RELATIONSHIP BETWEEN COEFFICIENT OF VARIATION MEASURED BY SPECTRAL REFLECTANCE AND PLANT DENSITY AT EARLY GROWTH STAGES

By

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NOMENCLATURE

CV	Coefficient of variation
ρ_{NIR}	=Fraction of emitted NIR radiation returned from the sensed area (reflectance)
ρ_{Red}	=Fraction of emitted Red radiation returned from the sensed area (reflectance)
GDD	Growing Degree Days = $(T_{min} + T_{max}/2) - 4.4$ ˚C
INSEY	In-Season Estimated Yield= NDVI (Feekes 4 to 6)/ days from planting to sensing (days with GDD>0) = YP_0
NDVI	$= (\rho_{NIR} - \rho_{Red})/(\rho_{NIR} + \rho_{Red})$
NUE	Nitrogen use efficiency
PGN	Calculate predicted grain N uptake at $YP_N(GNUP_{YPN})$, average percent N in the grain multiplied by YP_N: $GNUP_{YPN} = YP_N * PNG$
R^2	= Regression significance, Sum of Squares of the Model divided by the total sum of squares
RI_{NDVI}	= NDVI from plots receiving adequate but not excessive preplant N, divided by NDVI from the check plot where preplant N may or may not have been applied
$RI_{Harvest}$	=Maximum observed grain yield (treatment average with N fertilizer) divided by the observed grain yield from plots where no N was applied either preplant or topdress
$RI_{NDVI\text{-}CV}$	=NDVI from plots receiving adequate but not excessive preplant N, divided by NDVI from the check plot where preplant N was not applied times the square root of the check plot's CV.
YP_{Max}	=Maximum obtainable yield level for a specific environment determined by the farmer, or previously defined as a biological maximum by research agronomists for that crop, and for that region (units: Mg ha^{-1})

YP_0 = Predicted potential grain yield based on growing conditions up to the time of sensing, that can be achieved with no additional (topdress) N fertilization (units: kg ha^{-1})

YP_N = Predicted or potential yield that can be attained with added N (YP_N) fertilization based on the in-season response index (RI_{NDVI}) computed as follows: units: (YP_N in kg ha^{-1})

$$YP_N = (YP_0)*RI_{NDVI}$$

ABSTRACT

The use of by-plot coefficient of variation (CV) has not been used in precision agricultural work. Current methods of predicting mid-season yield potential could be improved if plant stand was included. This study evaluated the use of CV's determined from normalized difference vegetative index (NDVI) sensor readings collected from $1m^2$ areas. Three locations with 25 randomly selected plots, measuring 3m by 1m, at each location were used in this study. Initial work showed that CV was a good predictor of early season plant stand. Each plot was divided into three $1m^2$ sub-plots with N treatments; 0-N, 120 kg ha^{-1} N fall applied, and a 0-N pre-plant with 80 kg ha^{-1} N top-dress. Each plot was sensed at Feekes 5and Feekes 7 using the Green Seeker® hand held sensor. Seed row direction had no affect upon NDVI readings. CV was found to have no correlation with final grain yield. However a relationship between CV and early season plant stand was observed. This work supports the concept that CV could be used to better predict the yield potential obtainable if added fertilizer N is added.

INTRODUCTION

The world applied approximately 82 million metric tons of nitrogenous fertilizers in 2001, (FAO, 2002). Cereal grains accounted for 60% of the total N fertilizer applied in 1994 (FAO, 1995). Only 33% of the fertilizer N used for cereal grain crops is removed in the grain (Raun and Johnson, 1999).

Plant N losses in winter wheat have accounted for between 21% (Haper et al., 1987) and 41% (Diagger et al., 1976) of the unaccounted N using N^{15}. Loss of gaseous N due to denitrification is reported to range from 10% (conventional tillage) to 22% (no-till) in corn (Hilton et al., 1994). In addition, fertilizer N losses in surface runoff range between 1% (Belvins et al., 1996) and 13% (Chichester and Richardson, 1992) of the total N applied. Lower levels of losses due to run-off are usually associated with no-till conditions. An additional pathway for nitrogen loss is through leaching of NO_3^- when applied in excess of crop need. In cooler temperate climates, NO_3-N losses through tile drainage have approached 26 kg N ha^{-1} yr^{-1} under conventional tillage corn when only 115 kg N ha^{-1} was applied (Drury et al., 1996).

While plant loss accounts for a very large portion of N loss, loss from the soil environment still accounts for a high percentage. If any one of the pathways can be restricted and loss reduced, the benefit is significant. Johnson and Raun (2003) calculated that a 1% global increase in cereal NUE would have a value of $235 million in N fertilizer savings if yields were maintained.

Raun et al. (2002), reported an improvement in NUE of >15% when N fertilization was based on optically sensed in-season estimated yield (INSEY).

The GreenSeeker™ Hand Held Optical Sensor (NTech Industries, Inc.), developed by Oklahoma State University, senses a 0.6 x 0.01 m area when held at a distance approximately 0.6 to 1.0 m from the illuminated surface. The sensed dimensions remain approximately constant over the height range of the sensor. The sensor unit has self-contained illumination in both red (671 ± 10 nm) and NIR (780 ± 10 nm) bands. The device measures the fraction of emitted light in the sensed area that is returned to the sensor (reflectance). The algorithm currently used by N-Tech Industries, "WheatN1.0", includes several distinct components. Raun et al.(2004 b) identified three specific components: 1) mid-season prediction of grain yield, determined by dividing NDVI by the number of days from planting to sensing (estimate of biomass produced per day on the specific date when sensor readings are collected); 2) estimating temporally dependent responsiveness to applied N by placing non-N-limiting strips in production fields each year, and comparing these to the farmer practice (fertilizer response index); 3) determining the spatial variability within each 0.4 m^2 area using the CV from NDVI readings.

The results of previous work have shown that stand density and uniformity have an affect on grain yield. Weisz et al. (2001) reported that as plant stand or tiller density increased, grain yield tended to increase, and the variation within the field decreased. Nielsen (2001) showed that in corn for every 2.56 cm standard deviation of plant-to-plant spacing there was a decrease in yield of 1567 kg ha^{-1} from the average yield of 9800 kg ha^{-1}. This indicates the need to make fertilization recommendations with stand density as a factor. Flowers et al. (2002) validated the use of aerial photography for determining winter wheat tiller density. Using the density estimates, he determined that basing N application on a critical density threshold had an 85.5% success rate. Lukina et al. (2000) observed that as the vegetation coverage increased, the CV of NDVI values decreased. Raun et al. (2001) showed that NDVI values from mid-season sensor readings could be used to predict yield. Combining NDVI and CV independently may result in improved prediction of yield potential.

CV is defined as the standard deviation divided by the mean (Tippett, 1952; Senders, 1958; Steel et al., 1997; Lewis, 1963). Steel et al. (1997) describe CV as a quantity of use to the experimenter in evaluating results from different experiments of the same unit of measure, that are possibly conducted by different persons. Little and Hills (1978) suggested that CV can be used to compare experiments involving different units of measurements and/or plot sizes. The CV is a relative measure of variation and varies with every comparison on what is considered large or small, and only experience with similar data can determine its meaning (Steel et al., 1997).

Raun et al. (2004 a) found that CVs of spectral radiance measurements were useful in detecting the growth stage in corn where within-row-by-plant variability was the greatest and where treating that variability had the greatest impact.

In an evaluation of sixty-two, wheat field research projects, Taylor et al. (1999) observed that mean yield and CV were negatively correlated. Taylor's work also showed that CVs decreased with corresponding decreases in plot size. Washmon et al. (2002) suggested that if within field CVs could be predicted, the potential response to added nutrients may also be established, and in-season nutrient additions adjusted accordingly.

They further stated that the mid-season CV of a field could be equated to the response index, which is currently used by various researchers to determine topdress fertilizer rates.

Raun et al. (2004 b) predicted that when CV was low, a responsive field element should be capable of greater yield than when a similarly responsive field element CV was large. In testing this concept, they observed that $YP_{N\text{-}CV}$ (predicted yield with added N using INSEY and the CV at the time of sensing), values more closely followed observed yield than did YP_N (predicted yield using the INSEY equation) values. Morris (2004) noted that when plot CVs of NDVI readings were >18, maximum yields could not be achieved when N fertilizer was delayed until mid-season. When plot CVs were < 18, delaying all N fertilization until mid-season resulted in maximum yields and increased NUE.

The current GreenSeeker™ sensor collects more than 10 readings within each 0.4 m^2 traveling at 10 mph (Raun et al., 2004 b). Raun et al. (2004 b) states that the 10 readings collected from each 0.4 m^2 are considered to be sufficient to obtain a composite sample to reliably estimate the average, from such a small area, understanding that the 10 sensor readings were representative of the variability from the same 0.4 m^2 surface area.

The variable rate method is a vast improvement on the use of 15 soil samples to represent a unit area that could range from a few acres to several hundred acres (Johnson et al., 2000). If the goal is to maximize crop NUE, the use of average NDVI's presents a problem. Currently two 0.4 m^2 areas with similar NDVI's would receive the same treatment, but could need two different rates. A good stand of nutrient deficient wheat may have the same average NDVI as a poor stand of nutrient enriched wheat. The ability to index plant stand density on-the-go may provide the needed solution. The effect of plant population and tiller density on the GreenSeeker™ sensor's ability to correctly determine yield potential has not yet been assessed.

The objectives of this work were to determine the relationship between the coefficient of variation (CV) measured using spectral radiance measurements, and plant population at early growth stages. Sensing direction in relation to the crop row direction on the CV from spectral radiance measurements will also be evaluated, in addition to the change in CV over time.

MATERIALS AND METHODS

Experimental sites were established at EFAW Research farm in Stillwater, the Hajek farm in Hennessey, the Lake Carl Blackwell Research Station near Stillwater, and the Perkins Research Station near Perkins in the spring of 2003. The same sites were used in 2004 excluding the Hajek farm. Soil series classification and description for the experimental sites are presented in Table 1. All planting and management dates are reported in Table 2.

In 2003, thirty plots were randomly selected at the Hajek farm and the EFAW farm. Forty-five plots were randomly selected at the Perkins station and Lake Carl Blackwell farm. Plots were established after germination at Feekes 1(emergence). The plots were established at this stage so that the plots would be oriented with seed rows. Plot size measured 1.48 m^2, with each plot containing eight rows spaced 15 cm apart. A total of one hundred and fifty plots were used.

In 2004 the experiment was modified to include three nitrogen rates (0,120 kg ha^{-1} fall applied, and 80 kg ha^{-1} topdress) each applied to a plot of 1.48 m by 4.44 m, (Figure 1). The treatment structure was the same for all plots. Each plot was randomly selected within each location. Twenty-five plots were established at EFAW, Lake Carl Blackwell, and Perkins at Feekes 1.

Plant stand density was estimated for each plot at Feekes 1 by counting all plants within four rows randomly selected in each plot. This count was preformed prior to tillering; therefore, each shoot was recorded as a plant. The fall application nitrogen rate of 120 kg ha^{-1} was applied as urea (46-0-0, N-P-K) at plot establishment and the topdress application was applied at Feekes 6 (first node visible) using urea.

Spectral radiance measurements were taken using the GreenSeeker™ Hand Held Optical Sensor Unit. As described by Raun et al. (2003), the device used a patented technique to measure crop reflectance and to calculate NDVI. The equation for this calculation is shown below.

$$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}}$$

Where ρ_{NIR} - Fraction of emitted NIR radiation returned from the sensed area (reflectance)

ρ_{Red} - Fraction of emitted Red radiation returned from the sensed area (reflectance)

In the 2003 season at the EFAW research station and Lake Carl Blackwell farm locations, sensing was performed once a week until maturity. Readings were only taken from Feekes 5 (leaf sheaths strongly erect) through Feekes 8 (flag leaf visible) at the Hajek farm and Perkins Research Station. A total of four sensor passes were made on each plot, holding the sensor approximately 75 to 100 cm above the crop canopy. The sensor path was parallel to the seed rows; the first two readings were taken midway between rows 2 and 3, then 6 and 7 (Figure 2a). The final two sensor readings were taken by perpendicular to the seed rows holding the sensor approximately 30 cm from either border. Three seconds were allowed for each pass. Approximately sixty NDVI readings were collected with each pass.

In 2004, sensing began at all locations in January at or near Feekes 3 (tillers formed) and continued until physiological maturity. Also in 2004, a fifth pass was added to the sensing plan, directed at a 45-degree angle to the planting direction on each subplot (Figure 2b), for the purpose of complete evaluation of sensing direction.

For the 2003 season, wheat head counts were taken at maturity by counting the number of heads in of the rows, which had been used to estimate plant population. In both seasons, a 1 m^2 section from the center of each plot or sub-plot was harvested at maturity using a hand sickle and cutting slightly above the crown. The harvested samples were dried, weighed and threshed using a mechanized thresher. Sample grain was then weighed to determine yield of each plot. Total grain N content was determined using the Fisons NA 1500 Series 2 nitrogen analyzer, in the 2004 samples. From this measurement and grain yield data, nitrogen uptake of wheat was calculated. The data was analyzed using SAS (SAS Institute, 2002). Simple regression was the primary form of trend analysis, but both linear-linear and linear plateau models were also investigated.

RESULTS

The relationship between CV of NDVI readings and plant population was determined using a linear-plateau model (Figure 3), which resulted in a significant relationship ($R^2 = 0.36$). Figures 4, 5, and 6, illustrate the change in CV of treatments over time, from January until physiological maturity, for each of the three locations in the 2004 crop year. The maximum CV occurred near growth stage Feekes 6, (stem elongation) at all locations. Also, CV was affected by treatment, but the trend of CV over time was generally the same across treatments (Figures 4-6).

The linear relationship ($R^2 = 0.17$) between $RI_{Harvest}$ and vegetative RI (RI_{NDVI}) over all three locations is shown in Figure 7. Integrating CV into the calculation of RI as $RI_{NDVI-CV}$, calculation shown below, significantly improved the relationship with $RI_{Harvest}$ ($R^2 = 0.36$, Figure 8) when compared with that of RI_{NDVI} and $RI_{Harvest}$.

$$RI_{NDVI-CV} = \frac{\frac{NDVI_{N-Rich}}{NDVI_{Check}}}{\sqrt{CV_{Check}}}$$

Where $NDVI_{N-Rich}$ = Average NDVI of the N-Rich plot

$NDVI_{Check}$ = Average NDVI of the Check plot

CV_{Check} = Coefficient of Variation of NDVI reading taken from the check plot

Regression analysis of the relationship between average NDVI readings made in the direction of the seed row versus those taken from the same area moving perpendicular to the seed row is reported in Figure 9 for EFAW, Lake Carl Blackwell, Perkins, and Hennessey for 2003 and 2004. The trend line fits a linear relationship with a slope of 1.0 and an intercept of 0 with an R^2 of 0.97. These results are a compilation of 2 years of readings over 7 locations with 3660 observations. A highly significant linear relationship ($R^2 = 0.97$) was also found for NDVI readings taken in the direction of the seed row versus those taken from the same area moving at a 45-degree angle across the seed rows (Figure 10). This graph includes data from 2004 over 3 locations with 2325 observations. In Figure 11, the three sensing direction CVs over the growing season are graphed, revealing a separation of the across the seed row CV from the with the seed row and 45 degree angle to seed row CVs.

DISCUSSION

In this study 7 site years were used to evaluate plant population's affect on CV's of NDVI readings (Figure 3). From the linear-plateau relationship (joint), from the combination of all site years, a critical CV value of 20 was determined. No one site-year could be used to identify a critical CV because of the reduced level of population differences at any one site. The critical CV value determined from this study corresponds with the results presented by Morris (2004). Morris observed that plots of winter wheat, with a CV greater than 18 were unable to completely recover from early season nitrogen stress. This has the potential use in variable rate application because where areas of a field have a CV that exceeds the critical level of 20 the amount of N fertilizer applied could be reduced because it is recognized that the crop will not be able to utilize the additional nitrogen.

Raun et al. (2004a) observed a peak in CV in corn at the V6 stage and inferred that the peak could represent the best time to apply in-season foliar N fertilizer as this was the time when spatial variability of NDVI values were greatest. Similar results were found in this study. The first peaks in CV were observed near the Feekes 6 growth stage. This coincides with the time when spatial variability is the greatest. This in turn suggests the time when variable rate technology could have the greatest benefit. It is a necessity to apply topdress N prior to Feekes 6, because soon after stem elongation, it is much easier to damage the crop with applicator traffic. Commonly in Oklahoma topdress N application is timing is determined by weather and field conditions. Often the topdress N application takes place from December through March. This is typically well before the crop reaches Feekes 6.

The linear relationship found between the $RI_{Harvest}$ and the RI_{NDVI} was found to be poor in this small plot experiment (Figure 7). This result suggested that we were not able to reliably predict yield response to added N mid-season at this scale. Hodgen et al. (2004) found, that the relationship between $RI_{Harvest}$ and RI_{NDVI} was strong with a R^2 of 0.75. In his study, location averages were used to determine the relationship while this study used each individual plot. $RI_{NDVI-CV}$, which is a derivative of RI_{NDVI} that includes the CV of the check plot, has a much better relationship with $RI_{Harvest}$ ($R^2 = 0.36$) shown in Figure 8. This improvement of more than 50% indicates the ability of CV to identify the reduced yield potential in those plots with poor stands. In addition, the plots with solid plant stands did not encounter reduction in response potential. An improvement in RI estimation can be translated into improved variable rate nitrogen application and improved NUE.

Figure 9 and Figure 10 demonstrate the accuracy of NDVI readings in relationship to direction of movement over the seed row. This issue becomes important when considering that fertilizer applicators will be outfitted with the sensors. Unlike in research work where sensor direction can be carefully adjusted, the direction of the movement of sensors on an applicator is much more difficult to control in winter wheat. Both Figures 9 and 10 had strongly significant linear relationships with a slope of 1 and an intercept of 0. These results indicate that NDVI readings are independent of directional movement. However, as was expected, because of the pattern of the sensor, it was shown that perpendicular to the seed row CVs and parallel to the seed and 45 degree to seed row CVs were different (Figure 11). There was an increase in CV by 10% throughout much of the growing season with the perpendicular to the seed row CV. This is not surprising when considering how the sensor emits light in a wide band. If the sensor emitted light as another shape such as a cone, it may be observed that the sensing direction would have less effect upon CVs, much the same as with NDVI readings and sensing direction.

CONCLUSIONS

The relationship between plant population and CV of NDVI readings was evaluated over 7 site-years. From this evaluation a critical CV of 20 was determined using a linear-plateau model. When CV's were greater than 20, plant population was poor with < 100 plants/m^2. The ability of the crop to respond to added nitrogen was evaluated using several response indices ($RI_{Harvest}$, RI_{NDVI}, $RI_{NDVI\text{-}CV}$). It was found that $RI_{NDVI\text{-}CV}$ {$NDVI_{N\text{-}Rich}$ / ($NDVI_{Check}$ * SqRt CV_{Check})} provided improved prediction of $RI_{Harvest}$ compared to the conventional RI_{NDVI}. It is suggested that when this is implemented into the algorithm, variable rate applicators will apply less N over areas that have CV greater than 20. The reduction in N applied reduces the expense of farmers and risk of N being lost to the environment.

The observation that CV reached a peak at Feekes 5 – 6 suggests that current timing of application may have to be changed in order to maximize the technology's efficiency. As to application direction, it was also beneficial to see that it does not matter what direction the sensors are traveling across the seed row and that the NDVI values will remain the same. This is extremely important in that the applicators do not have the need to follow any rigid guidelines for the equipment to perform properly.

Integrating CV into N fertilization algorithms will be more challenging with the observation that across the seed row CV is consistently higher than other directions.

CV's can be used as an estimate of variation in plant stand densities by identifying the areas where plant stand is so poor that N application is unnecessary. The use of CV from NDVI readings could improve upon the efficiency at which variable topdress N is used.

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Table 1. Soil series classification and description for all experimental sites, (Lake Carl Blackwell, Perkins, EFAW, and Hajek Farm) in 2003-2004

Location	Soil Series and Description
Lake Carl Blackwell	Port; (fine-silty, mixed, superactive, thermic Cumulic Haplustoll)
Perkins	Konawa; (fine-loamy, mixed, active, thermic Ultic Haplustalf)
	Teller; (fine-loamy, mixed, active, thermic Udic Agriustoll)
EFAW	Norge; (fine-silty, mixed, active, thermic Udic Paleustoll)
Hajek Farm	Shellabarger; (fine-loamy, mixed, superactive, mesic Udic Argiustoll)

Table 2. Planting date, variety, seeding rate, and topdress application dates for all experimental sites, (Lake Carl Blackwell, Perkins, EFAW, and Hajek Farm) in 2003-2004

Location	Crop Year	Planting Date	Variety	Seeding Rate kg ha^{-1}	Topdress Date
Lake Carl Blackwell	2003	10/01/2002	Intrada	101	---
	2004	10/7/2003	Jagalene	95.3	3/30/2004
Perkins Station	2003	10/14/2002	Jagger	101	---
	2004	9/26/2003	Jagger	89.7	2/20/2004
EFAW Farm	2003	10/8/2002	2174	89.7	---
	2004	11/10/2003	OK 101	72.9	3/30/2004
Hajek Farm	2003	10/20/2002	Custer	89.7	---
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Figure 1. Treatment structure of three nitrogen treatments (0 N, 120 kg ha^{-1} N fall applied, and 80 kg ha^{-1} N applied as topdress) in 2004.

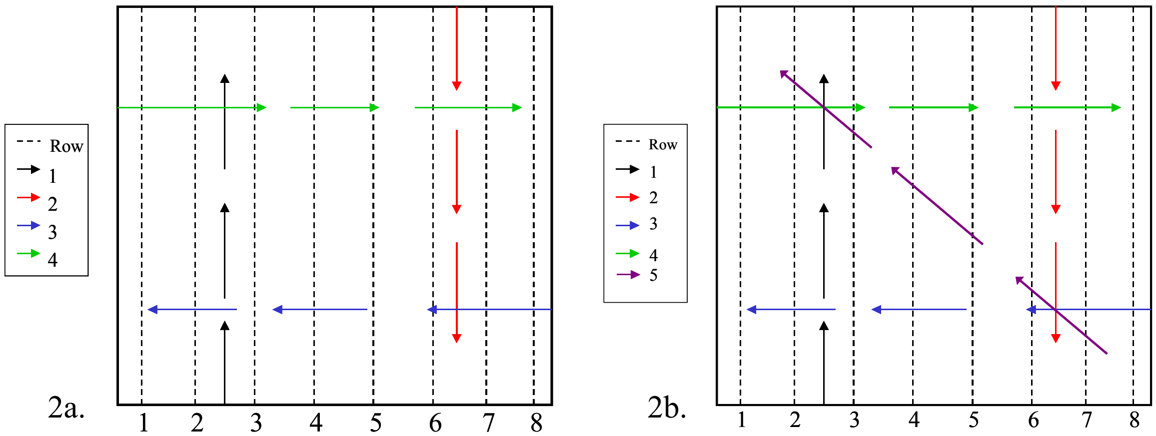

Figure 2a. Sensing sequence for the 2003 crop year. 4 total passes: 2 with the seed row and 2 across the seed row.

Figure 2b. Sensing sequence for the 2004 crop year. 5 total passes: 2 with the seed row, 2 across the seed row, and 1 pass at a 45-degree angle to the seed row.

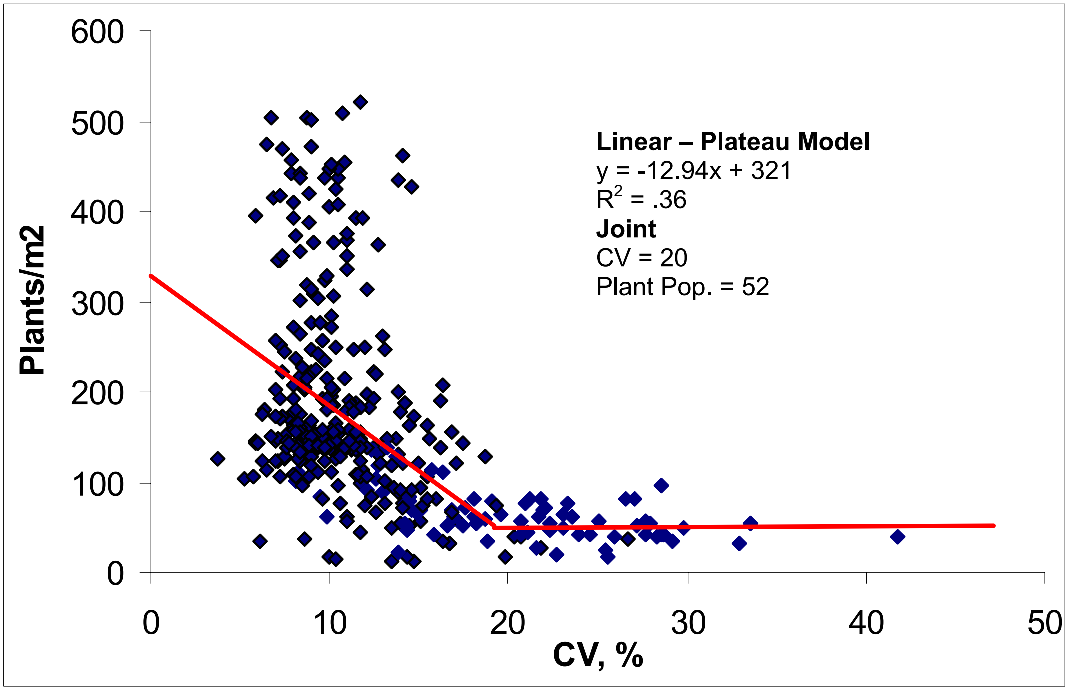

Figure 3. Relationship between the CV of NDVI readings and winter wheat plant population (7 locations, 2003-2004, multiple seeding rates and 6 varieties).

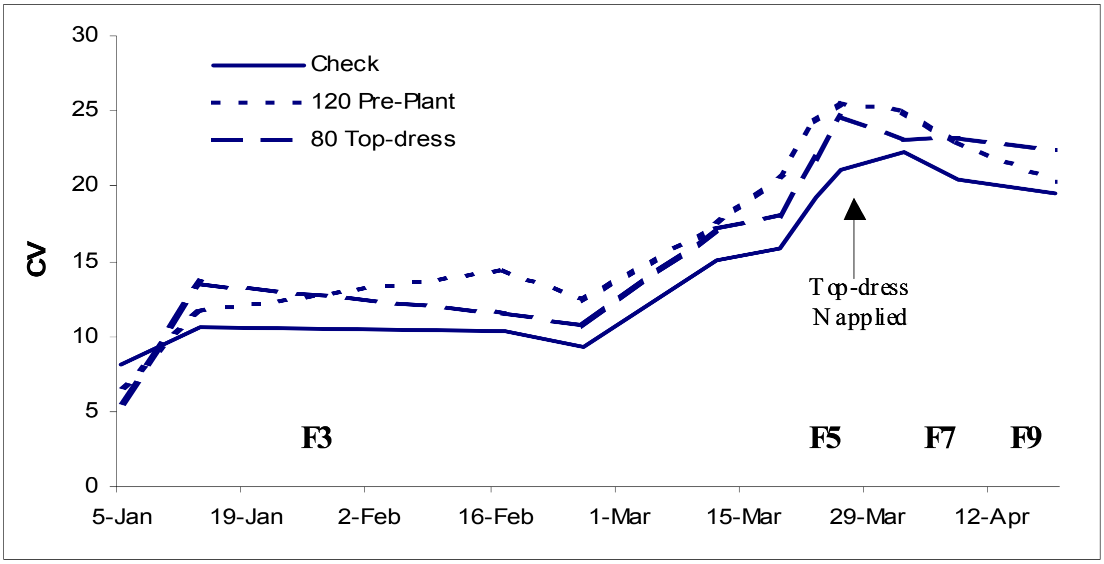

Figure 4. Change in CV, from NDVI readings collected from three N treatments in winter wheat, over time at the EFAW Research Farm, Stillwater Ok. (2004)

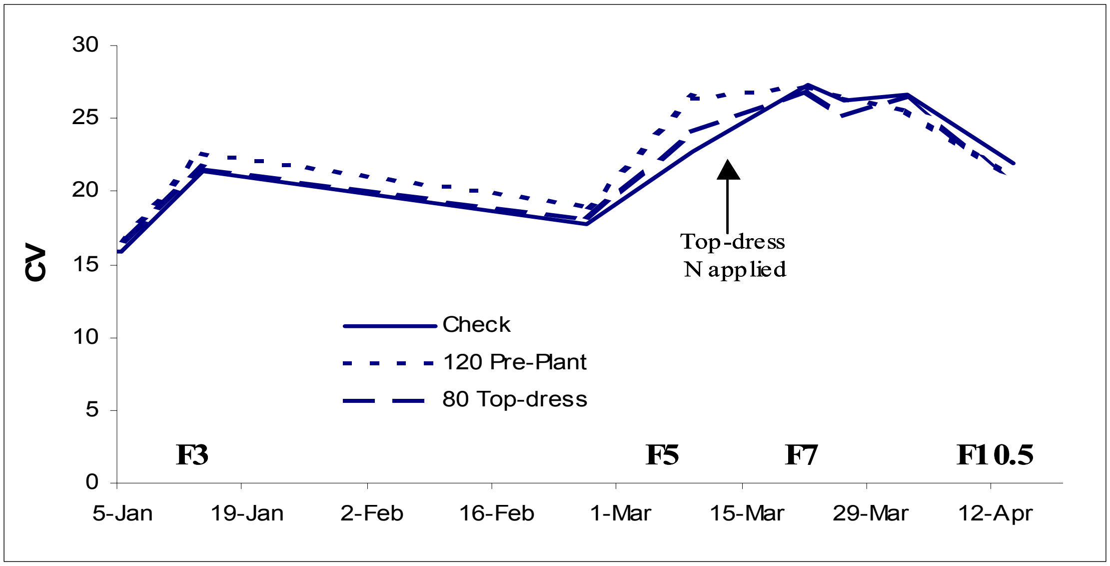

Figure 5. Change in CV, from NDVI readings collected from three N treatments in winter wheat, over time at Lake Carl Blackwell, Stillwater Ok. (2004)

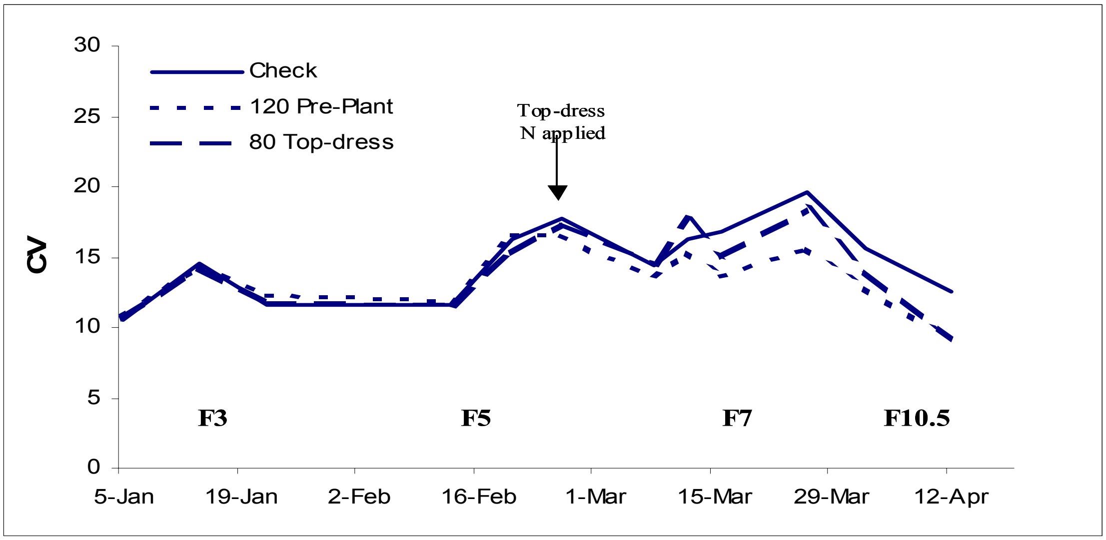

Figure 6. Change in CV, from NDVI readings collected from three N treatments in winter wheat, over time at the Perkins Research Station, Perkins Ok. (2004)

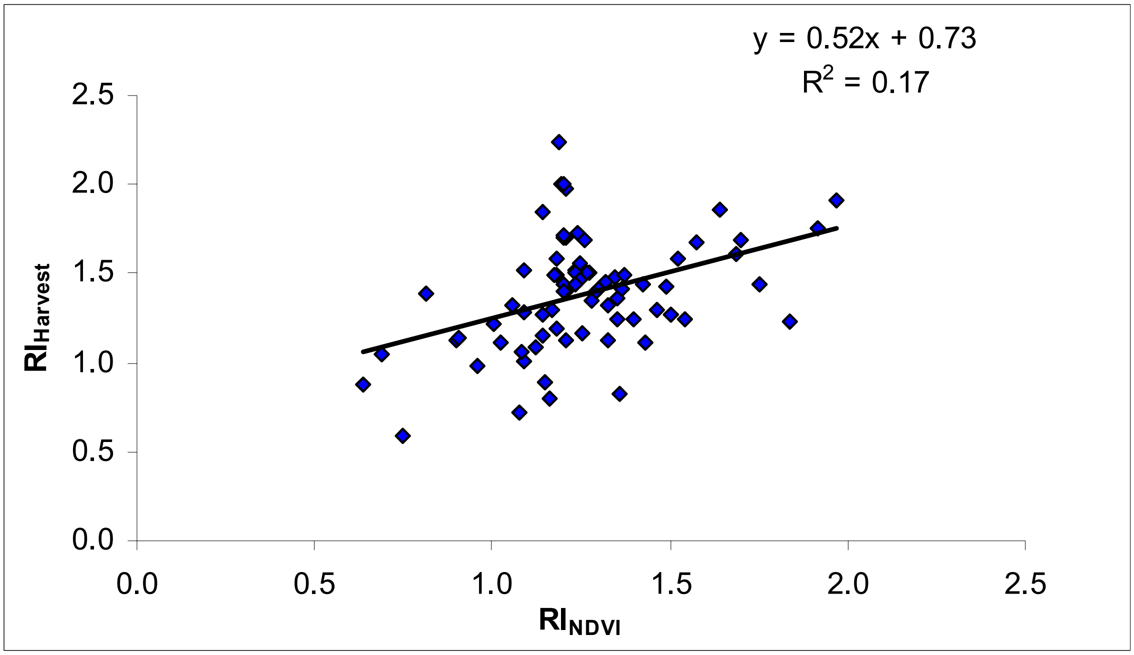

Figure 7. Comparison of $RI_{Harvest}$ (yield of N-rich plot / yield of check) versus RI_{NDVI} (NDVI of the N-rich plot / NDVI of the check).

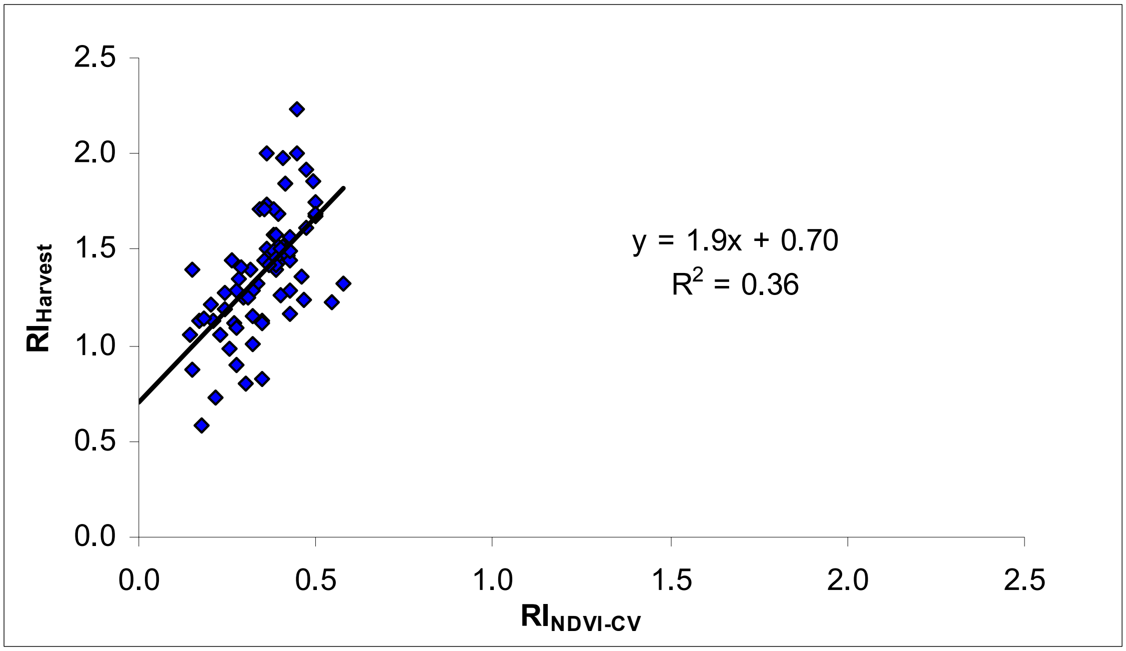

Figure 8. Comparison of $RI_{Harvest}$ (yield of N-rich plot / yield of check) versus $RI_{NDVI-CV}$ { NDVI of the N-rich plot / (NDVI of the check / SqRt of check CV)}.

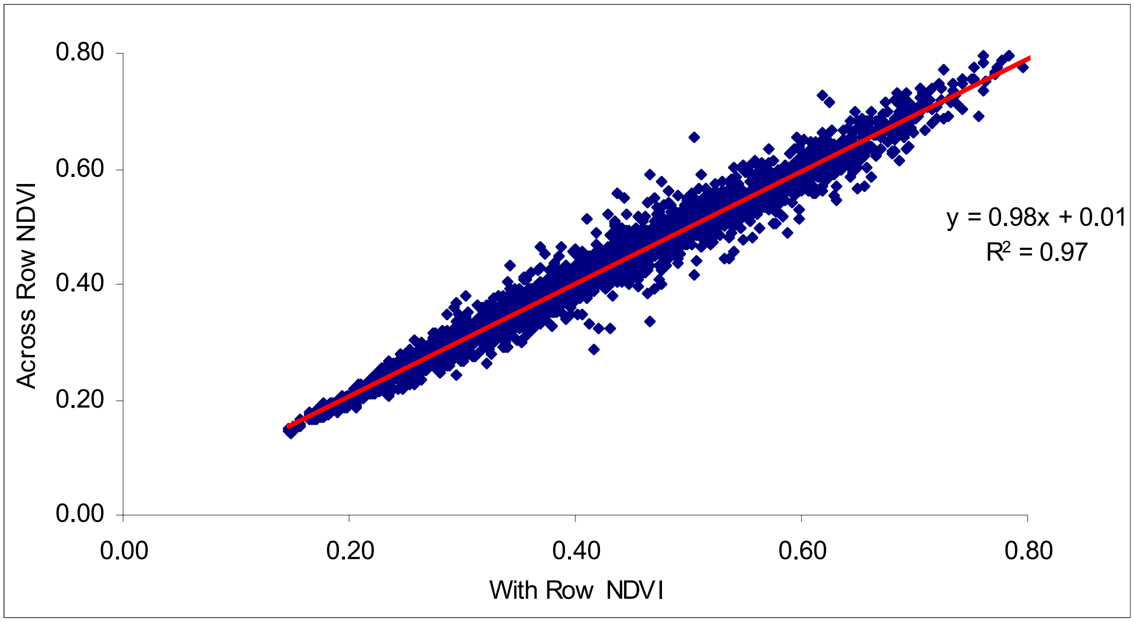

Figure 9. Comparison of with seed row NDVI readings versus across seed row NDVI readings. (7 locations, 2003-2004, multiple seeding rates and 6 varieties, n = 3660)

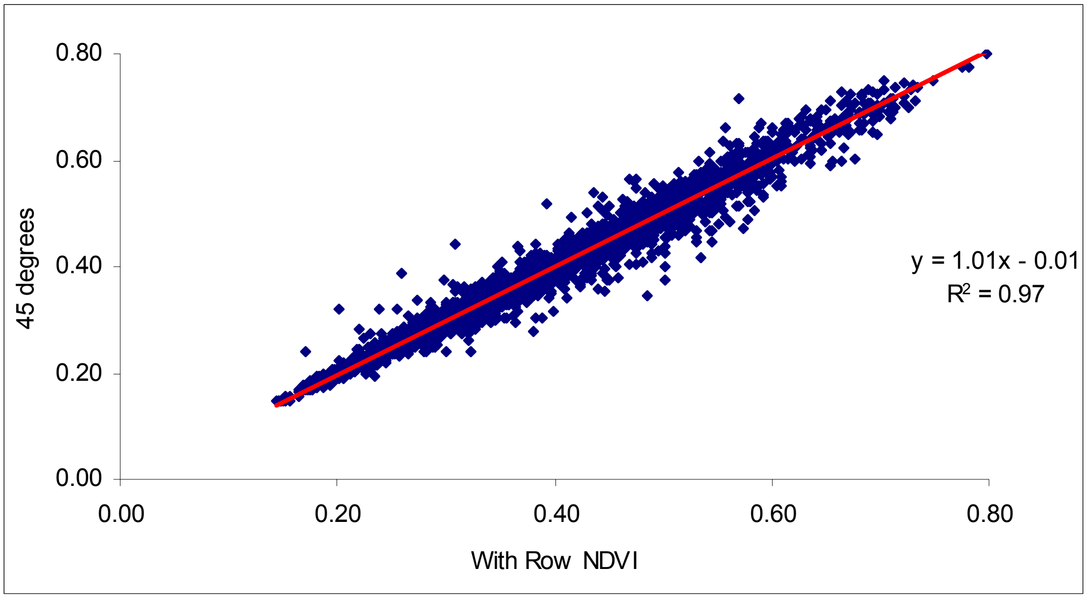

Figure 10. Comparison of with seed row NDVI readings versus 45-degree angle to the seed row NDVI readings. (3 locations, 2004 crop year, multiple seeding rates and 3 varieties, n = 2775)

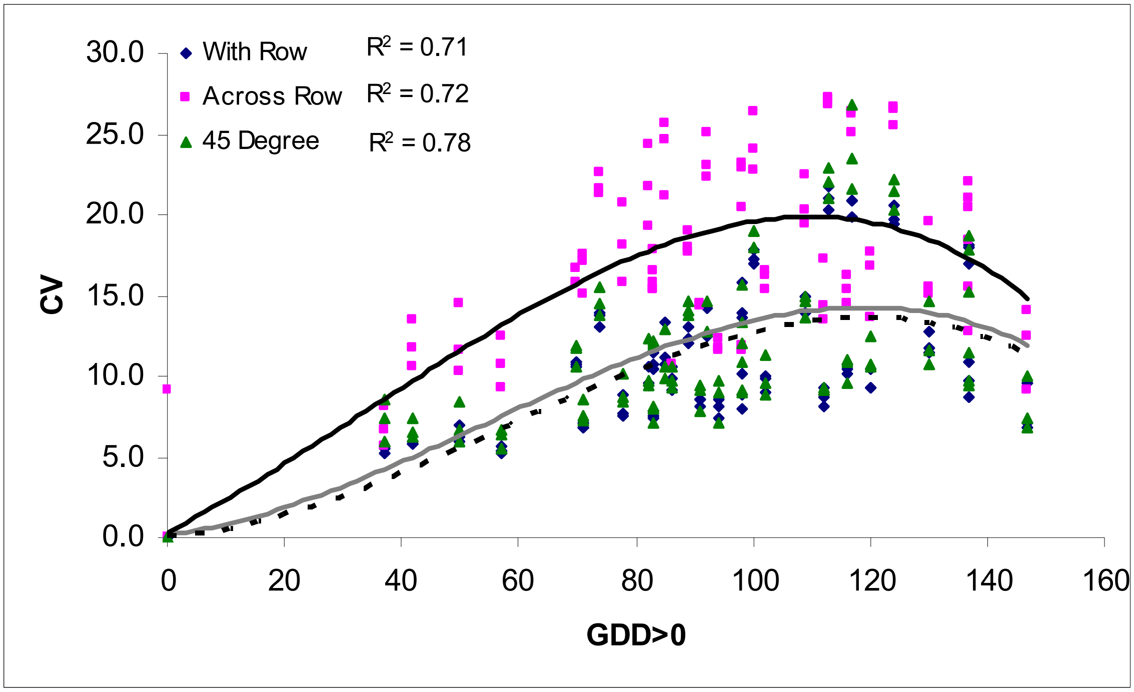

Figure 11. Relationship between with the seed row CV, across the seed row CV, and 45 degree angle to the seed row CV, plotted over time using cumulative growing degree days from planting, greater than 0 (GDD>0) 2004.

APPENDIX

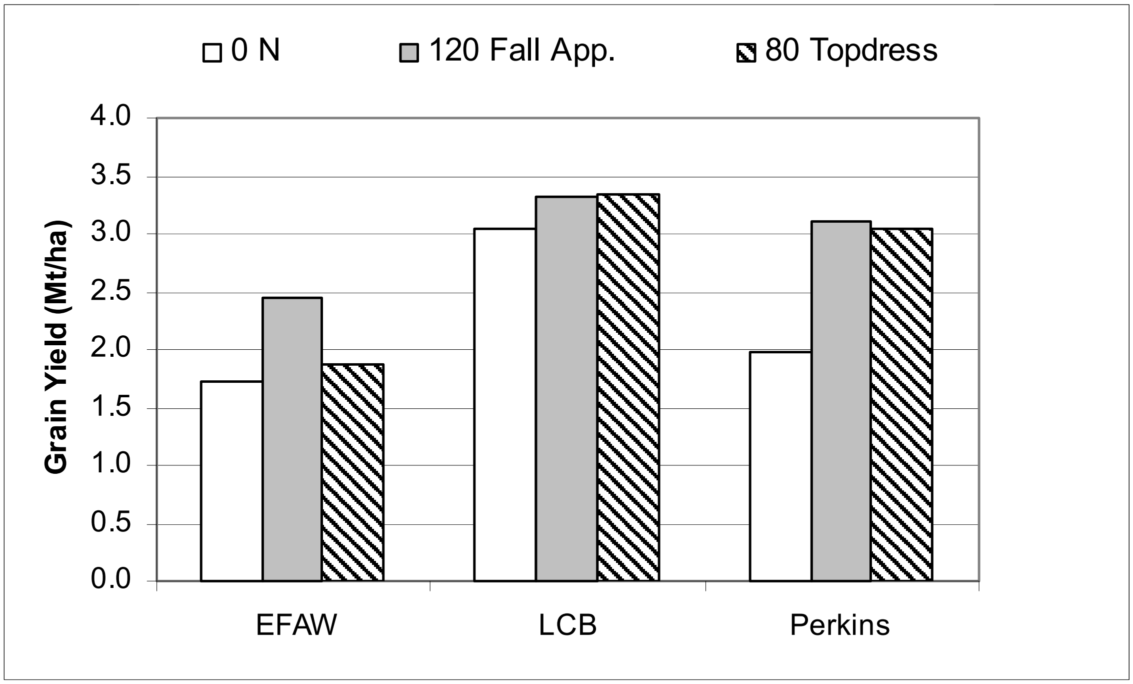

Figure A.1. Average grain yields (Mt/ha) of each nitrogen treatment at the three locations in the 2004 crop year.

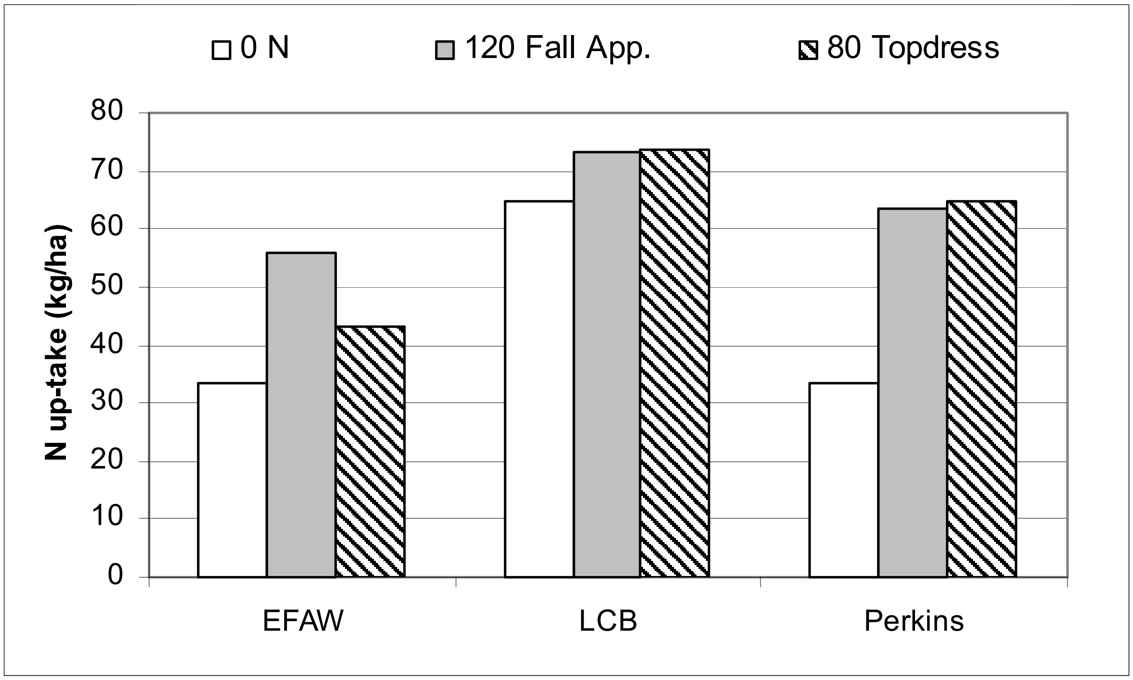

Figure A.2. Average N-uptake in grain yields (kg/ha) of each nitrogen treatment at the three locations in 2004 crop year.

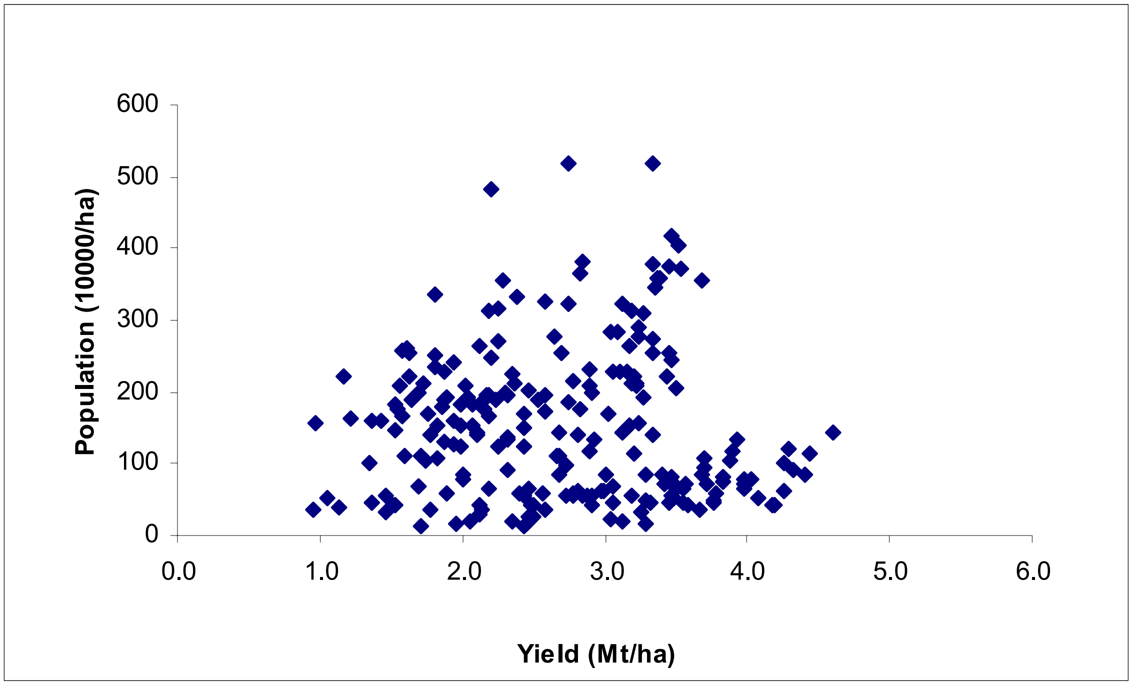

Figure A.3. Relationship of grain yield (Mt/ha) and plant population (10000 plants/ha) for the 2004 crop year.

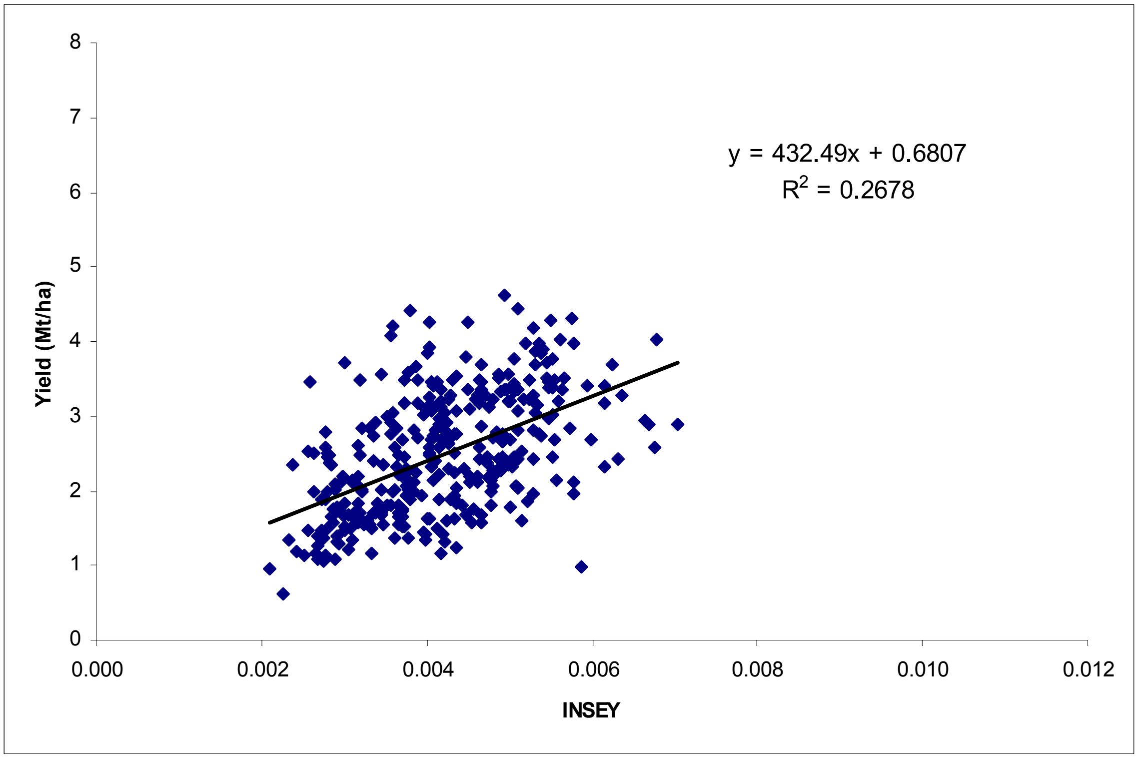

Figure A.4. The relationship between grain yield (Mt/ha) and INSEY (NDVI / GDDs>0).

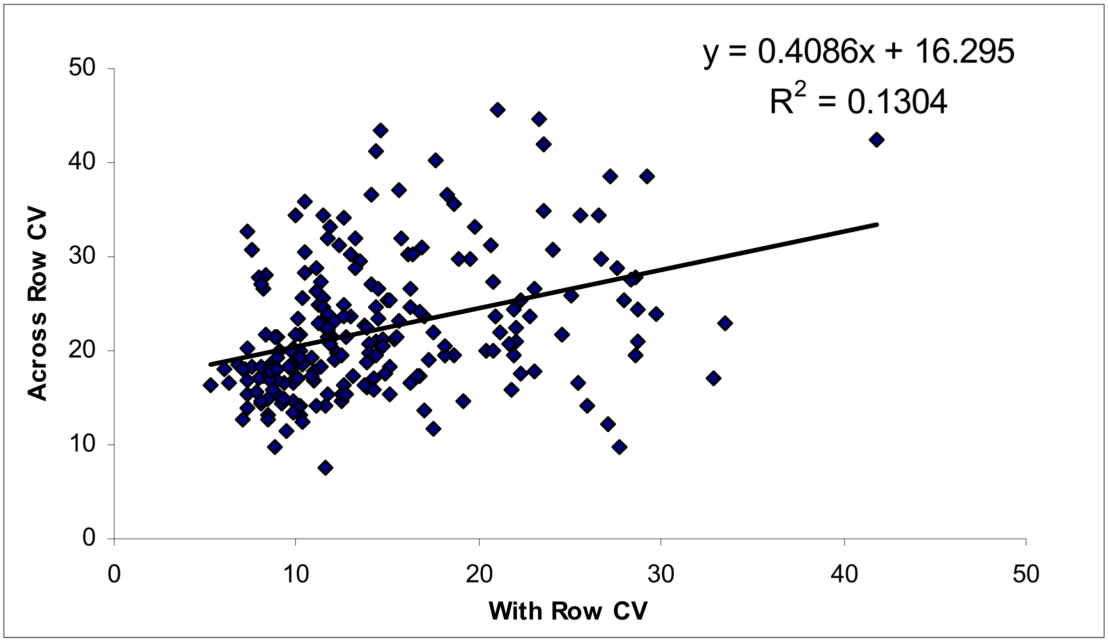

Figure A.5. Observed relationship between with the seed row CV and across the seed row CV at all locations for the 2004 crop year.

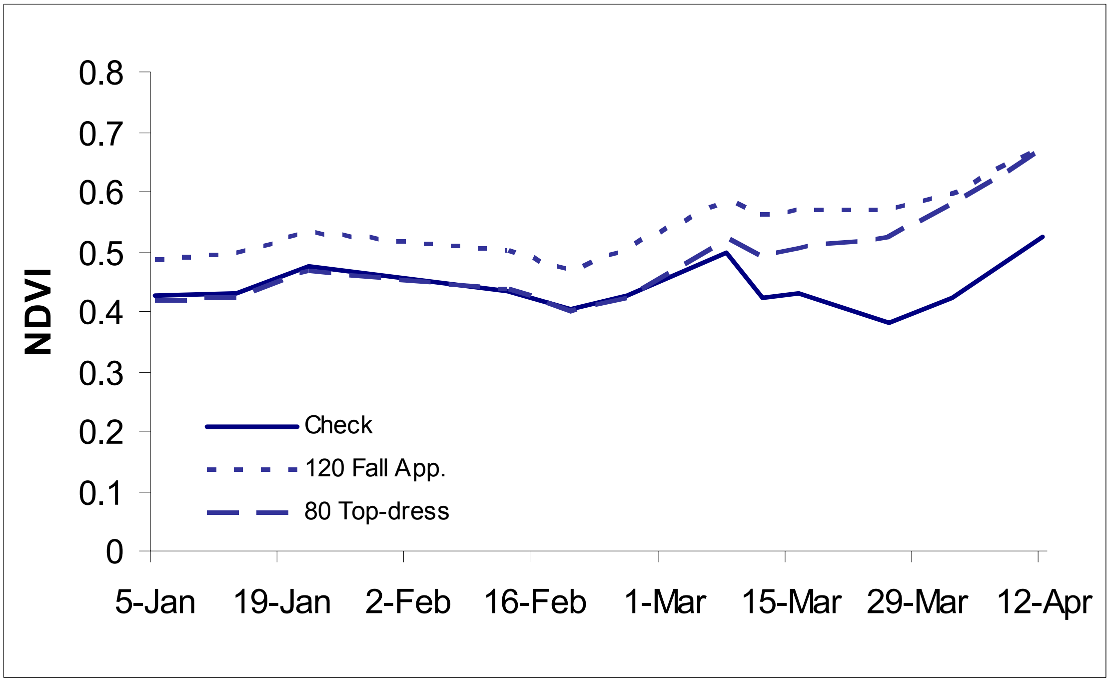

Figure A.6. Observed NDVI readings for the three nitrogen treatments at Perkins Research Station, Perkins Ok. (2004)

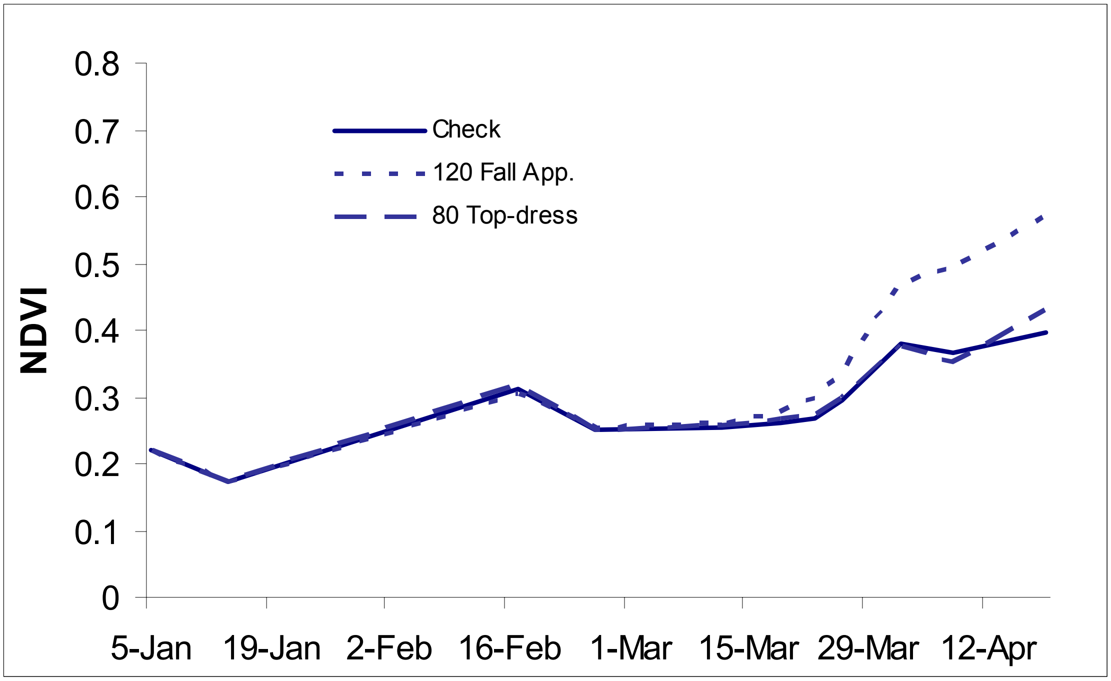

Figure A.7. Observed NDVI readings for the three nitrogen treatments at EFAW Research Farm, Stillwater Ok. (2004).

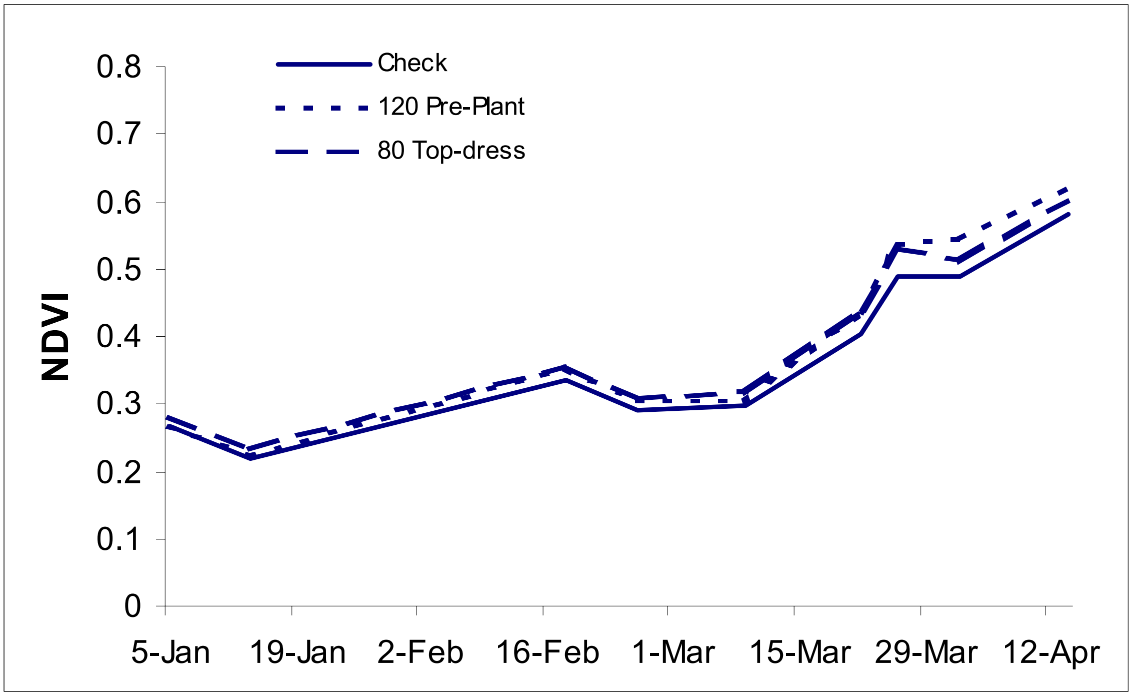

Figure A.8. Observed NDVI readings for the three nitrogen treatments at Lake Carl Blackwell Research Farm, Stillwater Ok. (2004)

VITA

Daryl Brian Arnall

Candidate for the Degree of

Master of Science

Thesis: RELATIONSHIP BETWEEN COEFFICIENT OF VARIATION MEASURED BY SPECTRAL REFLECTANCE AND PLANT DENSITY AT EARLY GROWTH STAGES

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Experience: Employed by Oklahoma State University, Soil Water Forage Analytical Laboratory, 2000-2002,; employed by Oklahoma State University, Department of Plant and Soil Sciences as a graduate research assistant, 2002 to present.

Name: Daryl Brian Arnall Date of Degree: December, 2004

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: RELATIONSHIP BETWEEN COEFFICIENT OF VARIATION MEASURED BY SPECTRAL REFLECTANCE AND PLANT DENSITY AT EARLY GROWTH STAGES

Pages in Study: 42 Candidate for the Degree of Master of Science

Section 1.01 Major Field: Soil Science

Scope and Method of Study: Nitrogen use efficiency (NUE) is estimated to be 33% throughout the world, current precision nitrogen application through precision sensing methods can improve NUE to a level of 50%. Statistical analysis of sensor data has not yet been evaluated for using in improving the prediction of potential yield. This study was conducted to evaluate the effect of plant population on the CV of early season NDVI values. Also evaluated in this study was the effect of seed row direction in relation to sensing direction on NDVI values.

Findings and Conclusions: In 2003-2004 the relationship between the CV of NDVI values and plant population was determined. From this relationship a critical CV value was determined to be 20. Also observed was the trend that CV follows over time. This tend was shown to hold true across nitrogen treatments. Sensing direction was shown to have no effect upon NDVI readings across seven site-years with multiple varieties, seeding rates, nitrogen rates and growth stages.

ADVISOR'S APPROVAL: Dr. William Raun