INVESTIGATION OF THE ABILITY TO CREDIT RESIDUAL NITROGEN BASED ON SOIL TEXTURE AND NUTRIENT MANAGEMENT ZONE IDENTIFICATION USING SOIL ELECTRICAL CONDUCTIVITY, pH AND REFLECTANCE

A Thesis

by

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ABSTRACT

Variation in soil properties within a production field can drastically differ in pH, nutrient, and water holding properties, thus benefiting from site-specific nutrient management. Previous research has shown a strong correlation between soil texture and both nutrient holding capacity and soil water dynamics, which influence nitrogen (N) retention. Nitrogen is the highest input cost in Texas row crop production and the most common yield-limiting nutrient, and effectively crediting residual soil NO_3-N will increase nitrogen use efficiency and return on investment (ROI). The relationship between bulk soil electrical conductivity (EC) and soil texture has been used to delineate management zones and can be collected and mapped quickly in commercial fields. Using Veris® EC, texture based site-specific nutrient management zones has demonstrated potential to spatially identify contrasting soil textures and manage residual soil N on a site specific basis. To test this hypothesis, a multi-year project was initiated on a 15.4 ha field near College Station TX in the spring of 2014 through 2017. Bulk soil EC was collected with the Veris® 3100 in 2013. In 2016, soil EC, soil pH, and soil reflectance were collected with a Veris® MSP3. Soil cores were pulled annually on a 0.73 hectare grid to a depth of 122 cm before the crop was planted to quantify extractable nitrate, phosphorus, potassium and minerals. Increasing N rates were applied on a corn (*Zea mays*) and cotton (*Gossipium hirsutum*) rotation to evaluate management and crediting of residual soil NO_3-N. A positive relationship (r^2=.754) of interpolated Veris® EC and soil texture from 0-15 cm depth was observed. Coarser textured areas of the field (<25% clay) had lower yields than that of the finer textured areas (>30% clay) in all four years. Cotton had no response to N fertilizer suggesting that residual NO_3-N was adequate to achieve optimum yields. Residual N could not be credited on coarse textured soils and yields were not maximized when soil residual Nitrogen was credited on these coarse textured soils. Veris pH showed a correlation to lab tested pH in variable soils. Veris reflectance data showed inconsistent result across the 3 locations.

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NOMENCLATURE

N	Nitrogen
NO_3^-	Nitrate
NO_3-N/ Nitrate-N	Nitrate Nitrogen
EC	Electrical Conductivity
NH_4^+	Ammonium
SOM	Soil Organic Matter
NUE	Nitrogen Use Efficiency
NFFB	Nodes to First Fruiting Branch
TN	Total Nodes
PH	Plant Height
NAHB	Nodes Above Harvestable Boll
HVI	High Volume Instrument
CEC	Cation Exchange Capacity

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CHAPTER I

LITERATURE REVIEW AND INTRODUCTION

Introduction

Influence of Soil Properties on Nutrient Availability

Differences in soil properties can drastically influence plant nutrient availability in soil. The cation exchange capacity (CEC), pH, and soil organic matter (SOM) content are major soil properties that govern nutrient availability (Brady and Weil, 2010). Cation exchange capacity is an inherent soil characteristic influenced by particle size and colloid type and is described as the amount of exchangeable cations a soil can adsorb (Brady and Weil, 2010). Clays such as smectites and vermiculites undergo a milder weathering process and are 2:1 clays which have a much higher CEC. The CEC of 2:1 clay comes from a negative charge due to isomorphic substitution during the formation of the clay. Whereas a kaolinite clay is more heavily weathered and are 1:1 clays with the CEC being pH dependent (Brady and Weil, 2010). Along with being related to CEC, clay content also influences soil water availability and holding capacity. The small particle size of clay means a greater surface area in a particular volume of soil for water to be adsorbed (Brady and Weil, 2010). More water being held in the soil profile means that there will be more plant available water.

Soil pH is the negative logarithm of the hydrogen concentration (H^+) in the soil solution. Changes in pH can affect microbial transformations of nutrients and change the chemical form of nutrients increasing or decreasing plant availability. As an example, acidic soils cause phosphorous to be adsorbed to iron and aluminum oxides, while in alkaline soils the phosphorous precipitates with calcium to become unavailable for plant uptake. Therefore, maintaining a near neutral pH is optimum for phosphorous availability. The nitrification process that converts ammonium (NH_4^+) to nitrate (NO_3^-) occurs at a pH of 4.2-9, but the optimum pH for nitrification is 8.2 (Havlin, et al., 2014).

Soil organic matter directly benefits nutrient availability in two ways; by nutrient cycling and increasing CEC. Crop residues return nutrients to the soil by decomposition and mineralization of the organic compounds into plant available forms (Wanjura, et al., 2014). The CEC of SOM can be up to 5 times higher than that of clays on a per mass basis and plays a prominent role in the cation exchange in A horizons in high organic matter soils (Brady and Weil, 2010). Microbial activity in the soil decomposes organic materials and SOM into inorganic forms of nutrients that are plant available. Macronutrients such as N, sulfur (S), and phosphorous (P) and several micronutrients are related to microbial activity on SOM from the nutrients being returned (Havlin, et al., 2014).

Importance of Nitrogen

There are seventeen elements that are considered to be essential for plant growth; hydrogen, carbon, oxygen, N, P, potassium (K), calcium, magnesium, sulfur, chloride, iron, boron, manganese, zinc, copper, nickel and molybdenum. Non-mineral mineral nutrients include carbon, hydrogen and oxygen and are obtained from the atmosphere as carbon dioxide (CO_2) or from water (H_2O). The remaining fourteen are broken down into macronutrients and micronutrients. Macronutrients are classified as N through sulfur and micronutrients are chloride through molybdenum, as listed previously. Concentration and plant demand for each element is dependent on species and environment, but the macronutrients are required in much higher quantities than the micronutrients. (Havlin, et al., 2014). Of the macronutrients, N is considered to be the most limiting in non-leguminous crops (Waskom, 1994; Stichler and McFarland, 2001; Blumenthal, et al., 2008; Lemon, et al., 2009; Main, et al., 2013). Sources of N can be organic or inorganic. Organic N would come from sources such as manure or crop residues and must be mineralized into an inorganic N for plant uptake. The two inorganic sources of N that are plant available are ammonium (NH_4^+) and nitrate (NO_3^-) (Brady and Weil, 2010). Uptake preference varies by plant species but both forms can be up taken by the plant by either mass flow or diffusion. Nutrient movement via mass flow is aided by solute potential and water potential. As water is transpired by the plant leaf the water potential in the leaves is lowered, and this draws water up the stem from the roots thus lowering the roots water potential. As the roots uptake water, nutrients are subsequently taken up. When this occurs, the water potential at the root surface is lowered so that water and nutrients in solution are pulled to the root surface by this potential (Barber, et al., 1963). Diffusion is a passive process where nutrients are moved by concentration gradient towards the roots.

As nutrients are up taken, ions are secreted by the plant resulting in reduced concentration gradient at the root surface meaning mobile nutrients such as NO_3^- can be diffused towards the root (Anderson, 2007). Once in the plant, NO_3^- can be translocated from the roots to shoots or stored in vacuoles for later use. However, NO_3^- must be converted to NH_4^+ in the cell before it can be metabolized into amino acids or proteins. While this conversion step makes the uptake of NO_3^- less energy efficient in the whole plant, it is still recommended that inorganic fertilizer sources have a 1:1 ratio of NO_3^- to NH_4^+ because large quantities of NH_4^+ can actually slow plant development (Havlin, et al., 2014). Both plant available forms of N are susceptible to environmental losses but differ in how the losses occur. This makes predicting short and long-term N losses and estimating plant available N challenging. Nitrate is an anion and does not bind tightly to the soil colloids, which makes it susceptible to leaching (Havlin, et al., 2014). Nitrate can also be lost by denitrification when NO_3^- is reduced by anaerobic bacteria and an electron acceptor such as organic matter to molecular nitrogen (Havlin, et al, 2014). Losses of ammonium can occur by fixation onto a clay colloid, volatilization, immobilization (converted into an organic form of N by microbes) or converted to NO_3^-, where it is susceptible to leaching and denitrification. Microbial activity in different environments influences the ratio of NO_3^- to NH_4^+. In warm and moist environments microorganisms such as Nitrosomonas and Nitrobacter quickly convert NH_4^+ to NO_3^- (Brady and Weil, 2010). This creates a more abundant source of NO_3^- compared to NH_4^+ so plants that are adapted to warmer climates such as that of South Texas are more adapted to assimilate NO_3^- (Teyker, 1992; Silvertooth and Norton, 2011; Havlin, et al., 2014).

Plant Growth and Nitrogen Management

The highest quantities of N are needed for both cotton (*Gossypium hirsutum L.*) and corn (*Zea mays L.*) during the reproductive phases. Their N demand curve follows a sigmoidal pattern with peak uptake occurring during the reproductive phases (Silvertooth and Norton, 2011; Bender, et al., 2013). At the first reproductive phase (R1) of corn the demand of N for grain fill increases and by R6 over 50% of the dry matter N is in the grain (Bender, et al., 2013). In natural environments, cotton is a perennial tree and has indeterminate growth and fruit set so the exact time of plant need changes and is less predictable (Stichler and McFarland, 2001). Peak uptake is generally between first bloom and first open boll while the plant is setting and filling out fruit (Silvertooth and Norton, 2011), and by harvest more than 50% of the N is in the seed (Stichler and McFarland, 2001).

Meeting the N requirements through N fertilizers is the highest input cost for both corn and cotton production in Texas and is one of the higher costs across the U.S. (USDA-ERS, 2016). Proper timing and placement are imperative to achieve optimum crop growth and profit potential (Waskom, 1994; Stichler and McFarland, 2001; Lemon, et al., 2009; Main, et al., 2013). Over application from using excessive N rates or decomposition of organic matter can result in large quantities of residual N in the soil profile. If residual N is not credited when calculating fertilizer application rates, or not recovering the residual N with a crop can result in N losses into the environment. Nitrate leaching, especially in coarser soils and areas with high annual precipitation, can result in contamination of groundwater sources (Peng, et al., 2015; Carter, et al., n.d.). Nitrate is the most commonly found nonpoint source agricultural chemical detected in groundwater systems (Baker, 1992; Wu, et al., 1997). In the coarser textured soils of the Texas High Plains, NO_3^- losses due to leaching averaged 3.14 kg ha^{-1} and runoff of NO_3- from fertilizers to surface water was 4.71 kg ha^{-1}. Corn production fields on average were responsible for more leaching and runoff than fields sown in cotton, sorghum (*Sorghum bicolor*) and wheat (*Triticum aestivum)*. Irrigated cotton was responsible for less runoff or leaching of NO_3^- than irrigated sorghum, irrigated corn and irrigated wheat (Wu, et al., 1997).

Research has been conducted to determine how soil NO_3^- can be credited to the incoming crop. On a watermelon and corn rotation Halvorson, et al. (2005) found residual NO_3-N content in the Arkansas River Bottom of Colorado to be near 252 kg $ha^{-1}$to a depth of 180 cm. Near Rocky Ford, CO, Halvorson, et al. (2002) also reported an average of 785 kg NO_3-N ha^{-1} in the soil down to 180 cm in an onion (*Allium cepa)* and corn rotation. At the Rocky Ford site soils were described as well drained with a water table of only 4.5 m so the potential for groundwater contamination from NO_3-N was high. Hons, et al. (2004) reported NO_3-N content to a depth of

122 cm to be over 112 kg ha^{-1} in 22 of the 39 site-years studied. Crediting the full amount of residual NO_3-N down to 61 cm in heavy clay soils along the upper gulf coast of Texas has maintained consistent yields while decreasing the amount of applied fertilizer, and as a result lower fertilizer input costs in corn (Fromme, et al., 2016). Halvorson, et al. (2005) found N fertilizer use efficiency was the highest at lower N rates that utilized soil residual NO_3-N when corn was sown following watermelon. In a potato study conducted in Quebec, the field was divided into soil EC management zones and N was applied based on EC zones at rates ranging from 0 to 202 kg NO_3-N ha^{-1}. As a result, the potato crop was able to effectively recover up to 65% of the residual NO_3-N content and the fertilizer use efficiency decreased as the applied fertilizer rate increased (Cambouris, et al., 2008). When considering residual NO_3^-N in estimating nitrogen use efficiency NUE, Main, et al. (2013) found a stronger and more accurate relationship of cotton growth to total inorganic N (applied and residual), than applied N. The study reported a positive correlation with cotton growth and yield to increasing total N up to 196 kg N ha^{-1}, where the yield to N trend became negative. Currently in Texas, the fertility recommendations for cotton is to apply 56 kg N ha^{-1} to produce 227 kg lint (Hons, et al., 2004; Lemon, et al., 2009). Corn recommendations range from 1.2 to 1.5 kg of N to produce 25.4 kg of grain (Stichler and McFarland, 2001; Camberato and Nielsen, 2017).

Currently, the most common strategy for meeting N requirements for crops are being met by broadcast preseason applications based on a yield goal (Camberato and Nielsen, 2017). While a single application reduces the risk of environmental conditions preventing subsequent applications, downsides to this method are the extended time between N application and the time of crop demand. Dividing the N requirements into multiple applications during the time of plant need can increase fertilizer use efficiency and reduce the potential for losses due to leaching and denitrification (Keeney, 1982). Cotton N requirements are low in the early vegetative growth stages but increase drastically during flowering and boll filling (Silvertooth and Norton, 2011). Applying a portion of the N around planting and the remainder applied at squaring has shown to result in greater NUE (Lemon, et al., 2009). Effectiveness of split applications of N in corn has been less conclusive. In environments that are not conducive for N losses, there is little to no agronomic benefit to split application (Barker and Sawyer, 2017). Peng, et al. (2015) showed that split applications can lead to an increase in fertilizer use efficiency and yield in coarser textured soil. Environments that receive high precipitation during the growing season have an increased risk of NO_3-N losses due to leaching below the rooting zone into groundwater sources (Slaton, et al., 2012). However, split applications were not as effective in finer textured soils, such as in the Texas Blackland Prairie. In that area Torbert, et al. (2001) showed no yield differences when comparing split applications to a single application in corn. Barker and Sawyer (2010) observed no yield difference in the single application, split application, or variable rate N management.

Differences in response by soil types highlights the importance of site specific N management (Shahandeh, et al., 2005). Site-specific management has the potential to maximize economic return and enhance environmental health (Wallace, 1994). Studies like the one conducted by Shahandeh, et al. (2005) demonstrate the potential for modifying soil nutrient recommendations based on soil texture. Other states already make N recommendations for crops based upon soil texture. In Tennessee, N recommendations for cotton range as high as 90 kg N ha^{-1} on coarse textures to 50 kg N ha^{-1} in bottom land soils or where excessive vegetative growth is an issue (Main, 2012). In Georgia, N fertilizer recommendations for cotton are as low as 38 kg N ha^{-1}. However, if it is on a coarse textured soil, continuous cotton, or a low yielding area, rates are increased by 25%. Inversely, for fields that are following a legume, grain crop, or have a history of excessive vegetative growth the 38 kg N ha^{-1} recommendation is to be reduced by 25% (Whitaker, et al., 2018).

Along with texture many soil and crop parameters have been investigated as a method for refining N recommendations. As indicated by Schmidt, et al. (2002), considering multiple soil parameters can provide a better approach to determining N management zones. Examples of these parameters include, normalized difference vegetation index (NDVI), electrical conductivity (EC), pH, organic matter content, and others (Schmidt, et al., 2002; Godwin and Miller, 2003; Shahandeh, et al., 2005; Sudduth, et al., 2005). Still, texture is considered to be one of the more effective parameters for basing N recommendations (Godwin and Miller, 2003). Of the three sites used in a study conducted by Cox, et al. (2003), clay content was more consistently related to yield compared to other measured soil or plant parameters. Texture can influence many other soil parameters such as EC, pH, nutrient content, and water holding content. Of these, EC can be easily sampled on a large scale for field management (Shahandeh, et al., 2005). The ease of gathering large scale spatial data of EC for a field has been done using three methods discussed by Sudduth, et al. (2005) as field sampling with probes or pulling cores, using an EM 38 (Geonics Limited, Mississauga, Ont., Canada), and Veris 3100 or MSP3 (Veris Technologies, Salina, KS). Since EC in non-saline soils is heavily influenced by cation exchange capacity and water holding capacity, two main factors for crop productivity, a relationship between EC and crop yield have been described (Godwin and Miller, 2003). Studies have found a relationship to the quantity of residual nutrients in the soil, such as NO_3^-, so EC could be used to predict NO_3^- content at that particular site (Doran, et al., 1996; Smith and Doran, 1996; Eigenberg, et al., 2002). However, other research suggests less of a direct connection to N availability, but rather a correlation to clay content and indirectly nutrient holding capacity of the soils (Lopez-Granados, et al., 2002; Shahandeh, et al., 2005). Based on the previous research, the objective of this study was to determine the effectiveness of using texture to identify management areas and determine how residual NO3-N could be credited based upon texture. Also, to test the accuracy of using on-the-go sampling technologies from Veris to actual soil properties, and their relevance in nutrient management.

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CHAPTER II

NITROGEN FERTILIZER AND RESIDUAL NITRATE EVALUATION

Introduction

Agronomical Importance of Nitrogen

Of the seventeen plant essential elements, nitrogen (N) is considered the most limiting nutrient for non-legume crops. Sources of N can be organic or inorganic with inorganic being the most commonly used supplemental sources in row crop production. Plant available inorganic forms of N are ammonium (NH_4^+) and nitrate (NO_3^-). Both of which are taken up by plants via mass flow and diffusion, while uptake preferences vary by plant species and cultivar. Plants adapted to warmer climates, such of that of South Texas, are more adapted to use NO_3^- rather than NH_4^+ due to the abundance of NO_3^- (Teyker, 1992; Silvertooth and Norton, 2011; Havlin, et al., 2014). Once in the plant, NO_3^- can be translocated from the roots to shoots or stored in vacuoles for later use, but NO_3^- must be converted to NH_4^+ in the cell before it can be metabolized into amino acids or proteins. While this conversion step makes assimilation of NO_3^- less energy efficient in the whole plant, it is still recommended that inorganic fertilizer sources have a 1:1 ratio of NO_3^- to NH_4^+, because large amounts of NH_4^+ can actually slow plant development (Havlin et al., 2014).

Both plant available forms of N are susceptible to environmental losses, but they differ in how the losses occur. This makes predicting N losses and estimating plant available N challenging. Ammonium, for instance, can be volatilized or reduced to NO_3^-, which can be leached. In warm and moist environments microorganisms such as Nitrosomonas and Nitrobacter quickly convert NH_4^+ to NO_3^- (Brady and Weil, 2010). Being an anion, NO_3^- does not bind to negatively charged clay particles, making it more susceptible to leaching (Havlin, et al., 2014).

With NH_4^+ and NO_3^- being prone to losses, timing and placement of N fertilizers can be just as critical as the rate being applied. For cotton in particular, N is needed in limited amounts during the early vegetative growth stages, though demand increases drastically during flowering and fruit set (Silvertooth and Norton, 2011). Nitrogen fertilizer response in corn has shown inconclusive results when comparing the entire rate applied preseason to split applications of a preseason application and followed by another at the V8- V10 growth stage (Barker and Sawyer, 2010; Slaton, et al., 2012). Studies using in-season applications based on canopy sensors have not shown statistical improvement of yield but can increase the fertilizer use efficiency (Barker and Sawyer, 2017).

Current Nitrogen Management

Depending on location, the recommendations for N in corn range from 1.2 to 1.5 kg of N to produce 25.4 kg of grain (Stichler and McFarland, 2001; Camberato and Nielsen, 2017). The N recommendation for cotton is 56 kg of N per 227 kg of lint for Texas (Lemon, et al., 2009). However, the N recommendations in cotton varies tremendously across the Cotton Belt. In Tennessee N recommendations range as high as 90 kg N ha^{-1} on course textured soil to as low as 50 kg ha^{-1} in bottom land soils or where excessive growth is an issue (Main, 2012). In Georgia, N fertilizer recommendations are as low as 38 kg N ha^{-1}. However, if it is on coarse textured soils, continuous cotton, or a low yielding area, rates are increased by 25% (Whitaker, et al., 2018). Inversely, for fields that are following a legume, grain crop, or have a history of excessive vegetative growth the 38 kg N ha^{-1} recommendation is to be reduced by 25% (Whitaker, et al., 2018). Managing N and applying N fertilizers to fields can be done several ways with pros and cons to each management strategy. As described by Camberato and Nielsen (2017) the method of uniform preseason applications is the most frequently used practice. The downside to this method is the extended time between N applications and the time of plant demand can lead to substantial N losses. Split applications of N fertilizers decrease the risk of losses and increase fertilizer use efficiency, especially in coarse soils (Peng, et al., 2015). Applying a portion at planting and then the remainder at squaring for cotton and V6-7 for corn can result in greater nitrogen use efficiency (NUE) and subsequently higher yields (Lemon, et al., 2009; Slaton, et al., 2012).

Along with yield, crop quality can be associated with N fertilizer application timing and placement. Corn grain protein content is directly correlated with the total amount of plant available N. Later season applications of fertilizer or having deeper residual N that is available later in the plants growing cycle has the greatest impact on corn grain protein content (Olsen, et al., 1976). Nitrogen timing and amount also factor into cotton quality but is more difficult to manage and quantify than corn. An abundance of N in cotton can prolong the vegetative growth stage and delay maturity because of its indeterminate growth habit (MCConnell, et al., 1996; Main, et al., 2013). Whitaker, et al. (2018) explains that along with increased input costs, over fertilization causes excessive or rank vegetative growth, can delay maturity, and lower defoliant efficacy. Variety genetics have the greatest influence on fiber quality parameters such as fiber length and strength, but N has been reported to increase micronaire, boll size, and ginning turnout percentage up to the rate of 135 kg N ha^{-1} (Saleem, et al., 2010)

Residual Nitrogen Content

Fulfilling the N use requirements through N fertilizers is the highest input cost for both cotton and corn production in Texas and is one of the higher costs in the U.S. (USDA-ERS, 2016). Optimum application timing and placement of N fertilizer can increase crop response and profitability potential (Waskom, 1994; Stichler and McFarland, 2001; Lemon, et al., 2009; Main, et al., 2013). Over time, excessive N fertilizer applications can result in large amounts of residual NO_3^- in the soil profile. Halvorson, et al. (2005) found residual NO_3^- content in the Arkansas River Valley in Colorado to be near 252 kg ha^{-1}. Hons, et al. (2004) reported NO_3^- levels greater than 112 kg ha^{-1} to a depth 122 cm in 22 of the 39 site-years studied. If over fertilization continues without recovering residual NO_3^-, it can potentially leach into groundwater (Ceplecha, et al., 2004).

Crediting residual nitrate-nitrogen (NO_3-N) to 61 cm in heavy clay soils along the upper gulf coast of Texas has shown consistent corn yields while decreasing the amount of applied fertilizer and resulted in lower fertilizer costs in corn (Fromme, et al., 2016). Halvorson, et al. (2005) found N fertilizer use efficiency was the highest at lower N rates that utilized soil residual NO_3^- when corn was sown following watermelon. In a potato study conducted in Quebec, the field was divided into soil EC management zones and N was applied based on electrical conductivity (EC) zones at rates ranging from 0 to 202 kg NO_3^- ha^{-1}. As a result, the potato crop was able to effectively recover up to 65% of the residual NO_3^- content. Fertilizer use efficiency decreased as the applied fertilizer rate increased (Cambouris, et al., 2008). When considering residual N in estimating NUE, Main, et al. (2013) found a stronger and more accurate relationship of cotton growth to total inorganic N (applied and residual), than applied N. The study reported a positive correlation with cotton growth and yield to increasing total N up to 90 kg N ha^{-1} where the yield to N trend became negative, further suggesting the need to investigate the influence of residual N.

Shahandeh, et al. (2005) found a relationship of residual NO_3^- and clay content and used texture to delineate N management zones. The relationship of texture to soil properties that influence plant growth factors such as water holding capacity and nutrient holding capacity has been shown to make it a more reliable approach to determining yield management zones compared to normalized difference vegetation index (NDVI), EC, pH, and organic matter content (Godwin and Miller, 2003). To build upon this previous research, the purpose of this study was to determine the ability to reliably use soil texture to establish management zones and refine residual N crediting recommendations based on these management zones in a corn-cotton rotation.

Materials and Methods

Nitrogen Rate Study to Determine Residual Nitrate Influence

Based upon previous EC readings using Veris 3100 in 2013, thirteen locations were selected that capture different soil types and a wide range of soil properties in a 15.4 ha field (Appendix A: Figure 2.1). The locations selected range from 19 to 41.5% clay in the surface horizon, this variability in texture will allow more differences between textures to be seen. The two soil series were a Weswood silt loam and a Yahola fine sandy loam (Appendix A: Figure 2.2). The majority of the field was the Weswood and was described as fine-silty, mixed, superactive, thermic Udifluventic Haplustepts (USDA-NRCS, 2001). The Yahola was described as coarse-loamy, mixed, superactive, calcareous, thermic Udic Ustifluvents (USDA-NRCS, 2016). Previous research has shown strong correlation between clay content and soil EC so the field was divided into clay management zones based on the EC map produced by Veris (Doran, et al., 1996; Johnson, et al., 2001; Eigenberg, et al., 2002; Shahandeh, et al., 2005; Sudduth, et al., 2005). The field was under a center pivot irrigation system with the well head located at 30.529756, -96.425089.

The pest management, insecticides and herbicides, were managed by Farm Services employees based on the current recommendations set forth by Texas A&M Agrilife Extension for each crop. The yield goal application rate for both crops was set based on the recommendations from the Texas A&M Soil, Water and Forage Testing Laboratory of 11,926 kg grain ha-1 and 1,614 kg lint ha-1 for corn and cotton, respectively (Texas A&M Agrilife Extension Service, 2012). The high N application rate for corn was set at a yield goal of 11,926 kg grain ha^{-1}, based on reported yields in the College Station field trials conducted by Texas A&M Agrilife Extension Service (2018). Maximum N application rate for cotton was set for a yield goal of 1,614 kg lint ha^{-1} based on the achievable yields from Texas A&M Agrilife Extension Service (2018). Nitrogen was applied at the V-6 stage for both corn years and at first bloom for cotton in 2015 and squaring for cotton in 2017 (Appendix B: Table 2.1)

A two-year rotation of cotton and corn with cotton in 2015 and 2017 and corn in 2014 and 2016 (Appendix B: Table 2.2), was evaluated for the influence of soil residual NO_3^- content on yield, quality, and NUE within a growing season. At each of the selected 13 locations, four row plots with a row spacing of 0.76 m for corn and 1 m for cotton were planted at lengths of 48.8 m, 18.3 m, 24.4 m and 18.3 m in 2014, 2015, 2016 and 2017, respectfully. Nitrogen treatments were arranged in a randomized complete block design with a minimum of three replications in each clay zone. Nitrogen rates from 0-252 kg ha^{-1} for corn and 0-135 kg ha^{-1} (Appendix B: Table 2.1) for cotton were applied as urea ammonium nitrate (UAN, 32% N) for both crops at a depth of 15 cm using a John Blue injection pump and a knife applicator.

Three 5.1 cm diameter soil cores were pulled four weeks prior to planting from each blocked replication location and blended into a composite. Soil samples were analyzed by depths of 0-15, 15-30, 30-61, 61-91, and 91-122 cm by the Texas A&M Soil, Water and Forage Testing laboratory. The Mehlich III extraction method was used to extract P, K, Mg, Na, and S and concentrations and were determined by inductively coupled plasma (Mehlich, 1978; Mehlich, 1984). All samples were analyzed for NO_3-N using the cadmium reduction method (Kachurina, et al., 2000). The pH was determined from a solution of 2:1 deionized water: soil using a hydrogen selective probe (Schofield and Taylor, 1955). Electrical conductivity was determined by using a 1:2 soil:water extraction with deionized water and assessed with a conductivity meter (Rhoades, 1982). Soil texture was determined using the hydrometer procedure and reported on a dry soil basis (Day, 1965). The irrigation water was tested using a cadmium column followed by a spectrophotometric measurement and found to contain 0.22 mg NO_3-N L^{-1} or 0.09 kg in 10 cm of irrigation (Keeney and Nelson, 1982).

In 2014, the field was planted with the corn variety Dekalb 66-40 but was terminated due to poor stand and replanted with Dekalb 62-08 RIB on the 20th of March. It is described as having exceptional top-end yield potential and good drought tolerance (Monsanto Company, 2012). In 2016, the corn variety 8895 VTTP from B-H Genetics was chosen and planted on the 2nd of March. It is described as having above average early vigor and stress tolerance and 116-118 days to maturity (BH Genetics, 2014). Target plant populations for 2014 and 2016 were 59,300 plants ha^{-1}. Nitrogen rates for corn in 2014 were 0, 112, 168, 196, 224 and 252 kg N ha^{-1} and in 2016 the N rates were 0, 56, 112, 168, 196, 224 and 252 kg N ha^{-1}. In 2014 and 2016 fertilizer rates were applied at the V-6 growth stage.

Crop data taken on corn in 2016 included plant height and chlorophyll measurements using a SPAD 502 chlorophyll meter (Konica Minolta; Ramsey, NJ) taken halfway down the ear leaf once at the blister stage and again at the dent stage. The recorded value was an average of 10 leaf measurements per plot. Final plant heights were taken just prior to harvest with the recorded values being an average of 10 plants per plot. The middle two rows were harvested with a John Deere 3300 combine equipped with a Harvest Master HM 800 system to collect moisture, test weight and yield of the corn. For comparison, yield data were corrected to a uniform moisture of 15.5% using the method described by Lauer (2002).

The cultivar Phytogen 444 WRF was planted in both cotton producing years on the 16th of April in 2015 and 4th of April in 2017 at an average population of 111,200 seeds ha^{-1}. It is described as a mid-maturing, smooth leaf variety with an exceptional fiber quality package (Dow Chemical Company, n.d.). Nitrogen rates used in cotton were 0, 34, 68, 101 and 135 kg N ha^{-1} and were applied at first bloom in 2015 and first square in 2017. In-season crop growth data collected on cotton included final plant height taken two weeks prior to harvest, nodes to first fruiting branch taken after N application during squaring, nodes above harvestable boll taken after the application of harvest aids, and total nodes at the time of harvest. Reported values for each parameter were the mean of six plants per plot. Cotton was harvested from the middle two rows of each plot using a John Deere 9910 spindle cotton picker. Seed cotton weights were collected, and samples were ginned on a 20-saw tabletop gin to determine lint turnout and lint yields for each individual plot. Fiber samples were collected at ginning and were run on the High Volume Instrument (HVI) at the Texas Tech Fiber and Biopolymer Research Institute (Lubbock, TX). HVI reports on fiber quality characteristics and include: micronaire, maturity, length, strength, moisture, color, trash, and spinning consistency index (Uster Technologies, 2017)

When analyzing yields to minimize the effect caused by field variation among replications, relative yield was calculated as described by Adamchuk, et al. (2004). The relative yield was calculated as actual yield in each plot divided by the average yield of the replication to calculate each plot’s relative yield, as shown below. Using relative yield there was not a significant interaction of clay content and N treatment so rates were compiled across all soil types. The interaction of year and treatment was non-significant so years with the same crop types were combined for analysis as well and by individual year.

$$Yield_{relative} = \frac{Yield_{actual}}{Yield_{average}}$$

To estimate NUE, the method described by Fromme et al. (2016) was used by dividing increase in yield over the unfertilized control by the amount of fertilizer applied on a per plot basis.

$$NUE = \frac{(Yield_{treated} - Yield_{untreated})}{Applied\ N}$$

Treatment effects of N rate and clay content were analyzed using a general linear analysis of variance (ANOVA) procedure at a significance level of $P < 0.05$ using SAS 9.4. Means of significant effects were separated using the t test at $P < 0.05$. For means separations on uneven data sets a Duncan’s separation was used with $P < 0.05$ (SAS Institute Inc., Cary, NC).

Results and Discussion

Climate and Site

The field location was in the Brazos River bottom and the soil was considered to be alluvially deposited soil from the Brazos River. In this particular site there is great variability of soil textures across the field and by depth. Across the field surface clay content is variable;

however, throughout the sampled locations the clay content decreases consistently with depth (Appendix B: Table A.1). Coarser soils lower in the profile will influence N mobility and could potentially decrease effectiveness of crediting NO_3-N measured pre-plant at different depths.

The 30-year average precipitation in this area is 101.6 cm annually (National Weather Service, 2018). Each of the four years of this trial, the field received above average rainfall receiving 111.6, 158.1, 134.9 and 140.9 cm in 2014, 2015 2016 and 2017, respectively (National Weather Service, 2018). During the cropping season, from the time the crop was planted till harvested, rainfall received was 56.1, 60.8, 61.8 and 102.1 cm for the four years (Appendix B: Table 2.2). In 2017, the cotton received one half of the precipitation the third week of August from Hurricane Harvey after 80% of the bolls were open. This untimely precipitation came just two days after harvest aids were applied.

To account for potential differences among the soil series and other factors in the field, Weswood and Yahola, the N response for each replication was looked at individually and only the replications with a significant N response were used in determining the ability to credit NO_3-N. Only one of the two replications in the Yahola Series (Appendix A: Figure 2.2) had a significant response in any of the 4 years. The most northern replication in Appendix A: Figure 2.1 had a significant N response in both 2014 and 2016. The texture at that location in the top 15 cm is a silty clay loam more similar to the Weswood series than that of the sandy loam described in the Yahola series.

Crediting Zone Delineation

Optimum Depth Method

The 13 locations across textures were used to determine the N crediting based on the clay content derived from the EC readings from Veris (Appendix B: Table 2.3). In 2015 and 2017, none of the 26 replications of cotton plots showed a significant response ($P < 0.05$) to N so only the corn years (2014 and 2016) were analyzed for optimum rate. In 2014, nine of the 13 replications had a significant response curve, and in 2016, eight N response curves were significant ($P < 0.05$) (Appendix A: Figure 2.3). Based on the results, a final equation for recommended rate (R_R) can be formulated to account for observed relationships between, clay content, depth, N rate, and NO_3-N content. For the R_R equation, the maximum point in the quadratic N response curves were considered to be the optimum N rate, for linear response curves the optimum N rate was assumed to be over 252 kg ha^{-1}. Using the N response curve and the theoretical N determined using the set yield goal rate for corn in this field of 252 kg ha^{-1} subtracted by the residual NO_3-N at a particular depth, a credit depth response curve was made (Appendix A: Figure 2.4). The maximum point of the credit depth curve was considered to be the optimum credit depth. Using the response curve generated by plotting optimum credit depth by clay content, the optimum sampling depth can be found for a particular clay content (Appendix A: Figure 2.5). As shown in Appendix A: Figure 2.5 the optimum credit depth for coarser soils (<25% clay) is less than 10 cm, where as in soils with >30% clay the depth is below 30 cm, similar to Hons, et al. (2004) which found the crediting depth of heavy clays to be near 60 cm. The optimum rate for a specific clay content can be found using the response curve of optimum rate by clay content (Appendix A: Figure 2.6). For example, at a clay content of 30% the optimum N rate is 201 kg N ha^{-1} from Appendix A: Figure 2.6. Using the parameters optimum credit depth and optimum N rate for the specific clay content the recommended application rate can be determined using Equation 1.

Equation 1:

$$R_R^{\dagger} = R_O^{\P} - N_S^{\ddagger}$$

†R_R is the recommended rate for a specific clay content
‡R_O is the optimum N rate for a specific clay content
ǂN_S is the NO_3-N sampled to the optimum sample depth for a specific clay content

Consistent Depth Method

Similar to the optimum depth method, the consistent depth crediting approach uses the optimum rate and the yield goal rate. However, unlike the previously described crediting method, the consistent depth approach uses only one credit depth across all textures. Previous work by Hons, et al. (2004) and Fromme, et al. (2016) has shown that in clay soils 100% of the sampled NO_3-N to 61 cm can be credited to both corn and cotton. Continuing from this work the consistent crediting method credits to a depth of 61 cm. As described above only the replications with a significant N response were used considered (Appendix A: Figure 2.3). The optimum N rate is the maximum point of the N response curve. The percent of the sample residual NO_3-N to a depth of 61 cm for a specific clay content can be found by subtracting the optimum N rate from the yield goal rate and dividing by the amount of sampled NO_3-N to a depth of 61 cm. Plotting the credit percentage by clay content produces a credit percent response curve where a known clay percentage could be used to determine the amount of sampled NO_3-N sampled to a depth of 61 cm that can be credited to the crop. The optimum rate for a specific clay content can be found using the response curve of optimum rate by clay content (Appendix A: Figure 2.6). The percent credit to a depth of 61 cm for a specific clay content can be found by plotting the percent credit by clay content (Appendix A: Figure 2.7). For example, from the 2 parameter logistic curve in Appendix A: Figure 2.7, at a clay content of 30%, 95% of the sampled NO_3-N can be credited to

61 cm. Based on the findings of the parameters the recommended rate can be determined and implemented into Equation 2.

Equation 2

$$R_R^{\dagger} = R_O^{\P} - (N_{61}^{\ddagger} * PC^{i})$$

$^{\dagger}R_R$ is the recommended rate
$^{\P}R_O$ is the optimum N rate
$^{\ddagger}N_{61}$ is the NO3-N sampled to a depth 61 cm
^{i}PC is the percent of the NO3-N sampled that can be credited for a specific clay content

Zone Management Yields

To validate the use of this model for determining management zones the percent of NO_3-N that can be credited was used. At a clay content of 24.27, 50% of the sampled NO_3-N can be credited, while 100% can be credited at a clay content of 29.17 and above (Appendix A: Figure 2.7). Breaks in the kriged interpolation map were set at 25 and 30% clay using EC values determined by the linear regression between Veris EC and clay content at 33 and 46 mS m^{-1} (Appendix A: Figure 2.8). This map was them delineated into the management zones in Appendix A: Figure 2.9.

When comparing the yields in each year and crop to the clay categories, a significant interaction by year occurred and years were analyzed separately (Appendix A: Figure 2.10a-d). Three of the four years (2015, 2016 and 2017) the area of the field with <25% clay content had significantly lower yields. In 2016, the highest yields were seen in the 25-30% clay category. The 2014 season followed a similar pattern with the higher yields being in the middle clay category but the differences were not significant. Cotton in 2017 had the highest yields in the areas of the fields with a clay content over 30%. These differences are explained by the relationship of clay to other soil characteristics. Areas of the field that have a higher clay content have a higher water holding capacity as well as CEC. These two soil characteristics alone would make those areas of the field have a higher yield potential for both corn and cotton. The lower infiltration rate with higher increasing clay content also suggests that more of the residual NO_3-N could be retained higher in the profile and would remain plant available from year to year (Peng, et al., 2015)

Residual Nitrate-N Content

To determine the clay categories ability to retain different amounts of residual NO_3-N, an average of each clay category was determined and compared by total amount from 0 to 122 cm and at depth increments. Appendix A: Figure 2.11a-d compares the cumulative amount of residual nitrate-N down to 122cm by the clay categories across all four years of this study. Similar to the findings in previous research, Appendix B: Table 2.4 demonstrates that of the four years there was not a significant relationship when grouping was based upon clay categories, suggesting that texture does not influence the spatial distribution of residual NO_3-N as much as other factors, such as topography and precipitation (Johnson, et al., 2001; Shahandeh, et al., 2005). When comparing residual NO_3-N by depth and clay categories (Appendix B: Table 2.5, Appendix A: Figure 2.12), NO_3-N was deeper in the profile in areas of the field between 25 and 30% clay in 2014. In 2015, NO_3-N was deeper in the profile in all three of the texture groups, while in 2016 there was no relation between depth and the amount of NO_3-N. In 2017, NO_3-N was deeper in coarser textured areas of the field. Nitrate-N leaching will be more severe and faster in the courser textured soils explaining why the majority of the NO_3-N in the low clay zone was deeper in the profile two of the four years (Peng, et al., 2015). Precipitation and irrigation are also driving factors in how fast and deep NO_3-N can be leached down through the profile. MCConnell, et al. (1996) found that in center pivot and furrow irrigated fields that NO_3-N had accumulated lower in the profile than in non-irrigated fields. Excessive precipitation or excessive irrigation could potentially leach NO_3-N below the rooting zone for crops.

Corn In-season Crop Data Analysis

The SPAD meter measures the relative amount of chlorophyll in the leaf as described by Piekkielek and Fox (1992). The SPAD meter measures the light transmitted on the red and infrared wavelengths and was expressed as a ratio of these two wavelengths. This ratio estimates the relative amount of chlorophyll in the measured leaf. The interaction of the clay groups and N rate were not significant for SPAD and corn plant height measurements were combined across N rates and clay groups as well. In-season crop data from the SPAD measurements in 2016 were not correlated to increasing clay percentage. However, the SPAD readings did identify differences between the unfertilized and 56 kg N ha-1 rate compared to N rates of 112 kg N ha^{-1} and higher at the blister and dent stages. Final plant height was unaffected by N rate but was significantly and positively impacted by clay groups with higher clay, above 25%, resulting in taller corn plants than the coarser textured areas (Appendix B: Table 2.6, Appendix A: Figure 2.13).

Corn Relative Yield Analysis

The 10 year county average for irrigated corn was 8,066 kg grain ha^{-1}, and non-irrigated corn was 6,591 kg grain ha^{-1} (USDA-NASS, 2018). The 2014 corn grain yields averaged 8,700 kg ha^{-1} and the range was 2,653 to 11,350 kg ha^{-1}. In 2016, mechanical problems with the irrigation system during the growing season inhibited irrigation, but the crop received timely rains during later parts of the growing season, and yield was not thought to be majorly hindered. The study average for 2016 was still 7,909 kg grain ha^{-1} across N rates, well above that of the long-term county average for non-irrigated corn.

For the 2014 relative corn yield, the highest yields were numerically observed from the highest N rates and were positively correlated to applied N up to the point of 196 kg N ha^{-1} but no significant yield increase was observed above 112 kg N ha^{-1}. Relative corn yield for 2016 produced similar results to 2014 grain yield with significant yield increases not observed above 112 kg of applied N (Appendix A: Figure 2.14). The effects of replications and years was not significant and data were combined for the two years of corn, 2014 and 2016. The combined data for both years (Appendix B: Table 2.7) of corn shows a significant effect by only the rate of applied N. For the combined years a significant yield increase was observed up to the 112 kg N ha-1 rate

Corn Nitrogen Use Efficiency

The NUE of applied N was calculated to determine areas of the field with a higher NUE. In both 2014 and 2016, significant effects by N rate and clay categories were observed (Appendix B: Table 2.8). For both years, the clay percentage negatively influenced NUE. In 2014, the areas of the field with 25 and 30% clay had a significantly lower NUE compared to the other clay categories, while in 2016 NUE was lower in areas with clay content above 30%.

Corn Crop Quality Comparisons

Test weight of corn was analyzed to determine the effects increasing N rates and soil texture have on grain test weight (Appendix B: Table 2.9). There was no significant interaction between year and either N rate or clay content. Analysis for differences in clay content were done across all N rates and differences between N rates were analyzed across all clay contents.

The combined year analysis on corn test weight was unaffected by either N rate or clay categories.

Cotton In-season Crop Data

In-season crop data were collected in 2017 to determine how N rate and clay categories effect cotton growth and development. No significant interaction of N rate and clay content were observed, and the analyses were compiled across all textural classes for N rate and differences in clay content were compiled across N rates (Appendix B: Table 2.10). Increasing the N rate had no effect on the total nodes. However, average total nodes were significantly higher in the higher clay soils. Final cotton plant height was not affected by N fertilizer application rate, but height did increase as clay percentage increased. Nodes to first fruiting branch and nodes above the upper most harvestable boll showed no significant differences when compared by clay category or applied N rate.

Cotton Relative Yield Analysis

When comparing yield by N rate on the 2015 and 2017 cotton plots for each individual year and the two years combined, there were no differences between any of the applied rates, including the 0 kg ha^{-1} rate (Appendix B: Table 2.7 and 2.11). Average yield by N treatment in 2017 shows an inverse relationship to applied N suggesting an abundance of N detrimentally impacting yields. This validates the need to further investigate the influence of residual NO_3^- in soils and its impact on cotton. The lack of a response to applied N corresponds with the findings from Main, et al. (2013) where there was no yield response to applied N for 11 or the 20 site-years. The 2015 cotton had more than 116 kg residual NO_3-N ha^{-1} (Appendix B: Table A.3) well above the current recommendations for a yield goal of 1,614 kg lint ha^{-1}. Hons, et al. (2004) also reported that cotton can use residual NO_3-N to achieve optimum yields and reported only 8 of the 39 site-years showed a significant response to applied N. Thus, this study confirms the need for crediting NO_3-N for corn and cotton and that it can be done on a textural basis. In 2015 and 2017 cotton yields for the site were 1,009 and 799 kg lint ha^{-1}, respectively. Both years produced below the county average for irrigated cotton of 1,370 kg lint ha^{-1} (USDA-NASS, 2018), but again it was across all N rates. Erratic weather in 2017 also contributed to a lower yield average than expected. High winds and heavy rains from hurricane Harvey lowered yields by causing seed cotton to fall from the already open bolls and decreasing harvest efficiency due to hardlock cotton bolls.

Cotton Nitrogen Use Efficiency

Comparing NUE of cotton in both 2015 and 2017 there were no differences by N rate or clay categories. However, NUE numerically decreased with increasing N rates in both years with cotton due to a lack of N yield response. It was also worth noting in 2017 the highest numerical NUE was in the course textured clay category and which corresponded to the limited residual NO_3-N in the soil (Appendix B: Table 2.8).

Cotton Crop Quality Comparisons

There was not a significant interaction of clay categories and treatment but a significant interaction was observed between years and N rate, so fiber quality parameters were analyzed per separately for each year. Since there was no interaction between clay categories and N rate the analyses for differences were done across all N rates and analysis for differences in N rate were done across clay categories (Appendix B: Table 2.12). Similar to the findings of Saleem, et al. (2010) most of the fiber quality traits were not affected by fertility except for micronaire, which was consistently significantly affected by clay content in this study. In both 2015 and

2017, micronaire was significantly higher in areas of the field above 25% clay. In 2017, areas of the field with a clay content lower than 25% clay had a significantly lower leaf grade.

Conclusions

Based upon the current yield-based recommendations for corn in South Texas, to achieve the average study yields the amount of N needed was 165 kg N ha^{-1} for 2014 and 157 kg N ha^{-1} for 2016. The lack of a response above 112 kg of applied N ha^{-1} is similar to the current recommendations. The optimum depth crediting method can be used to more precisely credit NO3-N to variable depths but requires more input work pulling soil cores to different depths, while to consistent credit depth method is a more simplistic approach when sampling. Managing crops by soil types shows potential to refine fertilizer inputs required in differently textured soils. In areas of the field with lower clay content in a semi-humid climate the ability to credit NO_3-N was limited. So coarser textured soils will require more applied N whereas the fine textured areas can be credited down to 98 cm. Areas of the field that were between 25 and 30% clay should be credited down to 57 cm, similar to N crediting depths reported by Hons, et al. (2004) and Fromme, et al. (2016). The crediting approach used in this study was applicable in alluvial type soils such as the one used for this study. Crediting in different environments will have to account for differences in yield potential and soil types. Drier environments have less potential for NO_3^- leaching so a higher percentage of the sampled residual N could be credited. Humid environments that have increasing clay contents deeper in the profile could account for residual N deeper in the profile.

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CHAPTER III

DELINEATING SPATIALLY DERIVED NITRATE MANAGEMENT ZONES

Introduction

Nitrate in the Soil

Without proper management of soil nutrients, the producers can either over apply or under apply nutrients, having both economic and environmental impacts (Machado, et al., 2000; Lopez-Granados, et al., 2002). Of the crop nutrients, nitrogen (N) is the most common yield limiting nutrient in row crop production (Blumenthal, et al., 2008). Nitrogen fertilizer is the highest input cost for row crop in Texas and is one of the highest in U.S. (USDA-ERS, 2016). Knowing this, management of N in cropping fields is economically beneficial to producers but also environmentally important. Nitrate is one of the most important sources of N to plants because it is mobile in the soil and in warmer moist environments can be more abundant (Silvertooth and Norton, 2011; Havlin, et al., 2014). These same benefits of NO_3^- also are weaknesses in the sense of losses, because it is mobile in the soil, and it is susceptible to leaching. (Wu, et al., 1997; Havlin, et al., 2014; Peng, et al., 2015). Nitrate is the most commonly found agricultural pollutant in groundwater (Baker, 1992; Wu, et al., 1997). In wet environments or those with coarse soil textures, NO_3^- can be leached down into the groundwater (Peng, et al., 2015). In the Arkansas River Valley of Colorado, over application of N fertilizers has led to leaching and N runoff causing elevated nitrate levels in the surface and ground water (Halvorson, et al., 2005). In the irrigated fields in the High Plains of Texas where sandier soils are predominant, nitrate runoff averaged 4.71 kg N ha^{-1} and leaching losses averaged 3.14 kg N ha^{-1} (Wu, et al., 1997). Of the major crops in that region, including cotton (*Gossipium hirsutum*), corn (*Zea mays*), sorghum (*Sorghum bicolor*) and wheat (*Triticum aestivum*), corn production fields were responsible for the highest amount of leaching and runoff (Wu, et al., 1997).

Relationship of EC to Soil Properties

Site-specific management has the potential to maximize economic return and enhance environmental health (Wallace, 1994). Studies like the one conducted by Shahandeh, et al. (2005) demonstrated the potential to modify soil nutrient recommendations based on soil texture. As indicated by Schmidt, et al. (2002), considering multiple soil parameters can provide a better approach to determining N management zones. Several soil parameters have been used to spatially estimate nutrient needs in a field such as texture, normalized difference vegetation index (NDVI), electrical conductivity (EC), pH, organic matter content, and others (Schmidt, et al., 2002; Godwin and Miller, 2003; Shahandeh, et al., 2005; Sudduth, et al., 2005). Compared to other soil parameters, EC can be easily determined on the large scale necessary for site-specific N management (Shahandeh, et al., 2005). The ease of gathering large scale spatial data of EC for a field has been done using three methods discussed by Sudduth et al. (2005): 1) as field sampling with probes or pulling cores; 2) using an EM 38 (Geonics Limited, Mississauga, Ont., Canada); and, 3) using a Veris 3100 or MSP3 (Veris Technologies, Salina, KS).

Spatial EC data has been correlated to different soil properties to test their predictability based on EC values. Properties, such as clay content, cation exchange capacity (CEC), water holding capacity, and salinity have been reported to have strong direct or inverse correlations to measured EC (Eigenberg, et al., 2002; Sudduth, et al., 2005). Using EC, Johnson, et al. (2001) delineated production fields into zones to separate areas with different yield potentials. Some studies have found a correlation between soil EC and available residual NO_3-N and can be estimated based on EC values for that particular site (Doran, et al., 1996; Eigenberg, et al., 2002). However, other studies have reported that there is less of a correlation between soil EC and available nutrient content, specifically NO_3^-, but rather a connection of residual NO_3^- to clay content (Shahandeh, et al., 2005). Studies have reported that soil EC can be directly correlated to clay content, so this can be an indirect method for delineating N management zones based on texture (Shahandeh, et al., 2005; Sudduth, et al., 2005).

Textural based N recommendations are already being used in some areas of the cotton belt. In Tennessee, the recommended rate to produce a bale of (227 kg lint) on course textured soils is 90 kg N ha^{-1} compared to just 50 kg ha^{-1} in finer textured or bottom land soils (Main, 2012). In Georgia recommendations per bale are 38 kg N ha^{-1}. However, in course textured soils it is recommended to increase the rate by 25% (Whitaker, et al., 2018). Soil data collection tools such as those available from Veris have been used to delineate nutrient management zones using soil properties such as EC, reflectance and pH. The objective of this study was to determine the accuracy of available on-the-go soil data collection technologies from Veris and their potential to delineate nutrient management zones.

Methodology

Spatial Data Collection and Zone Identification

Three fields were selected to compare the accuracy and relevance of Veris collected soil properties. A 15.4 hectare field with a center pivot irrigation system with the well head located at 30.529756, -96.425089 was selected in the Brazos River Bottom in Burleson County, TX that occurs on two soil types with highly variability in soil properties. The other two fields selected were on the Stiles Farm Foundation Farm in Williamson County. The Eastern Williamson

County location is located at 30.595561, -97.302513, and the Western Williamson County location is at 30.597174, -97.296539. The two soil types on the Burleson County location are a Weswood silt loam and a Yahola fine sandy loam (Appendix A: Figure 3.1). The majority of the field is the Weswood soil and is described as fine-silty, mixed, superactive, thermic Udifluventic Haplustepts (USDA-NRCS, 2001). The Yahola is described as coarse-loamy, mixed, superactive, calcareous, thermic Udic Ustifluvents (USDA-NRCS, 2016). The soil series on the Eastern Williamson County location are a Burleson clay and a Krum silty clay. The primary soil series on the Western Williamson County are a Burleson clay and a Branyon clay. The Burleson series is described as a Fine, smectitic, thermic Udic Haplusterts. The Krum is described as Fine, smectitic, thermic Udertic Haplustolls, and the Branyon is described as Fine, smectitic, thermic Udic Haplusterts. To derive management zones, a Veris® 3100 was pulled across the Burleson County location with a 22.9 m swath width to produce a spatial soil EC map in 2013. The point data were interpolated using the Kriging tool in ArcMap 10.4 (ESRI, Redlands, CA) with the classification set to “Jenks Natural Breaks” to determine the zones. To refine the delineated zones, a Veris MSP3 was pulled across all three locations with a 7.6 m swath pattern at the Burleson County location and a 22.9 m swath width on both of the Williamson County locations to gather shallow EC (30 cm), deep EC (61 cm), soil color, and pH the winter of 2016. Veris recommends that EC measurements be taken when available soil water is uniform and is between 20% available soil water and field capacity; however, in fields with drastic textural changes a uniform soil water level was unachievable because clay soils retain more soil water than coarse soils (Brady and Weil, 2010). To achieve higher amount of soil water in 2016, the Veris was run four days following a 5 cm rain event at the Burleson County location and 5 days after a 2 cm rain even for both of the Williamson County locations. The optical sensor for soil color measurements uses a dual-wavelength sensor with an LED light source to collect red light and infrared light reflectance once per second with the optimum depth for the optic sensor is 5-6.5 cm deep. Veris pH probes were antimony sensors that were placed into a soil sample collected at a depth of 10 cm autonomously by Veris every 21-35 seconds depending on wash time and log time. A wash time of 3 seconds was sufficient to clean the electrodes while limiting time between samples. The pH electrodes were calibrated prior to the start of the field in standardized solutions with a pH 4 and 10. Veris recommends a speed of 3.4 m s^{-1} when mapping pH. When only mapping EC and color reflectance a maximum speed of 6.7 m s^{-1} is recommended (Veris Technologies, Salina, KS). Slower speeds will improve interpolated resolution by having more data points to base interpolated maps, and for this particular study Veris was pulled at a speed of 1 m s^{-1} at all three locations.

Additionally, a 0.73 hectare grid was sampled at the Burleson County location and a random based sampling technique was used on both Williamson County locations with three 2.5 cm soil cores pulled and composited. Soil samples were separated by depth at 0-15, 15-30, 30-61, 61-91, and 91-122 cm and analyzed by the Texas A&M Soil, Water and Forage Testing laboratory. Mehlich III extraction method was used to extract P, K, Mg, Na, and S and concentrations were determined by inductively coupled plasma (Mehlich, 1978; Mehlich, 1984). All samples were analyzed for NO_3-N using the cadmium reduction method (Kachurina, et al., 2000). Laboratory pH was determined from a solution of 2:1 deionized water: soil using a hydrogen selective probe (Schofield and Taylor, 1955). Electrical conductivity was determined by using a 1:2 soil:water extraction with deionized water and assessed with a conductivity meter (Rhoades, 1982). Soil texture was determined using the hydrometer procedure and reported on a dry soil basis (Day, 1965).

When analyzing Veris data to the soil sample results, the kriged EC value at the exact point and an average of a 30 m range of the kriged EC value were extracted for each soil sample location. Veris can take EC readings down to 61 cm and soil texture values were used for 0- 61 cm depths. The shallow EC readings from Veris were compared to the texture analysis at both the 0-15 cm and the 0-30 cm depths. The deep EC reading from Veris were compared to the average clay content of the 0-61 cm texture analyses. To determine the optimum swath width, data collected from 7.6 m Veris' passes were removed to create swath widths of 15.2 m, 30.5 m, 45.7 m, 61.0 m, 76.2 m and 91.4 m. Parameter effects were analyzed using a general linear model (PROC GLM) procedure at a significance level of $P < 0.05$ using SAS 9.4. Means of significant effects were separated using Fishers protected LSD at $P < 0.05$. For means separations on uneven data sets a Duncan's separation was used with $P < 0.05$. For testing the correlations between multiple parameters, a Pearson's correlation (PROC CORR) was used with $P < 0.05$ (SAS Institute Inc., Cary, NC).

Results and Discussion

EC and Clay Relationship

Since texture data were only collected for the Burleson County location, EC and texture correlations are only presented from the Burleson County location. Using the 7.6 m swath width Veris EC measurement, interpolated EC values and clay content from the 0-15 cm depth were significantly correlated (Appendix A: Figure 3.2 and Appendix B: Table 3.1). The shallow EC values from 0-30 cm were not correlated to average clay content nor were the deep EC values correlated with clay content at 0-61 cm depth (Appendix B: Table 3.1). Similarly, Sudduth, et al. (2005) determined that the correlation of Veris EC was highest when considering soil properties shallower than 30 cm. Based off of these finding, interpolated values of the shallow Veris EC measurements can be used as a reliable predictor for clay content in the top 15 cm (Appendix B: Table 3.1). Using estimations of NO_3-N crediting adjusted by soil clay content, Veris EC and its' relationship to soil clay content may be useful for delineating N management zones. Using Kriging as the interpolation method and classification, set to Jenks natural breaks, a spatial map of the soil EC was produced (Appendix A: Figure 3.3). Applying the regression equation derived from Veris EC soil clay content (EC= -32.59+2.606*clay percentage), clay content can be estimated for individual fields with similar soil physical and chemical properties to this location. The ability to estimate clay content and identify field variability will help direct soil sampling to areas of the field with different soil properties that effect nutrient holding content or availability.

On-the Go pH Measurement

At the speed of 1 m s^{-1},Veris was collecting a pH sample point at an interval of 22 m on a 7.6 m swath averaging 60 samples ha^{-1} at the Burleson County location. At both Williamson County locations, Veris was collecting a pH sample at an interval of 22 m on a 22.8 m swath width averaging 20 samples ha^{-1}. The interpolated pH values were extracted at the same location where the lab tested sample was pulled for comparison. Much like the results of Schirrmann, et al. (2011) which found a correlation of Veris pH with laboratory pH for 3 different sites, the interpolated pH values from the Veris correlated to lab pH for both the Eastern Williamson County location (P = 0.02) and the Western Williamson County location (P = <0.01). The Burleson County location was not correlated to lab pH (P = 0.591).These findings at the Burleson County location were more similar to those of Olfs, et al. (2010) which shows that the Veris pH values were more variable and did not correlate to laboratory tested pH. For all of the soil sample locations, the Veris derived pH was lower and more variable from location to location (Appendix B: Table 3.2). The pH range at the Burleson County location was 7.9-8.1. The minimal differences in pH variability across the Burleson County location could explain why the correlation was not significant. at that location. Other causes of differences could be explained by the differences in sampling method and limitations of the pH probes used. In laboratory analysis the pH was measured in a 2:1 deionized water: soil mixture while Veris was measuring pH of the soil in field conditions. Also, the laboratory method used a glass electrode as described by Schofield and Taylor (1955) while Veris was using antimony electrodes. Antimony electrodes are less as accurate and are more susceptible to drift than a glass electrode (McLauchlan, et al., 1987; Geus, et al., 1995).

Soil Reflectance Measurement

The reflectance of red and infrared light from the Veris color meter was compared to the nutrient content of the 2016 soil samples at the Burleson County location and the 2013 soil samples for both Williamson County locations to determine if it can be correlated to any nutrient content and/or to the soil organic matter (SOM) samples. Due to software malfunction, Veris soil reflectance data were only recovered for the first six of the soil sample locations at the Burleson County location so correlations shown for that location in Appendix B: Table 3.3 are based off of six data points rather than 13 for the pH and EC correlations.

For the Burleson County location as seen in the Appendix B: Table 3.3, clay content was correlated to NO_3-N, K, Ca, Mg, Fe, Cu and SOM. At higher clay contents the nutrient holding capacity is greater so it expected that clay content be correlated to nutrients. Infrared reflectance was only correlated to Ca, while visible red reflectance was correlated to K, Mg, Fe, Cu and SOM, of which Mg, Fe, and Cu are considered immobile in their plant available form (Havlin, et al., 2014). This supports the finding of He, et al. (2009) who found a relationship of SOM within the red spectral light range, but no correlation of SOM with non-visible light. Of the 11 parameters measured, SOM was correlated to five nutrients; K, Ca, Mg, Fe and Cu. Unlike the Burleson County location, the red reflectance at the Eastern Williamson County location was not correlated to SOM or any nutrients. However, the infrared reflectance was correlated to SOM, K, S, Zn, and Cu. Of the 10 nutrients considered, differences in SOM were correlated to differences in K and Zn (Appendix B: Table 3.4). The correlation of SOM to nutrients is from the breakdown of plant material releasing nutrients back to the soil in plant available (Wanjura, et al., 2014). Neither the red reflectance nor infrared reflectance were correlated to any of the tested nutrients for the Western Williamson County location. Soil organic matter content in the Western Williamson County location was correlated to the K, S, Cu, and B. (Appendix B: Table 3.5).

Considering the soil series at each location and the hue, value, and chroma of each explains the differences of which wavelength of reflectance was correlated at each location. At the Burleson County location the Weswood series is listed as a brown (USDA-NRCS, 2001) and the Yahola is categorized as a reddish brown (USDA-NRCS, 2016). At the Williamson County locations the Burleson is listed as a very dark gray (USDA-NRCS, 2014), the Krum is a dark grayish brown (USDA-NRCS, 2014), and the Branyon is a dark gray (USDA-NRCS, 2014). As described by Toulios, et al. (1998) there is a strong relationship between the Munsell color system and the red, green, and blue spectrums of light. The color values at the Burleson County location have more red so seeing a relationship to red reflectance was more expected. Whereas in both Williamson County locations the color values are all grays so differences in red reflectance was expected to be minimal. The lack of a correlation of the red or infrared reflectance at either Williamson county locations are similar to the findings of Escadafal, et al. (1989) who shows that in dull and dark soils there is less than 20% reflectance across the visible light spectrum.

Swath Width Determination

Since texture data were only taken for the Burleson County location, swath width correlations were only done with data for the corresponding location. To determine the optimum swath width, the relationship of the kriged interpolation EC was compared to the clay content at swath widths of 7.6, 15.2, 30.5, 45.7, 61.0, 76.2 and 91.4 m. Comparatively, a narrower width of 6 m was used when EC was collected with a Veris 3100 and EM 38 by Sudduth, et al. (2005). When the EM 38 was used to collect EC in a study by Eigenberg, et al. (2002) a swath width of 6.1 m was used at a speed of 6 m s^{-1}. However, both studies were directed to attempt and maximize accuracy of the interpolated EC maps. A narrow swath width requires more time and inputs to collect, so using wider swath width that provides sufficient interpolation accuracy is more practical for large scale sampling. When comparing the 7.62, 15.24, 30.48, 45.72, 60.96, 76.2 and 91.44 m swath widths the correlation to clay content began to weaken at swaths greater than 15.24 m but was still significant (P<0.05) using a swath width out to 76.2 m (Appendix B: Table 3.6). As swath width was widened the resolution and accuracy of interpolation maps decreased. For fields with less drastic changes in soil properties a wider swath width up to 76.2 m could be used for this field and still achieve accurate interpolations. In fields with more sudden changes in soil textures, higher range of variability or when more interpolation precision is wanted a narrower swath width should be used.

Conclusions

The relationship of clay content in the top 15 cm of the Burleson County location was highly correlated to the shallow Veris EC value which means there could be value in predicting field surface textural differences using Veris EC. The narrow range of pH values at the Burleson

County location suggest that in fields with only minor differences in pH the Veris pH is not an accurate predictor of pH. However, for both of the Williamson County locations where more drastic changes in pH differences occurred, the Veris pH data were correlated to lab test pH. As a result, use of Veris derived maps for soil pH to predict nutrient availability and pH correction techniques, such as liming, should only be used in fields with larger range of pH values. Fields with changes in SOM will have different CEC from the organic matter as well as a higher return of nutrients from decomposition of SOM. Correlations with Veris pH values were inconsistent across locations and further research will need to be conducted to identify factors contributing to these inconsistent results. The inconsistency of reflectance data to SOM or nutrients suggests the reflectance data are have minimal value when determining nutrient management zones.

A narrower swath width provided a higher resolution interpolated map (Eigenberg, et al., 2002; Sudduth, et al., 2005), but wider swaths can be used to more efficiently produce large field scale maps. The maximum swath width that should be considered with Veris in a unidirectional pattern is 76.2 m. Running Veris in a bidirectional pattern with headings perpendicular should be investigated to determine if interpolation accuracy will increase for swaths wider than 76.2 m. For fields with drastic changes in soil properties, a tighter swath width should be used to have more interpolated accuracy.

Basing management zones on texture derived from Veris EC shows potential to identify areas of the field that can retain more residual NO_3^-. Since Veris EC can be related clay content changes in the field and clay content a contributing source of CEC in soils and influences water infiltration and leaching rates (Brady and Weil, 2010), sampling based on Veris EC zones can give a more accurate representation of nutrients particularly N, K, Ca, Mg, and Cu.

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CHAPTER IV

SUMMARY AND CONCLUSIONS

Corn yield results validated the current N recommendations for corn in Central Texas are within the range of 1.1-1.5 kg N ha^{-1}. Recommended N rates should remain based on a particular yield goal and should include residual NO_3-N in the soil. The amount of the residual NO_3-N that should be credited to corn can be derived based on clay content to further refine application rates. Interpolated maps of Veris EC can identify the finer textured areas of the field where a higher percentage of NO_3-N can be credited and to deeper depths. However, further investigation into the crediting of residual NO_3-N based on textures in different environments and soil types is needed to increase the robustness of this relationship and develop more confidence in refining N application rates in corn. Since there were not significant yield responses to applied N in cotton, this suggests that in a corn:cotton rotation, non-fertilizers sources of N, such as mineralized N, are being utilized by the cotton crop. Further investigation into other sources of N such as NH_4^+ and mineralization following a corn crop is needed to determine how N rates for cotton can be modified based off the crop rotation.

Differences in texture across a field were responsible for differences in corn yield potential, specifically retention of NO_3-N in this study. Comparing corn yields by soil texture showed that clay content influenced residual NO_3-N presence and crediting, thus the need for site-specific management to maximize yields and increase N use efficiency of corn has applicable potential. Cotton achieved maximum yields utilizing residual NO_3-N in all of the texture based management zones, suggesting that cotton can effectively recover NO_3-N across a wide range of textures and depths.

Veris proved to be useful in mapping fields to delineate nutrient management zones. In fields with more variable pH, Veris pH readings were correlated to lab pH and can be used to determine relative pH management zones. Infrared and red light reflectance showed inconsistent correlations across the five multiple soil types suggesting that it may not be as effective of a tool for determining nutrient management zones until additional correlations or calibrations are developed.

APPENDIX A

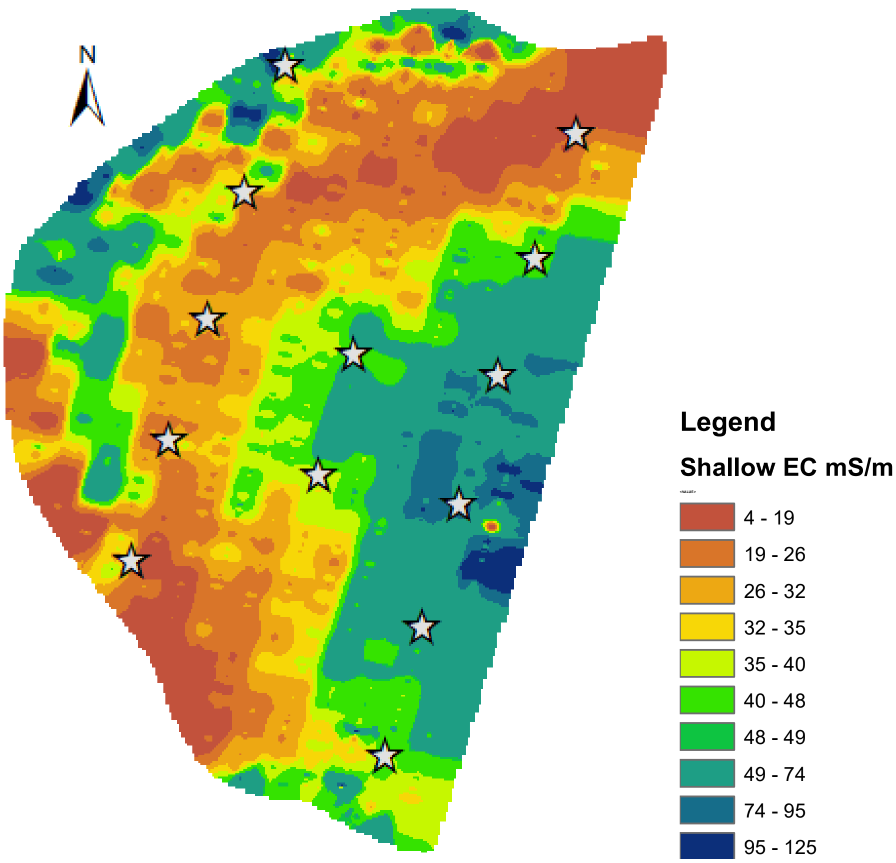

Figure 2.1. Kriged shallow EC map of the field in Burleson County, TX. Stars are the replication locations where plots were located

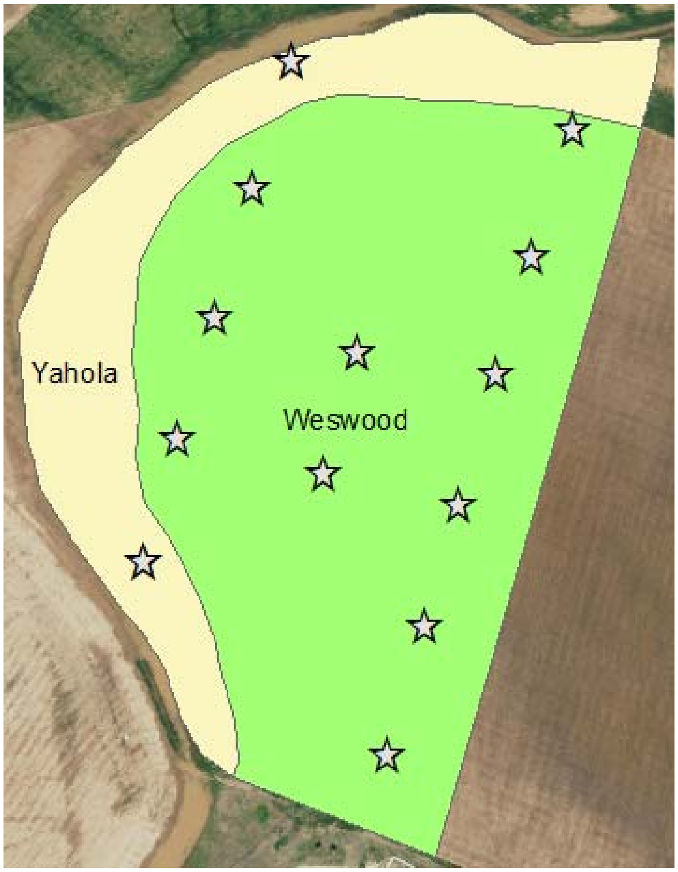

Figure 2.2. Soil types in the field. 77% of the field was a Weswood series and the remaining 23% was a Yahola series

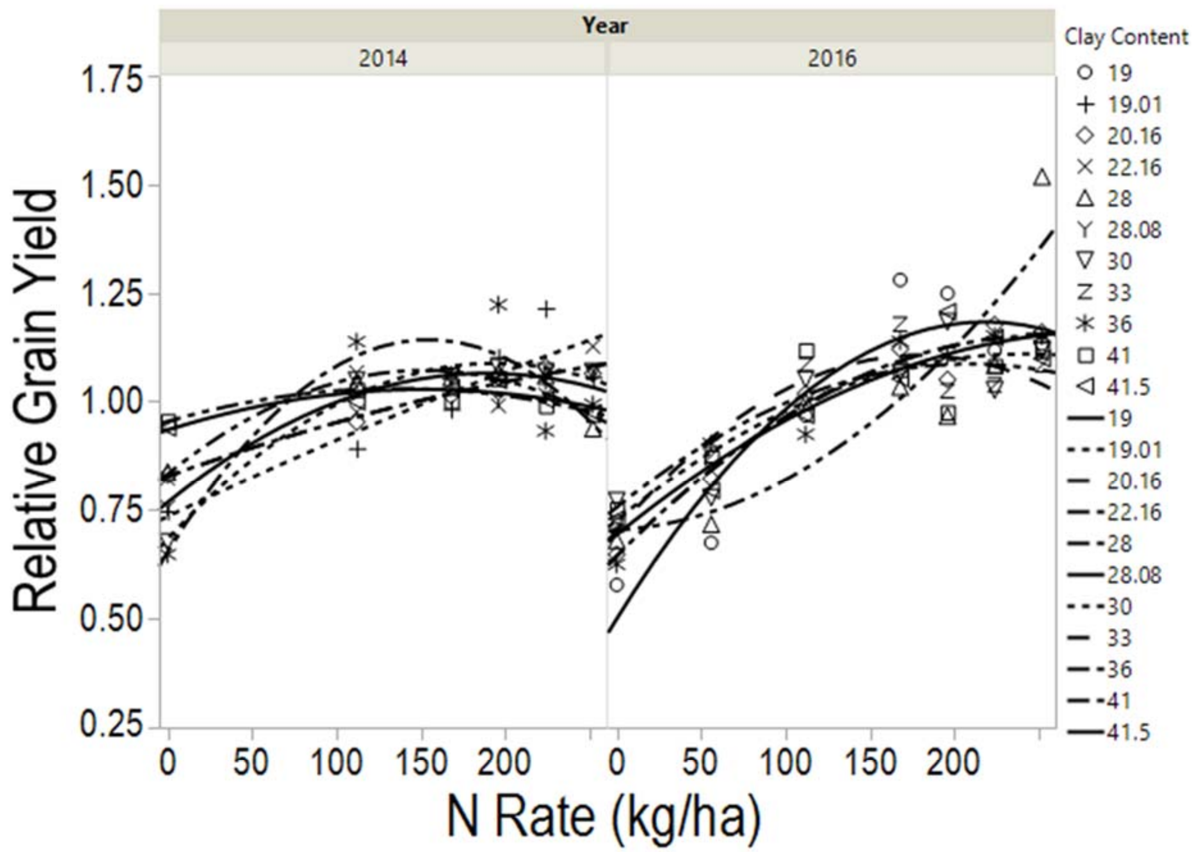

Figure 2.3. Relative yield by N rate for selected locations. Only replications with significant N response curves are shown separated by year.

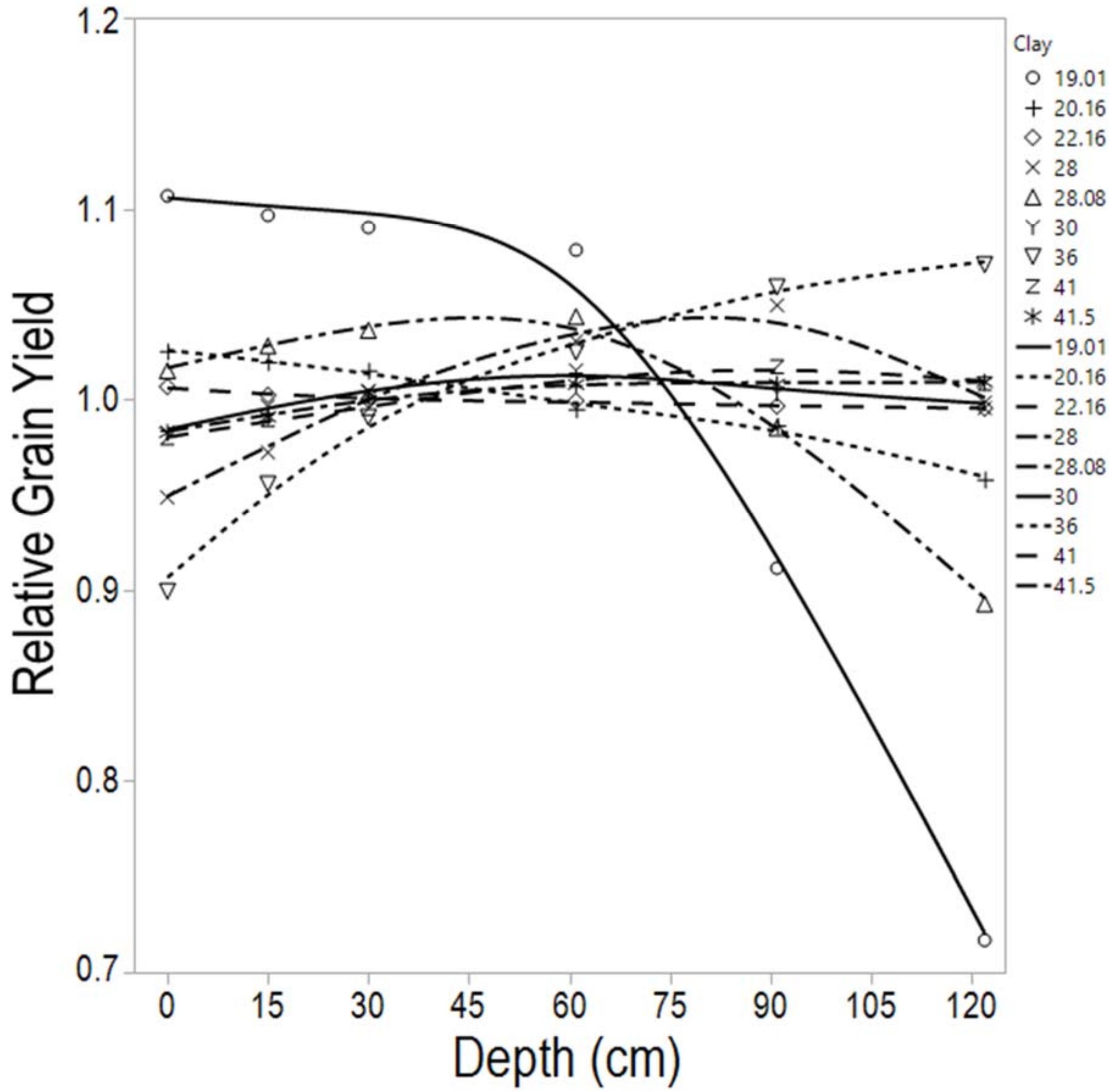

Figure 2.4. The relative grain yield when crediting NO_3-N by depth for 2014 and 2016. Points shown are the relative yield when crediting NO_3-N to the increasing depths. The horizontal axis is the depth that NO3-N was credited to. Only replications with a significant N response were used.

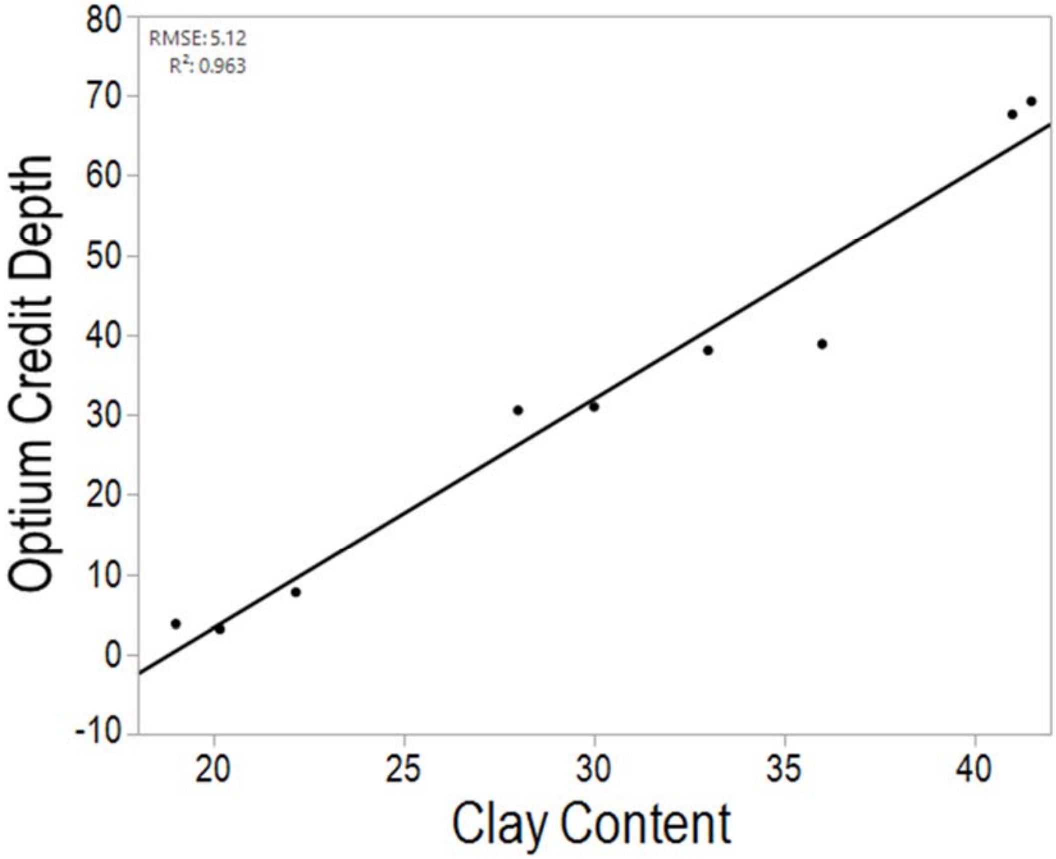

Figure 2.5. Optimum credit depth by clay content. Determined by finding the maximum point on the crediting depth curve shown in Figure 2.5. The clay content shown is the 0-15 cm depth.

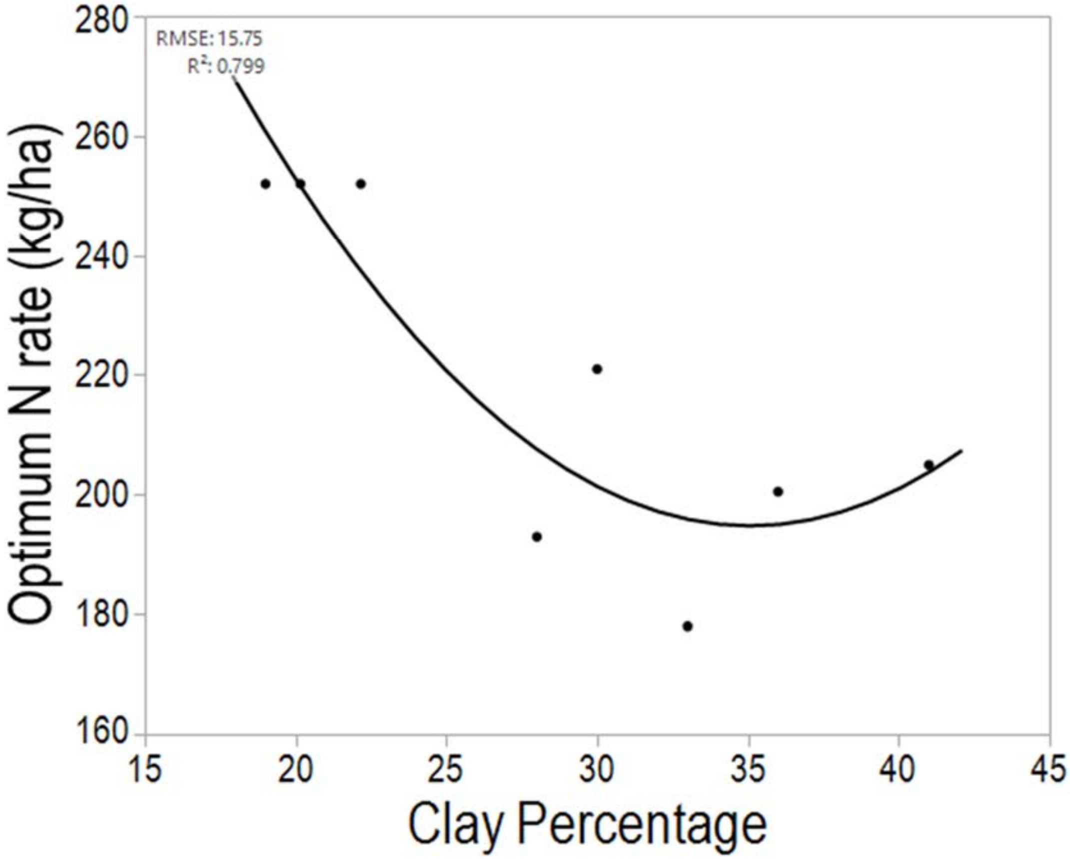

Figure 2.6. Optimum N rate by clay content. Determined by finding the maximum point on the N response curve. The clay content shown is the 0-15 cm depth. If the response cure was linear and had no maximum point the optimum rate was left at 252 kg N ha^{-1}

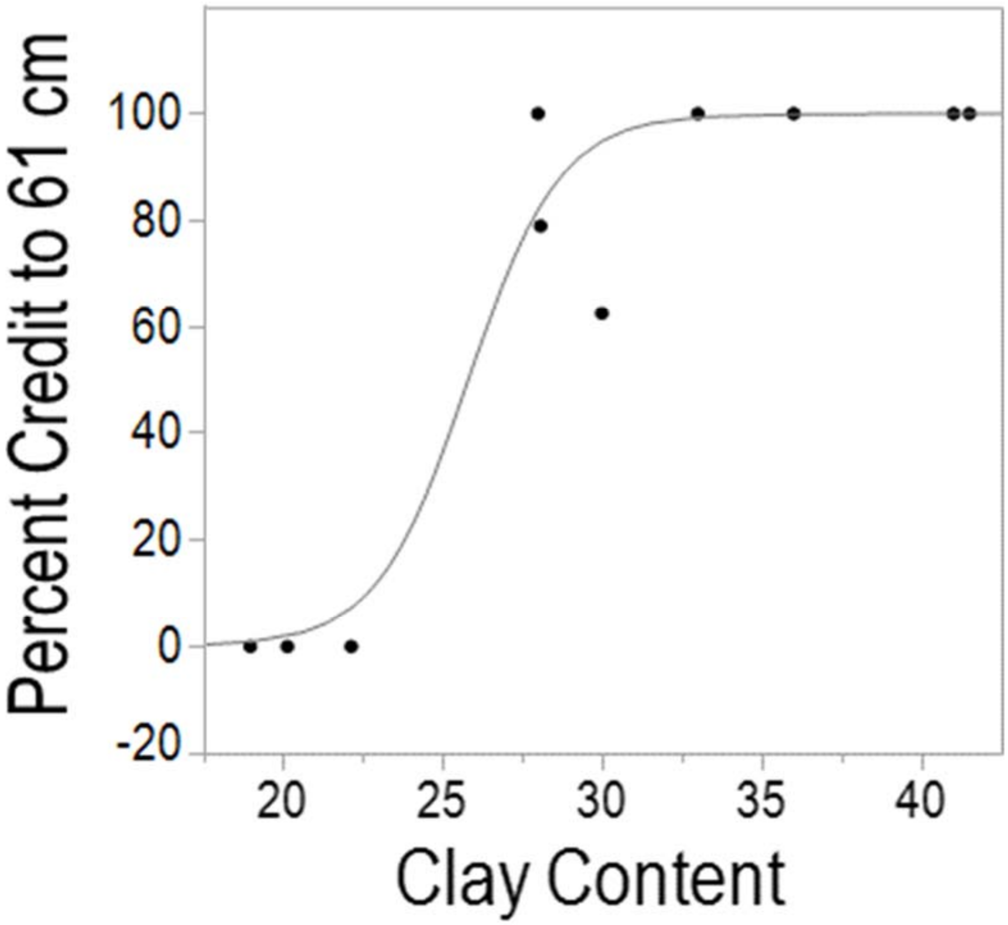

Figure 2.7. Percent of sampled NO_3-N that can be credited to the optimum sample depth by clay content. The clay content shown is the 0-15 cm depth.

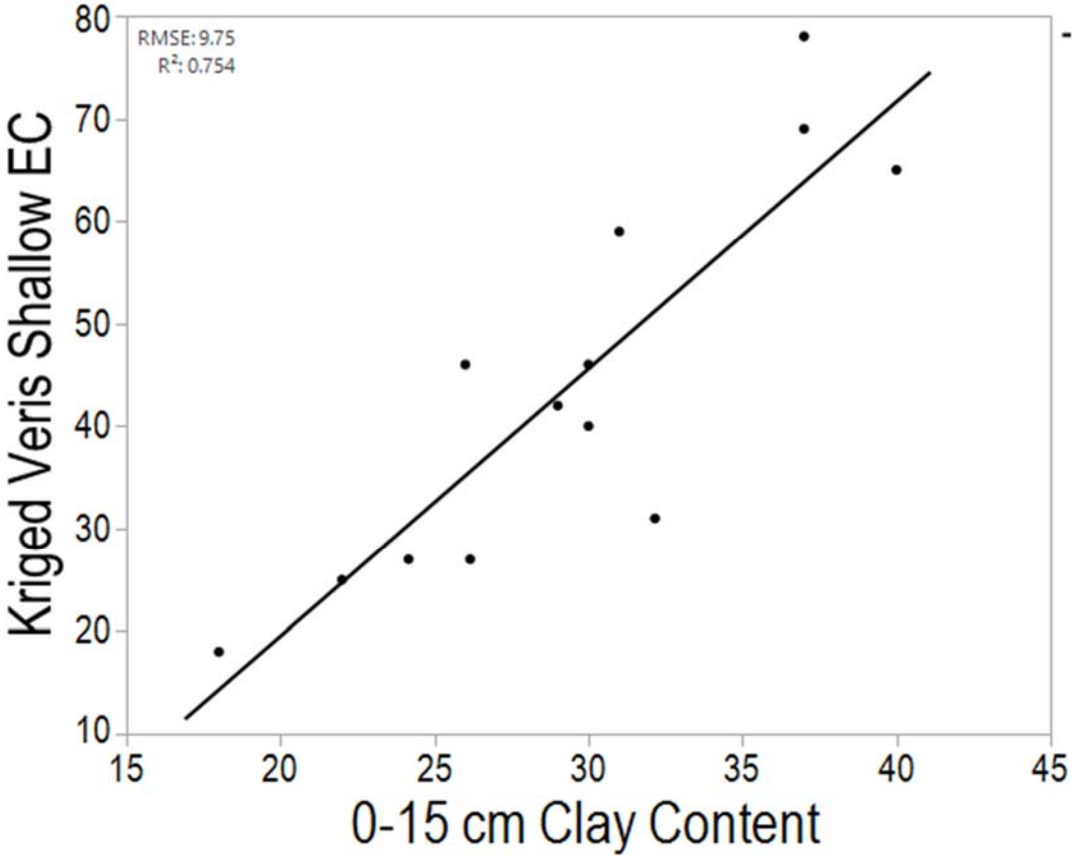

Figure 2.8. Kriged EC value nearest to the soil sample location compared to the clay categories in the top 15 cm.

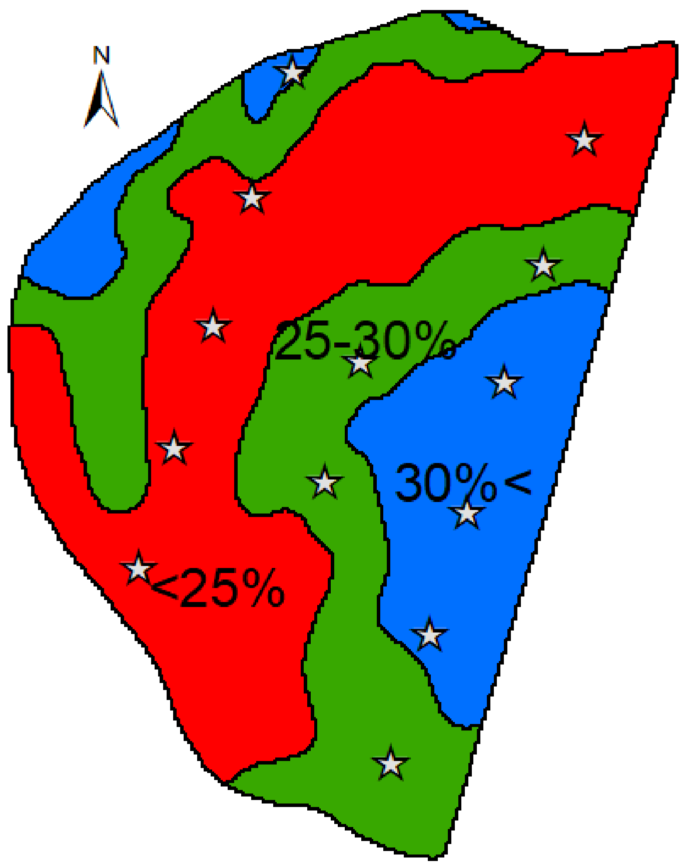

Figure 2.9. EC derived management zones based on clay percentages (<25%, 25-30%, and >30%)

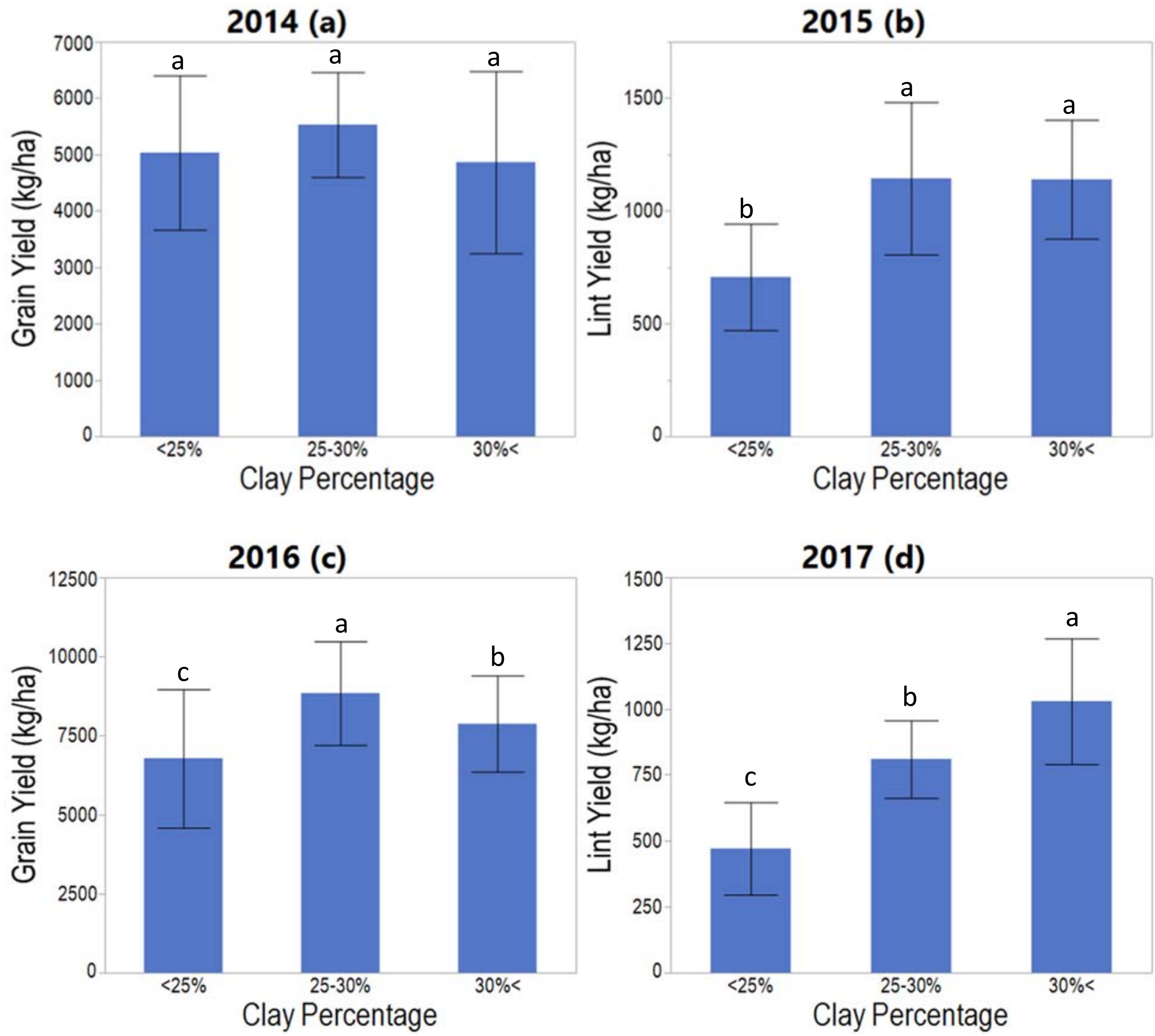

Figure 2.10(a-d). Yield averages based on clay percentages. Columns with different letters denotes significance.

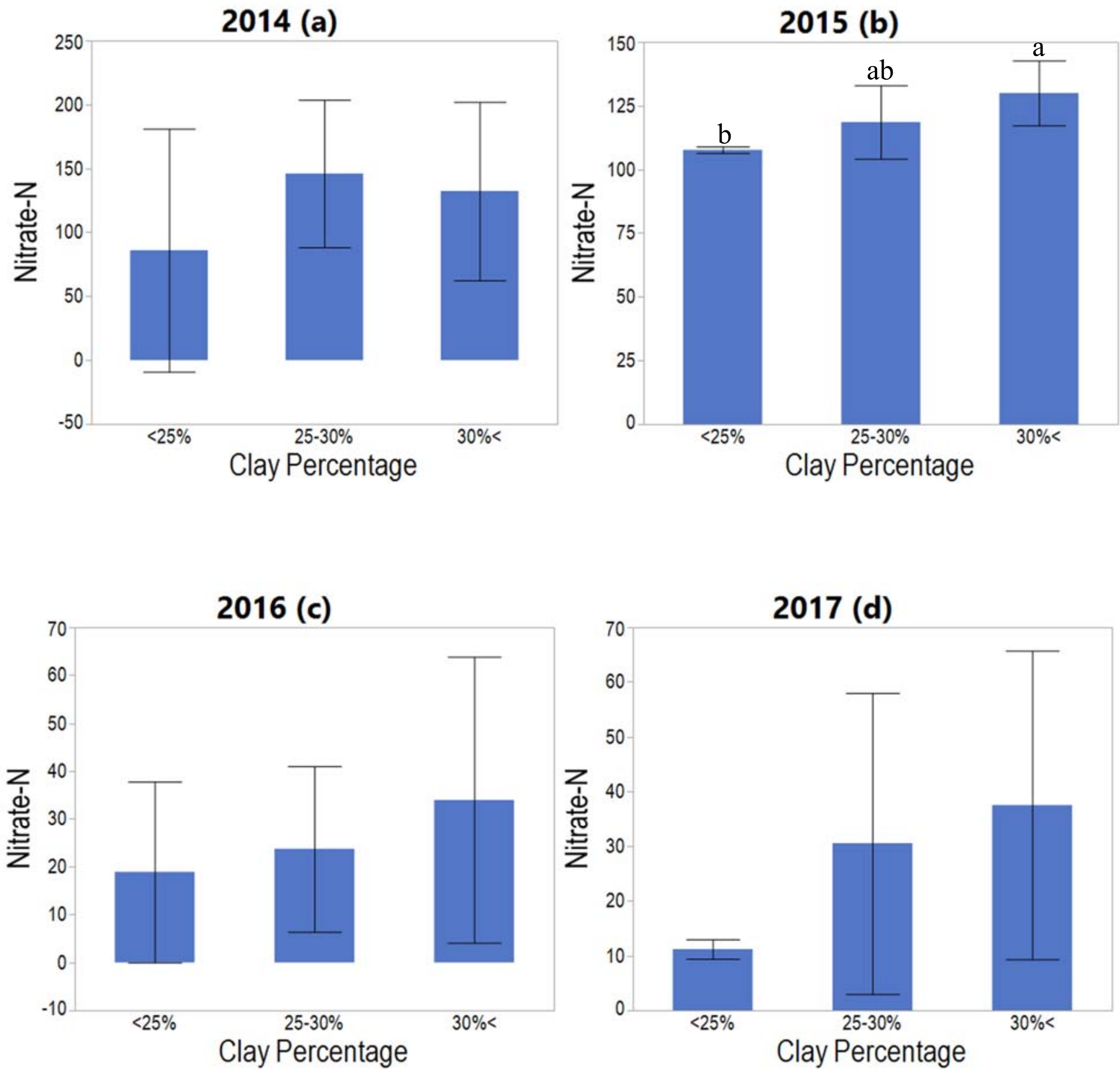

Figure 2.11: Total residual NO_3-N to 122 cm by year grouped by clay content. Error bars are one standard deviation. Columns with different lettering denotes significance.

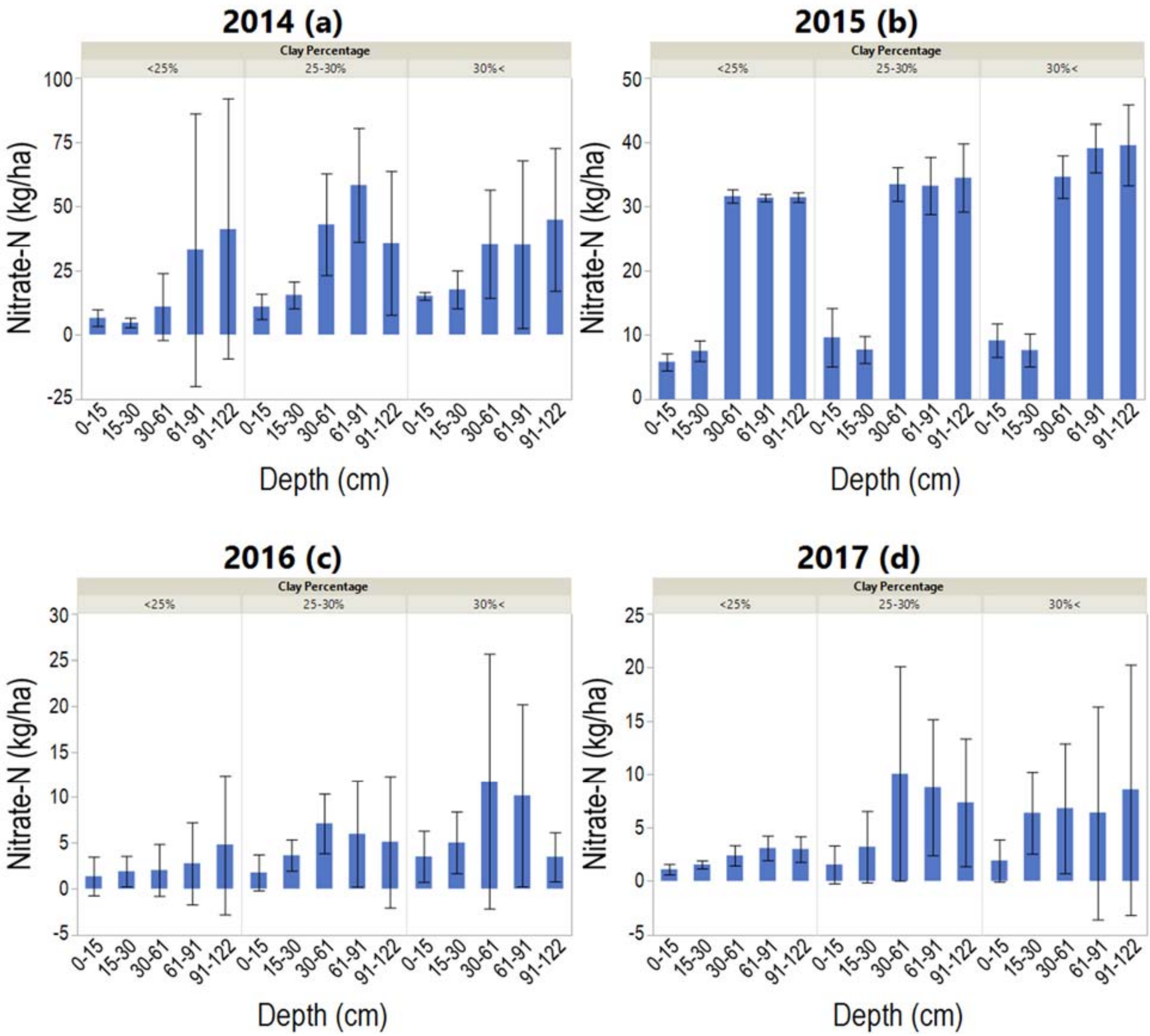

Figure 2.12: NO_3-N content by year grouped by clay grouping and depth. Errors bars are one standard deviation.

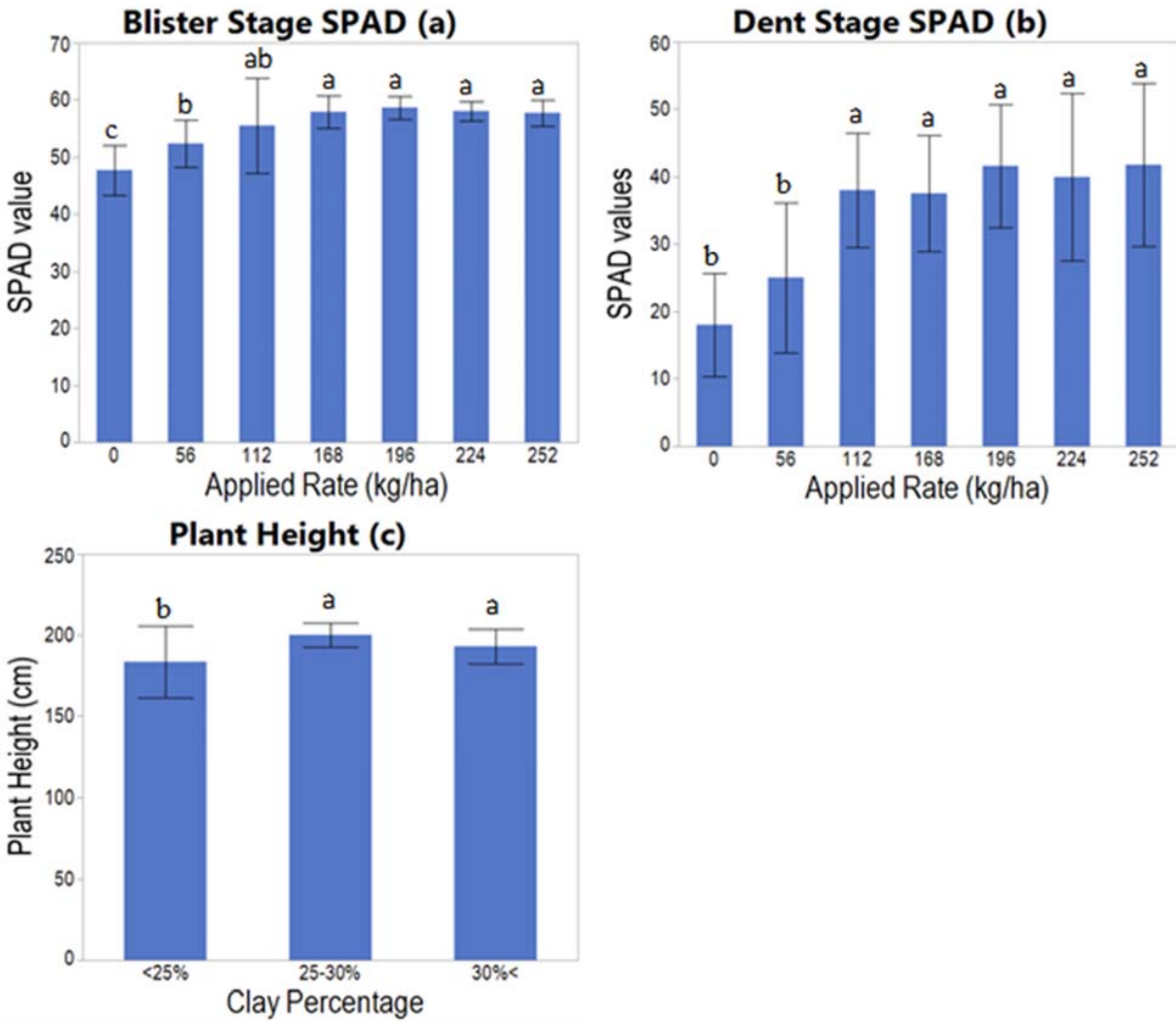

Figure 2.13(a-c). 2016 in-season corn data. Blister SPAD, Dent SPAD, and Plant height for corn. Columns with different letters denotes significance.

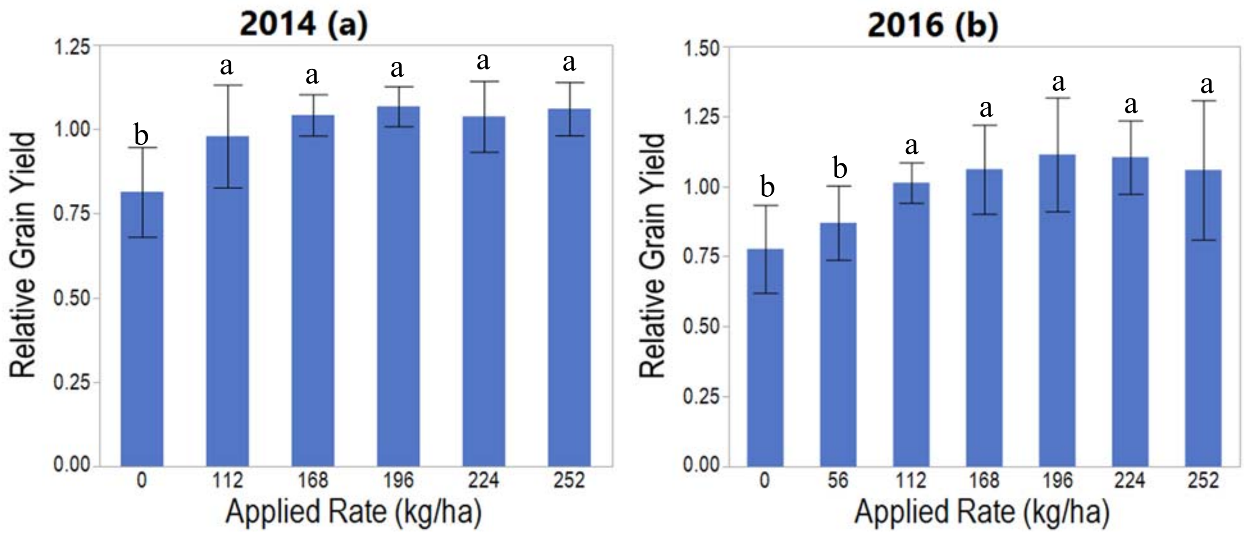

Figure 2.14(a&b). Relative corn yield by applied nitrogen rate. Columns with different lettering denotes significance

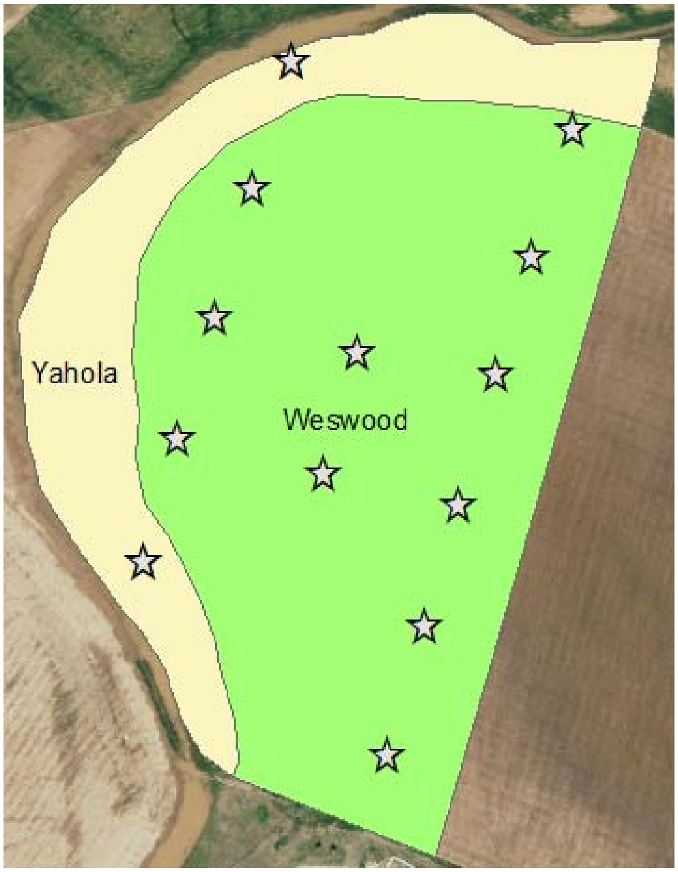

Figure 3.1: Soil types in the field. 77% of the field was a Weswood series and the remaining 23% was a Yahola series in Burleson county.

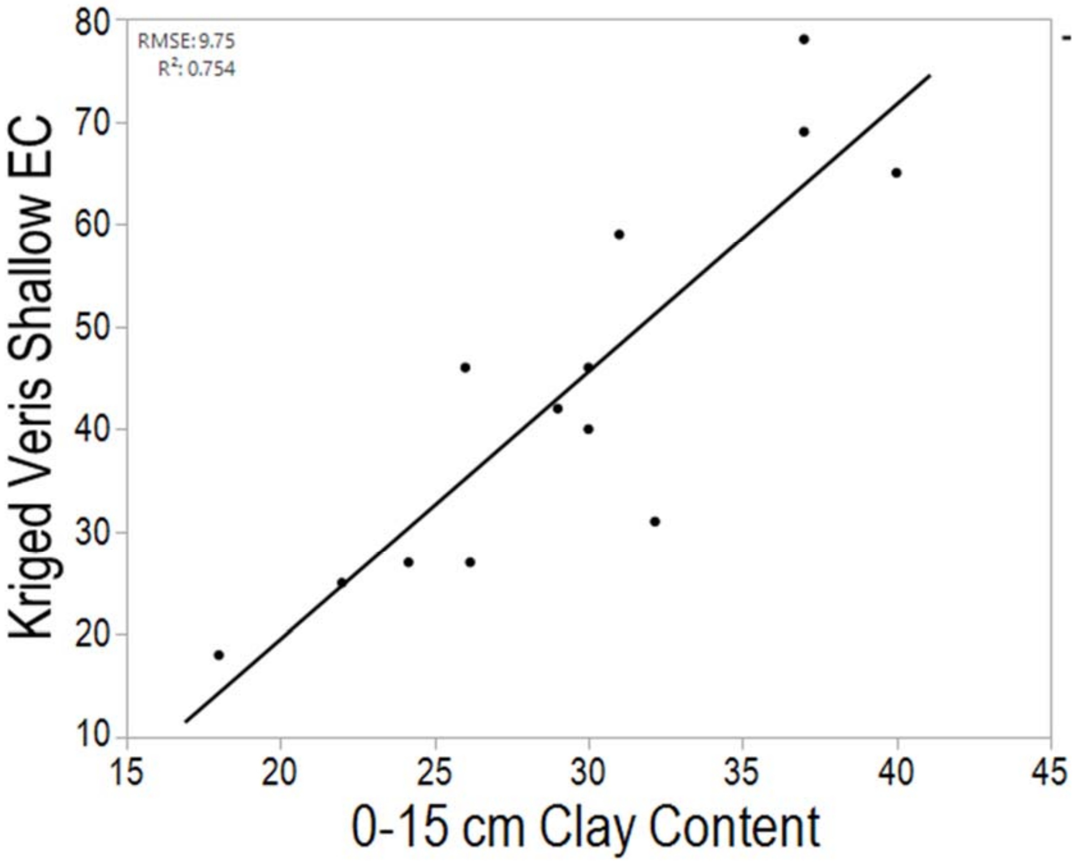

Figure 3.2: Kriged EC value nearest to the soil sample location compared to the clay percentage in the top 15 cm soil sample, Burleson County TX.

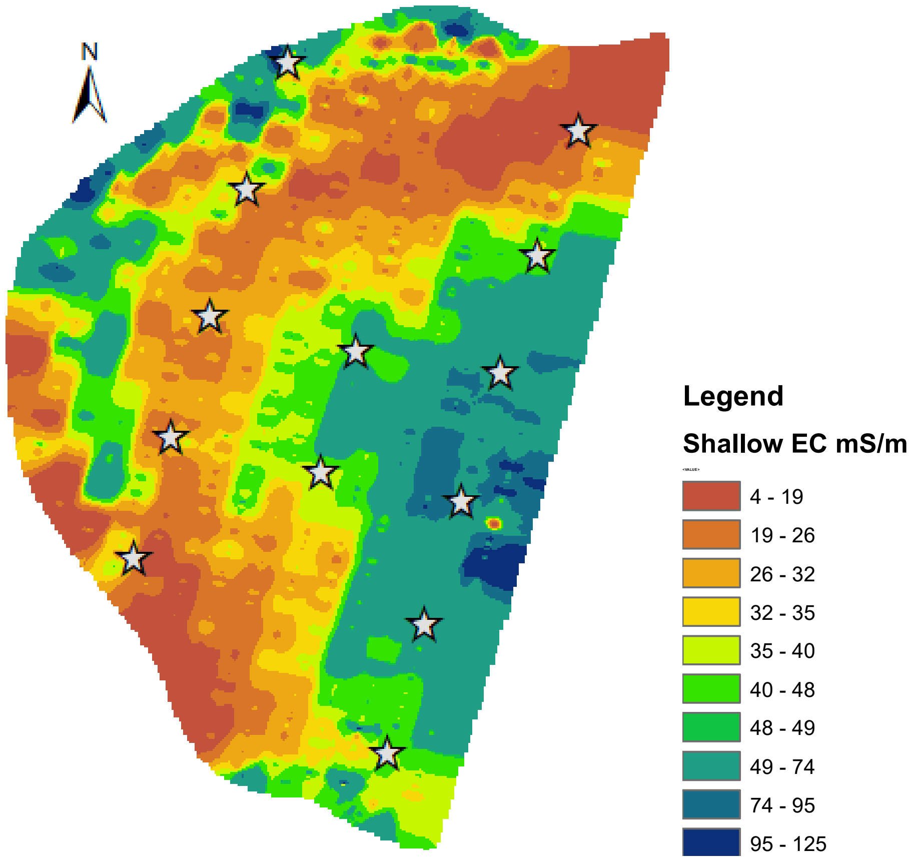

Figure 3.3: Interpolated shallow EC map on 7.62 m swath width in Burleson county. Stars are where replications were located for the duration of the study.

APPENDIX B

Table 2.1. Nitrogen Rate by year and crop type

Year	**Crop**	**Variety**	**Growth stage at fertilization**	**N rate (kg/ha)***						
2014	Corn	DKC 62-80	V6	0	112	168	196	224	252	
2015	Cotton	PHY 444 WRF	first bloom	0	34	68	101	135		
2016	Corn	B-H 8895 VTTP	V6	0	56	112	168	196	224	252
2017	Cotton	PHY 444 WRF	Squaring	0	34	68	101	135		

* Applied as UAN (32-0-0)

Table 2.2. Crop type and management, irrigation, and rainfall

Year	Crop type	Variety	Date planted	Growth regulators (product, rate(kg ai/ha))	Date harvested	Yearly irrigation (cm)	Yearly rainfall (cm)	In season Rainfall (cm)
2014	Corn	DKC 62-80	3/20/2014		9/9/2014	8.2	111.3	56.1
2015	Cotton	PHY 444 WRF	4/16/2015	Stance (.024)	9/13/2015	8.0	148.1	60.8
2016	Corn	B-H 8895 VTTP	3/2/2016		8/12/2016	0.0	118.8	61.8
2017	Cotton	PHY 444 WRF	4/4/2017	MepStar (.018)	10/11/2017	4.4	151.1	102.1

Table 2.3. 2016 Veris Measurements relationship to Clay Content

Depth (cm)	Source	Pr > F
0-15	30 M Shallow EC†	0.15
	Closest Shallow EC	0.38
	Kriged Shallow EC	0.03*
0-30	30 M Shallow EC	0.96
	Closest Shallow EC	0.95
	Kriged Shallow EC	0.11
0-61	30 M Deep EC†	0.07
	Closest Deep EC	0.33
	Kriged Deep EC	0.61

* Significant at 0.05 level

†Average of EC values within 30 m of the soil sample point

Table 2.4. Effect of Residual nitrate-N by clay percentage

Year	Source	Pr > F
2014	Clay %	0.49
2015	Clay %	0.06
2016	Clay %	0.63
2017	Clay %	0.29

* Significant at 0.05 level

Table 2.5. Influence of depth on nitrate-N by year and clay percentage

Year	Clay Content	**Source**	**Pr > F**
2014	<25%	Depth	0.43
	25-30%	Depth	<.01*
	30%<	Depth	0.28
2015	<25%	Depth	<.01*
	25-30%	Depth	<.01*
	30%<	Depth	<.01*
2016	<25%	Depth	0.58
	25-30%	Depth	0.40
	30%<	Depth	0.46
2017	<25%	Depth	0.02*
	25-30%	Depth	0.16
	30%<	Depth	0.65

* Significant at 0.05 level

Table 2.6. 2016 in-season data SPAD and plant height

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Parameter	**Source**	**Pr > F**
Blister SPAD	Clay %	0.66
	N Rate	<.01*
Dent SPAD	Clay %	0.06
	N Rate	<.01*
PH	Clay %	<.01*
	N Rate	0.72

* Significant at 0.05 level

Table 2.7. Combined years by crop type for effect of replication and application rate on relative crop yield

Crop Type	Source	Pr > F
Corn	Replication	1
	N Rate	<.01*
	Year	0.35
Cotton	Replication	1.00
	N Rate	0.64
	Year	1

* Significant at 0.05 level

Table 2.8. Agronomic nitrogen use efficiency by clay percentage and N rate

Year	Crop type	Parameter	Pr > F
2014	Corn	Clay %	<.01*
		N Rate	0.84
2015	Cotton	Clay %	0.37
		N Rate	0.85
2016	Corn	Clay %	<.01*
		N Rate	0.73
2017	Cotton	Clay %	0.67
		N Rate	0.72

* Significant at 0.05 level

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Table 2.9. Effect of N rate and clay percentage on grain test weight for 2014, 2016 and corn years combined

Year	**Parameter**	**Source**	**Pr > F**
2014	Test Weight	Clay %	0.6777
		N Rate	0.1385
2016	Test Weight	Clay %	0.4748
		N Rate	0.0612
Combined	Test Weight	Clay %	0.434
		N Rate	0.5179

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Table 2.10: 2017 Effect of N rate and clay content on cotton growth

Parameter	**Source**	**Pr > F**
TN	N Rate	0.05*
	Clay %	<.01*
NFFB	N Rate	0.11
	Clay %	0.21
NAHB	N Rate	0.19
	Clay %	0.67
PH	N Rate	0.38
	Clay %	<.01*

* Significant at 0.05 level

TN= total nodes, NFFB= nodes to first fruiting branch, NABH= nodes above harvestable boll, PH= plant height

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Table 2.11. Analysis of Replication and application rate on relative yield

Year	Crop Type	Source	Pr > F
2017	Cotton	Replication	1
	Cotton	N Rate	0.43
2016	Corn	Replication	1
	Corn	N Rate	<.01*
2015	Cotton	Replication	1
	Cotton	N Rate	0.34
2014	Corn	Replication	1
	Corn	N Rate	<.01*

* Significant at 0.05 level

Table 2.12. 2015 and 2017 effect of N rate and clay percentage on cotton fiber quality from HVI analysis

Year	Parameter	Source	Pr > F
2015	Leaf Grade	Clay %	0.40
		N Rate	0.70
	Micronaire	Clay %	0.02*
		N Rate	0.17
	Length	Clay %	0.04*
		N Rate	0.69
	Strength	Clay %	0.28
		N Rate	0.24
	Uniformity	Clay %	0.23
		N Rate	0.80
	Elongation	Clay %	0.70
		N Rate	0.57
	Whiteness	Clay %	0.79
		N Rate	0.57
	Yellowness	Clay %	0.71
		N Rate	0.21
2017	Leaf Grade	Clay %	<.01*
		N Rate	0.22
	Micronaire	Clay %	<.01*
		N Rate	0.96
	Length	Clay %	<.01*
		N Rate	0.62
	Strength	Clay %	<.01*
		N Rate	0.73
	Uniformity	Clay %	<.01*
		N Rate	0.91
	Elongation	Clay %	0.35
		N Rate	0.18
	Whiteness	Clay %	0.09
		N Rate	0.85
	Yellowness	Clay %	0.09
		N Rate	0.85

* Significant at 0.05 level

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Table 3.1. 2016 Veris Measurements relationship to Clay Content

Depth (cm)	Source	Pr > F
0-15	30 M Shallow EC†	0.15
	Closest Shallow EC	0.38
	Kriged Shallow EC	0.03*
0-30	30 M Shallow EC†	0.96
	Closest Shallow EC	0.95
	Kriged Shallow EC	0.11
0-61	30 M Deep EC†	0.07
	Closest Deep EC	0.33
	Kriged Deep EC	0.61

* Significant at 0.05 level

†Average of EC values within 30 m of the soil sample point

Table 3.2: Pearson's Correlation and P-value of lab tested pH and Veris pH for the Burleson, Eastern Williamson, and Western Williamson County locations

Location	Pearson's Correlation Value	Pr >F
Burleson County	0.16	0.59
Eastern Williamson County	0.62	0.02*
Western Williamson County	0.87	<0.01*

* Significant at 0.05 level

Table 3.3: Pearson's Correlation of Clay and Infrared and Red reflectance with soil nutrients and Organic Matter at the Burleson county location. Top value is the Pearson's value and the bottom value is the P value

	Clay	Infrared	Red	N	P	K	Ca	Mg	S	Na	Fe	Zn	Mn	Cu	SOM†
Clay															
Infrared	-0.78														
	0.06														
Red	0.80	-0.34													
	0.05	0.51													
N	0.84	-0.79	0.42												
	0.04*	0.06	0.40												
P	-0.35	0.63	0.05	-0.40											
	0.49	0.18	0.93	0.43											
K	0.91	-0.67	0.87	0.72	-0.05										
	0.01*	0.15	0.03*	0.10	0.92										
Ca	0.96	-0.91	0.68	0.85	-0.39	0.90									
	<.01*	0.01*	0.14	0.03*	0.44	0.01*									
Mg	0.82	-0.44	0.97	0.40	-0.02	0.85	0.73								
	0.05*	0.38	<.01*	0.44	0.96	0.03*	0.10								
S	0.37	-0.13	0.61	0.09	0.63	0.63	0.39	0.64							
	0.47	0.81	0.20	0.87	0.18	0.18	0.44	0.17							
Na	0.01	0.43	0.40	-0.40	0.37	-0.04	-0.20	0.44	0.34						
	0.99	0.39	0.43	0.43	0.48	0.94	0.71	0.38	0.51						
Fe	0.97	-0.72	0.84	0.78	-0.43	0.88	0.90	0.82	0.25	<.01*					
	<.01*	0.11	0.03*	0.07	0.40	0.01*	0.01*	0.04*	0.63	0.99					
Zn	0.37	0.03	0.80	-0.14	0.42	0.55	0.28	0.82	0.80	0.66	0.37				
	0.47	0.95	0.06	0.80	0.41	0.26	0.59	0.04*	0.06	0.15	0.46				
Mn	-0.28	0.60	0.23	-0.65	0.73	-0.12	-0.38	0.27	0.58	0.84	-0.31	0.72			
	0.59	0.21	0.66	0.16	0.10	0.82	0.46	0.61	0.23	0.03*	0.55	0.10			
Cu	0.86	-0.50	0.98	0.53	0.01	0.95	0.79	0.96	0.66	0.23	0.87	0.75	0.12		
	0.03*	0.32	<.01*	0.28	0.99	<.01*	0.06	<.01*	0.15	0.65	0.02*	0.09	0.82		
SOM†	0.87	-0.56	0.95	0.57	-0.13	0.95	0.82	0.92	0.54	0.10	0.91	0.66	-0.03	0.98	
	0.02*	0.24	<.01*	0.24	0.81	<.01*	0.05*	<.01*	0.26	0.85	0.01*	0.15	0.96	<.01*	

* Significant at 0.05 level
†Soil Organic Matter

Table 3.4: Pearson's Correlation of Infrared and Red reflectance with soil nutrients and Organic Matter at the Eastern Williamson County location

	SOM†	**K**	**Ca**	**Mg**	**S**	**Fe**	**Mn**	**Zn**	**Cu**	**B**	**Na**	**CEC**	**Infrared**
SOM†													
K	0.91												
	<0.01*												
Ca	0.29	0.37											
	0.31	0.19											
Mg	0.32	0.22	-0.71										
	0.26	0.45	<0.01*										
S	-0.52	-0.50	-0.34	-0.02									
	0.06	0.07	0.23	0.94									
Fe	-0.31	-0.39	-0.86	0.62	0.54								
	0.28	0.17	<0.01*	0.02*	0.05*								
Mn	-0.50	-0.43	-0.17	-0.16	0.45	0.22							
	0.07	0.13	0.57	0.57	0.11	0.45							
Zn	0.78	0.85	0.16	0.37	-0.24	-0.09	-0.20						
	<0.01*	<0.01*	0.59	0.19	0.41	0.75	0.49						
Cu	0.50	0.43	-0.54	0.78	-0.16	0.38	-0.04	0.53					
	0.07	0.13	0.05*	0.01*	0.58	0.17	0.90	0.05*					
B	0.33	0.45	0.93	-0.57	-0.46	-0.86	-0.06	0.23	-0.42				
	0.25	0.10	<0.01*	0.03*	0.09	<0.01*	0.84	0.42	0.13				
Na	-0.14	-0.20	-0.17	0.27	0.46	0.34	-0.04	-0.10	-0.20	-0.23			
	0.63	0.49	0.56	0.35	0.10	0.23	0.88	0.72	0.50	0.43			
CEC	0.22	0.10	0.46	-0.24	0.25	-0.36	-0.07	<0.01*	-0.14	0.32	0.04		
	0.46	0.74	0.10	0.41	0.39	0.20	0.82	0.97	0.62	0.27	0.88		
Infrared	0.65	0.63	0.09	0.32	-0.69	-0.28	-0.06	0.53	0.58	0.29	-0.42	-0.07	
	0.01*	0.01*	0.76	0.27	0.01*	0.34	0.85	0.05*	0.03*	0.31	0.13	0.82	
Red	0.25	0.30	0.34	-0.04	-0.29	-0.25	-0.13	0.02	-0.09	0.30	0.24	0.15	0.26
	0.38	0.30	0.24	0.90	0.32	0.39	0.65	0.94	0.75	0.30	0.40	0.61	0.37

* Significant at 0.05 level
†Soil Organic Matter

Table 3.5: Pearson's Correlation of Infrared and Red reflectance with soil nutrients and Organic Matter at the Western Williamson County location

	SOM†	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Na	CEC	Infrared
SOM†													
K	0.88												
	<0.01*												
Ca	0.51	0.78											
	0.09	<0.01*											
Mg	-0.36	-0.51	-0.52										
	0.26	0.09	0.08										
S	0.69	0.42	0.12	-0.30									
	<0.01*	0.18	0.72	0.34									
Fe	-0.43	-0.67	-0.80	0.68	-0.04								
	0.17	0.02*	<0.01*	0.02*	0.91								
Mn	0.38	0.62	0.51	-0.69	0.05	-0.49							
	0.23	0.03*	0.09	<0.01*	0.87	0.10							
Zn	0.03	0.28	0.06	-0.26	-0.11	-0.30	0.53						
	0.92	0.38	0.85	0.41	0.72	0.34	0.08						
Cu	0.64	0.79	0.43	-0.34	0.27	-0.56	0.51	0.72					
	0.02*	<0.01*	0.16	0.28	0.40	0.06	0.09	<0.01*					
B	0.65	0.83	0.88	-0.72	0.27	-0.85	0.71	0.27	0.56				
	0.02*	<0.01*	<0.01*	0.01*	0.40	<0.01*	<0.01*	0.40	0.06				
Na	-0.24	-0.41	-0.31	0.69	0.16	0.51	-0.57	-0.33	-0.34	-0.48			
	0.45	0.19	0.32	0.01*	0.63	0.09	0.05*	0.30	0.27	0.12			
CEC	0.39	0.51	0.78	-0.06	0.16	-0.34	0.13	-0.26	0.12	0.52	0.07		
	0.21	0.09	0.01*	0.84	0.61	0.29	0.68	0.42	0.72	0.08	0.82		
Infrared	0.54	0.41	0.17	-0.42	0.55	0.07	0.41	-0.09	0.16	0.34	-0.27	0.26	
	0.07	0.19	0.59	0.18	0.06	0.84	0.19	0.78	0.62	0.27	0.39	0.42	
Red	-0.01	-0.07	-0.30	0.11	-0.25	0.17	0.03	0.28	0.23	-0.21	-0.37	-0.18	0.23
	0.97	0.83	0.35	0.74	0.44	0.61	0.91	0.38	0.47	0.51	0.23	0.57	0.48

* Significant at 0.05 level
†Soil Organic Matter

Table 3.6. Pearson's Correlations and p-values for increasing swath width. Top value is the Pearson's value and the bottom value is the P value

	Clay Content	7.62 m	15.24 m	30.48 m	45.72 m	60.96 m	76.2 m	91.44 m
Clay Content								
7.62 m	0.87 <.01*							
15.24 m	0.87 <.01*	0.97 <.01*						
30.48 m	0.82 <.01*	0.99 <.01*	0.97 <.01*					
45.72 m	0.83 <.01*	0.98 <.01*	0.96 <.01*	0.99 <.01*				
60.96 m	0.73 <.01*	0.86 <.01*	0.86 <.01*	0.89 <.01*	0.90 <.01*			
76.2 m	0.77 <.01*	0.96 <.01*	0.93 <.01*	0.95 <.01*	0.96 <.01*	0.81 <.01*		
91.44 m	-0.33 0.28	-0.42 0.15	-0.31 0.30	-0.35 0.24	-0.31 0.30	-0.09 0.78	-0.45 0.12	

Table A.1. Rain Fall Distribution by month for 2014-2017

	Monthly (cm)												Yearly
Year	January	February	March	April	May	June	July	August	September	October	November	December	Total
2014	3.3	2.3	4.1	13.8	22.9	4.1	17.1	1.0	16.7	4.6	15.0	6.5	111.3
2015	16.9	1.9	14.8	12.2	24.7	13.2	0.8	3.5	4.4	22.4	12.8	20.5	148.1
2016	3.3	3.4	11.3	13.8	32.8	6.6	0.6	22.7	5.1	5.5	6.9	7.0	118.8
2017	9.5	8.3	4.5	13.8	24.7	14.6	2.0	53.4	2.5	7.5	1.5	8.9	151.1

Table A.2. Breakdown of NO_3-N by clay content and depth for all for years

Year	Clay Grouping	Depth (cm)					
		0-15	15-30	30-61	61-91	91-122	0-122
2014	30%<	15.0	4.0	35.5	35.3	44.9	134.7
	25-30%	9.9	16.2	41.5	55.7	32.1	155.3
	<25%	7.8	6.2	18.6	40.5	43.2	116.2
2015	30%<	7.3	7.1	31.0	32.2	31.6	109.2
	25-30%	9.2	8.2	34.1	35.2	35.8	122.6
	<25%	8.0	7.2	34.6	35.9	38.0	123.6
2016	30%<	3.5	5.0	11.7	10.2	3.5	34.0
	25-30%	1.8	3.7	7.1	6.0	5.1	23.7
	<25%	2.0	2.5	3.1	4.1	7.2	18.9
2017	30%<	1.6	5.4	9.9	6.6	6.4	30.0
	25-30%	1.6	3.3	7.3	5.4	5.6	23.2
	<25%	0.9	3.6	5.6	8.3	9.4	27.8

Table A.3. Clay content by depth and clay grouping

Clay Group	depth (cm)	Percent Sand	Percent Silt	Percent Clay
<25%	0-15	23.1	52.5	24.4
	15-30	22.1	56.0	22.9
	30-61	28.2	53.5	18.3
	61-91	45.1	41.3	13.6
	91-122	52.5	34.0	13.5
	0-122	34.2	47.5	18.5
25-30%	0-15	17.0	53.6	29.4
	15-30	14.8	58.6	26.6
	30-61	17.4	53.6	29.0
	61-91	24.2	49.2	26.6
	91-122	54.4	32.2	13.4
	0-122	25.6	49.4	25.0
30%<	0-15	12.8	50.0	37.2
	15-30	13.4	49.6	37.0
	30-61	16.8	53.0	30.2
	61-91	27.0	48.4	24.6
	91-122	29.2	50.4	20.4
	0-122	19.8	50.3	29.9