growing Degree Days)																										
Starter Nitrogen Rates			V2 (196)			V6 (278)			V7 (371)			V9 (537)			V11 (594)			R1-R2 (807)			Grain (1422)			Stover (1422)			R6 (1422)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
0N	vs.	28N, 56N	1.6	1.7		5.2	6.0	*	9.7	12.9	**	36.9	52.2	*	81.9	89.4		176.7	169.1		150.2	146.0		88.5	80.7		238.7	226.7	
28N, 56N	vs.	84N	1.7	1.6		6.0	5.7		12.9	13.5		52.2	53.6		89.4	93.0		169.1	167.7		146.0	145.8		80.7	82.1		226.7	227.9	
28N	vs.	56N	1.7	1.7		5.5	6.5		11.2	14.7	*	47.6	56.7		86.3	92.6		161.1	177.1		140.4	151.6		71.5	89.9		211.8	241.5	
56N	vs.	56NP	1.7	1.7		6.5	5.7		14.7	13.9		56.7	53.5		92.6	104.8		177.1	177.7		151.6	148.8		89.9	80.5		241.5	229.3	
0N	vs.	A.Zero	1.6	1.6		5.1	4.3		9.7	8.0	*	-	-		-	-		-	-		-	-		-	-		-	-	

*P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 29. NE corn N content by growth stage and growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific treatment means. CR A.Zero vs. Non-CR A.Zero significance was analyzed using a t-test, and was not included in the contrast analysis as described in the materials and methods. Contrast significance is indicated by an asterisk "*" and level of significance is indicated below the table.

NE			**Corn N content (kg N ha^{-1})**																										
Contrasts			Growth Stage (Growing Degree Days)																										
Treatments			V2 (156)			V4 (228)			V5 (320)			V7 (411)			V8 (468)			R1-R2 (725)			Grain (1244)			Stover (1244)			R6 (1244)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
	vs.	Non-CR 0N		0.5			1.8			9.9			26.1			31.0			126.3			148.3			96.3			244.6	
	vs.	CR 28N		0.5			1.8			7.4			45.2			25.5			123.6			152.0			80.1			232.1	
CR 0N	vs.	CR 56N	0.6	0.6		1.5	2.3	***	10.2	14.7	*	25.5	57.6	***	24.2	61.3	***	130.4	160.9		156.7	178.4		74.3	89.5		231.0	267.9	
	vs.	CR 56NP		0.6			2.4	****		14.7	*		52.3	**		41.0			146.8			147.6			83.3			230.8	
	vs.	CR 84N		0.6			2.1	**		13.7			57.7	***		51.2	**		149.3			172.4			102.7	**		275.1	*
	vs.	Non-CR 28N		0.7	**		2.3	*		8.9			45.8			35.5			144.6			181.4	**		96.9			279.4	
Non-CR 0N	vs.	Non-CR 56N	0.5	0.6		1.8	2.3		9.9	12.3		26.1	48.8	*	31.0	43.7		126.3	148.9		148.3	172.5		96.3	90.7		244.6	263.2	
	vs.	Non-CR 56NP		0.7	**		2.3	*		12.6			49.1	*		42.9			151.8			159.2			79.8			239.0	
	vs.	Non-CR 84N		0.7	**		2.1			10.5			56.2	**		46.5			160.5	*		167.0			87.4			254.3	
CR A.Zero	vs.	Non-CR A.Zero	0.6	0.5		1.7	1.4		10.0	8.3		32.5	23.0		28.0	23.6		106.1	88.9		69.7	63.5		32.8	31.9		102.5	95.5	
Coefficient of Variance C.V. (%)			17.5			20.9			26.7			34.0			39.5			19.7			14.4			19.8			14.4		

*P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 30. NE corn N content measured by growth stage including growing degree day sampled. Single-degree-of-freedom contrasts were used to compare specific starter N rate means. Contrast significance is indicated by an asterisk “*” and level of significance is indicated below the table.

Contrasts			**Corn N content (kg N ha^{-1})**																										
			Growth Stage (Growing Degree Days)																										
Starter Nitrogen Rate			V2 (156)			V4 (228)			V5 (320)			V7 (411)			V8 (468)			R1-R2 (725)			Grain (1244)			Stover (1244)			R6 (1244)		
(1)	vs.	(2)	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.	(1)	(2)	sig.
0N	vs.	28N, 56N	0.5	0.6		1.7	2.2	***	10.1	10.8		25.8	49.3	***	27.6	41.5	*	128.4	144.5		152.5	171.9	*	85.3	89.3		237.8	260.7	
28N, 56N	vs.	84N	0.6	0.6		2.2	2.1		10.8	12.1		49.3	56.9		41.5	48.8		144.5	154.9		171.9	169.7		89.3	95.0		260.7	264.7	
28N	vs.	56N	0.6	0.6		2.1	2.3		8.1	13.5	***	45.5	53.2		30.5	52.5	**	134.1	154.9		168.3	175.4		88.5	90.1		255.8	265.6	
56N	vs.	56NP	0.6	0.6		2.3	2.3		13.5	13.7		53.2	50.7		52.5	42.0		154.9	149.3		175.4	154.2	*	90.1	81.3		265.6	235.5	
0N	vs.	A.Zero	0.6	0.5		1.7	1.5		10.1	9.1		25.8	27.8		-	-		-	-		-	-		-	-		-	-	

‘P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 31. NRE, nitrogen recovery efficiency, by location. Single-degree-of-freedom contrasts were used to compare specific treatment means. Contrast significance is indicated by an asterisk “*” and level of significance is indicated below the table. NRE was calculated by taking R6 total N content from fertilized plots (NF) subtracted by R6 total N content from non-fertilized plots (NN) (A.Zero treatments) and then divided by total N rate applied (R). This was then multiplied by 100 to reach a NRE percentage. ((NF-NN)/R)*100=NRE.

						NRE					
	Contrasts Treatment		SE1 (%)			SE2 (%)			NE (%)		
(1)	vs.	(2)	(1)	(2)	Sig.	(1)	(2)	Sig.	(1)	(2)	Sig.
CR 0N	vs.	Non-CR 0N	67.6	93.2	**	74.7	81.1		43.6	46.3	
	vs.	CR 28N		77.7			52.1			40.0	
	vs.	CR 56N		63.8			76.8			56.0	
	vs.	CR 56NP		60.1			77.0			50.1	
	vs.	CR 84N		72.2			80.0			56.0	
Non-CR 0N	vs.	Non-CR 28N	93.2	80.1		81.1	80.6		46.3	52.5	
	vs.	Non-CR 56N		88.7			81.3			55.0	
	vs.	Non-CR 56NP		83.7			70.7			46.4	
	vs.	Non-CR 84N		90.8			66.5			47.0	

*P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 32. NRE, nitrogen recovery efficiency, by location. Single-degree-of-freedom contrasts were used to compare specific starter N rate means. Contrast significance is indicated by an asterisk “*” and level of significance is indicated below the table. NRE was calculated by taking R6 total N content from fertilized plots (NF) subtracted by R6 total N content from non-fertilized plots (NN) (A.Zero treatments) and then divided by total N rate applied (R). This was then multiplied by 100 to reach a NRE percentage. ((NF-NN)/R)*100=NRE.

						NRE					
Contrasts			SE1			SE2			NE		
Starter Nitrogen Rate			(%)			(%)			(%)		
(1)	vs.	(2)	(1)	(2)	Sig.	(1)	(2)	Sig.	(1)	(2)	Sig.
0N	vs.	28N, 56N	80.4	77.6		77.9	72.7		45.0	47.6	
28N, 56N	vs.	84N	77.6	81.5		72.7	73.2		47.6	51.5	
28N	vs.	56N	78.9	76.2		66.3	79.1		39.7	55.5	**
56N	vs.	56NP	76.2	71.9		79.1	73.8		55.5	48.2	

‘P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 33. Corn stalk nitrate by location. Single-degree-of-freedom contrasts were used to compare specific treatment means. Contrast significance is indicated by an asterisk "*" and level of significance is indicated below the table.

Contrasts Treatment			Corn Stalk Nitrate SE1 (ppm)			SE2 (ppm)			NE (ppm)		
(1)	vs.	(2)	(1)	(2)	Sig.	(1)	(2)	Sig.	(1)	(2)	Sig.
CR 0N	vs.	Non-CR 0N	1121.8	1653.8	**	2059.4	1088.7		1413.1	1242.2	
CR 0N	vs.	CR 28N	1121.8	1707.5		2059.4	230.8	***	1413.1	1004.1	
CR 0N	vs.	CR 56N	1121.8	2213.0	*	2059.4	1475.0		1413.1	1161.8	
CR 0N	vs.	CR 56NP	1121.8	657.7		2059.4	981.7	**	1413.1	1494.0	
CR 0N	vs.	CR 84N	1121.8	788.6		2059.4	1152.1	*	1413.1	983.2	
Non-CR 0N	vs.	Non-CR 28N	1653.8	1678.2		1088.7	1426.6		1242.2	1469.8	
Non-CR 0N	vs.	Non-CR 56N	1653.8	2299.4		1088.7	484.0		1242.2	1052.5	
Non-CR 0N	vs.	Non-CR 56NP	1653.8	837.9		1088.7	802.9		1242.2	1935.6	
Non-CR 0N	vs.	Non-CR 84N	1653.8	1061.5		1088.7	769.4		1242.2	1118.1	

*P-value $\leq$ 0.1
** P-value $\leq$ 0.5
*** P-value $\leq$ 0.01
**** P-value $\leq$ 0.001
sig. Significance level

Table 34. Corn stalk nitrate by location. Single-degree-of-freedom contrasts were used to compare specific starter N rate means. Contrast significance is indicated by an asterisk "*" and level of significance is indicated below the table.

			Corn Stalk Nitrate								
Contrasts Starter Nitrogen Rate			SE1 (ppm)			SE2 (ppm)			NE (ppm)		
(1)	vs.	(2)	(1)	(2)	Sig.	(1)	(2)	Sig.	(1)	(2)	Sig.
0N	vs.	28N, 56N	1387.8	1974.5	*	1574.0	887.9	**	1327.6	1172.0	
28N, 56N	vs.	84N	1974.5	925.0	***	887.9	960.7		1172.0	1050.7	
28N	vs.	56N	1692.9	2256.2		796.4	979.5		1237.0	1107.1	
56N	vs.	56NP	2256.2	747.8	****	979.5	779.6		1107.1	1714.8	*

*P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 35. Corn grain yield by location. Single-degree-of-freedom contrasts were used to compare specific treatment means. Contrast significance is indicated by an asterisk “*” and level of significance is indicated below the table.

			Grain Yield								
	Contrasts Treatment		SE1 ($Mg\ ha^{-1}$)			SE2 ($Mg\ ha^{-1}$)			NE ($Mg\ ha^{-1}$)		
(1)	vs.	(2)	(1)	(2)	Sig.	(1)	(2)	Sig.	(1)	(2)	Sig.
	vs.	Non-CR 0N		16.0	**		12.8			13.5	
	vs.	CR 28N		15.5			11.7			13.3	
CR 0N	vs.	CR 56N	14.7	14.9		12.5	12.9		12.6	14.5	****
	vs.	CR 56NP		14.6			12.4			14.3	***
	vs.	CR 84N		14.9			11.7			14.3	***
	vs.	Non-CR 28N		15.8			12.2			13.3	
Non-CR 0N	vs.	Non-CR 56N	16.0	15.8		12.8	13.7		13.5	14.4	
	vs.	Non-CR 56NP		15.5			12.5			14.6	*
	vs.	Non-CR 84N		15.2			11.8			13.8	
CR A.Zero	vs.	Non-CR A.Zero	3.8	6.5	***	1.9	2.7		6.4	6.6	

*P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 36. Corn grain yield by location. Single-degree-of-freedom contrasts were used to compare specific starter N rate means. Contrast significance is indicated by an asterisk “*” and level of significance is indicated below the table.

Contrasts Starter Nitrogen Rate			Grain Yield SE1 ($Mg\ ha^{-1}$)			SE2 ($Mg\ ha^{-1}$)			NE ($Mg\ ha^{-1}$)		
(1)	vs.	(2)	(1)	(2)	Sig.	(1)	(2)	Sig.	(1)	(2)	Sig.
0N	vs.	28N, 56N	15.4	15.5		12.6	12.6		13.0	13.9	**
28N, 56N	vs.	84N	15.5	15.1		12.6	11.8	*	13.9	14.1	
28N	vs.	56N	15.6	15.4		11.9	13.3	**	13.3	14.5	***
56N	vs.	56NP	15.4	15.1		13.3	12.4		14.5	14.4	

*P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 37. Corn grain moisture by location. Single-degree-of-freedom contrasts were used to compare specific treatment means. Contrast significance is indicated by an asterisk “*” and level of significance is indicated below the table.

Contrasts Treatment			Grain Moisture SE1 (%)			Grain Moisture SE2 (%)			Grain Moisture NE (%)		
(1)	vs.	(2)	(1)	(2)	Sig.	(1)	(2)	Sig.	(1)	(2)	Sig.
CR 0N	vs.	Non-CR 0N	16.5	16.8	**	17.7	17.7		18.9	19.0	
	vs.	CR 28N		16.3			17.5			19.1	
	vs.	CR 56N		16.2			16.9	***		19.0	
	vs.	CR 56NP		16.4			17.1	***		19.0	
	vs.	CR 84N		16.1	*		17.1	***		18.9	
Non-CR 0N	vs.	Non-CR 28N	16.8	16.6		17.7	17.6		19.0	18.3	***
	vs.	Non-CR 56N		16.5			16.9	***		18.9	
	vs.	Non-CR 56NP		16.5			17.1	**		18.8	
	vs.	Non-CR 84N		16.6			17.3			18.8	

*P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

Table 38. Corn grain moisture by location. Single-degree-of-freedom contrasts were used to compare specific starter N rate means. Contrast significance is indicated by an asterisk "*" and level of significance is indicated below the table.

			Grain Moisture								
Contrasts Starter Nitrogen Rate			SE1 (%)			SE2 (%)			NE (%)		
(1)	vs.	(2)	(1)	(2)	Sig.	(1)	(2)	Sig.	(1)	(2)	Sig.
0N	vs.	28N, 56N	16.6	16.4		17.7	17.2	***	18.9	18.8	
28N, 56N	vs.	84N	16.4	16.3		17.2	17.2		18.8	18.8	
28N	vs.	56N	16.4	16.4		17.5	16.9	***	18.7	19.0	
56N	vs.	56NP	16.4	16.5		16.9	17.1		19.0	18.9	

*P-value ≤ 0.1
** P-value ≤ 0.5
*** P-value ≤ 0.01
**** P-value ≤ 0.001
sig. Significance level

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APPENDIX

Table A- 1. CR ANOVA analysis.

CR ANOVA

CR Biomass

```
Analysis of Variance Table

Response: CRkgB_ha
          Df   Sum Sq Mean Sq F value    Pr(>F)
Field      2 11880466 5940233   24.12 7.359e-09 ***
Residuals 77 18963514  246279
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

CR N Content

```
Analysis of Variance Table

Response: CRkgN_ha
          Df Sum Sq Mean Sq F value    Pr(>F)
Field      2 2114.0 1057.01  26.075 9.096e-09 ***
Residuals 57 2310.7   40.54
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

CR C Content

```
Analysis of Variance Table

Response: CRkgC_ha
          Df  Sum Sq Mean Sq F value    Pr(>F)
Field      2  295305  147653  8.0136 0.0008573 ***
Residuals 57 1050245   18425
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

CR C:N ratio

```
Analysis of Variance Table

Response: Cnratio
          Df Sum Sq Mean Sq F value    Pr(>F)
Field      2 143.90  71.952  17.893 9.313e-07 ***
Residuals 57 229.21   4.021
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Table A- 2. Soil inorganic N ANOVA analysis.

Soil inorganic Nitrogen

NH_4-N

```
Analysis of Variance Table

Response: skgNH4_ha
          Df Sum Sq Mean Sq F value    Pr(>F)    
Field      2 8.3457  4.1728  85.759 1.542e-10 ***
Cover      1 3.9240  3.9240  80.645 1.869e-08 ***
Residuals 20 0.9732  0.0487                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’
0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

NO_3-N

```
Analysis of Variance Table

Response: skgNO3_ha
          Df  Sum Sq Mean Sq F value    Pr(>F)    
Field      2 1778.91  889.45  47.048 2.739e-08 ***
Cover      1  680.47  680.47  35.994 7.251e-06 ***
Residuals 20  378.10   18.91                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’
0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Total Soil Inorganic N
Analysis of Variance Table

Response: sinorganickgN_ha
          Df  Sum Sq Mean Sq F value    Pr(>F)    
Field      2 1567.67  783.83  38.001 1.540e-07 ***
Cover      1  787.74  787.74  38.190 4.891e-06 ***
Residuals 20  412.54   20.63                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’
0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Table A- 3. SE1 population ANOVA analysis.

SE1 population (plants ha^{-1})					
		V2 (202)			
	Analysis of Variance Table				
Response:	plants.ha				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	41338207	41338207	1.9571	0.1721
SN_rate	4	48633184	12158296	0.5756	0.6825
Cover:SN_rate	4	10870947	2717737	0.1287	0.9708
Residuals	30	633661784	21122059		
		V3 (298)			
	Analysis of Variance Table				
Response:	plants.ha				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	9154482	9154482	0.3392	0.5646
SN_rate	4	69230768	17307692	0.6413	0.6372
Cover:SN_rate	4	159631276	39907819	1.4788	0.2334
Residuals	30	809599480	26986649		
		V6 (379)			
	Analysis of Variance Table				
Response:	plants.ha				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	9154482	9154482	0.3392	0.5646
SN_rate	4	69230768	17307692	0.6413	0.6372
Cover:SN_rate	4	159631276	39907819	1.4788	0.2334
Residuals	30	809599480	26986649		
		V7 (473)			
	Analysis of Variance Table				
Response:	plants.ha				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	2288620	2288620	0.0583	0.81092
SN_rate	4	419675773	104918943	2.6705	0.05121
Cover:SN_rate	4	202256831	50564208	1.287	0.2972
Residuals	30	1178639526	39287984		
		V11 (627)			
	Analysis of Variance Table				
Response:	plants.ha				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	17307692	17307692	0.4327	0.5157
SN_rate	4	149618561	37404640	0.935	0.457
Cover:SN_rate	4	125015891	31253973	0.7813	0.5463
Residuals	30	1200095343	40003178		
		R1-R2 (810)			
	Analysis of Variance Table				
Response:	plants.ha				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	82390336	82390336	3.2727	0.08047
SN_rate	4	77240940	19310235	0.767	0.55511
Cover:SN_rate	4	169357913	42339478	1.6818	0.18019
Residuals	30	755244745	25174825		
		R6 (1524)			
	Analysis of Variance Table				
Response:	plants.ha				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	1287349	1287349	0.0349	0.853
SN_rate	4	92116973	23029243	0.6248	0.6484
Cover:SN_rate	4	76668785	19167196	0.5201	0.7216
Residuals	30	1105689750	36856325		
		Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1			

Table A- 4. SE2 population ANOVA analysis.

SE2 population (plants ha^{-1})					
V2 (196)					
Analysis of Variance Table					
Response:	plants.ha				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	2542912	2542912	0.1061	0.7472
SN_rate	4	98299427	24574857	1.0253	0.4128
Cover:SN_rate	4	30594405	7648601	0.3191	0.8626
Residuals	26	623172274	23968164		
V6 (278)					
Analysis of Variance Table					
Response:	plants.ha				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	10171646	10171646	0.642	0.4303
SN_rate	4	26700572	6675143	0.4213	0.7918
Cover:SN_rate	4	3178639	794660	0.0502	0.995
Residuals	26	411951679	15844295		
V7 (371)					
Analysis of Variance Table					
Response:	plants.ha				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	1430388	1430388	0.0591	0.8098
SN_rate	4	195247931	48811983	2.018	0.1214
Cover:SN_rate	4	36951684	9237921	0.3819	0.8195
Residuals	26	628893825	24188224		
V9 (537)					
Analysis of Variance Table					
Response:	plants.ha				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	2542912	2542912	0.1485	0.7031
SN_rate	4	101398600	25349650	1.48	0.237
Cover:SN_rate	4	39415130	9853782	0.5753	0.683
Residuals	26	445327394	17127977		
V11 (594)					
Analysis of Variance Table					
Response:	plants.ha				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	15893197	15893197	0.7104	0.407
SN_rate	4	83280355	20820089	0.9306	0.4615
Cover:SN_rate	4	12714558	3178639	0.1421	0.9649
Residuals	26	581691028	22372732		
R1-R2 (807)					
Analysis of Variance Table					
Response:	plants.ha				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	0	0	0	1
SN_rate	4	89478702	22369675	0.7313	0.5788
Cover:SN_rate	4	39574062	9893515	0.3234	0.8597
Residuals	26	795295603	30588292		
R6 (1422)					
Analysis of Variance Table					
Response:	plants.ha				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	70089001	70089001	2.6395	0.1163
SN_rate	4	52447552	13111888	0.4938	0.7403
Cover:SN_rate	4	38143674	9535918	0.3591	0.8353
Residuals	26	690400499	26553865		
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1					

Table A- 5. NE population ANOVA analysis.

NE population (plants ha^{-1})						
V2 (156)						
Type III Analysis of Variance Table with Satterthwaite's method						
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)
Cover	2860776	2860776	1	27	0.3239	0.574
SN_rate	41195168	10298792	4	27	1.1662	0.3476
Cover:SN_rate	14876033	3719008	4	27	0.4211	0.792
V4 (228)						
Type III Analysis of Variance Table with Satterthwaite's method						
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)
Cover	715194	715194	1	30	0.0714	0.7911
SN_rate	18881119	4720280	4	30	0.4714	0.7563
Cover:SN_rate	28035600	7008900	4	30	0.7	0.5981
V5 (320)						
Type III Analysis of Variance Table with Satterthwaite's method						
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)
Cover	2860776	2860776	1	27	0.1852	0.6703
SN_rate	26891290	6722823	4	27	0.4353	0.7819
Cover:SN_rate	44914176	11228544	4	27	0.7271	0.5812
V7 (411)						
Type III Analysis of Variance Table with Satterthwaite's method						
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)
Cover	0	0	1	27	0	1
SN_rate	41767323	10441831	4	27	1.8183	0.1544
Cover:SN_rate	12873490	3218372	4	27	0.5604	0.6933
V8 (468)						
Type III Analysis of Variance Table with Satterthwaite's method						
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)
Cover	11443102	11443102	1	27	1.102	0.3031
SN_rate	41767323	10441831	4	27	1.0056	0.4219
Cover:SN_rate	38048315	9512079	4	27	0.9161	0.4689
R1-R2 (725)						
Type III Analysis of Variance Table with Satterthwaite's method						
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)
Cover	57930705	57930705	1	30	2.4745	0.1262
SN_rate	173362998	43340750	4	30	1.8513	0.1451
Cover:SN_rate	168213602	42053401	4	30	1.7963	0.1556
R6 (1244)						
Type III Analysis of Variance Table with Satterthwaite's method						
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)
Cover	715194	715194	1	26.95	0.0427	0.8378
SN_rate	75445106	18861277	4	27.1	1.127	0.3645
Cover:SN_rate	58656154	14664039	4	27.127	0.8762	0.491
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1						

Table A- 6. SE1 corn development by growth stage ANOVA analysis.

SE1 Corn development measured by growth stage						
V2 (202)						
Analysis of Variance Table						
Response:	G.Stage					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	0.00025	0.00025	0.0163	0.8992	
SN_rate	4	0.02062	0.005156	0.3363	0.8513	
Cover:SN_rate	4	0.02787	0.006969	0.4545	0.7683	
Residuals	30	0.46	0.015333			
V3 (298)						
Analysis of Variance Table						
Response:	G.Stage					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	0.00454	0.004536	0.258	0.6152	
SN_rate	4	0.01662	0.004155	0.2363	0.9156	
Cover:SN_rate	4	0.08173	0.020431	1.1622	0.3471	
Residuals	30	0.5274	0.01758			
V6 (379)						
Analysis of Variance Table						
Response:	G.Stage					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	0.13198	0.131984	2.9478	0.0963	.
SN_rate	4	0.42986	0.107464	2.4002	0.07202	.
Cover:SN_rate	4	0.21656	0.05414	1.2092	0.32747	
Residuals	30	1.34321	0.044774			
V7 (473)						
Analysis of Variance Table						
Response:	G.Stage					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	0.1153	0.11526	0.864	0.36004	
SN_rate	4	1.826	0.4565	3.4218	0.02029	*
Cover:SN_rate	4	0.5485	0.13713	1.0279	0.40898	
Residuals	30	4.0022	0.13341			
V11 (627)						
Analysis of Variance Table						
Response:	G.Stage					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	1.597	1.5973	0.4234	0.5202	
SN_rate	4	9.487	2.3717	0.6287	0.6458	
Cover:SN_rate	4	8.908	2.2269	0.5903	0.6722	
Residuals	30	113.175	3.7725			
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1						

Table A- 7. SE2 corn development by growth stage ANOVA analysis.

SE2 Corn development measured by growth stage						
			V2 (196)			
Analysis of Variance Table						
Response:	G.Stage					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	0.0001	0.0001	0.0226	0.8817	
SN_rate	4	0.02086	0.00522	1.1731	0.3456	
Cover:SN_rate	4	0.00845	0.00211	0.4753	0.7534	
Residuals	26	0.11558	0.00445			
			V6 (278)			
Analysis of Variance Table						
Response:	G.Stage					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	0.02767	0.02767	0.8587	0.3626	
SN_rate	4	0.07544	0.01886	0.5853	0.6761	
Cover:SN_rate	4	0.10704	0.02676	0.8304	0.518	
Residuals	26	0.83783	0.03222			
			V7 (371)			
Analysis of Variance Table						
Response:	G.Stage					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	0.0873	0.08727	0.6802	0.417	
SN_rate	4	0.9743	0.24359	1.8986	0.1408	
Cover:SN_rate	4	0.4523	0.11308	0.8814	0.4887	
Residuals	26	3.3357	0.12829			
			V9 (537)			
Analysis of Variance Table						
Response:	G.Stage					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	0.24595	0.24595	2.0764	0.16152	
SN_rate	4	2.02884	0.50721	4.2822	0.00856	**
Cover:SN_rate	4	0.37843	0.09461	0.7987	0.53696	
Residuals	26	3.07961	0.11845			
			V11 (594)			
Analysis of Variance Table						
Response:	G.Stage					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	0.0768	0.07682	0.3119	0.58132	
SN_rate	4	3.7965	0.94913	3.8531	0.01375	*
Cover:SN_rate	4	0.2642	0.06606	0.2682	0.89575	
Residuals	26	6.4045	0.24633			
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1						

Table A- 8. NE corn development by growth stage ANOVA analysis.

NE Corn development measured by growth stage							
V2 (156)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	0.00125	0.00125	1	27	0.0328	0.8577	
SN_rate	0.05623	0.01406	4	27	0.369	0.8286	
Treatment	0.09996	0.02499	4	27	0.656	0.6278	
V4 (228)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	0.00624	0.00624	1	27	1.5713	0.2208	
SN_rate	0.01519	0.0038	4	27	0.956	0.4474	
Treatment	0.00112	0.00028	4	27	0.0702	0.9905	
V5 (320)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	0.01358	0.01358	1	27	0.4435	0.51107	
SN_rate	0.37596	0.09399	4	27	3.0705	0.03308	*
Treatment	0.06781	0.01695	4	27	0.5538	0.69791	
V7 (411)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	0.18515	0.18515	1	27	3.1293	0.0882	
SN_rate	0.36845	0.09211	4	27	1.5568	0.2143	
Treatment	0.24652	0.06163	4	27	1.0416	0.4041	
V8 (468)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	0.14367	0.14367	1	27	0.8678	0.3598	
SN_rate	0.83232	0.20808	4	27	1.2569	0.3111	
Treatment	0.36737	0.09184	4	27	0.5548	0.6973	
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1							

Table A- 9. SE1 corn biomass ANOVA analysis.

SE1 Corn biomass						
V2 (202)						
Analysis of Variance Table						
Response:	G.Stage					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	7.581	7.581	0.8601	0.3611	
SN_rate	4	311.388	77.847	8.8327	7.76E-05	***
Cover:SN_rate	4	52.284	13.071	1.483	0.2321	
Residuals	30	264.406	8.814			
V3 (298)						
Analysis of Variance Table						
Response:	G.Stage					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	376.7	376.73	1.0914	0.304504	
SN_rate	4	6617.3	1654.32	4.7927	0.004138	**
Cover:SN_rate	4	2378.9	594.71	1.7229	0.170966	
Residuals	30	10355.2	345.17			
V6 (379)						
Analysis of Variance Table						
Response:	G.Stage					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	2996	2995.8	0.6601	0.422928	
SN_rate	4	47509	11877.3	2.617	0.054771	.
Cover:SN_rate	4	78984	19746.1	4.3508	0.006809	**
Residuals	30	136153	4538.4			
V7 (473)						
Analysis of Variance Table						
Response:	G.Stage					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	121	121	0.004	0.950034	
SN_rate	4	643155	160789	5.3104	0.002349	**
Cover:SN_rate	4	104024	26006	0.8589	0.499725	
Residuals	30	908336	30278			
V11 (627)						
Analysis of Variance Table						
Response:	G.Stage					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	532041	532041	0.7029	0.4084	
SN_rate	4	2334364	583591	0.771	0.5526	
Cover:SN_rate	4	3141066	785267	1.0374	0.4043	
Residuals	30	22708108	756937			
R1-R2 (810)						
Analysis of Variance Table						
Response:	plants.ha					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	3470867	3470867	1.5643	0.2207	
SN_rate	4	6198243	1549561	0.6984	0.5991	
Cover:SN_rate	4	4074701	1018675	0.4591	0.765	
Residuals	30	66563079	2218769			
Grain (1524)						
Analysis of Variance Table						
Response:	plants.ha					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	14526288	14526288	6.6916	0.01478	*
SN_rate	4	13256494	3314124	1.5267	0.2196	
Cover:SN_rate	4	16886096	4221524	1.9447	0.12873	
Residuals	30	65124751	2170825			

Table A- 9. Continued

Stover (1524)

Analysis of Variance Table

Response:	plants.ha					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	2474158	2474158	2.5565	0.12032	
SN_rate	4	4279101	1069775	1.1054	0.37219	
Cover:SN_rate	4	8753548	2188387	2.2612	0.08593	.
Residuals	30	29034194	967806			

R6 (1524)

Analysis of Variance Table

Response:	plants.ha					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	28990497	28990497	5.4544	0.0264	*
SN_rate	4	29429241	7357310	1.3842	0.263	
Cover:SN_rate	4	42976460	10744115	2.0215	0.1167	
Residuals	30	159450601	5315020			

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table A- 10. SE2 corn biomass ANOVA analysis.

SE2 Corn biomass

V2 (196)

Analysis of Variance Table

Response:	biomass				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	25.31	25.312	1.1273	0.2981
SN_rate	4	13.29	3.321	0.1479	0.9623
Cover:SN_rate	4	127.79	31.948	1.4229	0.2544
Residuals	26	583.78	22.453		

V6 (278)

Analysis of Variance Table

Response:	biomass				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	239.6	239.63	0.4378	0.514
SN_rate	4	1773.8	443.46	0.8103	0.53
Cover:SN_rate	4	513	128.25	0.2343	0.9165
Residuals	26	14229.7	547.3		

V7 (371)

Analysis of Variance Table

Response:	biomass				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	2404	2404.5	0.3276	0.572
SN_rate	4	55073	13768.3	1.8757	0.1448
Cover:SN_rate	4	13768	3442.1	0.4689	0.758
Residuals	26	190847	7340.3		

V9 (537)

Analysis of Variance Table

Response:	biomass				
Df	Sum	Sq	Mean	Sq	F
Cover	1	96570	96570	0.3659	0.5505
SN_rate	4	2222963	555741	2.1057	0.1089
Cover:SN_rate	4	930675	232669	0.8816	0.4886
Residuals	26	6862020	263924		

V11 (594)

Analysis of Variance Table

Response:	biomass				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	172978	172978	0.1786	0.6761
SN_rate	4	4163531	1040883	1.0744	0.3893
Cover:SN_rate	4	765948	191487	0.1977	0.9374
Residuals	26	25188659	968795		

R1-R2 (807)

Analysis of Variance Table

Response:	biomass				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	3029190	3029190	2.1149	0.1578
SN_rate	4	3834575	958644	0.6693	0.6191
Cover:SN_rate	4	361007	90252	0.063	0.9922
Residuals	26	37240669	1432333		

Grain (1422)

Analysis of Variance Table

Response:	biomass				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	667790	667790	0.1658	0.6872
SN_rate	4	6408272	1602068	0.3977	0.8084
Cover:SN_rate	4	10340608	2585152	0.6418	0.6375
Residuals	26	104724051	4027848		

Table A- 10. Continued

Stover (1422)

Analysis of Variance Table

Response:	biomass				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	1145443	1145443	0.5921	0.4485
SN_rate	4	9684622	2421155	1.2516	0.3141
Cover:SN_rate	4	2624026	656006	0.3391	0.849
Residuals	26	50295152	1934429		

R6 (1422)

Analysis of Variance Table

Response:	biomass				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	3562420	3562420	0.3339	0.5684
SN_rate	4	30759242	7689811	0.7207	0.5856
Cover:SN_rate	4	22445113	5611278	0.5259	0.7176
Residuals	26	277435464	10670595		

Table A- 11. NE corn biomass ANOVA analysis.

NE Corn biomass							
V2 (156)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	0.8342	0.8342	1	27	0.2881	0.5958	
SN_rate	9.8034	2.4509	4	27	0.8465	0.5082	
Treatment	6.8834	1.7208	4	27	0.5943	0.6697	
V4 (228)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	99.246	99.246	1	27	2.9983	0.09477	.
SN_rate	143.756	35.939	4	27	1.0857	0.38326	
Treatment	201.402	50.35	4	27	1.5211	0.22408	
V5 (320)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	107.9	107.9	1	27	0.0271	0.8705	
SN_rate	10389.7	2597.4	4	27	0.652	0.6305	
Treatment	16501.6	4125.4	4	27	1.0355	0.4071	
V7 (411)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	83503	83503	1	27	0.352	0.5579	
SN_rate	1583451	395863	4	27	1.6687	0.1863	
Treatment	172421	43105	4	27	0.1817	0.9459	
V8 (468)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	181624	181624	1	30	0.3646	0.5505	
SN_rate	1131751	282938	4	30	0.568	0.6878	
Treatment	3048157	762039	4	30	1.5297	0.2187	
R1-R2 (725)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	85729	85729	1	30	0.0546	0.8169	
SN_rate	6431688	1607922	4	30	1.0238	0.411	
Treatment	7958629	1989657	4	30	1.2669	0.3048	
Grain (1244)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	2524	2524	1	30	0.0013	0.972	
SN_rate	5977610	1494403	4	30	0.7403	0.572	
Treatment	8453797	2113449	4	30	1.047	0.3996	
Stover (1244)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	6314337	6314337	1	30	1.5302	0.2257	
SN_rate	7637349	1909337	4	30	0.4627	0.7625	
Treatment	6590774	1647694	4	30	0.3993	0.8075	
R6 (1244)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	6569328	6569328	1	29	1.1103	0.3007	
SN_rate	10001989	2500497	4	29	0.4226	0.791	
Treatment	23430860	5857715	4	29	0.9901	0.4286	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table A- 12. SE1 corn N content ANOVA analysis.

SE1 Corn N content

V2 (202)

Analysis of Variance Table

Response:	G.Stage					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	0.01065	0.01065	0.2305	0.6346	
SN_rate	4	1.96648	0.49162	10.6449	1.72E-05	***
Cover:SN_rate	4	0.22209	0.05552	1.2022	0.3303	
Residuals	30	1.38551	0.04618			

V3 (298)

Analysis of Variance Table

Response:	G.Stage					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	0.449	0.4489	0.3841	0.54008	
SN_rate	4	27.044	6.7609	5.7854	0.00142	**
Cover:SN_rate	4	7.148	1.7871	1.5292	0.21889	
Residuals	30	35.059	1.1686			

V6 (379)

Analysis of Variance Table

Response:	G.Stage					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	8.86	8.859	0.8085	0.37574	
SN_rate	4	126.4	31.601	2.884	0.03923	*
Cover:SN_rate	4	127.2	31.801	2.9023	0.03835	*
Residuals	30	328.72	10.957			

V7 (473)

Analysis of Variance Table

Response:	G.Stage					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	12.44	12.438	0.1453	0.7058	
SN_rate	4	699.32	174.829	2.042	0.1137	
Cover:SN_rate	4	305.35	76.337	0.8916	0.481	
Residuals	30	2568.55	85.618			

V11 (627)

Analysis of Variance Table

Response:	G.Stage					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	574	574.2	0.1867	0.6688	
SN_rate	4	6024	1505.9	0.4896	0.7433	
Cover:SN_rate	4	15833	3958.1	1.2869	0.2972	
Residuals	30	92271	3075.7			

R1-R2 (810)

Analysis of Variance Table

Response:	plants.ha					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	17884	17883.9	2.1615	0.1519	
SN_rate	4	26924	6731	0.8136	0.5266	
Cover:SN_rate	4	51976	12993.9	1.5705	0.2077	
Residuals	30	248209	8273.6			

Grain (1524)

Analysis of Variance Table

Response:	plants.ha					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	10682.1	10682.1	16.6314	0.000308	***
SN_rate	4	2359.9	590	0.9186	0.466024	
Cover:SN_rate	4	2993.4	748.3	1.1651	0.34583	
Residuals	30	19268.5	642.3			

Table A- 12. Continued

Stover (1524)

Analysis of Variance Table

Response:	plants.ha					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	4212.8	4212.8	15.1562	0.000512	***
SN_rate	4	322.9	80.7	0.2904	0.881891	
Cover:SN_rate	4	1487.4	371.8	1.3378	0.278862	
Residuals	30	8338.7	278			

R6 (1524)

Analysis of Variance Table

Response:	plants.ha					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	28311	28311.4	19.0647	0.000138	***
SN_rate	4	3268	816.9	0.5501	0.700363	
Cover:SN_rate	4	8033	2008.3	1.3523	0.273802	
Residuals	30	44551	1485			

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table A- 13. SE2 corn N content ANOVA analysis.

SE2 Corn N content

V2 (196)

Analysis of Variance Table

Response:		N Content				
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Cover	1	0.06326	0.06326	1.0224	0.3213	
SN_rate	4	0.05119	0.0128	0.2068	0.9323	
Cover:SN_rate	4	0.44185	0.11046	1.7854	0.1621	
Residuals	26	1.60859	0.06187			

V6 (278)

Analysis of Variance Table

Response:		N Content				
Df	Sum	Sq	Mean	Sq	F	
Cover	1	0.077	0.07676	0.063	0.8038	
SN_rate	4	6.045	1.51137	1.2406	0.3183	
Cover:SN_rate	4	0.682	0.17043	0.1399	0.9659	
Residuals	26	31.676	1.21829			

V7 (371)

Analysis of Variance Table

Response:		N Content				
Df	Sum	Sq	Mean	Sq	F	
Cover	1	2.863	2.863	0.2928	0.59303	
SN_rate	4	125.993	31.4983	3.2216	0.02833	*
Cover:SN_rate	4	25.851	6.4628	0.661	0.62464	
Residuals	26	254.211	9.7773			

V9 (537)

Analysis of Variance Table

Response:		N Content				
Df	Sum	Sq	Mean	Sq	F	
Cover	1	106.7	106.68	0.3058	0.585	
SN_rate	4	1877.6	469.4	1.3456	0.2798	
Cover:SN_rate	4	1157.9	289.48	0.8298	0.5184	
Residuals	26	9070	348.85			

V11 (594)

Analysis of Variance Table

Response:		N Content				
Df	Sum	Sq	Mean	Sq	F	
Cover	1	388.4	388.38	0.3597	0.5539	
SN_rate	4	2337.6	584.4	0.5412	0.7068	
Cover:SN_rate	4	1083	270.74	0.2507	0.9066	
Residuals	26	28074.2	1079.78			

R1-R2 (807)

Analysis of Variance Table

Response:		N Content				
Df	Sum	Sq	Mean	Sq	F	
Cover	1	363.7	363.71	0.3314	0.5698	
SN_rate	4	1448.8	362.19	0.33	0.8553	
Cover:SN_rate	4	192.1	48.02	0.0437	0.9961	
Residuals	26	28538.6	1097.64			

Grain (1422)

Analysis of Variance Table

Response:		N Content				
Df	Sum	Sq	Mean	Sq	F	
Cover	1	134.1	134.09	0.1172	0.7348	
SN_rate	4	500.7	125.19	0.1094	0.9781	
Cover:SN_rate	4	3233.2	808.3	0.7065	0.5947	
Residuals	26	29744.4	1144.02			

Table A- 13. Continued

Stover (1422)

Analysis of Variance Table

Response:		N Content			
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	47.2	47.2	0.0863	0.7713
SN_rate	4	1384.2	346.04	0.6327	0.6436
Cover:SN_rate	4	1956.4	489.1	0.8943	0.4814
Residuals	26	14219.3	546.9		

R6 (1422)

Analysis of Variance Table

Response:		N Content			
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Cover	1	340	340.39	0.1107	0.742
SN_rate	4	3426	856.44	0.2786	0.8891
Cover:SN_rate	4	9303	2325.73	0.7566	0.5629
Residuals	26	79919	3073.8		

Table A- 14. NE corn N content ANOVA analysis.

NE Corn N content							
V2 (156)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	0.01145	0.01145	1	30	1.0233	0.3198	
SN_rate	0.08252	0.02063	4	30	1.8445	0.1463	
Treatment	0.0798	0.01995	4	30	1.7837	0.1582	
V4 (228)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	0.22013	0.22013	1	27	2.7107	0.1113	
SN_rate	0.62676	0.15669	4	27	1.9295	0.1343	
Treatment	0.45995	0.11499	4	27	1.416	0.2555	
V5 (320)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	0.235	0.235	1	27	0.0271	0.8705	
SN_rate	40.984	10.2459	4	27	1.1802	0.3418	
Treatment	28.561	7.1403	4	27	0.8225	0.5223	
V7 (411)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	0.6	0.6	1	30	0.0024	0.9613	
SN_rate	2055.36	513.84	4	30	2.0611	0.1109	
Treatment	120.06	30.01	4	30	0.1204	0.9741	
V8 (468)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	90.94	90.945	1	30	0.3586	0.5538	
SN_rate	662.55	165.638	4	30	0.653	0.6293	
Treatment	958.97	239.742	4	30	0.9452	0.4516	
R1-R2 (725)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	34.16	34.16	1	30	0.0423	0.8385	
SN_rate	2564.33	641.08	4	30	0.7936	0.5387	
Treatment	1327.07	331.77	4	30	0.4107	0.7995	
Grain (1244)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	142.96	142.96	1	30	0.2542	0.6178	
SN_rate	2797.86	699.47	4	30	1.2437	0.3137	
Treatment	2210.89	552.72	4	30	0.9828	0.4318	
Stover (1244)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	965.71	965.71	1	29	3.1697	0.0855	.
SN_rate	795.7	198.93	4	29	0.6529	0.6295	
Treatment	1833.34	458.34	4	29	1.5044	0.2268	
R6 (1244)							
Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr (>F)	
Cover	365.5	365.55	1	29	0.2782	0.6019	
SN_rate	4092.8	1023.2	4	29	0.7787	0.5482	
Treatment	5122.8	1280.69	4	29	0.9747	0.4365	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table A- 15. Corn stalk nitrate (NO_3-N) ANOVA analysis.

Stalk Nitrate

```
SE1
Analysis of Variance Table

Response: StalkNO3_ppm
              Df   Sum Sq Mean Sq F value   Pr(>F)
Cover          1   434512  434512  0.6317 0.432962
SN_rate        4 11759367 2939842  4.2742 0.007433 **
Cover:SN_rate  4   362026   90507  0.1316 0.969608
Residuals     30 20634130  687804
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’
1
```

```
SE2
Analysis of Variance Table

Response: StalkNO3_ppm
              Df   Sum Sq Mean Sq F value Pr(>F)
Cover          1     6501    6501  0.0101 0.9206
SN_rate        4  2931179  732795  1.1386 0.3573
Cover:SN_rate  4  8120305 2030076  3.1543 0.0281 *
Residuals     30 19307638  643588
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’
1
```

```
NE
Analysis of Variance Table

Response: StalkNO3_ppm
              Df   Sum Sq Mean Sq F value Pr(>F)
Cover          1   232320  232320  0.4023 0.5307
SN_rate        4  2202980  550745  0.9537 0.4470
Cover:SN_rate  4   710305  177576  0.3075 0.8707
Residuals     30 17325320  577511
```

Table A- 16. Nitrogen recovery efficiency (NRE) ANOVA analysis.

NRE

SE1

```
Analysis of Variance Table

Response: NRE
              Df Sum Sq Mean Sq F value   Pr(>F)
Cover          1 3624.0  3624.0 12.9548 0.001133 **
SN_rate        4  473.7   118.4  0.4234 0.790512
Cover:SN_rate  4  749.1   187.3  0.6695 0.618248
Residuals     30 8392.3   279.7
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’
1
```

SE2

```
Analysis of Variance Table

Response: NRE
              Df  Sum Sq Mean Sq F value Pr(>F)
Cover          1    42.8   42.81  0.0845 0.7733
SN_rate        4   753.2  188.30  0.3716 0.8270
Cover:SN_rate  4  1665.3  416.33  0.8217 0.5217
Residuals     30 15200.7  506.69
```

NE

```
Analysis of Variance Table

Response: NRE
              Df Sum Sq Mean Sq F value Pr(>F)
Cover          1   53.1  53.090  0.2265 0.6376
SN_rate        4 1179.1 294.777  1.2575 0.3083
Cover:SN_rate  4  155.4  38.846  0.1657 0.9541
Residuals     30 7032.3 234.409
```

Table A- 17. Corn grain yield ANOVA analysis.

Grain Yield

SE1

```
Analysis of Variance Table

Response: YieldMg_ha
              Df  Sum Sq Mean Sq F value   Pr(>F)   
Cover          1  6.1255  6.1255  8.0556 0.008061 **
SN_rate        4  1.8193  0.4548  0.5981 0.666792   
Cover:SN_rate  4  1.4290  0.3573  0.4698 0.757398   
Residuals     30 22.8121  0.7604                    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 
1
```

SE2

```
Analysis of Variance Table

Response: YieldMg_ha
              Df Sum Sq Mean Sq F value Pr(>F)
Cover          1  1.283  1.2834  0.4561 0.5046
SN_rate        4 13.111  3.2778  1.1650 0.3459
Cover:SN_rate  4  1.923  0.4807  0.1709 0.9516
Residuals     30 84.409  2.8136               
```

NE

```
Analysis of Variance Table

Response: YieldMg_ha
              Df  Sum Sq Mean Sq F value    Pr(>F)    
Cover          1  0.1200  0.1200  0.2926    0.5926    
SN_rate        4 14.0705  3.5176  8.5767 9.712e-05 ***
Cover:SN_rate  4  2.0444  0.5111  1.2462    0.3128    
Residuals     30 12.3041  0.4101                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 
1
```

Table A- 18. Corn grain moisture ANOVA analysis.

Grain Moisture

SE1

```
Analysis of Variance Table

Response: Mongmo
              Df  Sum Sq Mean Sq F value   Pr(>F)   
Cover          1 0.89810 0.89810  8.8027 0.005856 **
SN_rate        4 0.44841 0.11210  1.0988 0.375207   
Cover:SN_rate  4 0.13569 0.03392  0.3325 0.853897   
Residuals     30 3.06077 0.10203                    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 
1
```

SE2

```
Analysis of Variance Table

Response: Mongmo
              Df Sum Sq Mean Sq F value  Pr(>F)  
Cover          1 0.1162 0.11615  0.6523 0.42564  
SN_rate        4 2.8030 0.70076  3.9357 0.01101 *
Cover:SN_rate  4 0.2600 0.06501  0.3651 0.83148  
Residuals     30 5.3416 0.17805                  
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 
1
```

NE

```
Analysis of Variance Table

Response: Mongmo
              Df Sum Sq Mean Sq F value Pr(>F)
Cover          1 0.3468 0.34678  2.1096 0.1568
SN_rate        4 0.3584 0.08959  0.5450 0.7040
Cover:SN_rate  4 0.8479 0.21199  1.2896 0.2962
Residuals     30 4.9314 0.16438               
```