# EXPRESSION OF SPATIAL VARIABILITY IN CORN (ZEA MAYS L.) AS INFLUENCED BY GROWTH STAGE USING OPTICAL SENSOR MEASUREMENTS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

| | |
|---|---|
| NUE | Nitrogen Use Efficiency |
| CV | Coefficient of Variation |
| N | Nitrogen |
| NDVI | Normalized Difference Vegetative Index = $(\rho_{NIR}-\rho_{Red})/(\rho_{NIR}+\rho_{Red})$ |
| NIR | Near Infrared |
| LCB | Lake Carl Blackwell |
| FWHM | Full Width Half Maximum |

# ABSTRACT

Improving nitrogen use efficiency (NUE) with remote sensing devices is an emerging technology. With the utilization of optical sensors, researchers have demonstrated an ability to consistently improve NUE beyond that of previous N fertilization methods. This study characterized grain yield and biomass yield of corn (*Zea mays* L.) and evaluated the spatial variability of corn growth in terms of normalized difference vegetative index (NDVI). Four rows, 30 m in length were randomly selected for use in this study. A GreenSeeker™ Handheld sensor was used to collect NDVI readings at all possible growth stages during the life cycle of corn. NDVI increased with progression of vegetative growth stages until around V10, where somewhat of a plateau was encountered, followed by a decline in NDVI after the VT growth stage. Coefficient of variation (CV) data from the NDVI readings of each row revealed two dominant peaks during the life cycle of corn, one between the V6 and V8 growth stages and the second during the late reproductive growth stages. The CV data illustrated that the greatest variation expressed by corn during the vegetative growth stages was between the V6 and V8 growth stages. NDVI was found to have the highest correlation with yield at the V7 to V9 growth stages. Coefficient of variation and plant spacing had the highest correlation from the V7 to V9 growth stages and CV had a high negative correlation with grain and biomass yields at all growth stages. As remote sensing technology progresses, results indicate that the V8 growth stage will be vitally important as a physiological stage to best recognize spatial variability for nutrient application in corn.

# INTRODUCTION

Improving nitrogen use efficiency (NUE) has been a great concern to producers and researchers. NUE can be defined as yield per unit of nitrogen (N) available to the plant in the soil and is therefore calculated by dividing the amount of grain or forage production by the amount of N available in the soil (Thomason et al., 2000). Raun and Johnson (1999) explained that NUE for most cereal crops on a worldwide basis is about 33% and calculated the value of the 67% of N that was lost at approximately $15.9 billion annually. To improve the efficiency of N application, Freeney et al. (1995) proposed synchronization of N supply with plant demand to maximize plant uptake and minimize loss. Freeney et al. (1995) reported that applied fertilizer NUE increased when plant uptake was greatest and that foliar N application during this period was an alternative way to supply additional N to a crop. Wuest and Cassman (1992) found that NUE varied depending on the soil N supply, N uptake, developmental stage at which N was applied, and yield potential.

To increase NUE and operate more economically, producers and researchers must manage plant N needs more precisely. The conventional fertilizer management procedure consists of calculating one rate based on the average fertilizer need for the entire field. The rate of N fertilization for corn is calculated by multiplying 1.2 pounds of N by the yield goal and subtracting the amount of N in the soil (Hergert et al., 1995; Schmitt et al., 1998; Franzen, D.W., 2003). The variability within the field causes this single rate to be excessive or inadequate depending on the location in the field (Raun and Johnson, 1999). Solie et al. (1999) defined the spatial resolution at which soil nutrient variability exists as less than 1 $m^2$. With equipment now available to manage fertilizer inputs at this scale, this finding becomes increasingly important. Engineers have developed sensors and application equipment able to recognize and simultaneously apply fertilizer at this scale of <1 $m^2$ while moving through the field at 16 to 25 km $hr^{-1}$.

Having an accurate estimation of yield potential is an integral component in making any fertilizer N management decision, whether it is applying a flat rate of N over an entire field or utilizing the sensor-based applicator to apply N every 1 $m^2$. Crop yield may be expressed simply as a function of all conditions of the growing environment, or growth factors, and any preconceived yield goal or limit set by management (Johnson, 1991). When using precision agriculture equipment at its highest resolution, yield potential in corn may be based on individual plants. At this resolution, the estimation of yield potential should occur when a difference among plants can be discerned and partitioned by the responsiveness of each plant to N fertilizer.

Corn is an important crop in the United States and the world. Currently, corn is the second largest crop produced in the world with 6.02 X $10^8$ MT produced globally and 2.29 X $10^8$ MT produced in the United States (2002 estimates, www.faostat.org). It is important to know and identify any properties of corn that may increase production or decrease the cost of production. Corn seedlings that emerge late can become competitor plants (i.e. weeds) that produce little or no yield and essentially reduce the yield of the entire field (Raun et al., 1986; Nafziger et al., 1991). In a study conducted across Indiana, researchers found that a 0.0254 m (1 in.) increase in the standard deviation of the plant spacing resulted in a 157 kg $ha^{-1}$ (2.5 bushel $acre^{-1}$) reduction in yield (Nielsen, 2001). Nielsen (2001) also summarized the results of evaluating plant spatial variability in 350 commercial corn fields. Approximately 16% of the fields had a plant spacing standard deviation of 0.0762 m (3 in) or less, while 60% of the fields had standard deviations of plant spacing in the range of 0.1016 – 0.127 m (4-5 in). Plant spacing variability of 0.1524 m (6 in) or greater was found in about 24% of the fields. Thus 84% of the locations had standard deviations in excess of 0.1016 m (4 in). Likewise, Krall et al. (1977) found that when two locations were combined over two years, yield significantly decreased as plant spacing standard deviation increased. They also conducted a survey of within-row-variability of plant spacing in three counties in Kansas and found that planting more precisely could increase yields from 200 to 1200 kg $ha^{-1}$ without any change in planting rates. Nafziger et al. (1991) reported planting dates 10-12 days after the optimum decreased yield by 6% and that delaying the planting date to 22 days after the optimum date resulted in a 12% yield loss. They observed that uneven emergence caused a yield depression. When evaluating one of their treatments, they reported that all of the late planted plants at one location were barren. If a plant has a growth stage difference of 2 or more leaves as compared to an adjacent plant, the smaller plant will nearly always be unproductive at the end of the season (Nielsen, 2001). These studies demonstrate the concept of how inherent or imposed variability affects yield on a plot or field basis. This concept could be applied to a section of the field or even one plant if the observer simply magnifies their field of view from a section of the field to an individual plant. Understanding how the planting date (emergence date), plant spacing (distance to the plant's neighbor) and other factors leading to variability needs to be recognized in order to adjust fertilizer inputs.

Having the ability to recognize plant variability after emergence allows producers to make management decisions as to whether or not fertilizer applied will result in increased yield. Based on a 9 year study in Oklahoma, coefficient of variation (CV) for Landsat satellite images of wheat ranged between 16 and 38 % (Washmon et al., 2002). Washmon et al. (2002) also reported that if the within-field CVs could be predicted, the potential response to added nutrients could be established and in-season nutrient applications could be adjusted. Katsvairo et al. (2003) found that plant height measurements, which are correlated with yield in wet years, showed significant spatial variability and later concluded that more work should be done to evaluate its relationship with timing. Raun et al. (1998) detected field variability by using 0.30 x 0.30 m bermudagrass grids to show that large differences are present over small areas.

Coefficient of variation can be described as the ratio of the standard deviation to the mean, expressed in percentage terms, or simply the standard deviation as a proportion of the mean (Freund and Wilson, 2003). The time at which the in-season CVs for a field are at a maximum may be the most critical in making fertilizer management decisions and should be the easiest time to recognize differences in plant characteristics. There are many different methods by which these differences can be measured, but perhaps the most quantitative, precise, and non-destructive tool for evaluating the CV in-season is the GreenSeeker™ optical sensor. Furthermore, the value of this sensor relates directly to its ability to capture a wide range of comprehensive readings that can detect minute changes or differences in plant characteristics.

Sembiring et al. (1998) used a PSD1000 Ocean Optics fiber optic spectrometer to evaluate the relationship of spectral radiance to wheat forage biomass, N, and phosphorus uptake. This study used numerator/denominator indices and showed that numerator wavelengths between 705 and 735 nm and denominator wavelengths between 505 and

545 nm were good predictors of forage biomass, nitrogen, and phosphorus uptake at Feekes growth stages 4 to 6. The study by Sembiring et al. (1998) established and validated the basis for the GreenSeeker™ sensor, which is currently being commercially produced by NTech Industries Inc. (Ukiah, CA). This sensor measures normalized difference vegetative index (NDVI) and was shown by Lukina et al. (2001) to be a reliable predictor of plant N uptake and positively correlated with final grain yield in winter wheat. In earlier work by Lukina et al. (1999), wheat vegetation coverage was estimated using binary pseudo-color images and had a high correlation with NDVI measurements of the wheat canopy. Taylor et al. (1998) showed a variable rate wheat plot with a 60% reduction in fertilizer N produced the same yield as a flat rate plot.

The use of remote sensing technologies has the potential to greatly improve corn fertilization methods and economics of corn production. With the large quantity of corn production around the world, improvements on production practices become increasingly important.

The objectives of this study were to characterize the relation of plant growth, grain yield, biomass yield with the spatial variability of that growth as characterized by NDVI.

# MATERIALS AND METHODS

Two experimental sites were established in the spring of 2003, one at the Stillwater (EFAW) Research Station in Stillwater, Oklahoma on a Easpur loam (fine-loamy, mixed superactive thermic Fluventic Haplustoll) and one at the Lake Carl Blackwell Research Station West of Stillwater, Oklahoma on a Pulaski fine sandy loam soil (coarse-loamy, mixed, nonacid, thermic, Typic Ustifluvent). Each site was planted to corn (*Zea mays* L.) in late March or early April at a rate of approximately 75,000 plants $ha^{-1}$ with a row spacing of 0.76 m. Four rows were randomly identified from a total of 70 to 100 rows at each location and measured to an exact length of 30 m. In 2004, two of the rows at each location had plants removed to establish a plant population of 61,750 plants $ha^{-1}$, while the other two rows were thinned to a lower population of 37,050 plants $ha^{-1}$ (exact plant populations and planting dates are identified in Table 1). A tape measure was used to determine the location of each plant from the beginning of the row and each plant location was recorded.

Spectral reflectance measurements of the crop canopy were measured once for each growth stage (unless rainfall prohibited field access) using a GreenSeeker™ Hand Held Optical Sensor, which resulted in an accumulation of NDVI measurements over time. This patented instrument measures the crop canopy reflectance and calculates NDVI based on a 0.6 x 0.01 m area. For this device to function properly, it was held 0.6 to 1.0 m from the crop canopy. The GreenSeeker™ sensor pulses red and NIR (near-infrared) light using red (660± 10 nm FWHM) and NIR (767± 15 nm FWHM) photodiodes. It also minimizes cloud cover, shadows, and sun angle errors (Raun et al. 2001). The equation for this calculation is as follows:

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

Where:
$\rho_{NIR}$ – Fraction of emitted NIR radiation returned from the sensed area (reflectance)
$\rho_{Red}$ – Fraction of emitted red radiation returned from the sensed area (reflectance)

The sensor outputs 10 readings per second, which are calculated by averaging approximately 1000 measurements per second (100 measurements per output). While sensing corn, a minimum of 5 sensor readings is needed to accurately collect data for each plant. The sensor records a measurement approximately every 0.1 seconds, which translates to a minimum of 0.5 seconds of sensing per plant. For this study, the hand held sensor was held at a constant height of 0.8 to 0.9 m above the crop canopy with the sensor head parallel to the crop row so the sensed area remained uniform. After each day of data collection, the mean NDVI and the CV was calculated for each corn row, growth stage, and sensing date. The growth stages were identified using the classification terms developed at Iowa State University (1993).

When the corn was physiologically mature, each plant was harvested by cutting the plant at ground level and weighing the plant, including ears, for biomass weights (harvest dates are reported in Table 1). The ear or ears were removed from each plant and dried at 75°C for 4 days in a forced air oven and weighed. The kernels were then removed from the ears and weighed. Plant biomass yields and corn grain yields were calculated in units of kg $ha^{-1}$ for each row at each site.

The NDVI and CV data was plotted against time in Figures 1-8. The corn grain yield, biomass yield, and CV of each are reported in Table 2. The mean spacing between plants for each row at each location and the means for each location are located in Table 3.

Coefficients of determination ($R^2$) were calculated to evaluate the relationship between mean NDVI at each vegetative growth stage with mean grain and biomass yields and to analyze the correlation of plant spacing to CV taken at each vegetative growth stage. This analysis was performed using *proc corr* in SAS (SAS, 2002).

# RESULTS AND DISCUSSION

## NDVI Over Time

As Lukina et al. (2001) noted, NDVI can be used as an indirect tool for determining vegetation coverage. By collecting NDVI readings over the same rows throughout the life cycle of corn, the trend of NDVI plotted by date follows the expected progression of vegetation coverage. As the corn plants emerged, the biomass per unit land area was small, and the magnitude of NDVI was very low (Figure 1-4). The average NDVI of all rows at all sites during vegetative growth was lowest at the V3 growth stage. At these early growth stages, a large portion of data was collected from the soil surface. However, as the plants grew and developed, the NDVI rapidly increased (between growth stages V3 and V10) as the canopy covered the soil with overlapping leaves (Figures 1-4). During these stages, it was apparent that the NDVI was proportional to the level of vegetation coverage. This increase was greater in the 2004 crop year than 2003 as a result of more favorable growing conditions (rainfall, temperatures). This was evident because the field of view for the sensor allowed a greater portion of the data to be accumulated on the bare soil surface than on the plant tissue (Figure 1-4).

The change in NDVI values was more stable between the V10 growth stage and the VT growth stage, reaching a maximum value at or just before tasseling. At the point of canopy closure, the sensor was almost exclusively measuring plant material. Therefore, data acquired after canopy closure had almost no red reflected to contribute to the data collected by the sensor and the changes thereafter relied on the NIR collected data until NDVI began to decline. When the tassels were fully emerged, the NDVI decreased due to the yellow tassels. Sensing a corn plant at full tassel depressed NDVI values, which can cause discrepancies with the visual representation of the plant because the collected data included the tassel, which has little chlorophyll. As the plants entered the reproductive stages and senescence occurred on the lower portions of the plant, NDVI decreased more rapidly. As senescence moved to the top of the plant, the NDVI was depressed as low as 0.30. These results are similar to those reported by Raun et al. (2005) in a study conducted near Texacoco, Mexico. Therefore, similar observations may be expected to occur in many production systems in many different locations.

The values of NDVI ranged from approximately 0.35 just after emergence to >0.80 at the highest point after canopy closure (V12 to VT), then decreased to values as low as 0.20 at physiological maturity. This curve follows the expected trend based on the visual appearance of percent vegetation coverage and the occurrence of senescence.

The same trend for NDVI was observed in 2004 as in 2003. The only variation encountered was that the NDVI values of the low population were slightly lower than that of the high population, thus shifting the curve to lower NDVI values.

The use of NDVI collected over time can be used to evaluate the health and biomass of corn plants. Documentation of NDVI over time may have applications for various uses of remote sensors that may be available in the future.

## CV Over Time

Figures 5-8 show the data for each specific site for both years. During the early growth stages (V3 to V4), the NDVI data was generated from the soil surface and a very small portion of plant material. Therefore, CVs for each row were low. The corn rapidly increased with the growth stage of corn in CV values, reaching a maximum value between the V6 and V8 growth stages (Figures 5, 7, and 8). At this peak, the plants accumulated enough vegetation to cover much of the soil surface, but expressed the greatest amount of variability that could be recognized by the sensor. After one to two additional growth stages, a rapid decline followed.

The CVs reached a minimum value at or just before the VT growth stage, followed by another rapid increase in CV (Figures 5-8). These growth stages (V12 to VT) correspond to the time at which the NDVI values reached their highest point as illustrated in Figures 1-4. As a visual determination, the corn at the V10 to V12 growth stage appeared to be at the most uniform stage, as differences were very difficult to recognize. Likewise, the CV data generated over time reached its lowest value just prior to tasseling when complete coverage, leaf overlap and the ability to discern individual plants was no longer possible. Immediately after tasseling, the small peak in CV values expressed in some years (EFAW 2003, EFAW 2004) was likely due to the full expression of the tassels and the different times at which they emerged (Figure 5, 7). The light color, combined with the darker leaves at the top of the plant caused the CV to increase, but the increase was limited because of the small amount of surface area represented by the tassels. This small peak carried over into the early reproductive growth stages (R1 to R2) at the EFAW location.

Some differences occurred between locations although they did follow the same trend. In 2003, the Lake Carl Blackwell location experienced severe wildlife damage. Although the data here appears similar to that of EFAW and the 2004 data, the CV values that were experienced in the other site-years were lower in the late vegetative growth stages and during tasseling except for the low population at Lake Carl Blackwell in 2004 (rows 3 and 4). This damage probably had an effect on the measurements taken after the damage occurred. At Lake Carl Blackwell in 2004, storm damage caused 5 m to be excluded from the middle of rows one and two. Therefore, this section of the row was eliminated from all sensing dates. Although this adjustment was made, the trend for Lake Carl Blackwell in 2004 still followed that of the other sites.

The CV data plotted as a function of time are very similar to that reported by Raun et al. (2005). If differences can be detected and if nutrient application decisions can be made between the V6 and V8 growth stages (early in the rapid nutrient uptake, and while CVs are high), the application will result in greater precision by better recognition of small scale or by-plant differences.

After the reproductive stages, the expressed CV of the NDVI values increased. During these growth stages (R2 to R5), the highest CVs were found. As senescence occurred, the sensor measured NDVI from leaves containing a wide range of green color intensities. The highest CVs were found as the plants approached full maturity, when the senescence neared the top of the plant and the lighter color had a greater impact on NDVI values.

In 2004, the low population exhibited CVs of NDVI values greater than the high population for the entire growth cycle at both locations. The low population also maintained the peak CV values for a longer period of time than in the high population (Figures 7-8). However, the pattern of the low population CV as a function of time continued much like that of the higher population.

Corn Grain and Plant Biomass Yields

The corn grain and plant biomass yields reported in Table 2 were calculated for each row and averaged over each location. *Proc corr* (SAS, 2002) was used to evaluate the relationship between mean NDVI at each growth stage with mean grain yields and mean biomass yields for each row (Table 4). At the early growth stages (V3 to V5), both grain and biomass yields were poorly correlated with NDVI ($R^2$<0.12, P>0.26). During the V6 and V7 growth stages, NDVI was somewhat correlated with grain and biomass yields ($R^2$<0.29, P>0.03). However, from the V8 growth stage to the V12 growth stage, NDVI was highly correlated with grain and biomass yields at P<0.008 and $R^2$ = 0.56 to 0.66 for grain yields and P<0.006 at $R^2$ = 0.59 to 0.66 for biomass yields. The highest relationship was found at the V8 growth stage for both grain and biomass yields ($R^2$ = 0.66).

Since NDVI was highly correlated with grain yield and biomass yield at the V8 growth stage, this would be the appropriate stage to evaluate corn for potential grain yield and biomass estimation. At all locations, the expressed variability was greatest at the V6 to V8 growth stage (high CV) compared to the later growth stages. The V8 growth stage may be the best time to sense corn for optimum yield potential estimation and for expressed spatial variability. The greatest benefit from using the sensor for nutrient application should be found when the greatest differences between plants can be distinguished and the plants can most efficiently utilize added fertilizer. Also, rapid uptake of N, phosphorus, and potassium begin just after the V6 growth stage (V8 to V10), (Iowa State University, 1993). Varvel et al. (1997) used a SPAD meter to find that when the sufficiency index was lower than 90% at the V8 growth stage, added sidedress fertilizer applications did not produce maximum yields because the available N early in the growing season was below that needed for optimum growth. Therefore, the decision to apply added N fertilizer should take place at or before the V8 growth stage.

## Plant Spacing

Arnall (2004) used a GreenSeeker™ hand-held sensor to evaluate the relationship of CV of NDVI readings and the plant density in wheat. They found that CV increased as plant density decreased. Likewise, this study showed that the CV of NDVI measurements was related to plant spacing (Table 4). The stage with the highest correlation of CV to plant spacing was between V7 to V9 ($R^2>0.85$, $P<0.0001$) (Figure 9). At the earlier growth stages (V3 to V6), the correlation was between 0.59 and 0.77. After the V9 growth stage, the $R^2$ decreased from 0.85 to 0.56 at V10 and continued to decrease thereafter. Based on these results, the sensor has the ability to recognize changes in plant spacing as a function of CV from NDVI readings. The relationship decreased dramatically as canopy closure occurred (V10 growth stage), thus suggesting that sensor technology application for assessment of plant spacing should occur before the V10 growth stage.

If sensor technology used in corn based on measurements from high resolution fixed areas, determining the spatial variability within each fixed area via CV generated from remote sensors will be very important. In wheat, integrating the CV component into the fertilizer application system allowed Arnall (2004) to recognize plant stands that would not reach the yield potential determined by NDVI alone. In corn, CV should allow for the indirect estimation of plant spacing, thus revealing those plants that are spaced too far apart to reach maximum yield potential. Plant spacing was related to grain yield ($R^2$ = 0.64, P<0.0002) and biomass yield ($R^2$ = 0.71, P<0.0001) with a negative slope. Therefore, results from this study show that as the plant spacing increases, the grain yield decreases. It could be inferred from the relationships described here that the CV of NDVI readings and the yield of both grain and biomass would be related, which was the case. Grain and biomass yields were related with CV at $R^2$>0.52 and P<0.05 (containing a negative slope) at the vegetative growth stages (V3 to VT) (Table 4), thus showing that the yield decreases as the variability in the corn increases.

## CONCLUSIONS

This study documents the progression of NDVI and CV over time, which is similar to that found in previous studies. The NDVI trend can be used to estimate vegetation coverage throughout the life cycle of corn. The CV data revealed that the growth stage at which remote sensors can identify variations in plant characteristics is centered around the V6 to V7 growth stage, but is still relatively good at recognizing these variations from the V5 to the V8 growth stages. If remote sensing devices are used for management decisions, they must be able to recognize differences between plants to make the best management decisions.

Corn grain and plant biomass yields were found to have the highest correlation with NDVI from the V8 to V12 growth stages. Since remote sensing devices are commonly used to evaluate expressed plant characteristics and ultimately estimate yield potential, the time at which sensors have the greatest correlation with yield is the time at which these sensors should be used. It is convenient that this time frame corresponds to the period of rapid nutrient uptake that could be applied based on information generated from sensors.

Plant spacing has been shown to effect grain yield (Nielsen, 2001) and was highly correlated to the CV from NDVI readings at the V7 to V9 growth stages and decreased at V10. Also, corn grain and biomass yields were negatively correlated with both plant spacing and CV. Therefore, CV of NDVI measurements should be able to improve yield potential estimation above that of NDVI alone. Coefficient of variation could be used to assess the influence of plant spacing on yield or could be used to identify a threshold CV in corn similar to that of Arnall (2004).

By combining the results found from NDVI generated over time, CV over time, yield, and plant spacing, the growth stage at which remote sensors should be used can be made based on the purpose of the sensor data.  For yield potential estimation, many of these factors will be important depending on the development of a yield potential prediction equation.  One common growth stage appears to exist for optimum sensor measurement, the V8 growth stage.  The V8 growth stage combines the ability to recognize variability with high correlation with NDVI and CV to yield and plant spacing to CV.  Therefore, the V8 growth stage should be the ideal growth stage to sense and treat corn to estimate yield potential.

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Table 1. Planting date, harvest date, plant population, and maturity for each location (EFAW and Lake Carl Blackwell) in 2003 and 2004.

| Location | Planting Date | Harvest Date | Plant Population (plants $ha^{-1}$) | Maturity |
|---|---|---|---|---|
| | -------------------------------------------- | 2003 | -------------------------------------------- | |
| EFAW, OK | 3/31/2003 | 8/5/2003 | 51547 | 111 day |
| Lake Carl Blackwell, OK | 4/8/2003 | 8/11/2003 | 30940 | 108 day |
| | -------------------------------------------- | 2004 | -------------------------------------------- | |
| EFAW, OK† | 4/7/2004 | 8/25/2004 | 68186 | 108 day |
| EFAW, OK§ | 4/7/2004 | 8/25/2004 | 37029 | 108 day |
| Lake Carl Blackwell, OK† | 4/3/2004 | 8/2/2004 | 59656 | 108 day |
| Lake Carl Blackwell, OK§ | 4/3/2004 | 8/2/2004 | 36392 | 108 day |

† high plant population of rows 1 and 2 at EFAW and rows 1 and 2 at Lake Carl Blackwell.
§ low plant population of rows 3 and 4 at EFAW and rows 3 and 4 at Lake Carl Blackwell.

Table 2. Mean and CV for corn grain yield and plant biomass yield over each row and averaged for each location (EFAW and Lake Carl Blackwell) in 2003 and 2004.

| Location | Row | Mean ($kg\ ha^{-1}$) | CV (%) | Mean ($kg\ ha^{-1}$) | CV (%) |
|---|---|---|---|---|---|
| | | ---------Corn Grain---------- | | -----------Biomass----------- | |
| EFAW 2003 | 1 | 6480 | 34.6 | 20681 | 35.0 |
| EFAW 2003 | 2 | 6231 | 29.7 | 20839 | 30.0 |
| EFAW 2003 | 3 | 6589 | 35.9 | 21716 | 36.1 |
| EFAW 2003 | 4 | 6954 | 36.0 | 23154 | 36.9 |
| | Mean | 6564 | 34.0 | 21598 | 34.5 |
| LCB 2003 | 1 | 4224 | 46.2 | 11485 | 51.9 |
| LCB 2003 | 2 | 5233 | 31.9 | 13350 | 39.2 |
| LCB 2003 | 3 | 3449 | 43.0 | 18634 | 38.7 |
| LCB 2003 | 4 | 4539 | 51.0 | 10315 | 57.0 |
| | Mean | 4361 | 43.0 | 13446 | 46.7 |
| EFAW 2004† | 1 | 8759 | 33.3 | 25063 | 33.4 |
| EFAW 2004† | 2 | 8943 | 29.6 | 25277 | 37.0 |
| | Mean | 8551 | 31.5 | 25170 | 35.2 |
| EFAW 2004§ | 3 | 6223 | 21.1 | 19726 | 22.2 |
| EFAW 2004§ | 4 | 5806 | 27.2 | 18485 | 33.4 |
| | Mean | 6015 | 24.1 | 19106 | 27.8 |
| LCB 2004† | 1 | 5783 | 42.6 | 20285 | 38.1 |
| LCB 2004† | 2 | 5848 | 45.0 | 18355 | 39.9 |
| | Mean | 5815 | 43.8 | 19320 | 39.0 |
| LCB 2004§ | 3 | 4855 | 31.7 | 14014 | 25.6 |
| LCB 2004§ | 4 | 4094 | 36.3 | 12790 | 35.7 |
| | Mean | 4474 | 34.0 | 13402 | 30.7 |

LCB is the Lake Carl Blackwell research site.

† high plant population of rows 1 and 2 at EFAW and rows 1 and 2 at Lake Carl Blackwell.

§ low plant population of rows 3 and 4 at EFAW and rows 3 and 4 at Lake Carl Blackwell.

Table 3. Mean plant spacing averaged over each row and each location in 2003 and 2004.

| Location | Row | Mean Plant Spacing (cm) |
|---|---|---|
| -----2003----- | | |
| EFAW | 1 | 24.7 |
| EFAW | 2 | 24.4 |
| EFAW | 3 | 26.6 |
| EFAW | 4 | 26.0 |
| | Mean | 25.4 |
| Lake Carl Blackwell | 1 | 45.9 |
| Lake Carl Blackwell | 2 | 40.8 |
| Lake Carl Blackwell | 3 | 39.9 |
| Lake Carl Blackwell | 4 | 43.7 |
| | Mean | 42.6 |
| -----2004----- | | |
| EFAW† | 1 | 20.1 |
| EFAW† | 2 | 18.5 |
| | Mean | 19.3 |
| EFAW§ | 3 | 36.2 |
| EFAW§ | 4 | 34.7 |
| | Mean | 35.5 |
| Lake Carl Blackwell† | 1 | 21.6 |
| Lake Carl Blackwell† | 2 | 20.8 |
| | Mean | 21.2 |
| Lake Carl Blackwell§ | 3 | 35.2 |
| Lake Carl Blackwell§ | 4 | 37.0 |
| | Mean | 36.1 |

† high plant population of rows 1 and 2 at EFAW and rows 1 and 2 at Lake Carl Blackwell.

§ low plant population of rows 3 and 4 at EFAW and rows 3 and 4 at Lake Carl Blackwell.

Table 4. Coefficients of determination ($R^2$) of grain yield, biomass yield, and plant spacing to NDVI and CV of NDVI measurements at growth stages V3 to VT determined using *proc corr* in SAS.

| | Growth Stage | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | V3 | V4 | V5 | V6 | V7 | V8 | V9 | V10 | V12 | VT |
| | NDVI | | | | | | | | | |
| Grain Yield | 0.12$^{NS}$ | 0.00$^{NS}$ | 0.05$^{NS}$ | 0.29$^{**}$ | 0.26$^{**}$ | 0.66$^{***}$ | 0.61$^{***}$ | 0.56$^{***}$ | 0.64$^{***}$ | 0.40$^{**}$ |
| Biomass Yield | 0.02$^{NS}$ | 0.00$^{NS}$ | 0.00$^{NS}$ | 0.20$^{*}$ | 0.19$^{*}$ | 0.66$^{***}$ | 0.64$^{***}$ | 0.61$^{***}$ | 0.59$^{***}$ | 0.42$^{**}$ |
| Plant Spacing | 0.03$^{NS}$ | 0.02$^{NS}$ | 0.01$^{NS}$ | 0.30$^{**}$ | 0.34$^{**}$ | 0.66$^{***}$ | 0.72$^{***}$ | 0.59$^{***}$ | 0.27$^{**}$ | 0.12$^{NS}$ |
| | CV (%) | | | | | | | | | |
| Grain Yield | 0.66$^{**}$ | 0.69$^{***}$ | 0.66$^{**}$ | 0.74$^{***}$ | 0.52$^{**}$ | 0.62$^{***}$ | 0.69$^{***}$ | 0.67$^{***}$ | 0.72$^{***}$ | 0.66$^{***}$ |
| Biomass Yield | 0.61$^{**}$ | 0.76$^{***}$ | 0.77$^{***}$ | 0.74$^{***}$ | 0.62$^{***}$ | 0.66$^{***}$ | 0.72$^{***}$ | 0.69$^{***}$ | 0.79$^{***}$ | 0.69$^{***}$ |
| Plant Spacing | 0.74$^{***}$ | 0.77$^{***}$ | 0.59$^{**}$ | 0.72$^{***}$ | 0.86$^{***}$ | 0.90$^{***}$ | 0.85$^{***}$ | 0.56$^{***}$ | 0.49$^{**}$ | 0.36$^{**}$ |

$^{NS}$, $^{*}$, $^{**}$, $^{***}$ not significant, significant at the 0.10, 0.05, and 0.01 levels, respectively

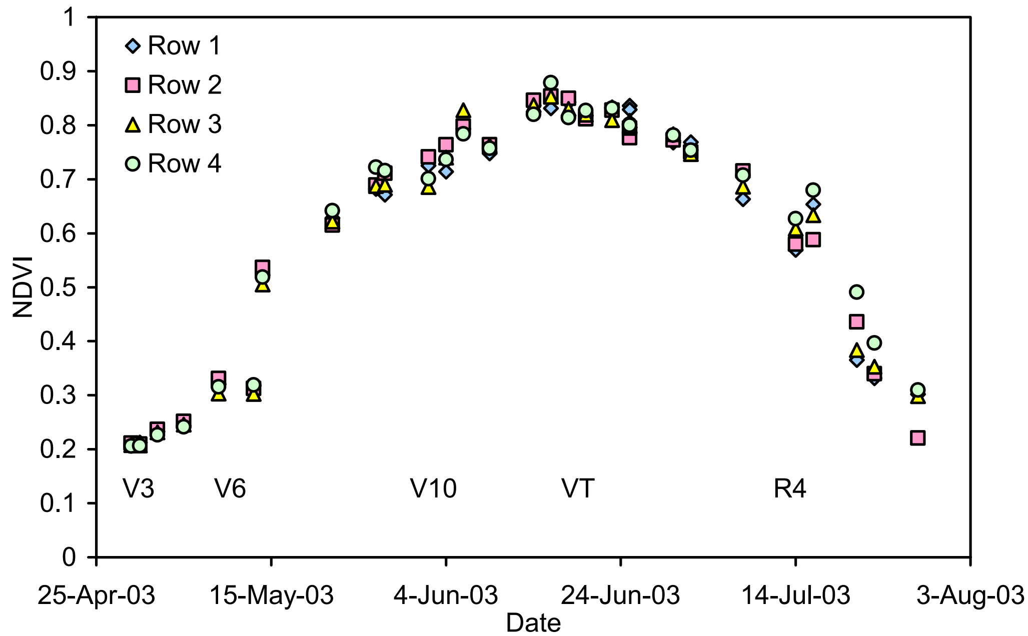


Figure 1. Mean NDVI for each row over time and growth stage at EFAW in 2003.

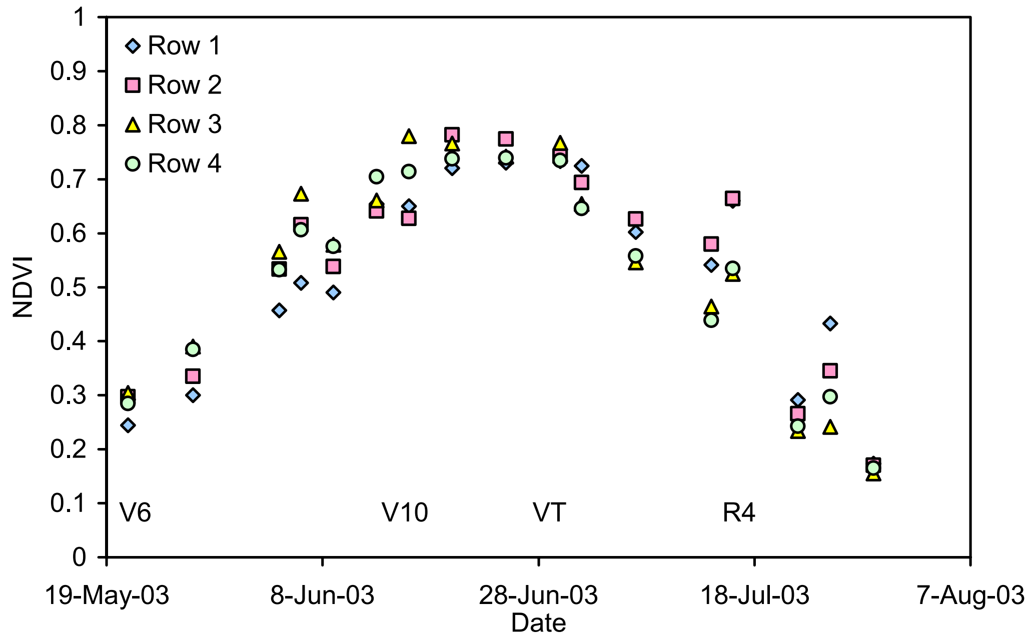


Figure 2. Mean NDVI for each row over time and growth stage at Lake Carl Blackwell in 2003.

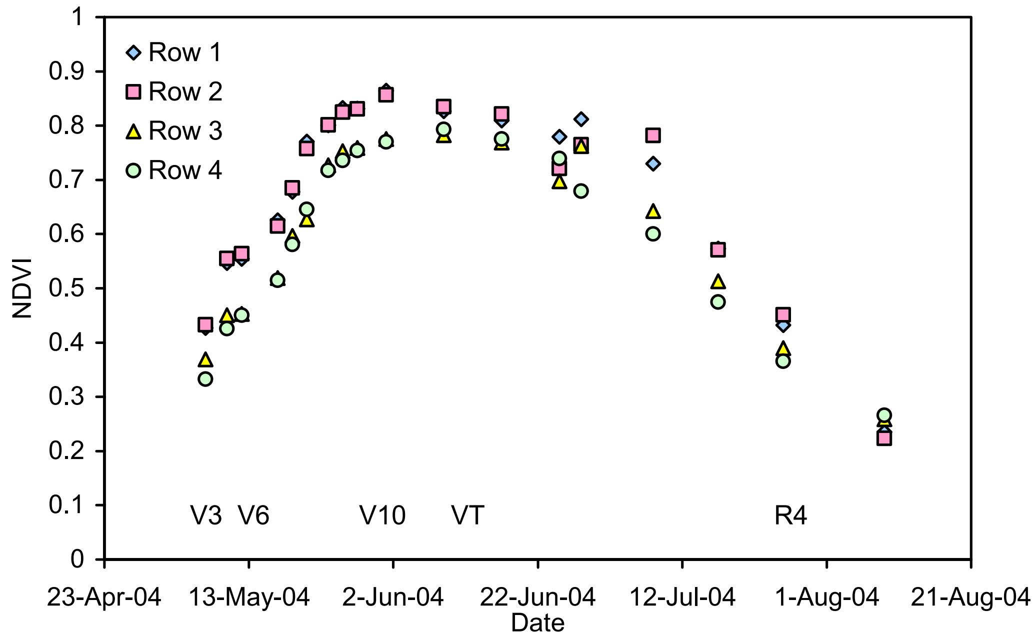


Figure 3. Mean NDVI for each row over time and growth stage at EFAW in 2004.

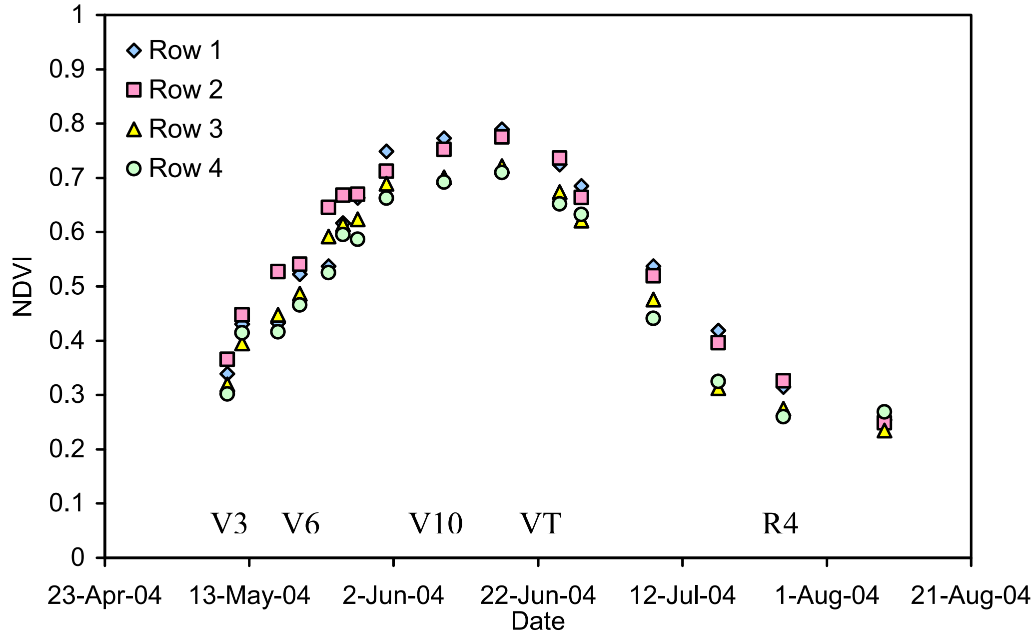


Figure 4. Mean NDVI for each row over time and growth stage at Lake Carl Blackwell in 2004.

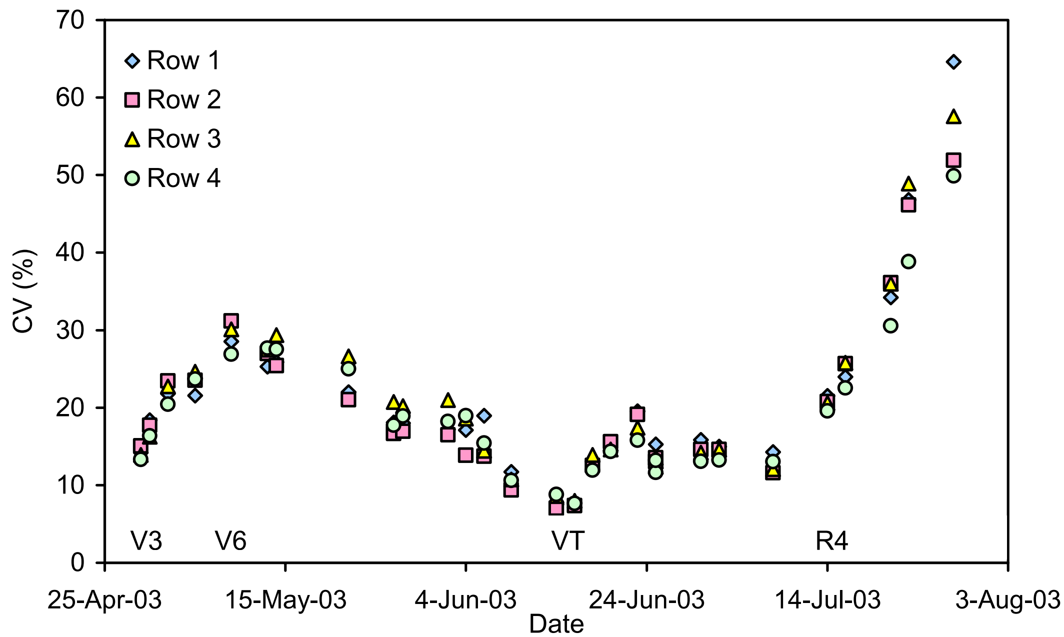


Figure 5. Coefficient of variation for each row over time and growth stage at EFAW in 2003.

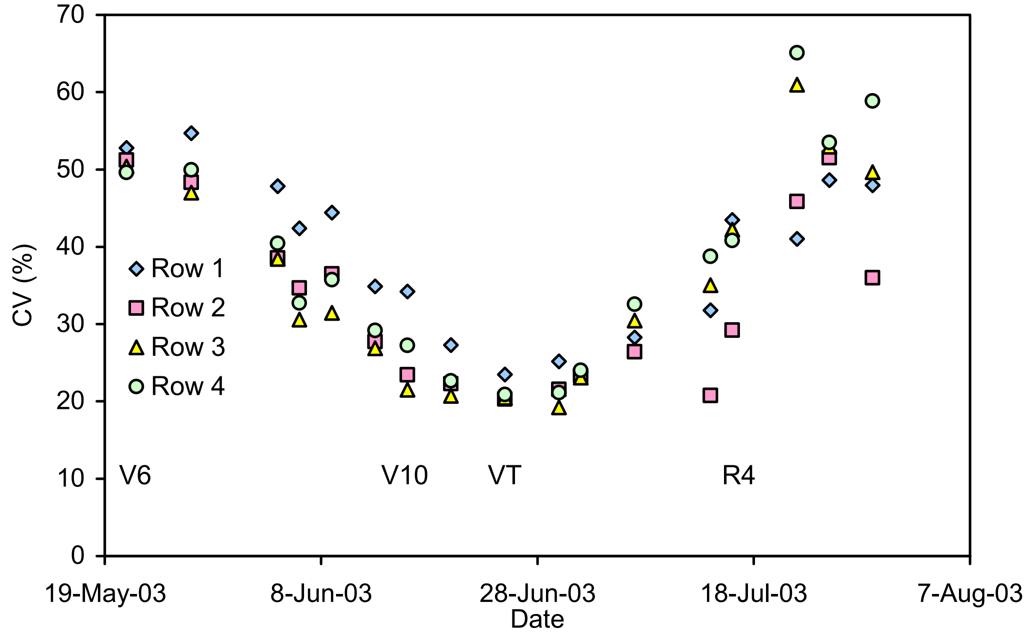

Figure 6. Coefficient of variation for each row over time and growth stage at Lake Carl Blackwell in 2003.

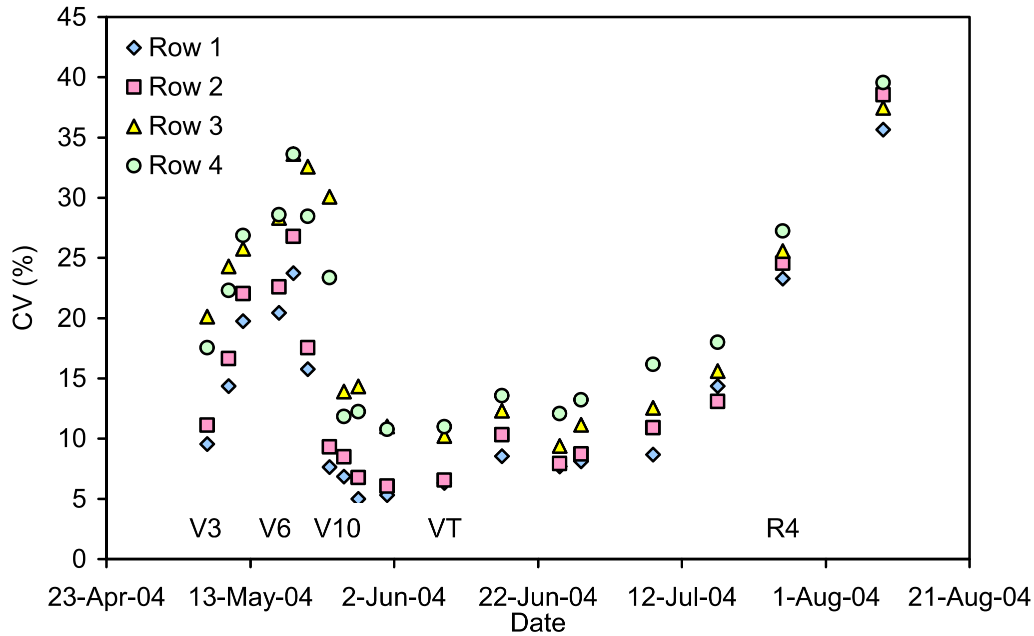


Figure 7. Coefficient of variation of each row over time and growth stage at EFAW in 2004.

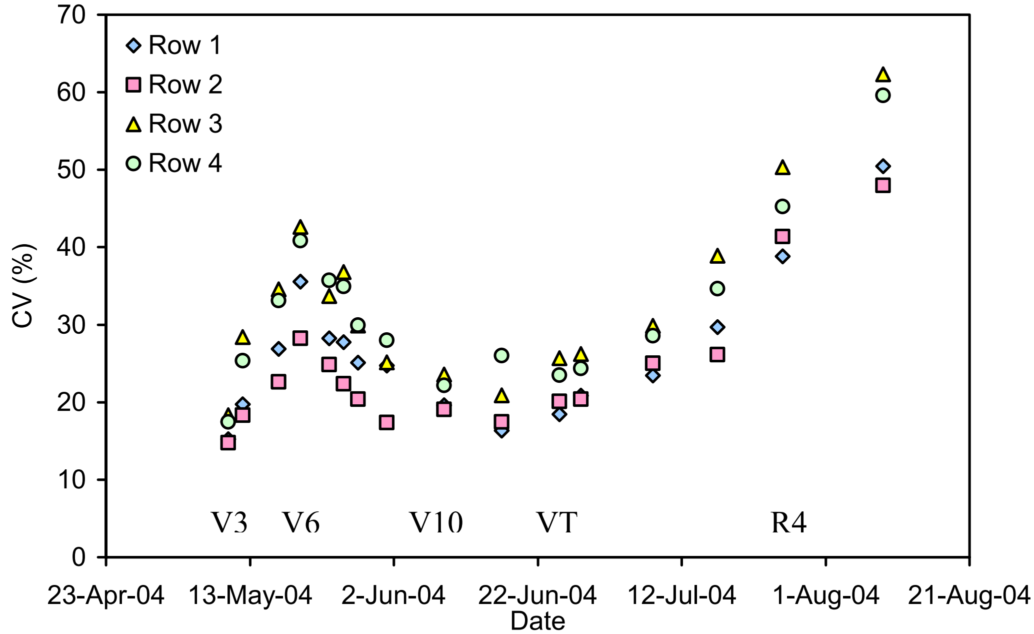


Figure 8. Coefficient of variation of each row over time and growth stage at Lake Carl Blackwell in 2004.

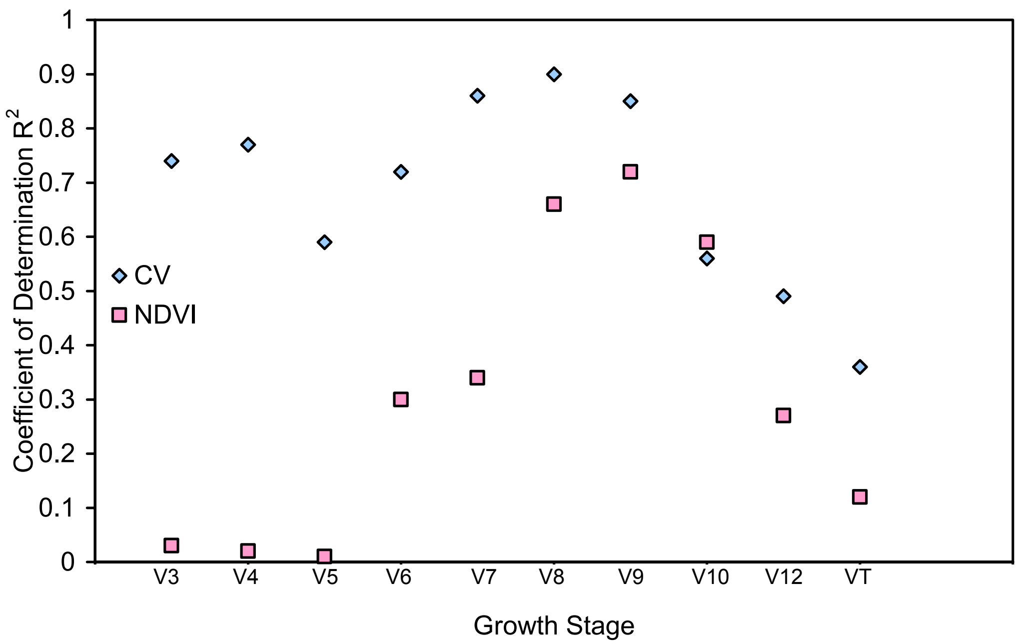


Figure 9. Correlation coefficient (r) of the mean NDVI and mean CV for all rows at all locations with plant spacing at various growth stages.

APPENDIX

Table 5. Growth stage means for NDVI and CV from all rows at each location in 2003 and 2004.

| Growth | --EFAW 2003-- | | ----LCB 2003---- | | --------------EFAW 2004-------------- | | | | -----------------LCB 2004--------------- | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stage | NDVI | CV(%) | NDVI | CV(%) | NDVI | | CV (%) | | NDVI | | CV (%) | |
| V3 | 0.2089 | 14.11 | - | - | 0.4297[†] | 0.3509[§] | 10.35[†] | 18.85[§] | 0.3525[†] | 0.3109[§] | 15.01[†] | 17.90[§] |
| V4 | 0.2204 | 19.65 | - | - | 0.5508 | 0.4382 | 15.50 | 23.29 | 0.4390 | 0.4047 | 19.05 | 26.89 |
| V5 | 0.2456 | 23.36 | - | - | 0.5592 | 0.4517 | 20.90 | 26.31 | 0.4799 | 0.4318 | 24.76 | 33.84 |
| V6 | 0.3175 | 29.18 | 0.2827 | 51.01 | 0.6202 | 0.5169 | 21.51 | 28.46 | 0.5315 | 0.4760 | 31.91 | 41.74 |
| V7 | 0.4167 | 26.95 | 0.3525 | 49.99 | 0.6816 | 0.5888 | 25.27 | 33.62 | 0.6170 | 0.5820 | 25.82 | 35.30 |
| V8 | 0.6268 | 23.66 | 0.5615 | 38.20 | 0.7642 | 0.6365 | 16.67 | 30.52 | 0.6666 | 0.6054 | 22.75 | 29.92 |
| V9 | 0.6962 | 18.41 | 0.5454 | 37.02 | 0.8010 | 0.7224 | 8.48 | 26.73 | 0.7305 | 0.6763 | 21.07 | 26.57 |
| V10 | 0.6452 | 15.71 | 0.6790 | 28.13 | 0.8286 | 0.7443 | 7.67 | 12.87 | 0.7629 | 0.6967 | 19.33 | 22.87 |
| V11 | 0.8008 | 15.64 | - | - | 0.8313 | 0.7567 | 5.88 | 13.28 | - | - | - | - |
| V12 | 0.7964 | 9.30 | 0.7516 | 23.24 | 0.8607 | 0.7728 | 5.68 | 10.90 | 0.7823 | 0.7159 | 16.91 | 23.45 |
| VT | 0.8541 | 7.67 | 0.7466 | 21.28 | 0.8307 | 0.7878 | 6.45 | 10.61 | 0.7307 | 0.6632 | 19.29 | 24.58 |
| R1 | 0.8265 | 13.80 | 0.7445 | 21.77 | 0.8154 | 0.7723 | 9.45 | 12.95 | 0.6748 | 0.6272 | 20.62 | 25.31 |
| R2 | 0.8121 | 14.72 | 0.6315 | 26.50 | 0.6154 | 0.5756 | 6.51 | 9.17 | 0.5283 | 0.4587 | 24.24 | 29.22 |
| R3 | 0.7655 | 14.39 | 0.5058 | 31.58 | 0.5310 | 0.4461 | 9.40 | 12.46 | 0.4075 | 0.3185 | 27.92 | 36.78 |
| R4 | 0.6445 | 16.68 | 0.4272 | 46.08 | 0.4418 | 0.3774 | 23.92 | 26.40 | 0.3203 | 0.2672 | 40.10 | 47.82 |
| R5 | 0.4239 | 39.96 | 0.2477 | 49.88 | 0.2296 | 0.2624 | 37.11 | 38.52 | 0.2514 | 0.2519 | 49.23 | 60.95 |

LCB is the Lake Carl Blackwell research site.
[†] high plant population of rows 1 and 2 at EFAW and rows 1 and 2 at Lake Carl Blackwell.
[§] low plant population of rows 3 and 4 at EFAW and rows 3 and 4 at Lake Carl Blackwell.
- designates growth stages where data was not collected.

Table 6. All NDVI and CV values over the entire row for each sensing date at EFAW in 2003.

| Date | Growth Stage | ---------Row 1--------- | | ---------Row 2--------- | | ---------Row 3--------- | | ---------Row 4--------- | |
|---|---|---|---|---|---|---|---|---|---|
| | | NDVI | CV (%) | NDVI | CV (%) | NDVI | CV (%) | NDVI | CV (%) |
| April 29, 2003 | V3 | 0.2106 | 14.17 | 0.2112 | 15.04 | 0.2078 | 13.89 | 0.2058 | 13.34 |
| April 30, 2003 | V4 | 0.2128 | 18.39 | 0.2094 | 17.74 | 0.2070 | 16.23 | 0.2068 | 16.36 |
| May 2, 2003 | V4 | 0.2327 | 21.80 | 0.2367 | 23.45 | 0.2314 | 22.76 | 0.2266 | 20.44 |
| May 5, 2003 | V5 | 0.2435 | 21.57 | 0.2517 | 23.53 | 0.2457 | 24.63 | 0.2416 | 23.69 |
| May 9, 2003 | V6 | 0.3202 | 28.56 | 0.3308 | 31.16 | 0.3033 | 30.12 | 0.3158 | 26.88 |
| May 13, 2003 | V7 | 0.3178 | 25.30 | 0.3124 | 27.00 | 0.3025 | 27.49 | 0.3194 | 27.66 |
| May 14, 2003 | V7 | 0.5220 | 25.86 | 0.5362 | 25.40 | 0.5050 | 29.37 | 0.5185 | 27.52 |
| May 22, 2003 | V8 | 0.6283 | 22.01 | 0.6151 | 21.00 | 0.6217 | 26.62 | 0.6419 | 24.99 |
| May 27, 2003 | V9 | 0.6820 | 18.08 | 0.6894 | 16.66 | 0.6873 | 20.72 | 0.7225 | 17.74 |
| May 28, 2003 | V9 | 0.6714 | 18.03 | 0.7113 | 16.94 | 0.6897 | 20.18 | 0.7157 | 18.90 |
| June 2, 2003 | V10 | 0.7255 | 17.20 | 0.7411 | 16.48 | 0.6856 | 20.97 | 0.7013 | 18.24 |
| June 4, 2003 | V10 | 0.7138 | 17.11 | 0.7637 | 13.85 | 0.7398 | 18.57 | 0.7364 | 18.97 |
| June 6, 2003 | V11 | 0.7932 | 18.95 | 0.7984 | 13.74 | 0.8276 | 14.44 | 0.7839 | 15.44 |
| June 9, 2003 | V12 | 0.7478 | 11.74 | 0.7636 | 9.36 | 0.7625 | 10.73 | 0.7575 | 10.62 |
| June 14, 2003 | V12 | 0.8363 | 7.52 | 0.8461 | 7.04 | 0.8374 | 8.58 | 0.8199 | 8.79 |
| June 16, 2003 | VT | 0.8311 | 7.70 | 0.8539 | 7.35 | 0.8528 | 7.97 | 0.8786 | 7.64 |
| June 18, 2003 | R1 | 0.8423 | 13.07 | 0.8498 | 12.55 | 0.8299 | 13.90 | 0.8140 | 11.92 |
| June 20, 2003 | R1 | 0.8174 | 14.46 | 0.8115 | 15.60 | 0.8196 | 14.58 | 0.8271 | 14.35 |
| June 23, 2003 | R2 | 0.8329 | 19.55 | 0.8275 | 19.13 | 0.8095 | 17.39 | 0.8313 | 15.78 |
| June 25, 2003 | R2 | 0.8360 | 12.23 | 0.7768 | 13.07 | 0.7986 | 12.36 | 0.8017 | 11.62 |
| June 25, 2003 | R2 | 0.8286 | 15.24 | 0.7948 | 13.54 | 0.8080 | 13.54 | 0.8000 | 13.19 |
| June 30, 2003 | R3 | 0.7680 | 15.84 | 0.7725 | 14.62 | 0.7832 | 14.19 | 0.7816 | 13.09 |
| July 2, 2003 | R3 | 0.7686 | 14.97 | 0.7503 | 14.62 | 0.7464 | 14.55 | 0.7535 | 13.23 |
| July 8, 2003 | R4 | 0.6630 | 14.27 | 0.7154 | 11.59 | 0.6865 | 12.07 | 0.7075 | 13.02 |
| July 14, 2003 | R4 | 0.5692 | 21.50 | 0.5796 | 20.76 | 0.6079 | 20.62 | 0.6272 | 19.57 |
| July 16, 2003 | R5 | 0.6535 | 23.97 | 0.5881 | 25.66 | 0.6337 | 25.78 | 0.6796 | 22.52 |
| July 21, 2003 | R5 | 0.3654 | 34.20 | 0.4359 | 36.12 | 0.3839 | 35.98 | 0.4909 | 30.55 |
| July 23, 2003 | R5 | 0.3317 | 46.82 | 0.3397 | 46.14 | 0.3528 | 48.90 | 0.3966 | 38.81 |
| July 28, 2003 | R5 | 0.3022 | 64.62 | 0.2206 | 51.92 | 0.2985 | 57.57 | 0.3096 | 49.87 |

Table 7. All NDVI and CV values over the entire row for each sensing date and growth stage at Lake Carl Blackwell in 2003.

| Date | Growth Stage | ---------Row 1--------- | | ---------Row 2--------- | | ---------Row 3--------- | | ---------Row 4--------- | |
|---|---|---|---|---|---|---|---|---|---|
| | | NDVI | CV (%) | NDVI | CV (%) | NDVI | CV (%) | NDVI | CV (%) |
| May 21, 2003 | V6 | 0.2443 | 52.80 | 0.2974 | 51.23 | 0.3044 | 50.38 | 0.2848 | 49.62 |
| May 27, 2003 | V7 | 0.3001 | 54.67 | 0.3353 | 48.32 | 0.3900 | 47.01 | 0.3847 | 49.94 |
| June 4, 2003 | V8 | 0.4571 | 47.83 | 0.5335 | 38.55 | 0.5653 | 38.42 | 0.5325 | 40.43 |
| June 6, 2003 | V8 | 0.5080 | 42.39 | 0.6157 | 34.66 | 0.6733 | 30.59 | 0.6065 | 32.75 |
| June 9, 2003 | V9 | 0.4900 | 44.41 | 0.5380 | 36.49 | 0.5783 | 31.43 | 0.5752 | 35.74 |
| June 13, 2003 | V10 | 0.6544 | 34.88 | 0.6410 | 27.75 | 0.6607 | 26.86 | 0.7045 | 29.16 |
| June 16, 2003 | V10 | 0.6503 | 34.20 | 0.6277 | 23.46 | 0.7795 | 21.51 | 0.7138 | 27.25 |
| June 20, 2003 | V12 | 0.7206 | 27.27 | 0.7819 | 22.30 | 0.7659 | 20.73 | 0.7380 | 22.67 |
| June 25, 2003 | VT | 0.7304 | 23.47 | 0.7744 | 20.30 | 0.7418 | 20.46 | 0.7396 | 20.89 |
| June 30, 2003 | R1 | 0.7333 | 25.19 | 0.7425 | 21.54 | 0.7676 | 19.24 | 0.7345 | 21.12 |
| July 2, 2003 | R2 | 0.7248 | 23.82 | 0.6941 | 23.33 | 0.6545 | 23.09 | 0.6461 | 24.02 |
| July 7, 2003 | R2 | 0.6024 | 28.27 | 0.6263 | 26.40 | 0.5461 | 30.45 | 0.5579 | 32.58 |
| July 14, 2003 | R3 | 0.5409 | 31.77 | 0.5796 | 20.76 | 0.4641 | 35.06 | 0.4386 | 38.74 |
| July 16, 2003 | R4 | 0.6603 | 43.45 | 0.6641 | 29.24 | 0.5248 | 42.23 | 0.5344 | 40.80 |
| July 22, 2003 | R4 | 0.2912 | 41.01 | 0.2660 | 45.87 | 0.2338 | 60.96 | 0.2429 | 65.07 |
| July 25, 2003 | R5 | 0.4329 | 48.64 | 0.3450 | 51.51 | 0.2418 | 52.97 | 0.2973 | 53.47 |
| July 29, 2003 | R5 | 0.1737 | 47.95 | 0.1707 | 35.97 | 0.1552 | 49.67 | 0.1653 | 58.84 |

Table 8. All NDVI and CV values over the entire row for each sensing date and growth stage at EFAW in 2004.

| Date | Growth Stage | ---------Row 1--------- | | ---------Row 2--------- | | ---------Row 3--------- | | ---------Row 4--------- | |
|---|---|---|---|---|---|---|---|---|---|
| | | NDVI | CV | NDVI | CV | NDVI | CV | NDVI | CV |
| May 7, 2004 | V3 | 0.4266 | 9.57 | 0.4327 | 11.12 | 0.3691 | 20.13 | 0.3326 | 17.56 |
| May 10, 2004 | V4 | 0.5466 | 14.35 | 0.5550 | 16.65 | 0.4507 | 24.28 | 0.4257 | 22.29 |
| May 12, 2004 | V5 | 0.5545 | 19.76 | 0.5638 | 22.04 | 0.4529 | 25.74 | 0.4505 | 26.87 |
| May 17, 2004 | V6 | 0.6256 | 20.44 | 0.6148 | 22.58 | 0.5188 | 28.33 | 0.5150 | 28.59 |
| May 19, 2004 | V7 | 0.6780 | 23.74 | 0.6851 | 26.79 | 0.5968 | 33.64 | 0.5807 | 33.60 |
| May 21, 2004 | V8 | 0.7705 | 15.78 | 0.7578 | 17.56 | 0.6273 | 32.57 | 0.6457 | 28.47 |
| May 24, 2004 | V9 | 0.8006 | 7.64 | 0.8014 | 9.32 | 0.7271 | 30.08 | 0.7177 | 23.37 |
| May 26, 2004 | V10 | 0.8326 | 6.84 | 0.8246 | 8.49 | 0.7527 | 13.90 | 0.7359 | 11.83 |
| May 28, 2004 | V11 | 0.8316 | 4.99 | 0.8310 | 6.77 | 0.7591 | 14.33 | 0.7543 | 12.23 |
| June 1, 2004 | V12 | 0.8646 | 5.32 | 0.8568 | 6.04 | 0.7756 | 11.02 | 0.7699 | 10.77 |
| June 9, 2004 | VT | 0.8266 | 6.33 | 0.8348 | 6.56 | 0.7824 | 10.23 | 0.7932 | 10.99 |
| June 17, 2004 | R1 | 0.8096 | 8.56 | 0.8212 | 10.33 | 0.7690 | 12.33 | 0.7756 | 13.56 |
| June 25, 2004 | R2 | 0.7793 | 7.71 | 0.7209 | 7.95 | 0.6978 | 9.41 | 0.7391 | 12.08 |
| June 28, 2004 | R2 | 0.8122 | 8.13 | 0.7648 | 8.74 | 0.7622 | 11.14 | 0.6790 | 13.21 |
| July 8, 2004 | R3 | 0.7298 | 8.67 | 0.7817 | 10.90 | 0.6425 | 12.56 | 0.6003 | 16.17 |
| July 17, 2004 | R3 | 0.5729 | 14.36 | 0.5705 | 13.09 | 0.5132 | 15.60 | 0.4744 | 17.99 |
| July 26, 2004 | R4 | 0.4322 | 23.27 | 0.4513 | 24.56 | 0.3895 | 25.56 | 0.3653 | 27.24 |
| August 9, 2004 | R5 | 0.2355 | 35.65 | 0.2236 | 38.56 | 0.2587 | 37.47 | 0.2660 | 39.56 |

Table 9. All NDVI and CV values over the entire row for each sensing date and growth stage at Lake Carl Blackwell in 2004.

| Date | Growth Stage | ---------Row 1--------- | | ---------Row 2--------- | | ---------Row 3--------- | | ---------Row 4--------- | |
|---|---|---|---|---|---|---|---|---|---|
| | | NDVI | CV | NDVI | CV | NDVI | CV | NDVI | CV |
| May 10, 2004 | V3 | 0.3392 | 15.23 | 0.3657 | 14.79 | 0.3197 | 18.32 | 0.3021 | 17.48 |
| May 12, 2004 | V4 | 0.4302 | 19.74 | 0.4478 | 18.35 | 0.3951 | 28.40 | 0.4143 | 25.37 |
| May 17, 2004 | V5 | 0.4327 | 26.89 | 0.5271 | 22.63 | 0.4473 | 34.56 | 0.4162 | 33.12 |
| May 20, 2004 | V6 | 0.5225 | 35.56 | 0.5404 | 28.26 | 0.4863 | 42.62 | 0.4657 | 40.85 |
| May 24, 2004 | V7 | 0.5371 | 28.25 | 0.6459 | 24.88 | 0.592 | 33.70 | 0.5254 | 35.74 |
| May 26, 2004 | V7 | 0.6167 | 27.76 | 0.6682 | 22.39 | 0.6146 | 36.80 | 0.5958 | 34.94 |
| May 28, 2004 | V8 | 0.6632 | 25.10 | 0.6699 | 20.40 | 0.6238 | 29.91 | 0.5869 | 29.93 |
| June 1, 2004 | V9 | 0.7489 | 24.74 | 0.7120 | 17.39 | 0.6895 | 25.15 | 0.6630 | 27.99 |
| June 9, 2004 | V10 | 0.7732 | 19.60 | 0.7526 | 19.06 | 0.7012 | 23.58 | 0.6921 | 22.16 |
| June 17, 2004 | V12 | 0.7893 | 16.35 | 0.7752 | 17.47 | 0.7215 | 20.88 | 0.7102 | 26.02 |
| June 25, 2004 | VT | 0.7248 | 18.48 | 0.7365 | 20.10 | 0.6741 | 25.68 | 0.6523 | 23.48 |
| June 28, 2004 | R1 | 0.6854 | 20.85 | 0.6641 | 20.39 | 0.6215 | 26.24 | 0.6328 | 24.37 |
| July 8, 2004 | R2 | 0.5369 | 23.47 | 0.5196 | 25.01 | 0.4761 | 29.87 | 0.4412 | 28.56 |
| July 17, 2004 | R3 | 0.4185 | 29.68 | 0.3965 | 26.15 | 0.3124 | 38.91 | 0.3246 | 34.65 |
| July 26, 2004 | R4 | 0.3147 | 38.81 | 0.3258 | 41.38 | 0.2746 | 50.36 | 0.2598 | 45.27 |
| August 9, 2004 | R5 | 0.2541 | 50.47 | 0.2486 | 47.99 | 0.2348 | 62.32 | 0.2689 | 59.58 |

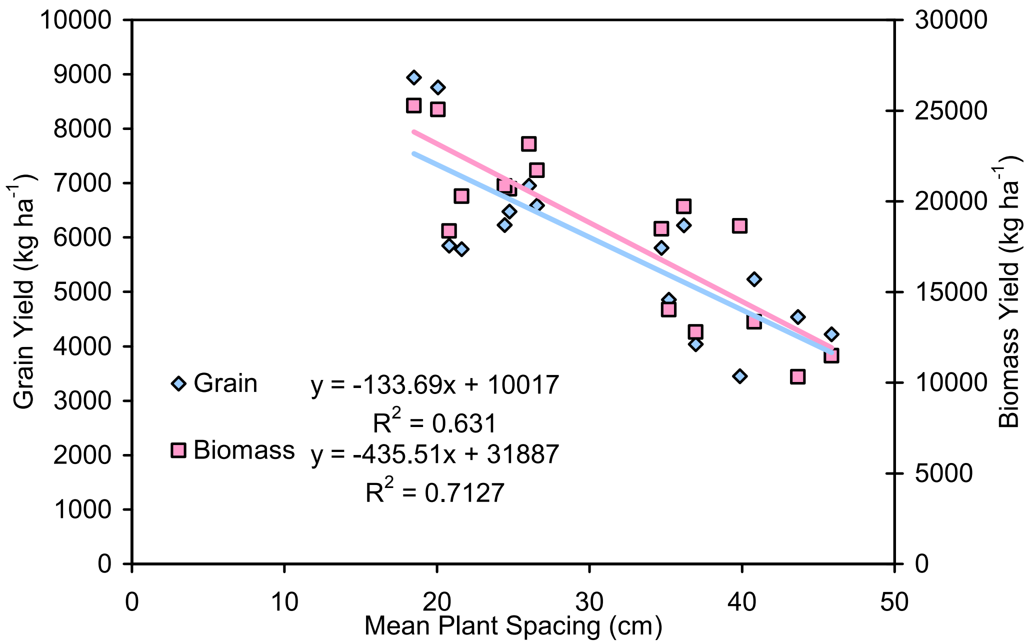


Figure 10. Correlation of plant spacing with both grain yield and biomass yield for all rows at all locations.

VITA

Kent L. Martin

Candidate for the Degree of

Master of Science

Thesis: EXPRESSION OF SPATIAL VARIABILITY IN CORN (ZEA MAYS L.) AS INFLUENCED BY GROWTH STAGE USING OPTICAL SENSOR MEASUREMENTS

Major Field: Plant and Soil Sciences

Biographical:

Personal Data: Born in Enid, Oklahoma on July 11, 1980.

Education: Graduated from Alva High School, Alva, Oklahoma in May of 1998; attended Northwestern Oklahoma State University, Alva, Oklahoma for two years, and received Bachelors of Science degree in December 2002. Completed the requirements for Master of Science degree with a major in Plant and Soil Sciences at Oklahoma State University in May 2005.

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Name: Kent L. Martin Date of Degree: May, 2005

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: EXPRESSION OF SPATIAL VARIABILITY IN CORN (ZEA MAYS L.) AS INFLUENCED BY GROWTH STAGE USING OPTICAL SENSOR MEASUREMENTS

Pages in Study: 41 Candidate for the Degree of Master of Science

Major Field: Soil Science

Scope and Method of Study: The time at which remote sensing technology can quantify differences in corn plants should be the time at which the CV of the measured data is the highest. At that growth stage, the corn produces the greatest amount of expressed variability. The relationship of NDVI with grain and biomass yields can be used to determine the most appropriate time for management based on sensor technology. Also, if sensors have the ability to indirectly determine plant spacing and to determine the CV of data collected, it could greatly improve yield prediction based on NDVI alone over fixed distances.

Findings and Conclusions: The documentation of CV over time in corn produced similar trends over all years and locations in which the initial peak in CV occurred around the V6 to V7 growth stage. A second peak also occurred in the late reproductive growth stages. Based on these results, the peak at V6 to V7 is the growth stage at which the greatest amount of variability is expressed by corn. The relationship if NDVI to grain and biomass yields showed that the V8 growth stage had the highest correlation with yield. It was also found that CV is positively related to plant spacing. This study showed that the best time to recognize variability, predict grain and biomass yields, and determine plant spacing is at the V8 growth stage.

ADVISOR'S APPROVAL: Dr. William Raun