Improving Early Season Sidedress Nitrogen Rate Prescriptions for Corn

Justin R. Jones

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Wade E. Thomason
Marcus M. Alley
Mark S. Reiter

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ABSTRACT

Corn requires the most nitrogen (N) of cereal grain crops and N supply is correlated with grain yield. Canopy reflectance has been used to assess crop N needs and to derive optimum application rates in mid-season corn. Canopy reflectance has not been useful for N rate determination in early season corn because of low biomass and the sensing background can interfere, or overwhelm crop canopy reflectance measures. Widespread adoption of canopy reflectance as a basis for generating in-season corn N rates would be more likely if N rate recommendations could be made early, i.e. by the V6 growth stage. The objectives of this research were to: i) examine the influence of soil color, soil moisture, surface crop residues, and sensor orientation on normalized difference vegetation index (NDVI) readings from corn from planting through the V6 growth stage; and ii) evaluate the effect of sensor orientation and field of view at early corn growth stages on the relationship between NDVI and corn biomass, N uptake, and chlorophyll meter readings. Soil color, soil moisture, crop residue type, and sensor orientation influenced reflectance and these factors were much more influential when sensing plants with low biomass. Canopy reflectance was capable of differentiating between N rates in the field and altering sensor orientation did not minimize sensing background influence or improve the ability of the sensor to distinguish plant N status. Even when canopy reflectance detected differences in crop N status, N rate prescription based on NDVI was consistently below the profitable estimated sidedress N rate.

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Table of Contents

CHAPTER II- Influence of soil color, crop residue, and sensor orientations on NDVI readings

CHAPTER III- Improved Detection of Early Season N Need with Alternate Sensor Orientation

List of Tables

CHAPTER I

CHAPTER II

CHAPTER III

List of Figures

CHAPTER I

CHAPTER II

CHAPTER III

List of Abbreviations

ANOVA - Analysis of variance

EONR - Economically optimal nitrogen rate

K - Potasium

LSD - Least significant difference

N - Nitrogen

NDVI - Normalized difference vegetation index

NIR - Near infrared

NUE - Nitrogen use efficiency

P - Phosphorus

PSNT - Pre-sidedress soil nitrate test

RMSE - Root mean square error

UAN - Urea ammonium nitrate

VCA - Virginia corn algorithm

VR - Variable rate

CHAPTER I- Introduction and Justification

Corn (*Zea Mays* L.) has been utilized as a food crop for centuries (Mangelsdorf et al., 1964) and currently plays a significant role in the U.S. economy. Corn is not only grown for human consumption; it is used in industrial products, as a component of livestock feed, and in the production of biofuels. Feed and byproduct feed usage has traditionally been the primary end use of corn in the U.S., but in 2011 more grain was allocated for the production of biofuel than for byproduct feed usage . During the 2009/2010 season, grain used for feed/byproduct feed and fuel production was 130 million Mg and 107 million Mg, respectively (Baker et al., 2009). During the 2010/2011 season, corn usage for feed/byproduct feed and fuel production was 122 million Mg and 128 million Mg, respectively (Capehart et al., 2012). Corn use projections made by Capehart et al. (2012) for the 2012/2013 season are predicted to follow the same trend; corn end use trends and quantities can be seen in Table 1. Corn produced in the U.S. that is exported accounts for, on average, 11% of U.S. agricultural exports and the U.S. is currently the largest producer and exporter of corn grain in the world (USDA-ERS, 2012b).

The world population is increasing daily, recently surpassing 7 billion people (U.S. Department of Commerce, Bureau of Census, 2012), and the demand for corn grain is increasing with population increases. Average corn grain yield and per capita consumption of corn in the U.S. has increased by approximately 215% and 383%, respectively, in the last 40 years (FAO, 2013; USDA-ERS, 2013). There are two main factors that have led to grain yield increases, the use of hybrids and a better understanding of plant nutrition (Assefa et al., 2012; Cardwell, 1982). Better understanding of soil fertility and plant nutrition has led producers to better manage synthetic fertilizers, organic fertilizers and the use of cover crops to meet corn nutritional needs.

In order to meet the increased future demand for corn grain, researchers seek to continually improve soil fertility management. Nitrogen (N) is the most common limiting nutrient in cropping systems (Weih et al., 2011) and corn requires more total N inputs than other comparable cereal crops (Ma and Dwyer, 1998; Ma et al., 2003). Nitrogen use efficiency (NUE) has been defined using a number of factors of input and recovery (Moll et al., 1982; Raun and Johnson, 1999; Semenov et al., 2007). According to Cassman et al. (2002) the NUE of a cropping system is the proportion of applied N recovered in the harvested crop, contained in recycled crop residues, and incorporated into soil organic matter. The N not recovered in these pools is lost from the system and contributes to the reactive N load in the environment external to the cropping system. Thus, NUE of a cropping system may be increased through greater crop uptake and recovery of applied N, by decreasing N losses, or both.

Anhydrous ammonia, granular urea and urea-based fertilizer solutions, such as urea ammonium nitrate solution (UAN), are the most common N sources used in corn production in the U.S. (USDA-ERS, 2011); with upwards of 9 million Mg of nitrogen solutions being applied annually in the U.S. The price of 30% UAN solution has recently increased dramatically in the U.S. In 2001, UAN 30% was \$208 Mg^{-1} as compared to \$312 Mg^{-1} in 2010 (USDA-ERS, 2012a); therefore, reducing N loss while increasing NUE is of upmost concern (Robertson and Vitousek, 2009) in order to ensure that corn producers operate sustainably and profitably.

In order to minimize N losses and increase NUE, many producers have adopted the practice of split applications, which involves applying N numerous times throughout the growing season and typically at lower rates, compared to methods in which the required N rate is applied at once prior to planting. The reduced rates of pre-plant N reduce the potential for large amounts of N loss in the spring months. In-season applications, often referred to as sidedress applications, supply a majority of the plant N requirement when the plant is actively taking up N and loss potential is subsequently minimized as seen in Figure 1.1. Sidedress applications are effective at meeting corn N requirements and increasing NUE. Fox et al. (1986) reported increased NUE with a sidedress application when compared to other N applications when using ammonium nitrate, urea or UAN solution. Jung et al. (1972) observed similar results when a single sidedress application was applied in a window from week 5 to 8 after planting or from the V5 to V12 corn growth stage.

Regardless of why a producer may choose to apply sidedress N, one problem is the limited window of time for making effective sidedress applications. Sidedressing must occur while plants are small enough to allow equipment access and before deficiency occurs. The optimal growth stage for sidedressing corn depends on the nutrient status of the crop. When N is sufficient, the timing is less critical than corn that is highly N deficient (Binder et al., 2000). The greater the N deficiency, the earlier a sidedress N application is warranted, and if the deficiency is not corrected by V6 overall grain yields have been shown to decrease as much as 0.32% per day (Binder et al., 2000).

Calculating accurate sidedress rates to meet crop needs poses a problem to producers. Johnson (1991) and Dahnke et al. (1988) stated that N application rates can be determined by the average grain yield from the previous five years. Meisinger et al. (2008) stated once a yield goal has been estimated a producer must determine the likely yield of that particular season and adjust the N rate accordingly. Currently, many corn producers use yield goal based methods to calculate sidedress N rates because N rates will ensure nutrient sufficiency and the calculated rate will contribute to reaching a realistic yield goal based on crop history. Rising N prices and greater emphasis on environmental quality has led some producers to utilize in-season diagnostic tests to determine an N rate that optimizes NUE and profitability. Two common plant based tests used for calculating N rates are tissue sampling and the use of chlorophyll meters such as the SPAD 502 (Konica Minolta Sensing, Inc., Osaka, Japan). Scharf et al. (2006) reported that the SPAD meter was a good indicator of the environmentally optimal nitrogen rate which can be used as a factor to determine sidedress N rates. The rate the farmer determines, either by yield history or plant testing is then typically applied to a whole field or area disregarding any nutrient variability within the field (Inman et al., 2005). Raun et al. (1998) reported that N availability can vary at a field scale as small as 1 m^2 on a loam and sandy loam soil. In the past, when N prices were lower and pollution was not a factor of concern that influenced N rate calculations, a uniform N rate was standard. Currently, producers are beginning to take field N variability and environmental impacts into consideration by practicing variable rate (VR) N applications.

A VR application allows producers to site-specifically apply N at the sub-field level (Ruffo et al., 2006). Variable rate applications are used to supply N based on variability within a field to maximize crop output while reducing N inputs. To accurately account for in-field N variability, variation must first be assessed; which can be expensive and labor intensive. To reduce time and manual labor for estimating field N availability and plant N needs some researchers have looked towards remote sensing. Remote sensing has been effectively used in U.S. agriculture for over 50 years (Campbell and Wynne, 2011). In recent years, aerial imagery was utilized to determine N needs. Sripada et al. (2005) reported that aerial imagery can be used to predict in-season economical optimal N rates (EONR) for corn growing in numerous soil series. Aerial imagery is considered to be a “passive” sensing technique; which means it relies on natural energy to collect remotely sensed data. Aerial imagery can be costly and the capturing of data is highly dependent on the weather as cloud cover can restrict sunlight intensity and hinder capturing of aerial images (Shaver et al., 2010). As an alternative, the use of "active" crop sensors as a basis for in-season variable rate N applications has been proposed.

Active remote sensing systems use their own energy source and are not limited by constraints that accompany passive systems, such as aerial imagery (Inman et al., 2007). Active sensors commonly used for corn production in the U.S. are the GreenSeeker® (Trimble Navigation LTD., Sunnyvale, CA), Crop Circle ACS-430® (Holland Scientific Inc., Lincoln, NE) and OptRx® (AG Leader Technology, Ames, IA). All three sensors can be utilized to make "real time" variable rate N prescriptions. The GreenSeeker® uses light emitting diodes that direct light onto the crop canopy. Specifically, light emitted is near infrared (NIR) (780 ± 10 nm) and red (670 ± 10 nm) while the light reflected off the plant canopy is measured using silicon diodes (Harrell et al., 2011; Shaver et al., 2010). All three sensors work in a similar manner (Ag Leader Technology, 2011; Holland Scientific Inc., 2011). The reflected light is used to determine spectral vegetation indices such as normalized difference vegetation index (NDVI); which is used to estimate physiological changes in the plant and gather information with respect to crop yield potential (Peñuelas et al., 1994; Raun et al., 2001).

When the GreenSeeker® sensor is paired with a computer, crop physiological data can be used as an input to an algorithm to determine sidedress N rates. The algorithm uses "reference strips" to generate a N response index that is an indicator of potential crop response to additional N fertilizer (Raun et al., 2005). Data collected from reference strips are entered into an algorithm that generates N rates for the targeted corn. As the applicator and sensor travel through the field, the algorithm generated N rates are applied in "real time" to account for field variability. The resolution of the variable rate application is dependent on numerous factors including but not limited to equipment size and applicator speed. Previous research (Solari et al., 2010; Tubaña et al., 2008) has shown that algorithms provide accurate in-season N rate calculations for corn. Scharf et al. (2011) used the GreenSeeker® to compare N algorithm rates against producer-chosen N rates and reported that the sensor–based rate recommendations reduced N application by 16 kg N ha^{-1} or 25% as compared to the producer calculated rates and in some years, increased grain yield. Previous research (Barker and Sawyer, 2010; Teal et al., 2006) has analyzed the accuracy of the sensor in terms of algorithm calculated N rates at different growth stages of corn in the central U.S. and determined algorithm calculated N rates are good indicators of crop N needs when plants reach mid-vegetative growth. Furthermore Teal et al. (2006) used exponential equations to expand the sensing window and concluded that grain yield potential can be accurately determined from the V7 to V9 growth stage. Research conducted by Thomason et al. (2007), in the mid-Atlantic reported that NDVI values were sensitive to change in plant greenness and leaf area from corn growth stages V5 to V9.

Dellinger et al. (2008) found that relative NDVI is strongly correlated with EONR when pronounced N deficiencies were present on loamy soils in the mid-Atlantic, but when N deficiencies were subtle the correlation was weak. This can be troublesome due to the fact that severe N deficiencies are not always apparent before V6, prior to the large increase in corn N demand (Abendroth et al., 2011) and can result in yield losses.

If GreenSeeker® prescribed N rates accurately depict crop N needs during early season growth, active sensors could reduce severe yield losses that occur with early season N deficiencies and permit fertilizer application equipment access which could potentially increase sensor adoption as an N management tool in the mid-Atlantic. However, Hutchinson (1982) stated that vegetation data, such as plant greenness, is difficult to extrapolate from remote sensed data when biomass is at or below 30% ground cover due to soil background interference. The influence of sensing background on NDVI is dependent on soil series, soil moisture and organic matter content (Huete 1988). With production practices transitioning to conservation tillage in the mid-Atlantic, sensing backgrounds are becoming more diverse. Previous research (Gilabert et al., 2002; Huete 1988; Liu and Huete 1995; Martin et al. 2012) has addressed the effect of sensing background and researchers have proposed techniques such as altering sensor orientation or adjusting vegetative indices to reduce the influence of sensing background on canopy reflectance readings. Soil background is known to influence NDVI readings when collected from low biomass plants when leaf area index (LAI) is at or less than one (Huete 1988). This influence is hypothesized to be the reason N rates and plant physiological information, such as N status, are difficult to extract in the early growth stages of corn.

The overall goal of this study was to improve N sidedress rate prescriptions using active sensors at early growth stages of corn by assessing various methods for obtaining remotely sensed data. Specific objectives were to:

(1) Examine the influence of soil color, soil moisture, surface crop residues, and sensor orientation on corn NDVI readings from planting through the V6 growth stages.

(2) Evaluate the effect of sensor orientation and field of view at early corn growth stages on the relationship between NDVI and corn biomass, N uptake, and chlorophyll meter readings.

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Table 1.1 Historic and projected quantities and uses of corn grain in the U.S. from the 2009/2011season through the 2012/2013 season.†

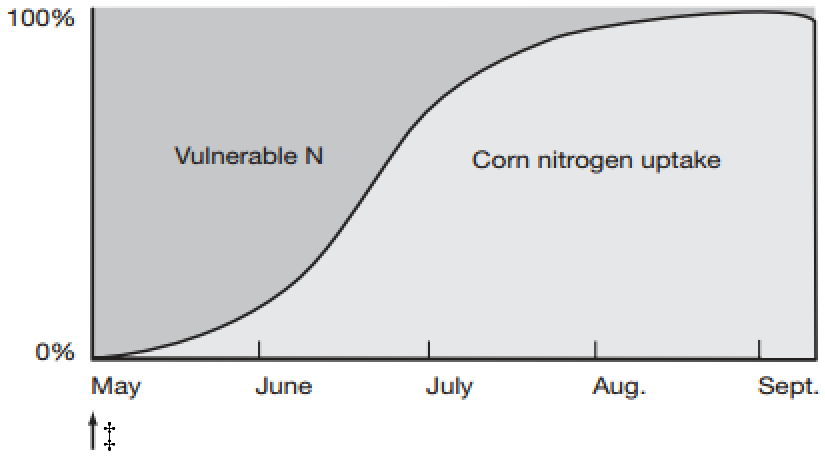
End Use	2009/2010	2010/2011	2011/2012	2012/2013
	---------------------------------Million Mg	---------------------------------		
Feed and Residual Use	137.45	134.90	163.16	122.05
Exports	53.45	49.64	40.73	50.40
High Fructose Corn Syrup	11.96	13.11	106.90	13.07
Glucose and Dextrose	5.85	6.62	6.75	7.49
Starch	5.85	6.36	6.62	6.46
Alcohol for Fuel	106.90	122.18	127.27	127.55
Alcohol for beverages and manufacturing	3.41	3.44	3.44	3.47
Cereals and other products	4.92	5.01	5.13	5.17
Seed	138.92‡	0.58	0.60	0.62
Total	468.75	341.85	460.60	336.30

† Baker et al., (2009); Baker et al., (2010); Capehart and Allen (2011); Capehart et al. (2012).

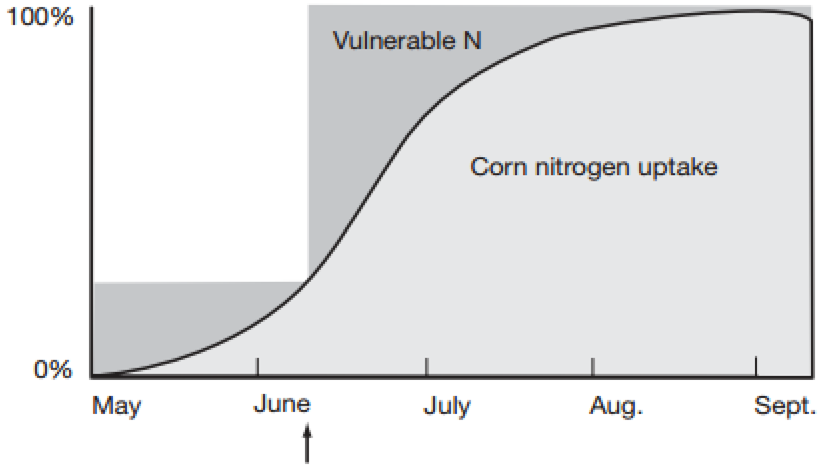
‡ Seed data presented for the 2009/2010 growing season includes grain used for food, seed or industrial purposes.

Figure 1.1 Relative vulnerability of applied N at different application timings to loss by leaching and denitrification.†

A. All N applied pre-plant



B. Bulk of N applied in-season



†Source: Beegle, D.B. and P.T. Durst. 2003. Agronomy facts 12: Nitrogen fertilization of corn. CAT UC049. Penn State College of Agriculture Sciences Cooperative Extension, University Park, PA. Copied with permission.

‡ Arrows indicate fertilizer application date.

Chapter II - Influence of soil color, crop residue, and sensor orientations on NDVI readings

Abstract

Site-specific in-season corn (*Zea mays* L.) nitrogen (N) rate recommendations based on remote sensing can increase nitrogen use efficiency (NUE) but most approaches require the corn to be at the V8 growth stage. Success in estimating N needs during early vegetative growth has been limited due to low plant biomass and background interference. The objective of this experiment was to measure the influence of soil color, soil moisture, surface crop residues, and sensor orientation on Normalized Difference Vegetation Index (NDVI) from soils prior to planting and corn from planting through the V6 growth stage. A controlled experiment was conducted in Virginia using four soil types commonly used for corn production. Spectral reflectance readings were measured using the GreenSeeker® sensor from the soils and four crop residues at four sensor orientations. The four soils used in this study had varying reflectance at all orientations examined before plant emergence, as much as 0.16 units within an orientation. Variation in NDVI between soils increased with the addition of water with differences of up to 0.18 units between moisture levels. The various crop residues initially produced different NDVI values, but NDVI variation decreased as plants matured. Altering sensor orientations changed relative NDVI but did not minimize NDVI variation generated by the sensing background. Sensing background (soil and residue) influenced NDVI readings during early vegetative growth so for this system to be employed during early vegetative growth, the sensing background for the reference areas should be uniform and similar to the larger field.

Introduction

Corn (*Zea Mays* L.) has been domesticated and grown for human and animal consumption for over 7000 years (Mangelsdorf et al. 1964) and is currently the most widely grown agronomic crop in the U.S. (USDA-NASS 2012) and is an important U.S. agricultural export. Corn requires more nitrogen (N) inputs than other cereal grain crops due to the amount of grain produced per hectare with average total N uptake of 224 kg N ha^{-1} for a crop producing 14.1 Mg ha^{-1} (0.016 kg N ha^{-1}) (Ma and Dwyer 1998; Ma et al. 2003; Abendroth et al. 2011).

According to Abendroth et al. (2011), N uptake and biomass accumulation in corn is minimal prior to V5 when less than 5% of total season N is accumulated in plant tissue. Once the plant reaches the V5 growth stage N uptake occurs at an increasing rate as biomass increases through the onset of reproduction. Over 50% of total season N uptake occurs during the rapid biomass production of V5 through R1 therefore it is pertinent to ensure adequate N fertility during this growth period. Nitrogen uptake slows at R1 but continues through the R5 growth stage and then decreases through physiological maturity. At harvest, approximately 11.0 g N kg^{-1} of grain is removed (Abendroth et al. 2011; Bender et al. 2013; Heckman et al. 2003).

In order to reduce negative environmental effects of excess N applications and increase grower profitability, N fertility research aims to improve nitrogen use efficiency (NUE). A technique practiced in the mid-Atlantic to increase NUE is use of split in-season N applications (Maguire et al. 2009). Jung et al. (1972) reported that on a loamy sand soil in Wisconsin, compared to supplying all N pre-plant, a low rate pre-plant N application paired with a single in-season N application applied from the V5 to V12 growth stage increased NUE. Nitrogen rates for in-season applications have traditionally been based on average grain yields of the previous five years; in addition to the calculated rate, an additional 10-30% of the rate is applied to account for N loss and to prevent N deficiencies (Johnson 1991; Dahnke et al. 1988). Camberato (2012) analyzed approximately 150 field scale N rate response trials in Indiana and concluded that N rate recommendations should not be tied to yield goals, but rather to economic returns such as economic optimal N rates (EONR). This idea is further supported by Mamo et al. (2003) who stated that EONR varies by location within a field and is influenced by spatial and temporal N availability. Producers in the Midwest have access to an N rate calculator that uses numerous N rate studies to determine rates based off of the “Maximum Return to N Approach”; which takes into account the EONR and factors such as crop rotation (Sawyer and Nafziger 2005). This system bases N rates on response measured under similar site conditions and not yield goal. A similar system could be implemented across the U.S. if sufficient N response data were available.

In recent years, some producers have adopted the practice of variable rate (VR) N applications to capture variation of N availability within a field and site specifically apply needed N (Ruffo et al. 2006); this practice has been employed primarily in regions where high N variability occurs within fields. Chlorophyll meters and the pre-sidedress soil nitrate test (PSNT) are two common tests used to improve estimates of in-season corn N need. Scharf et al. (2006) reported that a chlorophyll meter can be used to determine in-season N rates in five Midwest and two central U.S. states because chlorophyll meter readings correlate with economically optimal N rates. Schmidt et al. (2009) also reported that SPAD meter readings were correlated with EONR (R^2= 0.72) at the V6 growth stage in similar work in the mid-Atlantic U.S. Research conducted in northern Missouri showed that the PSNT can be used to determine an accurate N rate that reduces N inputs, compared to yield based rates, and the PSNT derived rates do not negatively impact profitability (Scharf 2001). Evanylo and Alley (1997) found similar results in the mid-Atlantic and concluded that the PSNT is a valuable tool to assess corn N needs. However, sampling with a chlorophyll meter or the PSNT must be conducted on a spatial pattern and resolution that can be mapped if those data are to be used for VR applications. Practical labor constraints generally dictate that any map based on these data be coarser than what can be developed with an on-the-go sensor system.

Alternatively, an active sensor system, such as the GreenSeeker® (Trimble Navigation Limited, Sunnyvale, CA), OptRx® (Ag Leader Technology, Ames, IA) and the Crop Circle ACS-430® (Holland Scientific Inc., Lincoln, NE), are designed to actively sense crop N status and make a VR N application in one pass. Active sensor systems emit and measure light and are not limited by constraints (cloud cover, high humidity, and atmospheric pollution) that accompany passive systems such as aerial imagery (Inman et al. 2007). The GreenSeeker® uses light emitting diodes that direct near infrared (NIR) (780 ± 10 nm) and red (670 ± 10 nm) light onto the crop canopy and measures, using silicon diodes, the amount of light that is reflected back (Solari et al. 2008; Harrell et al. 2011). Reflected light is used to determine normalized difference vegetation index (NDVI); which can be used to estimate physiological changes in plants and gather information to estimate crop yield potential (Peñuelas et al. 1994; Raun et al. 2001; Thomason et al. 2007). Reflectance data collected from reference strips (used to estimate N response of a field) can be used as an input for calibrated algorithms used to generate in-season N rates or N prescriptions. Raun et al. (2005) found that using active sensors increased NUE by as much as 15% in wheat (*Triticum aestivum* L.) in the central U.S. when compared to fixed in rates. Thomason et al. (2011) concluded that the use of canopy reflectance in the mid-Atlantic for calculating N topdress rates in wheat produced prescriptions that were comparable to the EONR. Tubana et al. (2008) reported better NUE, up to 9%, when using algorithms to prescribe N rates compared to fixed N rates for corn in Oklahoma.

Influence of sensing background on NDVI is dependent on numerous factors. Soil color is thought to be a factor that varies tremendously throughout the U.S. as soil color is determined by the particular soil series and is influenced by climate, organic matter, and parent material. In the mid-Atlantic, soil types and consequently color is known to fluctuate multiple times within some fields (Khosla and Alley 1999). The presence of crop residue and the type of crop residue present can vary tremendously within a given region. The practice of no-till farming in the mid-Atlantic has been employed for more than 40 years (Jones et al. 1968). In 2007, 77.3% of corn hectares planted in Virginia were planted using conservation tillage, an increase of 19.5% from 1989 (Reiter 2009). By 2007, only 13.7% of corn hectares were planted using conventional tillage systems in Virginia (Reiter 2009). The type of residue present on the soil depends on the crop rotation of that particular field.

Soil moisture is also known to influence NDVI readings. When analyzing the effects of soil moisture on various soil types, Huete et al. (1985) concluded that the addition of water to a soil surface increased NDVI when compared to dry soils readings. Soil color, residue type, residue coverage, and soil moisture are unique to a given field and together these factors comprise the sensing background.

Hutchinson (1982) reported that vegetative information, such as vegetative indices, are difficult to determine through remote sensed data when canopy cover is less than 30%, due to background influence, and these findings have been supported by Huete et al. (1985) and Martin et al. (2012). The components of the sensing background have various reflectance signatures; thus, different backgrounds could influence NDVI readings in different ways. To date, research has primarily focused on creating and improving the accuracy of vegetative indices (Gilabert et al. 2002; Huete 1988; Liu and Huete 1995) because previous research stated NDVI is not representative of the plant until percent vegetative cover reaches 70% or beyond (Huete et al. 1985). While some researchers have proposed concepts to reduce background effects on NDVI, (Liu and Huete 1995; Martin et al. 2012; Qi et al. 1994; Huete 1988), few reports exist that document the impact of sensing background on NDVI at early corn growth stages.

The objective of this experiment was to measure the influence of soil color, soil moisture, surface crop residues, and sensor orientation on NDVI readings from soils prior to planting and corn from planting through the V6 growth stage. We hypothesize that more knowledge of sensing background and plant size can improve early season predictions of corn N fertilizer need by the GreenSeeker® system.

Materials and Methods

Cultural practices

A single experiment was conducted in Blacksburg, VA during June and July of 2012. Eight wooden planting boxes 102 cm wide, 102 cm long, and 14 cm deep were constructed and filled with one of four soil types (0-15 cm profile) commonly found in Virginia (Table 2.1). Soils were air-dried and passed through a 2.5 cm sieve prior to filling the boxes. All soils were amended with calcium hydroxide, phosphorus (diammonium phosphate) and potassium (potassium chloride) to achieve a 6.5 soil pH and optimal nutrient levels outlined by the Soil Test Recommendations for Virginia (Maguire and Heckendorn 2011).

The corn hybrid Pioneer Brand P1184HR was planted in two rows per box on 64 cm wide row spacings at a population equivalent to 71,600 seeds ha^{-1}. After planting, drip irrigation was installed and over the course of the experiment the plants received approximately 17 cm of water from irrigation and rainfall. After emergence, pelletized gypsum (224 kg ha^{-1}) and foliar fertilizer containing N, boron, copper, manganese and zinc (1.12, 0.28, 1.12, 0.84 and 0.84 kg ha^{-1}, respectively) were hand-applied to prevent nutrient deficiencies.

Data collection

Spectral reflectance readings were collected using the GreenSeeker® sensor from a position of approximately 1 m above the target, either bare soil or plant canopy, depending on the sensing timing. Reflectance readings were collected from one of four sensor orientations and NDVI was calculated. In the case of bare soil readings, the NDVI was still calculated, even though there was no actual plant vegetation in the sensor field of view. At the first orientation, nadir, the sensor head was positioned approximately 1 m above the plant canopy and the light band, which is 60 cm wide, was perpendicular to the crop row. The nadir orientation is the orientation recommended by the GreenSeeeker® sensor developer NTech Industries Inc. (2008) and its success was reinforced by Solari (2006). The parallel orientation was identical to the nadir orientation except the 60 cm light band was oriented parallel to the corn row. The parallel orientation has been recommended for sensing crops with low biomass (i.e. early season corn) (Martin et al. 2012). The 15 cm mask orientation was employed in the same manner as the nadir orientation in which the light band was perpendicular to the row, but instead of a 60 cm light band the emitted light was restricted to only 15 cm in width. The 45° off nadir orientation was laterally offset from the row by approximately 70 cm; the sensor was set approximately 70 cm above the corn canopy and the sensor was directed at the target at a 45° angle; the light band width was 60 cm and oriented perpendicular with the corn row. The four different sensor orientations (Fig. 1 & 2) were used to sense bare soil prior to planting and corn from the V2 through V6 growth stages.

Soil moisture

Prior to plant emergence, each soil color was sensed bare at all four orientations to determine dry NDVI for each soil color. Soil colors will be referred to by their unique soil series name (USDA-NRCS 2013). Immediately thereafter, 15 L of water were applied using a flat fan nozzle to the soils to create a moist soil surface. Each wet soil was similarly sensed at all four orientations to determine a moist NDVI. Moist and dry NDVI readings collected at all four orientations were compared among soils and between moist and dry soil surfaces for each soil.

Crop residue

Residue treatments included: soybean (*Glycine max* L.), corn, wheat, and blank (no residue, which mimicked conventional tillage). Residues used were collected from local fields where that specific crop was grown the previous year. Residues were air-dried in a greenhouse to prevent further decay, to facilitate storage during the experiment, and prevent soil cross contamination. Once residues were dry they were placed into mesh bags to facilitate installation and removal during the experiment. Residue was added to the bags until 70% soil cover was achieved as determined by the line and transects method (USDA-NRCS 2011). Spectral reflectance readings were taken from residue alone and residue contained within the mesh bags; the addition of the mesh did not influence the NDVI of the residues.

After corn emergence, NDVI readings were taken at each growth stage from V2 through V6, determined by methodology of Abendroth et al. (2011) and from each soil color at four sensor orientations (Fig. 2.2). Soil moisture at these timings was moist, but not saturated. Previous crop residue bags were placed onto each soil and additional residue was added on top of the bags and between plants to generate 70% residue cover over the entire box, determined using the line and transects method at numerous locations within each box. Soil residue cover of 70% or more is common in the mid-Atlantic where no-till farming practices have been established (Reiter 2009). Once the residue was in place, NDVI readings were collected at every orientation, then residue was removed and replaced with a different residue treatment.

Statistical analyses

Soil moisture, crop residue type, soil color, and sensor orientation effects on NDVI values were analyzed by analysis of variance (ANOVA) using the GLM procedure available in SAS (SAS Institute 2008). Mean comparisons using a protected least significant difference (LSD) test were made to separate effects of soil color, soil moisture, residue, and sensor orientation where F-tests indicated that significant differences existed ($P<0.05$).

Results and discussion

Soil color

Normalized difference vegetation index from the four sensor orientations was collected from each dry, bare soil at the beginning of the experiment to determine influence of soil color on NDVI (Table 2.2). There was a significant interaction between soil color and sensor orientation ($P<.0001$). Spectral reflectance readings were lower for the Davidson soil compared to the other soil types at each sensor orientation (Table 2.2). The Bojac resulted in NDVI values that were generally higher, or as high, as the other soils sensed across all orientations (Table 2.2).

At every orientation examined, it is apparent that NDVI values varied between soil colors. Spectral reflectance data collected at the 15 cm mask orientation resulted in a 0.16 unit difference between the highest and lowest NDVI values; a difference of this magnitude could affect N prescriptions. Solie et al. (2012) reported the relationship of NDVI and predicted wheat and corn grain yield in Oklahoma and showed a variation of 0.25 units could result in a difference of 1 Mg in grain yield ha^{-1}. A difference of 0.16 units could lead to over or under estimation of grain yield by approximately 500 kg ha^{-1}.

Soil Moisture

There was a significant interaction between soil color, moisture regime and sensor orientation ($P<.0001$) so the effects of soil moisture and sensor orientation are reported by each soil type. Spectral reflectance readings collected using the 45^{o} off nadir orientation resulted in higher NDVI values for moist Bojac, Hayter and Pamunkey soils; there was no difference between moist and dry readings for the Davidson soil (Fig. 2.3). Values for NDVI were similarly higher for wet Davidson, Hayter and Pamunkey soils when readings were collected using the 15 cm mask (Fig. 2.3). Data collected at the parallel orientation resulted in differences between wet and dry soil treatments on every soil sensed (Fig. 2.3). Lastly, the nadir orientation had higher NDVI values between moisture levels on the moist Bojac, Hayter and Pamunkey soils (Fig. 2.3). Results for the nadir and parallel measurements were very similar over soils. The nadir and parallel orientations (Fig. 2.1) are virtually identical in the absence of plants, which explains the similar NDVI values between the two orientations. In all cases where a difference was detected between moisture treatments, dry soil had a lower NDVI than moist soil. Adding water darkened each soil and led to higher NDVI values. This follows results found by Huete et al. (1985), who reported that darker soil backgrounds produced overall higher NDVI values measured from cotton (*Gossypium hirsutum* L.). Higher NDVI on moist soils could restrict sensor use in field environments where moisture levels vary as sensing a moist soil could potentially lead to higher NDVI values that do not represent the plant canopy.

Crop residue

An interaction of soil color, sensor orientation and residue type with crop growth stage occurred, indicating that residue type and soil color influenced NDVI readings differently at different corn growth stages. Because of these interactions, data are analyzed and presented by growth stage.

At V2 the ANOVA revealed a significant interaction between soil color and sensor orientation; NDVI collected from the Davidson soil at the parallel orientation was significantly lower (0.12 units) than the Bojac soil which was significantly higher than the other soils (Table 2.3). Data collected using the 15 cm mask on the Hayter soil revealed a significantly higher NDVI than either the Davidson or Pamunkey soils (Table 2.3). At the V2 growth stage there was also a significant interaction between residue cover and soil color so data are presented by soil (Table 2.4). There were significant differences in NDVI among residue types for each soil sensed; however these trends for different residues were not consistent over soils. Wheat residue resulted in significantly higher NDVI than the no residue treatment on the Davidson soil, the corn and soybean residue placed on the Bojac soil and corn residue placed on the Pamunkey soil (Table 2.4). Corn residue cover generated NDVI values that were lower than the no residue treatment readings on all soils but the Davidson. The overall red appearance of an object, in this case the Davidson soil, is a result of the increased red light reflectance surface (Campbell and

Wynne 2011); the increased red reflectance decreases NDVI consequently leading to lower NDVI values when compared to crop residues with less red reflectance. Soybean residue NDVI was similar to corn across all soils at V2 (Table 2.4). The similarities of corn and soybean residue reflectance lead to minimal variations in NDVI, which permits use of the sensor on a field scale when these two residues are both present in the field. Lastly, NDVI collected from the no residue treatment on the Hayter soil at V2 had significantly higher NDVI (range of 0.057 to 0.093 units) compared to the corn, small grain, or soybean residues among which there were no differences (Table 2.4).

The results indicated that sensing data collected at the parallel orientation resulted in NDVI differences between soils. Martin et al. (2012) hypothesized that when sensing plants with low biomass the parallel orientation should include more plant tissue and less soil background in the sensor viewing area which would make it less sensitive to background influence.

Reflectance readings taken at V3 using the parallel orientation resulted in higher NDVI values than the other orientations for the Bojac soil (Table 2.3). Similarly, NDVI for the 45° off nadir orientation was 0.07 and 0.06 units higher than the Davidson and Hayter, respectively, when sensed from the Bojac soil (Table 2.3). As with the V2 readings, there was also an interaction of residue type and soil color at the V3 growth stage so data are presented by soil and residue type, over sensor orientations (Table 2.4). Values for NDVI measured from the no residue treatment at V3 were similar to the highest NDVI value for all treatments for all soils (Table 2.3). Results indicated as the plant matured one leaf stage, NDVI variation between residue treatments declined when compared to the V2 readings. Wheat residue on the Davidson soil generated a 0.07 units higher NDVI when compared to corn or soybean residue (Table 2.4).

Again at V3, corn and soybean residue NDVI values were similar regardless of the soil color sensed (Table 2.4). As with the V2 growth stage, consistent differences were found when data were collected at the parallel orientation indicating the parallel orientation was greatly influenced by the sensing background.

This phenomenon was not expected because this orientation was thought to reduce the amount of soil in the viewing window and the hypothesis was supported by Martin et al. (2012) who found less background interference when sensing at the parallel orientation. The differing results between this work and that of Martin et al. (2012) are likely due to the differences in experimental methods. In this experiment the sensing background was exposed between plants while sensing the low biomass corn plants and therefore sensing background was still a factor in NDVI readings. Martin et al. (2012) concluded that the parallel orientation was a valuable tool to reduce sensing background influence when sensing ryegrass (*Lolium perenne*). Ryegrass provides more vegetative ground cover compared to corn and there is less soil background reflectance with ryegrass.

At the V4 and V5 growth stages, there were significant interactions between soil color, residue type and sensor orientation so data were analyzed and presented by soil and sensor orientation (Table 2.5). At the V4 growth stage, NDVI measured using the 45^{o} off nadir orientation from the no residue treatment on the Bojac soil was lower, a range of 0.12 to 0.17 units, than that measured from any of the crop residues (Table 2.5). Normalized difference vegetation index collected using the 15 cm mask orientation was higher when collected from corn residue on the Hayter soil (Table 2.5). This finding was not typical for corn residue among soils and sensor orientations and may be an artifact of the relatively low NDVI values at this growth stage using the 15 cm mask. Nadir orientation NDVI was lower (0.16 and 0.2 units for no residue and soybeans, respectively) for wheat residue on the Pamunkey soil compared to no residue and soybean treatment (Table 2.5).

Overall, impacts of residue type on NDVI readings at V4 were rarely significant and differences were generally minute and inconsistent when present (Table 2.5), but the differences between the no residue and residue treatments could be important for predicting crop N needs. In this experiment residue levels were kept constant at 70% cover. It would be a rarity when residue cover levels would fluctuate between 70% and 0% across a given field, but if this did occur, N rates prescribed could fluctuate between the residue cover levels. As seen with NDVI collected at the nadir orientation from the Pamunkey soil series the wheat residue resulted in 0.20 units lower NDVI than the no residue treatment. Again, examining a model of NDVI with predicted yield, a difference of 0.20 units is a difference of approximately 800 kg grain ha^{-1} (Solie et al. 2012).

At V5, significant differences in NDVI due to residue cover were similarly inconsistent (Table 2.5). No residue NDVI was higher than corn and soybean residue on the Davidson soil when sensed using the parallel orientation and higher than soybean and wheat residue on the Pamunkey soil when sensed using the 15 cm mask (Table 2.5). The NDVI from the no residue treatment was lower than any residue cover for the nadir orientation measurement from the Bojac and Hayter soils (Table 2.5). No residue NDVI was also lower than NDVI measured from corn or soybean residue sensed using the 45° off nadir orientation on the Hayter soil, and lower than all residues when sensed from the Pamunkey (Table 2.5). The mean NDVI value at V5 among orientations was over 0.58 for all orientations except the 15 cm mask which had a mean NDVI of 0.45 (Table 2.5). At V5 there were no trends observed with the data, but differences were found indicating that various sensing backgrounds influence NDVI readings.

Similar to what was observed at V2 and V3, an interaction between soil color and sensor orientation was indicated by analysis of variance at the V6 growth stage (Table 2.3). At the 45^o off nadir orientation the Pamunkey and Davidson soils generated higher NDVI than the Bojac or Hayter soils (Table 2.3). Bojac soil NDVI collected at the nadir orientation was 0.09 to 0.15 units lower than the other soil types at V6. Similar to NDVI measurements at other growth stages, NDVI was lower when using the 15 cm mask than the other sensor orientations, but other treatment factors were not consistent. At the V6 growth stage, the ANOVA also showed significance with regard to residue type; there were no interactions of residue type and soil color or orientations so data are presented over soils and orientations (Table 2.6). The no residue treatment NDVI was significantly lower than any crop residue between soils at this stage (Table 2.6).

It is relevant that there were no differences in NDVI among any of the crop residue backgrounds at this time (V6), which is similar to results from V4 and V5 stages. Minimal variation between crop residues at this growth stage would indicate that differences observed at the V6 growth stage would be representative of the crop and not the sensing background when collected on a single soil type. Throughout this experiment even when sensing background influenced NDVI readings, NDVI values were similar to those reported by Thomason et al. (2007) working with corn planted into either previous corn or soybean residue. Similar results indicate that the backgrounds examined in this study did not influence NDVI readings to the point where a sensor should not be used as a N management tool.

Conclusions

Sensor orientation did influence NDVI values with respect to soil moisture and crop residue. Wetting soils resulted in an overall darker appearance and higher NDVI for all soils when compared to the dry soil readings. The different crop residues used in this experiment lead to variations in NDVI at the V2 and V3 growth stage, but differences were minimal at V4 and beyond. The different NDVI values generated from different moisture levels, soil colors and residue types can drastically influence N rate prescriptions if sensing background is not consistent. There is no evidence to conclude any of the orientations examined reduced the influence of soil moisture, crop residue or varying soil color, therefore the sensor orientation nadir, currently the industry standard, should remain the standard GreenSeeker® orientation in the field. This experiment supports the idea that reference strips used for N algorithms should be representative of the field being sensed with regards to soil types and moisture conditions whenever possible. Furthermore it may necessary to establish multiple reference strips in a field with multiple soil types and little or no residue cover as this would be expected to consider background influence on NDVI and improve N rate recommendations. Findings also infer that after the V3 growth stage the presence of a crop residue, compared to no residue, reduces NDVI variation within a soil type.

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Table 2.1 Description of series used for reflectance measurements

Series	Taxonomic Class	Typical Pedon	Dry Soil Color[a]	Wet Soil Color[b]
Bojac	Coarse-loamy, mixed, semiactive, thermic Typic Hapludults	Loamy fine sand	7.5 yr 5/4	5 yr 4/4
Davidson	Fine, kaolinitic, thermic Rhodic Kandiudults	Loam	10 R 4/4	10 R 2.5/4
Hayter	Fine-loamy, mixed, active, mesic Ultic Hapludalfs	Loam	5 yr 5/4	5 yr 2.5/1
Pamunkey	Fine-loamy, mixed, semiactive, thermic Ultic Hapludalfs	Fine sandy loam	7.5 yr 5/3	5 yr 3/3

[a] Dry soil colors determined using Munsell Soil Color Charts (Munsell 2000)

[b] Wet soil colors determined using Munsell Soil Color Charts (Munsell 2000)

Soil Taxonomic Class and Typical Pedon information retrieved from (USDA-NRCS 2013)

Table 2.2 Sensor orientation and soil color effects on NDVI readings from bare soil prior to planting.

Soil Series	Sensor orientation											
	45^o Off Nadir			15 cm Mask			Parallel			Nadir		
	---NDVI---											
Davidson	0.213	c[a]	A[b]	0.117	d	B	0.204	c	A	0.202	b	A
Bojac	0.263	a	A	0.279	a	A	0.246	a	A	0.254	a	A
Hayter	0.262	a	A	0.221	b	B	0.251	a	A	0.248	a	A
Pamunkey	0.244	b	A	0.188	c	B	0.229	b	A	0.236	a	A

[a] Lower case letter denotes significant difference ($P \leq 0.05$) determined by protected LSD test between soil types within sensor orientation

[b] Upper case letter denotes significant difference ($P \leq 0.05$) determined by protected LSD test between sensor orientations within soil types

Table 2.3 Sensor orientation and soil color effects on NDVI from corn at V2, V3, and V6.

Growth stage/soil series	Sensor orientation											
	45° Off Nadir			15 cm Mask			Parallel			Nadir		
V2	--------------------------------NDVI--------------------------------											
Davidson	0.448	a[a]	A[b]	0.329	b	C	0.374	c	B	0.456	a	A
Bojac	0.478	a	A	0.370	b	B	0.489	a	A	0.485	a	A
Hayter	0.451	a	A	0.410	a	A	0.431	b	A	0.468	a	A
Pamunkey	0.482	a	BA	0.338	b	C	0.433	b	B	0.505	a	A
V3												
Davidson	0.477	b	A	0.343	a	C	0.414	b	B	0.464	a	A
Bojac	0.548	a	A	0.341	a	B	0.530	a	A	0.555	a	A
Hayter	0.489	b	A	0.394	a	B	0.444	b	A	0.486	a	A
Pamunkey	0.511	ba	A	0.374	a	C	0.458	b	B	0.531	a	A
V6												
Davidson	0.638	a	B	0.466	a	C	0.721	a	A	0.710	a	A
Bojac	0.545	b	B	0.485	a	C	0.644	a	A	0.565	b	B
Hayter	0.569	b	B	0.478	a	C	0.678	a	A	0.653	a	A
Pamunkey	0.667	a	A	0.457	a	B	0.710	a	A	0.657	a	A

[a] Lower case letter denotes significant difference ($P \leq 0.05$) determined by protected LSD test between soil types within sensor orientation and growth stage determined by protected LSD test

[b] Upper case letter denotes significant difference ($P \leq 0.05$) determined by protected LSD test between sensor orientations within soil types

Table 2.4 Soil color and residue coverage influence on NDVI at the V2 and V3 corn growth stages.

Growth stage/residue type	Soil Series											
	Davidson			Bojac			Hayter			Pamunkey		
V2	--------------------------------NDVI--------------------------------											
No Residue	0.363	b[a]	B[b]	0.487	a	A	0.495	a	A	0.465	a	A
Soybean	0.406	ab	A	0.431	b	A	0.402	b	A	0.419	ab	A
Corn	0.402	ab	A	0.394	b	A	0.438	b	A	0.393	b	A
Wheat	0.436	a	B	0.510	a	A	0.425	b	B	0.481	a	A
V3												
No Residue	0.417	ab	C	0.556	a	A	0.492	a	B	0.477	a	CB
Soybean	0.402	b	B	0.495	a	A	0.411	b	B	0.447	a	B
Corn	0.403	b	B	0.427	b	B	0.462	ab	A	0.455	a	A
Wheat	0.476	a	A	0.496	a	A	0.448	ab	A	0.496	a	A

[a] Lower case letter denotes significant difference ($P \leq 0.05$) determined by protected LSD test between crop residue types within soil type and growth stage

[b] Upper case letter denotes significant difference ($P \leq 0.05$) determined by protected LSD test between sensor orientations within soil types

Table 2.5 Sensor orientation, soil series, and residue coverage influence on NDVI at the V4 and V5 growth stages.

Growth stage/soil series/	Sensor orientation											
residue type	45° Off Nadir			15 cm Mask			Parallel			Nadir		
V4												
Davidson	--------------------------------NDVI--------------------------------											
No residue	0.500	a[a]	BA[b]	0.376	a	C	0.456	a	BC	0.582	a	A
Soybean	0.469	a	A	0.389	a	A	0.420	a	A	0.495	a	A
Corn	0.571	a	A	0.411	a	B	0.498	a	A	0.523	a	A
Wheat	0.502	a	A	0.372	a	B	0.472	a	A	0.496	a	A
Bojac												
No residue	0.453	b	B	0.503	a	BA	0.635	a	A	0.598	a	A
Soybean	0.612	a	A	0.432	a	B	0.578	a	A	0.597	a	A
Corn	0.574	a	A	0.455	a	A	0.564	a	A	0.588	a	A
Wheat	0.618	a	A	0.423	a	B	0.598	a	A	0.601	a	A
Hayter												
No residue	0.564	a	A	0.268	b	B	0.599	a	A	0.514	a	A
Soybean	0.538	a	A	0.301	b	C	0.459	a	B	0.578	a	A
Corn	0.456	a	A	0.463	a	A	0.531	a	A	0.486	a	A
Wheat	0.484	a	A	0.349	b	B	0.519	a	A	0.580	a	A
Pamunkey												
No residue	0.654	a	A	0.491	a	B	0.676	a	A	0.696	a	A
Soybean	0.581	a	A	0.415	a	B	0.561	a	A	0.653	a	A
Corn	0.657	a	A	0.477	a	B	0.572	a	BA	0.550	ba	BA
Wheat	0.637	a	A	0.507	a	A	0.546	a	A	0.494	b	A

Table 2.5 Continued

Growth stage/soil series/ residue type	Sensor orientation											
	45^o Off Nadir			15 cm Mask			Parallel			Nadir		
V5												
Davidson	--NDVI------------------------------------											
No residue	0.628	a[a]	A[b]	0.450	a	B	0.667	a	A	0.659	a	A
Soybean	0.565	a	BA	0.409	a	C	0.478	b	BC	0.626	a	A
Corn	0.602	a	A	0.422	a	B	0.539	b	A	0.607	a	A
Wheat	0.551	a	A	0.508	a	A	0.571	ba	A	0.630	a	A
Bojac												
No residue	0.442	a	A	0.519	a	A	0.648	a	A	0.496	c	A
Soybean	0.539	a	A	0.474	a	A	0.583	a	A	0.669	ba	A
Corn	0.528	a	A	0.496	a	A	0.619	a	A	0.654	b	A
Wheat	0.682	a	BA	0.561	a	B	0.569	a	B	0.761	a	A
Hayter												
No residue	0.549	b	B	0.498	a	B	0.675	a	A	0.374	b	C
Soybean	0.645	a	A	0.374	a	B	0.583	a	A	0.674	a	A
Corn	0.696	a	A	0.412	a	C	0.543	a	B	0.687	a	A
Wheat	0.611	ba	A	0.438	a	B	0.639	a	A	0.656	a	A
Pamunkey												
No residue	0.498	b	A	0.479	a	A	0.496	a	A	0.623	a	A
Soybean	0.581	a	BA	0.408	bc	C	0.549	a	B	0.636	a	A
Corn	0.610	a	A	0.444	ba	B	0.595	a	A	0.639	a	A
Wheat	0.590	a	A	0.370	c	B	0.640	a	A	0.600	a	A

[a] Lower case letter denotes significant difference ($P \leq 0.05$) determined by protected LSD test between crop residue types by sensor orientation within soil type and growth stage

[b] Upper case letter denotes significant difference ($P \leq 0.05$) determined by protected LSD test between sensor orientations by residue types within soil type and growth stage

Table 2.6 Residue coverage influence on NDVI over soils and orientations at V6

Growth stage/residue type/treatment	NDVI	
V6		
Residue Type		
No Residue	0.548	b[a]
Soybean	0.602	a
Corn	0.627	a
Wheat	0.634	a

[a] Lower case letter denotes significant difference ($P \leq 0.05$) determined by protected LSD test between crop residue types within growth stage

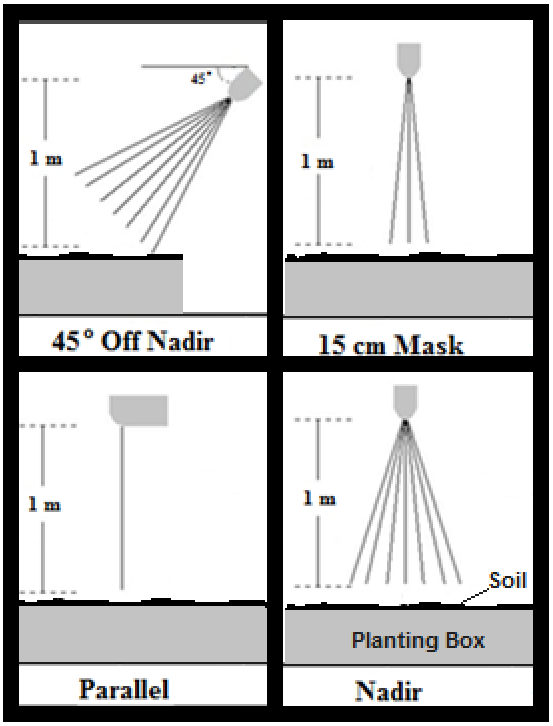

Fig. 2.1 Diagram of the four sensor orientations (45^{o} off nadir, 15 cm mask, parallel and nadir) to soil surface (not drawn to scale) to analyze the influence of soil moisture and soil color on NDVI

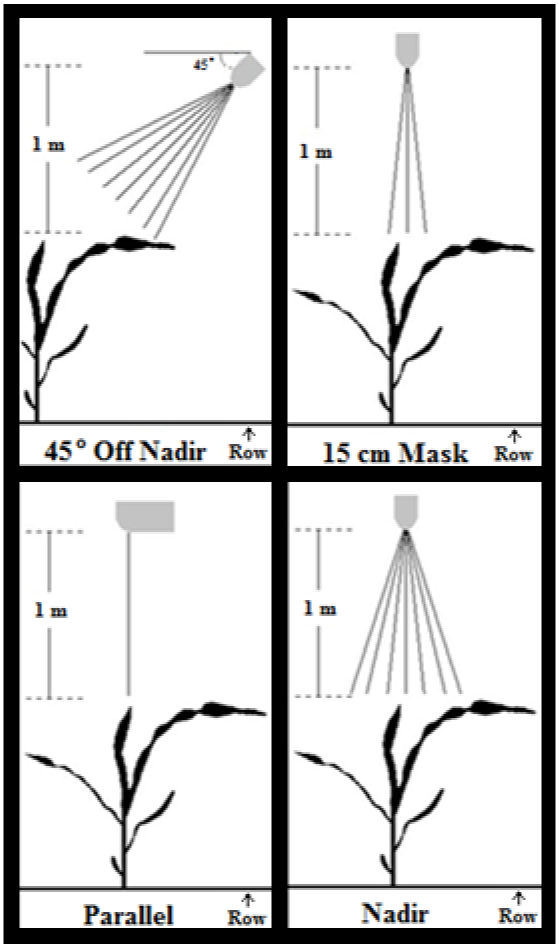

Fig. 2.2 Diagram of the four sensor orientations (45^{o} off nadir, 15 cm mask, parallel and nadir) to corn plants (not drawn to scale) to analyze the influence of crop residue type and soil type on NDVI

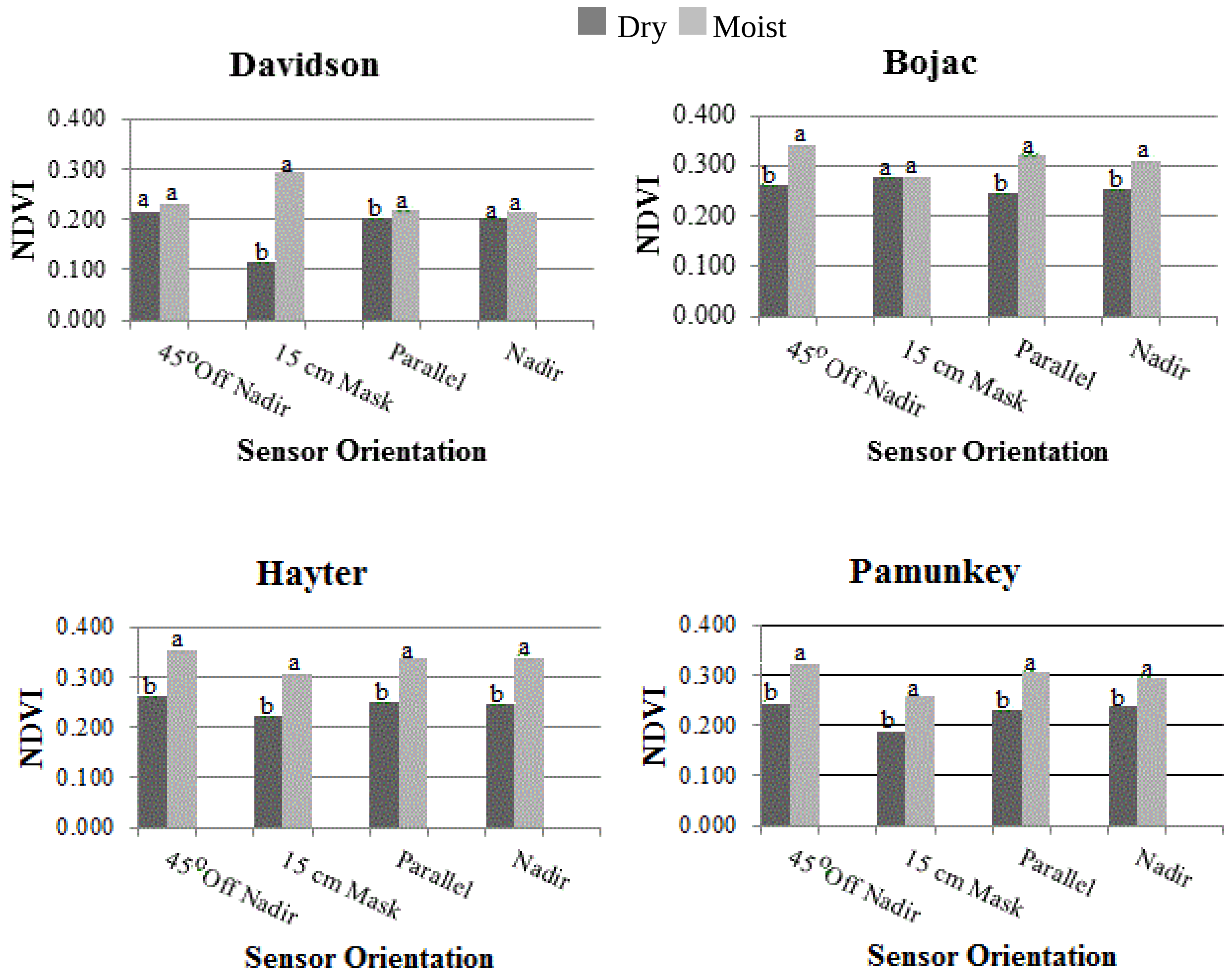

Fig. 2.3 NDVI means of two soil moisture levels by sensor orientation and soil color. Means followed by the same letter within each sensor orientation and each soil type are not significantly different at $P \leq 0.05$ according to LSD test

Chapter III - Improved Detection of Early Season N Need with Alternate Sensor Orientation

ABSTRACT

Using remote sensing to estimate optimum in-season nitrogen (N) application rates has been unsuccessful in corn during early season growth. Expanding the effective window for using this technology earlier in the season could increase adoption. The objective of this study was to evaluate the effects of GreenSeeker® field of view and orientation on normalized difference vegetation index (NDVI) measured from high and low N treatments from corn at V2 to V5 growth stages. Five field experiments were conducted in Virginia during 2011 and 2012. Ten N treatments, including high and low pre-plant N reference plots, were applied in a randomized complete block and replicated four times at each site. From the high and low reference plots, NDVI was collected from five sensor orientations using the GreenSeeker®. The ability of the sensor to distinguish between N treatments was compared against traditional methods used to determine plant N status. Early season nitrogen rate effects on tissue N were observed at four of five sites. When significant differences in N concentration existed between treatments, the SPAD meter and NDVI were able to detect the differences, however, SPAD readings did not detect N treatment differences as accurately as the GreenSeeker®. Altering sensor orientations and field of view did not improve detection of N concentration differences. Though differences in NDVI between the high and low N references were detectable, N rate prescriptions were consistently below the measured optimum N rates from the N rate plots.

INTRODUCTION

Corn (*Zea Mays* L.) has been an important food source for humans for thousands of years (Mangelsdorf et al., 1964) and with the world population surpassing 7 billion people (U.S. Department of Commerce, Bureau of Census, 2012), the demand for corn is at an all-time high. Soil fertility and plant nutrition research is a targeted focus to increase grain yield to meet the growing population. Nitrogen is the most common limiting nutrient in corn and corn has the highest N requirement of all cereal grain crops (Ma and Dwyer, 1998; Ma et al., 2003). Nitrogen is a component of chlorophyll molecules (Havlin et al., 2005), and the greater the quantity of N present in a plant the more chlorophyll molecules produced (Evans, 1989). Increasing N concentration in plants while decreasing N inputs or increasing N use efficiency (NUE) is a common goal in fertility research and is essential to operating sustainability (Moll et al., 1982; Raun and Johnson, 1999; Semenov et al., 2007). Nitrogen use efficiency was defined by Cassman et al. (2002) as the proportion of applied N that is recovered in the harvested crop, recycled through crop residues and incorporated into the ecosystem after harvest, specifically soil organic matter.

Traditionally, and somewhat still in practice today, producers have used a yield based approach to calculate N rates. Using this approach, the N rate is based on yield potential for a specific field or farm which is determined from a five year yield history (Dahnke et al., 1988; Johnson, 1991). Alternately, producers in Virginia can look to the Virginia Nutrient Management Standards and Criteria (Virginia-DCR, 2005) which provides information about expected crop yields on various soil types; again a yield goal-based, method.

As price of common N fertilizer sources has drastically increased, 30% urea ammonium nitrate solution increased 50% ton^{-1} from 2001 to 2010 (USDA-ERS, 2012), producers in the mid-Atlantic have adopted split N applications to increase yields while reducing or maintaining N inputs. A split N application is a process where N is applied multiple times throughout the growing season when the crop is actively taking up the nutrient which increases NUE (Russelle et al., 1983). According to Fox et al., 1986 NUE was increased with the application of a starter fertilizer and in-season applications when applied to corn growing in a silt loam soil and (Jung et al., 1972) concluded similar results on a loamy sand soil when in-season applications were made during early to mid-season vegetative growth.

In recent years, producers have become more financially and environmentally conscious when determining in-season N rates and methods that are not tied to yield goals have been proposed. Camberato (2012) examined nearly 150 N rate response trials in the mid-west and concluded that N rates do not correlate with grain yield, but do correlate with the economic optimal N rate (EONR). The EONR is defined as the point where an increment of N returns enough grain yield to cover the cost of the nutrient (Sawyer et al. 2006). Mamo et al. (2003) studied spatial and temporal variation in corn yield on silt loam soils in Minnesota and reported that EONR varies by location and year so annual diagnostic tests to determine N rates based on economic returns are expected to be most valuable. The use of remote sensing has also become an integral tool used to calculate in-season N rates for some producers in the U.S. Remote sensing, specifically aerial imagery, has been used in agriculture since the 1950’s (Campbell and Wynne, 2011). Sripada et al. (2005) took aerial imagery one step further by using the technology to successfully predict the EONR for corn in numerous fields containing multiple soil types in North Carolina. Aerial imagery is a “passive” sensing approach which depends on natural sunlight as the energy source. To combat the atmospheric limitations that accompany passive sensors, "active" ground based sensors that are not susceptible to atmospheric conditions have been developed and deployed (Inman et al., 2007).

The Crop Circle ACS-430® (Holland Scientific Inc., Lincoln, NE) is an active sensor that emits light in 670 nm, 730 nm and 780 nm wavelengths and measures the amount of light that is reflected from the plant canopy (Holland Scientific Inc., 2011). Barker and Sawyer (2010) stated that the sensor was a good indicator of N stress for corn grown in Iowa, and could be used to calculate in-season N rates when the plants had reached the V10 to V12 growth stage. The Crop Circle® sensor was a precursor to the OptRx® (Ag Leader Technology, Ames, IA) sensor system and works in the same manner as the Crop Circle® in which it emits light in the red and near infrared (NIR) portion of the electromagnetic spectrum (Ag Leader Technology, 2011b; Holland Scientific Inc., 2011). The OptRx® sensor has been successfully used to generate sidedress N rate recommendations that lead to profitability. An experiment conducted on nine corn fields in Missouri resulted in increased profitability when the sensor was employed on eight of the fields when compared to fixed N rates (Ag Leader Technology, 2011a). Another active sensor that is currently available is the GreenSeeker RT200® (Trimble Navigation Limited, Sunnyvale, CA). The GreenSeeker® emits NIR (780±10 nm) and red light (670±10 nm) onto the plant canopy and the reflected light is measured using silicon diodes (Harrell et al., 2011; Solari et al., 2008). The GreenSeeker®, as with the other sensors, has been shown to be a successful N management tool. Scharf et al. (2011) conducted 55 field experiments in Missouri corn fields and the sensor decreased N inputs by 25% when compared to producer-chosen rates, but maintained profitability. The OptRx®, Crop Circle® and GreenSeeker® systems calculate "real time" N prescriptions that use the output of the sensors along with field specific inputs to derive N rates (Ag Leader Technology, 2011b; Holland Scientific Inc., 2011; NTech Industries

Inc., 2008b). Research in the past decade lead to the development of numerous algorithms for the GreenSeeker® sensor to work in numerous environments for multiple crops and these algorithms have proven to increase NUE (NTech Industries Inc., 2008b; Raun et al., 2005; Tubaña et al., 2008). These algorithms use “reference strips” to calculate the N response of the given site that is to be fertilized. Real time N prescriptions and applications can eliminate labor and time intensive in-season diagnostic tests, such as the pre-sidedress soil nitrate test or soil grid sampling, that often accompany split N applications.

Thomason et al. (2007) reported that the GreenSeeker® has the ability to accurately measure the greenness of a corn plant as early as the V5 growth stage, and that these measures of greenness can be translated to grain yield potential and further to N rates. Binder et al. (2000) concluded that in cases where N deficiencies were present at the V6 growth stage and left uncorrected on a silty clay loam soil, the early season N deficiencies lead to overall yield decreases. Research examining the ability of the GreenSeeker® to prescribe EONR in real time prior to the V5 growth stage has been limited. Research to improve the accuracy of N prescriptions generated by the GreenSeeker® at corn growth stages earlier than V5 is necessary to increase the adoption of the sensor in the mid-Atlantic where in-season N applications are common. Furthermore increasing the sampling window to as early as the V3 growth stage has the potential to reduce yield loss associated with early season N deficiencies and facilitates fertilizer application equipment access.

Our hypothesis was that varying the GreenSeeker® field of view, sensor orientation and altering management of N reference strips could improve detection of N needs at early growth stages of corn. The objective of this study was to evaluate the effects of GreenSeeker® field of view and orientation on NDVI readings from corn at the V3 to V5 corn growth stages.

MATERIALS AND METHODS

A total of five field experiments were conducted in Virginia in 2011 and 2012 evaluating 10 treatments of various N rates and timings (Table 3.1) replicated four times in a randomized complete block design. Locations and soil series were: Kentland 2011 – Guernsey and McGary silt loam; Blackstone 2012 – Appling and Durham sandy loam; Holland 2012 – Nansemond fine loamy sand ; Kentland 2012 – Unison and Guernsey loam and silt loam, respectively; and Washington 2012 – Wyrick and Marbie silt loam. The Blackstone 2012 site was conventional tillage and the Washington 2012 was planted no-till into wheat residue. Kentland 2011 and 2012 were planted no-till into corn stubble, and Holland 2012 was planted no-till into cotton stalks. Aside from the N rate treatments, production practices at every site followed recommendations from Virginia Cooperative Extension (Hagood and Herbert, 2011; Thomason et al., 2009). The experimental plots were 4 rows wide, planted on 76.2 cm row centers by 7.62 m in length at four sites; the fifth site had a plot length of 12.3 m. The hybrids used in these studies in 2011 and 2012 were Pioneer Brand 1184HR and Mid-Atlantic 5121GT3, respectively and all studies were seeded at 65,000 seeds ha^{-1}.

Treatment 10 received pre-plant N, phosphorus (P), and potassium (K), and treatment two only N as broadcast urea (Table 3.1). The addition of P and K to the high N rate was in place to provide a balanced fertilizer regime to increase N uptake and overall plant health. A control treatment (treatment 1) received 0 kg N ha^{-1}, all other treatments received 34 kg N ha^{-1} as UAN pre-plant and the designated rate as sidedress at the V6, growth stage (V7 at Blackstone 2012 and Holland 2012) (Table 3.1). For the UAN treatments, fertilizer was applied in a band between rows using a CO_2 backpack sprayer equipped with drop nozzles. In the case of urea, fertilizer was spread uniformly across the entire plot area. Spectral reflectance measurements were collected using the GreenSeeker® active sensor beginning at the V2 growth stage and continued through the V5 growth stage from three treatments; the check or 0 kg ha^{-1} rate, and the two treatments receiving 224 kg N ha^{-1}, one with additional P and K. The treatments will be referred to as the low N, high N and high N, P and K rates (Table 3.1). The low N and high N treatments were used as inputs to the Virginia Corn Algorithm (VCA) (NTech Industries Inc., 2008b) to generate recommended sidedress N rates.

Spectral reflectance readings were gathered at five different orientations (Fig. 3.1 A-F) from the two center rows of each plot. The nadir orientation is currently the orientation recommended by the sensor developer, N Tech Industries, and this recommendation was validated in a field study conducted by Solari (2006). The nadir orientation places the sensor head approximately 1 m above the crop canopy and the 60 cm light band generated by the sensor is oriented perpendicular to the crop row (Fig. 3.1 A).

The influence of soil background reflectance on NDVI readings was hypothesized to be the reason NDVI has not been a useful N management tool on early season or low biomass corn. The remaining orientations were compared against the current standard of nadir to determine if altering the sensor orientation yielded better determination of crop N status during early season growth. The 15 cm mask orientation as seen in figure 3.1 B is oriented like the nadir orientation, but unlike the nadir orientation the full 60 cm light band was restricted to 15 cm. The purpose of restricting the light band was to increase the ratio of vegetation reflectance to sensing background reflectance. The third orientation, parallel (Fig. 3.1 C), was proposed by Martin et al. (2012) for use on crops with low biomass (i.e. early season corn). Like the nadir orientation, the sensor was held approximately 1 m over the crop canopy, but the light band was oriented parallel to the crop row unlike the nadir orientation (Fig. 3.1 C). The parallel orientation was proposed to be useful when sensing plants with low biomass because the light band is constantly sensing vegetation less light is received from the sensing background. The 45^o off nadir orientation was evaluated by Sudduth et al. (2011) who stated that oblique sensor orientations are less affected by sensing background reflectance and are representative of plant chlorophyll status. The 45^o off nadir orientation was laterally offset approximately 70 cm to the crop row and approximately 70 cm above the canopy and light was directed at the plant canopy at a 45^o angle (Fig. 3.1 D). The last orientation used was the inverted orientation. In 2011 while using the inverted orientation the sensor head was placed between crop rows and the 60 cm light band was oriented parallel to the soil surface and emitted to the side of the crop row (Fig. 3.1 E). In 2012 the inverted orientation (Fig. 3.1 F) was rotated 90 degrees from the 2011 inverted orientation (Fig. 3.1 E) and the 60 cm light band was oriented perpendicular to the soil surface (Fig. 3.1 F). The alteration was made because it was hypothesized the rotation of the light band would result in more plant tissue in the sensing window.

In addition to canopy reflectance readings, a SPAD-502 chlorophyll meter (Konica Minolta Sensing Inc., Osaka, Japan) was used to examine the chlorophyll status of the selected plots on the same dates. Five plants were selected from the center two rows of each plot and readings were taken on the youngest leaf that had completely emerged from the whorl and possessed a fully developed collar at approximately half the distance from the leaf collar to the leaf tip and approximately half the distance from the leaf margin to the leaf midrib; following Peterson et al., (1993). The five SPAD readings of each plot were averaged and a mean value calculated for each plot.

On each sampling date, whole plant samples were collected from 60 consecutive cm of row from rows one and four in the low N, high N, and high N, P, K plots. Destructive plant sampling occurred in rows one and four because it would not affect grain harvest from rows two and three. Plant samples were dried in a forced air drier and ground to pass a 0.05 mm screen. The dried and ground tissue was analyzed for total N with dry combustion using a Vario MAX CNS macro elemental analyzer (Elementar, Hanau, Germany). Nitrogen uptake was calculated as the product of dry matter yield and N concentration.

At maturity, grain was harvested from the two center rows of each plot using a Kincaid 8XP plot combine (Kincaid Equipment Manufacturing, Haven, KS) or by hand harvesting 6 m of row from the two center rows of each plot. With machine harvest, total weight, moisture and test weight of each plot was measured by a Graingage^{TM} system (Juniper Systems Inc., Logan, UT). For hand harvest, field weight of the harvested area was recorded and a six ear subsample was collected and weighed. The subsample was dried, reweighed, shelled and moisture and test weight determine using a Dickey-John GAC2000 grain sampler (DICKEY-john Corporation, Auburn, IL). Grain yields are reported on a 155 g kg^{-1} moisture basis.

Analysis of variance was performed using the GLM procedure available in SAS (SAS Institute, 2008). The influence of N treatment on plant N concentration, N uptake, SPAD readings and NDVI measured from different sensor orientations at each growth stage (V2 to V5) was separated using a protected Least Significant Difference (LSD) test when F-tests indicated that significant differences existed ($P<0.05$). Because of significant interactions, data are analyzed and presented by growing year, site location and growth stage.

In addition to examining the ability of the GreenSeeker to detect differences in NDVI between N rates at various growth stages, sidedress rates estimated by the VCA using NDVI from the V5 sensing date were compared to the optimum sidedress N rates determined for each experimental site in 2012. Using the PROC REG procedure in SAS (SAS Institute, 2008), yield data collected from the UAN sidedress treatments was used to fit a linear or quadratic model representing N response for Kentland 2011, Holland 2012, Kentland 2012 and Washington 2012. The highest order model that was significantly significant ($P \leq 0.05$) is presented. When the grain response to N fertilizer was fit using a quadratic model the first derivative was used to determine the EONR for each site using the three year (2010-2012) U.S. average N price of \$1.23 kg N^{-1} (USDA-ERS, 2012) and corn price of \$195.77 Mg^{-1} (USDA-ERS, 2013). For comparison, a standard rate was estimated using the guidelines set forth by Virginia Nutrient Management Standards and Criteria (Virginia-DCR, 2005). Yield estimates were determined based on soil productivity of each site and N recommendations based on prescribing 1 kg N ha^{-1} for every 56 kg of estimated grain yield ha^{-1} and then subtracting the pre-plant fertilizer of 34 kg N ha^{-1}. Normalized difference vegetation index values collected from the high N and the low N reference plots from each replication at each research site were entered into the VCA to calculate potential N response (response index) and average NDVI from the rest of the experimental area (all treated the same to this point) used to estimate the VCA prescribed N rate. The standard N and algorithm derived N rates were compared against the actual EONR by calculating the root square mean error (RSME) of the rates being compared.

RESULTS

V2 Growth Stage

At the V2 growth stage at Holland 2012, tissue N was highest for the high N treatment, followed by the high N, P and K, and then the low N (Table 3.2). There was a difference of 7 g N kg^{-1} detected between the high N and low N reference treatments (Table 3.2). Tissue N data collected at Blackstone 2012 at V2 did not show in significant differences between N treatments.

Average N concentration was 46 g N kg^{-1} for all treatments at Blackstone compared to a maximum of 40 g N kg^{-1} for the high N treatment at Holland 2012. The higher values and lack of differences among treatments at the Blackstone site indicates greater available soil N, at least at the V2 observation.

At the V2 stage at Holland 2012, N uptake was similar between the high N and high N, P and K treatments (1.0 and 0.9 kg N ha^{-1}, respectively). There was significantly less N accumulation in the low N treatment at 0.8 kg N ha^{-1} (Table 3.2). No differences in N uptake between treatments were found at the V2 stage at Blackstone 2012. Nitrogen treatments did not influence NDVI readings collected at V2 at any of the locations.

V3 Growth Stage

At the V3 growth stage there were differences in tissue N concentration between N treatments in three of five instances. In all sites where differences were detected, the low N treatment had a lower N concentration when compared to the other treatments (Table 3.3). Data collected at Kentland 2011 and Holland 2012 revealed that N concentration in the high N treatment was significantly higher than the high N, P and K treatment (13 g N kg^{-1} and 4 g N kg^{-1} higher for each site, respectively), and the high N, P and K treatment was significantly higher (3 g N kg^{-1} and 2 g N kg^{-1} higher between treatments for each site, respectively) than the low N reference (Table 3.3). Nitrogen concentration from Kentland 2012 revealed the high N, P and K treatment contained the highest N concentration between treatments, but the high N treatment was still significantly higher than the low N reference by 5 g N kg^{-1} (Table 3.3).

Nitrogen treatments influenced N uptake at the V3 growth stage at Blackstone 2012, Holland 2012 and Kentland 2012. Nitrogen uptake results were similar for Blackstone 2012 and Holland 2012 where the low N reference had taken up more N than the high N and high N, P and

K treatments (Table 3.3). The high N and high N, P and K treatments at both of these sites took up similar quantities of N, the high N and high N, P and K treatments had taken up 0.2 kg N ha^{-1} less than the low N reference (Table 3.3). The higher N uptake with the low N treatment was unexpected and was likely caused by low quantities of N uptake and high field variability with regard to N. The high N, P and K treatment took up 2.0 kg N ha^{-1} at Kentland 2012 which was significantly higher than the high N treatment; both were higher than the low N treatment (Table 3.3).

At V3 SPAD chlorophyll meter readings differed in response to treatments at every site except Washington 2012. Kentland 2011 and Kentland 2012 SPAD values from the high N, P and K treatment generated significantly higher SPAD values when compared to the other treatments (Table 3.3). SPAD readings collected at Blackstone 2012 revealed that the low N reference treatment yielded higher values than the high N and high N, P and K treatment by 3.8 and 4.1 units, respectively (Table 3.3). At V3 results from Holland 2012 revealed that the high N treatment was significantly higher than the low N and high N, P and K treatment, specifically it was 5.7 units higher than the low N reference (Table 3.3).

At Holland 2012 at V3, the high N, P and K treatment had a significantly higher NDVI than the low N and high N treatments at the nadir and Parallel orientation (Table 3.3). At the nadir orientation the high N, P and K returned a NDVI of 0.237 which was 0.02 and 0.01 units greater than the low N and high N treatments, respectively (Table 3.3). At the parallel orientation the high N, P and K resulted in a NDVI of 0.265 which was 0.22 units higher than the other treatments (Table 3.3). Differences between N treatments occurred at Washington 2012 when readings were taken at all except the inverted orientation. At the nadir, 15 cm mask and 45^{o} off nadir orientation the highest NDVI was collected from the low N reference treatment, the high N and high N, P and K treatments returned similar results and were not significantly different from one another (Table 3.3). Spectral reflectance readings from the parallel orientation from low N treatment were higher than the high N, P and K treatment by 0.04 units (Table 3.3). It should be noted that no differences in tissue N concentration, N uptake or SPAD readings were detected at this site. According to the sensor specifications sheet (NTech Industries Inc. 2008a) NDVI values can fluctuate ±0.04. So the statistical differences detected at the Washington 2012 site might have been generated by sensor error and not by biological differences in plant chlorophyll content.

V4 Growth Stage

Tissue N concentration at V4 revealed differences between N treatments at both the Kentland 2011 and Kentland 2012 site, specifically the low N treatment showed a significantly lower N concentration compared to the other treatments (Table 3.4). At Kentland 2011 the high N and high N, P and K had similar N concentrations that were higher than the low N treatment (Table 3.4). Results from Kentland 2012 revealed the highest concentration of N with the high N, P and K treatment which was 4 g N kg^{-1} greater than the high N treatment (Table 3.4). By the V4 stage, seminal root growth has stopped, nodal roots are increasing in size and root hairs are developing. Plants are dependent more on soil availability of nutrients and so by this time, differences among treatments at multiple sites were expected.

Nitrogen uptake at V4 for Kentland 2012 was similar to what was observed at the V2 growth stage in which the low N reference treatment took up the lowest quantity of N among N treatments (Table 3.4). The low N reference took up 1.2 kg N ha^{-1}, which was 0.7 kg N ha^{-1} less than the high N treatment (Table 3.4). The high N, P and K treatment was significantly higher than the high N treatment which had taken up 2.3 kg N ha^{-1} (Table 3.4). There were no differences in N uptake at the V4 stage at Washington 2012.

Chlorophyll meter readings collected at the V4 growth stage showed significant differences between N treatments at Kentland 2011, Kentland 2012 and Washington 2012. At Kentland 2011 and Kentland 2012 the high N and high N, P and K treatments resulted in SPAD values that were significantly higher than the low N reference (Table 3.4). At Washington 2012 the high N, P and K treatment resulted in higher SPAD values when compared to the low N and high N treatment, specifically the high N, P and K treatment was 3.8 units higher than the low N treatments (Table 3.4).

Spectral reflectance readings were collected at three of five sites at the V4 growth stage. Kentland 2011 had significantly higher NDVI from the high N, P and K treatment verses the low N treatment, a difference of 0.06 units when the parallel orientation was employed (Table 3.4), the high N treatment yielded results that were similar to the low N and high N, P and K treatment. Regardless of sensor orientation, NDVI values were higher for the high N, P and K treatment than the low N treatment at Kentland 2012 (Table 3.4). Normalized difference vegetation index values collected at Washington 2012 at the V4 growth stage were generally higher for the low N treatment compared to others (Table 3.4). This is counter to the expected result but is consistent with other measures at this site and growth stage. As with the V3 growth stage, differences in NDVI were within the range of instrument error and were likely not real biological differences in plant N content.

V5 Growth Stage

Measurements collected from all sites at the V5 growth stage, except at Blackstone 2012, indicated that N treatments influenced tissue N concentration. Nitrogen concentration was also not different among treatments at the Blackstone 2012 site for V4. This site experienced moisture stress during early season growth (Appendix A), and the result may have been reduced plant vigor and nutrient uptake. Tissue N concentration of the low N treatment at Kentland 2011, Holland 2012, and Kentland 2012 was the lowest out of all N treatments (Table 3.5). The high N and high N, P and K reference treatments at Kentland 2011 and Kentland 2012 displayed similar N concentration, 36 g N kg^{-1} and 43 g N kg^{-1} for Kentland 2011 and 2012, respectively, which were significantly higher than the low N treatment (Table 3.5). Nitrogen content determined for Holland 2012 revealed that the highest N concentration occurred in plots receiving the high N treatment; the high N, P and K treatment was 2 g N kg^{-1} lower than the high N treatment (Table 3.5). Lastly the low N reference treatment at Washington 2012 resulted in a lower N concentration when compared to the high N, P and K treatment by 2 g N kg^{-1}, the high N treatment tissue N concentration was similar to the low N and high N, P and K treatments (Table 3.5).

Significant differences in N uptake occurred at three of the five locations at the V5 growth stage. At Blackstone 2012 and Kentland 2012 the high N, P and K treatment had taken up more N than the other N treatments (Table 3.5). The low N and high N treatments were not significantly different at Blackstone 2012 and had taken up 1.6 and 2.5 kg N ha^{-1}, respectively, less than the high N, P and K treatment (Table 3.5). At Kentland 2012 the high N reference had taken up a significantly higher quantity of N compared to the low N reference (1.4 kg N ha^{-1} additional N), but had taken up a significantly lower quantity (1.4 kg N ha^{-1}) compared to the high N, P and K treatment (Table 3.5). Lastly results from Washington 2012 indicated that the low N and high N, P and K treatment had taken up comparable amounts of N and were significantly higher than the high N treatment.

At the last observation date, V5, every site showed significant differences in SPAD values between N treatments except for Washington 2012. Like the V3 and V4 readings, at Kentland 2011 and Kentland 2012 the high N, P and K treatment resulted in the highest SPAD values, the high N treatment followed and was significantly higher than the low N treatment (Table 3.5). The high N, P and K treatment at Kentland 2011 and 2012 were 7.1 and 8.4 units, respectively, higher than the low N reference (Table 3.5). At Blackstone 2012 the high N reference was significantly higher than the high N, P and K treatment by 3.4 units; the low N treatment was significantly lower than the high N, P and K treatment by 3.5 units (Table 3.5). Lastly the Holland 2012 site resulted in the highest SPAD measurements collected from the high N, P and K treatment at 29.8 units (Table 3.5). The low N and high N reference yielded similar results (24.6 and 26.8, respectively) and the treatments were significantly lower than the high N, P and K treatment (Table 3.5).

Spectral reflectance readings collected at various sensor orientations at the V5 growth stage reflect N treatment differences at every location except Blackstone 2012. At Kentland 2011 and Kentland 2012 at the nadir and 15 cm mask orientation the low N treatment resulted in significantly lower NDVI compared to the high N and high N, P and K treatments which returned similar results (Table 3.5). Data collected from Kentland 2011 at the inverted orientation showed that the high N, P and K treatment was significantly higher than the low N and high N treatment which yielded comparable NDVI values (Table 3.5). Readings collected at Holland 2012 resulted in similar NDVI values when collected from the 15 cm mask, parallel and the 45^o off nadir orientation. At these orientations the high N, P and K reference resulted in a significantly higher NDVI compared to the low N and high N treatments, which returned NDVI values that were similar (Table 3.5). Data collected from Kentland 2012 at the parallel orientation resulted in significantly higher NDVI values (0.08 units) collected from the high N, P and K treatment when compared to the low N treatment (Table 3.5). The high N treatment results were similar to the low N and high N, P and K treatment (Table 3.5). Data collected from the 45^{o} off nadir orientation at Kentland 2012 showed lower NDVI values when data were collected from the low N reference when compared to the high N and high N, P and K treatments which were not significantly different (Table 3.5). The nadir and 15 cm mask orientation measurements collected from Washington 2012 resulted in similar results in which the low N reference treatment resulted in higher NDVI values when compared to the high N and high N, P and K treatments (Table 3.5). The parallel orientation indicated the low N treatment had a higher NDVI when compared to the high N treatment (Table 3.5). Furthermore data collected from the parallel orientation at Washington 2012 from the high N, P and K treatment showed that this treatment had similar NDVI values when compared to the low N and the high N treatments (Table 3.5). Unlike the V4 and V5 growth stages, differences in NDVI detected at Washington 2012 at V6 were likely due to true biological differences in N status. The NDVI values collected did not reflect tissue N concentration or N uptake indicating a factor other than nutrient content influenced NDVI values and at this point that factor is unknown.

Addition of Phosphorus and Potassium

The addition of P and K to the high N rate was to ensure a balanced fertilizer regime compared to the high N only reference. The additional nutrients were hypothesized to act synergistically with to enhance N uptake. At the V3 and V4 growth stage at Kentland 2012, N concentration was higher with the high N, P and K treatment compared to the other two treatments. At Kentland 2012 N uptake was significantly higher with the high N, P and K treatment when compared to the other two treatments which lead to the high N tissue concentration. As with Kentland 2012 at the Blackstone 2012 site the high N, P and K treatment had taken up a greater quantity of N compared to the other treatments but this did not translate to higher tissue N concentrations.

Grain Yield

A grain yield response to N fertilizer among the low N, high N and high N, P and K treatments occurred at Kentland 2011 and Kentland 2012 (Fig. 3.2 A-D). At the sites where a grain yield response was detected the low N treatment resulted in lower grain yields when compared to the high N and high N, P and K which yielded similar quantities of grain (Fig 3.2 A-D). As mentioned previously the addition of P and K influenced N uptake and tissue N concentration at Kentland 2012 and Blackstone 2012 but no difference in final grain yield was found at Kentland 2012 and grain was not harvested at Blackstone 2012 due to severe drought.

Analyzing the seven treatments which received a sidedress application of 30% UAN solution showed a positive grain response to N fertilizer at every site (Fig. 3.3 A-D). At Holland 2012 the grain response to N fertilizer was linear indicating the sidedress rates applied did not result in maximum yield (Fig. 3.3 B). This was unexpected and not typical because the sandy soils found at this location typically lead to corn that is limited by water and on an average year the rates applied would have reached maximum yield. Nitrogen rates at the remaining sites were sufficient and resulted in maximum yields and the response was fit using quadratic models (Fig.3.3 A C D).

DISCUSSION

Plant Nutrient Response

Throughout the experiment every site except Washington 2012 showed increased N concentration and N uptake with additional N fertilizer (Tables 3.2 to 3.5). A positive grain yield response was apparent through harvest at Kentland 2012 and Kentland 2011 and the influence of N fertilization on grain yield of the reference plots can be seen in Fig. 3.2. At Holland 2012 during early season data collection it was apparent that the crop responded to additional N (Tables 3.2 to 3.5), but the response was not detected in grain yield differences among treatments.

The addition of P and K increased tissue N concentration at Kentland 2012 at V3 and V4 (Table 3.3 and 3.4). Nitrogen uptake was increased at Kentland 2012 and Blackstone 2012 indicating the crop responded to the additional nutrients, but there was no effect on grain yield (Fig. 3.2).

Early season response to N rate treatments did not always result in differences in grain yield. This is likely due to stress that occurred later in the growing cycle that limited yield response. It might also reflect later season root access of additional soil nutrients. Early season tissue N concentration can be used to estimate the current N status of a crop, but the ability of this measure alone to predict final grain yield response to N is weak. Scharf (2011) reported at V4 toV5, tissue N concentration and optimal N rates had a weak correlation (R^2=0.22) thus did not maximize grain yield, but the correlation increased (R^2= 0.52) when sampled at the V6 growth stage.

It was not uncommon to see treatment differences with small relative differences in N uptake. These results were likely caused by the minimal N uptake throughout data collection.

According to Abendroth et al. (2011), N uptake is minimal until approximately V5, after this point N uptake increases at an increasing rate. The collection of data concluded at the V5 growth stage prior to the major increase in N uptake. Furthermore weather conditions from planting through V5 could have hindered N uptake, specifically low temperature and low rainfall, depending on the site (Appendix A).

Similar to N tissue concentration the addition of P and K to the high N treatment was hypothesized to increase overall plant health thus leading to increased N uptake. The high N, P and K treatment had higher N uptake than the high N treatment at Kentland 2012 and Blackstone 2012 due to increased biomass (Tables 3.2 and 3.3). Potassium is directly involved in the activation of the enzymes that are responsible for N metabolism (Havlin et al. 2005) and the addition of K may have increased N utilization and thus N uptake which resulted in higher tissue N concentration. No response to additional P and K was observed at Holland 2012 and Washington 2012 for tissue N or N uptake.

Remote Sensor Accuracy

SPAD Meter

In response to high N or high N, P and K, SPAD readings were significantly different between readings in 11 out of 13 observations. The addition of P and K to the high N treatment led to significantly higher SPAD values in 50% of observations collected at the V4 and V5 growth stage (Tables 3.4 and 3.5). SPAD meter readings matched closely with tissue N concentration in three of five environments at the V3 growth stage. At the V4 and V5 growth stage the SPAD meter reflected tissue N concentration in one of three and two of five sites, respectively. Our results indicate that the SPAD meter was proficient at distinguishing between N treatments and estimating N status during early vegetative growth, specifically V3-V5. Other researchers, though working at more advanced stages of growth also report on the ability of the SPAD to diagnose corn N status (Bullock and Anderson, 1998).

Normalized Difference Vegetation Index

Throughout this experiment absolute NDVI values collected from V2-V5 were similar to those collected by Thomason et al., (2007) and over locations and growth stages, we observed significant differences in NDVI in nine environments, compared with 10 environments where differences for N concentration were found to exist (Tables 3.2 to 3.5). Of the 10 observations where differences in N concentration were present, NDVI values collected from the nadir orientation mirrored those differences in five environments (Tables 3.2 to 3.5). Readings collected from the nadir orientation indicated there were seven environments with significant differences among treatments, but two of those observations, Washington V3 and V4, did not display differences in N concentration (Tables 3.3 and 3.4). This could have been considered a “false positive” in which the sensor detected treatment differences that were not present, or it could have been the sensor revealed treatment differences that were not detected when analyzing tissue for N concentration. Shaver et al. (2011) conducted a study in a semi-arid climate and concluded that in dry conditions biomass accumulations do not become significantly different until V12 and prior to that point NDVI cannot be used to assess treatment differences accurately. Furthermore research has shown that variations in plant biomass can influence NDVI and in many cases has a stronger impact on NDVI than does N concentration (Shaver et al., 2011; Sudduth et al., 2011; Teal et al., 2006). Differences in biomass accumulation were minimal during data collection and could have limited the number of treatment differences detected with NDVI.

Four other orientations (Fig. 3.1) were examined to compare the discriminating ability of N response to the current standard sensing technique, nadir. The 45° off nadir orientation detected significant differences between N treatments in five out of the 15 observations (Tables 3.2 to 3.5). Of the five observations where differences in NDVI were found, three of the observations also exhibited a significant difference in N concentration (Tables 3.2 to 3.5). The inverted orientation detected differences in NDVI among N treatments in three environments (Tables 3.2 to 3.5). An N concentration difference was present in all three of those observations (Tables 3.2 to 3.5). The 15 cm mask orientation lead to significant differences between N treatments in seven out of 15 observations (Tables 3.2 to 3.5), of the seven observations five were found where a difference in N concentration was present (Tables 3.2 to 3.5) . Lastly the parallel orientation indicated significant differences were present in eight out of 15 sensing environments, of the eight environments six of them contained differences in N concentration. When differences in NDVI were detected and N concentrations were not significantly different between N treatments it is possible biomass influenced NDVI readings, Sudduth et al. (2011) stated this was a common occurance when using the GreenSeeker®. Differences in plant biomass and N uptake may explain why NDVI values did not consistently reflect N concentration values.

It should be noted that the 15 cm mask orientation resulted in generally overall lower NDVI values compared to the other orientations and the inverted orientation resulted in generally higher NDVI values when compared to the other orientations. Because the 15 cm mask and inverted orientation resulted in lower and higher NDVI values, respectively, if these alternative sensor orientations are used instead of nadir placement, these differences should be considered.

The high N, P and K treatment led to a higher N concentration at Kentland 2012 at the V3 and V4 growth stages and at Washington V5 when compared to the low N and high N reference (Tables 3.2 to 3.5). Results indicate the addition of P and K influenced NDVI and SPAD readings and led to higher values when compared to the other treatments.

Nitrogen Rate Prescription Accuracy

Depending on the early season N responsiveness of a site, these data support the conclusion that the GreenSeeker® is capable of distinguishing between high and low N treatments beginning at the V4 stage, but discriminating ability increases as the plant matures. Comparing NDVI measured using the various sensor orientations relationship with other measured parameters evaluated in this research indicated the nadir orientation was the best estimator of tissue N content. Therefore, if the GreenSeeker® is to be used to prescribe N rates on a field scale, the nadir orientation should be implemented.

Grain yield response to sidedress N rate at the four harvested sites is presented in Figure 3.3 a-d. The Blackstone 2012 site was not harvested due to severe drought. At each site, the sidedress rate that would have been prescribed based on soil type (standard) or based on the VCA (GreenSeeker® N Rate) are also presented and compared to the EONR at sidedress. At Holland 2012, maximum yield was not achieved with the N rates applied in this study which resulted in a linear grain yield response to N fertilizer (Fig. 3.3b). The observed grain yields from Holland 2012 were not typical for this location, and because the grain yield N response was linear, EONR was beyond the range of rates evaluated. The recommended standard rate for Holland 2012 was approximately 83 kg N ha^{-1} higher than the VCA sidedress N rate prescription (Fig. 3.3b). The VCA N rate prescribed at this site was well below optimum and would have resulted in estimated yield losses of over 1200 kg ha^{-1} or approximately \$130 ha^{-1}. There were no differences in NDVI values between the low and high N treatments at V5 sensing thus the VCA-based rate was prescribed assuming low potential for N response. There were differences among treatments for N concentration and SPAD readings, that were not reflected in NDVI measured at the same time.

Similar results were found at Kentland 2012 in which the N prescription was considerably lower than the standard recommended N rate (Fig. 3.3c). Specifically the N prescription was approximately 85 kg N ha^{-1} lower than the standard sidedress N recommendation (Fig. 3.4). The EONR for Kentland 2012 was 144 kg N ha^{-1}. The standard N rate was slightly lower than the EONR (9 kg N ha^{-1}) and the GreenSeeker® prescribed N rate was considerably lower (81 kg N ha^{-1}) than the EONR (Fig. 3.3c). Comparing the EONR to the standard N rate revealed a RMSE of 6.36 which was lower than the RMSE of the EONR and N prescription which resulted in a RMSE of 57.28. With regards to grain yield the EONR was estimated to yield approximately 7700 kg grain ha^{-1} which was only 50 kg grain ha^{-1} higher than the yield that would be achieved with the standard rate (Fig. 3.3c). The VCA derived N rate was estimated to yield approximately 6680 kg grain ha^{-1} which is a difference of approximately 1020 kg grain ha^{-1} when compared to the yield of the EONR (Fig. 3.3c) and would result in a loss of approximately \$98 ha^{-1}. At Kentland 2012 applying the standard N rate compared to the EONR would have little impact on grain yield or profitability, applying the N prescription in place of the standard N rate or the EONR would drastically decrease yield and thus decrease profitability. Again, this reflects the limited N response estimated at the V5 sensing.

Grain yield response to N fertilizer at Washington 2012 was estimated using a quadratic model as was Kentland 2012. The calculated EONR at Washington 2012 was 65 kg N ha^{-1} which was 18 kg N ha^{-1} higher than the VCA derived rate, but 80 kg N ha^{-1} lower than the standard N rate (Fig. 3.3). Comparing the standard N rate to EONR resulted in a RMSE of 56.57, which was higher than the RMSE computed from the EONR and GreenSeeker® N rate which was 12.73. Differences between N rates at Washington 2012 did not translate to drastically different yields; the highest yield was estimated to be approximately 6750 kg grain ha^{-1} and occurred with the standard N rate which was only approximately 225 kg grain ha^{-1} greater than the lowest estimated yield from the VCA derived rate.

The VCA consistently underestimated the optimum sidedress N rate in our studies. The low N rates were a result of a low response index (RI) which is calculated by quotient of the high N reference NDVI and the low N reference NDVI. At Holland 2012 and Washington 2012 NDVI differences between the low N and high N reference treatments were on the edge of the sensor detection limits (±0.04 NDVI). At Kentland 2012, the RI was 1.2. The N rate at Kentland 2012 was lower than the EONR when there was a positive RI measured at this time did not accurately reflect grain yield response. The sensitivity of NDVI to detecting N need in corn plants has been addressed previously (Bausch and Duke, 1996; Chang et al., 2003; Shanahan et al., 2001) but most researchers indicate that corn should be at V8 or later growth stages for accurate N need estimates (i.e. Teal et al., 2006). After V5, corn N uptake increases drastically (Abendroth et al., 2011), so if readings were collected at a later growth stage. Increased N uptake could result in more pronounced plant N differences and better prediction of the EONR.

CONCLUSIONS

The addition of P and K to the high N rate reference strip did increase tissue N concentration and N uptake, but only occasionally. Differences in tissue N concentration were detected at the V2 growth stage at some sites and continued throughout the experiment. The

SPAD meter did not replicate results found with tissue N concentration until the V3 growth stage, but matched N concentration closely through the remaining observations. Examining the five sensor orientations revealed that the nadir orientation represented tissue N concentration better than the other orientations. Specifically the nadir orientation detected differences between N treatments that related to tissue N concentration exactly at two sites at the V5 observations.

While NDVI was capable of assessing relative plant N status using the VCA to prescribe N rates proved unreliable. At the majority of experimental sites the VCA derived N rates were substantially lower than the EONR. Based on these data, it appears NDVI measured at V5 or before is an unreliable basis for in-season N rate prescriptions.

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Table 3.1. Pre-plant and in-season N treatments, 2011 and 2012.

	Timing		
Treatment	**Pre-plant**	**In-season†**	**In-season N source**
	------kg ha^{-1}------		
1‡	0	0	--
2¶	224	0	--
3	34	0	--
4	34	45	UAN
5	34	90	UAN
6	34	135	UAN
7	34	179	UAN
8	34	90	Urea
9	34	135	Urea
10§#	224	0	--

† In-season applications were made at V6/V7 depending on location

‡ Treatment 1 is referred to the low N rate

¶ Treatment 2 is referred to the high N rate

§ Treatment 10 is referred to the high N, P and K rate

Also received 112 and 90 kg ha^{-1} of P_2O_5 and K_2O, respectively.

Table 3.2. Plant tissue N concentration, N uptake, SPAD meter readings, and NDVI at various sensor orientations at the V2 growth stage as affected by treatment.

					Sensor orientation				
Location	N treatment	Tissue N concentration	N uptake	SPAD	Nadir	15 cm mask	Parallel	45° off nadir	Inverted
		g N kg^{-1}	--kg ha^{-1}--		NDVI				
Blackstone 2012	Low N	46 a†	1.0 a	na‡	0.358 a	0.294 a	0.333 a	0.355 a	0.470 a
	High N	46 a	1.0 a	na	0.394 a	0.274 a	0.309 a	0.338 a	0.475 a
	High N,P,K	46 a	1.0 a	na	0.373 a	0.300 a	0.320 a	0.352 a	0.473 a
Holland 2012	Low N	33 c	0.8 b	na	0.291 a	0.255 a	0.288 a	0.315 a	0.444 a
	High N	40 a	1.0 a	na	0.295 a	0.248 a	0.280 a	0.301 a	0.426 a
	High N,P,K	38 b	0.9 a	na	0.290 a	0.259 a	0.299 a	0.309 a	0.454 a

† Treatment means within locations followed by the same lower case letter are not significantly different according to LSD (0.05)

‡na - not available

Table 3.3. Plant tissue N concentration, N uptake, SPAD meter readings, and NDVI at various sensor orientations at the V3 growth stage as affected by treatment.

								Sensor orientation									
Location	**N treatment**	**Tissue N concentration**		**N uptake**		**SPAD**		**Nadir**		**15 cm mask**		**Parallel**		**45^{o} off nadir**		**Inverted**	
		--g N kg^{-1}--		--kg ha^{-1}--				--------------------------------NDVI--------------------------------									
Kentland 2011	Low N	30	c†	na‡		35.4	b	0.391	a	0.345	a	0.378	a	0.394	a	0.641	a
	High N	43	a	na		36.4	b	0.414	a	0.355	a	0.406	a	0.442	a	0.617	a
	High N,P,K	40	b	na		39.5	a	0.410	a	0.356	a	0.391	a	0.429	a	0.613	a
Blackstone 2012	Low N	39	a	1.4	a	26.8	a	0.304	a	0.251	a	0.267	a	0.317	a	0.306	a
	High N	39	a	1.2	b	23.0	b	0.295	a	0.269	a	0.259	a	0.304	a	0.323	a
	High N,P,K	39	a	1.2	b	22.7	b	0.303	a	0.241	a	0.279	a	0.314	a	0.329	a
Holland 2012	Low N	32	c	1.1	a	20.2	b	0.221	b	0.177	a	0.243	b	0.257	a	0.413	a
	High N	36	a	0.9	b	25.9	a	0.223	b	0.179	a	0.243	b	0.256	a	0.407	a
	High N,P,K	34	b	0.9	b	22.1	b	0.237	a	0.201	a	0.265	a	0.278	a	0.440	a
Kentland 2012	Low N	47	c	1.0	c	28.8	b	0.363	a	0.291	a	0.385	a	0.400	a	0.529	a
	High N	52	b	1.4	b	30.7	b	0.376	a	0.301	a	0.406	a	0.411	a	0.563	a
	High N,P,K	54	a	2.0	a	34.5	a	0.377	a	0.296	a	0.410	a	0.406	a	0.571	a
Washington 2012	Low N	50	a	0.9	a	33.9	a	0.331	a	0.258	a	0.351	ab	0.345	a	0.383	a
	High N	50	a	0.9	a	33.4	a	0.300	b	0.227	b	0.318	a	0.327	b	0.384	a
	High N,P,K	49	a	0.8	a	33.3	a	0.297	b	0.224	b	0.310	b	0.313	b	0.376	a

† Treatment means within locations followed by the same lower case letter are not significantly different according to LSD (0.05)

‡na - not available

Table 3.4. Plant tissue N concentration, N uptake, SPAD meter readings, and NDVI at various sensor orientations at the V4 growth stage as affected by treatment.

					Sensor orientation				
Location	**N treatment**	**Tissue N concentration**	**N uptake**	**SPAD**	**Nadir**	**15 cm mask**	**Parallel**	**45^{o} off nadir**	**Inverted**
		--g N kg^{-1}--	--kg ha^{-1}--		----------NDVI----------				
Kentland 2011	Low N	30 b†	na‡	36.5 b	0.588 a	0.418 a	0.671 b	0.625 a	0.822 a
	High N	37 a	na	42.0 a	0.631 a	0.459 a	0.704 ba	0.657 a	0.831 a
	High N,P,K	39 a	na	42.4 a	0.641 a	0.485 a	0.732 a	0.605 a	0.796 a
Kentland 2012	Low N	34 c	1.2 c	31.8 b	0.292 a	0.247 b	0.295 c	0.302 c	0.478 b
	High N	36 b	1.9 b	35.4 a	0.319 a	0.286 a	0.326 b	0.326 b	0.508 ba
	High N,P,K	40 a	2.3 a	36.5 a	0.323 b	0.294 a	0.362 a	0.339 a	0.522 a
Washington 2012	Low N	44 a	1.0 a	31.8 b	0.353 a	0.295 a	0.401 a	0.373 a	0.438 a
	High N	45 a	1.1 a	32.1 b	0.304 b	0.251 b	0.375 ba	0.337 b	0.428 a
	High N,P,K	45 a	1.1 a	35.6 a	0.308 b	0.255 b	0.356 b	0.335 b	0.405 a

† Treatment means within locations followed by the same lower case letter are not significantly different according to LSD (0.05)

‡na - not available

Table 3.5. Plant tissue N concentration, N uptake, SPAD meter readings, and NDVI at various sensor orientations at the V5 growth stage as affected by treatment.

					Sensor orientation				
Location	N treatment	Tissue N concentration	N uptake	SPAD	Nadir	15 cm mask	Parallel	45° off nadir	Inverted
		--g N kg^{-1}--	--kg ha^{-1}--		--------------------------------NDVI--------------------------------				
Kentland 2011	Low N	25 b†	na‡	38.9 c	0.499 b	0.306 b	0.636 a	0.613 a	0.630 b
	High N	36 a	na	43.6 b	0.584 a	0.361 a	0.644 a	0.632 a	0.661 b
	High N,P,K	35 a	na	46.0 a	0.602 a	0.360 a	0.639 a	0.573 a	0.739 a
Blackstone 2012	Low N	42 a	6.1 b	27.6 c	0.368 a	0.282 a	0.434 a	0.401 a	0.583 a
	High N	42 a	5.2 b	34.5 a	0.356 a	0.271 a	0.450 a	0.393 a	0.571 a
	High N,P,K	43 a	7.7 a	31.1 b	0.377 a	0.291 a	0.466 a	0.410 a	0.585 a
Holland 2012	Low N	28 c	1.2 a	24.6 b	0.309 a	0.245 b	0.313 b	0.340 b	0.531 a
	High N	32 a	1.0 a	26.8 b	0.280 a	0.225 b	0.285 b	0.312 b	0.482 a
	High N,P,K	30 b	1.4 a	29.8 a	0.391 a	0.322 a	0.378 a	0.402 a	0.557 a
Kentland 2012	Low N	38 b	2.8 c	25.4 c	0.329 b	0.307 b	0.379 b	0.371 b	0.515 b
	High N	43 a	4.2 b	31.8 b	0.377 a	0.349 a	0.443 ba	0.432 a	0.574 a
	High N,P,K	43 a	5.6 a	33.8 a	0.375 a	0.350 a	0.457 a	0.441 a	0.576 a
Washington 2012	Low N	37 b	2.3 a	37.3 a	0.359 a	0.348 a	0.436 a	0.406 a	0.453 a
	High N	39 ba	2.2 b	37.0 a	0.316 b	0.294 b	0.304 b	0.380 a	0.436 a
	High N,P,K	39 a	2.5 a	36.4 a	0.318 b	0.298 b	0.361 ba	0.375 a	0.427 a

† Treatment means within locations followed by the same lower case letter are not significantly different according to LSD (0.05)

‡na - not available

Figure 3.1. GreenSeeker® sensor orientations (nadir, 15 cm mask, parallel, 45^{o} off nadir and inverted) used at every location during 2011 and 2012.

† This inverted orientation was used at the Kentland 2011 site.

‡ This inverted orientation was used at the Blackstone 2012, Holland 2012, Kentland 2012 and Washington 2012

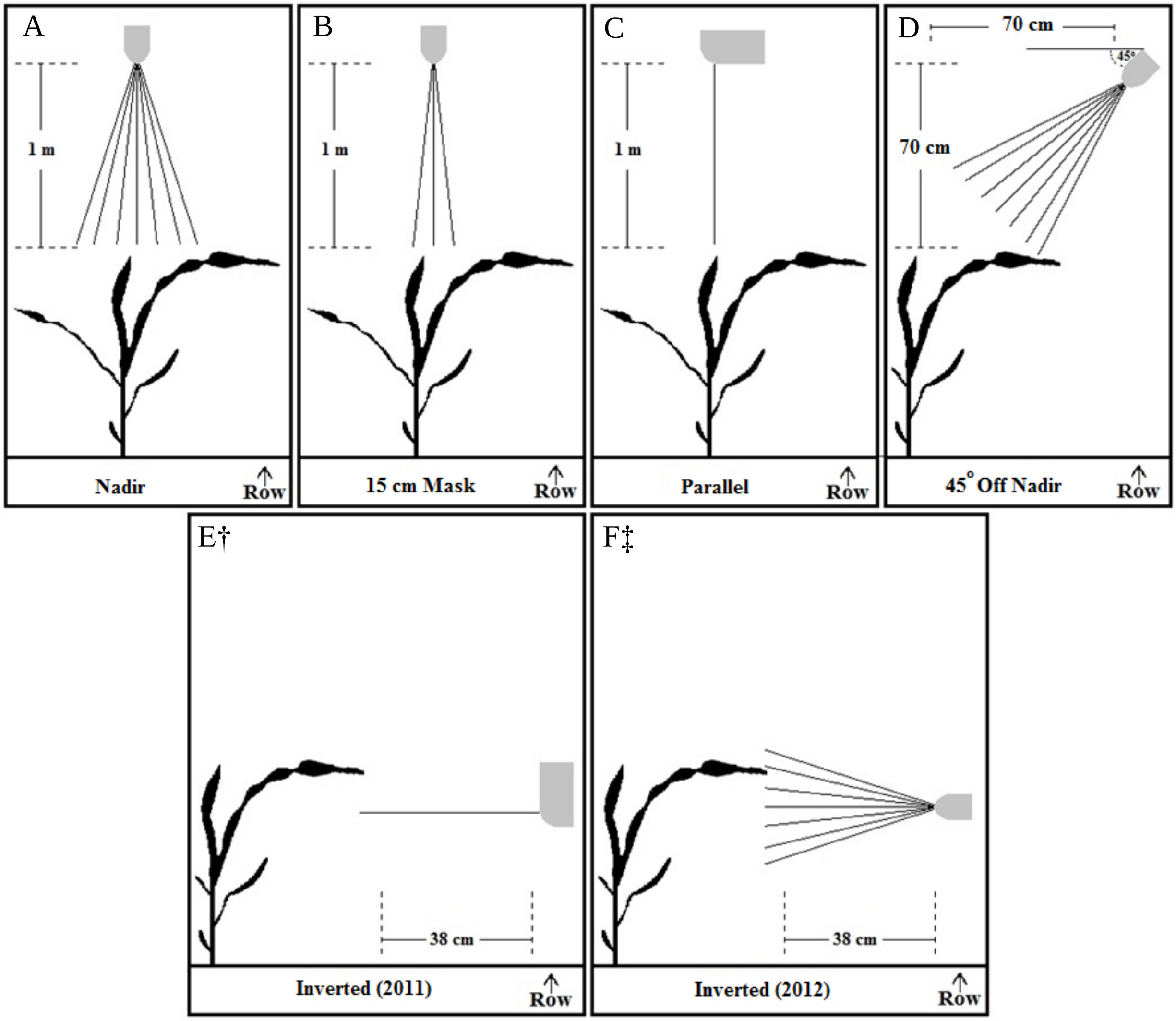

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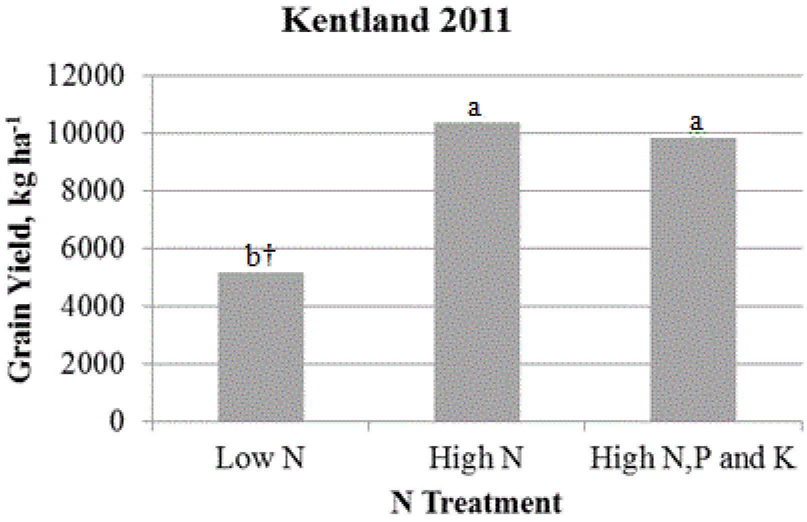
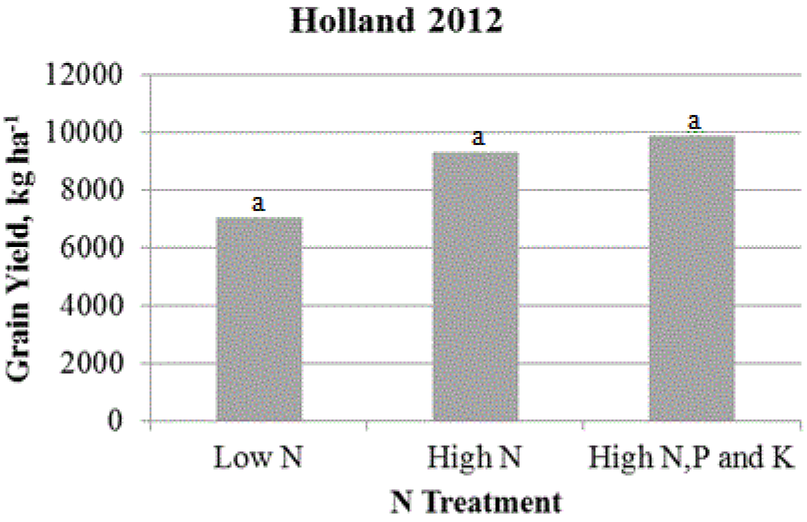
Figure 3.2. Grain yield response to low N, high N and high N, P and K treatments for: a) Kentland 2011, b) Holland 2012, c) Kentland 2012 and d) Washington 2012.
† Treatment means within locations followed by the same lower case letter are not significantly different according to LSD (0.05)

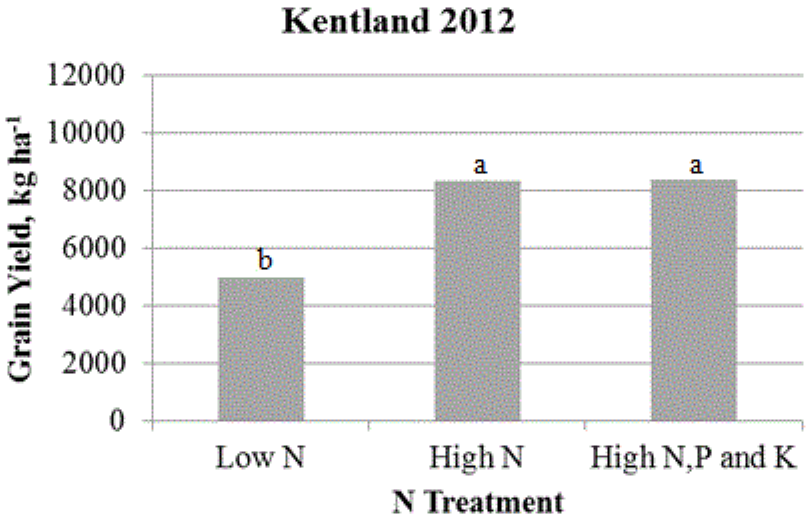
a)



b)



c)


Kentland 2012
Grain Yield, kg ha-1
12000
10000
8000
6000
4000
2000
0
b
a
a
Low N
High N
High N,P and K
N Treatment

d)

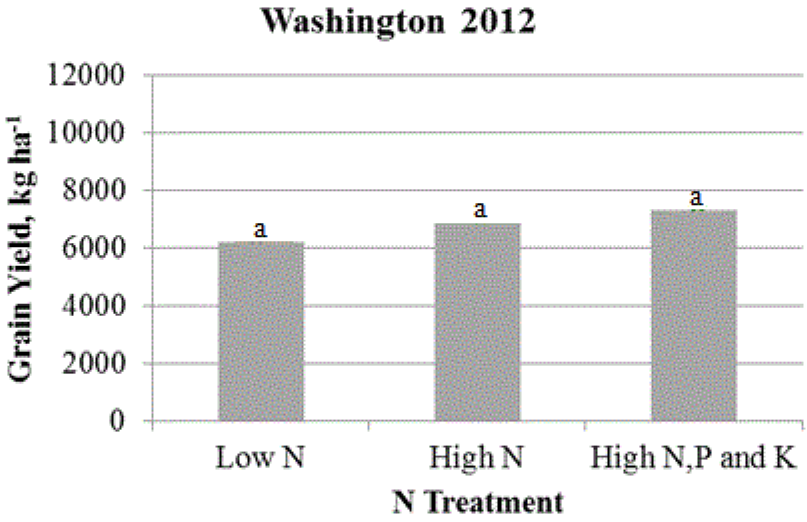
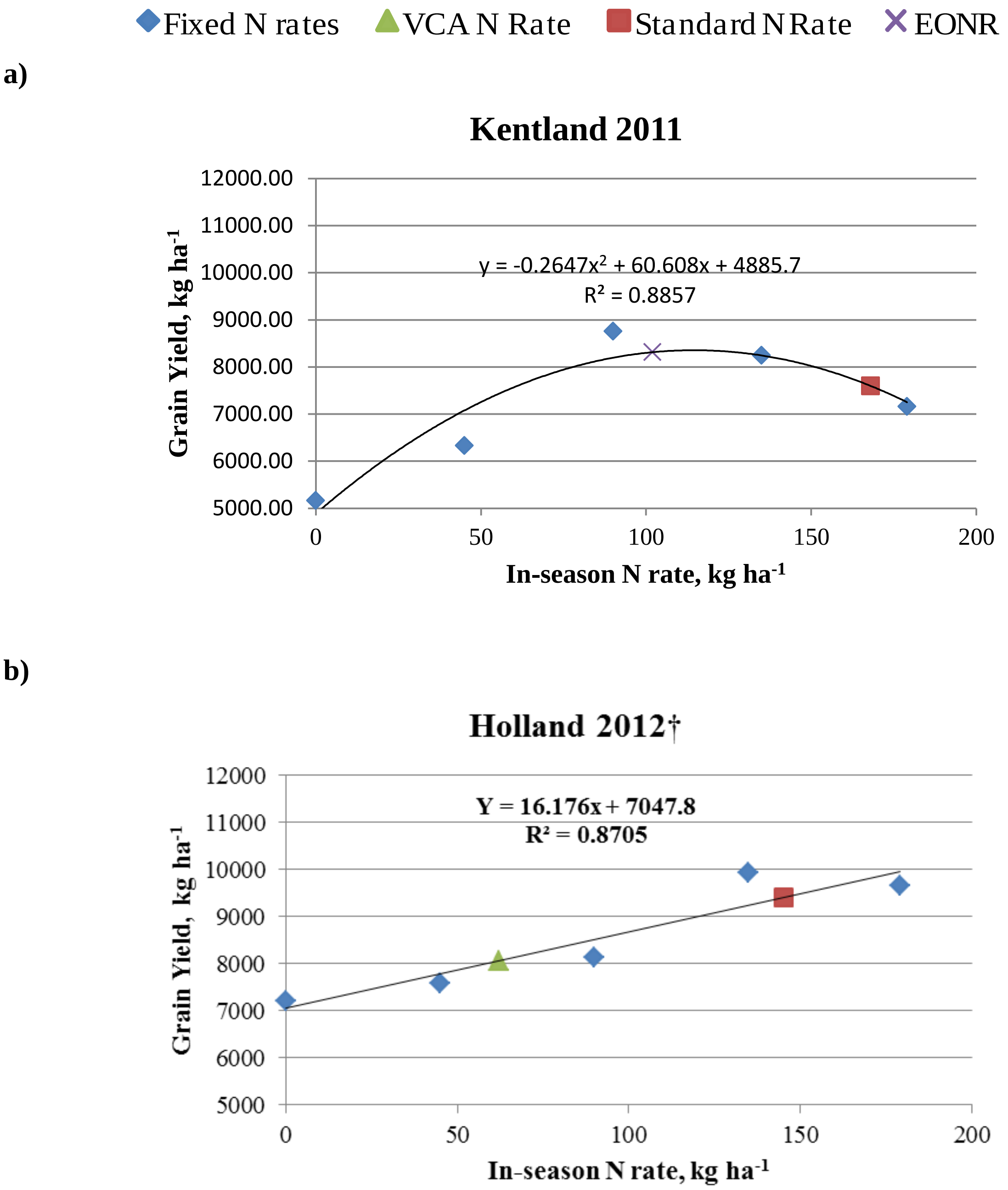

Washington 2012
Grain Yield, kg ha-1
12000
10000
8000
6000
4000
2000
0
a
a
a
Low N
High N
High N,P and K
N Treatment

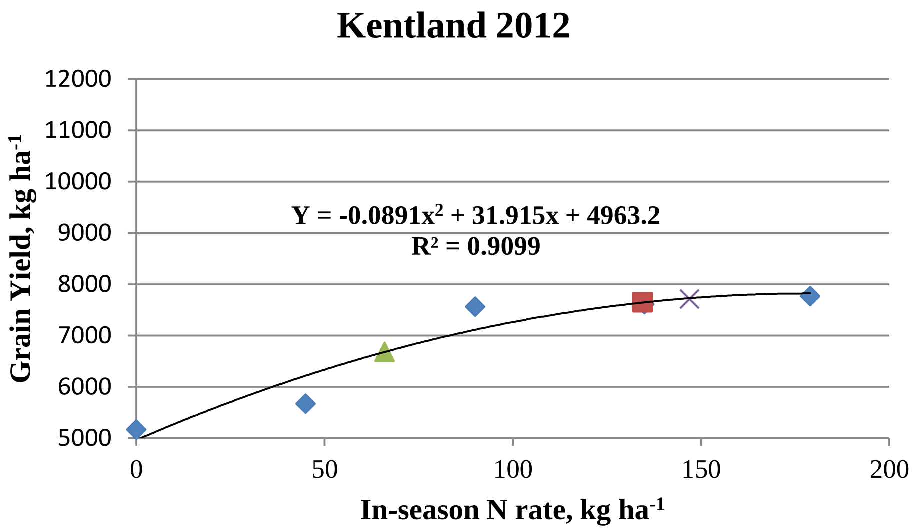
Figure 3.3. Grain yield response to in-season UAN application and EONR plotted against Virginia Corn Algorithm prescribed N rate and standard N rate for a) Kentland 2011, b) Holland 2012, c) Kentland 2012 and d) Washington 2012.

VCA prescribed rate could not be calculated at Kentland 2011.

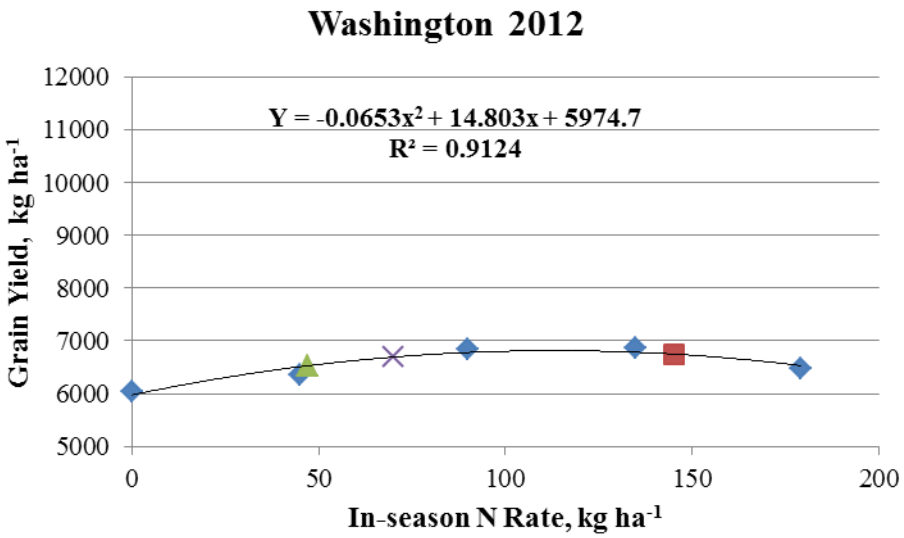
† EONR was not estimable for Holland 2012



c)


Kentland 2012
12000
11000
10000
9000
8000
7000
6000
5000
Grain Yield, kg ha-1
Y = -0.0891x2 + 31.915x + 4963.2
R² = 0.9099
0
50
100
150
200
In-season N rate, kg ha-1

d)


Washington 2012
12000
11000
10000
9000
8000
7000
6000
5000
Grain Yield, kg ha-1
Y = -0.0653x2 + 14.803x + 5974.7
R² = 0.9124
0
50
100
150
200
In-season N Rate, kg ha-1

CONCLUSIONS

It was hypothesized that normalized difference vegetation index (NDVI) readings collected from low biomass corn is significantly influenced by changes in sensing background reflectance due to different soil colors, crop residue types present and various levels of soil moisture. Analyzing the effects of various sensing backgrounds on NDVI readings collected at low biomass resulted in NDVI readings that varied between backgrounds and in certain environments this variation neared 0.2 units. Results from this research indicated that as plants matured (increased in biomass) the variation in NDVI caused by sensing backgrounds diminished. This implies that NDVI readings collected at later growth stages (V5-V6) will be more representative of plant N status compared to readings collected at V2.

Altering the GreenSeeker® **(**Trimble Navigation Limited, Sunnyvale, CA**)** sensor orientation and field of view did not reduce the influence of sensing background on NDVI readings at low biomass when compared to the current industry standard nadir orientation. Findings in this experiment indicate that when using the sensor as a nitrogen (N) management tool the sensor should be employed at the nadir orientation. Because plant greenness measurements using this sensor are influenced by several sensing backgrounds the sensors success is dependent on reference strips that are representative of the entire field to be sensed. In cases where the field to be sensed contains multiple soil series it may be necessary to establish multiple reference strips based on soil series to ensure algorithms used for calculating N rates generate rates that reflect the nutrient needs of the crops.

Results from five field sites indicate that the SPAD chlorophyll meter (Konica Minolta Sensing, Inc., Osaka, Japan**)** and GreenSeeker sensor are unreliable indicators of plant N content prior to the V4 growth stage. Once the plants reached the V4 growth stage, both systems accurately predicted differences in plant N content at three of five sites. The GreenSeeker sensor deployed at the nadir orientation was a better indicator of plant N concentration than was the SPAD meter.

Because the GreenSeeker was able to distinguish between differences in plant tissue concentration the sensor should have been an accurate measure of plant N status and thus plant N needs. Using the Virginia Corn Algorithm (VCA) and data collected from three locations N rate prescriptions were generated and compared to the economically optimal N rate (EONR) for each of those locations. Nitrogen rate prescriptions will consistently lower than the EONR and if the algorithm generated rate was used in place of the EONR would have resulted in yield losses and substantial profit losses at all three sites. It is hypothesized that when reflectance readings were collected for use in the VCA N uptake rates were too low to accurately predict crop response to N fertilizer. It is thought that if readings were taken at a later growth stage (i.e. the V8 growth stage) the continued N uptake would have provided a more accurate prediction of crop response to N rates and thus the algorithms would have generated N rates that would better reflect the EONR.

Appendix A. Temperature, GDD and precipitation for all sites in 2011 and 2012 from planting though V5 data collection.

Kentland 2011					
	---Temperature C^{o}--				
Days after Planting	Max	Mean	Min	GDD base 10^{o} C	Precipitation cm
0	33	23	15	13	0.00
1	32	23	15	13	0.00
2	29	24	20	14	0.00
3	29	20	12	10	0.00
4	30	20	9	10	0.03
5	30	23	17	13	0.00
6	30	22	13	12	0.00
7	31	20	12	10	0.00
8	33	23	15	13	1.07
9	33	23	16	13	0.03
10	30	22	15	12	0.15
11	30	22	16	12	0.36
12	29	22	17	12	0.00
13	26	20	16	10	0.00
14	24	18	10	8	0.00
15	24	17	9	7	0.00
16	27	20	14	10	0.00
17	29	20	11	10	0.15
18	29	20	14	10	0.00
19	27	22	17	12	0.08
20	28	23	19	13	0.18
21	31	23	16	13	0.33
22	29	23	18	13	0.20
23	25	22	19	12	0.00
24	28	22	17	12	0.00
25	26	21	16	11	0.00
26	26	19	11	9	0.00
27	31	23	18	13	0.10
Total	33	21	9	321	2.7

Appendix A. Continued.

Blackstone 2012					
	---Temperature C^o--				
Days after Planting	Max	Mean	Min	GDD base 10^o C	Precipitation cm
0	24	14	6	4	0.0
1	13	8	4	0	0.0
2	18	10	3	0	0.0
3	21	11	2	1	0.0
4	26	13	2	3	0.0
5	30	23	17	13	0.0
6	32	24	18	14	0.0
7	29	22	16	12	0.0
8	19	16	12	6	0.3
9	23	17	11	7	0.3
10	25	16	7	6	0.0
11	28	19	11	9	0.6
12	18	14	10	4	4.1
13	11	9	6	0	0.2
14	18	11	4	1	0.0
15	23	12	2	2	0.0
16	21	16	12	6	0.7
17	23	17	11	7	0.0
18	16	13	10	3	0.5
19	20	16	11	6	0.0
20	22	18	14	8	0.0
21	31	24	18	14	0.0
22	32	24	18	14	0.0
23	29	23	17	13	0.0
24	31	24	19	14	0.0
25	29	23	17	13	0.1
26	24	20	16	10	0.0
27	26	19	12	9	0.0
28	26	19	13	9	0.0
29	26	21	16	11	4.0
30	23	17	12	7	0.0
31	23	16	9	6	0.0
32	26	16	6	6	0.0
33	27	20	13	10	0.1
34	26	21	17	11	0.4
35	29	24	19	14	0.2
36	27	22	18	12	0.2
Total	32	18	2	284	11.6

Appendix A Continued

Holland 2012					
	---Temperature C^o--				
Days after Planting	Max	Mean	Min	GDD base 10^o C	Precipitation cm
0	15	10	6	0	0.0
1	18	10	2	0	0.0
2	20	11	2	1	0.0
3	25	14	3	4	0.0
4	28	22	17	12	0.0
5	31	23	17	13	0.0
6	31	23	14	13	0.0
7	20	16	12	6	0.0
8	20	16	11	6	0.0
9	25	17	8	7	0.0
10	29	22	16	12	0.0
11	19	14	10	4	0.0
12	13	10	7	0	0.0
13	18	11	5	1	0.0
14	22	12	3	2	0.0
15	24	18	13	8	0.0
16	22	17	12	7	0.0
17	17	12	8	2	0.0
18	19	14	11	4	0.0
19	24	18	13	8	0.0
20	31	24	18	14	0.0
21	32	26	19	16	0.0
22	29	22	16	12	0.0
23	32	24	18	14	0.0
24	31	24	18	14	0.0
25	23	18	13	8	0.0
26	24	18	12	8	0.0
27	28	20	12	10	0.0
28	23	20	16	10	0.0
29	23	18	13	8	0.0
30	23	17	11	7	0.0
31	26	17	9	7	0.0
32	27	21	15	11	0.0
33	27	22	18	12	0.0
34	30	25	20	15	0.0
35	28	23	19	13	0.0
total	32	18	2	292	0

Appendix A. Continued.

Kentland 2012					
	---Temperature C^o---				
Days after Planting	Max	Mean	Min	GDD base 10^o C	Precipitation cm
0	23	13	3	3	0.0
1	21	16	10	6	0.5
2	22	16	14	6	4.5
3	22	18	14	8	0.4
4	25	18	12	8	0.0
5	26	17	10	7	0.3
6	22	17	12	7	0.0
7	24	16	8	6	0.0
8	26	17	9	7	0.0
9	27	18	9	8	0.0
10	25	18	15	8	0.5
11	22	18	15	8	0.0
12	25	19	14	9	0.2
13	30	22	15	12	0.0
14	30	22	14	12	0.0
15	30	22	16	12	0.0
16	30	22	15	12	0.0
17	29	21	15	11	0.8
18	28	22	17	12	0.0
19	29	20	12	10	0.4
20	24	18	16	8	0.7
21	19	15	10	5	0.0
22	24	15	6	5	0.0
23	24	18	11	8	0.0
24	22	16	10	6	0.0
25	20	15	12	5	0.9
26	24	17	10	7	0.0
Total	30	18	3	214	9.2

Appendix A. Continued.

Washington 2012					
	---Temperature C^{o}---				
Days after Planting	Max	Mean	Min	GDD base 10^{o} C	Precipitation cm
0	26	19	11	9	0.0
1	26	20	14	10	0.0
2	25	19	14	9	0.0
3	27	20	13	10	0.0
4	27	21	14	11	0.0
5	23	18	12	8	1.0
6	22	18	15	8	0.4
7	27	21	14	11	0.1
8	29	22	16	12	0.0
9	31	23	16	13	0.0
10	31	25	19	15	0.0
11	31	24	18	14	0.0
12	28	23	17	13	0.0
13	27	22	17	12	0.0
14	29	21	14	11	0.0
15	24	18	13	8	0.0
16	19	14	10	4	0.0
17	24	17	10	7	0.2
18	24	18	13	8	0.1
19	22	17	11	7	0.0
20	22	18	13	8	0.0
21	24	18	12	8	0.0
22	26	18	11	8	0.0
23	28	20	12	10	0.0
Total	31	20	10	236	1.7