Effects of Application Timing and Soil Type on Optimal N Rate Requirement of Sugarcane (Saccharum spp.) and Changes in Soil Inorganic and Leaf N Concentrations

Joseph Martin Garrett
Louisiana State University and Agricultural and Mechanical College, jmgarrett360@gmail.com

Follow this and additional works at: https://digitalcommons.lsu.edu/gradschool_theses
Part of the Agriculture Commons

Recommended Citation
https://digitalcommons.lsu.edu/gradschool_theses/4703
EFFECTS OF APPLICATION TIMING AND SOIL TYPE ON OPTIMAL N RATE REQUIREMENT OF SUGARCANE (Saccharum spp.) AND CHANGES IN SOIL INORGANIC AND LEAF N CONCENTRATIONS

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

Joseph Martin Garrett
B.S., Louisiana State University, 2015
May 2018
Acknowledgements

I am blessed by God for the opportunity and continued strength in my pursuit of higher education. Through times of struggle and times of joy I would like to thank everyone who has been an influence towards my education. This manuscript is dedicated to my Grandfather the late Martin Reymond Koch “Cane-cutter Koch,” as he is the main influence who fostered my love and appreciation for nature and sugarcane in Louisiana. As an early sugarcane farmer in the 1950’s, he helped to build the foundation of what sugarcane production has become today. I would also like to thank my parents for their continued support in helping me to challenge myself and become a better person. I would not be who I am today without them or my beautiful sisters: Helen, Jean and Marie.

This research would not have been possible without the guidance of my major professor Dr. Brenda Tubana. She has been a major influence on my deep respect for nature and the stewardship of our cropping systems in Louisiana. She has consistently supported me in my research and facilitated a great working experience that I will never forget or take for granted. I am also very fortunate for my accomplished committee members Dr. Richard Johnson and Dr. Lisa Fultz, and the knowledge I have gained from them.

My co-workers in the soil fertility program have provided constant entertainment and admiration for this field of research and I am proud to know them and appreciative of all the hard work they have put into this project: Samuel Kwakye, Murilo Martins, Marilyn Dalen, Wooiklee S. Paye, Daniel Forestieri “Cunado,” Flávia Bastos Agostinho, and Bruno Nicho. I would also like to thank Ms. Gertrude Hawkins, Mr. Alphonse Coco, and Mr. Todd Robert for their help at the LSU AgCenter Sugar Research station in St. Gabriel, LA as well as Mr. Jeff Corken at the W.A. Callegari Environmental Center.
Table of Contents

Acknowledgements ........................................................................................................... ii

List of Tables .................................................................................................................... iv

List of Figures ..................................................................................................................... v

Abstract ............................................................................................................................. vi

Chapter 1. Introduction ..................................................................................................... 1
  1.1 References .................................................................................................................. 8

Chapter 2. Effect of Nitrogen Fertilizer Application Timing and Soil Type on Optimal Nitrogen Rate Requirement of Louisiana Sugarcane ................................................................. 14
  2.1 Introduction ................................................................................................................ 14
  2.2 Materials and Methods ............................................................................................. 18
  2.3 Results ....................................................................................................................... 24
  2.4 Discussion .................................................................................................................. 42
  2.5 Conclusions .............................................................................................................. 49
  2.6 References ............................................................................................................... 50

Chapter 3. The Relationship of Soil and Leaf Nitrogen Status at Different Critical Growth Stages with Sugarcane Yield ........................................................................................................... 55
  3.1 Introduction ................................................................................................................. 55
  3.2 Materials and Methods ............................................................................................. 59
  3.3 Results ....................................................................................................................... 65
  3.4 Discussion .................................................................................................................. 72
  3.5 Conclusion ................................................................................................................ 78
  3.6 References ............................................................................................................... 79

Chapter 4. Conclusions ..................................................................................................... 83

Vita .................................................................................................................................... 86
List of Tables

Table 2.1. Treatment structure of the study established at the LSU AgCenter Sugar Research Station in St. Gabriel, LA 2016-2017 .................................................................20

Table 2.2. Analysis of variance and p-values for yield and quality components of sugarcane in response to factors year and treatment for each soil type. ..............................................35

Table 2.3. Mean values of cane and sugar yield treated with different N source and rate applied in March and April on two soil types in 2016 and 2017 at the LSU AgCenter Sugar Research Station in St. Gabriel, LA .................................................................36

Table 3.1. Treatment structure of the study established at the LSU AgCenter Sugar Research Station in St. Gabriel, LA, 2016-2017 .................................................................61

Table 3.2. Leaf and soil sampling dates collected at the LSU AgCenter Sugar Research Station in St. Gabriel, LA, 2016-2017 ........................................................................62

Table 3.3. Range and average leaf N content across year, soil type and sampling dates. ........65

Table 3.4. Correlation coefficient (r) between leaf N content measured at different sampling times and yield (stalk and sugar) of cane variety L01-299 grown on clay and silt loam soils at the LSU AgCenter Sugar Research Station in St. Gabriel, LA, 2016-2017 .........................................................68

Table 3.5. Correlation coefficient (r) between leaf N content measured at different sampling times and soil inorganic N (NH₄⁺ and NO₃⁻) of cane variety L01-299 grown on clay and silt loam soils at the LSU AgCenter Sugar Research Station in St. Gabriel, LA, 2016-2017 .....................69
List of Figures

Figure 2.1. Monthly precipitation in 2016 and 2017 and 30 year monthly average precipitation at the LSU AgCenter Sugar Research Station in St. Gabriel, LA .................................................................25

Figure 2.2. Monthly average temperature in 2016 and 2017 and 30 year average temperature at the LSU AgCenter Sugar Research Station in St. Gabriel, LA .................................................................25

Figure 2.3. Ammonium (NH$_4^+$) concentration at 0-15 cm depth of clay and silt loam soil treated with UAN in March and April in 2016 and 2017, LSU AgCenter Sugarcane Research Station in St. Gabriel, LA .................................................................30

Figure 2.4. Ammonium (NH$_4^+$) concentration at 15-30 cm depth of clay and silt loam soil treated with UAN in March and April in 2016 and 2017, LSU AgCenter Sugar Research Station in St. Gabriel, LA .................................................................31

Figure 2.5. Nitrate (NO$_3^-$) concentration at 0-15 cm depth of clay and silt loam soil treated with UAN in March and April in 2016 and 2017, LSU AgCenter Sugar Research Station in St. Gabriel, LA ....................................................................................................................32

Figure 2.6. Nitrate (NO$_3^-$) concentration at 15-30 cm depth of clay and silt loam soil treated with UAN in March and April in 2016 and 2017, LSU AgCenter Sugar Research Station in St. Gabriel, LA ....................................................................................................................33

Figure 2.7. Sugar and cane yield response to different rate and application time of UAN and CRF as N sources, 2016 plant cane on silt loam soil at the LSU AgCenter Research Station in St. Gabriel, LA ....................................................................................................................39

Figure 2.8. Sugar and cane yield response to different rate and application time of UAN and CRF as N sources, 2017 second ratoon crop on clay soil at the LSU AgCenter Research Station in St. Gabriel, LA ....................................................................................................................40

Figure 2.9. Sugar and cane yield response to different rate and application time of UAN and CRF as N sources, 2017 first ratoon crop on silt loam soil at the LSU AgCenter Research Station in St. Gabriel, LA ....................................................................................................................41

Figure 3.1. Relationship of leaf N content with cane yield and sugar yield of cane applied with urea ammonium nitrate solution in March and April on a silt loam soil at the LSU AgCenter Sugar Research Station in St. Gabriel, LA ....................................................................................................................70

Figure 3.2. Relationship of leaf N content with soil ammonium and nitrate concentration of cane applied with urea ammonium nitrate solution in March and April on a silt loam soil at the LSU AgCenter Sugar Research Station in St. Gabriel, LA ....................................................................................................................71
Abstract

Research is limited on the effects of soil types and early nitrogen (N) fertilizer applications to N management strategies in sugarcane (Saccharum spp.) production in Louisiana. This study was established in 2015 at two locations in St. Gabriel, LA to 1) determine the effect of fertilizer application timing and soil type on the optimal N rate requirement and yield of sugarcane and 2) relate the relationship of soil and leaf N content to yield at different growth stages with sugarcane yield. Treatments were set in a randomized block design on a clay soil and in a complete randomized design on silt loam soil, using sugarcane variety L01-299. Granular (Agrocote Max®, 45%N) and solution (urea ammonium nitrate solution-UAN, 32%N) N sources were applied at rates of 45, 90 and 135 kg N ha\(^{-1}\) and at two application timings (March and April). All treatments including a control (0 kg N ha\(^{-1}\)) were replicated four times. Sugarcane yield was recorded at harvest. Sequential sampling of soil were done at two depths (0-15 and 15-30 cm) and leaf below the top visible dewlap (TVD). The N application timing did not have a large effect on inorganic N release within the soil particularly outside the active N uptake growth period of sugarcane. The optimal N rates on the silt loam soil using UAN fertilizer applied in March were 39 and 43 kg N ha\(^{-1}\), yielding 14,102 kg sugar ha\(^{-1}\) and 117 Mg cane ha\(^{-1}\). Yield for sugarcane applied with CRF were maximized at lower N rates, but resulted in lower yields. The positive linear relationship between leaf N content and yield was highest in mid-May sampling with \(r = 0.85\) for cane and sugar yield. Highest correlations between leaf N content and soil inorganic N were all within 8 WANF, with April-applied fertilizer showing high correlations between the two variables earlier than March-applied fertilizer. The dynamic nature of inorganic N in Louisiana can be better understood and more efficiently utilized for sugarcane production through further research on the effects of N management practices and site-specific factors.
Chapter 1. Introduction

Sugarcane (*Saccharum spp.*) is a perennial grass plant hybrid produced in various countries throughout the globe in suitable climates for its growth. Sugarcane has origins from South and Southeast Asia and is best suited for cultivation in warm tropical environments (Fischer et al., 2008). In the United States, sugarcane production is centralized primarily in southern states such as Louisiana and Florida, but is also grown in southern Texas. The National Average Statistical Service of the United States Department of Agriculture recorded 361,343 hectares of sugarcane harvested in the US for the year 2017 equaling to 29.2 million Mg of cane and an average yield of 81 Mg of sugarcane per hectare (USDA-NASS, 2017). It has been a staple Louisiana agronomic crop for the past two centuries by way of economic contribution, continued production and distribution within the state (Hilliard et al., 1979; Kim et al., 2011). Cane crops are mainly valued for their extractable sugar content. Global sugar production hit a record high of 179 million Mg as well as increased consumption in 2017 (USDA-FAS, 2017). Sugarcane is also becoming of more interest for its potential role in biofuel production. However, practical challenges prevent biofuel from being the dominant value and production purpose for sugarcane in the United States (Kim et al., 2011). Other countries such as Brazil have a much larger emphasis on sugarcane biofuel production than the US sugarcane industry (Arruda et al., 2011).

Since sugarcane is a perennial plant, crops can be utilized for multiple growing years by producers. Planting is initiated to start the multi-year growing cycle of the crop. The first year growth directly after planting is termed plant cane. Each consecutive growing season is called a ratoon. As years progress, ratoon decline can take place along with reduced yield potential (Ramburan et al., 2013). Louisiana sugarcane producers usually utilize three ratoon crops before
the field is replanted or rotated with another crop. When planting cane in Louisiana, producers place billets or whole stalk seed cane into open furrows. These vegetative cuttings of a selected cane variety are then covered by soil. From August to September is when Louisiana sugarcane planting reaches its height (Garrison et al., 2000). The growing season for sugarcane in Louisiana spans nine months and the crop is harvested from as early as September to late as January (Beuzelin et al, 2011). Control of the crop is always sought after from producers, and chemical ripeners can be used to achieve favorable uniform maturation times of the cane and ease the harvesting process (Viana et al., 2016). According to the 2017 Louisiana Acreage Report released by the USDA, there were 171,991 hectares of sugarcane harvested in the state for the 2017 year (USDA- LAR, 2017). This is second to harvest acreage of sugarcane in Florida. After harvest, truckloads of billet cane are transported to the mills for processing. Sugar mills in Louisiana are most actively running operations in October. Farmers will typically burn their field after harvest to rid the area of cane residue (Selim et al., 2016).

Advancements in variety development for Louisiana sugarcane support the sustainability and efficiency of the crop. Various sugarcane varieties are continually produced in Louisiana to increase the expression of favorable commodity traits such as yield increase, pest resistance and disease resistance. The main focus of breeding technology for sugarcane is to benefit the sugarcane industry as a whole (Bischoff and Gravois, 2004). Favorable varieties of sugarcane for producers in Louisiana include L01-299 and HoCP96-540 (Kimbeng et al., 2015). Both of these varieties have comparable sugar yield, but express different resistance and susceptibility traits to diseases and pest pressure (Gravois et al., 2014). Sugarcane produces ample amounts of biomass and requires sufficient nutrient input to support the growth and development of the crop.
Furthering the understanding of management practices involved in sugarcane production will aid in the sustainability of cane crops at present and in future practice.

For today’s agricultural standards, nutrient management intervention by fertilization is required to sustain the current progression of yield achievements in US sugarcane production history. Nitrogen (N) is an essential primary macronutrient and can be taken up by plants in two inorganic forms: nitrate (NO$_3^-$) and ammonium (NH$_4^+$) (Masclaux-Daubresse et al., 2010). To meet global demands, N is industrially fixed from the air by the Haber-Bosch process, which involves intense fuel energy input and pressurization, which converts atmospheric di-nitrogen gas (N$_2$) into ammonia (NH$_3$) (Dawson et al., 2010). The synthetic NH$_3$ form of N created from this process is produced in abundance over other forms of N throughout the world (Smil et al., 2001). There are many studies towards developing alternative large scale N$_2$ fixation methods that may not depend as much on intensive energy and pressure input as required by the Haber-Bosch process (Ritter et al., 2017).

Nitrogen is an integral component of chlorophyll in plant leaves, and when deficient can reduce green leaf area and photosynthesis (Bojovic et al., 2009). Nitrogen is also required for plant formation of amino acids (Ramage et al., 2002). Bioavailable N can also be incorporated into the cropping soil by applying or encouraging the establishment of various organic matter substances through no-till and no-burn management practices. The retention and mineralization of sugarcane organic matter after harvest could over time result in the reduction of N fertilizer demand of the crop (Chapman, 1994).

Bioavailable inorganic N can enter a cropping system through both anthropogenic and natural causation. Sugarcane producers can apply different sources of N fertilizers to their crops.
Fertilizer source is not considered a primary concern over convenience and cost, which can be tailored to the unique production system of each individual sugarcane producer (Gravois et al., 2014). Urea ammonium nitrate (UAN, 28-32% N) solution is a common N fertilizer source in present Louisiana sugarcane production (Dattamudi et al., 2016). The popularity of UAN is attributed to relative low cost, high N content, availability and convenience of application for farmers. Many cane producers in south Louisiana have applicators for liquid fertilizer solutions.

Controlled release fertilizer (CRF) is another fertilizer source composed of membrane coated nutrient granules. Water diffuses through the membrane of CRF and dissolves the nutrient contained inside for release into the soil (Shavit et al., 1995). Controlled release fertilizer has the potential to increase Nitrogen Use Efficiency (NUE) by reducing N losses and increasing N recovery percentage in plants (Oertli, 1980; Shoji et al., 2007; Verburg et al., 2016). One study conducted in Australia revealed that applications of CRF compared to conventional urea fertilizer resulted in the increase of yield and NUE of sugarcane (Di Bella et al., 2015). Harmful environmental NO\textsubscript{x} gas emissions can also be reduced by CRF fertilizer (Zwieten et al., 2014). Total fractions of N available to loss are lower in CRF than conventional fertilizers because of the slow release from the membrane coating. Liquid conventional N fertilizers are applied in total and immediately susceptible to losses via volatilization, leaching and denitrification.

Inputs of bioavailable N into a cropping system can also happen through naturally occurring processes. Agriculture soil environments contain microbes which naturally facilitate the conversion of inert or unavailable N into bioavailable form (Vimal et al., 2017). One of these processes is called nitrification and is achieved through bacteria possessing the ability to oxidize ammonia (NH\textsubscript{3}+) present in the soil to NO\textsubscript{3}– (Kowelchuk et al., 2001). Mineralization is also a naturally occurring process where microbes decompose organic matter into inorganic N,
contributing to the bioavailable N pool increase for an agronomic system (Mariano et al., 2016). Another natural process which leads to N fixation and does not involve microbes is achieved through lightning flash reactions with atmospheric N\textsubscript{2} (Fengxia et al., 2016). Lightning produces enough energy to separate N\textsubscript{2} molecules (Ze’dovich et al., 1967). The reaction results in the formation of nitrogen oxides (NO and NO\textsubscript{2}), which are then reduced to NO\textsubscript{3}\textsuperscript{−} and deposited by rainfall to the earth surface (Liang et al., 2015). One study from 1984 was conducted to compare various total lightning fixation experiments and a best estimate was reached of 2.6 x 10\textsuperscript{6} kg N yr\textsuperscript{−1} fixed globally by lightning (Borucki et al., 1984). Although naturally occurring N input processes exist, most sugarcane operations require N fertilization to maintain competitive yields.

There are multiple pathways present in which N can be lost from an agricultural system. This can be defined as N moving away from the possible acquisition from the sugarcane roots. Loss pathways of inorganic N concerning for Louisiana sugarcane production are leaching, runoff, volatilization and denitrification (Thorburn et al., 2011). Nitrogen loss is problematic in agriculture production systems, because it reduces the efficiency of fertilizer applied to crops. Both leaching and runoff occur in rain-fed and irrigated environments. Bioavailable NO\textsubscript{3}\textsuperscript{−} is mobile in soils and exceeds the mobility of NH\textsubscript{4}\textsuperscript{+}, resulting in higher leaching loss potential of NO\textsubscript{3}\textsuperscript{−} (Owen et al., 2000). Ammonium has been shown to be more favorable for sugarcane uptake (de Armas et al., 1992; Robinson et al., 2011; Hajari et al., 2014). Due to its ability to solubilize into a water solution, NO\textsubscript{3}\textsuperscript{−} moves through the soil profile with water away from the root zone of sugarcane plants (Ghiberto et al., 2009). Areas cultivated in sugarcane can also lose N from surface runoff, with severity of loss increased with closer proximity of rainfall events to fertilizer application (Kwong et al., 2001). Ammonia volatilization occurs in dry conditions and is a contributing factor to substantial N loss typically measured to be near 20\% or upper of 40\%
loss of N fertilizer applied (Freney et al., 1992; Cantarella et al., 2008; Mariano et al., 2012; Dattamudi et al., 2016). Leaching, runoff and ammonia volatilization have the potential to contribute to eutrophication in nearby water systems upsetting the ecosystem of the water body effected (Cameron et al., 2013). Under anaerobic conditions, NO$_3^-$ can be transformed into environmentally harmful nitrous oxide gases by the need of the microbial community to utilize NO$_3^-$ as an electron acceptor, which results in significantly reduced efficiency of NO$_3^-$ containing fertilizer (Li et al., 1992; Weier et al., 1996). These N loss pathways are realities to a sugarcane producer experience and results in the reduction of overall NUE. Greenhouse gas emissions and contaminations of water systems through agriculture production contribute negatively to environmental health, human safety and public view of agronomic producers.

Soil tests are sometimes performed to create recommendation rates, but applying N fertilizer based on soil inorganic N readings is controversial in its ability to accurately formulate N fertilizer rate recommendations in south Louisiana soil conditions (Sander et al., 1994). This controversy revolves around the susceptibility of bioavailable N or precursors to bioavailable N to be quickly lost from the agronomic system through multiple loss pathways. One test reading of soil inorganic N may be drastically different from day to day depending on the weather conditions and environments conducive for N loss.

Nutrient limitation can be one of the most important aspects to consider when working towards increases in agronomic crop management efficiency and yield return. Nitrogen is widely comprehended as being a highly depended upon and expensive mineral nutrient input in various agriculture systems (Vitousek et al., 1991; Masclaux-Daubresse et al., 2010). Fertilizer rate is a critical consideration for the increase of NUE in Louisiana sugarcane production. Nitrogen recovery is often calculated to quantify the efficiency of N fertilizer applied by farmers and the
total plant utilization of applied fertilizer. Rate recommendations are typically altered depending on cane crop age and soil type. Optimal N rates positively affect increase in biomass and sugar yield. Developing technologies are showing potential for NUE increase in sugarcane through variable rate technology using reflectance readings of sugarcane biomass (Amaral et al., 2015). This technology counters conventional uniform applications of N (Portz et al., 2011). High N rates have also been shown to have a limit in its ability to increasing sugarcane root and shoot biomass along with N accumulation (Otto et al., 2014). Excessive N rich environments can actually reduce sugar yield through reducing levels of sucrose content (Muchow et al., 1996; Wendler et al., 1991). Sugarcane can also experience a reduction in sucrose content when lodging occurs (Singh et al., 2002). Increasing NUE will help producers to better utilize the resources at hand to produce a more efficient crop.

The goal of optimal N application timing is to match the demand of N from the plant with supply of N fertilizer, so that sugarcane response from the N fertilizer is maximized. State fertilization recommendations from the LSU AgCenter advise farmers to apply in the month of April (Gravois et al, 2014). In some cases, late application of N fertilizer in May has been shown to not have a major decrease in sugarcane yield in Louisiana (Lofton and Tubana, 2015). However, various rainfall patterns can prevent farmers from applying fertilizer when recommended. Based on the severity of rainfall, equipment access to water logged fields may not be possible. Other various factors like equipment failure or farm size could also prevent producers from applying N fertilizer within a one month period. A lack of research exists looking at the significance of early N fertilization applications in March. If March applications do not compromise production the window of N application could be increased.
Regardless of proper nutrient management and implementation, uncontrollable factors have an influence over sugarcane yields. Changes in weather patterns have the ability to vary sugarcane yields throughout each growing season (Kumar, 1984). Some sugarcane growing seasons are more conducive for sugarcane growth and result in higher yields. A study published in 2005 takes an in depth view on the relationship between climate variability and sugarcane yield in Louisiana. Results from this study indicate that relative increases in temperature and reduction in rainfall can lead to higher sugarcane yields within Louisiana (Greenland, 2005).

There is a continued need to improve the nutrient management strategies of agronomic systems across the nation. As the world population increases, so is the advancement of fertilization practices on agronomic food crops (Vitousek et al., 1997; Hirel et al., 2007). Movement in the direction towards higher yields per land base area will not only benefit producer efficiency, but will also increase advancement toward food security and environmental stewardship. The opportunity of this study lends benefit to increasing efficiency for the production of sugarcane across the United States in comprehension and better implementation of nutrient management practices. In order to further the discovery of truth behind sugarcane N management practices, the objectives of this study were to 1) analyze the effects of N application timing on yield and optimal N rate requirement of sugarcane grown on two soil texture types (coarse and fine), and 2) evaluate the relationship of soil inorganic N content and leaf N % at various growth stages with sugarcane yield.

1.1 References


Chapter 2. Effect of Nitrogen Fertilizer Application Timing and Soil Type on Optimal Nitrogen Rate Requirement of Louisiana Sugarcane

2.1 Introduction

Sugarcane (*Saccharum spp.*) is a perennial grass plant hybrid produced in various countries under suitable climate conditions. Sugarcane has origins from South and Southeast Asia and is best suited for cultivation in warm tropical environments (Fischer et al., 2008). In the United States, sugarcane production is centralized primarily in southern states including Louisiana, Florida, and Southern Texas. In 2017, the total area of sugarcane harvested in the United States was 361,343 hectares equaling to total production of 29.2 million Mg of cane with an average yield of 81 Mg ha$^{-1}$ (USDA-NASS, 2017). It has been a primary agronomic crop in Louisiana for the past two centuries by way of economic contribution, continued production and distribution within the state (Hilliard et al., 1979; Kim et al., 2011). Cane crops are mainly valued for their extractable sugar content. Global sugar production hit a record high at 179 million Mg as well as increased consumption in 2017 (USDA-FAS, 2017). Sugarcane is also becoming of more interest for its potential role in biofuel production. However, practical challenges prevent biofuel from being the dominant value and production purpose for sugarcane in the United States (Kim et al., 2011). Other countries such as Brazil have a much larger emphasis on sugarcane biofuel production than the US sugarcane industry (Arruda, 2011).

Sugarcane in Southern Louisiana is commonly cultivated on alluvial soils. Many cane fields are established by farmers near the Mississippi River. Louisiana has a large variety of alluvial soils with common soil series including Sharkey and Commerce (Weindorf et al., 2013). Sharkey clay and Commerce silt loam are common soil types within proximity to the Mississippi River. For cultivation purposes, both soil types tend to contain sufficient levels of phosphorous
(P) and potassium (K), but low nitrogen (N) content according to the USDA Soil Survey of East Baton Rouge Parish (USDA, 1968). Soil properties such as texture can have an impact on retention of bio-available N in a soil system (Volpi et al., 2017). Denitrification can be expected to occur at higher rates in fine textured soils compared to coarse (Groffman et al., 1992). Not only can soil texture influence the increase or decrease of inorganic N loss, but has also been shown to have an impact on N mineralization of soil organic matter (Herlihy, 1979; Cote et al., 2000; McLauchlan, 2006).

Nitrogen is an integral component of chlorophyll in plant leaves, and when deficient it can reduce green leaf area and photosynthesis (Bojovic et al., 2009). Nitrogen is also required for plant formation of amino acids (Ramage et al., 2002). Bioavailable N can also be incorporated into the cropping soil by applying or encouraging the establishment of various organic matter substances through minimum till and no-burn management practices (Graham et al., 2002). The retention and mineralization of sugarcane organic matter after harvest could over time result in the reduction of N fertilizer demand of the crop (Chapman, 1994).

There are many different methods for testing soil inorganic N. Some methods may be more reliable than others for N rate recommendations, based on the stability of N for individual soil systems. The most common simultaneous extracting solution for NH$_4^+$ and NO$_3^-$ is 1 M potassium chloride (KCl) (Pansu et al., 2006). Other common extracting salt solutions for inorganic N are potassium sulfate (K$_2$SO$_4$) and calcium sulfate (CaSO$_4$) (Li et al., 2012). Spectrophotometry is often used to quantify the concentration of inorganic N, once it is extracted from soil samples (Pasquali et al., 2007). Soil tests are sometimes performed to create recommendation rates, but applying N fertilizer based on soil inorganic N readings is controversial in its ability to accurately formulate N fertilizer rate recommendations in southern
Louisiana soil conditions (Sander et al., 1994). This controversy revolves around the susceptibility of bioavailable N or precursors to bioavailable N to be quickly lost from the agronomic system through multiple loss pathways. One test reading of soil inorganic N may be drastically different from day to day depending on the weather conditions and environments conducive for N loss.

Optimal N fertilization rates can vary based on crop cycle (plant cane or ratoon cane) and soil type (coarse or fine). Nitrogen rates within Louisiana range from 67 kg N ha\(^{-1}\) to 135 kg N ha\(^{-1}\) (Gravois et al., 2014). Consideration for application timing is also an important factor that is coupled with optimal N rate application to increase N use efficiency (NUE). The goal of optimal N application timing is to match the demand of N with the plant, so that sugarcane N fertilizer use is maximized. In Texas, Thomas et al. (1984) reports that application timing can have an effect on sugarcane growth and quality parameters. In Louisiana, late application of N fertilizer showed no negative effect on sugarcane yield, suggesting that the window of application can be extended by one month (Lofton and Tubana, 2012). Reports from Texas show that N application timing can be within a two month period at N fertilizer rate >224 kg N ha\(^{-1}\) for ratoon crops, which further suggests the extension of N fertilizer application times past a one month period (Wiedenfeld, 1997).

Sugarcane growth periods can be characterized by five stages: germination, seedling, tillering, grand growth and maturation (Lin et al., 2009). Sugarcane response to N fertilization may be affected by water stress in periods of rapid growth, such as the grand growth period and also by yearly variation in temperature (Wiedenfeld, 2000; Forestieri, 2017). Drought stress on the other hand is not a typical concern for sugarcane production in Louisiana. The USDA and LSU AgCenter advise farmers to apply N fertilizer in the month of April (Johnson et al., 2008;
Gravois et al., 2014). However, various rainfall patterns can prevent farmers from applying fertilizer as recommended. Based on the severity of rainfall, equipment access to water logged fields may not be possible. Various other factors like equipment failure or farm operation size could also prevent producers from applying N fertilizer within a one month period. Currently, there is limited information on the effect of early N fertilization in Louisiana sugarcane production systems.

Nitrogen is an essential primary macronutrient and can be taken up by plants in two inorganic forms: nitrate (NO$_3^-$) and ammonium (NH$_4^+$) (Masclaux-Daubresse et al., 2010). There are multiple transformations of soil inorganic N, which makes it susceptible to loss into the atmosphere and bodies of water (Thorburn et al., 2011). Due to these transformations, efficient N fertilizer management can be compromised. Loss pathways of inorganic N concerning for Louisiana sugarcane production are leaching, runoff, volatilization and denitrification (Freney et al., 1992; Owen et al., 2001; Thorburn et al., 2011). Soil type has been shown to influence the accumulation of inorganic N forms with consideration to the different loss pathways; NO$_3^-$ for example has a higher accumulation potential in well aerated soil compared to soil types with poor aeration (Buresh et al., 2008). The effect of soil type can also be seen in soil NO$_3^-$ concentrations, as leaching potential is greater in soils with fast infiltration rates and good aggregation compared to soils with slow infiltration and poor aggregation (Zhao et al., 2007). The more time applied fertilizer N spends in certain soil types, the more exposed it is to loss pathways, making application timing and soil type crucial factors for N management.

Understanding soil inorganic N distribution and the effects of soil type and application timing on yield production for sugarcane in Louisiana will give insight on optimal N rate applications and contribute to the precision of N management within the state. The main
objective for this study was to document the impact of N application timing on yield and optimal N rate requirement of sugarcane grown on coarse and heavy textured soil. To accomplish this objective, 1) the distribution and changes in soil NO$_3^-$ and NH$_4^+$ content within 0-15 and 15-30 cm depth of two soil types (silt loam and clay) applied with UAN at two different times of application (March and April) was documented, and 2) the effect of N application timing on the optimal N rate requirement of sugarcane using UAN and CRF N source was determined.

2.2 Materials and Methods

2.2.1 Site Description, Planting Method, and Treatment Structure

Two sites were selected for this research. Sites were located in Iberville parish, Louisiana at the St. Gabriel LSU AgCenter Sugar Research Station. Soil survey information was acquired through the Natural Resources Conservation Service (NRCS) soil survey website, and was utilized to determine soil distribution of each site location. Site 1 has a mixture of Sharkey clay (very-fine, smectitic, thermic Chromic Epiaquerts) and Commerce silty clay loam soil, with Sharkey clay being the dominant soil type (NRCS, 2018). It is a heavy textured clay soil with poor drainage. Site 1 will be referred to as clay soil and has a total area of 7826 m$^2$ (1.9 acres). Site 2 consists of a light textured and well drained Commerce silt loam (fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts) soil type (NRCS, 2018). Site 2 has a total area of 5844 m$^2$ (1.4 acres) and will be referred to as silt loam soil. Both are alluvial soils located near the Mississippi River. In proximity to the river, Site 1 is 800 m (2,624 ft) away and Site 2 is closer within 600 m (1,968 ft) distance from the river. Latitude and longitude of site 1 and 2 is: 30.26639°, -91.09741° and 30.26852°, -91.10578°. The length of this experiment spanned the course of two harvest seasons (2 years), 2016 and 2017.
Both sites were planted with sugarcane variety L01-299. Soil was mechanically disked before planting. Seed cane (whole stalks) measuring about 1 meter in length were placed by hand from a tractor wagon into open furrows. All stalks placed to have a minimum of 8 cm overlap before covered by soil the same day. Site 1 was planted in October 2014 and Site 2 was planted in October 2015. For Site 2, a 1.5 m (5 ft) alley gap was arranged by not placing stalks in order to separate treatment plots.

A total of 18 treatments were implemented on Site 1 and Site 2. For the purpose of this study, selected treatments were used to address the objectives of this study and are presented in Table 2.1. Site 1 (clay soil) was a randomized block design (RBD) with treatment plots 15 m (50 ft) long and 5.5 m (18 ft) (3-rows) wide. Site 2 (silt loam soil) was a complete randomized design (CRD) with treatment plots 12 m (40 ft) long and also 5.5 m wide. Buffer rows were placed on the south east side of both Sites. Treatments were divided by N fertilizer source, N fertilizer application timing and N rate. Each treatment was replicated four times for both sites. The different fertilizer sources were urea ammonium nitrate (UAN, 32% N) solution and granular Agrocote Max® Controlled-Release Fertilizer (CRF, 45% N). The two application timings were March and April. Three N fertilizer rates were applied along with a control (0 N) rate for each site at: 45, 90 and 135 kg N ha\(^{-1}\). Twelve treatments in total were established for both years of this experiment. Along with N application, a uniform standard application rate of potassium (90 kg K ha\(^{-1}\)) was also applied on all treatment plots using muriate of potash (MOP, 50% K). A detailed chart of the treatment structure is presented in Table 2.1.
Table 2.1. Treatment structure of the study established at the LSU AgCenter Sugar Research Station in St. Gabriel, LA 2016-2017.

<table>
<thead>
<tr>
<th>Treatment Number</th>
<th>Application Time</th>
<th>N Source</th>
<th>N Rate (kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Control (April)</td>
<td>UAN</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>March</td>
<td>UAN</td>
<td>45</td>
</tr>
<tr>
<td>3</td>
<td>March</td>
<td>UAN</td>
<td>90</td>
</tr>
<tr>
<td>4</td>
<td>March</td>
<td>UAN</td>
<td>135</td>
</tr>
<tr>
<td>5</td>
<td>March</td>
<td>CRF</td>
<td>90</td>
</tr>
<tr>
<td>6</td>
<td>March</td>
<td>CRF</td>
<td>135</td>
</tr>
<tr>
<td>7</td>
<td>April</td>
<td>UAN</td>
<td>45</td>
</tr>
<tr>
<td>8</td>
<td>April</td>
<td>UAN</td>
<td>90</td>
</tr>
<tr>
<td>9</td>
<td>April</td>
<td>UAN</td>
<td>135</td>
</tr>
<tr>
<td>10</td>
<td>April</td>
<td>CRF</td>
<td>45</td>
</tr>
<tr>
<td>11</td>
<td>April</td>
<td>CRF</td>
<td>90</td>
</tr>
<tr>
<td>12</td>
<td>April</td>
<td>CRF</td>
<td>135</td>
</tr>
</tbody>
</table>

UAN – Urea Ammonium Nitrate; CRF – Control Release Fertilizer; MOP – Muriate of Potash

2.2.2 Fertilization

The CRF was evenly distributed by hand to each row within each corresponding treatment plot. The mass of N ha\(^{-1}\) was converted to mass of N for individual rows (kg N ha\(^{-1}\) to g N row\(^{-1}\)) to achieve correct application rates for the different treatments. To simplify the process and minimize application error, plastic bags containing appropriate CRF weights were assigned and placed on each row the day of fertilization. For UAN application, the solution was knifed-in mechanically into the shoulder of each row using a variable rate pump tank on a tractor with a hydraulic knife-in implement. The implement consisted of six knife-in components capable of double shoulder, three row UAN applications. Before UAN application, the pump tank was calibrated to appropriate N rate treatments. March treatment fertilizer applications occurred on the 23\(^{rd}\) and 15\(^{th}\) for 2016 and 2017 on both sites. April treatment fertilizer applications occurred on the 25\(^{th}\) and 19\(^{th}\) for 2016 and 2017 on both sites.
2.2.3 Soil Sampling

Soil samples were collected manually using JMC® foot step samplers with a 30 cm sample depth capability. Soil was placed directly into paper bags upon sampling. Every plot in each soil type (Site 1 and Site 2) was sampled every two weeks after each fertilization date (March and April) and after every harvest for years 2016 and 2017. Soil sample dates for Site 1 and 2, 2016 were: April 6th, April 19th, May 5th, May 16th, May 31th and Nov. 16th (after harvest). Soil sample dates for Site 1 and 2, 2017 were: March 29th, April 12th, April 26th, May 10th, May 26th and Oct. 18th (after harvest). Four samples were taken on each shoulder of each row within the plots resulting in sixteen, 0-30 cm samples. Each soil core sample was separated into 0-15 cm and 15-30 cm. Soil samples were immediately placed into an oven at 60° C for a minimum of three days (72 hours) and processed through a stainless steel Humboldt soil grinder. Samples were then placed into enclosed 120 ml plastic cups and stored at room temperature pre-laboratory analysis.

2.2.4 Soil Analysis

To determine soil NH$_4^+$ and NO$_3^-$ concentrations, processed soil samples were extracted using the KCl extraction procedure. To accomplish this, 5 grams of soil were weighed and placed inside a 125 ml plastic bottle. Each bottle was then filled with 35 ml of 1 M KCl and placed on a reciprocal shaker for 1 hour. The soil solution was then filtered using No. 42 Whatman® filter paper. Once filtered, samples were refrigerated until auto analyzed for NH$_4^+$-N and NO$_3^-$-N. Simultaneous auto analysis of NH$_4^+$ and NO$_3^-$ was completed through calorimetry readings using a flow injection analyzer (FIA; Lachat QuickChem 8500 series 2). Through FIA procedures, NO$_3^-$-N is quantified by the reduction of NO$_3^-$ to NO$_2^-$ when passing through a
cadmium column and the reaction of NO$_2^-$ with a sulfanilamide reagent. The NH$_4^+$-N is quantified by its reaction with salicylate when heated. Both inorganic N determinations are measured by calorimetry at 520 nm (NO$_3^-$) and 660 nm (NH$_4^+$). This procedure was similar to the one discussed in a review by Pasquali et al. (2007) of simultaneous NH$_4^+$ and NO$_3^-$ FIA.

2.2.5 Yield and Quality Parameter Determination

Cane yield was determined for individual rows within plots. A single-row combine was used to cut stalks from the base and cut them further into billets. A weigh wagon with an electronic load cell was used to collect harvested billets from the combine and determine cane yield weight of each row. Flag markers were carried and waved to signal the end of each row to the combine and wagon operators. The wagon scale was tared after the stalk weight for each row was collected and recorded by the wagon operator.

To determine quality parameters, ten cane stalks were sampled from the middle row of each plot during harvest. The non-millable portions of the cane stalk at the distal end of the plant were cut and the leaves were stripped. Stalks were then shredded and analyzed by a SpectraCane NIR analyzer (Bruker Corporation, Billerica, Massachusetts). Results of analysis included quality parameters such as: theoretical recoverable sugars (TRS), brix, sucrose purity, polarity, moisture and fiber. Sugar yield was determined as the product of TRS and cane tonnage.

2.2.6 Data Analysis and Climate Record Compilation

Collected data was analyzed through SAS 9.4 software. Analysis of variance was conducted to determine two-way ANOVA interactions between year and N treatment for both soil types. Cane yield, sugar yield and quality parameters were analyzed as the major response variables. Optimal N rates for specified years and soil types showing significant differences were
estimated using the linear-plateau model (PROC NLIN in SAS). Trend of NH$_4^+$ and NO$_3^-$ concentration at 0-15 and 15-30 cm across sampling dates from 2016 and 2017 was graphed using Microsoft Excel software.

The plateau represents the maximized yield. The intercept represents the sugarcane yield at 0 applied N and the joint is the corresponding optimal N rate aligned with the yield plateau. The model formula used for optimal N rate determination from this output is as follows where $Y =$ sugarcane yield parameter:

$$Y = (\text{slope}) \times (\text{N rate}) + (\text{intercept}) \text{ if N rate}<\text{joint, if N rate}>\text{joint} \text{ } Y=\text{plateau}$$

There were four N rates for UAN applied plots 0, 45, 90 and 135 kg N ha$^{-1}$ for both March and April applications. The CRF rates for April were also 0, 45, 90 and 135 kg N ha$^{-1}$, but only 0, 90 and 135 kg N ha$^{-1}$ for March applied plots. This can be seen in the treatment design (Table 2.1). For this reason, linear plateau models were not acceptable to generate for only three N rates of the CRF March applied plots. In order to compare yields of CRF March applications with UAN March applications, bar graphs containing the standard error ranges were made. The N rate comparison was determined by the optimal UAN March rate from the linear plateau model.

For utilization and insight on St. Gabriel climatic patterns, data was collected for two specific environmental factors. For each month the average temperature and precipitation readings were taken from the LSU AgCenter Louisiana Agriclimatic Information System from January 2016 to December 2017, as well as the 30 year average readings for temperature and precipitation.
2.3 Results

2.3.1 Temperature and Precipitation Conditions

Seven of the twelve months in 2016 and 2017 had higher precipitation totals than the 30 year average (Figure 2.1). Specifically, the 30 year average for monthly precipitation totals was lower from months of March to August, when sugarcane was in its rapid growth period compared to both study year precipitation totals for those months. Higher monthly precipitation occurred in 2016 compared to 2017 when the first fertilizer applications were applied in March. When the second fertilizer applications were applied in April, 2017 monthly precipitation was higher compared to 2016. The sum of precipitation for year 2016 was higher than in year 2017, reaching a total amount of 197 cm, whereas it was 169 cm for year 2017. According to the 30 year average temperatures presented in Figure 2.2, both years followed the same trend having similar average monthly temperatures for both 2016 and 2017. Research from Clements (1980) reports optimal growth temperatures for sugarcane to be from 25 °C to 35 °C. During the most rapid period of sugarcane growth in Louisiana (May, June and July), average monthly temperatures were similar and ranged from 23 °C to 28 °C for year 2016 and 22 °C to 27 °C for year 2017.
Figure 2.1. Monthly precipitation in 2016 and 2017 and 30 year monthly average precipitation at the LSU AgCenter Sugar Research Station in St. Gabriel, LA.

Figure 2.2. Monthly average temperature in 2016 and 2017 and 30 year average temperature at the LSU AgCenter Sugar Research Station in St. Gabriel, LA.
2.3.2 Effect of Soil Type and Application Timing on Changes in Soil Inorganic N

Site 1 (clay) and Site 2 (silt loam) soil showed large changes in soil NH$_4^+$ and NO$_3^-$ concentration between sampling dates in 2016 and 2017 (Figures 2.3 to 2.6). The NH$_4^+$ levels for both soils had similar concentration ranges at the 0-15 cm depth (Figure 2.3). The NH$_4^+$ concentration in control plots were consistently lower than UAN-treated plots. On average (control and UAN-treated plots), the clay soil NH$_4^+$ concentration ranged from 5-32 mg kg$^{-1}$, while the silt loam soil NH$_4^+$ concentrations ranged from 2-27 mg kg$^{-1}$ in year 2016 (Figures 2.3 and 2.4). The range of NH$_4^+$ soil concentration was narrower in year 2017 with the clay soil having 4-8 mg NH$_4^+$ kg$^{-1}$ and 3-19 mg NH$_4^+$ kg$^{-1}$ for the silt loam soil.

Notable peaks in NH$_4^+$ concentration were observed in the clay soil applied with UAN in March; sampling dates include 6-Apr (17 mg kg$^{-1}$) and 5-May (32 mg kg$^{-1}$) in 2016 which were 2 and 6 weeks after N fertilization (WANF), respectively. In 2017, NH$_4^+$ peaks were observed at later sampling dates (4 and 8 WANF) at substantially lower concentrations. For the silt loam soil, the NH$_4^+$ concentration peaked 2 and 6 WANF in 2016 then 2 and 4 WANF in 2017. All these dates where NH$_4^+$ concentration peaked are within the time frame of N fertilizer application in Louisiana sugarcane production systems. In 2017, NH$_4^+$ concentration in the silt loam soil was higher than the clay soil.

The UAN April-applied soil (0-15 cm depth) had notable NH$_4^+$ peaks in the clay soil 2 WANF in 2016; concentration peaks were not as notable in 2017, but occurred 4 WANF. Compared to NH$_4^+$ concentration peaks in UAN March-applied soil, UAN April-applied soil peaked in NH$_4^+$ concentration faster within the clay soil (Figure 2.3). Results for NH$_4^+$ concentration peaks were similar in the 2016 silt loam soil, showing peaked NH$_4^+$ levels 2
WANF for UAN April-applied soil, which again is faster than NH$_4^+$ concentration peak time for UAN March-applied silt loam soil at 6 WANF (Figure 2.3). Regardless of application time and soil type in 2016, NH$_4^+$ concentrations peaked at the same time for UAN March- and April-applied soil on 5-May. However, in 2017 UAN March-applied soil NH$_4^+$ peaked sooner (2 WANF) than NH$_4^+$ concentration in UAN April-applied silt loam soil (4 WANF) (Figure 2.3).

Figure 2.5 shows the varying levels of soil NO$_3^-$ concentrations for the March- and April-applied UAN along with the control for both soil types at 0-15 cm depth. The NO$_3^-$ concentrations were consistently lower in control plots compared to UAN-fertilized plots. The overall NO$_3^-$ concentration for the clay soil across both application times in 2016 and 2017 ranged from 2-25 mg kg$^{-1}$ and 1-8 mg kg$^{-1}$, respectively. In the silt loam soil, overall NO$_3^-$ concentration ranges for 2016 and 2017 were 3-34 mg kg$^{-1}$ and 2-33 mg kg$^{-1}$. The concentration range for NO$_3^-$ in the clay soil is smaller in 2017 than 2016 by 17 units. However, for the silt loam soil, overall NO$_3^-$ differences in range between 2016 and 2017 was only 1 unit.

Notable UAN March-applied soil (0-15 cm depth) concentration peaks for NO$_3^-$ in the 2016 clay soil were on 19-Apr 4 WANF and 16-May 8 WANF (Figure 2.5). In 2017, soil NO$_3^-$ concentration peaks occurred on 29-March 2 WANF and 10-May 8 WANF, but were substantially lower in concentration than in 2016. In the silt loam soil, peaked NO$_3^-$ concentrations occurred on 6-April 2 WANF and 5-May 6 WANF. The UAN March-applied soil in 2017 peaked in NO$_3^-$ concentration 2 WANF on 29-March and was larger than the UAN April-applied soil NO$_3^-$ concentration peak.

In general, plots which were fertilized with UAN in April had consistently lower soil NO$_3^-$ concentration across sampling dates than plots fertilized in March for both soil types at 0-
15 cm depth (Figure 2.5). The sampling dates where the highest NO$_3^-$ concentration recorded for clay soil applied with UAN in March for 2016 and 2017 were on 16-May (16 mg kg$^{-1}$, 4 WANF) and 29-March (6 mg kg$^{-1}$, 2 WANF), respectively. For the silt loam soil, the highest NO$_3^-$ concentration was obtained from plots treated with UAN in March for 2016 and 2017 were on 5-May (34 mg kg$^{-1}$, 2 WANF) and 29-March (32 mg kg$^{-1}$, 2 WANF). The UAN April-applied soil NO$_3^-$ concentrations peaked sooner after fertilization compared to UAN March-applied soil NO$_3^-$ peaks, at 2 WANF for both soil types in 2016 (Figure 2.5). However in 2017, NO$_3^-$ concentration peaks were observed at 4 WANF for UAN April-applied soil, compared to 2 WANF for UAN March-applied soil.

Soil NH$_4^+$ and NO$_3^-$ concentrations at depths 15-30 cm highly differed from 0-15 cm depths (Figures 2.4 and 2.6). In both years, NH$_4^+$ and NO$_3^-$ concentrations at the 15-30 cm depth were generally lower than the 0-15 cm depth for the clay soil. However, the magnitude of difference within NO$_3^-$ and NH$_4^+$ concentrations between 0-15 and 15-30 cm depths was smaller in the silt loam soil than the clay soil. Effect of N treatment on soil inorganic N concentration was not apparent in 2017 for the clay soil at 15-30 cm sampling depths. The silt loam soil treated with UAN had higher NH$_4^+$ and NO$_3^-$ concentrations than the soil without N applied (control) for both years.

The NO$_3^-$ silt loam soil concentrations were highest in 2016 UAN March-applied soils, peaking on 5-May (24 mg kg$^{-1}$, 6 WANF). The effect of March and April UAN application on NH$_4^+$ concentrations was comparable in 2016, both peaking on 5-May (20 mg kg$^{-1}$, 6 and 2 WANF) on silt loam soil. In 2017, UAN April-applied soils had the highest NH$_4^+$ concentration on 12-April (23 mg kg$^{-1}$), which was before N application on 19-April. However, standard error bars for this data point show a range of 24 mg kg$^{-1}$ error (Figure 2.4). The control plots had
comparatively low NH$_4^+$ and NO$_3^-$ concentration peaks (15-30 cm depth) than UAN-treated soil, with highest N concentration peaks recorded in the silt loam soil at 10 mg NH$_4^+$ kg$^{-1}$ and 5 mg NO$_3^-$ kg$^{-1}$ (Figures 2.4 and 2.6).
Figure 2.3. Ammonium (NH$_4^+$) concentration at 0-15 cm depth of clay and silt loam soil treated with UAN in March and April in 2016 and 2017, LSU AgCenter Sugarcane Research Station in St Gabriel, LA.
Figure 2.4. Ammonium ($\text{NH}_4^+$) concentration at 15-30 cm depth of clay and silt loam soil treated with UAN in March and April in 2016 and 2017, LSU AgCenter Sugar Research Station in St. Gabriel, LA.
Figure 2.5. Nitrate (NO$_3^-$) concentration at 0-15 cm depth of clay and silt loam soil treated with UAN in March and April in 2016 and 2017, LSU AgCenter Sugar Research Station in St. Gabriel, LA.
Figure 2.6. Nitrate (NO₃⁻) concentration at 15-30 cm depth of clay and silt loam soil treated with UAN in March and April in 2016 and 2017, LSU AgCenter Sugar Research Station in St. Gabriel, LA.
2.3.3 Effect of N Application Timing and Soil Type on the Optimal N Rate Requirement of Sugarcane

The analysis of variance revealed that cane and sugar yield of sugarcane planted on clay and silt loam soil were significantly different between years and treatments (Table 2.2.). The two-factor interaction effect was significant only on cane yield for the clay soil. All quality parameters were significantly different from year 2016 to 2017 for both soil types. The treatment and year x treatment interaction effects were significant for only a few quality parameters and were not consistent on both soils. The optimal N rate for sugar and cane yield using linear plateau models were made for each year of each soil type, but not for the clay soil in 2016.

The average yields for both cropping seasons (2016-2017) along with standard error are presented in Table 2.3. In 2016 clay soil, the control plots had higher yield than most of the plots fertilized with N. Essentially, there was no significant response of both cane and sugar yield to N fertilizer. For this reason, there was no further analysis made i.e., optimal N rate estimation based on linear plateau model. The cane on silt loam soil had higher yield response to N for both years compared to the cane on clay soil. Cane planted on silt loam soil had higher yield than cane planted on clay soil in 2016, which coincided with the lower soil inorganic N concentrations in 2017 (Figures 2.3 and 2.4). Although sugarcane yields in 2017 silt loam soil were lower than 2016, cane planted in silt loam still achieved a higher average yield than cane planted on clay soil for both years.
Table 2.2. Analysis of variance and $p$-values for yield and quality components of sugarcane in response to factors year and treatment for each soil type.

<table>
<thead>
<tr>
<th>Soil</th>
<th>Factors</th>
<th>DF</th>
<th>Cane Yield</th>
<th>Sugar Yield</th>
<th>TRS</th>
<th>Brix</th>
<th>Sucrose</th>
<th>Purity</th>
<th>Polarity</th>
<th>Moisture</th>
<th>Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>Year (Y)</td>
<td>1</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.0086</td>
<td>&lt;0.0001</td>
<td>0.0006</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Treatment (T)</td>
<td>11</td>
<td>0.0041</td>
<td>0.0171</td>
<td>0.7994</td>
<td>0.5894</td>
<td>0.757</td>
<td>0.9182</td>
<td>0.7486</td>
<td>0.9312</td>
<td>0.508</td>
</tr>
<tr>
<td></td>
<td>Y*T</td>
<td>11</td>
<td>0.3517</td>
<td>0.0253</td>
<td>0.0454</td>
<td>0.0555</td>
<td>0.0428</td>
<td>0.1096</td>
<td>0.0427</td>
<td>0.0674</td>
<td>0.0959</td>
</tr>
<tr>
<td>Silt Loam</td>
<td>Year</td>
<td>1</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.002</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Treatment</td>
<td>11</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.2723</td>
<td>0.1078</td>
<td>0.2162</td>
<td>0.6582</td>
<td>0.2103</td>
<td>0.0272</td>
<td>0.0647</td>
</tr>
<tr>
<td></td>
<td>Y*T</td>
<td>11</td>
<td>0.0039</td>
<td>0.0024</td>
<td>0.9081</td>
<td>0.5436</td>
<td>0.8537</td>
<td>0.9812</td>
<td>0.8435</td>
<td>0.8659</td>
<td>0.6994</td>
</tr>
</tbody>
</table>

Treatment – combinations of two application timings and N sources including control
DF – Degrees of Freedom (numerator)
TRS – Theoretical Recoverable Sugar
Significant interaction measured by probability of making a type I error $< \alpha=0.05$
Table 2.3. Mean values of cane and sugar yield treated with different N source and rate applied in March and April on two soil types in 2016 and 2017 at the LSU AgCenter Sugar Research Station in St. Gabriel, LA.

<table>
<thead>
<tr>
<th>Time</th>
<th>Source</th>
<th>N Rate kg ha⁻¹</th>
<th>Site 1 - Clay Soil</th>
<th>Site 2 - Silt Loam Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>2016 (1ˢᵗ Ratoon)</td>
<td>2017 (2ⁿᵈ Ratoon)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2016 (Plant Cane)</td>
<td>2017 (1ˢᵗ Ratoon)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cane Yield Mg ha⁻¹</td>
<td>Sugar Yield kg ha⁻¹</td>
<td>Cane Yield Mg ha⁻¹</td>
</tr>
<tr>
<td>Control</td>
<td>0</td>
<td>73</td>
<td>8346</td>
<td>53</td>
</tr>
<tr>
<td>March</td>
<td>UAN 45</td>
<td>65</td>
<td>7320</td>
<td>57</td>
</tr>
<tr>
<td>March</td>
<td>UAN 90</td>
<td>67</td>
<td>6788</td>
<td>61</td>
</tr>
<tr>
<td>March</td>
<td>UAN 135</td>
<td>78</td>
<td>8390</td>
<td>67</td>
</tr>
<tr>
<td>March</td>
<td>CRF 90</td>
<td>68</td>
<td>7453</td>
<td>67</td>
</tr>
<tr>
<td>March</td>
<td>CRF 135</td>
<td>67</td>
<td>7453</td>
<td>60</td>
</tr>
<tr>
<td>April</td>
<td>UAN 45</td>
<td>65</td>
<td>7040</td>
<td>62</td>
</tr>
<tr>
<td>April</td>
<td>UAN 90</td>
<td>68</td>
<td>7496</td>
<td>61</td>
</tr>
<tr>
<td>April</td>
<td>UAN 135</td>
<td>81</td>
<td>9264</td>
<td>69</td>
</tr>
<tr>
<td>April</td>
<td>CRF 45</td>
<td>76</td>
<td>8828</td>
<td>62</td>
</tr>
<tr>
<td>April</td>
<td>CRF 90</td>
<td>73</td>
<td>7856</td>
<td>69</td>
</tr>
<tr>
<td>April</td>
<td>CRF 135</td>
<td>67</td>
<td>7065</td>
<td>65</td>
</tr>
<tr>
<td>SE ±</td>
<td>1.7</td>
<td>249.6</td>
<td>1.7</td>
<td>166.7</td>
</tr>
</tbody>
</table>

UAN – Urea Ammonium Nitrate; CRF – Controlled Release Fertilizer
SE ± = Standard Error plus or minus given value
Sugar and cane yield response to N rate and application time (for both UAN and CRF as N sources) of the 2016 plant cane on silt loam soil is presented in Figure 2.7. The optimal N rates for sugar yield and cane yield based on linear plateau analysis were 39 and 43 kg N ha\(^{-1}\), respectively, using UAN as N source applied in March. The optimal N rate for sugar yield showed near significance (\(p\)-value=0.067), while the cane yield resulted in higher significance (\(p\)-value=0.023). The April-applied UAN and CRF had similar optimal N rates but has lower \(r^2\) correlations compared to UAN March-applied cane. To compare optimal N rates between N sources applied in March the 90 kg N ha\(^{-1}\) rate was chosen, as this was the closest March-applied CRF N rate to compare with the optimal N rate of March-applied UAN source of 39 kg N ha\(^{-1}\) (Figure 2.7). The UAN source performed significantly better than CRF in March N applications, with the average sugar yield achieving 14,385 kg sugar ha\(^{-1}\) at 90 kg N ha\(^{-1}\) in contrast to the CRF sugar yield of 13,067 kg sugar ha\(^{-1}\). The comparison of cane yield between CRF and UAN March-applied sugarcane yield was not significant.

The following results for the optimal N rates of the 2017 2\(^{nd}\) ratoon clay soil are presented in Figure 2.8. The optimal N rates were different between the two N sources and two application timing. For cane with March-applied UAN, the optimal N rates for sugar yield and cane yield were 145 kg N ha\(^{-1}\) and 165 kg N ha\(^{-1}\), respectively. Optimal N rates for cane applied with UAN in April was 90 kg N ha\(^{-1}\) for sugar yield and 156 kg N ha\(^{-1}\) for cane yield. Sugarcane applied with CRF in April had optimal N rates of 43 kg N ha\(^{-1}\) and 76 kg N ha\(^{-1}\) for sugar and cane yield, respectively. In comparison of these optimal N rates, UAN March-applied plots attained the highest sugar yield with N rate of 145 kg N ha\(^{-1}\). However, the UAN April-applied plots resulted in the highest cane yield with optimal N rate of 156 kg N ha\(^{-1}\). The comparison between N sources in March-applied plots (presented in the bar graphs) showed that at 135 kg N
ha\(^{-1}\) rate, using UAN as N source achieved significantly higher sugar yields (7070 kg sugar ha\(^{-1}\)) than CRF (6006 kg sugar ha\(^{-1}\)) (Figure 2.8). No difference between N sources was observed for March-applied N when cane yield was used as response variable.

The optimal N rates in 2017 1\(^{st}\) ratoon crop on silt loam soil were also different between N source and application timing (Figure 2.9). For cane applied with UAN in March, the optimal N rate was 143 kg N ha\(^{-1}\) and 113 kg N ha\(^{-1}\) for sugar and cane yield, respectively. The optimal N rates for sugarcane applied with UAN in April was 99 kg N ha\(^{-1}\) and 100 kg N ha\(^{-1}\) for corresponding sugar and cane yield. Optimal N rates for cane applied with CRF in April were higher than UAN applied source at 160 kg N ha\(^{-1}\) and 118 kg N ha\(^{-1}\) for sugar and cane yield, respectively. Differences between sources were not observed when comparing 135 kg N ha\(^{-1}\) rates for cane applied with N in March (Figure 2.9).
Figure 2.7. Sugar and cane yield response to different rate and application time of UAN and CRF as N sources, 2016 plant cane on silt loam soil at the LSU AgCenter Research Station in St. Gabriel, LA.
Figure 2.8. Sugar and cane yield response to different rate and application time of UAN and CRF as N sources, 2017 second raton crop on clay soil at the LSU AgCenter Research Station in St. Gabriel, LA.
Figure 2.9. Sugar and cane yield response to different rate and application time of UAN and CRF as N sources, 2017 first ratoon crop on silt loam soil at the LSU AgCenter Research Station in St. Gabriel, LA.
2.4 Discussion

2.4.1 Distribution of Soil NH$_4^+$ and NO$_3^-$

Some distinctions between the distribution of NH$_4^+$ and NO$_3^-$ can be made. In addition, their concentration varied with soil type, year and application timing of UAN fertilizer (Figures 2.3-2.6). Soil NH$_4^+$ concentrations were higher in 2016 compared to 2017 for clay soil, regardless of N rates having been applied in both years (Figure 2.3). This occurred possibly due to precipitation events, which may have caused different average NH$_4^+$ concentration between 2016 and 2017. Rainfall events a few days after N application in 2017 being 5.7 cm in total, likely contributed to the reduction in soil concentration of NH$_4^+$ through runoff of exposed UAN solution or leaching (Figure 2.1 and 2.2). A study revealed that NH$_4^+$ and NO$_3^-$ are most susceptible to runoff losses within closer proximity of application time and rainfall events (King and Torbert, 2007).

Similar results were found with a decline in overall NO$_3^-$ concentration in 2017 on the clay soil (Figure 2.5). Soil NO$_3^-$ is highly mobile in the soil and very susceptible to loss from rainfall events via runoff, leaching and denitrification (Owen et al., 2001). A decline in NO$_3^-$ concentration for 2017 was also likely a result from the 5.7 cm total rainfall event within 3 days of UAN application. Rainfall creates an anaerobic environment conducive for the denitrification process of NO$_3^-$ to occur, particularly in clay soils. A review of denitrification trends across soil types showed that 30-50% of N is lost by denitrification process emitting N$_2$O gas on fine texture soil compared to less than 1% N loss through denitrification on coarse texture soil (Weier, 1998). This supports the findings found for NO$_3^-$ in Figures 2.5, as the concentration is consistently higher in the silt loam soil compared to the clay soil.
Soil NO$_3^-$ stayed at higher concentrations more consistently across years than NH$_4^+$ in the silt loam soil. This may be the result of soil NH$_4^+$ transformation to NO$_3^-$. Low concentration of NH$_4^+$ was documented by Mariano et al. (2016) due to oxidation of NH$_4^+$ to NO$_3^-$. Volpi et al. (2017) also reported that the conversion of NH$_4^+$ to NO$_3^-$ being higher in coarse texture soil compared to finer texture, with conversion rates as high as 10 mg N kg$^{-1}$ per day. Other published literature also noted that NO$_3^-$ will be dominant in well aerated soils such as silt loam where nitrification increases, but NH$_4^+$ is likely to accumulate in soils prone to water logging where nitrification is inhibited (Crawford and Forde, 2002). Comparatively, soil NH$_4^+$ may also be lower in concentration due to its uptake preferability over NO$_3^-$ by sugarcane roots (Hajari et al., 2014). The silt loam soil may have been a more suitable environment for the increase of NH$_4^+$ oxidation to NO$_3^-$, due to the high level of oxygen (well-aerated soil) and a more conducive environment for nitrifying bacteria. As shown in a study conducted by Cameron et al. (2012), the transformation of NH$_4^+$ increases with increase in ammonia-oxidizing bacteria populations. Another possible explanation for higher average NO$_3^-$ concentrations in the silt loam soil can be attributed to greater microbial NH$_4^+$-N immobilization compared to NO$_3^-$. Soil NH$_4^+$ concentration has been shown to be depleted through immobilization in priority to NO$_3^-$ when both are present in the same cropping system (Powlson et al., 1986; Recous et al., 1990). The microbial preference of NH$_4^+$ immobilization could lead to a higher possibility of NO$_3^-$ accumulation in soils as seen in this study.

Between March and April application timing effects on NH$_4^+$ and NO$_3^-$ concentrations, soils which received UAN in March showed consistently higher NH$_4^+$ and NO$_3^-$ concentration (Figures 2.3 and 2.5). This again may be attributed to environment conditions which were conducive for several N loss pathways. For example, the average temperature for both years in
April was higher than March. This may result in higher loss potential through volatilization of ammonium in the April-applied UAN solution. A volatilization study shows that near half (40%) of applied N from urea fertilizer can be lost through volatilization (Freney et al., 1992).

As time progressed throughout the cropping season (after application of UAN fertilizer), soil inorganic N consistently declined in concentration for both soil types and years. The release of inorganic N from applied UAN fertilizer generally occurred from 2 to 4 WANF and coincided with the period of active N uptake of sugarcane. It appears that this occurred for both application times of UAN in March and in April. Therefore, this shows that the maximum release of plant available N into the soil was not compromised by application timings of UAN fertilizer. The factor which seems to limit the plant availability of applied NH$_4^+$ and NO$_3^-$ ultimately affecting the N health status of the sugarcane appears to be soil type. The effects of soil type on plant available N concentration in both soils was further compounded by environmental conditions, in particular rainfall events for this experiment. Some studies show positive effects of split-application methods on sugarcane yield, which can shorten the amount of time the applied N is exposed and vulnerable to loss from the soil system (Wiedenfield, 1997; Saleem et al., 2012). This seems to be a reasonable solution to maximize the use of soil inorganic N, instead of one time application of total UAN fertilizer. However, split-application of N fertilizer may offset its agronomic and environmental benefits, as it can require more labor and fuel use depending on the farm operation.

2.4.2 Optimal N Rates as Affected by Application Timing and Soil Type

Optimal N rates for sugar yield differed between the two soil types and cropping year. The optimal N rate for the silt loam soil in 2016 was 39 kg N ha$^{-1}$ and 143 kg N ha$^{-1}$ in 2017.
using UAN as the fertilizer source applied in March (Figures 2.7 and 2.9). Both optimal N rates were outside the range of LSU AgCenter N recommendation, which is 68-112 kg N ha\(^{-1}\) for coarse texture soil (Gravois et al., 2014). Sugarcane on the clay soil also reached the maximum yield (plateau) with March-applied UAN at N rate of 145 kg ha\(^{-1}\) (Figure 2.8); this is higher than state recommendations (112-135 kg N ha\(^{-1}\)) for ratoon cane on fine texture soil (Gravois et al., 2014). These outcomes suggest that optimal N rates varied highly with soil type, crop age and year. In order to have more precise N rate recommendations, other crop and soil information in addition to crop age and soil type should be considered. A more refined N-cycling model for sugarcane is needed (Thorburn et al., 2005). Other research work addressing the N requirement of sugarcane is also being established by remote sensing technology and can be a promising alternative or supplemental tool for determining N rate recommendations (Kanke et al., 2016). This technology allows growers to have an on-the-go evaluation of sugarcane N health status and derive N recommendations based on canopy reflectance readings (Tubana et al., 2012).

Lofton and Tubana (2015) estimated the optimal N rate for a ratoon cane on silt loam soil at 55 kg N ha\(^{-1}\), which is less than half of 143 kg N ha\(^{-1}\) reported in the present study for the same crop age and soil type. Additionally, the maximum sugar yield reported by Lofton was >3,000 kg ha\(^{-1}\) lower than the maximum sugar yield reported in this study. High variations in optimal N rates and the maximum sugarcane yield achieved indicate that there is high variability from year to year response of sugarcane to N applied fertilizer. Variability in sugarcane yield response to N fertilization has also been shown in other recent studies in Louisiana (Kanke et al., 2016). Differences in cane yield potential can be affected by the growing environment (highly determined by the soil type) through factors pertaining to root growth, ratooning and overall soil fertility. Along with the growing environment of the cane, plant available soil N also affects
yield potential, which is further affected by climatic conditions such as rainfall and temperature as discussed previously.

The estimated optimal N rate for cane yield was similar to the optimal N rate for sugar yield in the 2016 silt loam soil (Figure 2.7). The cane yield was maximized (117 Mg ha\(^{-1}\)) in plots applied with N in March as UAN at the rate of 43 kg N ha\(^{-1}\). This demonstrates that the highest stalk yield can be achieved with a modest amount of N rate applied. Conversely, high stalk and sugar yield may require higher application rates as demonstrated in a study conducted by Forestieri (2017) that could range from 90 to >135 kg N ha\(^{-1}\). These N rates are two to three times higher than the optimal N rate achieved for this study in 2016, but with lower yields of 87 Mg cane ha\(^{-1}\) and 9,545 kg sugar ha\(^{-1}\). Otto et al. (2013) reported in his study that sugarcane cane yield response to N fertilizer rates were as high as 200 kg N ha\(^{-1}\) in Brazil, which is also relatively high in comparison to the optimal N rate achieved for cane in this present study. The maximum cane yield varied across years and soil types. The highest variability recorded was between canes in 2016 on silt loam and 2017 on clay soils (117 Mg ha\(^{-1}\) vs. 70 Mg ha\(^{-1}\)). Such high variation on sugarcane stalk yield in St. Gabriel has been reported before even within identical varieties; the highest yield variation resulting in a 54 Mg ha\(^{-1}\) difference between 1999 and 2000 (Greenland, 2005).

The silt loam soil’s low inorganic N concentrations may explain the rise in N rate requirement of cane from 2016 to 2017. Particularly, the soil NH\(_4\)\(^+\) and NO\(_3\)\(^-\) concentrations were lower in 2017, thus a higher N rate would likely be needed to reach the same yield level as compared to the year before when NH\(_4\)\(^+\) and NO\(_3\)\(^-\) concentrations were higher in the soil. The variability in weather conditions between years must be taken into consideration as demonstrated in this study wherein the sugar yield level and optimal N rate for cane planted on the same field
were different in 2016 and 2017. More favorable growing temperatures may have also influenced the variation of yield between years. A study conducted in India showed significantly higher sugarcane yields in years with warmer temperatures during the early part of the growing season compared to years where temperatures were cooler during the same period (Kumar et al., 1984). The average temperature for June and July were higher for 2016 compared to 2017 (Figure 2.2). These two months corresponded to the grand growth period of sugarcane in Louisiana, where growth rates are greatest in June, July and August (Greenland, 2005). Therefore, the temperature differences in the grand growth period and the soil inorganic N levels between 2016 and 2017 may partly explain the higher sugarcane yields in 2016.

Yield potential was primarily maximized in sugarcane applied with UAN in March compared to sugarcane applied with UAN in April. This was in exception to year 2017, where cane yield potential was maximized with UAN applications being in April. These results support the notion that UAN fertilization of sugarcane in March will not negatively influence sugarcane yield potential and in this study actually resulted in the increase of sugarcane yields compared to cane fertilized with UAN in April. The benefit of March N application demonstrated in this study is in agreement with N recommendation for sugarcane in Texas, confirming March as an acceptable application time for sugarcane (Wiedenfeld, 1997).

While the estimates for optimal N rates for both sugar and cane yield were close with only 4 kg N ha\(^{-1}\) difference, the timing of application varied on the influence of optimal N rate for cane yield; this was not the case for sugar yield (Figures 2.8 and 2.9). Optimal N rates for sugar yield were achieved in cane applied with UAN in March for both years and soil types. However, optimal N rates for cane yield were achieved in cane applied with UAN in March for year 2016 only, but in April for year 2017 in both soil types. In 2017 on silt loam soil, plots
applied with UAN in April had higher inorganic N concentrations in the latter part of the
growing season compared to plots fertilized in March (Figure 2.3 and 2.5). This may be an
explanation for why maximum cane yields were achieved in plots applied with UAN in April for
the year 2017 as compared to 2016 where yield was maximized with UAN March fertilization.
This indicates that there is variation on maximized cane and sugar yield based on the application
time of UAN fertilizer, which was likely related to plant available N concentrations in the soil.

At first, it appears that when CRF was applied to sugarcane, it did not show any benefit
in terms of improving sugar yields compared to cane applied with UAN. However, considering
the amount of N rate requirement to maximize yield being lower when CRF was used over UAN,
further evaluation should be made on CRF potentials. For example, in the 2017 clay soil,
sugarcane yield from CRF-treated plots was maximized with 33% less of the N rate required to
maximize sugarcane yield applied with UAN (Figure 2.8). The difference in fertilizer source N
requirement from sugarcane may result in savings for growers if CRF is applied. Depending on
the farm operation and other variables, it may be possible to save on N fertilizer cost due to
lower N rate requirement of CRF and possibly offset the yield loss as observed in this study
(Morgan, 2009). Another consideration between the two N sources is that the emissions of
greenhouse gasses and groundwater contamination will likely be less in the soil applied with
CRF, since the optimal N level may be lower and less N would need to be applied (Zwieten et
al., 2016; Volpi et al., 2017). It seems that careful consideration of yield effect must be taken into
account when using CRF technology in sugarcane production, since optimal N rates and yields
varied between the use of CRF and UAN as fertilizer source. Choosing the right N source
seemed to be less important in sugarcane production in Louisiana when comparison was made
among conventional fertilizers such as urea, ammonium nitrate (AN) and UAN (Forestieri, 2017).

Optimal N rates for sugar and cane yield in this study were varied with year and soil type ranging from 39 kg N ha\(^{-1}\) to as high as 156 kg N ha\(^{-1}\). Earlier studies showed that on the same location and soil type, optimal N rate requirements of sugarcane ranged from 60 kg N ha\(^{-1}\) to >135 kg N ha\(^{-1}\) (Lofton and Tubana, 2015; Forestieri, 2017). This study showed that altering the application timing to March instead of April did not have a negative impact on sugarcane yield, which was also found to be the case in Texas sugarcane production (Wiedenfeld, 1997). The CRF source resulted in lower yields, but also a lower optimal N rate requirement compared to UAN, which is similar to results presented by Verburg et al. (2016). Overall, sugarcane productivity varied with soil type and year, consistent with other reports on Louisiana sugarcane production systems (Greenland, 2005; Lofton and Tubana 2015; Kanke et al., 2016).

2.5 Conclusions

The soil inorganic N concentration levels varied from year to year on both soil types and showed some degree of influence on sugarcane yield production. Monitoring soil inorganic N concentrations for improving N management may not be a sufficient indicator of the N health status of sugarcane in Louisiana. Even so, information on soil inorganic N in combination with multiple factors such as soil type, climate conditions, and leaf N status maybe a viable approach when deriving an N management strategy for sugarcane. Application timing of UAN fertilizer also seemed to have varying effects on the level of soil inorganic N concentration, but mostly did not affect the release of plant available N into the soil for months associated with active N uptake for sugarcane in Louisiana.
Overall, N application timing and soil type varied in effect on the optimal N rate requirement of sugarcane. Optimal N rates showed high and low differences to current N recommendations in Louisiana and were primarily observed in sugarcane applied with UAN in March compared to April. This was likely influenced by the inorganic N loss potential over time in certain soil types, which was further compounded by temperature variations and rainfall events. Consideration on site specific fertilizer N management is evident according to the results of this experiment. The potential benefit of CRF through lowering the optimal N rate requirement of sugarcane was reported, but further research into the economics of this is needed as yield reduction may offset the savings of applying less N fertilizer. The results reported in this current study gives further confirmation to the variable yield outcomes experienced in sugarcane production between soil types and cropping seasons within the state. There are potential positive effects in diversifying fertilizer N management in Louisiana sugarcane by creating a more accurate site specific N management strategy and by extending the window of early N application timing into May.

2.6 References


Thorburn, P. J., E. A. Meier, and M. E. Probert (2005): Modelling, nitrogen dynamics in sugarcane systems: Recent advances and applications. *Field Crops Research* 92, 337.


Weindorf, D. C. (2013): Understanding Louisiana soils. *Louisiana State University AgCenter Baton Rouge, LA.*


Chapter 3. The Relationship of Soil and Leaf Nitrogen Status at Different Critical Growth Stages with Sugarcane Yield

3.1 Introduction

Leaf nitrogen (N) concentration in sugarcane (*Saccharum* spp.) is used to monitor sugarcane N status and obtain insights on productivity. A research study conducted in India shows the significant relationship of % leaf N and yield on eleven tested varieties of sugarcane (Kumar and Verma, 1997). Accurately predicting the nutritional requirement of crops can allow producers to maximize yield in nutrient deficient soils without having to apply uniform applications of fertilizer N rates. Leaf N analysis is used by some growers as a yield prediction index for sugarcane production, while soil N testing remains the basis of N rate requirement for most producers in states such as Florida (McCray et al., 2010). Optimal and critical leaf N concentration values are generated across multiple studies and generally site specific (Vale et al., 2012). Research in developing leaf N concentration relationships to yield and soil N for popular sugarcane varieties in Louisiana such as L01-299 are lacking.

Different models can be used to express the critical and optimal leaf N concentration values, which limit or reflect optimal yield in sugarcane. Two commonly used examples of these models are the diagnosis and recommendation integrated system (DRIS) and critical value approach (CVA) (Mccray et al., 2010; Muchovej et al., 2005). The distinction of benefit when using DRIS models is that CVA models are subjected to sampling at specific growth stages of the sugarcane from which reference sample values were generated (Elwali and Gascho, 1984). However, DRIS models consist of nutrient ratios across a broad range of sampling dates and growth stages (Beaufils and Sumner, 1977; Serra et al., 2013). Establishing corrective N application based on leaf N status requires multiple years of research to establish leaf N levels.
under specific site conditions (Thomas, 1984). One review study shows that DRIS can vary with accuracy and should be developed over time in localized areas for the most accurate N recommendations from foliar analysis (Jones, 1993).

Sugarcane plants contain structures called dewlaps or “joint triangles,” which can be found on completely emerged leaves near the top of a sugarcane plant (Artschwager, 1951; Allison et al., 1997). The dewlap is below the spindle leaf which is the uppermost portion of the sugarcane plant (Thomas, 1984). This dewlap structure is often used as a marker to ensure uniform leaf sampling techniques for leaf nutrient analysis research studies. To identify which leaves were sampled, Kuijper’s leaf numbering system is commonly used, which numbers the leaves starting from the top of the plant at the top visible dewlap (TVD) to the bottom (Ambrosano et al., 2005; Cheavegatti-Gianotto et al., 2011). For N status of sugarcane, many research studies will sample leaves at the TVD or leaves directly below (Beaufils and Sumner, 1977; Wood, 1990; Kumar and Verma, 1997; Glaz et al., 2008;). Leaf analysis research from Thomas (1984) and Vale et al. (2012) both take composite samples of three leaves starting at the TVD. A variety of studies will practice the removal of the mid rib portion of a leaf sample for nutrient analysis, while other studies leave the midrib, which can result in lower measured N concentration values (Muchovej et al., 2005). Regardless of sampling method it is important to keep leaf sampling consistent across the term of the experiment. There is also a gaining interest in research involving canopy reflectance readings to determine leaf N status for fertilizer N application. This method is considered faster than leaf sampling methods because it does not require manual leaf collecting and laboratory analysis (Miphokasak et al., 2012). Nitrogen concentrations have been shown to display a positive relationship with photosynthetic activity within sugarcane leaves (Bassi et al., 2018). The importance of N acquisition for sugarcane...
leaves is the formation of proteins involved in photosynthesis (Dinh et al., 2017). Nitrogen is an integral component of chlorophyll in plant leaves, and when N deficiency occurs it can cause a reduction in green leaf area and photosynthesis of sugarcane (Bojović et al., 2009). Regardless of inorganic form and energy requirements, one study shows no significant difference of nitrate ($\text{NO}_3^-$) and ammonium ($\text{NH}_4^+$) supplied N on the net photosynthesis specifically in sugarcane (de Armas et al., 1992). Nitrogen is also required for plant formation of amino acids (Ramage et al., 2002). Although N promotes growth of sugarcane it can reach a concentration point where it has no linear increasing effect and additional N application would be considered excess fertilization (Zhao et al., 2014). A research study from Allison et al. (1997) shows the linear increasing effect of leaf N concentration from 1.0 % to 1.9 % on increasing the rate of photosynthesis in sugarcane leaves. The amount of N accumulated and photosynthetic activity can vary throughout sugarcane leaves. Variation of photosynthetic activity within same plant species is largely due to temperature, water availability, level of irradiance and N supply (Loomis, 1997). Leaf N accumulation has been shown to be a factor of soil type and sugarcane variety (Orlando et al., 1997). The level of N concentration in the leaves has also been shown to vary based on the crop age of the sugarcane plant and across ratoon seasons (Humbert, 1968; Allison et al., 1997; Poswa and Miles 2016).

Inorganic N uptake by plant roots is primarily through mass flow and diffusion processes in the soil (de Willigen et al., 1986; Oyewole et al., 2013). Mass flow is water mediated and usually the main source of $\text{NO}_3^-$ transportation to plant roots, while acquisition of $\text{NH}_4^+$ by plant roots rely on diffusion gradients (BassiriRad et al., 2008). Uptake of $\text{NO}_3^-$ can be regulated by the supply of both $\text{NO}_3^-$ and $\text{NH}_4^+$, as well as plant demand (Crawford and Forde, 2002). Soil inorganic N is extremely variable due to the dynamic nature of N cycling that occurs with
differences by many factors including physical and biological differences between sites (Bloom et al., 2002). Inorganic N is assimilated by plants into organic amino acid forms glutamine and glutamate, which are distributed throughout the plant and important for plant growth (Lam et al., 1996). Both $\text{NH}_4^+$ and $\text{NO}_3^-$ must be reduced to ammonia ($\text{NH}_3$) before it can be converted into glutamine or glutamate, which can occur either in the leaves or roots of the plant (Hoff et al., 1994; Williams and Miller, 2001). The enzymes responsible for reduction of $\text{NO}_3^-$ into $\text{NH}_3$ are the nitrate reductase and nitrite reductase enzymes (Galvan and Fernandez, 2001). The rate of $\text{NO}_3^-$ reduction has been shown to be limited by micronutrient molybdenum deficiency, as it is a major component of nitrate reductase (Li-Ping et al., 2007; Balcoelho, 2015). Dry matter plant material such as leaf N content is composed of a variety of N forms to which 75% can be linked to the photosynthetic process (Loomis, 1997; Miller and Cramer, 2004). All of these justify the use of leaf N content for monitoring plant health status and use as an index for seasonal yield outcome for sugarcane production.

Soil tests can be performed to create recommendation rates, but applying N fertilizer based on soil inorganic N readings is controversial in its ability to accurately formulate N fertilizer rate recommendations in south Louisiana soil conditions (Sander et al., 1994). This controversy revolves around the susceptibility of bioavailable N or precursors to bioavailable N to be quickly lost from the agronomic system through multiple loss pathways. One test reading of soil inorganic N may be drastically different from day to day depending on the weather conditions and environments conducive for N loss. A review paper by Wood (1990) on sugarcane fertilization suggests that leaf N and soil inorganic N should be complementary in overall analysis of fertilizer recommendations.
Since recent sugarcane varieties such as L01-299 are being used in Louisiana sugarcane production accompanied by a lack of nutritional leaf N content research, it is important to establish leaf N analysis procedures to further the accuracy of yield prediction along with the relationship of soil inorganic N. Establishing accurate procedures to understanding the relationship between leaf N analysis, soil inorganic N and sugarcane yield will help increase yield potential through early season fertilization adjustments. The objectives for this study were to: 1) measure sugarcane leaf N content at different growth stages and relate it with cane and sugar yield to identify the critical stage of leaf collection that would best relate the N status of sugarcane, and 2) evaluate the relationship of leaf N and soil inorganic NH$_4^+$ and NO$_3^-$ content at different growth stages of sugarcane.

3.2 Materials and Methods

3.2.1 Site Description, Planting Method, and Treatment Structure

Two sites were selected for this research. Sites were located in Iberville parish, Louisiana at the LSU AgCenter Sugar Research Station. Soil survey information was acquired through the Natural Resources Conservation Service (NRCS) soil survey website, and was utilized to determine soil distribution of each site. Site 1 is a mixture of Sharkey clay (very-fine, smectitic, thermic Chromic Epiaquerts) and Commerce silty clay loam soil, with Sharkey clay being the dominant soil type (NRCS, 2018). It is a heavy textured clay soil with poor drainage. Site 1 will be referred to as clay soil (hereafter) and has a total area of 7826 m$^2$ (1.9 acres). Site 2 consists of a light textured and well-drained Commerce silt loam (fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts) soil (NRCS, 2018). Site 2 has a total area of 5844 m$^2$ (1.4 acres) and will be referred to as silt loam soil hereafter. Both soil sites are alluvial soils located
near the Mississippi River. In proximity to the river, the clay soil is 800 m (2,624 ft) away and the silt loam soil is closer within 600 m (1,968 ft) distance from the river. Latitudes and longitudes of the clay and silt loam soil sites are: 30.26639°, -91.09741° and 30.26852°, -91.10578°. The length of this experiment spanned the course of two harvest seasons (2 years), 2016 and 2017.

Both sites were planted with sugarcane variety L01-299. Soil was mechanically disked before planting. Seed cane (whole stalks) measuring about 1 meter in length were placed by hand from a tractor wagon into open furrows. All stalks placed to have a minimum of 8 cm overlap before covering with soil on the same day. Site 1 was planted in October 2014 and Site 2 was planted in October 2015. For Site 2, a 1.5 m (5 ft) alley gap was arranged by not placing stalks in order to separate treatment plots.

A total of 18 treatments were established on the two sites and only 7 were used in this experiment, as presented in Table 3.1. Treatments on the clay soil were arranged in a randomized complete block design (RBD) with plot dimensions of 15 m (50 ft) long and 5.5 m (18 ft) (3-rows) wide. Treatments on the silt loam soil were arranged in a complete randomized design (CRD) with plot dimensions of 12 m (40 ft) long and also 5.5 m wide. Buffer rows were placed on the south east side of both sites. Treatments were divided by N fertilizer application timing and N rate. Each treatment was replicated four times for both Sites. The fertilizer source used was urea ammonium nitrate (UAN, 32% N) solution. The two application timings were March and April. Three N fertilizer rates were applied along with a control (0 N) rate for each site at: 45, 90 and 135 kg N ha⁻¹. Along with N application, a uniform standard application rate of potassium (90 kg K ha⁻¹) was also applied on all treatment plots using muriate of potash (MOP, 60% K) as source. A detailed chart of the treatment structure is presented in Table 3.1.
3.2.2 Fertilization

The UAN solution was knifed-in mechanically into the shoulder of each row using a variable rate pump tank on a tractor with a hydraulic knife-in implement. The implement consisted of six knife-in components capable of double shoulder, three row UAN applications. Before UAN application, the pump tank was calibrated to appropriate N rate treatments. March treatment fertilizer applications were done on the 23rd and 15th for 2016 and 2017, respectively on both sites. April treatment fertilizer applications were done on the 25th and 19th for 2016 and 2017, respectively on both sites.

3.2.3 Soil and Leaf Sampling

Collection dates for soil and leaf samples are presented in Table 3.2. Soil samples were collected manually using JMC® foot step samplers with a 30 cm sample depth capability. Soil was placed directly into paper bags upon sampling. Every plot in each soil type was sampled in tandem with leaf samples. In all plots, four samples were taken on each shoulder of each row.
within the plots resulting in sixteen, 0-15 cm samples. Each sample was placed into a paper bag directly after taken from the plots. Soil samples were immediately placed into an oven at 60° C

Table 3.2. Leaf and soil sampling dates collected at the LSU AgCenter Sugar Research Station in St. Gabriel, LA, 2016-2017.

<table>
<thead>
<tr>
<th>Year</th>
<th>Crop Age</th>
<th>Soil Type</th>
<th>Date</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>1st Ratoon</td>
<td>Clay</td>
<td>5-May</td>
<td>Leaf+Soil</td>
</tr>
<tr>
<td>2016</td>
<td>1st Ratoon</td>
<td>Clay</td>
<td>16-May</td>
<td>Leaf+Soil</td>
</tr>
<tr>
<td>2016</td>
<td>1st Ratoon</td>
<td>Clay</td>
<td>31-May</td>
<td>Leaf+Soil</td>
</tr>
<tr>
<td>2016</td>
<td>1st Ratoon</td>
<td>Clay</td>
<td>27-Jun</td>
<td>Leaf</td>
</tr>
<tr>
<td>2016</td>
<td>1st Ratoon</td>
<td>Clay</td>
<td>26-Jul</td>
<td>Leaf</td>
</tr>
<tr>
<td>2016</td>
<td>Plant Cane</td>
<td>Silt Loam</td>
<td>20-Apr</td>
<td>Leaf</td>
</tr>
<tr>
<td>2016</td>
<td>Plant Cane</td>
<td>Silt Loam</td>
<td>5-May</td>
<td>Leaf+Soil</td>
</tr>
<tr>
<td>2016</td>
<td>Plant Cane</td>
<td>Silt Loam</td>
<td>16-May</td>
<td>Leaf+Soil</td>
</tr>
<tr>
<td>2016</td>
<td>Plant Cane</td>
<td>Silt Loam</td>
<td>31-May</td>
<td>Leaf+Soil</td>
</tr>
<tr>
<td>2016</td>
<td>Plant Cane</td>
<td>Silt Loam</td>
<td>27-Jun</td>
<td>Leaf</td>
</tr>
<tr>
<td>2016</td>
<td>Plant Cane</td>
<td>Silt Loam</td>
<td>26-Jul</td>
<td>Leaf</td>
</tr>
<tr>
<td>2017</td>
<td>2nd Ratoon</td>
<td>Clay</td>
<td>26-Apr</td>
<td>Leaf+Soil</td>
</tr>
<tr>
<td>2017</td>
<td>2nd Ratoon</td>
<td>Clay</td>
<td>9-May</td>
<td>Leaf+Soil</td>
</tr>
<tr>
<td>2017</td>
<td>2nd Ratoon</td>
<td>Clay</td>
<td>26-May</td>
<td>Leaf+Soil</td>
</tr>
<tr>
<td>2017</td>
<td>2nd Ratoon</td>
<td>Clay</td>
<td>27-Jun</td>
<td>Leaf</td>
</tr>
<tr>
<td>2017</td>
<td>2nd Ratoon</td>
<td>Clay</td>
<td>24-Jul</td>
<td>Leaf</td>
</tr>
<tr>
<td>2017</td>
<td>1st Ratoon</td>
<td>Silt Loam</td>
<td>12-Apr</td>
<td>Leaf</td>
</tr>
<tr>
<td>2017</td>
<td>1st Ratoon</td>
<td>Silt Loam</td>
<td>26-Apr</td>
<td>Leaf+Soil</td>
</tr>
<tr>
<td>2017</td>
<td>1st Ratoon</td>
<td>Silt Loam</td>
<td>9-May</td>
<td>Leaf+Soil</td>
</tr>
<tr>
<td>2017</td>
<td>1st Ratoon</td>
<td>Silt Loam</td>
<td>26-May</td>
<td>Leaf+Soil</td>
</tr>
<tr>
<td>2017</td>
<td>1st Ratoon</td>
<td>Silt Loam</td>
<td>27-Jun</td>
<td>Leaf</td>
</tr>
<tr>
<td>2017</td>
<td>1st Ratoon</td>
<td>Silt Loam</td>
<td>24-Jul</td>
<td>Leaf</td>
</tr>
</tbody>
</table>

¥ Extra collection date added in silt loam soil due to earlier leaf emergence

for a minimum of three days (72 hours), and processed through a stainless steel Humboldt soil grinder. Samples were then placed into enclosed 120 ml plastic cups and stored at room temperature pre-laboratory analysis.

From each row of the three row plots, 6 leaves were collected and placed into a paper bag. Within each defined plot, a total of 18 leaves were collected on a sampling day. For every leaf sampling occasion, the first leaf below the TVD (leaf +2 in accordance with Kuijper’s
numbering system) was chosen from each random cane plant picked within a plot row. Samples were dried in an oven on the day of sampling and kept there for a minimum of 72 hours at a constant temperature of 60º C. After drying, leaf samples were then processed using a stainless steel Wiley Mill grinding machine (Model No. 3, Arthur H. Thomas CO. Philadelphia, USA) and sieved through a 1 mm diameter metal sieve plate.

3.2.4 Soil Inorganic N and Leaf N Analysis

To determine soil NH$_4^+$ and NO$_3^-$ concentrations, processed soil samples were extracted using the KCl extraction procedure. To accomplish this, 5 grams of soil were weighed and placed inside a 125 ml plastic bottle. Each bottle was then filled with 35 ml of 1 M KCl and placed on a reciprocal shaker for 1 hour. The soil solution was then filtered using No. 42 Whatman® filter paper. Once filtered, samples were refrigerated until auto analyzed for NH$_4^+$-N and NO$_3^-$-N. Simultaneous auto analysis of NH$_4^+$ and NO$_3^-$ was completed through calorimetry readings using a flow injection analyzer (FIA; Lachat QuickChem 8500 series 2). Through FIA procedures, NO$_3^-$-N is quantified by the reduction of NO$_3^-$ to NO$_2^-$ when passing through a cadmium column and the reaction of NO$_2^-$ with a sulfanilamide reagent. The NH$_4^+$-N is quantified by its reaction with salicylate when heated. Both inorganic N determinations are measured by calorimetry at 520 nm (NO$_3^-$) and 660 nm (NH$_4^+$). This procedure was similar as discussed in a review by Pasquali et al. (2006) of simultaneous inorganic N FIA.

To analyze the N status of shredded cane leaves a C:N analyzer (Elementar Americas Inc, Vario EL Cube) was used to quantify leaf N %. To prepare a sample for the analyzer, 20 mg of shredded leaf sample was weighed and placed inside a tin foil capsule. Samples were then combusted inside the machine at 1800º C and leaf N % peaks logged in the system.
3.2.5 Yield Determination

Cane yield was determined for individual rows within plots. A single-row combine was used to cut stalks from the base and further cut into billets. A weigh wagon with an electronic load cell was used to collect harvested billets from the combine and determine cane yield weight of each row. Flag markers were carried and waved to signal the end of each row to the combine and wagon operators. The wagon scale was tared after the stalk weight for each row was collected and recorded by the wagon operator. Estimation of cane yield in Mg ha$^{-1}$ was calculated based on the area of the plots harvested. To determine sugar yield, ten cane stalks were sampled from the middle row of each plot during harvest. The non-millable portions of the cane stalk at the distal end of the plant were cut and the leaves were stripped. Stalks were then shredded and analyzed by a SpectraCane NIR analyzer (Bruker Corporation, Billerica, Massachusetts). Results of analysis included the quality parameter theoretical recoverable sugars (TRS), which was used as a factor with cane tonnage to estimate sugar yield in kg ha$^{-1}$.

2.2.6 Data Analysis

To determine the relationship of leaf N content and sugarcane yield, the leaf N from each sampling date was regressed with cane yield and sugar yield. Leaf N was also regressed with soil inorganic NH$_4^+$ and NO$_3^-$ at 0-15 cm depths. The correlation coefficient ($r$) measured in terms of sum of squares from which $r^2$ is a derivative was used to represent the strength of relationship between variables such as leaf N content, sugarcane yield, and soil inorganic N concentration. All $r$ values were computed using PROC CORR in SAS 9.4 software. The correlation strengthens as $r$ values approach 1 or -1. The $r$ value provides more insight into the relationship
of the two variables, as the $r^2$ value is not revealing of the nature of relationships (positive or negative) between them.

### 3.3 Results

#### 3.3.1 Correlation between Leaf N and Yield

The average leaf N content across all sugarcane plots are presented in Table 3.3. Generally, leaf N content declined with crop age. The highest N concentration value collected from all sugarcane plots was 3.13 % and occurred in leaves fertilized with UAN at rate 135 kg N ha$^{-1}$. The lowest N concentration measured was 1.12 % in leaves from a control plot (0-applied N). Average leaf N content was typically higher in the clay soil compared to silt loam soil within the same year of collection.

Table 3.3. Range and average leaf N content across year, soil type and sampling dates.

<table>
<thead>
<tr>
<th>Year</th>
<th>Soil Type</th>
<th>Crop Age</th>
<th>Sample Time Range</th>
<th>Leaf N %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Range</td>
</tr>
<tr>
<td>2016</td>
<td>Clay</td>
<td>1$^{st}$ Ratoon</td>
<td>5-May to 26-July</td>
<td>1.13 - 2.72</td>
</tr>
<tr>
<td>2016</td>
<td>Silt Loam</td>
<td>Plant Cane</td>
<td>20-April to 26-July</td>
<td>1.17 - 2.40</td>
</tr>
<tr>
<td>2017</td>
<td>Clay</td>
<td>2$^{nd}$ Ratoon</td>
<td>26-April to 24-July</td>
<td>1.22 - 3.13</td>
</tr>
<tr>
<td>2017</td>
<td>Silt Loam</td>
<td>1$^{st}$ Ratoon</td>
<td>12-April to 24-July</td>
<td>1.12 - 2.61</td>
</tr>
</tbody>
</table>

A various range of $r$ values between leaf N and yield were generated across year, soil type and UAN application timing for the different leaf tissue sampling dates (Table 3.4). The highest (negative) $r$ values generated in 2016 clay soil was -0.649 on 5-May (UAN March application) for sugar yield and -0.604 on 16-May (UAN April application) for cane yield. Like most $r$ correlation values for 2016 clay soil, these $r$ values are negative, indicating a strong linear
decrease in yield as leaf N content increases. The highest $r$ correlation values occurring in 2016 silt loam soil was 0.827 on 16-May (UAN April application) for sugar yield and 0.747 on 16-May (UAN April application) for cane yield. The positive $r$ correlation from these two values indicates a linear increase of yield as leaf N content increases. Another notable observation from the 2016 silt loam soil is that $r$ values for UAN March and April applied soil primarily showed a positive linear correlation between leaf N content and yield compared to 2016 clay soil. In 2017 clay soil, N content of leaf samples collected on May 26 (UAN April application) obtained the highest correlation with sugar and cane yield with $r = 0.752$ and $r = 0.658$, respectively. In the 2017 silt loam soil, N content of leaf samples collected on May 9 (UAN March application) obtained the highest correlation with sugar and cane yield with $r = 0.854$ and $r = 0.850$, respectively. These are the highest correlation values achieved across all regression made between leaf N content and yield (considering both positive and negative $r$ values).

3.3.2 Correlation between Soil Inorganic N and Leaf N

The relationships of soil NH$_4^+$ and NO$_3^-$ concentrations with leaf N content are reported in Table 3.5. The highest correlation between NH$_4^+$ concentration and leaf N content in 2016 clay soil was obtained from the 16-May sampling date (UAN March application) with $r = 0.420$, but was insignificant. On the same sampling date, the correlation between soil NO$_3^-$ and leaf N content was 0.608. In the 2016 silt loam soil, leaf N had an $r = 0.307$ on 31-May sampling date (UAN April application) for NH$_4^+$, and $r = 0.609$ on 31-May sampling date (UAN April application) for NO$_3^-$. The greatest correlation of leaf N in 2017 clay soil occurred with $r = 0.361$ on 26-April sampling date (UAN April application) for NH$_4^+$, and $r = 0.622$ on 26-April sampling date (UAN April application) for NO$_3^-$. In the 2017 silt loam soil, the highest
correlation values were $r = 0.377$ on 9-May sampling date (UAN March application) for $\text{NH}_4^+$, and $r = 0.663$ on 9-May sampling date (UAN April application) for $\text{NO}_3^-$.

Correlation values varied in both years and soil type typically observed from mid- to late-May in plots fertilized with UAN in March. For plots fertilized with UAN in April, correlation values were highest from late-April to early-May in 2017, but highly variable in 2016. The graphs showing the highest correlation between leaf N content and inorganic N are presented in Figure 3.2. The highest correlation value between leaf N and $\text{NO}_3^-$ occurred 8 WANF, when sugarcane was fertilized in March. When cane was fertilized with N in April, the highest correlation between $\text{NO}_3^-$ and leaf N content occurred 2 WANF (Table 3.5). The highest correlation value between leaf N content and $\text{NH}_4^+$ was observed 3 WANF, when N was applied to cane in March, but correlations involving $\text{NH}_4^+$ were insignificant. When N fertilizer was applied to cane in April, leaf N content and $\text{NH}_4^+$ had the highest correlation 2 WANF. Highest correlating values between leaf N and soil inorganic N mostly occurred earlier after N application in cane with UAN in April compared to cane fertilized with UAN in March (Table 3.5). The form of soil inorganic N regressed with leaf N also seemed to have an effect on correlation strength. Overall, correlation values were much higher when $\text{NO}_3^-$ was regressed with leaf N content across years, soil type and N application timings in comparison to $\text{NH}_4^+$. 
Table 3.4. Correlation coefficient ($r$) between leaf N content measured at different sampling times and yield (stalk and sugar) of cane variety L01-299 grown on clay and silt loam soils at the LSU AgCenter Sugar Research Station in St. Gabriel, LA, 2016-2017.

<table>
<thead>
<tr>
<th>Year</th>
<th>Soil</th>
<th>Crop Age</th>
<th>Sampling Date</th>
<th>N Applied in March</th>
<th>Cane Yield</th>
<th>Sugar</th>
<th>N Applied in April</th>
<th>Cane Yield</th>
<th>Sugar</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>Clay</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Ratoon</td>
<td>5-May</td>
<td>-0.475</td>
<td>-0.649**</td>
<td></td>
<td>-0.585*</td>
<td>-0.630**</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>Clay</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Ratoon</td>
<td>16-May</td>
<td>-0.358</td>
<td>-0.538*</td>
<td></td>
<td>-0.604*</td>
<td>-0.646**</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>Clay</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Ratoon</td>
<td>31-May</td>
<td>-0.300</td>
<td>-0.473</td>
<td></td>
<td>-0.194</td>
<td>-0.264</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>Clay</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Ratoon</td>
<td>27-Jun</td>
<td>0.017</td>
<td>-0.212</td>
<td></td>
<td>-0.077</td>
<td>-0.115</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>Clay</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Ratoon</td>
<td>26-Jul</td>
<td>-0.468</td>
<td>-0.472</td>
<td></td>
<td>-0.085</td>
<td>-0.177</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>Silt Loam</td>
<td>Plant Cane</td>
<td>20-Apr</td>
<td>0.010</td>
<td>0.358</td>
<td></td>
<td>-0.342</td>
<td>-0.087</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>Silt Loam</td>
<td>Plant Cane</td>
<td>5-May</td>
<td>0.348</td>
<td>0.454</td>
<td></td>
<td>0.503*</td>
<td>0.463</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>Silt Loam</td>
<td>Plant Cane</td>
<td>16-May</td>
<td>-0.165</td>
<td>0.411</td>
<td></td>
<td>0.747**</td>
<td>0.827***</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>Silt Loam</td>
<td>Plant Cane</td>
<td>31-May</td>
<td>0.171</td>
<td>0.409</td>
<td></td>
<td>0.571*</td>
<td>0.609*</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>Silt Loam</td>
<td>Plant Cane</td>
<td>27-Jun</td>
<td>0.088</td>
<td>0.190</td>
<td></td>
<td>0.673**</td>
<td>0.671**</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>Silt Loam</td>
<td>Plant Cane</td>
<td>26-Jul</td>
<td>0.266</td>
<td>0.139</td>
<td></td>
<td>0.626**</td>
<td>0.359</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>Clay</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; Ratoon</td>
<td>26-Apr</td>
<td>0.342</td>
<td>0.392</td>
<td></td>
<td>0.280</td>
<td>0.397</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>Clay</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; Ratoon</td>
<td>9-May</td>
<td>0.017</td>
<td>0.148</td>
<td></td>
<td>-0.103</td>
<td>-0.235</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>Clay</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; Ratoon</td>
<td>26-May</td>
<td>0.404</td>
<td>0.547*</td>
<td></td>
<td>0.658**</td>
<td>0.752**</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>Clay</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; Ratoon</td>
<td>27-Jun</td>
<td>0.488</td>
<td>0.494</td>
<td></td>
<td>0.576*</td>
<td>0.527*</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>Clay</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; Ratoon</td>
<td>24-Jul</td>
<td>0.400</td>
<td>0.324</td>
<td></td>
<td>0.185</td>
<td>0.190</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>Silt Loam</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Ratoon</td>
<td>12-Apr</td>
<td>0.692**</td>
<td>0.555*</td>
<td></td>
<td>0.460</td>
<td>0.354</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>Silt Loam</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Ratoon</td>
<td>26-Apr</td>
<td>0.790**</td>
<td>0.751**</td>
<td></td>
<td>0.682**</td>
<td>0.625**</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>Silt Loam</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Ratoon</td>
<td>9-May</td>
<td>0.850***</td>
<td>0.854***</td>
<td></td>
<td>0.632**</td>
<td>0.701**</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>Silt Loam</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Ratoon</td>
<td>26-May</td>
<td>0.750**</td>
<td>0.794**</td>
<td></td>
<td>0.497</td>
<td>0.570*</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>Silt Loam</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Ratoon</td>
<td>27-Jun</td>
<td>0.405</td>
<td>0.553*</td>
<td></td>
<td>0.558*</td>
<td>0.618*</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>Silt Loam</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Ratoon</td>
<td>24-Jul</td>
<td>0.335</td>
<td>0.271</td>
<td></td>
<td>-0.074</td>
<td>-0.024</td>
<td></td>
</tr>
</tbody>
</table>

*p-value < 0.05, **p-value < 0.01, ***p-value < 0.0001
Table 3.5. Correlation coefficient ($r$) between leaf N content measured at different sampling times and soil inorganic N (NH$_4^+$ and NO$_3^-$) of cane variety L01-299 grown on clay and silt loam soils at the LSU AgCenter Sugar Research Station in St. Gabriel, LA, 2016-2017.

<table>
<thead>
<tr>
<th>Year</th>
<th>Soil</th>
<th>Crop Age</th>
<th>Sampling Date</th>
<th>Ammonium</th>
<th>Nitrate</th>
<th>Ammonium</th>
<th>Nitrate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>Clay</td>
<td>1st Ratoon</td>
<td>5-May</td>
<td>-0.087</td>
<td>0.211</td>
<td>0.165</td>
<td>0.379</td>
</tr>
<tr>
<td>2016</td>
<td>Clay</td>
<td>1st Ratoon</td>
<td>16-May</td>
<td>0.420</td>
<td>0.608*</td>
<td>0.066</td>
<td>0.517*</td>
</tr>
<tr>
<td>2016</td>
<td>Clay</td>
<td>1st Ratoon</td>
<td>31-May</td>
<td>-0.008</td>
<td>0.377</td>
<td>0.111</td>
<td>0.380</td>
</tr>
<tr>
<td>2016</td>
<td>Silt Loam</td>
<td>Plant Cane</td>
<td>5-May</td>
<td>0.132</td>
<td>0.508*</td>
<td>-0.260</td>
<td>-0.387</td>
</tr>
<tr>
<td>2016</td>
<td>Silt Loam</td>
<td>Plant Cane</td>
<td>16-May</td>
<td>-0.035</td>
<td>0.137</td>
<td>-0.049</td>
<td>0.014</td>
</tr>
<tr>
<td>2016</td>
<td>Silt Loam</td>
<td>Plant Cane</td>
<td>31-May</td>
<td>0.017</td>
<td>0.384</td>
<td>0.307</td>
<td>0.609*</td>
</tr>
<tr>
<td>2017</td>
<td>Clay</td>
<td>2nd Ratoon</td>
<td>26-Apr</td>
<td>0.109</td>
<td>0.503</td>
<td>0.361</td>
<td>0.622*</td>
</tr>
<tr>
<td>2017</td>
<td>Clay</td>
<td>2nd Ratoon</td>
<td>9-May</td>
<td>0.229</td>
<td>0.416</td>
<td>0.000</td>
<td>0.377</td>
</tr>
<tr>
<td>2017</td>
<td>Clay</td>
<td>2nd Ratoon</td>
<td>26-May</td>
<td>-0.250</td>
<td>0.560*</td>
<td>-0.335</td>
<td>0.397</td>
</tr>
<tr>
<td>2017</td>
<td>Silt Loam</td>
<td>1st Ratoon</td>
<td>26-Apr</td>
<td>0.105</td>
<td>0.355</td>
<td>0.142</td>
<td>0.493</td>
</tr>
<tr>
<td>2017</td>
<td>Silt Loam</td>
<td>1st Ratoon</td>
<td>9-May</td>
<td>0.377</td>
<td>0.663**</td>
<td>0.314</td>
<td>0.414</td>
</tr>
<tr>
<td>2017</td>
<td>Silt Loam</td>
<td>1st Ratoon</td>
<td>26-May</td>
<td>-0.106</td>
<td>0.145</td>
<td>-0.217</td>
<td>0.313</td>
</tr>
</tbody>
</table>

*p-value < 0.05, **p-value < 0.01
Figure 3.1. Relationship of leaf N content with cane yield and sugar yield of cane applied with urea ammonium nitrate solution in March and April on a silt loam soil at the LSU AgCenter Sugar Research Station in St. Gabriel, LA.
Figure 3.2. Relationship of leaf N content with soil ammonium and nitrate concentration of cane applied with urea ammonium nitrate solution in March and April on a silt loam soil at the LSU AgCenter Sugar Research Station in St. Gabriel, LA.
3.4 Discussion

3.4.1 Correlation between Leaf N and Yield

The purpose of regressing leaf N content with yield in this study is to identify the sampling times that show the highest correlation between parameters which best reflect the N health status of sugarcane. Establishing the sampling time where leaf N content and soil inorganic N content can both relate with sugarcane N health status and yield is important for successful implementation of in-season N decision tools for sugarcane. With the availability of such decision N tools, producers can make necessary fertilization adjustments to meet those N requirements for optimal yield. The averages of leaf N content for each year and soil type (Table 3.3) were within the range of optimal leaf N content based on multiple studies, where the optimal leaf N ranges from 1.34 % to 2.5 % depending on sampling time (Humbert, 1968; Reis and Monnerat, 2003; Vale et al., 2012). However, optimal leaf N content reported by McCray et al. (2010) for Florida ranges from 2.0 % to 2.6 %, which puts the values in this present study below optimum range in comparison to sugarcane production in Florida (McCray et al., 2010). These reports from Florida does not necessarily apply to leaf N content interpretation for Louisiana. The disparity in values perhaps is due to variation in procedure and processing of leaf samples such as removal of the leaf midrib. Midrib removal is commonly practiced in Florida sugarcane tissue analysis and has been shown by Muchovej et al. (2006) to increase N concentration readings in processed cane leaves, which in turn could also affect the optimal leaf N interpretation. Producers need to collect leaf samples early enough to accomplish timely application of the determined N rate requirement (Abdel-Rahman et al., 2010). This study included some sampling dates between late April and late March, which is early enough in the season to apply N fertilizer without causing mechanical damage to the sugarcane plant.
Further studies are needed in order to establish a critical N leaf value, interpretation and corresponding N recommendation. This can be done by establishing standards from multiple test years and regression analysis of large volume of data on N rate and leaf N content (Thomas, 1984).

Leaf N content varied across sample collection time, soil type and application timing for both years (Table 3.3). This variability was also observed by Muchovej and Newman (2004) in a research study conducted in Florida. The highest correlation between leaf N content and yield (cane and sugar), occurred in plots applied with UAN in March 6 WANF (Figure 3.1). A research study released in 2008 showed similar results wherein cane yield and sucrose content increased with increasing leaf N content (Kumar and Verma, 2008). Also, their study showed a comparable r value for the relationship between cane yield and leaf N content (r = 0.84) with the highest cane yield correlation found in this study (r = 0.85). Other research studies conducted in India and Texas also found a positive correlation between cane yield and leaf N content (Thomas, 1984; Sreenivas et al., 1990). The positive correlation of leaf N with cane yield is likely due to the corresponding increase in chlorophyll content and photosynthetic rate (Allison et al., 1997). Increase in leaf chlorophyll content has been shown to be related to increasing sugarcane growth in research studies conducted in Florida and Japan (Zhao et al., 2014; Dinh et al., 2017). Park et al. (2005) explains in his research that N contributes to photosynthetic capacity and leaf area expansion. Although the increase in leaf N content is correlated with increased growth of sugarcane, another study displays a negative relationship between sugar quality and leaf N content (Sreenivas et al., 1990). While leaf N concentration increases photosynthesis and ultimately plant growth in sugarcane, it may not be beneficial to a certain
extent due to the possibility of compromising sugar quality. The decrease in sugar quality (sucrose %) may ultimately result in the reduction of sugar yield.

The results from 2016 indicate that N content of leaf samples taken in mid-May on silt loam soil obtained a strong positive relationship with sugar and cane yield (Table 3.4). Correlation results for the 2017 silt loam soil also suggest that N content of leaf samples collected in mid-May was highly related to sugarcane yield. The results for the clay soil in 2017 show that correlation between leaf N content and yield is best observed when cane leaves are sampled in late-May. These results are aligned with sampling recommendations from Muchovej et al. (2005), stating that May is the best month for sugarcane leaf sampling compared to later months. Recommendations for leaf N sampling in Florida is in June and July, right before the grand growth period of sugarcane within the state (McCray and Mylavarapu, 2015). Across all years and soil types in the present study, the N content of leaf from May sampling had the highest correlation values with yield. This could be explained by growth stage of the sugarcane plants; the month of May coincides with the period right before the maximum three months of sugarcane growth in June, July and August (Greenland, 2005). Highest correlating models from Kumar and Verma (2008) in a research study on leaf N content and yield were found to be in the period of maximum growth of sugarcane. The proximity of mid to late-May and this high growth period could be the reason for the higher correlating models, likely because this is when the N taken up by cane is most utilized for growth. A study conducted by Poswa and Miles (2016) shows a decrease in leaf N content as the crop progresses towards the maturation stage, which also requires an adjustment on the critical leaf N concentration level. High correlation of leaf N content and sugarcane yield sampled in May indicates that this is when leaf N content can be used as a determinant of its relationship with sugarcane yield. This is supported by Samuels et al.
(1953) showing that there was an increased limitation of discerning leaf N content between 0 and 207 kg N ha\(^{-1}\) fertilized cane from 3, 6 and 10 months (late sampling dates) age of 4 different varieties in Puerto Rico. This also suggests that the effect of fertilizer and leaf N in relation to yield is more measurable at earlier growth stages of sugarcane as leaf N content values start to normalize in later plant growth stages.

In general, cane applied with UAN in March had lower correlation values between leaf N content and yield compared to cane applied with UAN in April, with exception to silt loam soil in 2017. High variability in correlation values was also evident across year. The trial on clay soil was established one year before the trial on silt loam soil, thus crop age may have influenced the correlations between leaf N content and yield. Humbert (1963) reports his findings in Hawaii, showing leaf N concentrations decreasing over a 21 month period, regardless of N fertilization. This is reflected in the results from this study, as there was a decline in average leaf N content in both soil types from year 2016 to year 2017 (Table 3.3). In contrast, another research study by Oliveira et al. (2013) showed excessive leaf N concentrations in ratoon crops compared to plant cane crops. Response to N fertilizer however, is likely to increase in ratoon crops compared to plant cane crops (Muchovej and Newman, 2004; Elhag et al., 2012). Response increases across years was observed in this present study; average sugar yield response to N fertilization from year 2016 to 2017 resulted in a 24 % increase on the clay soil and a 35 % increase on the silt loam soil compared to the control (0-applied N) cane. Cane yield showed a similar increasing response to N fertilization across ratoons for both soil types. Since the sugarcane response to N fertilizer and leaf N content varied across years, it is likely to also have variation in correlation strength across years as observed in this study. Humbert (1963) also explained that the reason for variation of leaf N content in sugarcane across years can be attributed to temperature, moisture
and climate variability. The different outcomes recorded from this 2-year study further highlight the need to conduct multi-year research studies on correlations among leaf N content, soil inorganic N, and sugarcane yield. This would help to further establish a standard sampling time, given the variability of leaf N content response to soil inorganic N from year to year.

3.4.2 Correlation between Leaf N and Inorganic N

The correlation analysis performed between leaf N content and inorganic soil N at different sampling times provides an overview of the dynamics of soil N and cane N uptake and their subsequent impact on the N health status of the cane. The overlapping sampling dates for soil and cane leaves spanned the course of three sampling dates from April to May (Table 3.5). Similar to leaf N content and yield relationships, the highest correlations between inorganic soil N and leaf N content was mostly observed in May as compared to April sampling dates. One exception for this occurred in the 2017 clay soil, which showed the highest correlation values to be in the late-April sampling. The highest correlation value was on 9-May in the 2017 silt loam soil across all sampling dates. This result further establishes the critical stage for collecting soil and leaf N samples to be in the month of May as the best sampling time to relate the N status of sugarcane.

At some sampling dates, inorganic soil N yielded negative correlation with leaf N content (Table 3.5). Many studies reported that there is little to no effect of N fertilizer rates on the leaf N content of sugarcane (Muchovej and Newman, 2004; Oliveira et al., 2013). On the other hand, some studies show that increasing N rates resulted in increased soil inorganic N which subsequently increased leaf N content. Thomas (1984) reports a linear increase of leaf N content from 0 to 112 kg N ha⁻¹ fertilizer applications. Silva et al. (2015) reported in his study a quadratic
relationship between cane leaf N content and N fertilization, revealing an increase of leaf N content from fertilizer application rates up to 109 kg N ha\(^{-1}\) and decreasing leaf N content at higher N fertilization rates. In this present study, the N application rates of 45, 90 and 135 kg N ha\(^{-1}\) resulted in a linear increase in soil inorganic N concentrations. Therefore, this study is showing increasing leaf N content at a higher rate (135 kg N ha\(^{-1}\)) compared to reports from Thomas (1984) and Silva et al. (2015). Based on the linear increase of leaf N content and inorganic N concentration in this present study, higher leaf N accumulation might have possibly been observed at higher UAN application rates.

Low correlation values between inorganic N content and leaf N content may be related to decreasing leaf N concentration. The leaf N dilution effect is reported in multiple studies and shows the accumulation of leaf N resulting in higher biomass accumulation, which in effect can reduce the measured leaf N concentration (Muchovej and Newman, 2004; Ambrosano et al., 2005; Poswa and Miles, 2016).

Comparing between NH\(_4^+\) and NO\(_3^-\), the measured soil NO\(_3^-\) concentrations were more related with leaf N status achieving higher correlation values and significance than NH\(_4^+\) across all years and soil types (Table 3.5). This may be due to its anionic charge and mobility in the soil as compared to NH\(_4^+\) (Muchovej and Newman, 2004). The instantaneous transformation of NH\(_4^+\) to NO\(_3^-\) can take place within the time after fertilization between sampling dates. Therefore, the soil NH\(_4^+\) concentration is susceptible to decreasing levels, before cane leaves begin to respond to it. Although sugarcane has been shown to have preference towards NH\(_4^+\) uptake, soil NO\(_3^-\) may be in higher concentration than soil NH\(_4^+\) as it can accumulate through nitrification of NH\(_4^+\) (Crawford and Forde, 2002). This could be the reason why NO\(_3^-\) is a more accurate index of leaf N status, since it can stay in its form more consistently than NH\(_4^+\). As long as moisture and
temperature do not enhance NO$_3^-$ loss through leaching or denitrification, soil NO$_3^-$ should remain a better index of leaf N status.

3.5 Conclusion

Highest correlation values between leaf N and sugarcane yield were different between years and highly variable between sampling dates. However, highest correlation values were recorded from leaves sampled in mid-May, which best defined a positive linear relationship between leaf N content and yield. Therefore, it appears that if leaf N is to be used as an index for N health status in Southern Louisiana sugarcane production, leaf tissue samples should be collected in mid-May. Furthermore, establishing the sampling time where leaf N content and soil inorganic N content can both relate with sugarcane N health status and yield is important for successful implementation of in-season N decision tools for sugarcane.

The majority of highest $r$ values between leaf and soil N were observed within 8 WANF, which was in mid-May for soils applied with UAN in March and earlier when UAN was applied in April. This was further affected by inorganic N form. A high variation in correlation values was observed with the form of inorganic N regressed with leaf N content. In this study, the relationship between soil inorganic N and leaf N status was best defined by soil NO$_3^-$, which can be dependent on soil type and moisture conditions. Overall, these findings can further the knowledge about N health status in Louisiana sugarcane production and give an expanded insight into the effects of site specific factors and management practices. As knowledge on these topics are pursued, sugarcane leaf N health status and ultimately N requirement can be more accurately determined, allowing producers to be more efficient with N fertilizer amendments.
3.6 References


Park, S. E., M. Robertson, and N.G. Inman-Bamber (2005): The decline in the growth of a sugarcane crop with age under high input conditions. *Field Crop Research* 92, 305.


Chapter 4. Conclusions

The dynamic nature of soil nitrogen (N) can make optimal management strategies for this essential nutrient in sugarcane (*Saccharum spp.*) highly variable in effectiveness. Sugarcane N decision tools can also be limited in their ability to accurately evaluate the N health status of sugarcane based on different management practices and climatic conditions. The primary objective of this research was to improve N management strategies in Louisiana sugarcane production by documenting the effects of application timing and soil type on the optimal N rate requirement and yield, as well as to relate the relationship of soil and leaf N status at different growth stages with sugarcane yield.

The soil inorganic N concentration levels varied from year to year on both soil types and appeared to have an influence on sugarcane yield production. Lower NH$_4^+$ and NO$_3^-$ concentrations were recorded in 2017 compared to 2016 for both clay and silt loam soils. The NO$_3^-$ concentration was almost consistently higher in the silt loam soil than the clay soil. Application timing of UAN fertilizer also seemed to have inconsistent effects on the level of soil inorganic N concentration, but mostly did not appear to affect the release of plant available N into the soil for months associated with active N uptake for sugarcane in Louisiana. Applying UAN in March resulted in higher NH$_4^+$ and NO$_3^-$ concentrations in the soil compared to April application. Based on the outcomes of this study, soil inorganic N concentration is not a sufficient indicator for the N health status of sugarcane in Louisiana. Even so, soil inorganic N concentration when combined with multiple site specific factors such as soil type, climate conditions, and leaf N status may be viable information to improve N management strategies for sugarcane.
The estimates of optimal N rates for sugar yield and cane yield varied between soil type and year. The optimal N rate for sugar yield was achieved in the silt loam soil in 2016 at 39 kg N ha\(^{-1}\) yielding 14,102 kg sugar ha\(^{-1}\). For cane yield the optimal N rate was 43 kg N ha\(^{-1}\) and yielded 117 Mg cane ha\(^{-1}\). Optimal N rates showed high and low deviations to current N recommendations in Louisiana and were primarily observed in sugarcane applied with UAN in March compared to April. This was likely influenced by the inorganic N loss potential over time in certain soil types, which was further compounded by temperature variations and rainfall events. Site specific consideration of fertilizer N management is evident according to the results of this study. The potential benefit of CRF through lowering the optimal N rate requirement of sugarcane was reported, but further research into the economics of this is needed as yield reduction may offset the savings of applying less N fertilizer. The results reported in this current study gives further confirmation to the variable yield outcomes experienced in sugarcane production between soil types and cropping seasons within the state. There are potential positive effects in diversifying fertilizer N management in Louisiana sugarcane by creating a more accurate site specific N management strategy and by extending the window of early N application timing into May.

Highest correlation values between leaf N and sugarcane yield were different between years and highly variable between sampling dates. However, highest correlation values were recorded from leaves sampled in mid-May, which best defined a positive linear relationship between leaf N content and yield. Highest correlation values achieved between leaf N content and yield were 0.854 for cane yield and 0.850 for sugar yield, when UAN was applied in March. Therefore, it appears that if leaf N is to be used as an index for N health status in Southern Louisiana sugarcane production, leaf tissue samples should be collected in mid-May. Further
establishing the sampling time where leaf N content and soil inorganic N content can both relate with sugarcane N health status and yield is important for successful implementation of in-season N decision tools for sugarcane.

The majority of highest $r$ values between leaf and soil N were observed within 8 WANF in mid-May for soils applied with UAN in March and earlier when UAN was applied in April. This was further affected by inorganic N form. A high variation in correlation values was observed with the form of inorganic N regressed with leaf N content. In this study, the relationship between soil inorganic N and leaf N status was best defined by soil NO$_3^-$, which can be dependent on soil type and moisture conditions. The highest correlation values occurring between leaf N content and soil NO$_3^-$ was 0.663. The highest correlation value between NH$_4^+$ and leaf N content was 0.420. Overall, these findings can further the knowledge about accurately determining N health status in Louisiana sugarcane production and give an expanded insight into the effects of site specific factors and management practices. As research on these topics increase, sugarcane leaf N health status and ultimately N rate requirement can be more accurately determined, allowing producers to be more efficient with N fertilizer amendments.
Vita

Joseph Martin Garrett was born in 1993 in Baton Rouge, Louisiana. He graduated with his Bachelor of Science degree in Horticultural Science in 2015 at Louisiana State University (LSU) Agriculture and Mechanical College, Baton Rouge. In the year 2016 he started his master’s degree program in the School of Plant, Environmental, and Soil Sciences at LSU. He is under the guidance of Dr. Brenda Tubana, working on nitrogen nutrition management in Louisiana sugarcane production. Specifically, he was observing the effects of different application timings of N fertilizer on sugarcane yield as well as establishing the most accurate sampling time for soil and leaf N to relate the N health status and yield of sugarcane.