2015

Integrating Soil Nitrate Level in Refining Nitrogen Fertilizer Management in Louisiana Corn Production Systems

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INTEGRATING SOIL NITRATE LEVEL IN REFINING NITROGEN FERTILIZER MANAGEMENT IN LOUISIANA CORN PRODUCTION SYSTEMS

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The School of Plant, Environmental, and Soil Sciences

by
Payton Dupree
B.S., University of Louisiana at Lafayette, 2011
August 2015

Acknowledgements

The support I have received throughout this program has been immeasurable. Many people were involved with this project and I will try to cover all of them.

To my boss, major professor, and mentor Dr. Brenda Tubana, thank you for your constant guidance, spot on advice, and seemingly endless patience with me. You have given me more opportunities than I can count and I am truly grateful. I could not have accomplished this without you, you believed in me even when I didn't believe in myself and I've grown in several ways thanks to the time spent working as your associate.

To Dr. Henry "Rick" Mascagni and Dr. Josh Lofton, thank yall so much for sharing your wisdom with me whenever you could and always checking on us while we were in the field to see if we needed help with anything. Your assistance with conducting the field trials was paramount and thank you for the opportunity to "play" with some of the equipment.

To my soil fertility group, Brandon, Tapasya, Marilyn, Saoli, Daniel, Murilo, Flavia, Wookilee, Sam, Gustavo, Lucas, Suelen, Yumiko, Ronaldo, Jessica, Anil, Rohan, Juan, and Wesley, without yall's constant support and putting up with the heat, cold, and even darkness and rain to take my soil samples year round, I could not have accomplished this feat. I will never forget your generosity and constant smiles despite the hard times. I'm forever in your debt. Other students that aided me in this journey were Scott Pensky, John Young, Negar Tafti, Kelly Arceneaux, Nutifafa Adotey, and April Newman.

To Michael Breithaupt, Sue Chin, and Rodney Henderson, thank you for letting me raid your lab on a seemingly monthly basis and always sharing your thoughts when I came seeking wisdom.

To Dr. Don Labonte, Dr. Steve Harrison, Dr. Kun-Jun Han, Dr. Chang Jeong, Dr. Maud Walsh, Dr. Magdi Selim, Dr. Jim Wang, Connie Dubois, Jere Townshed, Sheila Rohwer, and Becky Jolibois, thank you for your words of encouragement and positive attitudes.

To my family, Maureen, Tim, Ryan, Bea, Fry, Lois, Jim, and Sugar, you guys were so awesome during this time. Thank you so much for your steadfast support when I would call or visit while losing my mind.

Thank you to the Louisiana Soybean and Small Grain Research and Promotion Board for their funding and support.

Above all, I thank God for bringing me in contact with this group of people I've spent the last 2-3 years with and challenging me in multiple ways as I've worked through this program. I have felt his presence throughout this difficult challenge and it is only through him that I am able to accomplish anything.

Finally, I would like to thank the band 311 for their positive music and soothing vibes that would pick me up when I was struggling. "Stay positive and love your life!"

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Abstract

In some corn (*Zea mays* L.) producing regions of the US, soil testing is still recognized as an effective decision tool for nitrogen (N) fertilizer recommendation. This study was conducted to investigate the early-season N requirement of corn based on early-season soil nitrate level and document the seasonal changes of inorganic N distribution throughout the soil profile. A Gigger silt loam soil and a Sharkey clay soil were selected to establish the trial located in northeastern Louisiana. Treatments of varying N rates were arranged in a randomized complete block design with four replications. Nitrogen fertilizer rates of 0, 67, 134, 201, 268, 335, and 403 kg N ha^{-1} were applied at early-season VE-V3 leaf stage. Four split application treatments of the Louisiana N recommendation (268 kg N ha^{-1}) were applied at early-season and midseason V7-V9 leaf stages (0-268, 67-201, 134-134, 201-67 kg N ha^{-1}). Grain yield and yield components were determined. Soil inorganic N content was determined by 1 M KCl extraction procedure followed by continuous flow injection analysis. Gigger silt loam reached a maximum yield of 13.2 Mg ha^{-1} when the N rate was 134-134 kg N ha^{-1} and soil inorganic N content was 80 kg N ha^{-1}. Sharkey clay achieved a maximum yield of 13.1 Mg ha^{-1} when 268 kg N ha^{-1} was applied in early-season and soil inorganic N content was less than 60 kg N ha^{-1}. Split N applications optimized yield for the Gigger silt loam, but experience a yield reduction for the Sharkey clay. The optimum N rate for the Gigger silt loam was 134-134 kg N ha^{-1} treatment and 201 kg N ha^{-1} for the Sharkey clay soil applied only at early-season (P<0.05). Nitrogen rate had a significant effect on grain yield and 100-grain weight (*P*<0.01) as well as N uptake and total N grain content (*P*<0.05). Seasonal changes in inorganic N content occurred mostly in the 0-15 cm soil layer with decreasing variability with depth. These results show the potential for using inorganic N content to determine N application method in northeastern Louisiana corn production systems.

Chapter 1. Introduction

Corn (*Zea mays* L.) is the most widely produced feed grain in the United States. Roughly 32.3 million hectares of land in the US are planted to corn with most being in the heartland region (USDA - ERS, 2013). Furthermore, the US is the largest producer of corn accounting for 32% of the world's corn production and each American consumes approximately 11 kg of corn annually (NCGA, 2013). Archeological evidence suggests that the plant is as old as 80,000 years from pollen grain found 200 foot under Mexico City (Gibson and Benson, 2002). With the increase in technology over the last century along with research to improve farming practices, nationwide production has increased from 1.2 Mg ha^{-1} in 1912 to as much as 7.7 Mg ha^{-1} in 2012 (NCGA, 2013). Corn can be found in several different products such as food, drinks (in the form of corn syrup used as a sweetener), and even plastics. It is also mixed with livestock feed, which is what most of the US corn production is used for. It takes approximately 3 kg of corn feed to produce 0.45 kg of beef (NCGA, 2013). It is also used in bio-fuel production as well as bio-based plastics (Foley, 2013). With corn being such a versatile crop, a substantial amount of research has gone into improving its yield production, disease resistance, and nutrient quality (Saxena and Hooker, 1968; Castleberry et al., 1984; Collins et al., 1998; Tollenaar and Lee, 2002; Wisser et al., 2006; Amujoyegbe et al., 2007; Major et al., 2010). The corn plant is indigenous to the western hemisphere, although the exact location where the first corn plants emerged is not known.

In Louisiana, corn is the 3rd most produced grain crop, most of which is produced in the state's northeastern region. Planted hectares fluctuate from year to year, but have stabilized around ~220,000 hectares over the last few years. Although corn production has increased recently, rice (*Oryza sativa*) has passed corn in planted hectares, while soybean (*Glycine max*) still remains as the most planted crop in Louisiana. Price per kg ha^{-1} of corn produced also fluctuates from year to year, but has remained around $6 recently (USDA-NASS, 2014). Louisiana's average corn yield is about 10.8 Mg ha^{-1} which is above the national average of 7.7 Mg ha^{-1} (NCGA, 2013). Louisiana owes its high production potential partly to the hydrology and soils unique to the area. The Mississippi river is responsible for depositing fertile alluvial soils throughout Louisiana over the last few thousand years. Due to frequent flooding of the area, multiple dams, weirs, levees, etc. were constructed and subsequently, new sediment deposits have been cutoff leading to subsidence, particularly along the coast line. Common soils in the Mississippi river alluvial plain are Vertisols, Alfisols, Inceptisols, and Entisols. "They are thermic soils and typically have an aquic moisture regime that are loamy or clayey, and possess smectitic clay mineralogy" (Weindorf, 2008). The area is known to receive a high amount of rainfall and averages roughly 1500 to 1700 mm of rain annually (USDA-NASS, 2014) which can compromise the nutrient value of soils (Weindorf, 2008).

Nitrogen (N) is the most yield limiting nutrient in non-leguminous irrigated crop production systems. As a result it is the most heavily researched plant nutrient in an effort to understand its dynamics in soil and plant systems (Krantz et al., 1943; Stanley and Smith, 1956; Olsen et al., 1970; Devitt et al., 1976; Sinclair, 1986; Smil, 1999; Ercoli et al., 1999; Zhu and Chen, 2002). Nitrogen fertilizer application increased dramatically after World War II. As explained by the Wessels Living History Farm (2015), N is the main component in high explosives such as trinitrotoluene (TNT) and due to the need for explosives during wartime, multiple chemical plants were built to keep up with the demand. These chemical plants were then used to produce ammonia for agricultural fertilization purposes. Since researchers, as well as producers, already had knowledge of nutrient management as a way to help boost yields, fertilizer use increased significantly during this time period. During the 1940s most of the ammonia produced was applied as “ammonium nitrate pellets.” (Wessels Living History Farm, 2015). However, this form of fertilizer is highly explosive making it difficult to transport. After several accidents transporting the material, scientists began working on a way to use anhydrous ammonia as a fertilizer. Anhydrous ammonia is not explosive, but needs to be kept under pressure and refrigerated. In 1943, researchers at the Mississippi Experimental Research Station developed a system that uses knife like applicators to deposit the anhydrous ammonia about 15-20 cm below the soil surface. This application was immediately followed by a soil mixing tool that covered the hole left behind from application of the fertilizer thereby trapping it in the ground. This method began to replace the application of the pellet form of N fertilizers and is still used today in the Midwest.

As an insurance, most producers apply N in excess amounts to maximize yields. Unfortunately, this can have negative impacts on the environment through groundwater and surface water contamination via leaching and runoff (Power and Schepers, 1989; Ju et al., 2003). Excess N can also decrease disease resistance. Long et al. (2000) reported an increase in disease incidence of rice blast (*Magnaporthe grisea*) when N was applied in excess. Several different methods have been developed over the years to improve N fertilization conservation methods. One of which being the split application of N fertilizers in which a portion of the field recommendation is applied early-season VE-V3 leaf stage and the remainder applied midseason or at V7-V9 leaf stage. Abbasi et al. (2012) reported a 14% increase in N use efficiency (NUE) when N fertilizer is split applied for maize production. Similarly, Lopez-Bellido et al. (2005) reported increases in NUE in wheat (*Triticum aestivum*) when N fertilizer was split applied and experienced significantly increased yields when half or one-third of the N recommendation was applied at stem elongation.

The use of optical sensors to determine N deficiency level in plants and derive an N fertilizer recommendation is a relatively new N decision tool undergoing research in the past decade. Raun et al. (2001) developed a system that measures and records the crop reflectance of two parts of the N managed field using an optical sensor: A strip of the field that has been sufficiently fertilized and the rest of the field that has been applied with a portion of the N recommendation for the area. The difference in these two values is called a response index and can be used to calculate yield response to determine if further N should be applied.

While the previously mentioned N decision tool is proficient in many ways, soil testing has consistently been the best way to determine the nutrient content of soil. However, this can be labor intensive when used in large fields as well as financially detrimental to the producer, thus promoting the use of other methods. Multiple soil testing methods were developed for the purpose of determining soil N content and its impact in predicting proper fertilizer application. The first successful method, the Pre-Sidedress Nitrate Test, was pioneered by Magdoff et al. (1984). Samples are taken when the crop is approximately 15-30 cm tall. Once the soil inorganic N content is known, a proper N recommendation can be made and applied. This method only recommends N fertilizer based on soil N concentration and the yield goal of the crop (Magdoff, 1991). Another soil testing method, developed by Schmit and Randall (1994), takes 24 cm soil samples before planting and determines concentration of NO_3-N. With the concentrations of NO_3-N and calculating a soil N credit by “subtracting the optimum N rate, which was measured experimentally, from the tabular N recommendation presently used in Minnesota,” they were able to accurately determine N recommendations for corn. The advantages of this method are that it is able to estimate residual N from all other possible N sources that the current N recommendation is adjusted for and it does not necessarily call for further N applications.

Although extensive research has been conducted on N dynamics in different parts of the US, very limited research has been done in Louisiana relating soil inorganic N to corn production systems. This study was conducted to evaluate the relationship between soil inorganic N content and corn yield as well as to document the changes in inorganic N distribution patters throughout the root zone and lower rooting depth within two cropping seasons on soils in Northeastern Louisiana that are commonly grown to corn.

Chapter 2. Investigating Early-Season Nitrogen Requirement of Corn Based on Soil Texture and Early-Season Soil Nitrate Level.

2.1 Introduction

Corn (*Zea mays* L.) is the most widely produced feed grain in the United States. Roughly 32.3 million hectares of land in the US are planted to corn with most being in the Heartland region. Approximately 20% of the crop is exported to other countries (USDA - ERS, 2013). Corn ranks third in planted hectares in the state of Louisiana behind rice (*Oryza sativa*) (second) and soybeans (*Glycine max*) (first). Planted hectares typically fluctuate from year to year, but hover around ~220,000 ha each year with most of the crop being grown in the northeastern region (USDA – NASS, 2014). In Louisianan, corn is often times rotated with cotton which improves cotton (*Gossypium hirsutum*) lint yields (Boquet and Coco, 1994). They found that lint yields of cotton were higher when rotated with corn compared to continuous cotton.

Nitrogen (N) is the most limiting plant nutrient in non-leguminous irrigated crop production systems and because of this, extensive research has been done on understanding its effects on crop production (Broadbent et al., 1958; Fox and Hoffman., 1981; Varvel and Peterson., 1990; Benbi et al., 1991; Arregui and Quemada., 2008; Schmitt and Randal., 2013). Frequently, N is applied in excess of crop requirement as a means to minimize crop N deficiencies. While this will insure the crop will receive adequate N, it can lead to excessive vegetative growth that may cause the crop to lodge negatively affecting yields (Basak et al., 1962). Excess N can also cause nitrate pollution in surface waters via runoff and ground water via infiltration (Bijay-Singh et al., 1995). Understanding N dynamics within the soil profile is critical for proper N management. Soil texture plays an important role in N behavior. Tremblay et al. (2012) reported that soil textures (fine or medium texture) can have a large effect on N response. Crops growing on fine texture soils such as clays, silty clays, silty clay loams, and clay loams are more likely to have pronounced N responses than those planted on medium texture groups such as loams, silt loams, sandy clay loams, and loamy fine sands. A study by Ping et al. (2008) reported that corn grown on sandy soils would require less N fertilizer than corn grown on clayey soils. Nitrogen mineralization is less pronounced in clayey soils than soils with less clay content (Zhu et al., 2009; Ros et al., 2011). Physical changes to the soil profile such as compaction or water logging may lead to the development of anaerobic conditions, which can in turn lead to a decrease in microbial activity, stimulating ammonium (NH_4-N) formation and accumulation, and causing nitrate (NO_3-N) losses by denitrification (Jansson and Person, 1982). It is because of these dynamic transformation processes that make N one of the most challenging nutrients to understand and adjust for in agriculture. As a result, development of N fertilizer rate decision tools are being researched to help deliver the proper amount of N to the crop without causing detrimental effects to the environment. One N decision tool is the use of soil testing to determine the amount of inorganic N present in the soil in the early-season and using this to adjust N fertilizer rates to maximize crop yield without applying excess N. One such soil testing method is the Magdoff Pre-Sidedress Nitrate Test (PSNT; Magdoff, 1991) for corn in which soil samples are taken to a depth of 30 cm when the crop is 15-30 cm tall and then tested for available soil NO_3-N. This method uses the height of the crop as a gauge for determining soil sampling time. According to Magdoff (1991), a better estimate of plant available N and fertilizer recommendation can be drawn when soil sampling is done right before or as close as possible to when the N fertilization will be made.

Although the effects of N fertilization on crop yield has been researched extensively, very little research has been conducted to relate soil inorganic N to yield in Louisiana corn production systems. To better understand these concepts, a study was conducted to determine the optimum N fertilizer rate for corn production in northeastern Louisiana based on soil texture and early-season soil NO_3-N testing.

2.2 Materials and Methods

2.2.1 Site Description, Treatment Structure, and Trial Establishment

In 2013 and 2014, a corn research trial was established on two soils of differing textures in northeastern LA: a Sharkey clay soil in St. Joseph, LA at the Northeast Research Station (31°, 56', 28.94" N, 91°, 14', 11.43" W) and a Gigger silt loam soil in Winnsboro, LA at the Macon Ridge Research Station (32°, 08', 22.05" N; 91° 41', 13.93" W). Saint Joseph is located in Tensas Parish while Winnsboro is in Franklin Parish hereafter termed as NERS and MRRS, respectively (Fig 2.1). Sharkey clay is classified as; very fine, smectitic, thermic Chromic Epiaquerts (USDA - NCSS, 2013). This soil is very deep, poorly to very poorly drained, very slowly permeable that formed in an clayey alluvium. Gigger silt loam soil is classified as; fine-silty, mixed, active, thermic, Typic Frafiudalfs (USDA - NCSS, 2003) and is described as, very deep, moderately well drained, slowly permeable soils with fragipans that formed in a thin mantle of loess over loamy sediments. All four site-years were established and managed under an irrigated system. Irrigation at NERS was supplied using furrow irrigation via poly pipe and overhead sprinkler irrigation was used at MRRS. Important field activity dates can be found in Table 2.2. Initial chemical properties of soil from both locations are reported in Table 2.1.

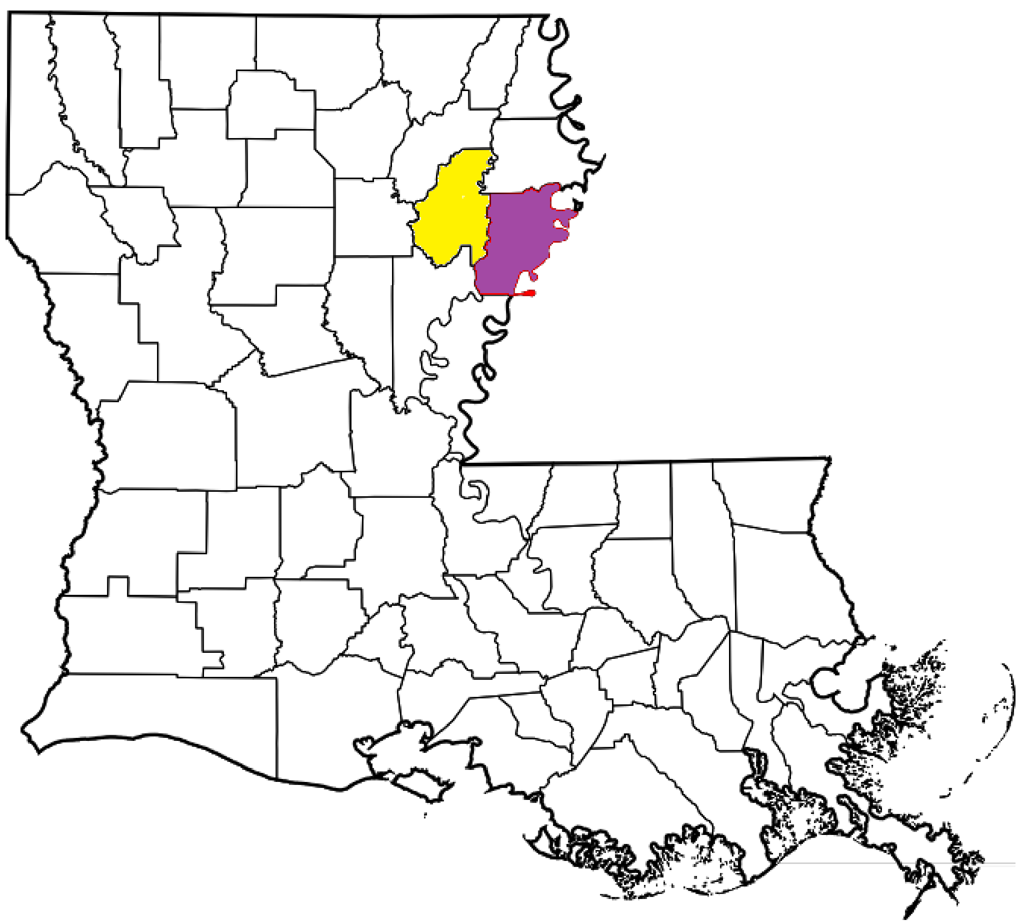

Figure 2.1 Map of Louisiana showing Tensas Parish (purple) and Franklin Parish (gold) where the two field trials were established (Family search, 2015).

Table 2.1 Chemical properties of soil at different depths for both locations.

‡Site	Depth, cm	*pH	Organic matter	Total N	Total C	P	K	S	Ca	Mg	Cu	Zn
			%	†mg kg^{-1}								
MRRS	0-15	6.7	2.24	6164	41164	26	74	12	994	109	1.1	2.7
	15-30	6.7	2.04	1885	10920	12	54	9	1,123	125	0.5	0.5
	30-45	5.4	-	1689	8524	9	80	18	1,084	167	1.1	0.2
	45-60	5.0	-	1518	7623	10	92	17	968	205	1.0	0.5
	>60	4.6	-	1514	7230	13	95	18	1,042	298	1.6	0.6
NERS	0-15	6.1	5.91	1354	12661	55	454	5	4,240	890	4.5	4.4
	15-30	6.6	5.95	1042	2517	32	361	2	4,780	1,005	6.2	2.9
	30-45	7.2	-	1030	2051	14	349	3	5,339	1,118	6.1	1.9
	45-60	7.6	-	1106	2410	11	349	4	5,446	1,151	5.8	1.9
	>60	7.8	-	1072	1764	13	353	6	5,261	1,132	5.2	2.1

*10g soil:10 mL DI $H_2 0$ for pH analysis procedure, equilibrate for 2 hours, then measured. †Total N and C were based on dry combustion while all other nutrients were based on Mehlich-3 procedure. ‡Site: MRRS – Macon Ridge Research Station, NERS – Northeast Research Station.

Table 2.2 Field activity dates and plot size for MRRS and NERS for years 2013 and 2014.

†Site-year Designation	¶Plot Size, m	Planting	*Early-Season N application	*Midseason N application	Harvest
MRRS 2013	13.76 x 4	10-Mar-13	27-Mar-13 (V3)	23-May-13 (V7-V8)	16-Aug-13
MRRS 2014	13.76 x 4	19-Mar-14	6-Apr-14 (V3)	8-May-14 (V8-V9)	19-Aug-14
NERS 2013	12.19 x 4	28-Mar-13	30-Apr-13 (V5)	20-May-13 (V8-V9)	27-Aug-13
NERS 2014	13.76 x 4	21-Apr-14	8-May-14 (V3)	27-May-14 (V8-V9)	16-Sept-14

*V# = leaf collar stage of corn crop. ¶Length x width. †Site : MRRS – Macon Ridge Research Station, NERS – Northeast Research Station.

Corn hybrids used were Pioneer 2088HYR and Pioneer 1319HR on Sharkey clay and Gigger silt loam, respectively. Seeding rates were 80,000 seeds per hectare with row spacing of 1 m. Irrigation was used when necessary via a poly pipe irrigation system for Sharkey clay soil and an overhead sprinkler system for Gigger silt loam soil. Eleven treatments consisted of N applications at varying N rates and different application times (Table 2.3). One check plot (0 applied N) was included in each replication. Nitrogen rates of 0, 67, 134, 201, 268, 335, and 403 kg ha^{-1} were applied at VE-V3 leaf stage, hereafter referred to as early-season, while the Louisiana N fertilizer recommendation of 268 kg N ha^{-1} was split into four applications (0-268, 67-201, 134-134, 201-67 kg ha^{-1}) and applied at early-season and the V8 leaf stage, hereafter referred to as midseason. Nitrogen source for Sharkey clay was UAN-S (32-0-0-2) injected with a fertilizer rig and granular urea (46-0-0) was broadcast by hand for Gigger silt loam. Phosphorus (P) and Potassium (K) rates were applied in accordance with test results performed by the LSU AgCenter Soil Testing and Plant Analysis Laboratory to maintain sufficient nutrient levels. Weed and pest management practices recommended by the LSU AgCenter were followed.

2.2.2 Soil Sampling

Soil samples were collected at the early-season and harvest stage with a standard soil probe (JMC; Model No. 641-792-8285) from the two middle rows of four-row plots. A total of eight soil cores from each plot were sampled to a depth

Table 2.3 Treatment description of the field trials conducted in St. Joseph, LA and Winnsboro, LA in 2013 and 2014.

Early-Season N rate, kg ha^{-1}	Midseason N rate, kg ha^{-1}
0	0
67	0
134	0
201	0
268	0
335	0
403	0
0	268
67	201
134	134
201	67

of 30 cm and then divided into 15 cm sections. Soil samples were then oven-dried (Despatch LBB series; model number LBB2-18-1) at 55°C for a minimum of 3 days, then processed using a Humboldt electric flail soil grinder, and then sieved through a built in 2 mm sieve.

2.2.3. Soil Analysis

Inorganic N content was determined by weighing 5 g of soil into 125 mL plastic bottles followed by the addition of 35 mL of 1 M KCl. Samples were shaken for 1 hour on a reciprocal shaker (Eberbach; model number-E6010.00) then filtered using No. 42 Whatman filter paper. Extracts were analyzed for NH_4-N and NO_3-N/nitrite (NO_2-N) content using a continuous flow injection analyzer (Lachat QuickChem 8500 series 2), simultaneously. The method for determining NO_3-N content is similar to that outlined by Keeney and Nelson (1982). Nitrate is reduced to NO_2-N by passing through a cadmium reduction column and then reacts with a color reagent (sulfanilamide) to produce a pinkish color that can be measured colorimetrically at 520 nm. Ammonium analysis method was similar to that outlined by Reardon (1966). Ammonium present in the sample reacts with salicylate-nitroprusside-hypochlorite mixture to produce an blue color that can be measured colorimetrically at 660 nm. Total inorganic N in kg ha^{-1} within the 0-30 cm soil layer was determined by summing the inorganic N content from the 0-15 cm and 15-30 cm soil samples for each plot. Conversions of mg L^{-1} to mg kg^{-1} to kg ha^{-1} are shown below.

$$\text{mg L x } \frac{0.035 \text{ L 1 M KCl}}{0.005 \text{ kg soil}} = \text{mg kg}^{-1}$$

$$\text{mg kg}^{-1} \text{x 2 = lbs acre}$$

$$\text{lbs ac x } \frac{1 \text{ lbs}}{1 \text{ ac}} \text{ x } \frac{2.47 \text{ ac}}{1 \text{ ha}} \text{ x } \frac{\text{kg}}{2.204 \text{ lb}} = 1.12 \text{ kg ha}^{-1}$$

$$\text{lbs acre x 1.12 = kg ha}^{-1}$$

Organic matter was determined using a modified version of the combustion method. First, 20-mL crucibles were weighed (g) and recorded. Ten grams of soil was then weighed into crucible and placed into a furnace for 8 hours at 550° C. After cooling, samples were weighed again and percent organic matter was estimated using the following equation:

<u>Equation 2.1</u>

$$\text{OM \%} = \frac{\text{Crucible+soil before combustion-Crucible+soil after combustion}}{\text{Crucible+soil before combustion}} \text{ x 100}$$

2.2.4 Grain Yield and Yield Components

At harvest, a plot combine (Massey Ferguson 8XP) was used to collect grains from the two middle rows of each plot. The harvester was equipped with Harvest Master Instrumentation to determine plot weight. Sub samples were taken to determine grain moisture and seed weight. Grain moisture for all four site-years was determined using a grain analysis computer (Dickey-john; model number – GAC2500 UGMA) for further analysis once plot yield was determined. Grain moisture was adjusted to 155 g kg^{-1} and yield was calculated in bushels per acre and then converted to kg ha^{-1} using the following equations:

Equation 2.2

$$\text{Yield 155 g kg}^{-1}\text{ moist adj. (lbs/ac)} = \left[\frac{\text{Plot yield (lbs)}}{\left(\frac{\text{Plot size}\left(\text{ft}^2\right)}{43560}\right)}\right] \times \left[\frac{(100\text{-moisture content})}{(100\text{-}15.5)}\right]$$

Equation 2.3

$$\text{Adjusted yield (bu/ac)} = \frac{\text{155 g kg}^{-1}\text{ moist adj. (lbs/ac)}}{56}$$

Equation 2.4

$$\text{Yield (kg ha}^{-1}\text{)} = \text{Yield (bu/ac)} \times \frac{\text{56 lbs}}{\text{bu}} \times \frac{\text{1 kg}}{\text{2.2 lbs}} \times \frac{\text{2.47 ac}}{\text{ha}}$$

One hundred (100) grains were counted using an Agriculex ESC-1 automated seed counter and weighed (g). Stalk and ear counts were taken in 2014 in both locations from the inner 3-m sections of the second and third rows of each plot. A 3-m polyvinyl chloride (PVC) pole was used to mark the section from which stalk and ear counts were taken. Plant population was determined by multiplying stalk count by the area of 1 ha then dividing by the area that stalk counts were measured. Kernels per ear were also determined. The equations are shown below:

Equation 2.5

$$\text{Plant population per ha} = \frac{\text{stalk ct. x 10000 m}^2}{\text{6.18 m}^2}$$

Equation 2.6

$$\text{Kernels per ear} = \left[\frac{\text{Yield kg ha}^{-1}}{\frac{\text{Ears ha}^{-1}}{\left(\frac{\text{Seed wt. (kg)}}{100}\right)}} \right]$$

2.2.5 Grain Nitrogen Analysis

Grain subsamples taken from each plot were oven dried at 55°C for a minimum of 48 hours, processed using a WonderMill grain processor (Model No. – WM200) and then dried again for 24 hours at 55°C before analysis. Each sample was then weighed to 20 mg and analyzed using a CN dry combustion analyzer (Elementar Americas Inc, Vario EL Cube) to determine total N content. Nitrogen uptake in kg ha^{-1} was computed using the following equation:

Equation 2.7

$$\text{N Uptake (kg ha}^{-1}\text{)} = \text{Plot Yield (kg ha}^{-1}\text{) x } \left(\frac{\text{Total N\%}}{100}\right)$$

2.2.6 Nitrogen Use Efficiency Determination

Nitrogen use efficiency (NUE) was calculated for all four site-years using the difference method outlined by Pomares-Garcia and Pratt (1978). This method calculates NUE by subtracting N uptake in kg ha^{-1} of the plants that were unfertilized from N uptake of plants that were fertilized, then dividing by the rate of N applied in kg ha^{-1}. The equation used to determine NUE can be found below.

Equation 2.8

$$\text{NUE (\%)}= \frac{\text{N uptake of fertilized crop } (\text{kg ha}^{-1})\text{- N uptake of unfertilized crop } (\text{kg ha}^{-1})}{\text{Rate of N fertilizer applied } (\text{kg ha}^{-1})} \text{ x } 100$$

2.2.7 Statistical Analysis of Measured Parameters

For each site-year, measured parameters were analyzed by performing one-way analysis of variance using PROC MIXED procedure in SAS 9.3 (SAS, 2012). Fixed variable was N treatment (rate and applications scheme) and random variable was replication. Mean separation procedure and contrast analysis were conducted for variables with statistically significant effect in ANOVA. Contrast analysis between the early-season only and split applications of the current Louisiana N recommendation of 268 kg N ha^{-1} was performed using orthogonal contrast. The least significant difference (LSD) method at the 5% level of confidence was used to determine significant differences among treatments unless otherwise indicated. Average, standard error, and standard deviation of soil inorganic N content were computed using Microsoft Excel 2010.

2.3 Results and Discussion

2.3.1. Effect of N Rate on Grain Yield

Grain yield results for MRRS 2013 and 2014 and NERS 2013 and 2014 can be found in Fig. 2.2 and Fig. 2.3, respectively. Maximum yield in 2013 was achieved with the application of 134-134 kg N ha^{-1} returning the highest yield (13.2 Mg ha^{-1}) for MRRS (P<0.05) and 268 kg N ha^{-1} in early-season returning the highest yield (13.1 Mg ha^{-1}) for NERS (P<0.05). For MRRS in 2013, the 134-134 kg N ha^{-1} split application had similar yields to single applications of 403 kg N ha^{-1} (13 Mg ha^{-1}) and 335 kg N ha^{-1} (12.6 Mg ha^{-1}), despite the reduced amount of applied N. Similarly, at NERS for 2013 the 268 kg N ha^{-1} treatment had similar yield (13.1 Mg ha^{-1}) to 403 (13 Mg ha^{-1}) and 335 (12.7 Mg ha^{-1}) kg N ha^{-1} treatments. The only split treatment of 268 kg N ha^{-1} that was significantly different was 67-201 kg N $ha^{-1}$for NERS in 2013. Yields for early-season only applications increased linearly and were significant up to 335 kg N ha^{-1} for MRRS 2013 and 268 kg N ha^{-1} for NERS 2013. Effects of increasing yield with increasing N rates were similar to those found by Halvorson et al. (2005), Shapiro et al. (2006), and Schlegel and Havlin (2013). These results suggest that the optimum N rate and application timing for MRRS and NERS in 2013 are 134-134 kg N ha^{-1} split application and 268 kg N ha^{-1} single application, respectively. Treatments of 67-201 kg N ha^{-1} and 268 kg N ha^{-1} were the optimum N rates and applied timings for MRRS and NERS in 2014, respectively.

The decrease in yield in 2014 compared to 2013 may be partially attributed to heavy rainfall in the early part of the growing season. For MRRS

2014, shortly after N application and corn was approximately at V2-V3 leaf stage, a heavy rain event passed through dropping ~65 mm of rain resulting in the trial being flooded for about 24 hours. With this event, there was a high likelihood that the N fertilizer was washed away which resulted in the trial experiencing a yield reduction averaging 26% for early-season only applications and 16% for split N applications compared to the previous year. These findings are consistent with those of Singh et al. (1985) and Mukhtar et al. (1990) wherein a reduction in grain yield was observed when the crop was exposed to flooded conditions for a minimum of 24 hours in the early part of their growing seasons. Although a 16% reduction in yield was a significant loss, it demonstrated the benefits of split applying N fertilizer in that it can reduce the loss to total yield if the early-season application of N were to be compromised by weather factors. The highest yield that an early-season only application of N attained for MRRS 2014 was 8.7 Mg ha^{-1} at 403 kg N ha^{-1}, while the split applications of 67-201 kg N ha^{-1} both had yields of 10 Mg ha^{-1}. In addition to the heavy rainfall, what appeared to be Diplodia ear rot (*Stenocarpella maydis*) was also present within the trial. Rating of corn grain for MRRS 2014 was done to qualitatively assess possible damage the disease had on the crop. Grain rating was also done for NERS 2014, even though no disease was found in the crop. Ratings of corn grains for site-years MRRS 2014 and NERS 2014 are reported in Table 2.6. Wet conditions prevented the timely planting of corn at NERS in 2014. Planting took place in mid-April when traditionally, planting occurs in mid-March. Due to the late planting, the yield potential of the crop was compromised resulting in the reduction in yield for this site-year. Early-season N treatments suffered an average loss of 58% while split N applied treatments suffered a loss of 46% when compared to the previous year. Mascagni and Boquet (1996) pointed out that the optimum planting dates for the area are from mid-March to mid-April and experienced similar results with some years showing a reduction in yield due to mid-April planting.

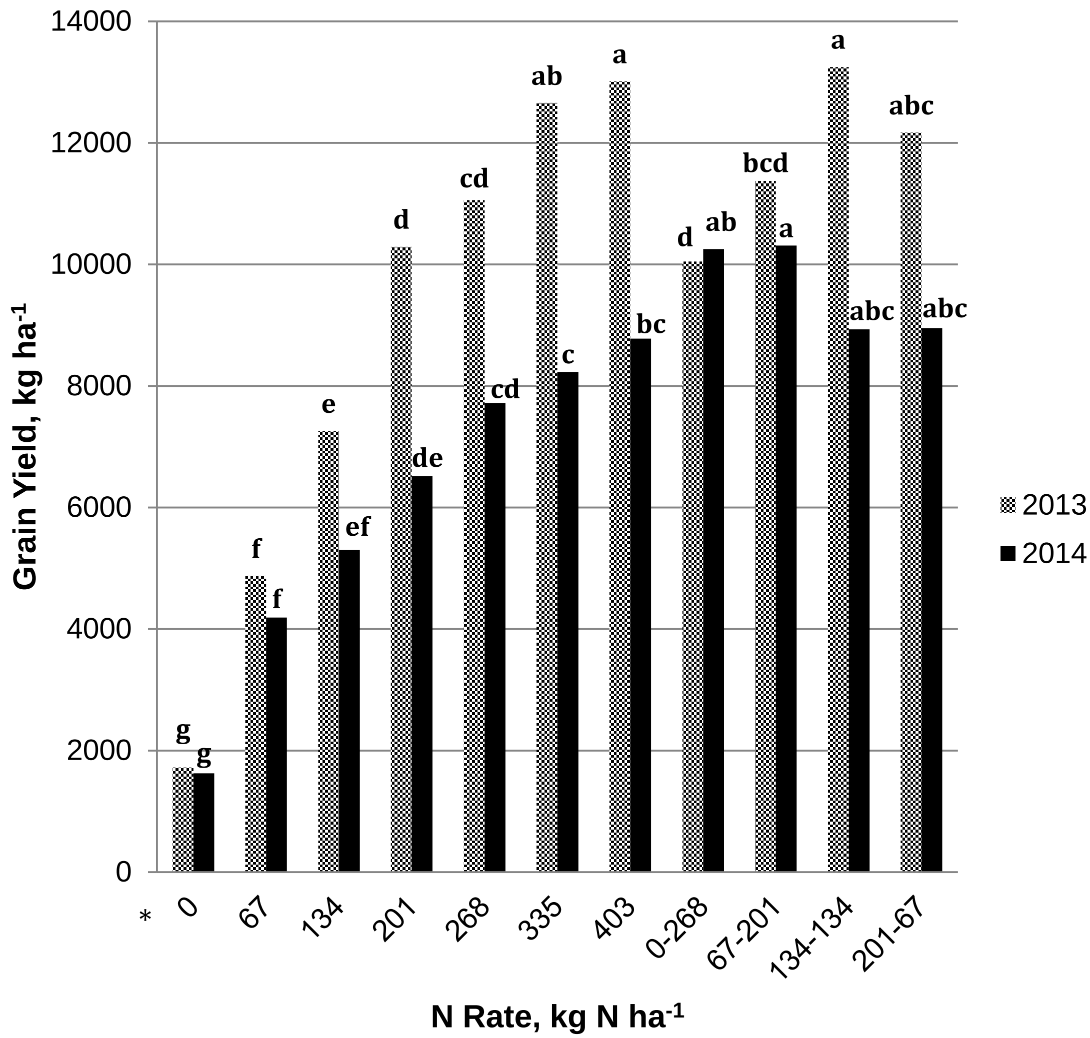

Figure 2.2 Grain yields of corn treated with varying N rate and timing applications at MRRS site in 2013 and 2014. *Differences in letter groups are results of mean separation using LSD in SAS (P<0.05).

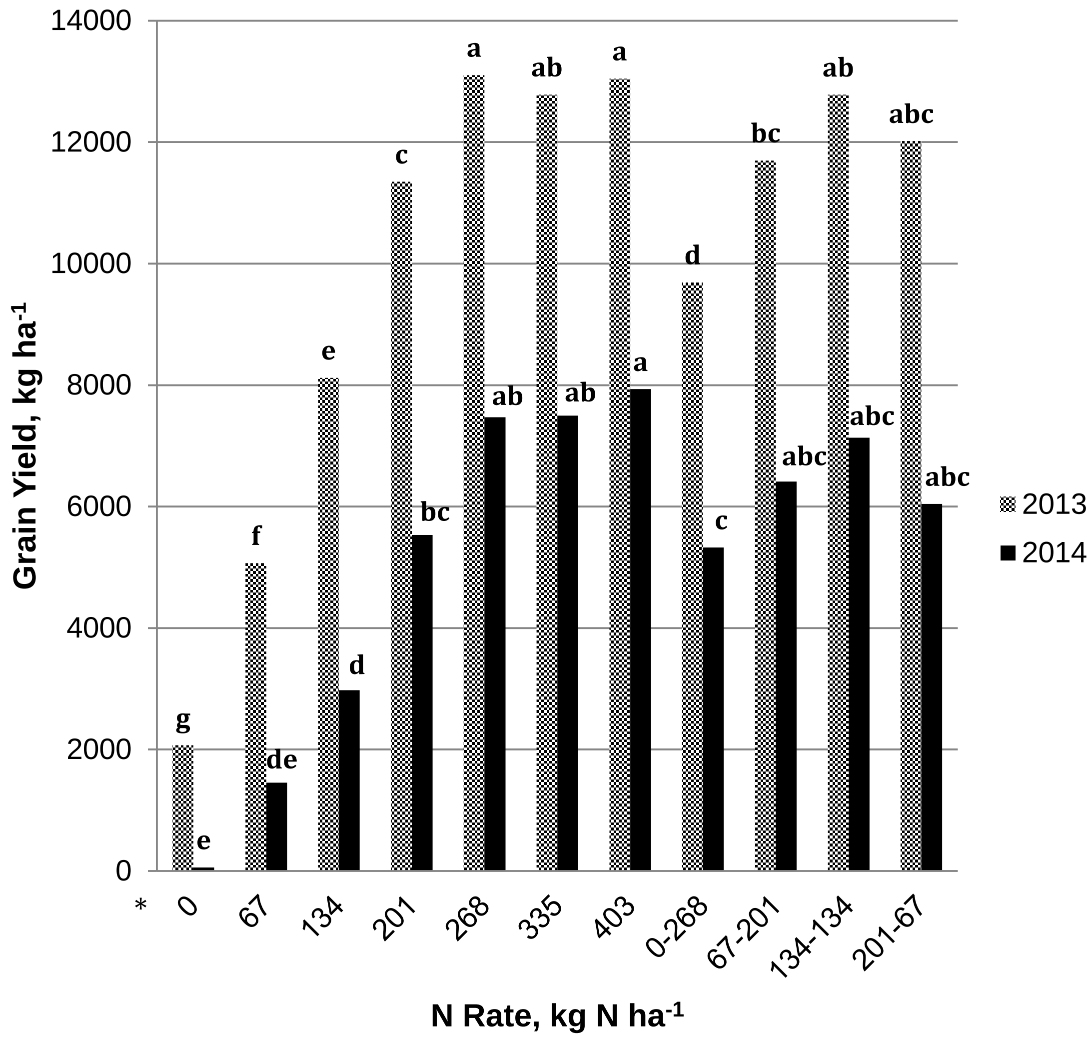

Figure 2.3 Grain yields of corn treated with varying N rate and timing applications at NERS in 2013 and 2014. *Differences in letter groups are results of mean separation using LSD in SAS (P<0.05).

2.3.2 Effect of Different N Application Method on Grain Yield

Mean corn grain yield under split and early-season only application of the Louisiana N fertilizer recommended rate of 268 kg N ha^{-1} is reported in Table 2.4 and Table 2.5. Two out of the four treatments returned high yields with significant differences (P<0.05) in MRRS 2013 with the even split application (134-134 kg N ha^{-1}) returning a 20% increase in yield and the highest yield out of all treatments. However, yield suffered a 9% reduction when the total N recommendation was applied at midseason for MRRS 2013 (P<0.05). For NERS 2013, all four treatments had a reduction in yield with the 0-268 kg N ha^{-1} application being significant at 26% (P<0.05). For MRRS 2014, yield increases as high as 33% were attained by treatments 0-268 and 67-201 kg N ha^{-1} (P<0.05). Yield increases of 16% were also seen in 134-134 and 201-67 kg N ha^{-1}, but were not significant. Similarly, site-year NERS 2014, experienced reductions in yield across all four treatments as high as 28% (P<0.1) alluding to the fact that split applications of N fertilizer are not conducive for this soil. Several studies have been conducted that point to the benefits of split application of N fertilizers. Gehl et al. (2005) reported that a 40% reduction of N rates could be expected when N was split applied. Herron et al. (1971), Gerwing et al. (1979), and Abbasi et al. (2012) all reported yield increases with the use of split N applications. Although split N treatments returned maximum yields in the Gigger silt loam soil and early-season only applications returned maximum yields in the Sharkey clay soil, it is difficult to say soil texture was the cause for the difference in timing of fertilizer application. Soil texture has been reported to have an effect on crop N response (Tremblay et al., 2012). However, no evidence was found to suggest soil texture would influence the timing of fertilizer application.

Table 2.4 Contrast analyses for early-season only vs split application of 268 kg N ha^{-1} for site MRRS 2013 and 2014.

†Site-Year	N Application kg N ha^{-1}	Yield, Mg ha^{-1}	% increase/decrease in yield	*P-value
MRRS 2013	268-0	11.0	-	-
	0-268	10.0	-9	<0.05
	67-201	11.3	+3	NS
	134-134	13.2	+20	<0.05
	201-67	12.1	+10	<0.05
MRRS 2014	268-0	7.7	-	
	0-268	10.2	+32	<0.05
	67-201	10.3	+33.5	<0.05
	134-134	8.9	+16	NS
	201-67	8.9	+16	NS

†Site: MRRS – Macon Ridge Research Station. *NS = Not significant at 0.05 probability level.

Table 2.5 Contrast analyses for early-season only vs split application of 268 kg N ha^{-1} for site NERS 2013 and 2014.

†Site-Year	N Application kg N ha^{-1}	Yield, Mg ha^{-1}	% increase/decrease in yield	*P-value
NERS 2013	268-0	13.1	-	-
	0-268	9.6	-26	<0.05
	67-201	11.6	-11	NS
	134-134	12.7	-2.5	NS
	201-67	12.0	-8	NS
NERS 2014	268-0	7.4	-	-
	0-268	5.3	-28	<0.1
	67-201	6.4	-14	NS
	134-134	7.1	-4.5	NS
	201-67	6.0	-19	NS

†Site: NERS – Northeast Research Station. *NS = Not significant at 0.05 probability level.

Table 2.6 Corn ratings for MRRS 2014 and NERS 2014.

†Site	N Rate, kg ha^{-1}	*,¶Rating
MRRS	0	1.5 d
	67	3.4 bcd
	134	3.0 cd
	201	4.1 bcd
	268	3.9 bcd
	335	5.5 abc
	403	3.6 bcd
	0-268	7.3 a
	67-201	5.8 abc
	134-134	6.0 ab
	201-67	5.9 abc
NERS	0	4 cd
	67	2.1 d
	134	5.1 bc
	201	6.8 b
	268	8.8 a
	335	8.1 a
	403	9.3 a
	0-268	8.1 a
	67-201	8 ab
	134-134	7.5 ab
	201-67	7.5 ab

*Differences in letter groups in columns are results of mean separation using LSD in SAS (*P*<0.05). ¶Rating scale on 1-10 with 1 being poor quality grain and 10 being premium quality grain. †Site: MRRS – Macon Ridge Research Station NERS – Northeast Research Station.

2.3.3 Effect of Soil Inorganic N Content on Yield

Early-season and harvest soil inorganic N content was averaged across the field for both soil depths (0-15, 15-30 cm) and then added together to determine the average total inorganic N content for both locations. Soil inorganic N content for both locations can be found in Tables 2.7. Results show approximately early-season N levels of 60 kg N ha^{-1} for NERS 2013 and 80 kg N

ha^{-1} for MRRS 2013 even before N application. These levels were rather high compared to unpublished data of previous years where the inorganic N content averaged only 10-15 kg N ha^{-1} for NERS and 50-60 kg N ha^{-1} for MRRS. Site-year NERS 2013 at harvest showed a slight increase in soil inorganic N content from 60-67 kg N ha^{-1} which appeared to be the result of increasing NO_3-N in the 0-15 cm soil layer. This may be due to residual NO_3-N remaining from UAN applications not taken up by the previous crop. On the other hand, there was, no apparent change in total inorganic N content seen in the 15-30 cm soil layer from early-season to harvest. Conversely, MRRS 2013 showed a substantial decrease in inorganic N from 80 to 30 kg N ha^{-1}. When looking at the breakdown of inorganic N, a substantial reduction in NH_4-N from 62 to 24 kg N ha^{-1} from early-season to harvest was observed in both the 0-15 and 15-30 cm layer as the probable cause for this drop in total inorganic N. There was a slight reduction in NO_3-N (18 to 13 kg N ha^{-1}), but this was not as substantial as the NH_4-N reduction. Soil inorganic N reductions for 2013 appeared to occur mostly in the 0-15 cm soil layer. Site-year NERS 2014 experienced a decrease in total inorganic soil N from 54 to 41 kg N ha^{-1} of which the decrease was attributed to a reduction in NH_4-N from 40 to 26 kg N ha^{-1} that occurred mostly in the 0-15 cm layer. Site-year MRRS 2014 reported an early-season soil N of 25 kg N ha^{-1} which was substantially less than the early-season soil N of the previous year (80 kg N ha^{-1}). At harvest, MRRS 2014 showed an increase in total inorganic soil N from 25 to 43 kg N ha^{-1} with a marked increase of NO_3-N in the 0-15 cm layer and NH_4-N in both the 0-15 and 15-30 cm layer.

For MRRS 2013 the maximum yield recorded was 13.2 Mg ha^{-1} from plots with early-season soil inorganic N level of approximately 80 kg N ha^{-1} and if treated with 134-134 kg N ha^{-1}. This N application resulted in a numerically higher yield when compared to the 403 kg N ha^{-1} treatment showing a yield increase, with less N applied. The following year early-season soil N dropped to 25 kg N ha^{-1} and the maximum yield recorded was 10 Mg ha^{-1} when the split application of 67-201 kg N ha^{-1} was applied. For NERS 2013, early-season soil N was 60 kg N ha^{-1} and the maximum yield achieved was 13.1 Mg ha^{-1} when 268 kg N ha^{-1} was applied. The following year, the early-season soil N level only reduced to 54 kg N ha^{-1}, but the maximum yield was reduced to 7.9 Mg ha^{-1}. Again, this was most likely the cause of late planting, not the reduction in soil inorganic N.

Soil testing could be used to determine N application rates on a field scale or a regional scale over may site-years (Blackmer et al., 1989). It was difficult to establish an optimal early-season soil inorganic N content level for both of these locations given that the second year of data was affected due to climatic conditions. In 2014, both locations had reductions in yield for different reasons: rain washing away the applied N for MRRS and rainfall delaying planting for NERS. Because of this, only the 2013 data can be used to estimate optimal N rate for each location weakening the estimation. Based on the data from 2013, the application of 134-134 kg N ha^{-1} when soil inorganic N is approximately 75-90 kg N ha^{-1} would potentially optimize yield. Likewise, application of 268 kg N ha^{-1} would be the optimal N rate when soil inorganic N was 55-65 kg N ha^{-1}.

2.3.4 Effect of N rate on Yield Components and N uptake

Yield components for MRRS 2014 and NERS 2014 can be found in Table 2.8. Nitrogen rate effect showed significant differences in yield and 100 grain weight for both site-years (P<0.01). Split N applications achieved higher grain weight than all other treatments for MRRS 2014, although these increases were not significant.

Table 2.7 Average of soil inorganic N distribution at 0-15 and 15-30 cm depth across the entire field for both locations in 2013 and 2014 for early-season and harvest sampling periods.

†Site-Year Sampling Time	Depth, cm	Ammonium, kg ha^{-1}	Nitrate, kg ha^{-1}	Total Inorganic N, kg ha^{-1}
MRRS 2013 Early-Season	0-15	35	11	46
	15-30	26	7	33
	sum	62	18	80
MRRS 2013 Harvest	0-15	13	8	22
	15-30	11	5	8
	sum	24	13	29
MRRS 2014 Early-Season	0-15	13	5	18
	15-30	6	1	7
	sum	19	6	25
MRRS 2014 Harvest	0-15	18	11	29
	15-30	12	2	14
	sum	30	13	43
NERS 2013 Early-Season	0-15	29	4	34
	15-30	15	11	26
	sum	44	16	60
NERS 2013 Harvest	0-15	23	18	41
	15-30	17	9	26
	sum	40	27	67
NERS 2014 Early-Season	0-15	24	6	30
	15-30	16	8	24
	sum	40	14	54
NERS 2014 Harvest	0-15	15	9	24
	15-30	11	6	17
	sum	26	15	41

†Site: MRRS – Macon Ridge Research Station, NERS – Northeast Research Station. *n=120

Conversely, the early-season only applications of 403, 335, and 268 kg N ha^{-1} achieved higher grain weight than the split N treatments for NERS 2014. These increases were also not significant. For MRRS 2014, the split N application of 67-201 and 134-134 kg N ha^{-1} achieved the maximum grain weight compared to all treatments and were significantly different from 0, 67, 134, 201, and 268 kg N ha^{-1} applied plots (P<0.01). However, the treatment of 67-201 kg N ha^{-1} resulted in a 15% increase in yield when compared to 134-134 kg N ha^{-1} that was significant (P<0.01). Nitrogen rate had no significant effect on plant population for both locations. For NERS in 2014, plant population averaged ~79,400 plants ha^{-1} for early-season only treatments and ~77,600 plants ha^{-1} for split N treatments. At MRRS in 2014, plant population averaged ~72,000 plants ha^{-1} for early-season only and ~74,000 plants ha^{-1}split N treatments. There was significant difference among treatments for kernels per ear at both locations. For MRRS 2014, there was no significant difference between the early-season only application of 268 kg N ha^{-1} and all split N applications. Treatments of 67, 134, 201, and 268 kg N ha^{-1} were all statistically similar (P<0.05). At NERS, the early-season only application of 268 kg N ha^{-1} was significantly different from the treatments of 0-268 kg N ha^{-1} (P<0.05).

A number of factors can affect yield components of corn. Extensive research has shown that increasing N rates can increase yield as well as yield components of corn (Samira et al., 1998; Eck, 1984; Kandil, 2013). While N rate can have an effect on grain weight, plant population can also affect this parameter. Arif et al. (2010) reported plant population had a significant effect on corn grain weight between populations of 7.5 (33.2 g) and 9 (30.4 g) plants m^2. Furthermore, N stress can reduce the number of ears m^2 (Pandey et al., 2000) and kernels per ear (Sticker et al., 1995), thus decreasing yields.

Grain N uptake can be found in Table 2.10 and 2.11. Nitrogen grain uptake significantly increased with N rate for all four site-years (P<0.05). Grain N uptake of corn receiving split N applications of 134-134 and 201-67 kg N ha^{-1} were significantly different from those which received 268 kg N ha^{-1} in MRRS 2013 (P<0.05). These treatments achieved numerically higher N uptake than 335 and 403 kg N ha^{-1} applications, but were not significant. There was no treatment effect observed on total N content of corn grain for MRRS in 2014. The effects of early-season only applications of 268, 335, and 403 kg N ha^{-1} on N uptake were all statistically similar in NERS 2013 and achieved numerically higher N uptake than all split N applications. However, the N rate of 403 kg N ha^{-1} was the only treatment that differed significantly (P<0.05). Plots applied with 335, 403, and 0-268 kg N ha^{-1} had the highest grain N content and were only significantly different from plots applied with 0, 67, 134, and 201 kg N ha^{-1} (P<0.05). For MRRS 2014, no significant differences were found for grain N content. Split N treatments that were significantly higher than the early-season only application (with the exception of 403 kg N ha^{-1}) were those fertilized with 0-268 and 67-201 kg N ha^{-1} (P<0.05). For NERS 2014, early-season only N applications achieved the numerically highest N uptake among the treatments, but only 403 kg N ha^{-1} was significantly different from all split N applications (P<0.05).

Table 2.8 Effect of N rate on corn yield components in 2014 for MRRS and NERS.

†Site	N rate, kg ha^{-1}	Yield, Mg ha^{-1}	Kernels per ear	Plant population , ha	100 Grain wt. (g)
MRRS	0	1.6 f	102.2 c	84547 a	21.4 d
	67	4.1 e	306.6 b	72411 ab	22.2 cd
	134	5.3 e	325.8 b	70793 ab	24.1 cd
	201	6.5 d	380.1 ab	76861 ab	24.4 cd
	268	7.7 c	411.2 ab	68366 ab	29.7 bc
	335	8.2 bc	457.2 a	72816 ab	26.9 ab
	403	8.7 bc	451.8 a	72411 ab	29.6 ab
	0-268	10.2 a	477.5 a	76052 ab	29.1 ab
	67-201	10.3 a	485.1 a	71602 ab	32.5 a
	134-134	8.9 b	461.2 a	67152 b	31.3 a
	201-67	8.9 b	445.5 a	73220 ab	29.7 ab
N effect *P*-value		<0.05	<0.05	NS	<0.01
NERS	0	0.6 f	3.4 e	79693 abc	24.4 bcd
	67	1.4 ef	95.1 d	76052 bc	19 e
	134	2.9 e	152.2 cd	80502 ab	22.9 de
	201	5.5 cd	275.6 ab	79693 abc	23.7 cd
	268	7.4 ab	305.5 a	82120 a	27.9 abc
	335	7.4 ab	309.5 a	78884 abc	28.6 ab
	403	7.9 a	327.4 a	79288 abc	28.9 ab
	0-268	5.3 d	222.3 bc	80906 ab	27.9 abc
	67-201	6.4 abcd	284.1 ab	80097 abc	25.9 abcd
	134-134	7.1 abc	319.2 a	75243 bc	27.8 abc
	201-67	6 bcd	309.3 a	74434 c	24.9 abcd
N effect *P*- value		<0.05	<0.05	NS	<0.01

*Differences in letter groups in columns are results of mean separation using LSD in SAS. †Site: MRRS – Macon Ridge Research Station, NERS – Northeast Research Station. ¶NS = Not significant at $\alpha = 0.05$.

Table 2.9 Effect of N rate on N uptake and grain N content for site MRRS 2013 and 2014.

†Site-year	N rate, kg ha^{-1}	*Grain N Content, %	*Grain N Uptake, kg ha^{-1}
MRRS 2013	0	1.12 abc	19 g
	67	1.04 cd	51 f
	134	1.00 d	73 e
	201	1.13 abc	116 cd
	268	1.13 ab	125 cd
	335	1.14 ab	144 ab
	403	1.19 ab	155 a
	0-268	1.11 bc	111 d
	67-201	1.17 ab	133 bc
	134-134	1.20 a	160 a
	201-67	1.21 a	146 ab
N effect *P* - value		<0.05	<0.05
MRRS 2014	0	1.21	20 f
	67	1.24	52 e
	134	1.29	68 de
	201	1.22	80 cd
	268	1.25	96 bc
	335	1.17	96 bc
	403	1.26	111 ab
	0-268	1.30	134 a
	67-201	1.31	134 a
	134-134	1.20	106 b
	201-67	1.24	112 ab
¶N effect *P* - value		NS	<0.05

*Differences in letter groups in columns are results of mean separation using LSD in SAS. †Site: MRRS – Macon Ridge Research Station, NERS – Northeast Research Station. ¶NS = Not significant.

Table 2.10 Effect of N rate on N uptake and grain N content for site NERS 2013 and 2014.

†Site-year	N Rate, kg ha^{-1}	*Grain N Content, %	*Grain N uptake, kg ha^{-1}
NERS 2013	0	1.13 def	23 g
	67	0.98 g	50 f
	134	1.05 fg	85 e
	201	1.11 ef	126 d
	268	1.21 bcde	159 abc
	335	1.29 ab	165 ab
	403	1.35 a	176 a
	0-268	1.28 abc	124 d
	67-201	1.25 abcd	146 bc
	134-134	1.21 bcde	155 bc
	201-67	1.16 cde	139 cd
N effect *P*- value		<0.05	<0.05
NERS 2014	0	1.07 abc	1 e
	67	1.07 abc	16 de
	134	1.01 c	30 d
	201	1.13 ab	63 bc
	268	1.04 bc	78 ab
	335	1.05 bc	78 ab
	403	1.18 a	94 a
	0-268	1.05 bc	56 c
	67-201	1.03 bc	66 bc
	134-134	1.07 abc	76 b
	201-67	1.13 ab	68 bc
N effect *P*- value		<0.05	<0.05

*Differences in letter groups of columns are results of mean separation using LSD in SAS. †Site: MRRS – Macon Ridge Research Station, NERS – Northeast Research Station.

2.3.5 Nitrogen Use Efficiency

Nitrogen use efficiency generally decreased with increasing N rates (Table 2.12). For MRRS in 2013, the highest NUE of 52% was achieved by corn treated with 134-134 kg N ha^{-1}. This was also the maximum NUE across all four site-years of the study. Furthermore, this N application was significantly different from all other 268 kg N ha^{-1} split applications with the exception of 201-67 kg N ha^{-1} treatment ($P<0.05$). Site-year NERS 2013 experienced high NUE percentages as well with 50 and 51% for 268 kg N ha^{-1} and 201 kg N ha^{-1} treatments, respectively. Plots which received 134-134 kg N ha^{-1} in MRRS 2013 and 268 kg N ha^{-1} in NERS 2013 had the highest yields that were greater than 13 Mg ha^{-1}. While 201 kg N ha^{-1} at NERS 2013 achieved an NUE of 51%, the yield was only 11 Mg ha^{-1} which was significantly lower than the plots applied with 268 kg N ha^{-1} ($P<0.05$). Furthermore, the NUE from 201 and 268 kg N ha^{-1} treatments were not significantly different from 3 out of the 4 split N applied plots (67-201, 134-134, 201-67 kg N ha^{-1}). When the NUE of early-season only and split N applications were averaged there was no difference between N application treatments in NUE for MRRS 2014 (44%) and NERS 2014 (25%). For MRRS 2013, NUE averaged 41% for early-season only N applied plots and 44% for split N applied plots. Likewise, NERS 2013 NUE averaged 31% for early-season only N applied plots and 38% for split N applied plots.

Similar studies reported an increase in NUE when N fertilizer is split applied (Varvel et al., 1997; Fernandez et al., 1998; Zhen-xie et al., 2006). Multiple factors can affect the NUE of corn, including soil type, N rate, crop rotation, pest, tillage and weed management practices can all cause a change in the NUE of the crop (Balasubramanian et al., 2004).

Table 2.11 Nitrogen use efficiency for MRRS and NERS in 2013 and 2014.

	NUE, %			
N Rate kg ha^{-1}	*MRRS 2013	*MRRS 2014	*NERS 2013	*NERS 2014
0	-	-	-	-
67	47 abc	48 a	39 b	22 cd
134	40 cde	36 abc	46 ab	22 cd
201	48 ab	30 bc	51 a	31 a
268	40 cde	28 c	50 a	29 ab
335	37 de	23 c	42 ab	23 bcd
403	34 e	23 c	38 b	23 bcd
0-268	34 de	43 ab	38 b	21 d
67-201	42 bcd	43 ab	46 ab	24 abcd
134-134	52 a	32 bc	49 a	28 abc
201-67	47 abc	34 abc	43 ab	25 abcd
Early-Season applied N	41	44	31	25
Split Applied N	44	44	38	25

*Difference in letter groups in columns are results of mean separation using LSD performed by SAS (P<0.05). MRRS = Macon Ridge Research Station in Winnsboro, LA. NERS = Northeast Research Station in St. Joseph, LA.

2.4 Conclusions

The outcomes of this study demonstrated that split application of N fertilizer would optimize yields if the early-season inorganic N content of the soil is approximately 80 – 100 kg N ha^{-1}. The optimum N rate to obtain maximum yields for MRRS 2013 and MRRS 2014 appeared to be 134-134 kg N ha^{-1} and 67-201 kg N ha^{-1}, respectively. Conversely, early-season only N applications performed best on the heavy clay soil with 268 kg N ha^{-1} being the optimum rate for NERS 2013 and 201 kg N ha^{-1} for NERS 2014. This study was unable to effectively produce a soil inorganic N content level recommendation given the climatic challenges that took place during the course of the experiment. However, this study showed the benefits of split application of N fertilizer when heavy rains occurred in the early part of the growing season. The heavy rains in the early part of the growing season may have washed the early-season applied N fertilizer. Given this scenario, significant reductions in yield were expected due to N deficiency, but with extra supply of N coming from midseason application of N fertilizer this reduction in yield was minimized. Nitrogen rate showed to have a significant impact on yield and grain weight. Further research would be required to refine the N recommendation based on soil inorganic N content at the time of planting. The purpose is that this information can then be used to enhance the Louisiana N recommendation for corn production and offer some guidance on improving fertilizer application practices.

2.5 References

Abbasi M.K., Tahir M.M., Sadiq A., Iqbal M., Zafar M. 2012. Yield and nitrogen use efficiency of rainfed maize response to splitting and nitrogen rates in Kashmir, Pakistan. *Agronomy Journal* 104:448-457.

Amujoyegbe B.J., Opabode J.T., Olayinka A. 2007. Effect of organic and inorganic fertilizer on yield and chlorophyll content of maize (*Zea mays* L.) and sorghum *Sorghum bicolour* (L.) Moench). *African Journal of Biotechnology* 6:1869-1873.

Arregui L.M., and Quemada M. 2008. Strategies to improve nitrogen use efficiency in winter cereal crops under rainfed conditions. *Agronomy Journal* 100:277-284.

Basak M.N., Sen S.K., Bhattacharjee P.K. 1962. Effects of high nitrogen fertilization and lodging on rice yield. *Agronomy Journal* 54:477-480.

Benbi D.K., Biswas C.R., Kalkat J.S. 1991. Nitrate distribution and accumulation in an ustochrept soil profile in a long term fertilizer experiment. *Fertilizer Researcher* 28:173-177.

Bijay-Singh, Yadvinder-Singh, G.S. Sekhon. 1995. Fertilizer-N use efficiency and nitrate pollution of groundwater in developing countries. *Journal of Contaminant Hydrology* 20:167-184.

Binder D.L., Sander D.H., Walkters D.T. 2000. Maize response to time of nitrogen application as affected by level of nitrogen deficiency. *Agronomy Journal* 92:1228-1236.

Blackmer A.M., Pottker D., Cerrate M.E., Wedd J. 1989. Correlations between soil nitrate concentrations in late spring and corn yields in Iowa. *Journal of Production Agriculture* 2:103-109.

Bouquet D.J., and A.B. Coco. 1994. Crop sequence effects on the productivity and organic matter content of Mississippi River alluvial soils. P. 77-82. *In* P.J. Bauer and W.J. Busscher (ed.) Proc. S. Conservation Tillage Conference for Sustainable Agriculture., Columbia, SC. 7-9 June 1994.

Broadbent F.E., Hill G.N., Tyler K.B. 1958. Transformations and Movement of urea in Soils. *Soil Science Society of America* 22:303-307.

Castleberry B.M., Crum C.W., Krull C.F. 1984. Genetic yield improvement of U.S. maize cultivars under varying fertility and climatic environments. *Crop Science* 24:33-36.

Collins N.C., Webb C.A., Seah S., Ellis J.G., Hulbert S.H., Pryor A. 1998. The isolation and mapping of disease resistance gene analogs in maize. *Molecular Plant-microbe Interactions* 11:968-978.

Devitt D., Letey J., Lund L.J., Blair J.W. 2002. Nitrate-nitrogen movement through soil as affected by soil profile characteristics. *Journal of Environmental Quality* 5:283-288.

Eck H.V., 1984. Irrigated corn yield response to nitrogen and water. *Agronomy Journal* 76:421-428.

Ercoli L., Mariotti M., Masoni A.,Bonari E. 1999. Effect of irrigation and nitrogen fertilization on biomass yield and efficiency of energy use in crop production of *Miscanthus*. *Field Crops Research Journal* 63:3-11.

Family Search. 2015. Tensas Parish, Louisiana Genealogy. Available on-line at https://familysearch.org/learn/wiki/en/Tensas_Parish,_Louisiana_Genealogy. Verfied April 17, 2015.

Fernandez J., Murilo J., Moreno F., Cabrera F., Fernandez-Boy E. 1998. Reducing fertilization for maize in southwest Spain. *Communication in Soil Science and Plant Analysis* 29:2829–2840

Foley J. 2013. It's time to rethink America's corn system. Ensia. Available on-line at http://ensia.com/voices/its-time-to-rethink-americas-corn-system/?viewAll=1 Verified May 1, 2015.

Fox R.H., and Hoffman L.D. 1981. The effect of N fertilizer source on grain yield, N uptake, soil pH, and lime requirement in no-till corn. *Agronomy Journal* 73:891-895.

Gehl R.J., Schmidt J.P., Maddux L.D., Gordon W.B. 2005. Corn yield response to nitrogen rate and timing in sandy irrigated soils. *Agronomy Journal* 97:1230-1238.

Gerwing J.R., Caldwell A.C., Goodroad L.L. 1979. Fertilizer nitrogen distribution under irrigation between soil, plant, and aquifer. *Journal of Environmental Quality* 8:281-284.

Halvorson A.D., Schweissing F.C., Bartolo M.E., Reule C.A. 2005. Corn response to nitrogen fertilization in a soil with high residual nitrogen. *Agronomy Journal* 97:1222-1229.

Hanway J.J. 1962. Corn growth and composition in relation to soil fertility: II. Uptake of N,P, and K and their distribution in different plant parts during the growing season. *Agronomy Journal* 54:217-222

Herron G.M., Dreier A.F., Flowerday A.D., Colville W.L., Olson R.A. 1971. Residual mineral N accumulation in soil and its utilization by irrigated corn (*Zea mays* L.) *Agronomy Journal* 63, March-April.

Ju X. T., Liu X.J., Zhang F.S. 2003. Accumulation and movement of NO_3-N in soil profile in winter wheat-summer maize rotation system. *Acta Pedologica Sinica* 40:538-546.

Kandil E.E.E. 2013. Response of some maize hybrids (*Zea mays.* L.) to different levels of nitrogenous fertilization. *Journal of Applied Sciences Research* 9:1902-1908.

Keeney D. R., and D.W. Nelson. 1982. Nitrogen-Inorganic forms. *Methods of Soil Analysis* 9:643-698.

Krantz B.A., Ohlrogge A.J., Scarseth G.D. 1943. Movement of nitrogen in soils. *Proceedings-Soil Science Society of America* pp. 189-191.

Long D.H., Lee F.N., TeBeest D.O. 2000. Effect of nitrogen fertilization on disease progress of rice blast on susceptible and resistant cultivars. *Plant Disease* 84:403-409.

Lopez-Bellido L., Lopez-Bellido R.J., Redondo R. 2005. Nitrogen efficiency in wheat under rainfed mediterranean conditions as affected by split nitrogen application. *Field Crops Research Journal* 94:86-97.

Magdoff F.R., Ross D., Amadon J. 1984. A soil test for nitrogen availability to corn. *Soil Society of America Journal* 48:1301-1304.

Magdoff F.R. 1991. Understanding the magdoff pre-sidedress nitrate test for corn. *Journal of Production Agriculture* 4:297-305.

Major J., Rondon M., Molina D., Riha S.J., Lehmann J. 2010. Maize yield and nutrition during 4 years after biochar application to a colombian savanna oxisol. *Plant and Soil* 333:117-128.

Mascagni H.J. and Boquet D.J. 1996. Starter fertilizer and planting date effects on corn rotated with cotton. *Agronomy Journal* 88:975-982.

Mukhtar S., Kanwar R.S., Baker J.L. 1990. Corn grown as affected by excess soil water. Agricultural and Biosystems Engineering Publications (pp. 437-442) Retrieved from http://lib.dr.iastate.edu/abe_eng_pubs/487/. Verified April 13th, 2015.

National Corn Growers Association. 2013. World of Corn. Available on-line at http://www.ncga.com/upload/files/documents/pdf/WOC%202013.pdf Verified April 30, 2015.

Olsen R.J., Hensler R.F., Attoe O.J., Witzel S.A., Peterson L.A. 1970. Fertilizer nitrogen and crop rotation in relation to movement of nitrate nitrogen through soil profiles. *Soil Science Society of America Journal* 34:448-452.

Ping J.L., Ferguson R.B., Dobermann A. 2008. Site-specific nitrogen and plant density management in irrigated maize. *Agronomy Journal* 100:1193-1204.

Pomares-Garcia F. and Pratt P.F. 1978. Recovery of ^{15}N-labeled fertilizer from manured and sludge-amended soil. *Soil Science Society of America Journal* 42:717-720.

Power J.F., and Schepers J.S. 1989. Nitrate contamination of groundwater in North America. *Agriculture, Ecosystems, and Environment Journal* 26:165-187.

Raun W.R., Solie J.B., Johnson G.V., Stone M.L., Lukina E.V., Thomason W.E., Schepers J.S. 2001. In-season prediction of potential grain yield in winter wheat using canopy reflectance. *Agronomy Journal* 93:131-138.

Reardon, J. Salicylate method for the quantitative determination of ammonia nitrogen. Patent no. 3,432,395. Filed June 8, 1966.

Ros G.H., Hanegraaf E., Hoffland E., Riemsdijk W.H. 2011. Predicting soil N mineralization: Relevance of organic matter fractions and soil properties. *Soil Biology Biochemistry* 43:1714-1722.

Samira M., Hussein A., Haikel M.A., El-Masry M.A., 1998. Effect of some preceding crops, hill spacing and nitrogen fertilization on yield attributes and grain yield of maize under reclaimed sandy soil conditions in East Delta. Proc. 8th Conference Agronomy, Suez Canal University. Ismailia, Egypt. 28-29 November. pp. 174-181.

SAS. 2012. The SAS system for Windows. Version 9.3. Cary, NC: SAS Institute.

Saxena K.M., and Hooker A.L. 1968. On the structure of a gene for disease resistance in maize. *Proceedings of the National Academy of Sciences of the United States of America* 61:1300-1305.

Schlegel A.J., and Havlin J.L. 2013. Corn response to long-term nitrogen and phosphorus fertilization. *Journal of Production Agriculture* 8:181-185.

Schmitt M.A., and Randall G.W. 2013. Developing a soil nitrogen test for improved recommendations for corn. *Journal of Production Agriculture* 7:328-334.

Shapiro C.A., and Wortmann C.S. 2006. Corn response to nitrogen rate, row spacing, and plant density in eastern Nebraska. *Agronomy Journal* 98:529-535.

Sinclair T.R. 1986. Water and nitrogen limitations in soybean grain production. I. Model development. *Field Crops Research Journal* 15:125-141.

Singh N.T., Vig A.C., Singh R. 1985. Nitrogen response of maize under temporary flooding. *Fertilizer Research* 60:111-120.

Smil V. 1999. Nitrogen in crop production: An account of global flows. *Global Biochemical Cycles* 13:647-662.

Stanley F.A., and Smith G.E. 1956. Effect of soil moisture and depth of application on retention of anhydrous ammonia. *Soil Science Society of America Journal* 20:557-561.

Tollenaar M., and Lee E.A. 2002. Yield potential, yield stability and stress tolerance in maize. *Field Crops Research* 75:161-169.

Tremblay N., Bouroubi Y.M., Belec C., Mullen R.W., Kitchen N.R., Thomason W.E., Ebelhar S., Mengel D.B., Raun W.R., Francis D.D., Vories E.D., Ortiz-Monasterio I. 2012. Corn response to nitrogen is influenced by soil texture and weather. *Agronomy Journal* 104:1658-1671.

United States Department of Agriculture - Economic Research Service. 2013. Corn Overview. Available on-line at http://www.ers.usda.gov/topics/crops/corn.aspx. Verified April 11th, 2015.

United States Department of Agriculture – National Agricultural Statistics Service. 2014. Quick Stats (U.S./states). Available on-line at http://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=LOUISIANA. Verified April 11th, 2015.

United States Department of Agriculture - National Cooperative Soil Survey. 2003. Gigger Series. *Official Soil Series Description (OSD)*. Available on-line at https://soilseries.sc.egov.usda.gov/OSD_Docs/G/GIGGER.html. Verified April 7, 2015.

United States Department of Agriculture - National Cooperative Soil Survey. 2013. Sharkey Series. *Official Soil Series Description (OSD)*. Available on-line at https://soilseries.sc.egov.usda.gov/OSD_Docs/S/SHARKEY.html. Verified April 7, 2015.

Varvel G., Schepers J.S., Francis D.D. 1997. Ability for in-season correction of nitrogen deficiency in corn using chlorophyll meter. *Soil Science Society of America Journal* 61:1233–1239.

Varvel G. E., and Todd A.P. 1990. Nitrogen fertilizer recovery by corn in monoculture and rotation systems. *Agronomy Journal* 82:935-938.

Weindorf D.C. 2008. An update of the field guide to Louisiana soil classification. LSU AgCenter Bulletin. 889. Louisiana Agriculture Experiment Station, Baton Rouge, LA.

Wessels Living History Farm. 2015. Postwar fertilizer explodes. Written by Bill Ganzel and Claudia Reinhardt of the Ganzel Group. Available on-line at http://www.livinghistoryfarm.org/farminginthe40s/crops_04.html Verified on May 12, 2015.

Wisser R.J., Balint-Kurti P.J., Nelson R.J. 2006. The genetic architecture of disease resistance in maize: A synthesis of published studies. *Phytopathology* 96:120-129.

Zhen-xie Y., Pu W., Zhang H., Li-xia S. 2006. Effect of type and application rate of nitrogen fertilizer on development and nitrogen utilization in summer maize. *Acta Agriculturae Boreali-Sinica* 1:025.

Zhu Q., Schmidt J.P., Lin H.S., Sripada R.P. 2009. Hydropedological processes and their implaications for nitrogen availability to corn. *Geoderma* 154:111-122.

Zhu Z.L., and Chen D.L. 2002. Nitrogen fertilizer use in china-contributions to food production, impacts on the environment and best management strategies. *Nutrient Cycling in Agroecosystems* 63:117-127.

Chapter 3. Documenting the Changes in Inorganic Nitrogen Level and Distribution in Soil Profile Within and Across Cropping Seasons at Varying Nitrogen Fertilization Levels.

3.1 Introduction

Over application of nitrogen (N) fertilizers can have detrimental effects to both crop production and the surrounding environment. Several studies have been conducted to determine N movement and its impacts on crop physiology and the environment (Krantz et al., 1943; Devitt et al., 1976; Gerwing et al., 1979; Datta et al., 1997; Pacheco and Cabrera, 1997; Di and Cameron, 2002). Aside from the negative physiological impacts that can occur in crops, ground and surface waters can become polluted when excess fertilizer is applied. Today, nitrate (NO_3) is one of the top water pollutants across the globe (Spalding and Exner, 1993). Agricultural runoff is considered to be a non-point source of NO_3 pollution, but NO_3 pollutions can also come from point sources such as irrigation of land by sewage effluent (Keeney, 1986; Bouchard et al., 1992; Eckhardt and Stackelberg, 1995; Mclay et al., 2001; Babiker et al., 2004). Since agricultural fertilization has the potential to be a big factor in groundwater contamination, N decision tools have begun to be developed as a means of regulating N fertilizer applications by determining if N application will significantly increase yields. One such tool is the Pre-Sidedress Nitrate Test developed by Magdoff et al. (1984). This test takes into account the soil NO_3-N present in the soil when the crop is 15-30 cm tall and roughly two weeks prior to in-season N application. With this information, proper recommendations can be made to maximize yield without over applying fertilizer N. Another N decision tool is the use of optical sensors to determine if N application will boost yields. Raun et al. (2001) developed this method which essentially determines the proper N application by measuring crop reflectance with optical sensors of an adequately N fertilized crop and a crop that is fertilized using a standard farmer's practice. The difference in these two readings is called a response index and this can be used to determine if added N fertilizer will improve yields. The general theme for these tools is that they take into account residual N that may have carried over from the previous year. Bundy and Malone (1988) concluded that profile NO_3-N can significantly influence corn (*Zea mays*) response to applied N and may be useful on soils in humid areas. In a study performed by Meisinger (1984), it was pointed out that soil characteristics and precipitation data would be required to properly estimate soil NO_3-N carrying over into another cropping season. Carryover of profile NO_3-N in humid regions is dependent to a large part upon over winter precipitation (Bundy and Malone, 1988).

Although research has been conducted to determine inorganic N seasonal patterns in the soil profile throughout the US, limited research has been carried out in the northern Louisiana area. Therefore, this study was conducted to document the seasonal changes in soil profile inorganic N at varying N rates on two different soil types.

3.2 Materials and Methods

3.2.1 Site Description, Treatment Structure, and Trial Establishment

This study was conducted across all four site-years from 2013-2014. Two soils of differing textures in Northeastern LA were selected to address the objective of this study. A Sharkey clay soil in St. Joseph, LA (31°, 56', 28.94" N, 91°, 14', 11.43" W) and a Gigger silt loam soil in Winnsboro, LA (32°, 08', 22.05" N; 91° 41', 13.93" W). St. Joseph is located in in Tensas Parish while Winnsboro is in Franklin Parish hereafter termed as NERS and MRRS, respectively. The Sharkey clay is a heavy textured soil classified as; very fine, smectitic, thermic Chromic Epiaquerts. (USDA, 2013) This soil is very deep, poorly to very poorly drained, very slowly permeable that formed in a clayey alluvium. Gigger silt loam soil is classified as; fine-silty, mixed, active, thermic, Typic Frafiudalfs. (USDA, 2003) and is described as, very deep, moderately well drained, slowly permeable soils with fragipans that formed in a thin mantle of loess over loamy sediments. All four site-years were established and managed under an irrigated system. No tillage took place for both locations throughout the 2 year study. Irrigation at NERS was supplied using furrow irrigation via poly pipe and overhead sprinkler irrigation was used at MRRS. Tables containing information on initial soil chemical properties (Table 3), (Table 3.2), and soil sampling dates (Table 3.3) are provided below. Corn hybrid varieties used were Pioneer 2088HYR and Pioneer 1319HR on Sharkey clay and Gigger silt loam, respectively. Seeds were 80,000 seeds per hectare with spacing being 30 cm between seeds. Irrigation was used when necessary via a poly pipe irrigation system for Sharkey clay soil and an overhead sprinkler system for Gigger silt loam soil. This study was superimposed from an existing trial on corn response to N rate and application time. The treatment structure is provided in Table 3.4. The applications of 0,

Table 3.1 Chemical properties of soil at different depths for both locations.

[‡]Site		pH	Organic matter	Total N	Total C	P	K	S	Ca	Mg	Cu	Zn
	Depth, cm		%	[†]mg kg^{-1}								
MRRS	0-15	6.7	2.24	6164	41164	26	74	12	994	109	1.1	2.7
	15-30	6.7	2.04	1885	10920	12	54	9	1,123	125	0.5	0.5
	30-45	5.4	-	1689	8524	9	80	18	1,084	167	1.1	0.2
	45-60	5.0	-	1518	7623	10	92	17	968	205	1.0	0.5
	>60	4.6	-	1514	7230	13	95	18	1,042	298	1.6	0.6
NERS	0-15	6.1	5.91	1354	12661	55	454	5	4,240	890	4.5	4.4
	15-30	6.6	5.95	1042	2517	32	361	2	4,780	1,005	6.2	2.9
	30-45	7.2	-	1030	2051	14	349	3	5,339	1,118	6.1	1.9
	45-60	7.6	-	1106	2410	11	349	4	5,446	1,151	5.8	1.9
	>60	7.8	-	1072	1764	13	353	6	5,261	1,132	5.2	2.1

*10g soil:10 mL DI H_20 for pH analysis procedure, equilibrate for 2 hours, then measured. [†]Total N and C were based on dry combustion while other nutrients were based on Mehlich-3 procedure. [‡]Site: MRRS – Macon Ridge Research Station, NERS – Northeast Research Station

Table 3.2 Field activity dates and plot size for MRRS and NERS for years 2013 and 2014.

Site-year Designation	Plot Size,[†] m	Planting	*Early-season N application	*Midseason N application	Harvest
MRRS 2013	13.76 x 4	10-Mar-13	27-Mar-13 (V3)	23-May-13 (V7-V8)	16-Aug-13
NERS 2013	12.19 x 4	28-Mar-13	30-Apr-13 (V5)	20-May-13 (V8-V9)	27-Aug-13
MRRS 2014	13.76 x 4	19-Mar-14	6-Apr-14 (V3)	8-May-14 (V8-V9)	19-Aug-14
NERS 2014	13.76 x 4	21-Apr-14	8-May-14 (V3)	27-May-14 (V8-V9)	16-Sept-14

*V# = leaf collar stage of corn crop.
[†] - length x width.

Table 3.3 Record of soil sampling dates for MRRS and NERS in 2013 and 2014.

Site-Year	March	ꟳMay	August	October	December
MRRS 2013	7-Mar-2013	22-May-2013	19-Aug-2013	26-Oct-2013	18-Dec-2013
NERS 2013	21-Mar-2013	17-May-2013	27-Aug-2013	31-Oct-2013	‡
MRRS 2014	*18-Feb-2014	8-May-2014	19-Aug-2014	27-Oct-2014	18-Dec-2014
NERS 2014	27-Mar-2014	26-May-2014	¶16-Sept-2014	21-Oct-2014	18-Dec-2014

*Sampling conducted in February. ¶Sampling conducted in September at harvest due to late planting. ꟳMay sampling times were conducted when crop was at V8 leaf stage. ‡Sampling did not occur due to poor field conditions.

201, and 403 kg N ha^{-1} at early-season only were selected for this study. Rates were selected on a "low", "medium", and "high" basis. One check plot (0 applied N) was included in each replication. Nitrogen source for Sharkey clay was UAN-S (32-0-0-2) knifed in with a mechanical applicator and granular urea (46-0-0) was broadcast by hand for Gigger silt loam. Phosphorus (P) and Potassium (K) rates were applied in accordance with test results performed by the LSU AgCenter Soil Testing and Plant Analysis Laboratory to maintain sufficient nutrient levels. Weed management practices recommended by the LSU AgCenter were followed.

Table 3.4 Treatment description of the field trials conducted in St. Joseph, LA and Winnsboro, LA in 2013 and 2014.

Early-Season N rate, kg ha^{-1}	Midseason N rate, kg ha^{-1}
0	0
67	0
134	0
201	0
268	0
335	0
403	0
0	268
67	201
134	134
201	67

3.2.2 Soil Sampling

Two deepcore samples were obtained from the center 3 m of the plot between the two middle rows of four-row plots in the months of March (early-season), May (V8 leaf stage), August (harvest), October and December. The V8 leaf stage was targeted for sampling since this is more or less a critical growth stage for the crop (Hanway, 1963). Determining the inorganic N content of the upper soil profile (0-30 cm) may be beneficial in predicting yields. During the months of March, August, October and December, a hydraulic powered probe (Giddings; model no. - GSRPS) with a 6.35 cm diameter probe mounted on a 4-wheel drive pick-up truck was used to obtain the deepcore samples. During the month of May at V8 leaf stage, samples were obtained by hand using a slide hammer (AMS; model no. – 400.99) mounted to a soil probe (AMS; model no. – 425.52) with a 60 cm slot. Due to the challenges involved with hand sampling to 60 cm depths, samples were unable to be collect at the >60 cm depth at MRRS 2013 and NERS 2013. However, in 2014 changes were made on the sampling scheme and samples were able to be collected at the >60 cm depth. Core samples were divided into 15 cm sections (0-15, 15-30, 30-45, 45-60, >60 cm) at the time of sampling. Soil samples were then oven-dried (Despatch LBB series; model number LBB2-18-1) at 55°C for a minimum of 3 days, processed using a Humboldt electric flail soil grinder, and then sieved through a 2 mm sieve.

3.2.3. Soil Analysis

Inorganic N content was determined by weighing 5 g of soil into 125 mL plastic bottles followed by the addition of 35 mL of 1 M KCl. Samples were shaken for 1 hour on a mechanical shaker (Eberbach; model number-E6010.00) then filtered using No. 42 Whatman filter paper. Extracts were then analyzed for ammonium (NH_4-N) and NO_3-N/nitrite (NO_2-N) content using a continuous flow injection analyzer (Lachat QuickChem 8500 series 2), simultaneously. The method for determining NO_3-N content is similar to that outlined by Keeney and Nelson (1982). Nitrate is reduced to NO_2-N by passing through a cadmium reduction column and then reacts with a color reagent (sulfanilamide) to produce a pinkish color that can be measured colorimetrically at 520 nm. Ammonium analysis method was similar to that outlined by Reardon (1966). Ammonium present in the sample reacts with salicylate-nitroprusside-hypochlorite mixture to produce a blue color that can be measure colorimetrically at 660 nm. Total inorganic N in kg ha^{-1} within the 0-30 cm soil layer was determined by summing the inorganic N content from the 0-15 cm and 15-30 cm soil samples for each plot. Conversion of inorganic N from mg L^{-1} to mg kg^{-1} to kg ha^{-1} is shown below.

$$\text{mg L x } \frac{\text{0.035 L 1 M KCl}}{\text{0.005 kg soil}} = \text{mg kg}^{-1}$$

$$\text{mg kg}^{-1} \text{x 2=lbs acre}$$

$$\text{lbs ac x } \frac{\text{1 lbs}}{\text{1 ac}} \text{ x } \frac{\text{2.47 ac}}{\text{1 ha}} \text{ x } \frac{\text{kg}}{\text{2.204 lb}} = \text{1.12 kg ha}^{-1}$$

$$\text{lbs acre x 1.12=kg ha}^{-1}$$

Organic matter was determined using a modified version of the combustion method. First, 20-mL crucibles were weighed (g) and recorded. Ten grams of soil was then weighed into crucible and placed into a furnace for 8 hours at 550° C. After cooling, samples were weighed again and percent organic matter was estimated using the following equation:

Equation 3.1

$$\% \text{ OM}= \frac{\text{Crucible+soil before combution-Cricible+soil after combustion}}{\text{Crucible+soil before combustion}} \text{ x } 100$$

3.2.4 Grain Yield

At harvest, a plot combine (Massey Ferguson 8XP) was used to collect grains from the two middle rows of each plot. The harvester was equipped with Harvest Master Instrumentation to determine plot weight. Sub samples were taken to determine grain moisture and seed weight. Grain moisture for all four site-years was determined using a grain analysis computer (Dickey-john; model number – GAC2500 UGMA) for further analysis once plot yield was determined. Grain moisture was adjusted to 155 g kg^{-1} and yield was calculated in bushels per acre and then converted to kg ha^{-1} using the following equations:

Equation 3.2

$$\text{Yield 155 g kg}^{-1} \text{ moist adj. (lbs/ac)}=\left[\frac{\text{Plot yield (lbs)}}{\left(\frac{\text{Plot size }\left(\text{ft}^2\right)}{43560}\right)}\right] \text{ x } \left[\frac{\text{(100-moisture content)}}{\text{(100-15.5)}}\right]$$

Equation 3.3

$$\text{Adjusted yield (bu/ac)}= \frac{\text{155 g kg}^{-1} \text{ moist adj. (lbs/ac)}}{56}$$

Equation 3.4

$$\text{Yield (kg ha}^{-1}\text{)=Yield (bu/ac) x } \frac{\text{56 lbs}}{\text{bu}} \text{ x } \frac{\text{1 kg}}{\text{2.2 lbs}} \text{ x } \frac{\text{2.47 ac}}{\text{ha}}$$

3.2.5 Soil Texture Analysis

One soil core was taken from each site to a depth of >60 cm, divided into 15 cm sections, and analyzed to determine soil texture. Texture analysis was performed using a modified version of the hydrometer (Humboldt; model no. – H4241) method similar to that outlined by Kettler et al. (2001). First, 10 g of soil were weighed and oven dried (Yamato DKN600) at 90° C for 24 hours and then weighed again to determine the soil moisture factor (SMF). Soil samples weighing either 30 g or 25 g (depending on clay content) were placed into 500 mL shake bottles. Twenty mL of 10% sodium hexametaphosphate was then added followed by about 250 mL of deionized water. Samples were then shaken (Eberbach; model number-E6010.00) over night or for about 16-20 hours. After shaking, a USA standard test sieve No. 270 was used to sift out the sand portion of the samples. Sand portions were then transferred to a small glass beaker of which the weights were pre-recorded and oven dried (Yamato DKN600) for about 24 hours at 90° C and then weighed (g). Remaining mixture of silt and clay was then transferred to a 1000 mL graduated cylinder. Deionized water was added to make a 1000 mL suspension, mixed with a plunger, then left undisturbed for 6 hours. Clay portions were measured using the hydrometer. Hydrometer readings were adjusted using a blank that followed the same process as the soil samples.

Silt portion was determined by subtracting sand and clay portions from one. Equations used for particle size analysis can be found below.

Equation 3.5

$$\text{SMF}= \frac{\text{10 g soil-Soil weight after drying (g)}}{\text{Soil weight after drying (g)}}+1$$

Equation 3.6

$$\text{Oven dry Wt.} = \frac{\text{Sample Wt. Shaken}}{\text{SMF}}$$

Equation 3.7

$$\text{Sand \%}= \frac{\text{Dried sand from sieveing (g)}}{\text{Oven Dry Wt.}}$$

Equation 3.8

$$\text{Clay \%}= \frac{\text{(Hydrometer Reading-Hydrometer Blank)}}{\text{Oven Dry Wt.}}$$

Equation 3.9

$$\text{Silt \%}=1-\text{Sand \%}-\text{Clay \%}$$

3.2.6 Weather Data Collection

Rainfall data for MRRS was measured at a weather station located in Chase, LA about 5 miles south of the research trial. For NERS, rainfall was measured using a rain gauge installed at the Northeast Research Station itself located less than one mile from the research trial.

3.2.7 Statistical Analysis of Measured Parameters

For each site-year, measured parameters were analyzed by performing analysis of variance using PROC MIXED procedure in SAS 9.3 (SAS, 2012). Fixed variable was N treatment (rate and application scheme) and random variables were replication and year. The least significant difference (LSD) method at the 5% level of confidence was used to determine significant differences among treatments unless otherwise indicated. Average, standard error, and standard deviation of soil inorganic N content were computed using Microsoft Excel 2010.

3.3 Results and Discussion

3.3.1 Texture Analysis

Soil texture data can be found in Table 3.5. For MRRS, soil texture was a silt loam from 0-45 cm soil layer. From 45 to >60 cm soil layer, soil texture changed to a silty clay loam. In NERS, soil texture was clay and consistent throughout the profile.

3.3.2 Soil Profile Inorganic N Distribution

Results for MRRS 2013 and 2014 inorganic N distribution can be found in Figures 3.1, 3.2, and 3.3. Inorganic N content throughout the profile had its highest level during the month of March in 2013. Inorganic N content was highest in the 0-15 cm layer for all sampling times. As depth increased, the lowest inorganic N level was typically found in the 15-30 cm layer. Below this layer inorganic N content slightly increased with each successive layer.

This was unexpected as we believed to find less inorganic N with each layer we passed in depth. In the check plots (0 kg N ha^{-1}) inorganic N content at the >60 cm layer (30 kg N ha^{-1}) had higher inorganic N than the 0-15 cm layer (25 kg N ha^{-1}) for the months of March and August in 2013. The spike in inorganic N content for the 0-15 cm layer of the N applied plots in May of 2013 is believed to be the result of early-season N applications of urea.

Table 3.5 Particle size distribution for MRRS and NERS.

*Location	Depth, cm	Sand %	Silt %	Clay %	Texture Classification
MRRS	0-15	7.24	79.29	13.47	Silt Loam
	15-30	6.23	76.94	16.83	Silt Loam
	30-45	4.65	71.61	23.74	Silt Loam
	45-60	5.56	63.71	30.73	Silt Clay Loam
	>60	6.43	66.20	27.37	Silt Clay Loam
NERS	0-15	2.64	38.66	58.70	Clay
	15-30	1.51	35.60	62.89	Clay
	30-45	1.47	31.45	67.08	Clay
	45-60	1.26	31.65	67.09	Clay
	>60	1.13	31.78	67.09	Clay

*MRRS – Macon Ridge Research Station; NERS – Northeast Research Station

The sampling period that returned the lowest amount of inorganic N throughout the soil profile appeared to be August. Throughout the year, fluctuations in total inorganic N appeared to be due to the change in NO_3-N. Ammonium-N appeared to be the majority of total inorganic N in the soil profile throughout the two year trial, except in the month of May following fertilization took place. Furthermore, there was no apparent change in the surface layer N during the month of May for N applied plots. Both treatments averaged ~70 kg N ha^{-1} in the

0-15 cm soil layer during the month of May and ~20 kg N ha^{-1} in the 15-30 cm soil layer. Nitrogen rates appeared to have no effect on increasing inorganic N content for these soil layers. The 15-30 cm soil layer reported similar inorganic N amounts for both treatments; however, 403 kg N ha^{-1} applied plots showed an increase in inorganic N content as depth increased when compared to 201 kg N ha^{-1} applied plots. The high N rate plots reported a total inorganic N content of 35 kg N ha^{-1} with most of it being in NO_3-N form (30 kg N ha^{-1}) in the 45-60 cm soil layer. Treatment 201 kg N ha^{-1} reported about 18 kg N ha^{-1} in total inorganic N and 12 kg N ha^{-1} being in NO_3-N form. This would suggest that the increased N rate had an increasing effect on NO_3-N leaching. All plots showed an increase in inorganic N of the 0-15 cm soil layer in the month of October in 2013. The 0 and 201 kg N ha^{-1} treatments had values of about 28 kg N ha^{-1} while the 403 kg N ha^{-1} treatment reported approximately 32 kg N ha^{-1}. Rainfall during this time was recorded as approximately 150 mm during September and 45 mm during October in 2013.

For MRRS in 2014 soil samples were taken in February to determine if soil inorganic N began to mineralize any sooner than March. This sampling period returned low inorganic N levels that were less than 10 kg N ha^{-1} across all treatments and less than the inorganic N content that was recorded in March 2013. Most of the inorganic N at this time was in NH_4-N form. In May of 2014, shortly after N treatments were applied, the site received ~65 mm of precipitation within a short period followed by a period of standing water for approximately 24 hours. With this event, there is a possibility that the N fertilizer that was applied was washed away leading to the reduction of inorganic N in the upper soil profile and no spike during the 2014 growing season. A study by Shaw (1962) reported that as much 134 kg N ha^{-1} of NO_3-N can be removed from the upper 15 cm soil layer by 20 cm of rain in a sandy soil. If an additional 20 cm of rain occurs, only about 40% of the applied N remained in the 30-45 cm soil layer (Olsen et al. 1970). The trial also received rain over the course of one week from May 27, 2014 to June 2, 2014 that measured about 180 mm (Figure 3.4). Significant rain events, which took place during the period of the trial, are shown in Figure 3.4. August was once again a low point throughout the growing season with inorganic N content being less than 10 kg N ha^{-1} across all treatments. However, increases were noted in the 0-15 cm soil layer during the months of October and December. Beneath the surface soil layer, inorganic N content varied little and was less than that seen the previous year. One week prior to soil sampling in October, the area experienced a four day rain event that dropped approximately 120 mm of rain on the trial. It is unknown if this rain event is responsible for the reduction in inorganic N levels when compared to the previous year. The area received a total of 2330 mm of rain throughout the year, which is much higher than its normal total of 1650 mm. Four single rain events dropped over 80 mm of rain throughout the year, three of which occurred during the months of November. For MRRS 2014, approximately 915 mm of rain fell during the growing season, which was much higher than the 560 mm of rain MRRS 2013 experienced.

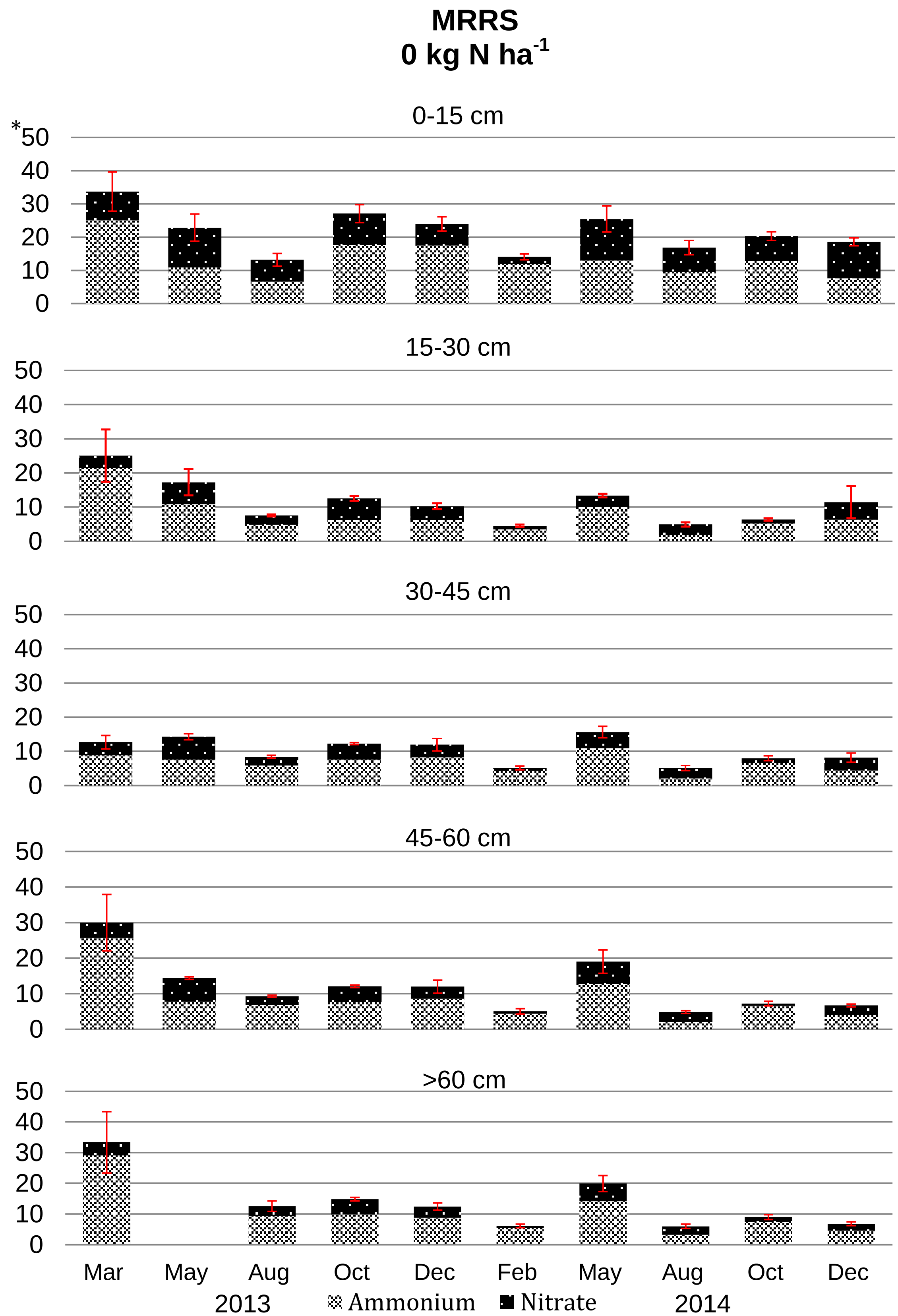

Figure 3.1 Inorganic N distribution within the profile of unfertilized (0 kg N ha^{-1}) soil in Winnsboro, LA (MRRS). *Values on y-axis are kg ha^{-1}. n=8

MRRS
201 kg N ha^{-1}

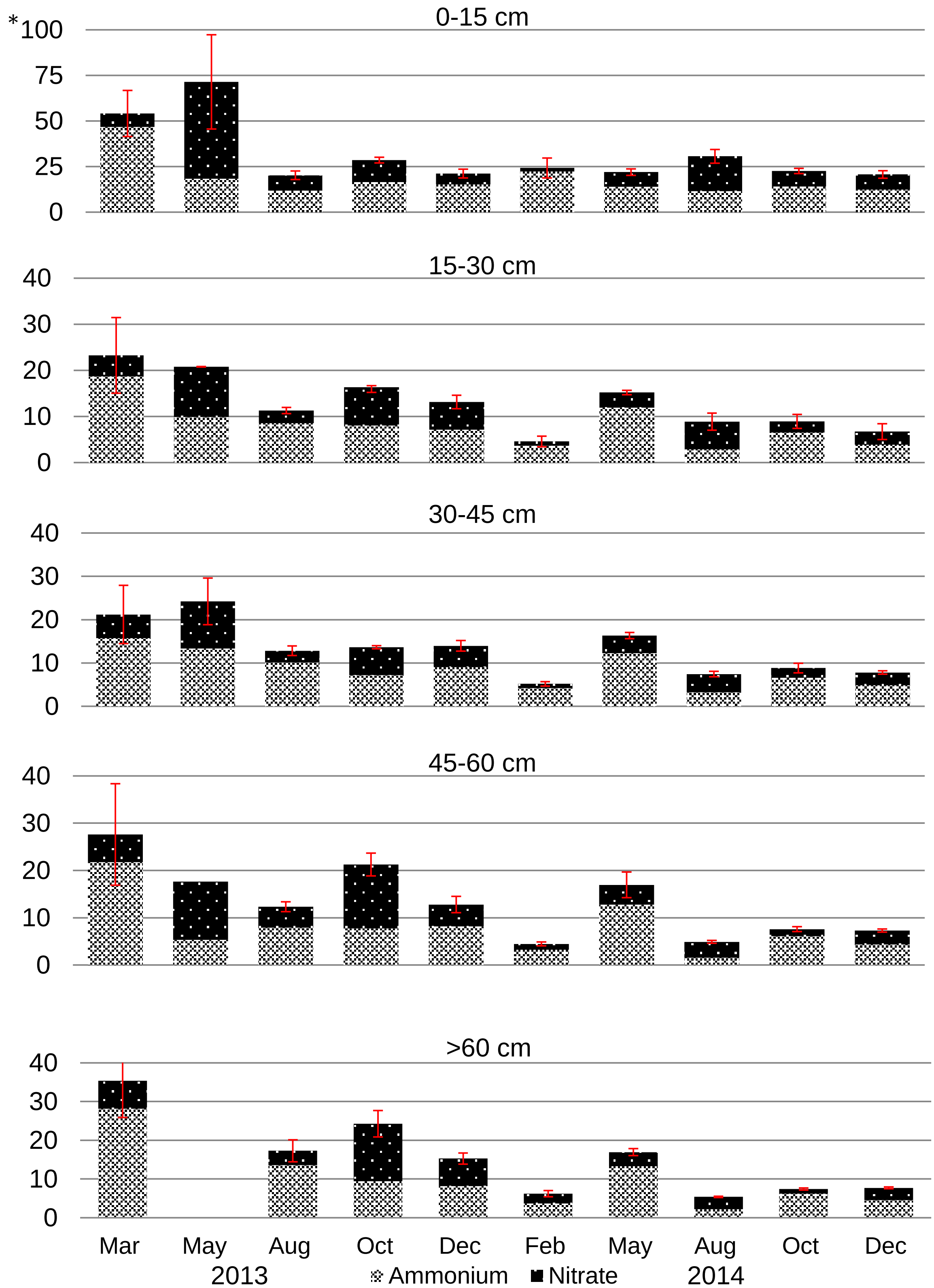

Figure 3.2 Inorganic N distribution within the profile of 201 kg N ha^{-1} treated soil in Winnsboro, LA (MRRS). *Values on y-axis are kg ha^{-1}. n=8

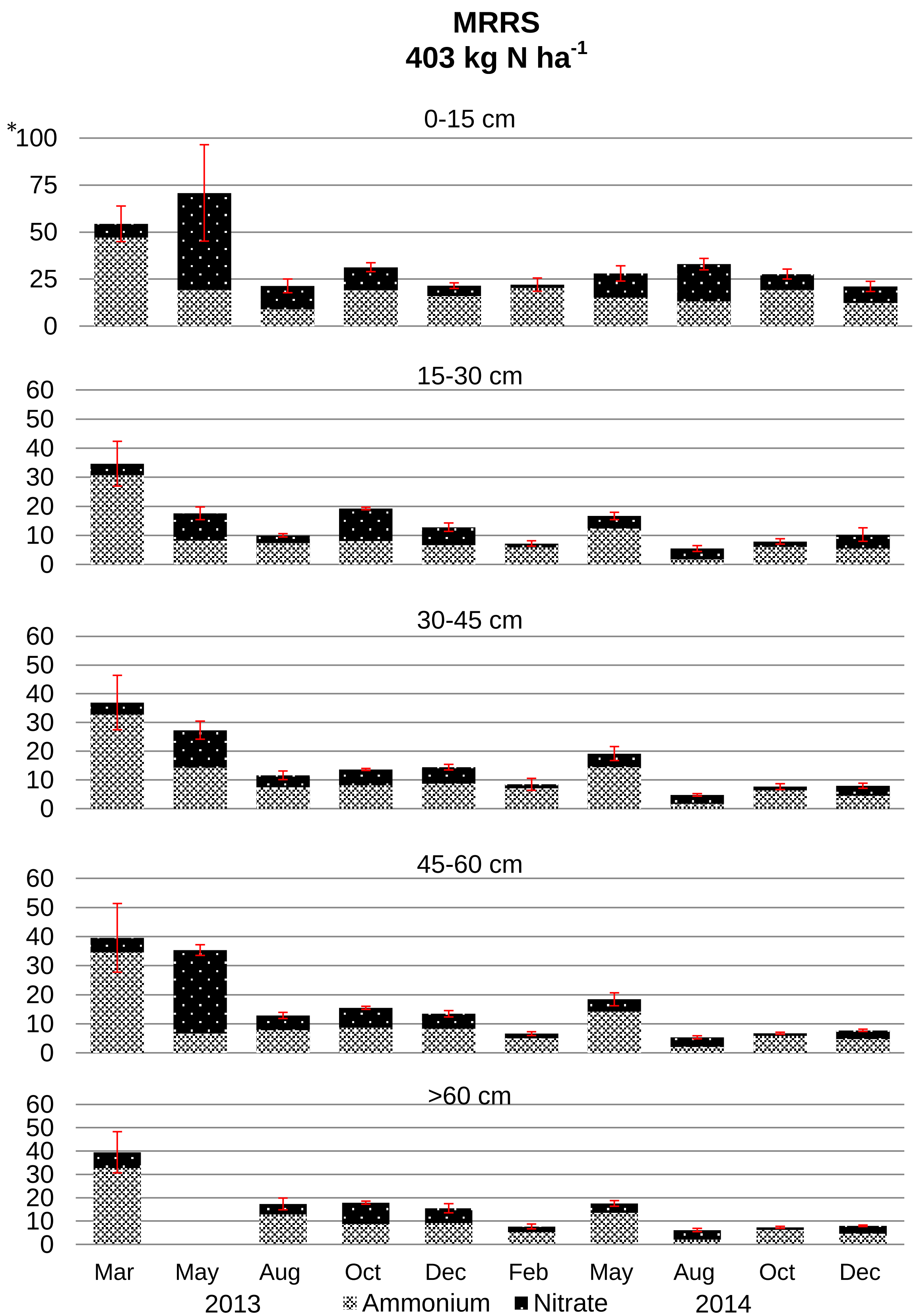

Figure 3.3 Inorganic N distribution within the profile of 403 kg N ha^{-1} treated soil in Winnsboro, LA (MRRS). *Values on y-axis are kg ha^{-1}. n=8

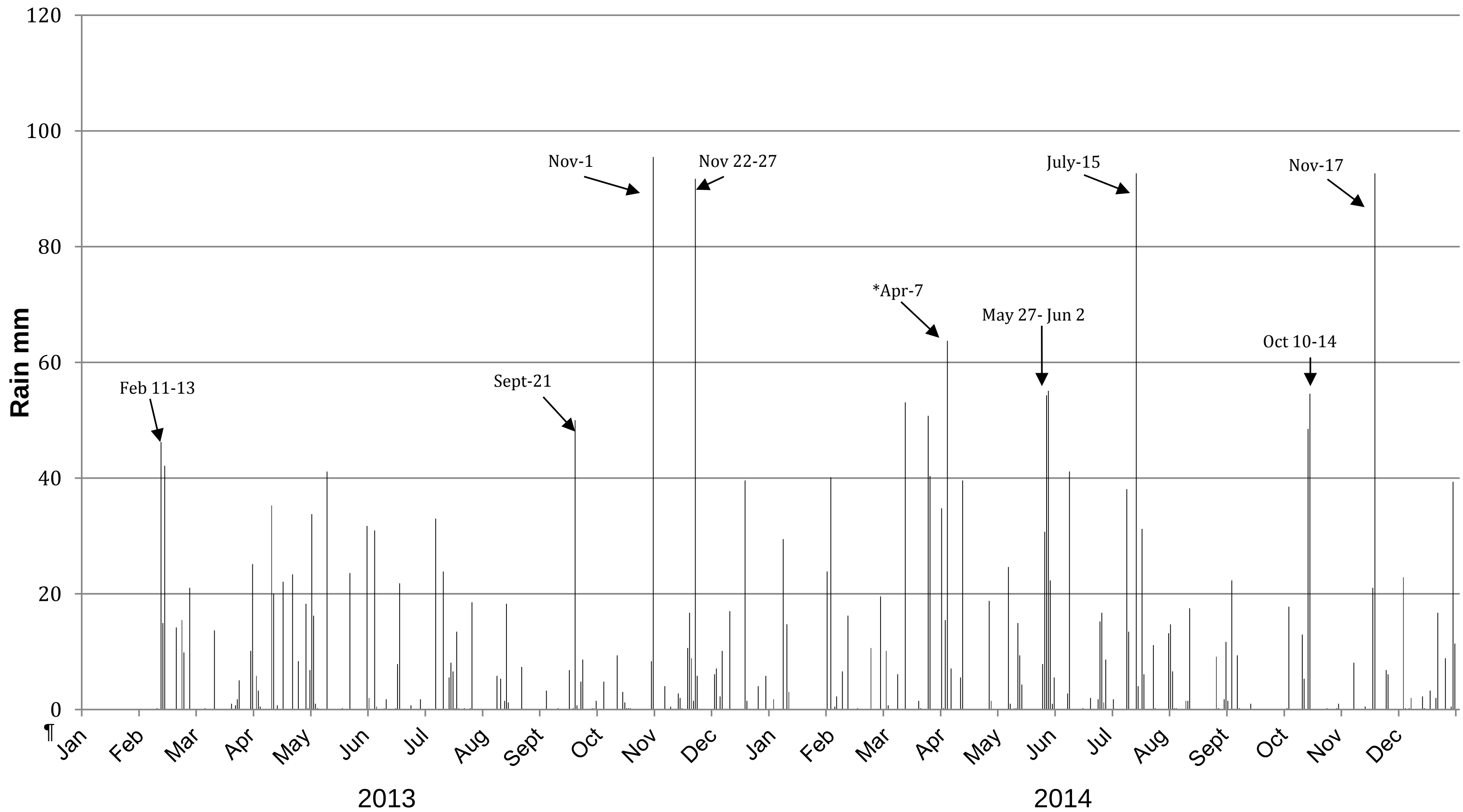

Figure 3.4 Amount and distribution of rainfall measured in Chase, LA from January 2013 to December 2014. ¶No data collected Jan 1, 2013-Feb 8, 2013. *One day after N application.

Results for NERS 2013 and 2014 soil inorganic N distribution can be found in Figures 3.5, 3.6, and 3.7. At NERS in 2013, reduction of inorganic N content was more pronounced as depth increased throughout the Sharkey clay profile. During the month of March, inorganic N content varied little across all treatments and depths. Unlike MRRS, the month of March reported little inorganic N content with the most being 35 kg N ha^{-1} in the 0-15 cm soil layer of the check plots. In January, this location received approximately 250 mm of within a week period (Figure 3.9). Whether this had a direct effect on the low amount of inorganic N present in the soil by March was unclear. Similar to MRRS, spikes in inorganic N were seen during the month of May, of which was mostly NO_3-N. This can be attributed to UAN fertilizer as the N source for this location. Around 25% of the N in UAN fertilizers is in NO_3 form (IPNI, 2015). For both site-years, N application appeared to have an effect on increasing the soil inorganic N content, although, only in the 0-15 cm soil layer. Inorganic N content of this layer was ~60 kg N ha^{-1} for 201 kg N ha^{-1} treatment and ~195 kg N ha^{-1} for 403 kg N ha^{-1} treatment. At the lower depths, little variability was observed during this sampling period with inorganic N content maintaining at ~20 kg N ha^{-1}. Inorganic N content for 403 kg N ha^{-1} treatment decreased by harvest in August to less than 50 kg N ha^{-1} in the 0-15 cm soil layer and less than 20 kg N ha^{-1} for soil layers; 30-45, 45-60 and >60 cm. The 201 kg N ha^{-1} treatment had similar results. Similar to MRRS location, a slight increase in inorganic N content was observed in October, potentially due to the breakdown of crop residue from harvest. Unfortunately, soil sampling data for December for this site-year is not available due to excessive moisture in the field.

Inorganic N distribution during the month of March in 2014 was similar to the distribution patterns recorded in 2013. In May of 2014, another spike was recorded that may potentially be due to fertilization. The 201 kg N ha^{-1} treatment averaged approximately 160 kg N ha^{-1} with about 121 kg N ha^{-1} being NO_3-N while the 403 kg N ha^{-1} treatment averaged 205 kg N ha^{-1} with about 170 kg N ha^{-1} being NO_3-N. In both N applied treatments, soil inorganic N dropped significantly in the 15-30 cm soil layer suggesting that most of the applied N remained on the surface soil layer exposing it to potential loss processes such as denitrification (Papendick and Campbell, 1981; Colbourn and Downdell, 1984; Groffman and Tiedje, 1989). Similar to 2013, NO_3-N reduced greatly by the time of harvest and was less than 30% of total inorganic N found in the soil during the months of October and December in 2014.

Results found in this study for this particular location are similar to those found by Bergstrom and Brink (1985) that studied if NO_3-N leaching increases with N fertilizer rate in heavy clay soils. They found total inorganic N displayed similar distribution patterns during September, or approximately harvesting time, and the fallow months of October and December. Inorganic N amounts were less than 40 kg ha^{-1} and decreased significantly with depth across treatments of 0, 100, and 200 kg N ha^{-1}. However, they also found NO_3-N accumulated in the 1.5 m to 3 m soil layers in the 200 kg N ha^{-1} treatment with NO_3-N content of ~40 kg N ha^{-1}. Since this study only soil sampled to a depth of ~76 cm, we were unable to determine if a NO_3-N pooling effect was taking place in this heavy clay soil as well. Bergstrom and Brink (1985) later concluded that applications of N over 100 kg ha^{-1} can increase the risk of introducing excess NO_3 into the environment. Probable causes for low residual N at the NERS location for both years may be related to its soil texture and the climate of the area. Rainfall during the growing season totaled approximately 725 mm. Leaching and denitrification can take place in areas that receive high annual rainfall. In a study performed by Peterson and Attoe (1965), retention of profile NO_3-N was documented in some soils in the humid Midwest (Bundy and Malone, 1988). Applications of large amounts of N can certainly have an effect on the seasonal changes in profile N content (Bergstrom and Brink, 1986).

3.3.3 Soil Inorganic N Content at V8 Leaf Stage and Its Effects on Yield

Results for soil inorganic N content in the upper 30 cm of the soil profile at the V8 leaf stage can be found in Table 3.6 and Table 3.7. Maximum yields were obtained for both site locations in 2013. Plots that had at least 80 kg N ha^{-1} produced yields of 10 Mg ha^{-1}or more, while plots that contained less than 50 kg N ha^{-1} returned yields less than 2 Mg in both locations. Conversely, 2014 showed the opposite effect. In MRRS 2014, all plots averaged anywhere from 35 to 45 kg N ha^{-1}, yet returned significantly different yields (P<0.001) with the highest being the 403 kg N ha^{-1} treatment producing 8 Mg ha^{-1}. For NERS 2014 despite that the 0-30 cm soil layer had ~200 kg N ha^{-1} at the V8 leaf stage, yield level was lower than the previous year. The late planting is believed to be the primary

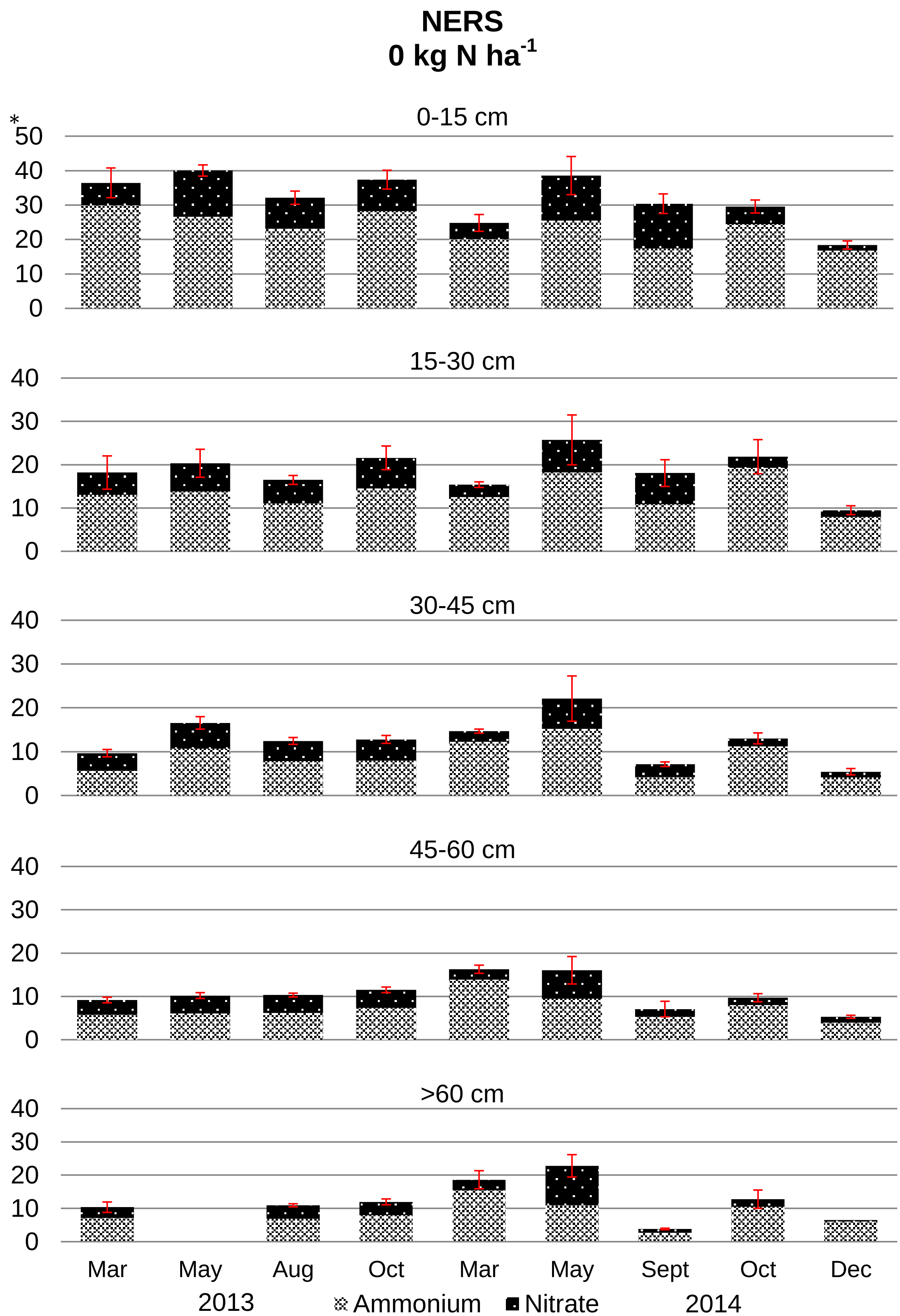

Figure 3.5 Inorganic N distribution within the profile of 0 kg N ha^{-1} treated soil in St. Joseph, LA (NERS). *Values on y-axis are kg ha^{-1}

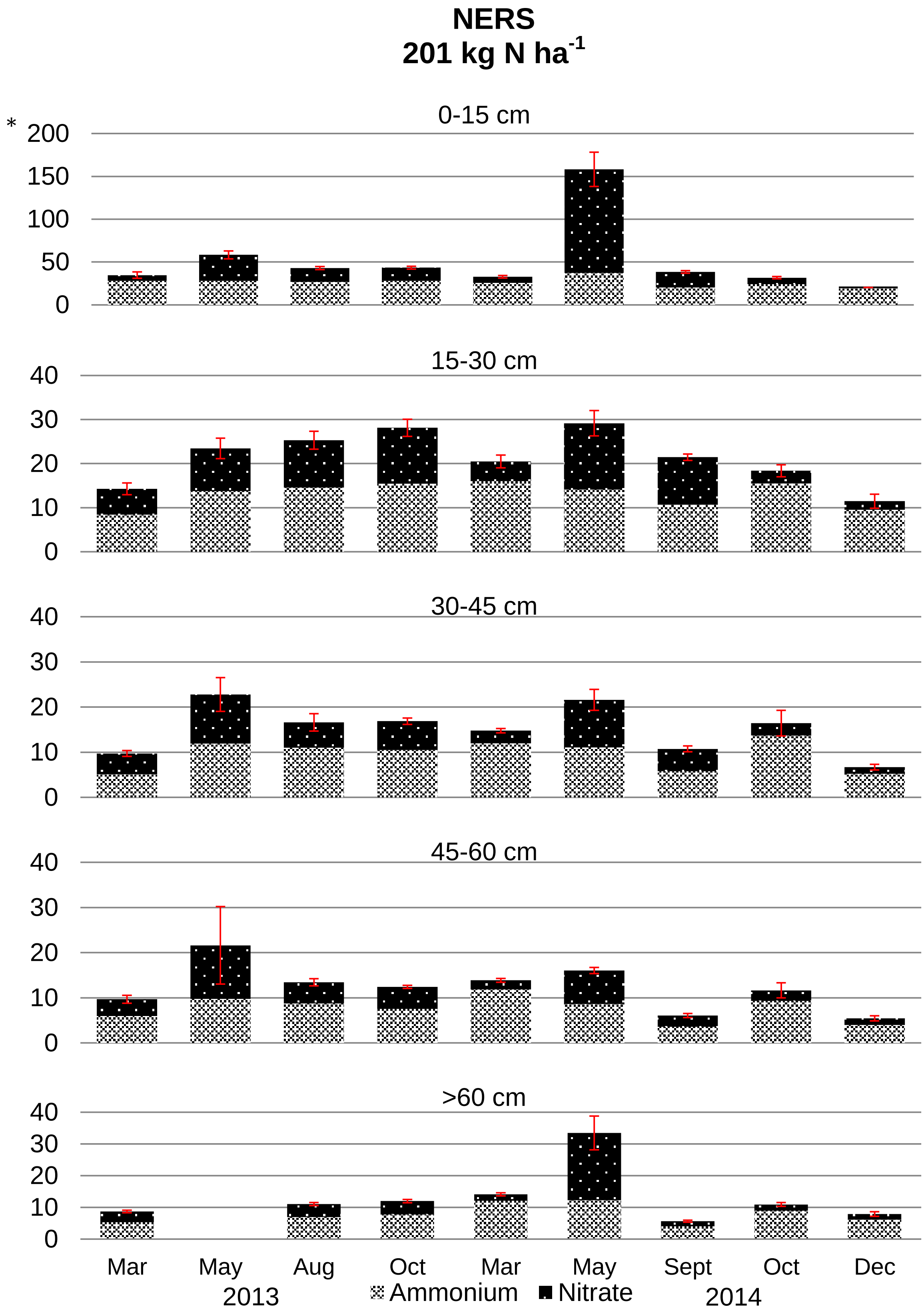

Figure 3.6 Inorganic N distribution within the profile of 201 kg N ha^{-1} treated soil in St. Joseph, LA (NERS). *Values on y-axis are kg ha^{-1}.

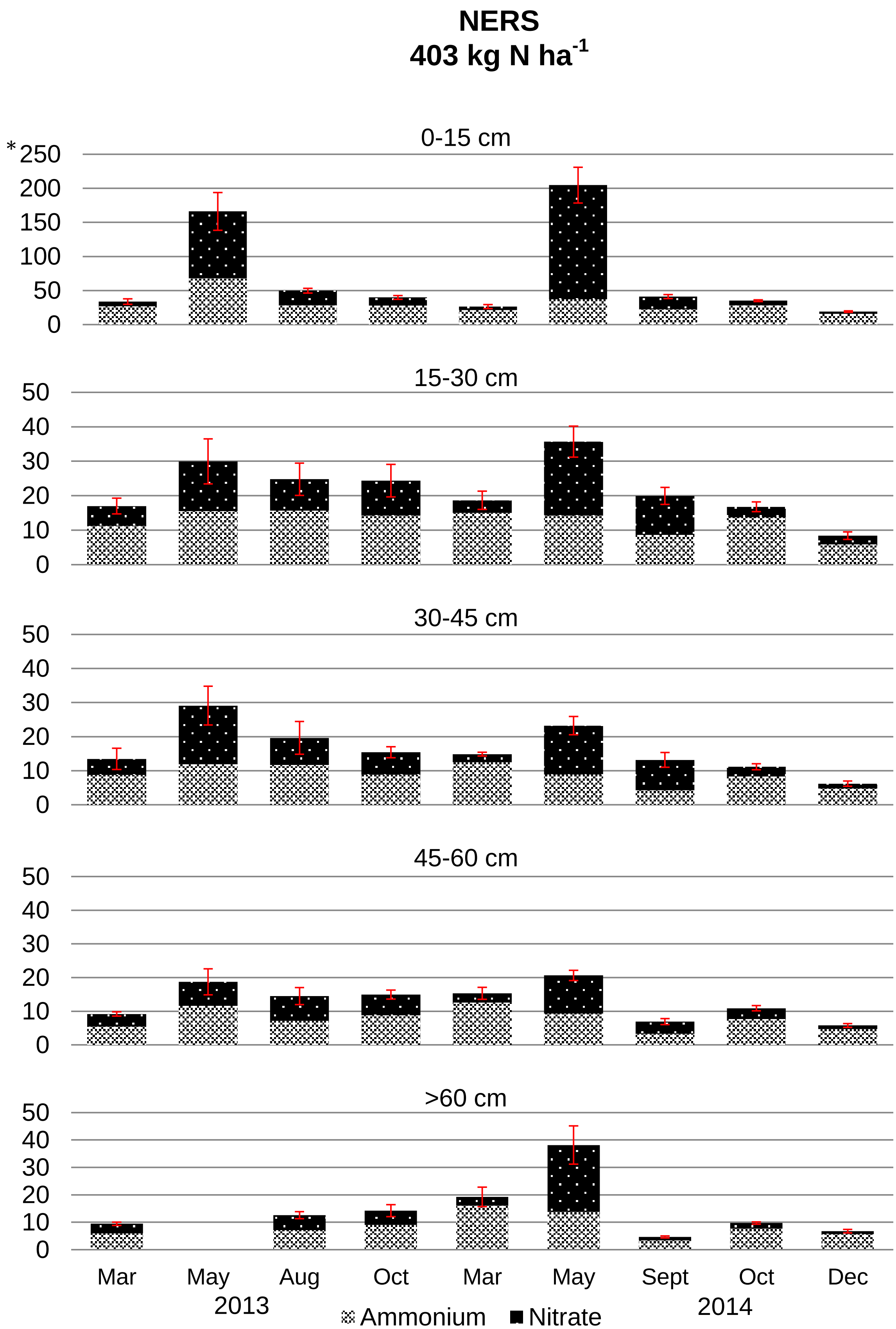

Figure 3.7 Inorganic N distribution within the profile of 403 kg N ha^{-1} treated soil in St. Joseph, LA (NERS). *Values on y-axis are kg ha^{-1}.

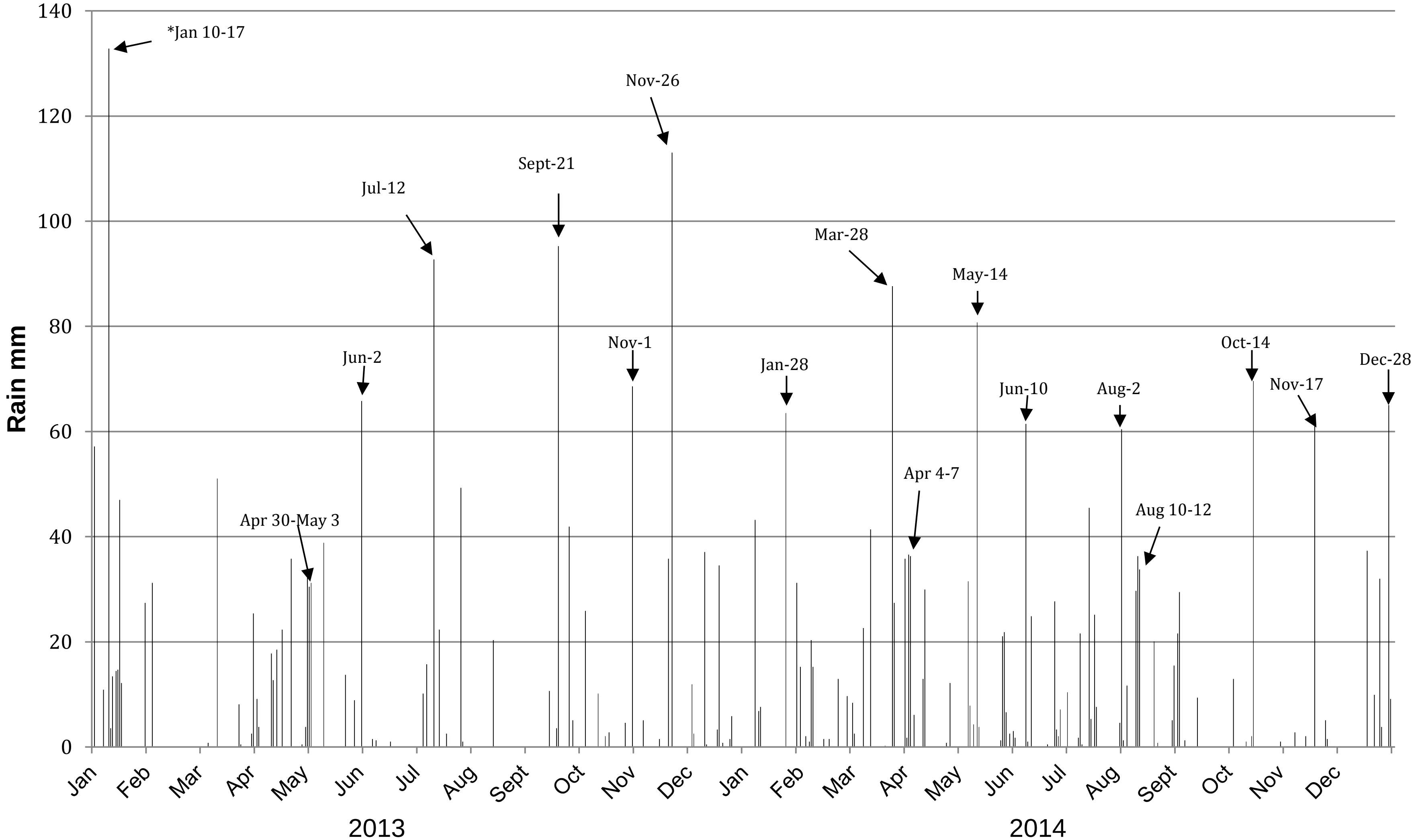

Figure 3.8 Amount and distribution of rainfall measured in St. Joseph, LA from January 2013 to December 2014. *Rain recorded for 6 days, no rain Jan-13.

cause for the yield reduction. However, it should be noted that both treatments had values of 51 kg N ha^{-1} as NH_4-N. Of the total inorganic N (~190 kg N ha^{-1}) in the upper 30 cm for the 201 kg N ha^{-1} treatment, 136 kg N ha^{-1} was in NO_3-N form. Similarly, for the 403 kg N ha^{-1} treatment, 190 kg N ha^{-1} of the 240 kg N ha^{-1} total inorganic N was in NO_3-N form suggesting that NO_3-N is probably contributing to the significant increase in yield for NERS 2014.

Similar studies have been conducted to establish an inorganic N level content that would optimize yields. Cui et al. (2008) reported that a minimum of ~90 kg N ha^{-1} of inorganic N in the upper 90 cm soil layer should be available to minimize N deficiency. Blackmer et al. (1989) reported that the optimal level of inorganic N should be 20 to 25 mg kg^{-1} in the 0-30 cm soil layer in Iowa. Binford et al. (1992) also reported optimal concentrations of inorganic N to be 23 to 26 mg kg^{-1}.

Table 3.6 Grain yield and inorganic N distribution within 0-30 cm soil depth of plots applied with 0, 201, 403 kg N ha^{-1}, for MRRS 2013 and 2014.

Year	Early-Season N rate, kg ha^{-1}	NH_4-N	NO_3-N	*Total Inorganic N	Yield, kg ha^{-1}
	--kg ha^{-1}--				
2013	0	22	18	40	†1720
	201	28	64	92	†10290
	403	27	61	88	†13011
2014	0	23	16	39	†1625
	201	26	11	37	†6515
	403	28	17	45	†8779

*Total inorganic N is the summation of NH_4-N and NO_3-N. †Significant differences at P<0.001.

Table 3.7 Grain yield and inorganic N distribution within 0-30 cm soil depth of plots applied with 0, 201, 403 kg N ha^{-1}, for NERS 2013 and 2014.

Year	Early-Season N rate, kg ha^{-1}	NH_4-N	NO_3-N	*Total inorganic N	Yield, kg ha^{-1}
	--------------------------------------	--------kg ha^{-1}--------	--------------------------------------		
2013	0	40	20	60	†2070
	201	42	40	82	†11348
	403	83	113	196	†13047
2014	0	44	21	64	†60
	201	51	136	187	†5532
	403	51	189	240	†7933

*Total inorganic N is the summation of NH_4-N and NO_3-N. † Significant differences at P<0.001.

3.4 Conclusions

Both soil types displayed different patterns of inorganic N distribution within the soil profile between cropping seasons. Inorganic N content in the Sharkey clay soil at NERS did not appear to change significantly, except following fertilizer application prior to soil sampling. Across all treatments and depths, inorganic N content in excess of 50 kg N ha^{-1} was only reported in the month of May at NERS. Soil inorganic N content was generally below 50 kg N ha^{-1} year round throughout the soil profile. Similar results were reported in the Gigger silt loam soil in both MRRS site-years. Except the only time inorganic N content reached >50 kg N ha^{-1} levels was in March of 2013 when the trial was established and May of 2013, due to fertilization weeks prior to soil sampling. Furthermore these amounts of greater than 50 kg N ha^{-1} inorganic N were only found in the 0-15 cm soil layer. In the 15-30 cm soil layer to >60 cm soil layer, inorganic N content was generally below 40 kg N ha^{-1}.

Inorganic N variability occurred mostly in the 0-15 soil layer. Some variability occurred in the 15-30 cm soil layer, but from there to the >60 cm soil layer, variability decreased. Soil inorganic N content appeared to follow a seasonal pattern of reduced content during the winter months and increased content during summer months. This study demonstrated the potential use of soil testing to help manage N fertilization and increase information on N dynamics for these two soil types. However, we were unable to establish a specific optimal inorganic N level for this region.

3.5 References

Babiker I.S., Mohammed A.A.M., Terao H., Kikuo K., Ohta K. 2004. Assessment of ground water contamination by nitrate leaching from intensive vegetable cultivation using geographical information system. *Environmental International* 29:1009-1017.

Bergstrom L., and Brink N. 1986. Effects of differentiated applications of fertilizer N on leaching losses and distribution of inorganic N in the soil. *Plant and Soil* 93:333-345.

Binford G.D., Blackmer A.M., Cerrato M.E. 1992. Relationships between corn yields and soil nitrate in late spring. *Agronomy Journal* 84:53-59.

Blackmer A.M., Pottker D., Cerrato M.E., Webb J. 1989. Correlations between soil nitrate concentration in late spring and corn yields in Iowa. *Journal of Production Agriculture* 2:103-109.

Bouchard D.C., Williams M.K., Surampalli R.Y. 1992. Nitrate combinations of groundwater sources and potential health effects. *Journal of American Medical Association* 7:85-90.

Bundy L.G., and Malone E.S. 1988. Effect of residual profile nitrate on corn response to applied nitrogen. *Soil Science Society of America Journal* 52:1377-1383.

Colbourn P., and Downdell R.J. 1984. Dentrification in field soils. *Plant and Soil* 76:213-226.

Cui Z., Zhang F., Miao Y., Sun Q., Li F., Chen X., Li J., Ye Y., Yang Z., Zhang Q., Liu C. 2008. Soil nitrate-N levels required for high yield maize production in the north china plain. *Nutrient Cycling in Agroecosystems* 82:187-196.

Datta P.S., Deb D.L., Tyagi S.K. 1997. Assessment of groundwater contamination from fertilizers in the Delhi area based on ^{18}O, NO_3^- and K^+ composition. *Journal of Contaminant Hydrology* 27:249-262.

Devitt D., Letey J., Lund L.J., Blair J.W. 2002. Nitrate-nitrogen movement through soil as affected by soil profile characteristics. *Journal of Environmental Quality* 5:283-288.

Di H.J., and Cameron K.C. 2002. Nitrate leaching in temperate agroecosystems: sources, factors and mitigating strategies. *Nutrient cycling in agroecosystems* 46:237-256.

Gerwing J.R., Caldwell A.C., Goodroad L.L. 1979. Fertilizer nitrogen distribution under irrigation between soil, plant, and aquifer. *Journal of Environmental Quality* 8:281-284.

Groffman P.M., and Tiedje J.M. 1989. Denitrification in north temperate forest soils: spatial and temporal patterns at the landscape and seasonal scales. *Soil Biology and Biochemistry* 21:613-620.

Groffman P.M., and Tiedje J.M. 1991. Relationship between dentrification, CO_2 production and air-filled porosity in soils of different texture and drainage. *Soil Biology and Biochemistry* 23:299-302.

Hanway J.J. 1963. Growth stages of corn (*Zea mays*, L.). *Agronomy Journal* 55:487-492.

International Plant Nutrition Institute. 2015. Nutrient source specifics. Available online at- http://www.ipni.net/publication/nss.nsf/0/5BB8639163BB14E3852579AF0075540B/$FILE/NSS-07%20Urea%20Ammonium%20Nitrate.pdf Verified June 4, 2015.

Keeney D. R., and D.W. Nelson. 1982. Nitrogen-Inorganic forms. *Methods of Soil Analysis* 9:643-698.

Keeny D. 1986. Sources of nitrate to groundwater. CRC Critical Reviews in *Environmental Control* 16:257-304.

Kettler T.A., Doran J.W., Gilbert T.L. 2001 Simplified method for soil particle-size determination to accompany soil-quality analyses. *Soil Science Society of America Journal* 65:849-852.

Krantz B.A., Ohlrogge A.J., Scarseth G.D. 1943. Movement of nitrogen in soils. *Proceedings-Soil Science Society of America* pp. 189-191.

Magdoff F.R., Ross D., Amadon J. 1984. A soil test for nitrogen availability to corn. *Soil Science Society of America Journal* 48:1301-1304.

McLay C.D.A., Dragten R., Sparling G., Selvarajah N. 2001. Predicting groundwater nitrate concentration in a region of mixed agricultural land use: a comparison of three approaches. *Environmental* Pollution 115:191-204.

Meisinger J.J. 1984. Evaluating plant-available nitrogen in soil-crop systems. *Nitrogen in crop production* (nitrogeninicropp), 391-416.

Olsen R.J., Hensler R.F., Attoe O.J., Witzel S.A., Peterson L.A. 1970. Fertilizer nitrogen and crop rotation in relation to movement of nitrate nitrogen through soil profiles. *Soil Science Society of America Journal* 34:448-452.

Pacheco J.A., Cabrera A.S. 1997. Groundwater contamination by nitrates in the yucatan peninsula. *Hydrogeology Journal* 5:47-53.

Papendick R.I., and Campbell G.S. 1981. Theory and measurement of water potential. in water potential relations in soil microbiology. *Water Potential in Soil Microbiology* 3:1-22.

Reardon, J. Salicylate method for the quantitative determination of ammonia nitrogen. Patent no. 3,432,395. Filed June 8, 1966.

Schmitt M.A., and Randall G.W. 1994. Developing a soil nitrogen test for improved recommendations for corn. *Journal of Production Agriculture* 7:328-334.

Shaw K. 1962. Loss of mineral nitrogen from soil. *Journal of Agricultural science* 58:145-152.

Spaulding R.F., and Exner M.E. 1993. Occurrence of nitrate in groundwater-A Review. *Journal of Environmental Quality* 22:392-402.

Chapter 4. Conclusions

Weather played a significant role during this study and two years of consistent data were unable to be obtained. However, all four site-years showed that with increasing N rates, yields also increased. Based on the data recorded in 2013, split application of the current recommended N rate for corn production in Louisiana worked best in the Gigger silt loam soil and early-season only applications returned the highest yields in the Sharkey clay soil. Split N applications also reported better NUE than the early-season only application methods. Furthermore, split applications of N fertilizer demonstrated its effectiveness in reducing yield losses if large amounts of rainfall were to occur in the early part of the growing season. The optimum N rate for the MRRS location appeared to be 134-134 N kg N ha^{-1} while 201 kg N ha^{-1} is estimated to be the recommendation for NERS. Nitrogen rates showed significant effects on grain weight, and N uptake for both locations.

Inorganic N content variability occurred mostly in the 0-15 cm soil layer. Nitrogen fertilizer application did not appear to have a significant effect on increasing inorganic N content in the Gigger silt loam soil. However, N rate did significantly increase inorganic N content in the Sharkey clay soil, but only in the 0-15 cm soil layer. The only time inorganic N content reached levels above 50 kg N ha^{-1} was recorded in the month of May only weeks after fertilization. Both soil types followed similar seasonal patterns with reduced inorganic N content during the winter and early spring months and increasing inorganic N content during the summer months.

Appendix A. Corn grain ratings in 2014 for MRRS and NERS.

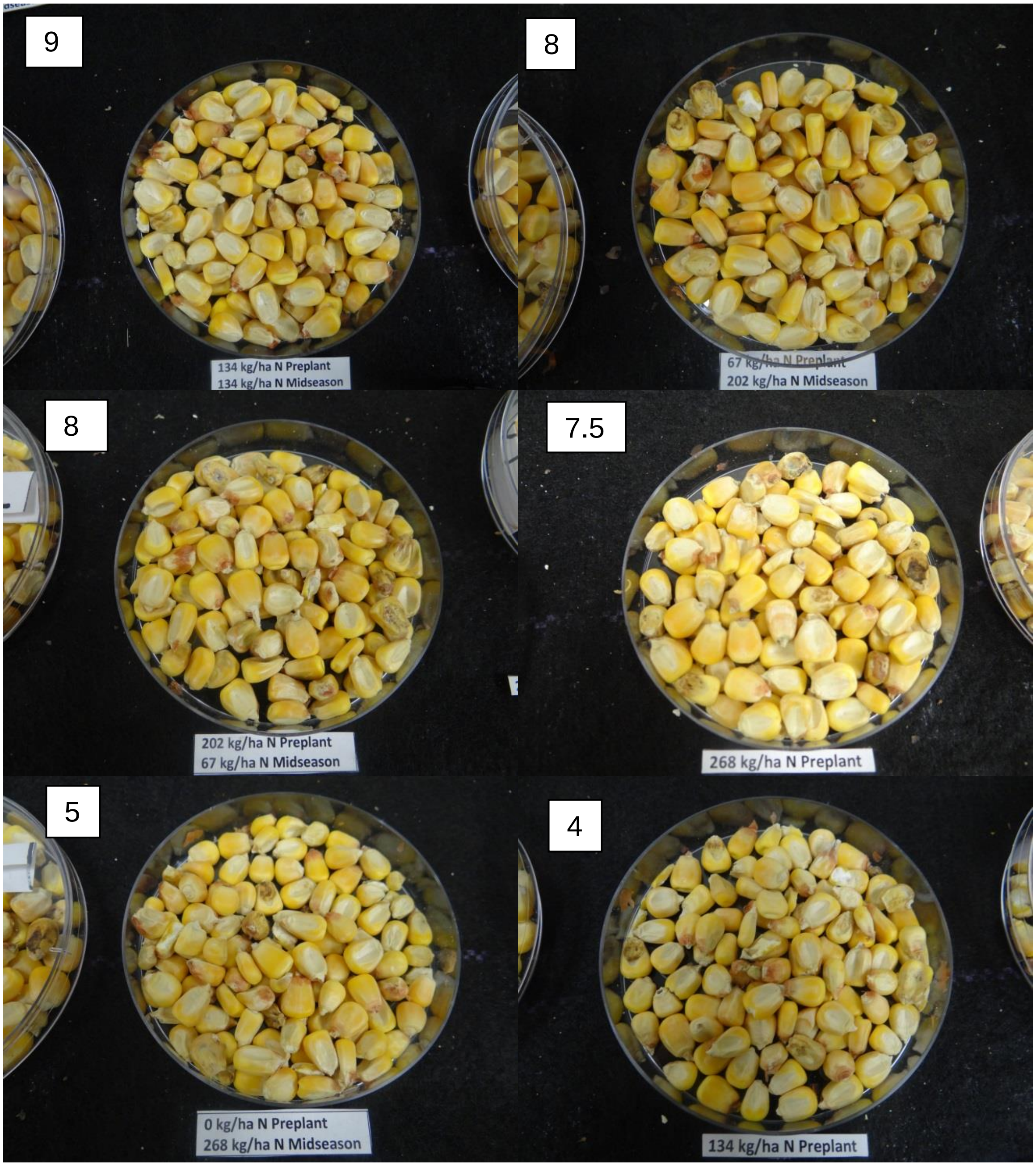

Figure A.1 Corn grain ratings for MRRS 2014. Scale is 1-10 with 10 being premium and 1 being poor quality.

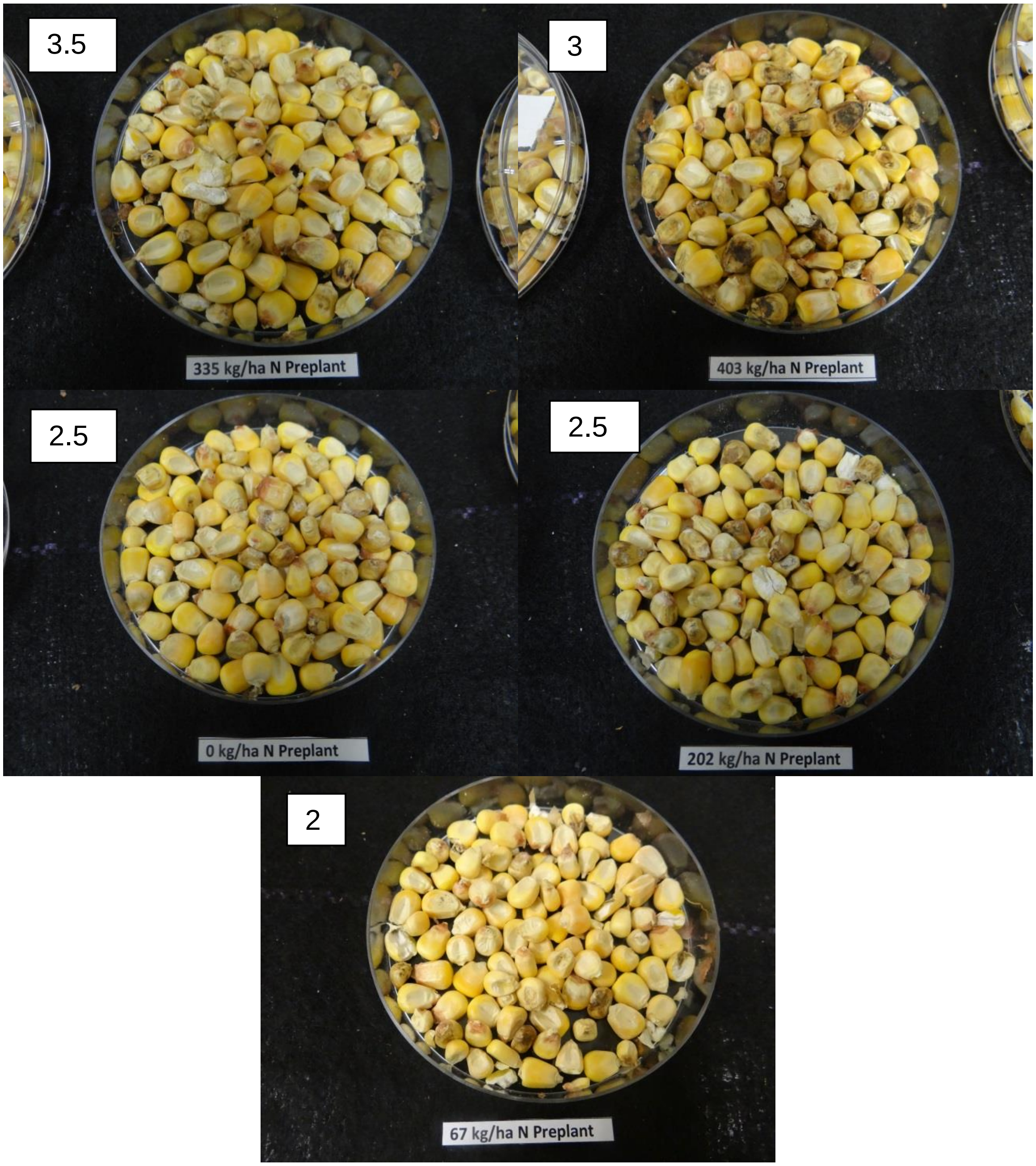

Figure A.1 (continued) Corn grain ratings for MRRS 2014. Scale is 1-10 with 10 being premium and 1 being poor quality.

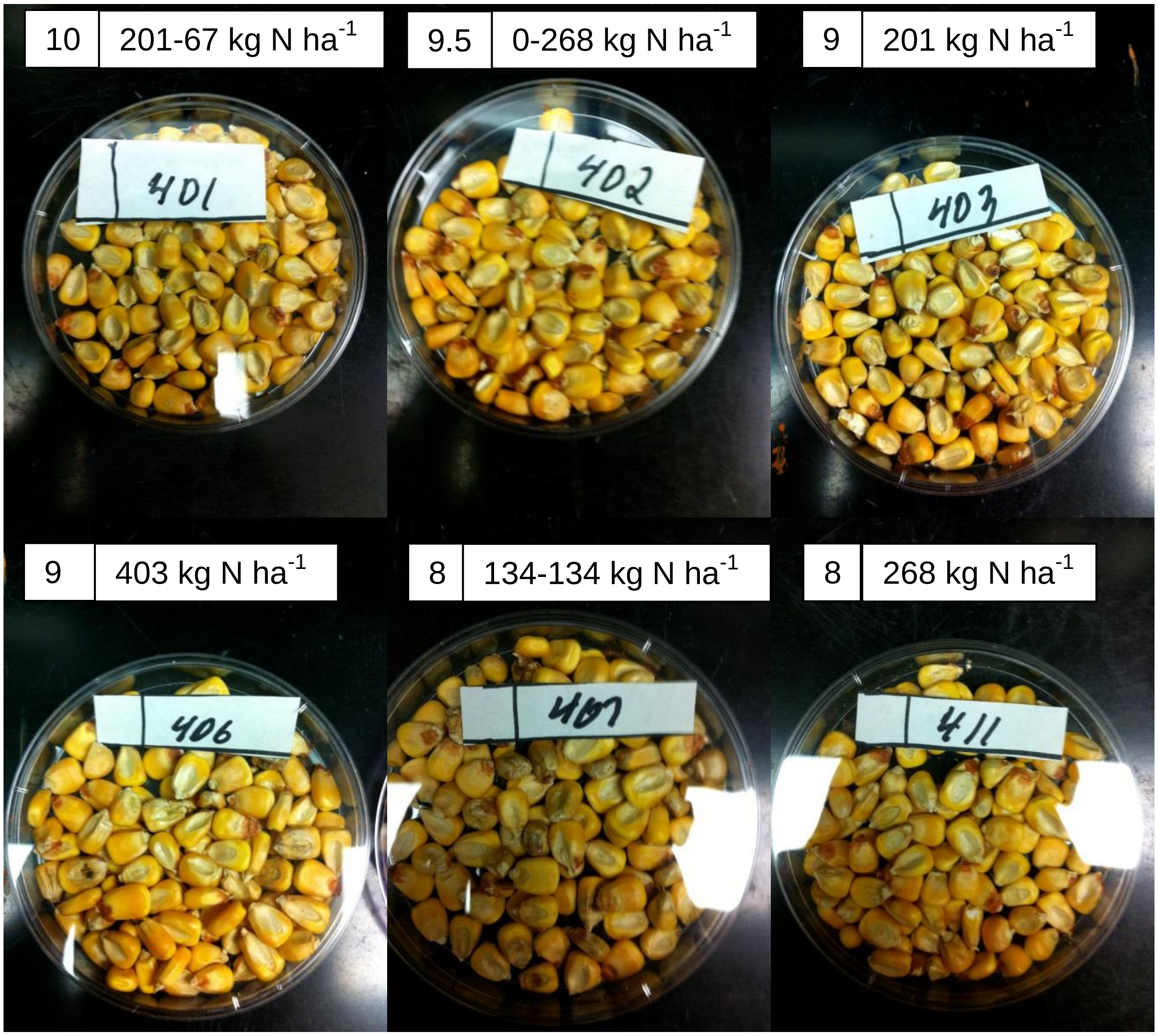

Figure A.2 Corn grain ratings for NERS 2014. Scale is 1-10 with 10 being premium and 1 being poor quality.

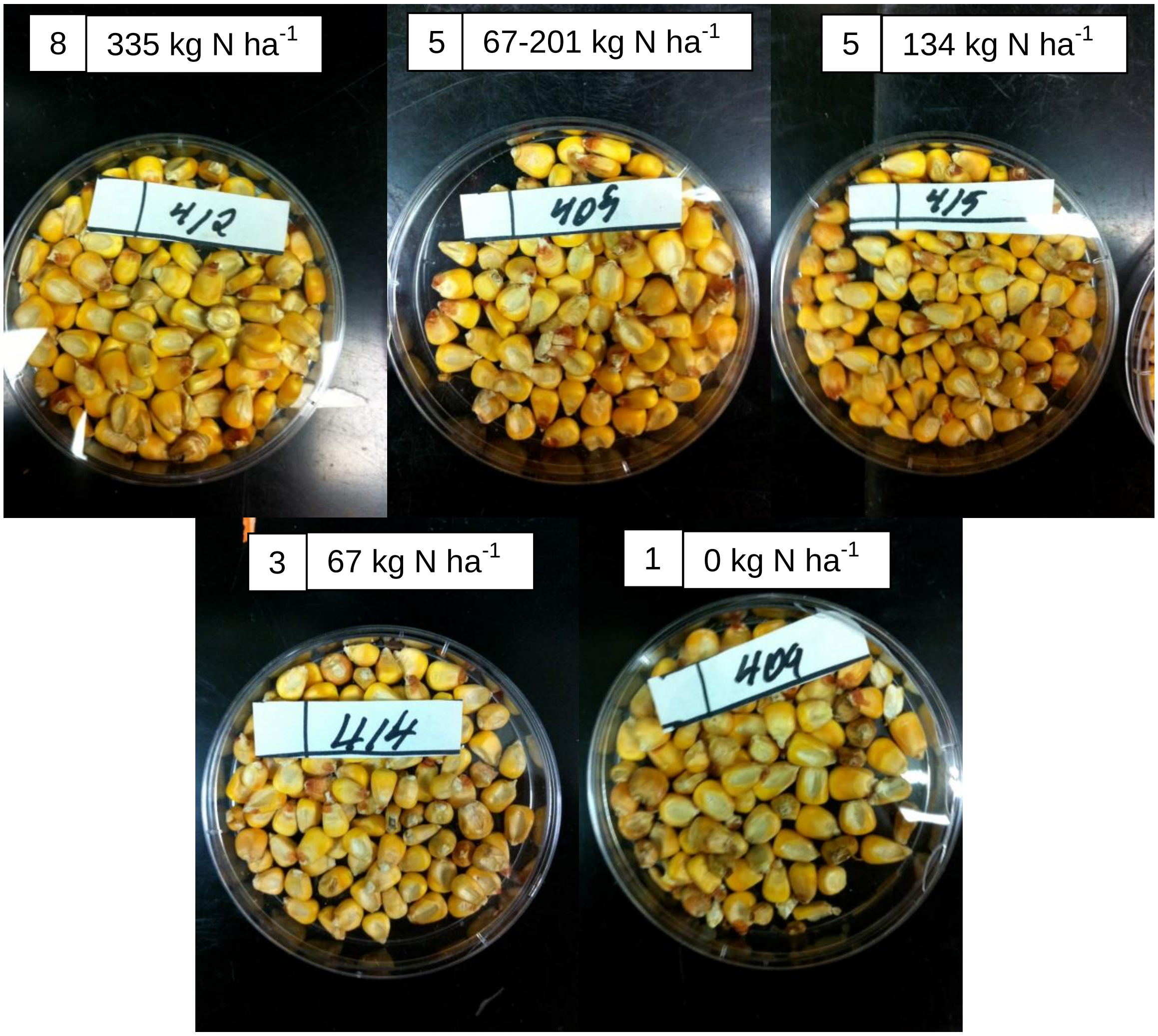

Figure A.2 (continued) Corn grain ratings for NERS 2014. Scale is 1-10 with 10 being premium and 1 being poor quality.

Appendix B. Rainfall data for MRRS and NERS in 2013 and 2014.

Table B.1 Rainfall data for MRRS 2013

Month Day	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
	mm											
1				25.1	6.9					0.3	95.5	
2					33.8	31.8				1.5		
3				5.8	16.3	2.0						
4				3.3	1.0				3.3			
5				0.5	0.3							
6			0.3			31.0				4.8		6.1
7						0.5					4.1	7.1
8							33.0					
9		0.3						5.8				2.3
10					41.1						0.5	10.2
11		46.2	13.7	35.3		0.3		5.3				
12		15.0		20.1		1.8	23.9		0.3			
13		42.2						1.5		9.4		
14				0.8				18.3				17.0
15							5.6	1.3		3.0		
16							8.1			1.3	2.8	
17						0.3	6.6			0.3	2.0	
18					0.3	7.9	0.3		6.9	0.3	0.3	
19		14.2		22.1		21.8	13.5			0.3		
20			1.0				0.3		0.3		10.7	
21									50.0		16.8	
22		15.5	0.8		23.6			7.4	0.8		8.9	39.6
23		9.9	1.8				0.3				1.5	1.5
24			5.1	23.4					4.8		93.2	
25				8.4		0.8			8.6		5.8	
26		21.1					0.3					
27							18.5					
28												
29				18.3								4.1
30				0.3		1.8			0.3			
31			10.2							8.4		
Total	0	164.3	32.8	163.3	123.2	99.8	110.2	39.6	75.2	29.5	242.1	87.9
Total for year		1167.9										

Table B.2 Rainfall data for MRRS 2014

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Day	mm											
1						1.0		13.2	1.5			
2	5.8					5.6		14.7		0.3		22.9
3		23.9	19.6				1.8	6.6	22.4	17.8		0.3
4				34.8				0.3				
5		40.1		0.3				0.3				0.3
6	1.8		10.2	15.5					9.4		8.1	2.0
7		0.5	0.8	63.8					0.3			
8		2.3										
9				7.1	24.6	2.8						
10					1.0	41.1	38.1	1.5		13.0		
11	29.5	6.6					13.5	1.5		5.3		
12			6.1		0.3			17.5			0.5	2.3
13	14.7	16.3			0.3				1.0	48.5		0.3
14	3.0			5.6	15.0					54.6		
15				39.6	9.4		92.7					
16			53.1		4.3	0.3	4.1				21.1	3.3
17											92.7	
18							31.2					
19		0.3					6.1					2.0
20												16.8
21						2.0						
22												
23			1.5							0.3	6.9	
24			0.3				11.2				6.1	8.9
25						1.8	0.3					
26		10.7				15.2		9.1				
27					7.9	16.8		0.3				0.5
28			50.8		30.7	1.3				0.3		39.4
29			40.4	18.8	54.4	8.6				1.0		11.4
30				1.5	55.1			1.8				
31					22.4			11.7				
Total	54.9	100.6	182.6	186.9	225.3	96.5	198.9	78.5	34.5	141.0	135.4	110.2
Total for year		1545.3										

Table B.3 Rainfall data for NERS 2013

Month Day	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
						mm						
1	NR			25.4	3.8						68.6	
2	57.2				33.8	65.8						
3	NR	31.75		9.1	30.5							NR
4	NR	NR		3.8	31.2							NR
5	NR	NR		NR			NR					NR
6	NR	NR	0.8				10.2			25.9		NR
7	10.9	NR				NR					5.1	11.9
8		NR				1.5	15.7				NR	2.5
9		NR			NR							NR
10	132.8	NR			38.9	1.3		NR				NR
11	3.6	NR	51.1	17.8				NR				NR
12	13.5	NR		12.7			92.7				NR	NR
13		NR							NR	10.2		NR
14	14.5	NR		18.5				20.3	10.7		NR	37.1
15	14.7	NR					22.4					0.5
16	47.0	NR									1.5	NR
17	12.2	NR		NR						2.0		NR
18	NR	NR				1.0				NR		NR
19		NR		22.4		NR	2.5			2.8	NR	NR
20		NR							3.6			NR
21		NR							95.3			3.3
22		NR	NR		13.7						NR	34.5
23		NR	8.1					NR		NR	NR	
24		NR	0.5	35.8					NR		35.8	0.8
25		NR					NR		41.9	NR	NR	
26		NR									NR	
27		NR					49.3				113.0	
28		NR		0.5			1.0			4.6		1.5
29					8.9	NR						5.8
30	27.4					NR			5.1	NR		
31			2.5							NR		
Total	333.756	31.8	63.0	146.1	160.8	69.6	193.8	20.3	156.5	45.5	224.0	98.0
Total for year		1543.1										

NR = No reading from weather station.

Table B.4 Rainfall data for NERS 2014

Month Day	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
						mm						
1						2.5		4.6				
2	NR							60.5	21.6			
3	NR	31.2	9.7			3.0	10.4	1.3	29.5	13.0		
4		0.2		35.8		1.8						
5		15.2		1.8				11.7				
6			8.4	36.6					1.3		2.8	
7			2.5	36.3								
8		2.0										
9				6.1	31.5		1.8					
10		1.0			7.9	61.5	21.6	29.7		1.0		
11	43.2	20.3				1.0	0.5	36.3				
12		15.2	22.6		4.3			33.8			2.0	
13	6.9					24.9			9.4	2.0		
14	7.6			13.0	80.8					69.6		
15				30.0	3.8		45.5					
16			41.4				5.3					37.3
17	NR								NR		62.7	
18		1.5					25.1					
19							7.6					
20				NR				20.1	NR			9.9
21		1.5										
22				NR		0.5		0.8				
23											5.1	32.0
24			0.3								1.5	3.8
25												
26		13.0	NR			27.7						
27				0.8	1.3	3.3						
28	63.5		87.6		21.1	2.0						65.0
29			27.4	12.2	21.8	7.1				1.0		9.1
30			NR		6.6			5.1				
31								15.5				
Total	121.2	101.2	199.9	172.5	179.1	135.4	117.9	219.2	61.7	86.6	74.2	157.2
Total for year		1626.0										

NR = No reading from weather station.

Vita

Payton Paul Dupree was born in White Castle, Louisiana in 1987. He attended the University of Louisiana at Lafayette and graduated with a Bachelor of Science in Environmental Sustainability with a concentration in Natural Resources and Environmental Quality in December of 2011. In August of 2012 he was hired as a Research Associate by Dr. Brenda Tubana. After working for a year he was offered the opportunity to pursue a Master of Science degree under the guidance of Dr. Brenda Tubana in the School of Plant, Environmental, and Soil Science and began in August of 2013. He graduated in August of 2015 and accepted the position of Health, Safety, and Environmental Specialist offered by Chicago Bridge & Iron.