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Nitrogen Rate Optimization for Grain Yield within Fall and Spring Applications

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This thesis is a comprehensive analysis of research, investigating the impact of fall and spring applied nitrogen at various rates on the vulnerability of fall applied nitrogen, nitrogen uptake, and corn yields. In addition, optimal nitrogen rates and timing were evaluated across East Central Illinois for corn yields.

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CHAPTER I

INTRODUCTION AND BACKGROUND

Areas of intense agriculture have been directly linked to being a significant source of nitrate leaching into water supplies that are jeopardizing water quality and ecosystems. In 2012, the Midwest suffered one of the worst droughts on record significantly reducing crop yields and increasing residual nitrogen left in the soil profile. The above average rainfall in the spring of 2013 promoted a large amount of nitrate to leach into tile drainage systems. As a result, the hypoxia zone in the Gulf of Mexico rose to 15,200 km^2 in 2013 doubling its size from 2012. As water quality issues continue to be a problem on both a national and local scale, it has become evident that alternative solutions to nitrogen management need to be considered.

Corn growers in the Midwest can influence management decisions such as nitrogen rate and timing that can directly impact the nitrogen levels found in the soil. Current nitrogen rate recommendations are based upon two models; the mass-balance approach and the economically optimal nitrogen rate (Scharf, 2003; Camberato, 2012). The traditional mass-balance approach defines the rate at which to apply nitrogen in order to achieve a desired yield goal. In contrast, the economically optimal nitrogen rate determines the rate that maximizes dollar return to the amount of nitrogen being applied by considering the ratio between nitrogen cost and grain price. However, varying field conditions, such as topography, soil type, and mineralization rates, have indicated the need for site specific research to avoid over and under application of nitrogen (Asghari et al., 1984). Furthermore, multiple studies have indicated that yield will plateau regardless of the amount of nitrogen found in the soil as it is no longer the most limiting nutrient (Schmidt et al., 2002). Differing opinions and finding by agricultural scientist indicates that more research is needed to establish rates that are beneficial to both growers and the surrounding environment.

Nitrogen timing is another critical factor in determining the fate of nitrogen once it is applied. Research indicates that even though fall application of N has both logistical and economic advantages, it poses a higher risk to the environment and may result in yield loss (Blackmer et al., 1996). Furthermore, studies have observed that spring application of nitrogen (pre or post plant) yield higher than fall application of N, especially under climate conditions through the winter that promote nitrogen loss (Scharf, 2002; Vetsch, 2004; Randall, 2005). However, if unfavorable spring weather conditions delay N application, then this could result in delayed planting and potential yield loss for systems that apply nitrogen pre-plant. As weather conditions continue to be less predictable, more research is needed to understand the relationship that nitrogen timing has on soil inorganic nitrogen and corn yield. Thus, the objectives of this study were to i) determine the vulnerability of all applied nitrogen in the spring, ii) determine the impact of nitrogen application rate and timing on total nitrogen uptake and yield for corn, and ii) evaluate practices for optimal nitrogen rates and timing in East Central Illinois following a drought year.

CHAPTER II

LITERATURE REVIEW

Water Quality

Hypoxic, or low oxygenated, waters have been prevalent in many ecosystems throughout the world and is often the result of nutrient pollution from human activities (Rabalais, 2002). The northern Gulf of Mexico is currently the second largest area of coastal hypoxia in the world and is fed by the outflows of the Mississippi and Atchafalaya Rivers (Renaud, 1986; Rabalais, 2002). This area is often times referred to as the “Dead Zone”, and refers to the inability of aquatic and marine ecosystems to survive (Renaud, 1986). Excessive nutrient loading, primarily from the Mississippi River has been indirectly linked as the cause of the seasonal hypoxia experienced in this area (Turner, 1994). The Mississippi River is responsible for draining 3.2 million km^2, which is equivalent to roughly 42% of the contiguous USA (Burkahart, 1999) and navigates through the heart of the Midwest, an area of intense agricultural practices. The growth of eutrophication and hypoxia in this area is reflected by the rapid growth of fertilizer use starting in the 1950s (Rabalais, 2002). Researchers have identified nitrate (NO_3^-) as being the primary nutrient being transported by the Mississippi River resulting in the hypoxia in the Gulf of Mexico (Burkhart, 1999), and can be traced to areas of intense agricultural practices (primarily corn, *Zea mays* L., and soybean, *Glycine max* (L.) Merr., production). In these areas, on land where corn is grown, nitrogen fertilizers are applied in the highest amounts in comparison to other nutrients asit is usually the limiting factor for optimal yields (Samborski, 2009). Even though there are various forms of nitrogen that growers utilize in their operations, there are only two molecular forms found in the soil that are available to the plant NH_4^+ and NO_3^-. Nitrogen found in the ammonium form (NH_4^+) is not susceptible to leaching into ground water and tiles until it is transformed into first nitrite by nitrobacter, and then nitrate by nitrosomonas bacteria, a process known as nitrification. The negative impacts of current nitrogen management practices indicate that alternative practices need to be implemented to prevent environmental harm.

Within the Midwest, nitrate levels often surpass the current maximum contaminant level for nitrate in drinking water dictated by the United States Environmental Protection Agency of 10 mg L^{-1} (Jaynes, 1999; Mitchel 2000). For example, Lake Bloomington serves a primary source of drinking water for the residents of Bloomington, IL, and historically has had levels of NO_3^- that exceed the MCL (Smiciklas, 2008). The Lake Bloomington watershed is comprised of an estimated 18,807 ha^{-1}, of which 93.2% is used for agricultural purposes (primarily corn and soybean production), 2.5% is urbanized, 2.5% is wetlands, and 1.8% forested or contains surface water (Smiciklas, 2008). If an alternative solution to current nitrogen management practices that lead to decreased amounts of nitrates found in this particular watershed can be discovered while growers maintain profitability, then it could be hypothesized that the same management practices could be applied to other watersheds located in Central Illinois. Furthermore, a decrease in nitrates in local watersheds could be a precursor to lowered amounts of nitrates being washed into the Mississippi River and contributing to the "Dead Zone".

The Effect of Nitrogen Management on Grain Yield

Historically, the Midwest has been a leader in corn production for the United States. In 2012 Iowa, Illinois, Indiana, Minnesota, and Nebraska accounted for approximately 60% of the corn harvested (USDA, 2012). Farmers in the Corn Belt conventionally use a corn-soybean-corn-soybean crop rotation, but growing continuous corn has been gaining in popularity due to potentially higher returns on investment. A model projected by the USDA-Economic Research Service's Regional Environmental and Agriculture Programming (REAP) indicates that by 2015, continuous corn will represent approximately 30% of the corn hectares in the USA (Malcolm, 2009). However, extensive research indicates that yields decline in systems that continuously grow corn compared to corn being rotated with soybeans (Gentry, 2013). High yielding corn requires high levels of N, often applied as fertilizer, but studies indicate that recovery of fertilizer N found in aboveground biomass is generally less than 50% (Cassman, 2002; Ladha, 2005). Corn growers in the Midwest use various types of N fertilizers consisting of liquids, solids, and gases that take the form of NO_3^- or NH_4^+ in order to supplement nitrogen to the soil. The production of food and fiber has significantly increased with the implementation of N fertilizer into nutrient management plans (Scharf, 2005). Without the invention of the Haber-Bosch process for the industrial fixation of N (ammonia) an estimated 40% of the current human population would not be living (Smil, 2001).

Proper N management should result in the application of N fertilizer at a rate at which the producer receives maximum return per dollar spent on N fertilizer while minimizing the amount of N lost to the environment (primarily leaching into drainage systems). The challenge in properly managing N is that the relationship between N and corn yield is impacted by many factors such as climate, soil type, tillage, topography, hybrid genetics, and their interactions (Asghari, 1984; Tsai, 1992; Sabata, 1992; Ahmadi, 1993; Sogbedji, 2001). In the Midwest, N fertilizer recommendations developed for corn production are based on yield goals, economic return, management practices, and measurements of soil productivity (Oberle, 1990). However, relatively low fertilizer N costs and high yield goals have led producers to over-apply N by applying the same rate of N fertilizer over whole fields to ensure N requirements by the plant are fulfilled (Scharf, 2005; Ruiz Diaz, 2008). Furthermore, the effects of both under and over applying N on profit margins are often overlooked (Lory, 2003). The effect that N rate has corn yield vary significantly among (Scharf, 2002) and within fields (Blackmer, 1998). The variation in corn yield in response to N rate has be linked to differences in the capabilities of soils to supply N (Meisinger, 1984). Multiple studies have shown that maximum corn yield is achieved at a certain level of N uptake that varies spatially regardless if additional N is applied (Schmidt, 2002; Scharf, 2005; Kwaw-Mensah, 2006; Miao, 2006; Al-Kaisi, 2007; Kwaw-Mensah, 2006; Miao, 2006; Dobermann, 2011). There are two approaches used to evaluate N rate recommendations that include the mass balance approach and economically optimal nitrogen rate (EONR). Traditional yield-based N rate recommendations are calculated from the mass balance approach (Lory,

2003) that are linked to its historical yield levels (Camberato, 2012). The mass balance approach for N rate recommendations for corn grain typically takes the form of:

$$N_f \text{ (kg ha}^{-1}\text{)} = 21.4 \text{ x YG} - N_s$$

$$N_f \text{ (bu acre}^{-1}\text{)} = 0.88 \text{ x YG} - N_s$$

Where N_f is the estimated EONR for a selected yield goal, N_s is the quantity of N supplied by the soil and YG is the expected grain yield. The EONR model defines the N rate that will result in the maximum dollar return to N by acknowledging the ratio between fertilizer N cost and grain price (Camberato, 2012). This ratio results in some degree of volatility in the EONR. Currently there is intensive research being conducted in order to adapt the EONR for N mineralization and site specificity.

The Impact of Nitrogen Timing on Grain Yield

The timing of nitrogen application can have a significant impact on corn yield. Nitrogen application occurs in the fall, spring pre-plant or post-emergence (via side dressing) each has its advantages and disadvantages. The planting time is one of the busiest and critical periods of the growing season for growers and is typically inconvenient time to apply N fertilizer (Scharf, 2002). Fall application of N has economic and logistical advantages for producers as well as the fertilizer industry (Vetsch, 2004). These advantages include more evenly distributed labor, equipment demands, time, and better conditions for field work (Bundy, 1986; Randall, 1998). In addition, the fertilizer industry offers an incentive to fall apply N as prices are usually cheaper than purchasing the same fertilizer the following spring (Smiciklas, 2008). However, fall application of N creates the highest risk of losing N and yield, as it is exposed to environmental factors for the longest period of time before the plant can utilize it. Growers that apply spring N (pre or post plant) increase nitrogen efficiency while gambling on weather being favorable for timely application that does not delay planting or decrease yield. Post-emergence application of N is gaining in popularity due to advancements in precision agriculture technology. By applying post-emergence N, growers have the ability to diagnose how much supplemental N is needed to achieve maximum yield while limiting inputs through plant tissue analysis, on-the-go sensors on the applicator, or satellite imagery. It is important to note that the literature indicates that the lack of algorithms that would be reliable in a variety of soil and weather conditions is an important limitation for current sensor-based diagnostic information (Sambroski, 2009). Studies indicate that spring pre-plant application of N result in higher yields versus fall applications (Vetsch, 2004; Randall, 2005). Furthermore, the yield difference is significantly noticeable when weather conditions results in N lost (Vetsch, 2004). Scharf (2002) found that post emergence N application resulted in no evidence of yield reduction when N applications were delayed as late as V11 as well as weak evidence of a small yield reduction (3%) when N applications were delayed until V12-16.

Cover Crops and Nitrogen Management

Cover cropping is an alternative style of production that is utilized on a large scale for organic production and on a much smaller scale in commercial agriculture. According to Paine (1993), the earliest documentation of cover cropping, also known as green manures, was in China 500 B.C. by Chia Szu Hsieh. Hsieh described the high fertilizing potential that lu tou and sio tou displayed when rotating these species into their existing rotations. During the 18th century, the European society was slow to adopt cover crops and other similar systems. This was a direct result of the rise in the tillage concept combined with the view of a clean-tilled field being a sign of good husbandry outlined in

Thomas Tusser's *Five Hundred Points of Good Husbandry*. In North America, the adoption of cover crops was further impeded as cheap, thus fertile land allowed farmers to ignore soil conservation. Several long-term research projects were initiated in England and the United States in an effort to analyze various cropping and management systems during the second half of the 19th century. Many of these studies such as the Rothhamsted plots are still being carried out today. In 1917, Adrian Pieters published a review of green manure/cover crop research that established the ability of cover crops to be a valuable tool in soil conservation efforts. However, during the 1920s and 30s tractors become more widely available thus increasing the amount of tillage used. In the 1970s the idea of utilizing alternative solutions such as cover crops and reduced tillage reemerged again in response to steep increase in fuel and petroleum-based farm chemicals (Paine, 1993). Up until the 1980s, legume and nonlegume cover crops were used primarily as green manure crops for the conservation in soil and water resources (Wagger, 1989). However in 1980s, there was dramatic increase in research for cover crops as new cropping strategies began emerging for winter annual cover crops (Wagger, 1989). During this time, legumes received considerable attention as a result of their ability to contribute significant amounts of biologically fixed N to the subsequent crop were (Wagger, 1989). Also, it was discovered that nonleguminous cover crops increased the potential for immobilization of N by having a relatively slow decomposition rates (Wagger, 1989). However, further research revealed that nonleguminous cover crops could scavenge residual N preventing it from leaching into water supplies (Sainju, 2008). The wake of positive side effects that cover crops could have on the industry goes far beyond just managing N including increased organic matter content and water penetration, weed suppression, and increases in beneficial insect populations (Benoit, 1962).

Nitrogen Rates and Cover Crops on Grain Yield

Recommended nitrogen rates for corn preceding a winter cover crop varies significantly based on the type of cover crop that is managed. Legume cover crops are efficient at fixing inorganic N from the atmosphere through a symbiotic relationship with bacteria; while nonlegume cover crops are efficient at increasing soil organic N through increased biomass production (Kuo, 1997; Sainju, 2000). Nonleguminous cover crops typically have low N contents and high C/N ratios, showing little or no beneficial effects on the succeeding corn yield in the short term (Kuo, 2002). Data from N rate studies have indicated the potential for fertilizer N immobilization in nonleguminous cover crop systems and that applications of higher rates of N fertilizer may be required to offset N immobilized (Hargrove, 1986; Tyler, 1987; Tollenaar, 1993). In contrast, legume cover crops generally possess low C/N ratios and have high N contents through N fixation. Studies indicate that leguminous cover crops can provide enough N (through fixation) to reduce fertilizer N requirements while achieving similar yields (Teasdale, 2007).

Nitrogen Timing and Cover Crops on Grain Yield

The correlation between nitrogen timing and cover crops and its impact on corn yield has not been thoroughly investigated by the science community. Current timing for N application for cover cropping systems is based on conventional tillage systems that do not use cover crops (Reeves, 1993). A three year study involving the timing of nitrogen applications for corn in a winter legume (hairy vetch) conservation-tillage system reported, based on linear regression models, maximum yield was obtained with a decreasing rates of N over time (Reeves, 1993). These results coincide with the results of other studies similar in nature (Decker, 1994; Roberts, 1998). The data also suggested that split applications are not necessary for corn grown in a winter legume conservation system because late-season N requirements were met through mineralized N from residues of the previous legume cover crops (Reeves, 1993). However, more research is needed to investigate the relationship between fall applied N and cover crops.

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CHAPTER III

INTERACTION OF NITROGEN RATES AND TIMING ON PLANT AVAILABLE NITROGEN CONCENTRATION IN SOIL

Abstract

Nitrogen (N) rates and timing are crucial components for a successful N management plan that optimizes yield and maintains environmental stewardship. Previous research has shown that fall applied N can be vulnerable to excessive loss via nitrate (NO_3^-) into tile drainage systems in comparison to spring application. The drought of 2011-2012 provided a unique opportunity to investigate the availability and depth distribution of spring soil inorganic N following fall applied N. These climatic conditions have not occurred since 1988. Thus, the objective of this study was to determine the amount of plant available N from fall applied N in the spring by partitioning the soil inorganic N into NO_3^- and ammonium (NH_4^+) at various rates of N applied at four depths down to 80 cm following a drought year. The experimental site was located at the Illinois State University farm located in Lexington, IL. Treatments included the fall application of anhydrous ammonia with nitrapyrin at rates of 0, 56, 112, 168, and 224 kg ha^{-1}. Soil samples were collected on 5/20/2013 at four depths down to 80 cm and analyzed for NO_3^- and NH_4^+. The spring sampling indicated that of 168 kg ha^{-1} rate of fall applied N significantly increased the NO_3^- levels found at the 50-80 cm depth, and the fall application of 224 kg ha^{-1} significantly increased the amount of NH_4^+ found at the 0-5, 20-50, and 50-80 cm depths. The percent fertilizer equivalent indicated

that 51-80% of the applied N had nitrified and leached below the sampling depth of 0-80 cm.

Introduction

In order to achieve maximize production, it is estimated that approximately 25% of the crop land in the United States needs tile drainage (Pavelis, 1987; Skaggs et al., 2012). However, in areas of intense agriculture, such as the Midwest, this provides a direct outlet of NO_3^- contaminated water into ground water, lakes, rivers, and streams.

Researchers estimate that 76% of the N loading into the Mississippi River, which fuels the "Dead Zone" in the Gulf of Mexico, can be attributed to fertilizer N (David et al., 2010). Large amounts of NO_3^- being added to water systems can have negative impact on water quality, ecosystems, and human health (Rabalais, 2002). Locally, Lake Bloomington, a watershed dominated by row crop land use, historically has had levels of NO_3^- that exceed the MCL despite it being a primary source of drinking water (Smiciklas, 2008).

Once fertilizer N has been introduced to the soil it becomes highly dynamic and could potentially be lost via NO_3^- into tile drainage systems. Furthermore, factors such as N rate and timing can directly impact the N levels found in the soil and its vulnerability to loss. Multiple studies have revealed that fall applied N is more susceptible to loss via leaching in comparison to spring applied N (Vetsch, 2004; Blackmer, 1988). Even though greater N loss has been documented with fall applied N, an estimated 25% of Midwest farmers still fall apply N.

Nitrate loss via tile drainage in the winter and early spring could come from three distinct sources: residual N from the previous year, naturally mineralized soil N, and fall applied N. The drought that began in late 2011 to 2012 offered a unique opportunity to examine the soil profile under conditions that haven't been comparable since 1988.

Previous research has indicated that during periods of extreme drought, especially during critical growth stages can be devastating to the health of the corn plant and can lead to extreme yield reductions (Forrestal et al., 2012). There can be an abundance of residual N remaining in the soil as the drought/stress hindered the ability of the crop to uptake N (Forrestal et al., 2012). Furthermore, soils that has the ability to expand and shrink trapped N in the form of NH_4^+ between the clay lattices making it unavailable to the plant, a phenomenon known as fixation. Little is known about the contribution of NO_3^- via from natural soil mineralization and the partitioning of fall applied N in the spring following a drought year. Therefore the objective of this study was to determine the amount of plant available N from fall applied N in the spring by partitioning the soil inorganic N into NO_3^- and NH_4^+ at various rates of N applied following a drought year.

Materials and Methods

A field experiment took place on a tile drained, silty clay loam soil type, with a corn-soybean rotation at the Illinois State University Farm located in Lexington, Illinois (Central Illinois). The soil organic matter (SOM) averaged 5.2% across the site. Eighteen treatments were arranged in a split-plot design, including three replications of each treatment (54 plots). The plot dimensions were 9.14 meters (m) by 18.29 m (167.17 m^2 per plot). Located at the end of the test plot was a 9.14 meter buffers along with 4.57 m buffers between each treatment with a total space requirement of 12416.49 m^2. The treatments (independent variables) that were analyzed include the timing of N (Spring side dress versus fall), N rates (0, 56, 112, 168, and 224 kg ha^{-1}), and the inclusion of an Indy blend cover crop (radish, rye, and clover) to determine the effect they have on grain yield (dependent variable). The N rates are in conjunction with a study conducted by the University of Illinois to reevaluate optimal N rates across the East Central region of Illinois. Nitrogen timing and N rate was randomized using a random numbers table in Microsoft Excel to generate nine experimental strips consisting of six plots for N application rate in respect to timing and allowed for a more precise and uniform amount of N being applied within plots. Within each strip a random numbers table was used again to determine which plots would receive the cover crop treatment. Nitrogen, treated with nitrapyrin (N-serve), was applied using an 11 shank toolbar at a depth of 25.4 centimeters (cm). The fall application of N occurred on 11/19/2012 when the average daily soil temperature fell below 10 º C and in the spring on 6/20/2013 when the soil conditions were dry enough for equipment. The cover crop were inter seeded into standing soybeans with a rear mounted PTO driven broadcaster calibrated to seed 21.3 kg ha^{-1} on 9/20/2012 upon 50% defoliation of the soybean plants. Seedbed preparation was achieved with a soil finisher prior to planting. In season weed control was achieved with Glyphosate on 6/5/2013. The corn hybrid used was H8969 by Syngenta and was planted with a 12 row John Deere planter at 85250 seeds a hectare.

Soil Sampling

Soil samples were collected on 11/19/2012 5/20/2013 to a depth of 80 cm (0-5, 5-20, 20-50, and 50-80 cm). The samples were collected from the center of each plot with a rear mounted hydraulically driven probe. Samples were analyzed in the Department of Agriculture research lab located in Normal, IL. Soil samples were dried with an air flow oven at 40.5º C for 24 hours and ground to pass a 2-mm sieve. Nitrate and ammonium was extracted through the addition of 50 mL solution of 0.01 M calcium chloride ($CaCl_2$) solution to 5 g of dried/ground soil, placed on a shaker at 200 EPMs for 30 minutes, centrifuged at 1500 RPMs for 5 minutes, filtered through #42 Whatman filter paper, and then analyzed through ion chromatography (IC). A LECO FP-528 was used to determine the total percent nitrogen of each sample by dry combusting 0.10 g of soil. Phosphate was extracted by adding 20 mL of Mehlich III solution to 2 g of soil dried/ground soil, placed on a shaker at 200 EPMs for five minutes, centrifuged at 1500 RPMS for 5 minutes, filtered through #42 Whatman filter paper, and analyzed with an inductively coupled plasma (ICP) instrument. The pH was measured using a 2:1 ratio of water to soil with a Fisher AR20 probe.

Statistics

A factorial statistical analysis of soil inorganic N concentrations was conducted using ANOVA as calculated by SAS (SAS I006EStitute, Cary NC). Tukey Multiple

Means comparisons were used to compare the control and treatments against each other. A P level of <0.05 was considered significant.

Results and Discussion

Weather

The average air temperature for 2013 was cooler than the 30 year average for the Central Illinois Region. The months of January-May were cooler than the regional average by an average of 1.33°C. During the growing season (May-October), average air temperatures were not different from the 30 year regional average. The average precipitation for 2013 was higher in the months of January-May by 22.72 mm. During the growing season, average precipitation was less than the 30 year regional average by 24.79mm. However, in the month of May the experimental site received 171.2 mm of rain, which was 57.83 mm above the 30 year regional average.

Spring Nitrate and Ammonium Levels

The spring soil sampling indicated that the fall application rate of 168 kg ha^{-1} significantly increased the NO_3^- levels found at the 50-80 cm depth (Appendix A: Figure 1). However, the fall application rate of 224 kg ha^{-1} significantly increased the amount of NH_4^+ found at the 0-5, 20-50, and 50-80 cm depths (Appendix A: Figure 2). This raised an interesting question as to why the fall application of 224 kg ha^{-1} still had a significant higher amount of N in the NH_4^+ form while the fall application rate of 168 kg ha^{-1} had significantly higher levels of NO_3^-. The fertilizer coop was contacted to investigate how they added the nitrapyrin to the anhydrous tanks and discovered that the ratio of nitrapyrin to kg ha^{-1} of anhydrous ammonia was 1 quart per 180 kg $ha^{-1}$of anhydrous ammonia. This relationship is both proportional and linear meaning that as the application rate increases, so does the amount of nitrapyrin added. However, it was not clear if the greater amount of nitrapyrin applied or the greater amount of NH_4^+ that the microorganisms had to nitrify caused the increased NH_4^+ concentrations at the lower depths. This phenomenon is currently being investigated at Illinois State University through a study that holds nitrapyrin application at one quart across three rates of N. It was interesting to note that the data for 56, 112, and 168 kg ha^{-1} demonstrated both a similar trend and range of ammonium being expressed in the soil profile.

The percent fertilizer equivalent (treatment average-control) for the fall applied N ranged from 20-49% indicating that 51-80% of the applied nitrogen had nitrified and leached below the target sampling range. Furthermore, the fall application of 224 kg ha^{-1} was the only treatment that still had N in the form of NH_4^+ (Appendix A: Figure 3). A three year study conducted from 1997-1999 by Vetsch and Randall (2004) revealed that under normal weather conditions, fall N percent fertilizer equivalents ranged from approximately 36-39% at a N rate of 123 kg ha^{-1}. However, in 1999 precipitation values for April and May were 84 and 48 mm higher respectively than the 30 year average. During this year fall N percent fertilizer equivalent was approximately 11%. In addition, other studies have indicated fertilizer recoveries of 35% (Bijeriego et al., 1979), 15-65% (Meisinger et al., 1985), 24-26% (Olson, 1980), 15-33% (Sanchez and Blackmer 1988), and 65% (Lacey et al., 2014).

Fall Nitrate and Ammonium Levels

The main effects tested for NO_3^- concentrations indicated that there was a significant interaction between N timing x N rate, N rate x depth, and N timing x depth. The interaction of N timing x N rate showed that at the control, 56, and 112 kg ha^{-1} there was no significant differences between timing. However, with the application rates of 168 and 224 kg ha^{-1}, spring timing significantly increased the NO_3^- concentration compared to the fall timing (APPENDIX A: Figure 4). The NO_3^- data indicates that the spring application rates of 168 and 224 kg ha^{-1} significantly increased the amount of NO_3^- found within the soil profile in comparison to the fall application. Past research has indicated similar trends of less fertilizer N being required for spring applications in comparison to the fall applications to obtain optimal yield (Forrestal et al., 2004). However, this raises an interesting point in environmental stewardship. This study shows that fall applications of N can be susceptible to large amounts of loss, but the two highest rates of spring applied N significantly increased the amount of NO_3^- and NH_4^+ present after harvest. If weather conditions are similar to those experienced in 2013, the excess N supplied by the 168 and 224 kg ha^{-1} will be at high risk of loss via leaching into tile drainage before the following cash crop can utilize it. Furthermore, research has indicated that corn plants can obtain up to 85% of their N from mineralized SOM (Blackmer et al., 1988).

The interaction between N rate x depth revealed that at the 0-5 cm depth, the 56, 112, 168, and 224 kg ha^{-1} treatments were significantly higher than the control. At the 20-50 cm depth, the application rate of 168 kg ha^{-1} significantly increased the NO_3^- concentrations relative to the control, 56, and 112 kg ha^{-1} rates. The application rate of 168 kg ha^{-1} was significantly higher than the control, 56, 112, and 224 kg ha^{-1} rates (APPENDIX A: Figure 5). The interaction between N timing x depth indicated that at the depths of 0-5, 20-50, and 50-80 cm, the spring timing significantly increased NO_3^- concentrations over the fall and control treatments. At the 5-20 cm depth, the spring timing was significantly higher than the fall (APPENDIX A: Figure 6). This further supports that the over application of spring N can lead to higher levels of residual NO_3^- in the soil profile following harvest.

The main effects tested for the NH_4^+ concentrations indicated that there was a significant interaction between N timing x rate and N rate x depth. The interaction of N rate x timing indicated that the 168 and 224 kg ha^{-1} application rates significantly increased NH_4^+ concentrations for the spring timing compared to the fall (APPENDIX A: Figure 7). These results are similar to what we found for the NO_3^- data suggesting that optimum yield for the spring treatments was reached at the 112 kg ha^{-1} rate. As spring application rates increased over this threshold, there was an increase in the amount of residual N found within the soil profile.

The interaction of N rate x depth indicated that at the 0-5 cm depth, the control rate was significantly higher than the 56, 112, and 168 kg ha^{-1}. Also, at the 0-5 cm depth, the 224 kg ha^{-1} rate was significantly higher than the 56 and 168 kg ha^{-1} rates, and the 112 kg ha^{-1} rate was significantly higher than the 56 kg ha^{-1} rate. At the 5-20 depth, the control rate was significantly higher than the 56, 112, 168, and 224 kg ha^{-1} rates, the 224 kg ha^{-1} rate was significantly higher than the 56 and 168 kg ha^{-1}, and the 112 kg ha^{-1} rate was significantly higher than the 56 kg ha^{-1} rate. The application rate of 224 kg ha^{-1} was significantly higher than the control, 56, 112, and 168 kg ha^{-1} rates at the 20-50 depth. At the 50-80 cm depth, the application rate of 112 kg ha^{-1} was significantly higher than 56 and 168 kg ha^{-1} rates (APPENDIX A: Figure 8). The control treatment had the highest amount of NH_4^+ present in the soil profile at 44.19 kg ha^{-1}. This suggests that a significant amount of N had been mineralized during the growing season lowering the optimal level of N needed to reach maximum yield in the spring treatments.

The main effects tested for total inorganic N (TIN) indicated that the N application rate and timing was significant. The spring application rate of 168 and 224 kg ha^{-1} significantly increased TIN by 29.72 and 48.35 kg ha^{-1} in comparison to the fall application. Total inorganic N ranged 47.13-100.63 kg ha^{-1} for the spring treatments and 38.82-60.39 kg ha^{-1} for the fall treatments (APPENDIX A: Figure 9). Again this data suggests that the spring application of N can result in higher residual N levels in the soil profile following harvest.

Conclusion

Currently, there are no restrictions in Illinois banning the application of N. My study has demonstrated that under weather conditions similar to the 2013 growing season, substantial losses of fall applied N may occur. An estimated 51-80% of the fall applied N was lost, which is detrimental to environmental stewardship and the economic sustainability of row crop agriculture. Furthermore, despite there being an inhibitor present in the form of nitrapyrin, rapid nitrification had already occurred by 5/20/2013 converting all fertilizer NH_4^+ with the exception of the 224 kg ha^{-1} treatment.

The soil sampling taken after harvest revealed that the spring application rates of NO_3^- and NH_4^+ within the soil profile compared to the fall application rates. This indicates that even though spring applications place the N closer to the time when the crop will utilize it, steps must be taken to calculate an optimal N rate. One step is to take a soil pre sidedress nitrate test in order to establish how much NO_3^- is in the soil profile prior to application. By doing this we can account for natural soil mineralization that is occurring and limit the over application of N decreasing the amount of residual N left in the soil profile after the growing season.

The Maximum Return to N (MRTN) calculator indicated that the optimal N rate for this region assuming $0.50 per pounds of actual N and corn prices at $5 to be 163 lbs/acre. This rate lies within the range of N applied that increased residual N following harvest, indicating that growers may still over apply N. Despite extensive literature studying the dynamics of N, this study has demonstrated that much more work is needed to better manage this input.

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CHAPTER IV

EAST CENTRAL ILLINOIS EVALUATION OF NITROGEN RATES AND TIMING FOR CORN PRODUCTION FOLLOWING THE 2012 DROUGHT

Abstract

Annually optimal nitrogen (N) rates and timing vary due to weather conditions that influence the dynamics of N throughout the soil profile. The 2012 growing season created extreme drought conditions throughout East Central Illinois. Past research has indicated that these types of conditions can diminish yields and leave large amounts of residual N in the soil profile. This provided a unique opportunity to examine how these conditions would affect optimal N rates, N timing, and yield for the subsequent growing season. Thus, the objectives of this study were to i) determine the impact of N application rate and timing on corn N uptake and yield, and ii) evaluate regional N practices for optimal timing and rate following a drought year. The experimental site for objective one was located at the Illinois State University Farm in Lexington, IL. Treatments included fall and spring side dressed applications of anhydrous ammonia with nitrapyrin at rates of 0, 56, 112, 168, and 224 kg ha^{-1}. The corn N uptake data revealed that a positive relationship between N rate and corn N uptake. The yield data revealed that overall the fall application of N yielded higher compared to the same spring rate with the exception of 112 kg ha^{-1} N rate. The only significant difference detected was that the fall application of 224 kg ha^{-1} yielded significantly higher than the spring application of

224 kg ha^{-1}. For objective two the experimental sites included Perdueville, Dewey, Pesotum, Bismarck, Clarence, Potomac, Tolono, and Lexington Illinois. Treatments included the fall and spring side dress applications of anhydrous ammonia with nitrapyrin at rates of 0, 56, 112, 168, and 224 kg ha^{-1}. The main effects indicated that despite the extremely wet spring, N rate was the only significant factor. Dominant soil types and their inherent ability to mineralize N influenced the optimal N rate for each location indicating that soil type is an important variable to consider when determining optimal N rates.

Introduction

Current N rate recommendations are based upon two models; the mass-balance approach and the economically optimal N rate (EONR) (Scharf, 2005; Camberato, 2012). The traditional mass-balance approach defines the rate at which to apply N in order to achieve a desired yield goal. In contrast, the EONR indicates the rate at which maximum dollar return to N by considering the ratio between nitrogen cost and grain price. However, varying field conditions, such as topography, soil type, and mineralization rates, have indicated the need for site specific research to avoid over and under application of N (Asghari et al., 1984). Furthermore, multiple studies have indicated that yield will plateau regardless of the amount of N found in the soil as it is no longer the most limiting factor (Schmidt et al., 2002). Differing opinions and findings by agricultural scientist indicates that more research is needed to establish rates that are beneficial to both growers and the surrounding environment.

Nitrogen timing is another critical factor in determining the fate of N once it is applied. Research indicates that even though fall application of N has both logistical and economic advantages, it inherits the highest risk of environmental and yield loss (Blackmer et al., 1996). Furthermore, studies have observed that spring application of N (pre or post plant) yield higher than fall application of N, especially under climate conditions through the winter that promote N loss (Scharf, 2002; Vetsch, 2004; Randall, 2005). However, if unfavorable spring weather conditions delay N application, then this could result in delayed planting and potential yield loss for systems that apply N pre-plant.

The drought of 2011-2012 has raised concerns that increased amounts of residual N left in the soil profile prior to the 2013 growing season could result in increased loss of NO_3^- from leaching into tile drainage. Research has demonstrated that prolonged drought conditions can result in dramatic yield losses leading to large amounts of residual N left in the soil profile that can be lost to tile drainage over time (Forrestal et al., 2004). To our knowledge, little research has been done on N rates and timing following a severe drought. Thus the objective of this study was to i) determine the impact of N application rate and timing on corn N uptake and yield, and ii) evaluate statewide N practices for optimal timing and rate following a drought year.

Materials and Methods

Illinois State University Farm Only

Plant Samples

Tissue samples were collected at the V6, V12, VT, and R6 growth stages in order to evaluate percent N. At V6, four randomly selected whole plant samples were collected from the center two rows of each plot. For V12 and VT the newest developed leaf was collected, and at R6 two whole plants were collected to calculate total N uptake. Tissue and grain samples were dried at 55º C to a constant weight, ground through a 1 mm sieve, and then .20 grams were analyzed with a LECO-FP 528.

Corn Yield

Grain yield was calculated by randomly hand harvesting six ears from the center two rows in a 4.6 m distance. Once collected, the ears of corn were immediately passed through an Al-Maco desheller separating the kernels from the cobs. Wet weights were measured, and then a sub-sample was collected. The sub-sample was brought back to the Illinois State University Lab where it was dried at 55º C. Corn yield was then adjusted to 15.5% moisture.

Statistical Analysis

A factorial statistical analysis of percent N concentration, corn N uptake, corn yield were conducted using ANOVA as calculated by SAS (SAS I006Estitute, Cary NC). Tukey Multiple Means comparisons were used to compare the control and treatments against each other. A P level of <0.05 was considered significant.

East Central Illinois

Perdueville

A field trial took place on a silt loam to silty clay loam (0-5% slope) soil type in Perdueville, Illinois, located in Ford County. Five treatments were arranged in a complete random block design including three replications of each treatment (15 plots). The plot dimensions were 9.14 m by 121.92 m. The treatments (independent variables) analyzed was that fall application of N rates at 0, 56, 112, 168, and 224 kg ha^{-1} as anhydrous ammonia (AA). The fall application of N occurred on 11/15/2012 in conjunction with average daily soil temperatures falling below 10º C. Prior to planting, 33.6 kg ha^{-1} of 28% Urea Ammonium Nitrate (UAN) was applied to each plot with a sprayer. Grain samples were collected on 10/22/2013 by harvesting a 6.096 m by 121.92 m swath from each plot. A subsample was taken to analyze moisture and then adjust yield to 15.5% moisture. The previous crop was soybeans that yielded 3.14 MG ha^{-1}.

Dewey

A field trial took place on a silt loam to silty clay loam (0-5% slope) soil type in Dewey, Illinois, located in Champaign County. Five treatments were arranged in a complete random block design including three replications of each treatment (15 plots). The plot dimensions were 9.14 m by 152.4 m. The treatments (independent variables) analyzed was the spring side dress application rates of N at 0, 56, 112, 168, and 224 kg ha^{-1} as 32% UAN. The side dress application occurred on 6/11/2013. Prior to planting, 33.6 kg ha^{-1} of 28% UAN was applied to each plot with a sprayer. Grain samples were collected by harvesting a 6.096 m by 152.4 m swath. Following this a subsample was taken to analyze moisture content and then adjust yield to 15.5% moisture. The previous crop was soybeans, which yielded 2.82 MG ha^{-1}.

Pesotum

A field trial took place on a silt loam to silty clay loam (0-2% slope) soil type in Pesotum, Illinois, located in Champaign County. Five Treatments were arranged in a complete random block design including three replications of each treatment (15 plots). The plot dimensions were 9.14 m by 115.21 m. The treatments (independent variables) analyzed was the fall application of N rates at 0, 56, 112, 168, and 224 kg ha^{-1} as AA. The fall application of N occurred on 11/15/2012. Prior to planting, 33.6 kg ha^{-1} of 28% UAN was applied to each plot with a sprayer. Grain samples were collected on 10/22/2013 by harvesting a 3.048 m by 115.21 m swath. A subsample was taken to analyze moisture content and then adjust yield to 15.5%. The previous crop was soybeans, which yielded 2.83 MG ha^{-1}.

Bismarck

A field trial took place on a silt loam to silty clay loam (0-4% slope) soil type in Bismarck, Illinois, located in Vermillion County. Five treatments were arranged in a complete random block design including three replications of each treatment (15 plots). The plot dimensions were 9.14 m by 124.97 m. The treatments (independent variables) analyzed was the fall application of N rates at 0, 56, 112, 168, and 224 kg ha^{-1} as AA. The fall application of N took place on 11/16/2012. Prior to planting, 33.6 kg ha^{-1} of 28% UAN was applied to each plot with a sprayer. Grain samples were collected on 10/25/2013 by harvesting a 4.57 m by 124.97 m swath. A subsample was taken to analyze moisture content and then adjust yield to 15.5%. The previous crop was soybeans, which yielded 2.67 MG ha^{-1}.

Clarence

A field trial took place on a silty clay to silty clay loam (0-5% slope) soil type in Clarence, Illinois, located in Ford County. Five treatments were arranged in a complete random block design including three replications of each treatment (15 plots). The plot dimensions were 9.14 m by 121.92 m. The treatments (independent variables) analyzed was the fall application of N rates at 0, 56, 112, 168, and 224 kg ha^{-1} as AA. The fall application of N took place on 11/17/2012. Prior to planting, 33.6 kg ha^{-1} of 28% UAN was applied to each plot with a sprayer. Grain samples were collected on 10/25/2013 by harvesting a 9.14 m by 121.92 m swath. A subsample was taken to analyze moisture content and then adjust yield to 15.5%. The previous crop was soybeans, which yielded 2.81 MG ha^{-1}.

Potomac

A field trial took place son a silt loam to silty clay loam (0-6% slope) soil type in Potomac, Illinois, located in Vermillion County. Ten treatments were arranged in a complete random block design including three replication of each treatment (30 plots). The plot dimensions were 9.14 m by 114 m. The treatments (independent variables) analyzed included the timing of N (spring side dress versus fall) and N rates (0, 56, 112, 168, and 224 kg ha^{-1}) as AA. The fall application occurred on 11/15/2012 and the spring application took place on 6/8/2013. Also, 224 kg ha^{-1} of diammonium phosphate (DAP) was broadcasted in the spring of 2013 to each plot. Grain samples were collected on 10/27/2013 by harvesting 4.572 m by 114 m. A subsample was taken to analyze moisture content and then adjust yield to 15.5% moisture. The 2012 crop was soybeans that yielded 3.45 MG ha^{-1}.

Tolono

A field trial took place on a silt loam to silty clay loam (0-5% slope) soil type in Tolono, Illinois, located in Champaign County. Ten treatments were arranged in a complete random block design including three replications of each treatment (30 plots). The plot dimensions were 9.14 m by 114 m. The treatments (independent variable) analyzed included the timing of N (spring side dress versus fall) and N rates (0, 56, 112, 168, and 224 kg ha^{-1}) as AA. The fall application occurred on 11/17/2013 and the spring application on 6/14/2013. During the fall, 196 kg ha^{-1} of DAP was applied. Prior to planting, 50.4 kg ha^{-1} of 28% was applied to each plot with a sprayer. Grain samples were collected on 10/24/2013 by harvesting 4.572 m by 114 m from each plot. A sub sample was taken to analyze moisture content of the grain and then adjust yield to 15.5%. The 2012 crop was soybeans, which yielded 3.12 MG ha^{-1}.

Statistical Analysis

A factorial statistical analysis of corn yields were conducted using ANOVA as calculated by SAS (SAS I006Estitute, Cary NC). Tukey Multiple Means comparisons were used to compare the control and treatments against each other. A P level of <0.05 was considered significant.

Results and Discussion

Illinois State University Farm Only

Cover Crops

Dry fall weather conditions prevented the growth of cover crops in both 2012 and 2013. Rain is an essential component to germination when any type of seed is broadcasted onto the soil surface. In both years there was not a rain event that promoted germination, thus the cover crops were deemed not to have an effect on any of the treatments. In 2013, cover crops were planted a standing corn crop that was at the R6 growth stage. A Haggie tractor that was made for detasseling seed corn was engineered and fabricated with a seed delivery system that dropped the cover crop seed in between the rows without damaging the corn crop. The fabrication consisted of two Gandy drop seeders that were interconnected with a drive shaft. Both drop seeders had dials that allowed consistent calibration of how much seed was being dropped. However, consistently establishing a good stand of cover crops is a challenge that many researchers are still trying to undertake.

For the 2014 cover crop planting, a new system will be employed that takes advantage of the harvest timeline. In Central Illinois the progression of harvest is consistent every year due to growth and development of corn and soybeans. Growers begin harvesting corn first in order capture premiums in the market, and more importantly maintain harvest efficiency. Corn can be harvested at high moisture levels without damage to the seed, which in excess will lead to discounted prices at the scale for poor seed quality, or slow down the speed at which they combine. Soybeans can’t be prematurely harvested without a dramatic decrease in harvest efficiency and seed quality.

As a result there is a shorter optimum harvesting window for soybeans at which growers will not receive lower prices for poor seed quality and optimal moisture levels. Therefore, when soybeans reach a moisture level at which they can be effectively harvested growers switch from corn to soybeans. Once soybean harvest starts, typically in late September to early October, it progresses rapidly in comparison to corn. This due to the fact that less material is entering the combines and therefore larger platforms can be used at higher traveling speeds. The rapid harvest progression of soybeans creates a window of opportunity for growers to either drill or broadcast and incorporate the cover crop seed into the ground. Placing the seed within the soil profile allows for enhanced seed to soil contact as well as access to any water within the top few centimeters of soil. Taking it one step further, a liquid N source such as ammonium sulfate (AMS) or urea ammonium nitrate (UAN) will be applied in an attempt to jump start the plants once it has germinated and emerged.

Tissue Samples

Tissue samples were taken to achieve a snapshot of the plants health in regard to percent N in the tissue. The only significant factor at the V6 tissue testing was N timing. The fall rates were significantly higher than the control and spring treatments, and the control was significantly higher than the spring treatment (APPENDIX B: Figure 1). At V12 the only significant factor was N rate. The application rate of 224 kg ha^{-1} was significantly higher than the 112 kg ha^{-1} and control, and the application rates of 168, 56, and 112 kg ha^{-1} were significantly higher than the control (APPENDIX B: FIGURE 2). The main effects tested at VT indicated that the factors of N rate and N timing were significant. The application rates of 224 and 168 kg ha^{-1} were significantly higher than control, 56, and 112 kg ha^{-1} treatments. Also the application rates of 56 and 112 kg ha^{-1} were significantly higher than the control. The spring treatments were significantly higher than the fall and control treatments, and the fall treatment was significantly higher than the control (APPENDIX B: Figure 3). At R6 the only significant factor was rate. The application rate of 224 kg ha^{-1} was significantly higher than the control, 56, and 112 kg ha^{-1} rate. The application rate of 168 kg ha^{-1} was significantly higher than the 56 kg ha^{-1} rate (APPENDIX B: Figure 4).

Visual symptoms of N deficiency within the control and spring treatments were present at the V6 stage. This was interesting as the control had received no fertilizer N, but five days prior to this sampling the side dressed N was applied to the spring treatments. Furthermore, the percent N revealed that all control and spring treatments fell into the deficiency range for N at that growth stage. This deficiency occurred during a critical period for determining maximum yield potential, or number of kernels. Stress between V5-V12 can interfere with the determination of the ear size and lead to fewer kernels (Nielson 2007) and was one explanation of the yield differences observed. Binford (1992) found that N availability related to the levels of N found in young corn plants, and that early NO_3^- availability explained the majority of the variability in grain yields. In contrast, Scharf (2002) found that maximum yield could be obtained with N applications being delayed as late as V11.

The V12 tissue samples indicated that there was no statistical difference between spring and fall treatments. This signifies that the N from the spring side dressed anhydrous ammonia was being expressed in the proteins of the plants. It is important to note that the plant height for all spring and control treatments were still visibly shorter in comparison to the fall treatments. Also it was interesting that there was no statistical difference between the 224, 168, and 56 kg ha^{-1} treatments suggesting the application rate of 56 kg ha^{-1} was able to provide sufficient levels of N. The VT tissue sampling indicated the spring treatments had significantly higher percent N than the fall and control treatments. The percent N at VT ranged from 1.9-3.8%, which was wider than the range of 1.7-2.7% that Schmidt (2002) found in a similar study. Also, the fall treatments were significantly higher than the control treatment (Appendix B: Figure 3). The fall treatments transitioned into reproductive growth two to three days ahead of the spring and control treatments and were also visibly taller. During the reproductive growth stages, N uptake shifts from supporting vegetative tissue to supporting kernel development. Percent N for the tissue samples at R6 revealed that as N rate increased, so did the percent N found in the tissue with the exception of the 56 and 112 kg ha^{-1}. Values ranged from 0.441-1.088 % (Appendix B: Figure 4).

Total N Uptake, Grain N Uptake, and Stover N Uptake

The only significant factor for total N uptake was N rate. The application rate of 168 and 224 kg ha^{-1} significantly increased total N uptake over the control and 56 kg ha^{-1} treatment. The 56, 112, 168, and 224 kg ha^{-1} increased total N uptake significantly over the control (Appendix B: Figure 5). Nitrogen rate was the only significant factor for grain N uptake. The application rate of 168 and 224 kg ha^{-1} significantly increased grain N uptake over the control and 56 kg ha^{-1} treatment. The 56, 112, 168, and 224 kg ha^{-1} increased total N uptake significantly over the control (Appendix B: Figure 5). The nitrogen rate was also the only significant factor for N uptake in the stover. The application rate of 168 and 224 kg ha^{-1} significantly increased N uptake in the stover.

Mean N uptake for the stover increased as application rate increased and plateaued at the 168 kg ha^{-1} (Appendix B: Figure 5). Despite there being an N deficiency at the V6 growth stage, N timing and the interaction effect of N rate X N timing was not significant indicating that the spring treatment was able to overcome this early deficiency. This provided further evidence that the early deficiency may have had a major impact on the yield differences observed. Total N uptake ranged from 137-283 kg ha^{-1} across the treatments. The control treatment, which received 0 kg ha^{-1} of fertilizer N, had a total N uptake of 137 kg ha^{-1}. This suggests that a significant amount of soil mineralization occurred during the 2013 growing season. Also, the highest fertilizer treatment was 224 kg ha^{-1}, but total N uptake values ranged up to 283 kg ha^{-1} further indicating that a large amount of mineralization occurred. In addition, we know through the spring soil sampling (5/20/13) that 51-80% of the fall N was lost. However, a three year study by Vetsch and Randall (2004) found that the timing of N application was significant. They also reported that under weather conditions that promoted significant loss, Total N uptake was significantly higher for treatments that received a spring application of N.

Corn Yield

Illinois State University Location

Fall application of 224 kg ha^{-1} yielded significantly higher than the spring application of 224 kg ha^{-1} (Appendix B: Figure 8). Overall, fall application of N yielded higher than the comparable spring rate with the exception of 112 kg ha^{-1}. The yield for the spring applications appeared to have plateaued at the 112 kg ha^{-1} and 168 kg ha^{-1} for the fall applications. Vetsch and Randall (2004) found that fall treatments yielded significantly lower than the spring treatments when the weather conditions promoted excessive N loss in the spring in a similar study comparing the timing of N. The calculated relative maximum yield indicated that more fertilizer N was required for the fall application versus the spring (Appendix B: Figure 9). This trend was expected with the exception that the relative maximum yield was higher for the fall application. Research has demonstrated that relative maximum yield curves should require less fertilizer to achieve higher yields in spring application systems due to the loss of N associated with fall application (Randall 2005).

East Central Illinois

The main effects tested indicated that N rate was the only factor significant. At the Perdueville and Dewey locations the application rates of 56, 112, 168, and 224 kg ha^{-1} yielded significantly higher than the control. For both locations the dominant soil type for the experimental sight was a Drummer silty clay loam 0-2% slope. At Pesotum and Lexington the application rates of 168 and 224 kg ha^{-1} yielded significantly higher than the control and 56 kg ha^{-1} rates, and the 112 and 56 kg ha^{-1} rates yielded significantly higher than the control. The dominant soil type for these locations were Flanagan silt loam 0-2% and Drummer silty clay loam 0-2% slope respectively. At Bismarck the 168 and 224 kg ha^{-1} application rates yielded significantly higher than the control and 56 kg ha^{-1} rates, and the application rate of 112 kg ha^{-1} yielded significantly higher than the control rate. The dominant soil type for this location was Ashkum silty clay loam 0-2% slope. At Clarence the application rates of 168 and 224 kg ha^{-1} yielded significantly higher than the control, 56, and 112 kg ha^{-1}, and the 112 kg ha^{-1} yielded significantly higher than the control rate. The dominant soil type for this location was Clarence silty clay loam 0-2% slope. At Potomac the 168 and 224 kg ha^{-1} yielded significantly higher than the control, 56, and 112 kg ha^{-1}, and the 56 and 112 kg ha^{-1} yielded significantly higher than the control rate. The dominant soil type was Ashkum silty clay loam 0-2% slope. At Tolono the application rates of 168 and 224 kg ha^{-1} yielded significantly higher than the control. The dominant soil type for this location was Drummer silty clay loam 0-2%.

The 168 and 224 kg ha^{-1} treatments were not significantly different from each other across all of the locations. This indicates that the extra 56 kg ha^{-1} of N added with the 224 kg ha^{-1} application rate did not significantly increase yield. At the Lexington location we saw yields plateau at 112 kg ha^{-1}, and applications higher than this resulted in elevated levels of TIN present in the soil profile. I hypothesize that the same effect could happen at the other locations. Furthermore, that residual N left in the soil profile could be at risk to loss if similar spring conditions experienced in 2013 occur in 2014.

Dominant soil type at each location appeared to have played a roll in the interaction between maximum yield and N rate. For example, the locations (Perdueville, Dewey, and Tolono, Lexington) that had a dominant soil type of drummer revealed that there were no significant differences in yield between 56-224 kg ha^{-1} treatments with the exception of Lexington. This indicates that applying N at the rate of 224 kg ha^{-1} would lose \$84 per $hecatare^{-1}$ assuming the cost of N at \$0.50 per pound of actual N. Furthermore, the control yields for each location with a Drummer soil type was higher than all other locations. After examining soil properties for each soil type, such as Cation Exchange Capacity (CEC), SOM, and available water capacity (APPENDIX B: Table 2), we discovered that the drummer soil type had the highest SOM with 5.5%, as well as the second highest CEC of 25.6 and available water capacity of 8.72 cm per cm down to the

50 cm depth. This indicates that there was large source of SOM that could mineralize N into a plant available form. The CEC and available water capacity reveals that this soil type can maintain water in the soil profile. This ability became important as the weather conditions shifted from above average precipitation in the spring, to below average precipitation throughout the summer and fall.

Conclusion

This study has proven that exceptional yields can be obtained even with large amounts of N being lost and delayed planting. Despite the early N deficiency exhibited at the V6 stage at the Lexington site, the spring treatments were able to overcome the deficiency and have significantly higher percent N by VT in comparison to the fall treatments. It is important to note that both spring and fall treatments fell into the sufficiency range at VT. The N uptake measurements indicated that as application rate increased, so did N uptake. The only significant difference found in yield was at the 224 kg ha^{-1} rate where the fall out yielded the spring treatment.

Overall, the fall treatments yielded higher than their respectable spring treatments. The tissue and N uptake data indicate that the only measured difference between the fall and spring treatments occurred at the V6 stage. It is believed that the N deficiency that occurred during this time in the plants development played a significant impact on the maximum yield potential for each treatment. Researchers have indicated that between V6 and V12, corn plants determine their maximum kernel potential and that any stress introduced to the plant at this time can have a negative impact yield. The regional study evaluating optimal N rate and timing across East Central Illinois reported similar results that were found at the Lexington site. Even with weather conditions promoting substantial loss of fall applied N, the application timing of N was not a significant factor. This study has indicated that the effect of soil type within a field may be a variable that needs to be accounted for to optimize an N management program.

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CHAPTER IV

CONCLUSIONS

Summary

The aftermath of the 2011-2012 drought was not evident from the start of this study. The fall sampling that took place on 11/19/2012 indicated that between 15.72-20.46 kg ha^{-1} of NO_3^- was still present in the agronomic depths of 0-20 cm. Nitrate concentrations from the 50-80 cm depths ranged from 45.97-67.04 kg ha^{-1}. This indicated that approximately 74-77% of the NO_3^- was located in the 20-50 and 50-80 cm depths suggesting it was vulnerable to leaching via tile drainage, and would not be available to the following crop. The lack of excessive residual N left in the agronomic depths was attributed to the soybeans being grown during the 2012 season. The spring of 2013 was both cool and wet with above normal rainfall totals for the months of April, and May. Researchers have well documented that these types of conditions promote the loss of N by leaching into tile drainage. The spring soil sampling that occurred on 5/20/2013 confirmed this allocation as the treatments that received fall applied N suffered substantial losses to total inorganic N in the 0-80 depths of 51-80%.

During the month of May the experimental site received 171.2 mm of rain. On 5/31/2013, 17 days after corn planting, a substantial rain event occurred totaling 101.6 mm of rain in approximately 20 minutes. This pushed back side dressing operations until the V5 stage, which occurred on 6/20/2013. The combination of this rain event and persistent rain throughout the month of May was suspected to have caused a large amount of N loss via NO_3^- leaching or denitrification. The severity of N loss was evident at the V6 tissue sampling that occurred on 6/25/2013. The V6 sampling indicated that all fall treatments were sufficient in N while the spring and control plots were deficient at this particular growth stage. Furthermore, the plants in the spring and control treatments were noticeably stunted in comparison to the plants in the fall treatments. This difference in plant size between the nitrogen application timing treatments was evident throughout the remainder of the growing season. By V12, the tissue samples indicated that there were no significant differences between the fall and spring treatments suggesting that the side dressed AA was available in amounts large enough for the spring treatments to overcome their deficiency. Starting in the month of June, there was an evident shift in the weather patterns as conditions turned warmer and drier in comparison to the spring. At the VT tissue sampling, the spring treatments indicated that they had significantly higher amounts of N in the leaf opposite and below the ear in comparison to the fall and control treatments. The fall treatments were sufficient throughout the entire growing season despite losing a significant amount of the applied fertilizer before the plant could utilize it. This was due to the significant amount of N being mineralized through the growing, which off set the fertilizer N losses.

Corn yields were above average across all treatments despite the diverse weather conditions at the Illinois State University farm. The control treatments yielded between 9.1-11.2 MG ha^{-1}. Also, on average the fall treatments yielded higher than the comparable spring treatment despite the confirmed excessive N lost for the fall applied N. However, previous research has indicated that under these weather conditions, the spring application of N had a significant yield advantage over fall application found that fall treatments yielded significantly lower than the spring treatments when the weather conditions promoted excessive N loss in the spring. So this leads to the question of what happened during this particular growing season for the results to be different. First, under these weather conditions it is known that large amounts of N can and were lost, but scientists have also shown that certain soil types can mineralize large amounts of N as well. The total N uptake surpassed the fertilizer N rate that was applied for each plot, and the N uptake for the control rate was 137.20 kg ha^{-1}. This suggests that a significant amount of mineralization occurred after the 5/20/2013 sampling. Second, the deficiency experienced at V6 occurred during a critical time in development where the corn plant is determining its maximum yield potential or maximum number of kernels that it will produce. Any stress introduced to the plant at this time will hinder maximum kernel potential. Once this number has been determined by the plant, there is no adding kernels later in the growing season.

The research done for the regional study indicates that despite above normal rainfall in the spring and excessive N losses from the fall treatments confirmed at the Lexington site, N timing was not a significant factor. Again, these results go against past research of similar nature and weather conditions. However, the data suggests that significant mineralization took place at these locations, and is believed to have offset the large amount of fall applied N that was lost. For example, at three of the locations there was no significant difference between the 56-224 kg ha^{-1}. At each of these locations, the dominant soil type was Drummer with a slope of 0-2%. This soil type also possessed the highest SOM value of 5.5% in comparison to all other dominant soil types. Furthermore, past research has revealed that up to 85% of the N required by the corn to achieve optimal yields can be obtained through SOM.

The fall soil sampling that occurred on 11/14/13 after harvest revealed that the spring application rates of 168 and 224 kg ha^{-1} significantly increased the amount of NO_3^- and NH_4^+ found in the soil profile. If similar weather conditions occur in 2014, the excess N left in the soil profile could be at high risk for loss via tile drainage. Overall, this study has proven that more research is needed to better understand the dynamics of N in order to maintain environmental stewardship, profitability, and optimal yields.

APPENDIX A

FIGURES AND TABELS FOR CHAPTER III: INTERACTION OF NITROGEN RATES AND TIMNG ON PLANT AVAILABLE NITROGEN CONCENTRAION IN SOIL

Table 1.) This table highlights important dates for soil sampling and field operations.

Activity	**Date**
Cover Crop Planting	9/20/2012
Soil Sampling (0-80 cm)	11/19/2012
Fall Anhydrous Application	11/19/2012
Burn Down Herbicide Application	5/8/2013
Spring Planting	5/14/2013
Soil Sampling (0-80 cm)	5/20/2013
Post-Emergence Herbicide Application	6/5/2013
Spring Side Dress Application	6/20/2013
Hand Harvest	10/8/2013
Soil Sampling (0-80 cm)	11/14/2013

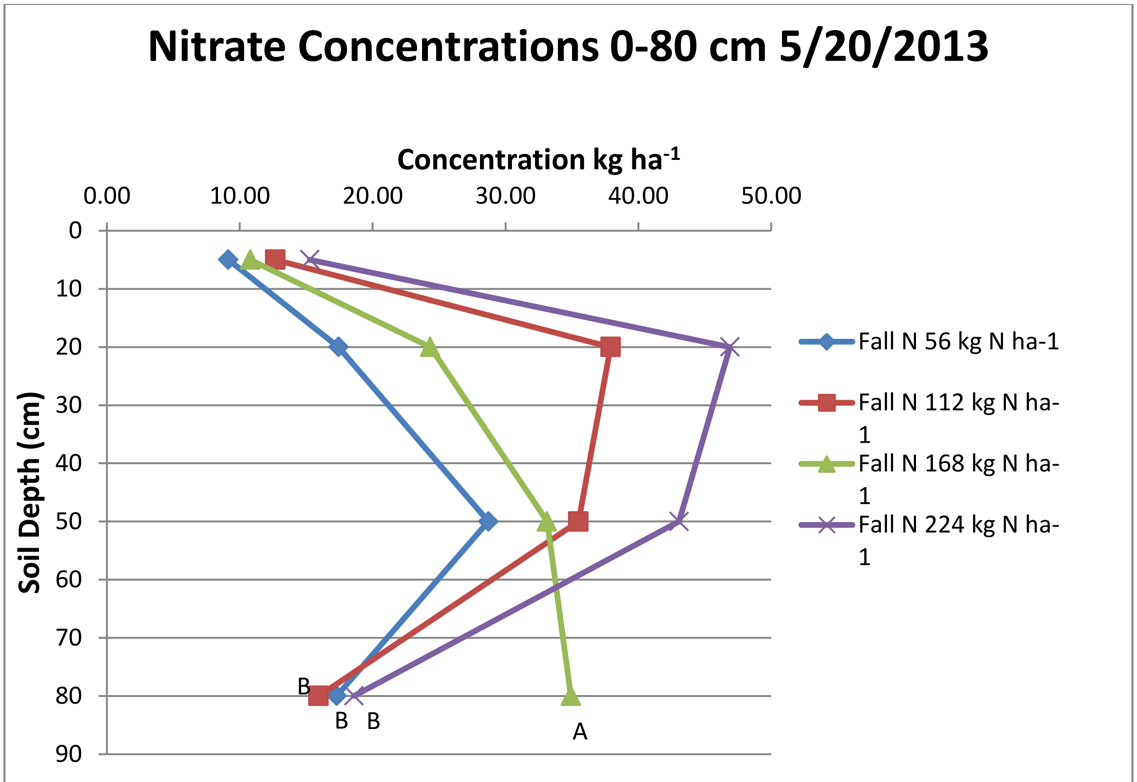

Figure 1: Soil nitrate (kg ha^{-1}) by depth (cm) sampled on 5/20/2013. Different letters by each treatment and/or depth indicates a significant difference at an alpha level of 0.05.

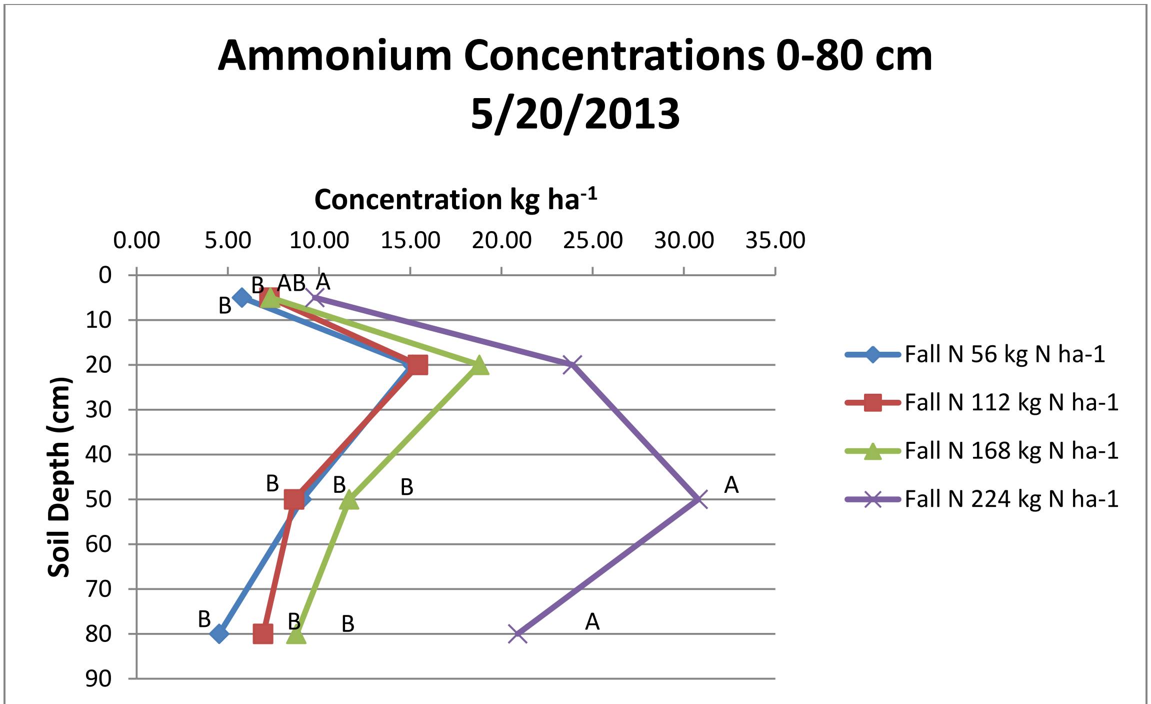

Figure 2: Soil ammonium (kg ha^{-1}) by depth (cm) sampled on 5/20/2013. Different letters by each treatment and/or depth indicates a significant difference at an alpha level of 0.05.

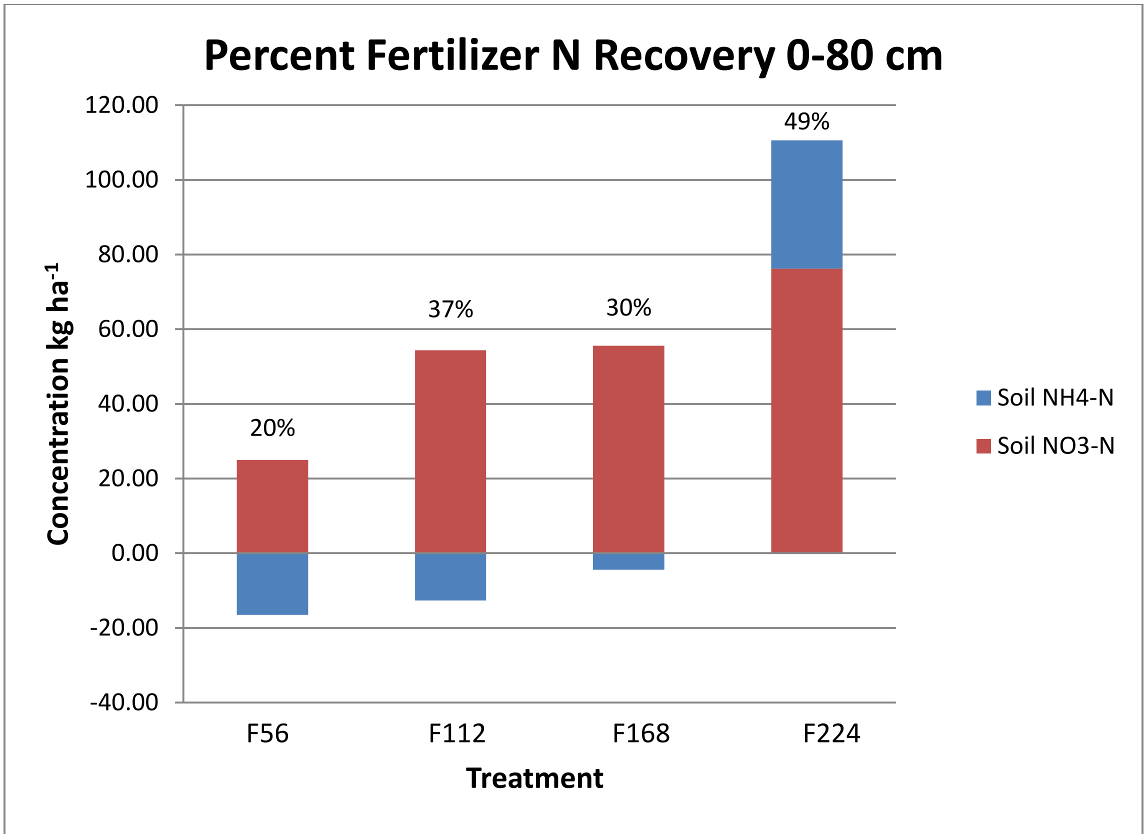

Figure 3: Percent fertilizer N recovery for soil samples collected 5/20/2013. These values were obtained by subtracting the average control values from each plot. The values below zero indicate that the control had more ammonium than the treatments. This indicates that all of the ammonium in those treatments had already been converted to nitrate.

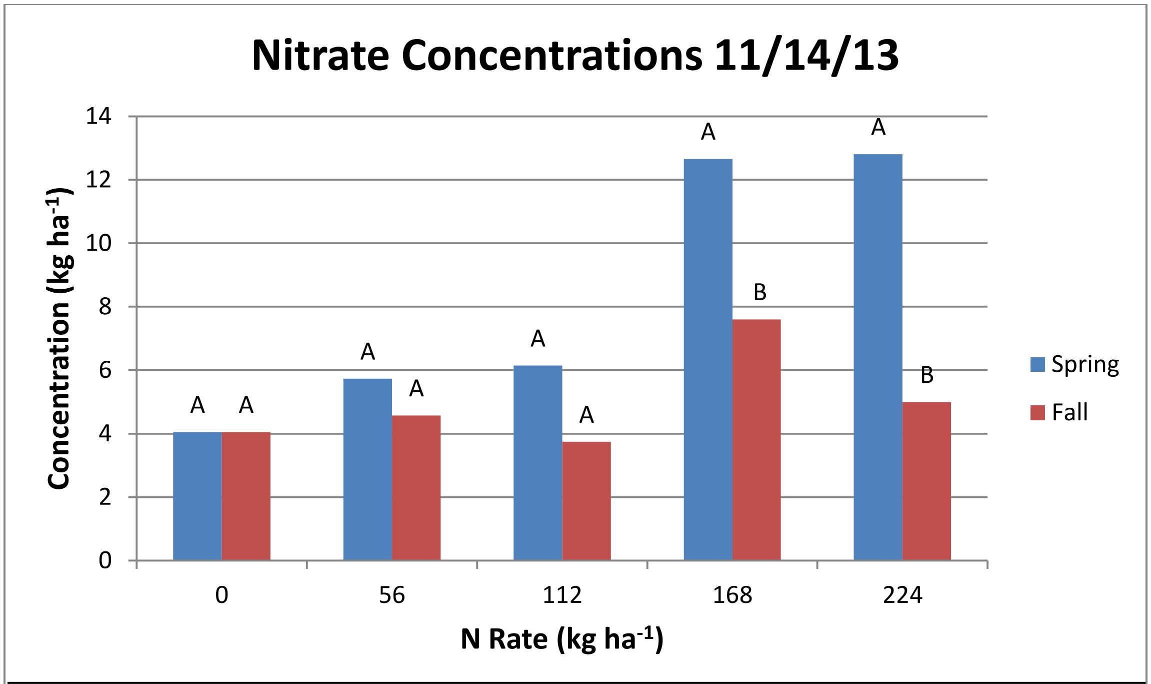

Figure 4: Soil nitrate concentration (kg ha^{-1}) by N application rate (kg ha^{-1}) and timing sampled on 11/14/2013. Different letters indicates a significant difference at an alpha level of 0.05.

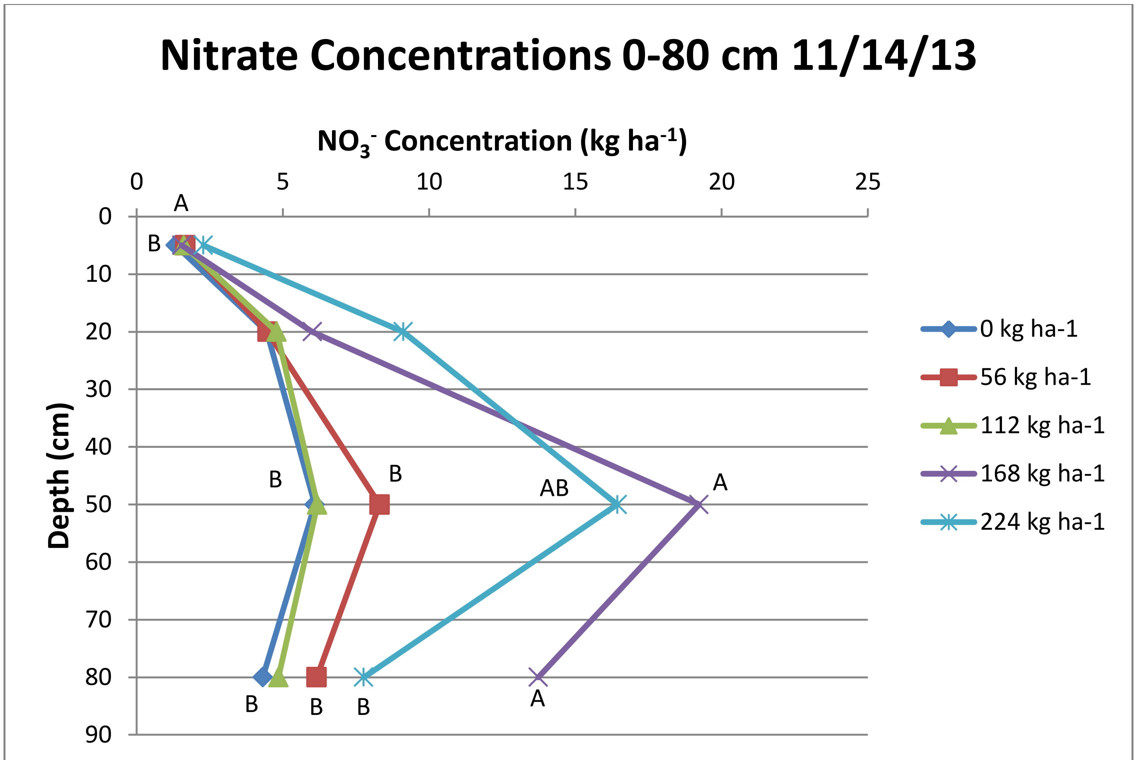

Figure 5: Soil nitrate (kg ha^{-1}) by depth (cm) and N application rate (kg ha^{-1}) sampled on 11/14/2013. Different letters by each treatment and/or depth indicates a significant difference at an alpha level of 0.05.

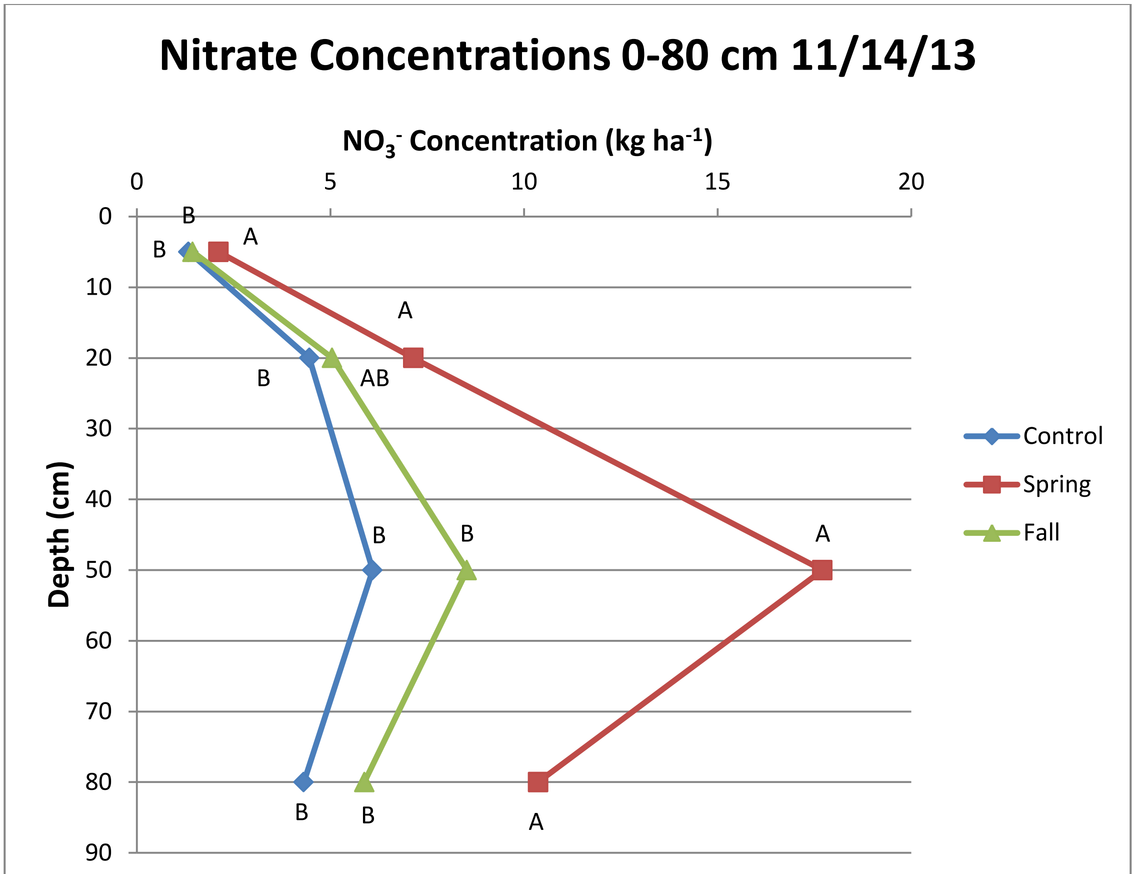

Figure 6: Soil ammonium (kg ha^{-1}) by depth (cm) and N timing sampled on 11/14/2013. Different letters by each treatment and/or depth indicates a significant difference at an alpha level of 0.05.

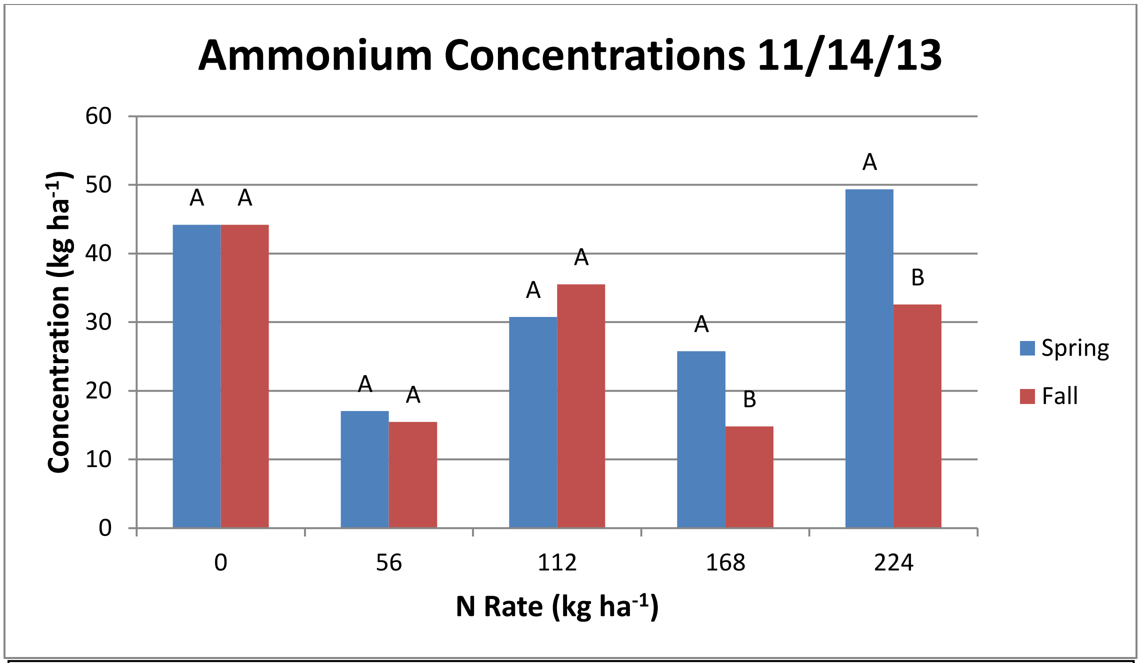

Figure 7: Soil ammonium (kg ha^{-1}) by N application rate (kg ha^{-1}) and timing 11/14/2013. Different letters indicates a significant difference at an alpha level of 0.05.

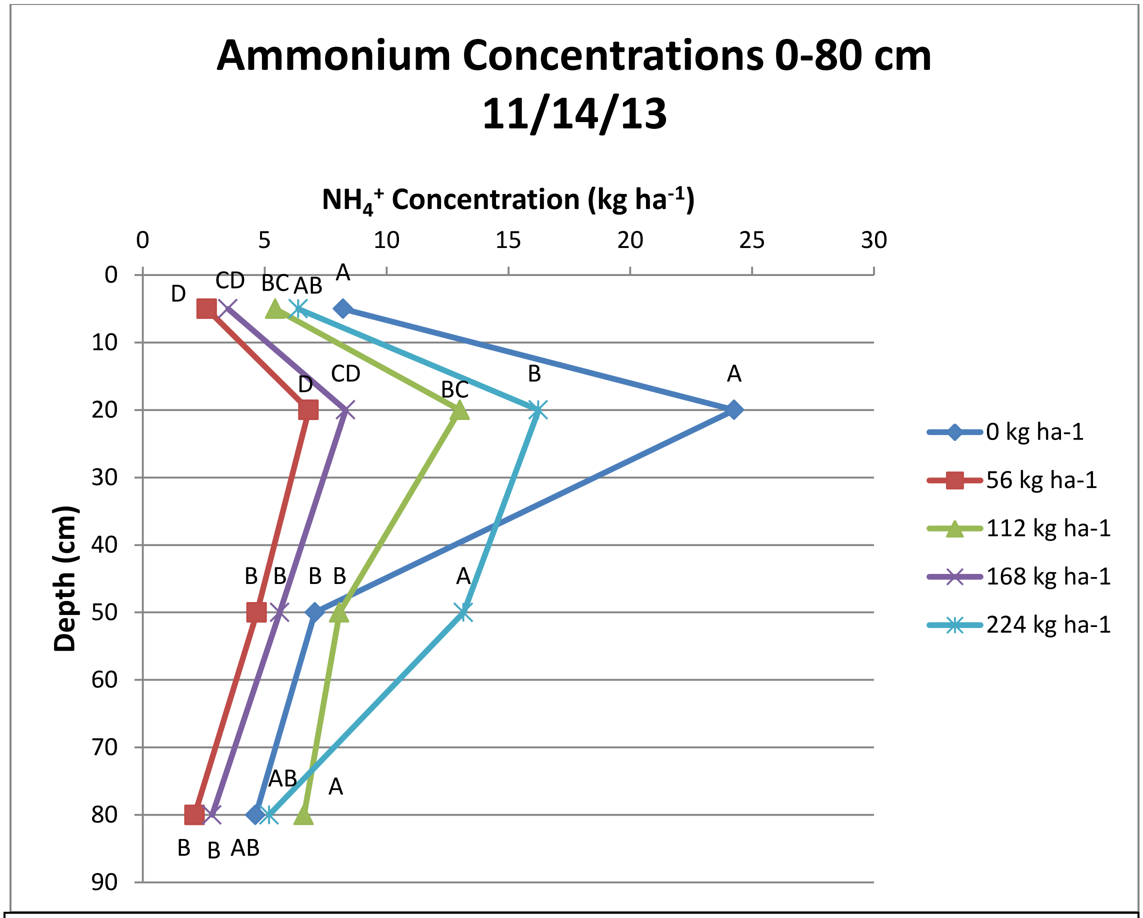

Figure 8: Soil ammonium (kg ha^{-1}) by depth (cm) and N application rate (kg ha^{-1}) sampled on 11/14/2013. Different letters by each treatment and/or depth indicates a significant difference at an alpha level of 0.05.

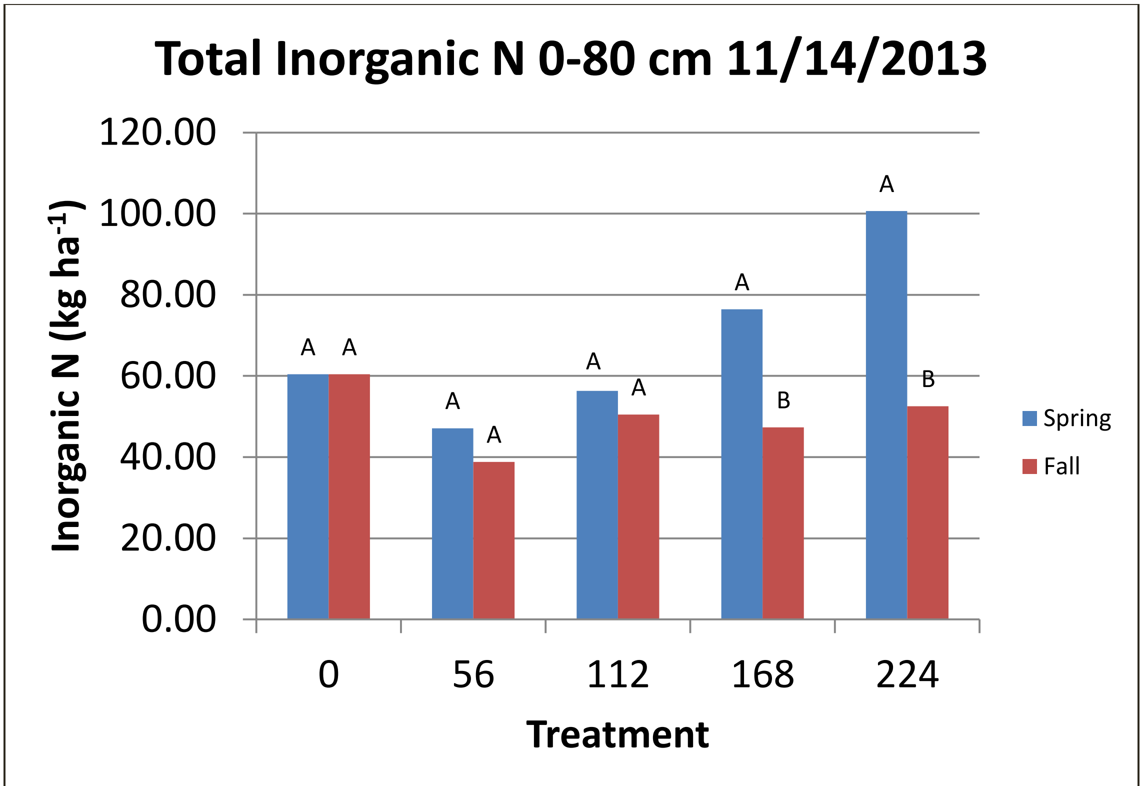

Figure 9: The interaction of Nrate and timing on total inorganic N (kg ha^{-1}) 11/14/2013. Different letters by each treatment and/or depth indicates a significant difference at an alpha level of 0.05.

APPENDIX B

FIGURES AND TABLES FOR CHAPTER IV: EAST CENTRAL ILLINOIS EVALUATION OF NITROGEN RATES AND TIMING FOR CORN PRODUCTION FOLLWING THE 2012 DROUGHT

Table 1.) This table highlights important dates for soil sampling and field operations for the Illinois State University Farm located in Lexington, Illinois, only.

Activity	**Date**
Cover Crop Planting	9/20/2012
Fall Anhydrous Application	11/19/2012
Burn Down Herbicide Application	5/8/2013
Spring Planting	5/14/2013
Post-Emergence Herbicide Application	6/5/2013
Spring Sidedress Application	6/20/2013
V6 (whole plant)	6/25/2013
V12 (youngest leaf)	7/16/2013
VT (youngest leaf)	7/24/2013
R6 (youngest leaf)	10/8/2013
Hand Harvest	10/8/2013
Soil Sampling (0-80 cm)	11/14/2013

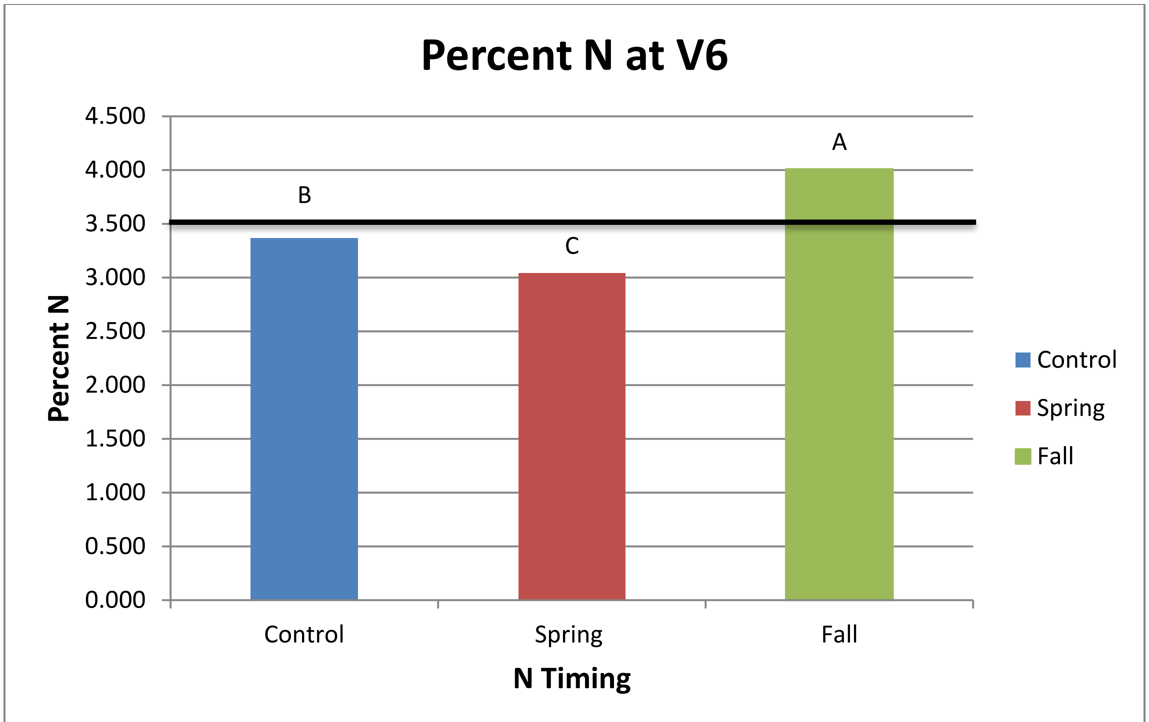

Figure 1: Percent N of the tissue analysis at V6 collected on 6/25/2013. Different letters indicate significance at an alpha level of 0.05. The black line at 3.5% indicates the deficient/sufficient line for corn at this growth stage.

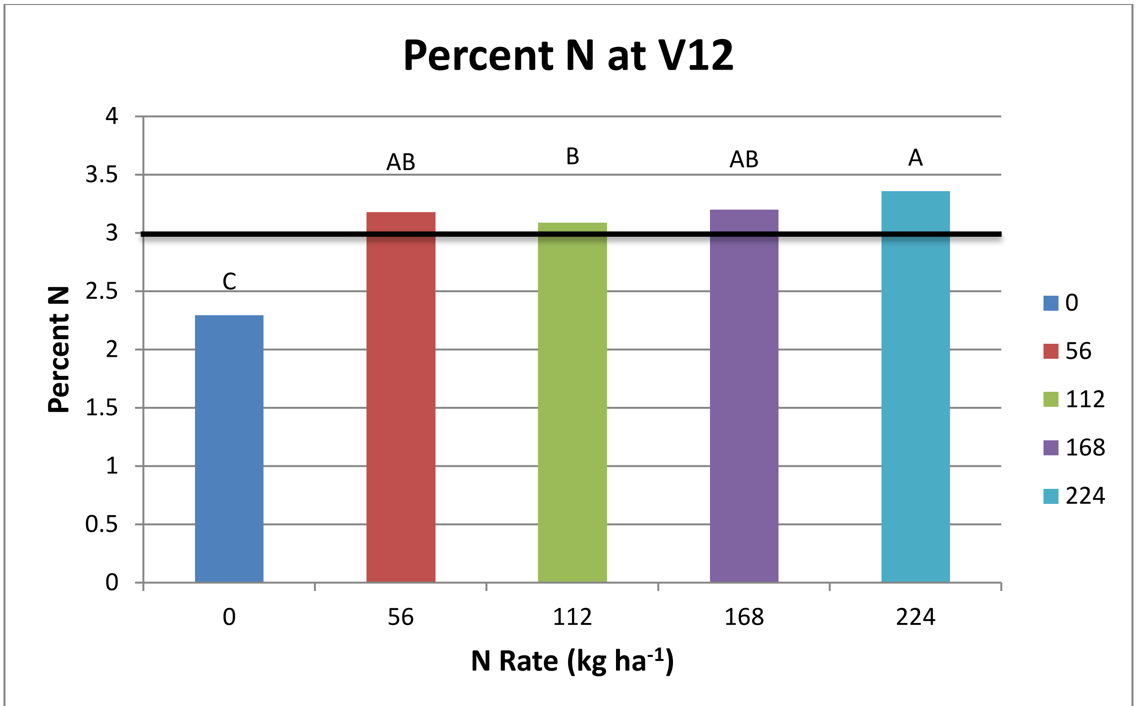

Figure 2: Percent N of the tissue analysis at V12 collected on 7/16/2013. Different letters indicate significance at an alpha level of 0.05. The black line at 3% indicates the deficient/sufficient line for corn at this growth stage.

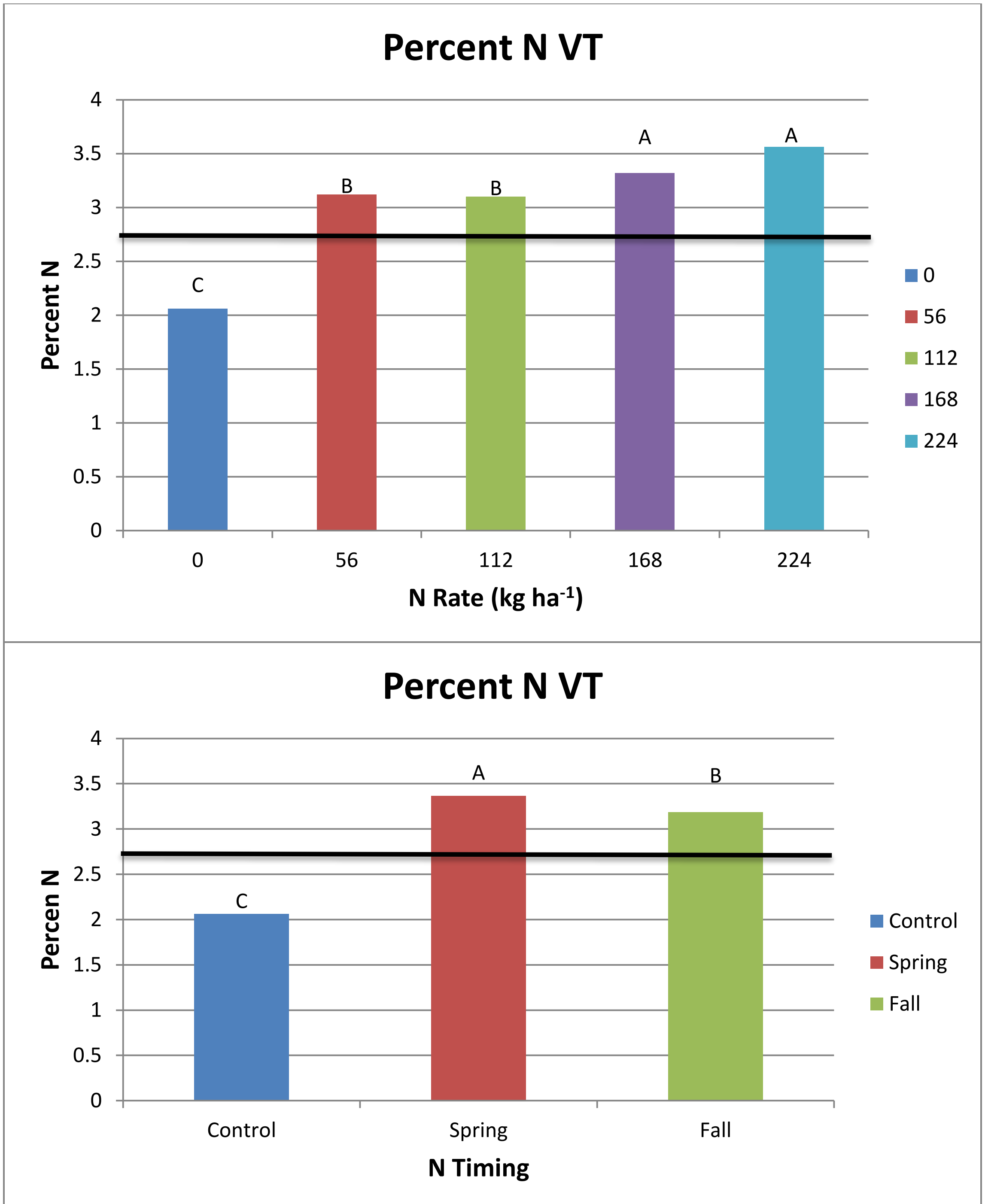

Figure 3: Percent N of the tissue analysis at VT collected on 7/24/2013. Different letters indicate significance at an alpha level of 0.05. The black line at 2.7% indicates the deficient/sufficient line for corn at this growth stage.

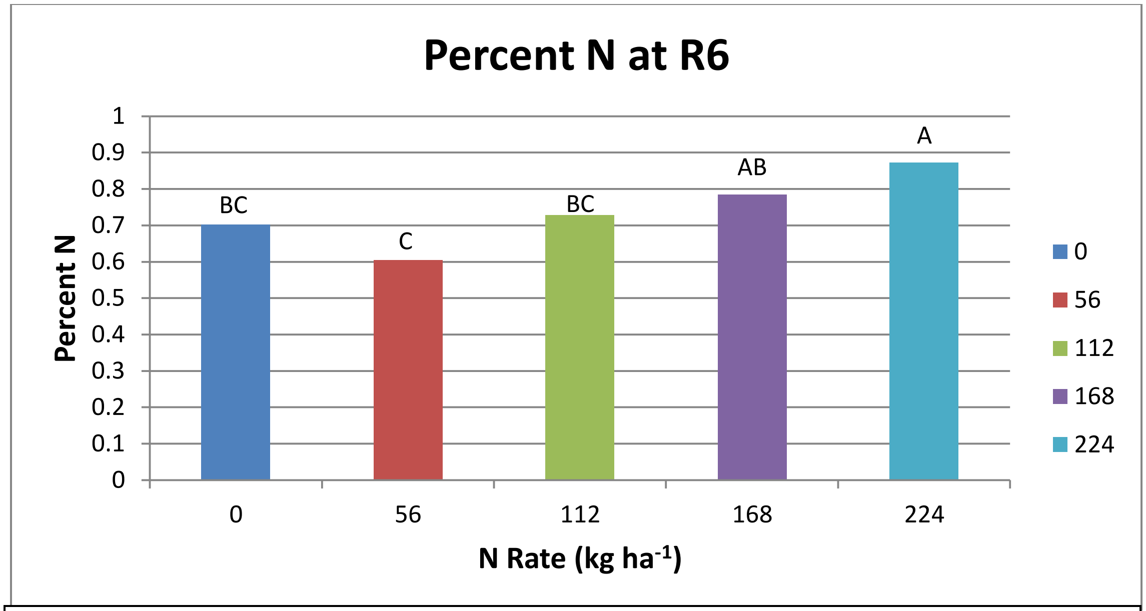

Figure 4: Percent N of the tissue analysis at R6 collected on 7/24/2013. No significant differences between treatments were observed.

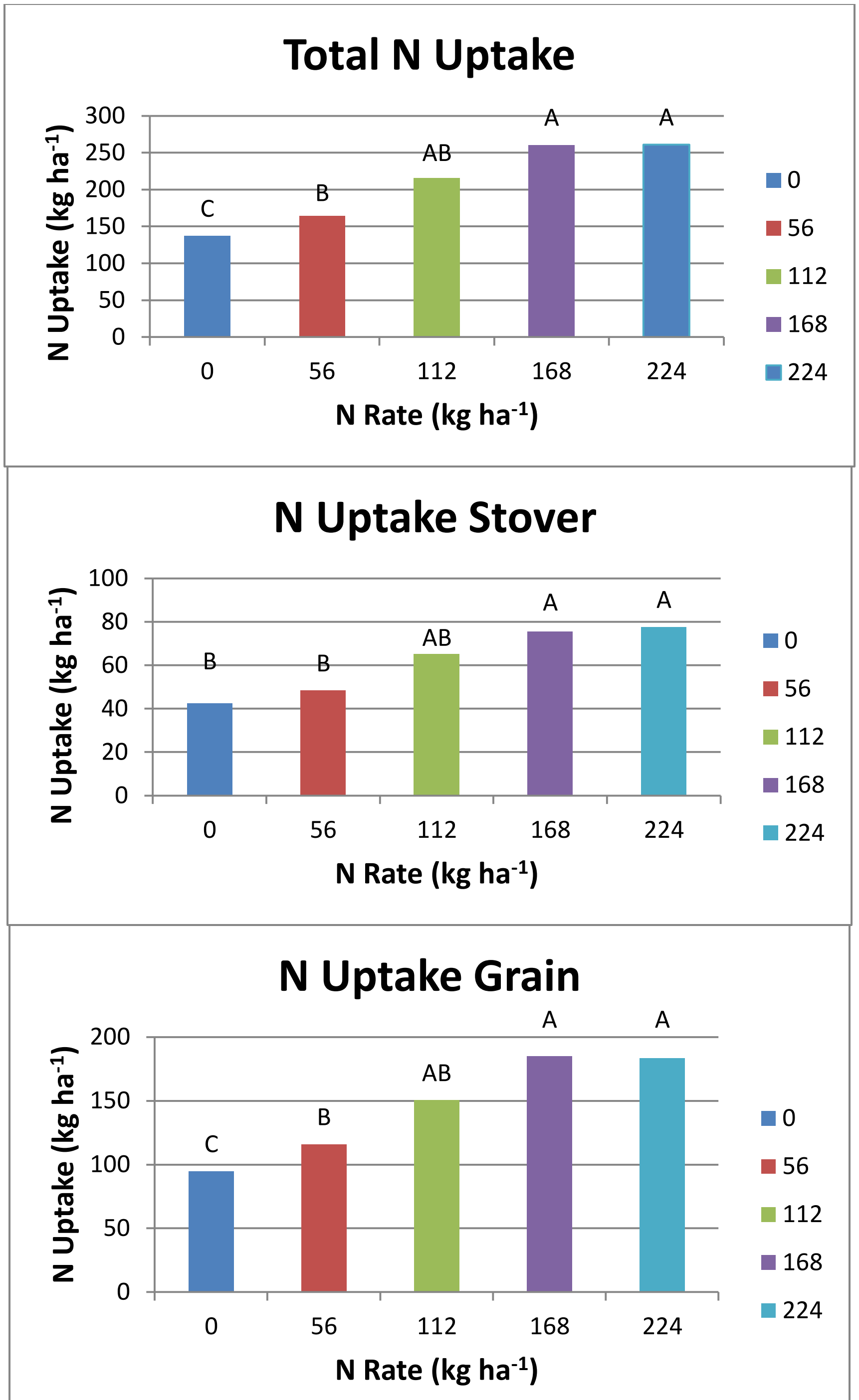

Figure 5: Nitrogen uptake for total, grain, and stover that was collected at R6. Different letters indicate significance at an alpha level of 0.05.

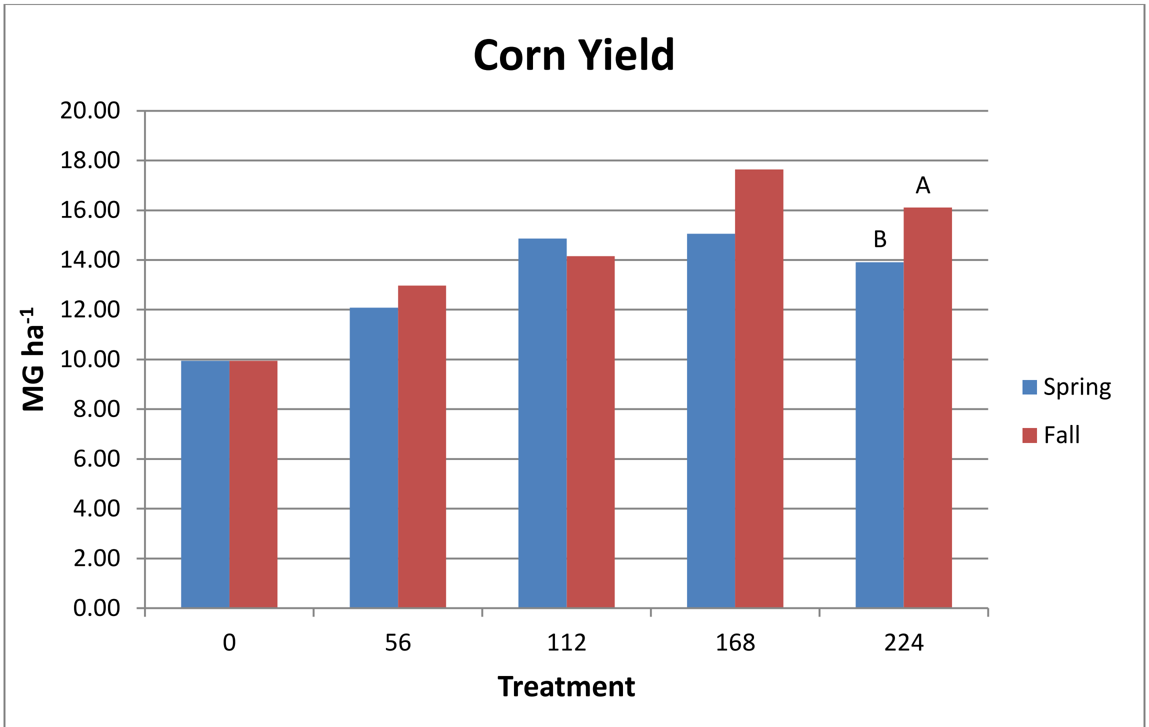

Figure 8: Grain yield (MG ha^{-1}) by rate (kg ha^{-1}) adjusted to 15.5% moisture content. Different letters indicate significance at an alpha level of 0.05.

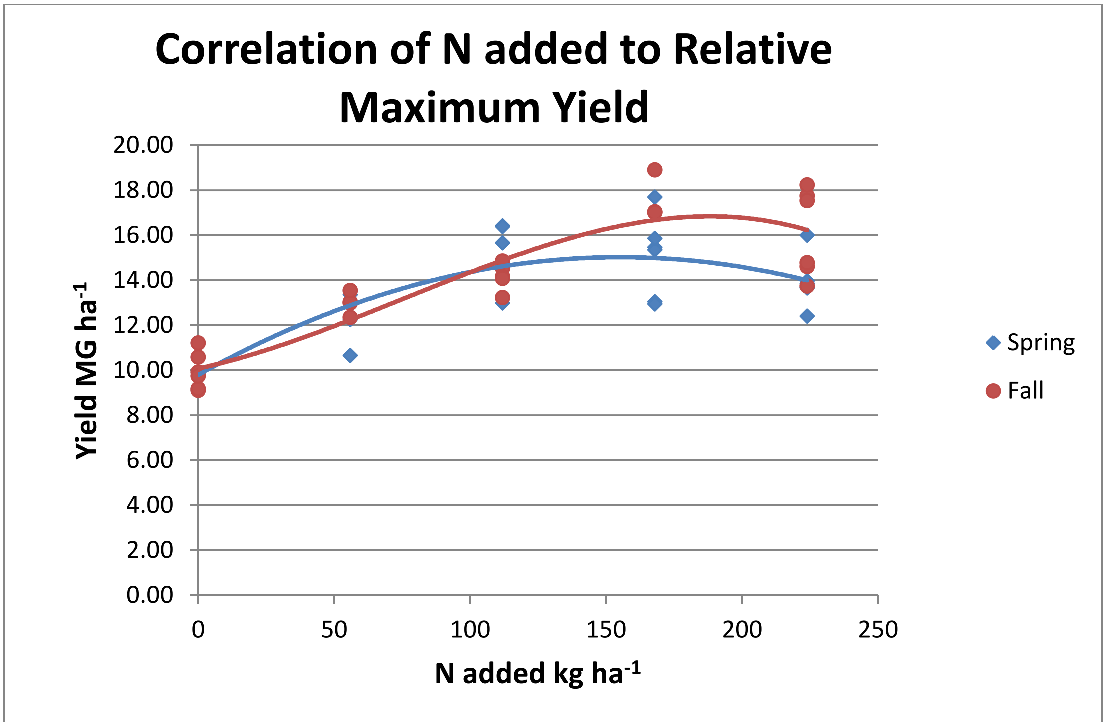

Figure 9: A correlation of grain yield (MG ha^{-1}) to fertilizer N added (kg ha^{-1}) gives a visual description of how yield is impacted by N rates.

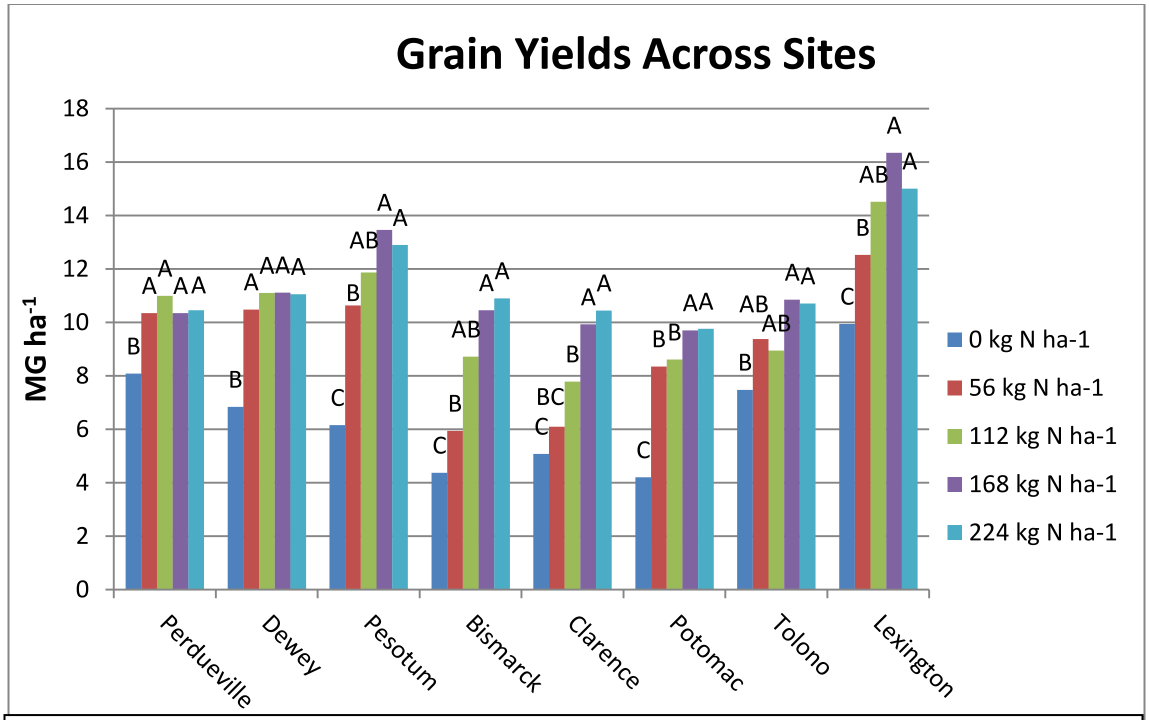

Figure 2: Grain yield (MG ha^{-1}) by location and N application rate within each location. Different letters at each location rate indicates a significant difference at an alpha level of 0.05.

Table 2.) This table indicates the dominant soil type at each location for the East Central Illinois study. For each soil type the percent slope, CEC, SOM, and available water capacity (cm) from 0-50 cm.

Location	Dominant Soil Type	Slope	CEC	SOM	Water Capacity 0-50 cm
Perdueville	Drummer silty clay loam	0-2%	25.6	5.5	8.72 cm
Dewey	Drummer silty clay loam	0-2%	25.6	5.5	8.72 cm
Pesotum	Flanagan silt loam	0-2%	20.3	4	9.42 cm
Bismarck	Ashkum silty clay loam	0-2%	30.8	5	7.9 cm
Clarence	Clarence silty clay loam	0-2%	24.5	4	6.8 cm
Potomac	Ashkum silty clay loam	0-2%	30.8	5	7.9 cm
Tolono	Drummer silty clay loam	0-2%	25.6	5.5	8.72 cm
Lexington	Drummer silty clay loam	0-2%	25.6	5.5	8.72 cm