# SPATIAL PATTERNS OF NITROGEN RESPONSE WITHIN CORN PRODUCTION FIELDS

**J.L. Hatfield**

USDA-ARS
National Soil Tilth Laboratory
2110 University Blvd
Ames, Iowa

## ABSTRACT

Corn (*Zea mays* L.) yield response to nitrogen (N) application is critical to being able to develop management practices that reduce N application or improve N use efficiency. Nitrogen rate studies have been conducted within small plots; however, there have been few field scale evaluations. This study was designed to evaluate N response across 14 corn fields in central Iowa using different rates of N applied in strips across fields. These fields ranged in size from 15 to 130 ha with N rates that typically ranged from 50 to 150 kg $ha^{-1}$. Some fields had three rates of N while others had four rates that included a 200 kg $ha^{-1}$ application rate. Within each field strips were randomized and treated as replicates and were a minimum of 50 m wide. Observations were made of the soil type, topography obtained with GPS units, leaf chlorophyll readings at three times during the season for 30 leaves from each strip, hyperspectral data obtained with aircraft scanners with a pixel size of 2 m at four times, and crop yield with the combine yield monitor. All data were georeferenced for each field and subjected to a number of statistical and spatial analyses. There was a nonsignificant relationship between yield and N application rate in this study because yield to N response varied among fields. There was a significant relationship with soil type across the study because of the effect of soil water availability during the late grain-fill period. Crop yield showed the same general frequency distribution for different N rates within a field; however, the lower N rates had a greater dispersion than the higher N rates. Higher N rates did not make the field more uniform. A similar response was found for the normalized difference vegetative index (NDVI), nir/red, and red/green ratios in which the NDVI showed little variation at any of the N rates and didn't change during the season. The red/green ratio was the most responsive to different times during the season and showed a significant correlation to yield. The spatial patterns of these vegetative indices showed that during the mid-season there was little variation. The spatial patterns within a field reveal information about the potential response of a field to management.

**Keywords:** Spatial patterns, remote sensing, nitrogen response, soil variation

## INTRODUCTION

Crop yield response to nitrogen (N) has been the focus of numerous agronomic studies for the past decades. These studies have been primarily conducted on small plots under relatively controlled conditions; however, the advent of systems to apply nitrogen across fields has opened up new possibilities for quantifying the N response across fields. Detection of N stress in crop plants through leaf color has created opportunities for field-scale evaluation of N response. Some of the methods that have been employed for N management have used the Soil-Plant Analyses Development (SPAD) chlorophyll meter, color photography, or canopy reflectance factors to assess N variation across corn fields (Schepers et al., 1992; 1996; Blackmer et al., 1993, 1994, 1996a, 1996b; Blackmer and Schepers, 1996). The application of these methods based on comparisons within the field from observations from an adequately-fertilized strip in the same field. This approach was used to eliminate the requirements for prior knowledge of the relationship between nutrient concentration and crop reflectance.

There have continued to be advances in the use of remote sensing methods to estimate N status in crops. Lee et al. (2008) used a single waveband at 0.735 μm to quantify N status in rice (*Oryza sativa* L.). In their method they used the first derivative of the reflectance at 0.735 μm as difference of the reflectance at 0.74 – 0.73 μm and dividing by 10. They found this is be as accurate as other indices including the normalized difference vegetative index (NDVI) expressed as $(R_{NIR} - R_{RED})/(R_{NIR} - R_{RED})$ where $R_{NIR}$ reflectance in the near-infrared waveband (0.78 – 0.79 μm) and $R_{RED}$ the reflectance in the 0.61 – 0.68 μm waveband. They also compared a simple ratio vegetative index expressed as $R_{NIR}/R_{RED}$. They used these wavelengths to create maps of canopy N status across fields at the panicle formation stage. They showed the variation in canopy N status but didn't evaluate the spatial patterns within fields.

Spatial analysis of field scale changes have recently been evaluated by Inman et al. (2008). They determined the relationship between early season NDVI, soil color-based management zones, and relative corn (*Zea mays* L.) yields. Values of NDVI were collected at the eight-leaf growth stage and regression models explained between 25 to 82% of the variability in relative yield where relative yield was defined as the ratio of the observed yield to the maximum yield for the field as defined by Brouder et al. (2000). Inman et al. (2008) found coupling NDVI with the color-based soil zones didn't increase the ability to explain yield within the field. A complimentary study was conducted by Massey et al. (2008) in which they analyzed 10 years of site-specific data for corn, soybean (*Glycine max* (L.) Merr.), and grain sorghum (*Sorghum bicolor* L.) for a 36.5 ha field in central Missouri with claypan soils. They developed profitability maps for the field and found that large areas of the field had negative profit due to areas of the field in which there was significant topsoil erosion.

There have been several studies that have related remote sensing indices to crop yield and detection of N status in plant leaves; however, there has been little research on the spatial patterns within the field that could lead to improved understanding of the changes that occur within the growing season. This study was conducted to evaluate the spatial patterns within fields that were being studied as part of a N evaluation study. The objective of this study was to evaluate the spatial patterns within different fields observed by remote sensing and yield maps collected at harvest with yield monitors to determine the information content contained in spatial analyses of agricultural fields.

## MATERIALS AND METHODS

Experiments were conducted in 14 different fields located in central Iowa from 2000 to 2002 (Table 1). These fields varied in size from 15 to 130 ha. The experimental design for each of the field experiments was very similar with strips arranged in the field with different N rates and in three of the study fields, variable planting rates were also used as a treatment variable. The strips were a minimum of 50 m wide covering at least 60 rows of corn. The arrangement for the N treatments was randomized across the field and strips were treated as replicates. When planting rates were used these were treated a blocks with N rates as subplots within a block. Planting rates were also randomized across the field. In each field the same corn hybrid was planted; however, hybrids varied among fields and years. A typical field layout is shown in Figure 1 for the Coon Rapids field in 2002.

Soil map units were extracted from the soil survey data and detailed topographic data were collected with GPS equipment for each field. Soil nutrient content data were collected from each field for the upper 1 m of the profile for a minimum of 30 locations within each field prior to the growing season. During the season, leaf chlorophyll readings were collected from 30 leaves in each treatment using a SPAD meter and these were collected at three times, prior to tasselling, beginning grain fill, and mid-grain fill. Yield data were obtained from each field using yield monitors on the producers combine and these were calibrated prior to harvest. Yields were corrected to 15.5% grain moisture content.

Table 1. Nitrogen rates and associated agronomic parameters for the field experiments from 2000 to 2002.

| **Year/Field** | **Nitrogen Rate (kg/ha)** | **Agronomic Variables** |
|---|---|---|
| 2000/Carroll 1 | 70, 116, 162, 210 | 72,000 plants/ha |
| 2000/Carroll 2 | 70, 116, 162, 210 | 72,000 plants/ha |
| 2000/Sac | 70, 116, 162, 210 | 72,000 plants/ha |
| 2000/Shelby | 70, 116, 162, 210 | 72,000 plants/ha |
| 2000/Story 1 | 52, 100, 145 | 72,000 plants/ha |
| 2000/Story 2 | 52, 100, 145, 191 | 72,000 plants/ha |
| 2001/Story 1 | 133, 180 | 75,000 plants/ha |
| 2001/Story 2 | 51, 102, 144 | 75,000 plants/ha |
| 2000/Story 3 | 57, 126, 173 | 75,000 plants/ha |
| 2002/Calhoun East | 60, 103, 146 | 79,000 plants/ha |
| 2002/Dallas South | 60, 103, 146 | 79,000 plants/ha |
| 2002/Calhoun West | 60, 95, 130 | 63,500; 76,000; 85,000 plants/ha |

| | | |
|---|---|---|
| 2002/Dawson | 69, 112, 155 | 57,000; 69,200; 81,500 plants/ha |
| 2002/Coon Rapids | 52, 103, 155 | 57,000; 69,200; 81,500 plants/ha |

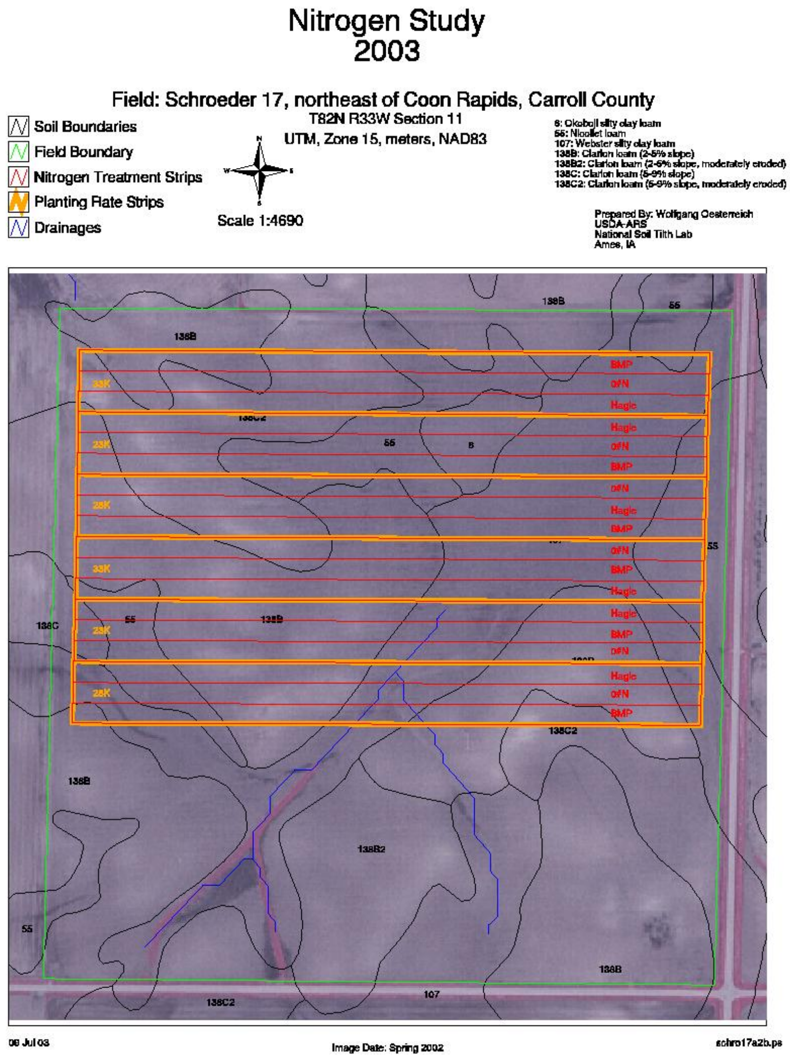


Figure 1. Field layout for the nitrogen experiment conducted across production scale fields in central Iowa.

Remote sensing observations for each field were obtained from an aircraft based hyperspectral unit with 35 wavebands (Table 2). Data were obtained on clear days at four times during the growing season, May, July, August, and September. These times were selected to obtain data after planting and before there was sufficient growth to affect the soil background (May), maximum vegetative growth (July), mid-grain fill (August), and near physiological maturity (September). The pixel sizes were nominally 2 x 2 m across the study sites. These data were collected with GPS signals to provide a location of each pixel and these were georeferenced to the yield data and other parameters collected from each field.

Table 2. Wavebands and bandwidth for the hyperspectral data collected over the field sites in 2000 to 2002.

| Band Number | Center Wavelength (µm) | Band Width (µm) | Band Number | Center Wavelength (µm) | Band Width (µm) | Band Number | Center Wavelength (µm) | Band Width (µm) |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.426 | 0.003 | 13 | 0.681 | 0.006 | 25 | 0.797 | 0.006 |
| 2 | 0.445 | 0.006 | 14 | 0.689 | 0.006 | 26 | 0.805 | 0.006 |
| 3 | 0.506 | 0.006 | 15 | 0.698 | 0.006 | 27 | 0.819 | 0.005 |
| 4 | 0.520 | 0.006 | 16 | 0.707 | 0.006 | 28 | 0.826 | 0.005 |
| 5 | 0.530 | 0.006 | 17 | 0.715 | 0.006 | 29 | 0.833 | 0.005 |
| 6 | 0.540 | 0.006 | 18 | 0.724 | 0.006 | 30 | 0.851 | 0.005 |
| 7 | 0.549 | 0.006 | 19 | 0.734 | 0.006 | 31 | 0.860 | 0.006 |
| 8 | 0.561 | 0.006 | 20 | 0.743 | 0.006 | 32 | 0.869 | 0.006 |
| 9 | 0.580 | 0.006 | 21 | 0.755 | 0.006 | 33 | 0.880 | 0.006 |
| 10 | 0.599 | 0.006 | 22 | 0.766 | 0.006 | 34 | 0.890 | 0.006 |
| 11 | 0.620 | 0.006 | 23 | 0.774 | 0.006 | 35 | 0.899 | 0.006 |
| 12 | 0.639 | 0.006 | 24 | 0.785 | 0.006 | | | |

Data were analyzed both on the individual N strip within the field and across the complete field. Vegetative indices were computed from the reflectance data obtained from the aircraft data and correlated to both strip yield and field corn yield observations. Correlations were conducted between N rate and corn yield for each individual field and across all fields for each year of the study. Spatial analysis was conducted for each field using GS+ version 5.1 to determine the spatial relationships among yield and the vegetative indices across different fields.

## RESULTS AND DISCUSSION

Corn yield response to N applications did not exhibit a consistent response among the different fields and among years (Fig. 2) and overall the relationship was nonsignificant. There were fields that showed an increase in grain yield with N application while others showed either no response or a negative response to N. These fields covered a wide range of soils within the fields. The correlation between N rate and soil type across the different fields was significant ($r = 0.38$, $p > 0.05$). Variation among the strips within each field showed a small variation; however, the variation was no sufficient to cause any change in the relationship for a given field. Understanding that N response is not consistent among the different fields creates questions about reasons for the types of responses observed among the fields. The lack of a consistent response was further evaluated and there were differences among soils within a field that was related to soil water holding capacity (Fig. 3). These data were collected across a single field as part of another study conducted by Hatfield and Prueger (2001) to evaluate crop water use patterns to N application and soils types. These results show that soils with a higher water holding capacity (Webster, Nicollet) had a different response to N compared to soils with lower water holding capacity (Clarion, Canisteo). Even though the studies were conducted at a different location the soils were similar to those encountered in the N studies so these results help explain the results shown in Fig. 2. These results are similar to those reported by Massey et al. (2008) in which the eroded soils had the lower yields and in this study the lower yields were associated with the soils with the lower water holding capacity.

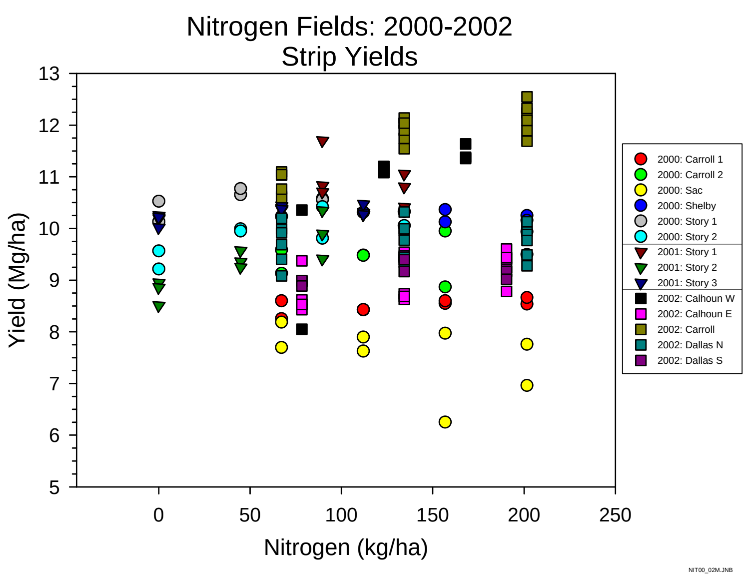


Figure 2. Corn yield response to applied nitrogen in different fields in central Iowa from 2000 to 2002.

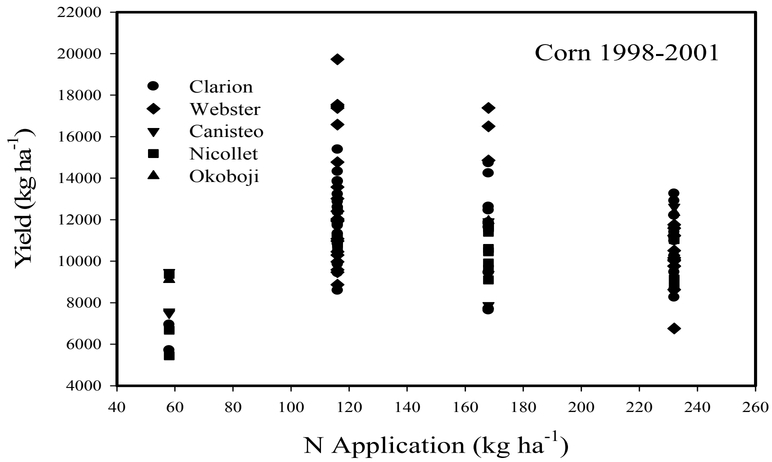


Figure 3. Corn yield response to applied nitrogen across five different soils for a field in central Iowa for 1998 to 2001.

Variation of yields within corn fields revealed that the frequency distribution of yields covered a wide range (Figs. 4, 5, and 6). These distributions were observed from the three different N rates used within Coon Rapids field and are similar to the fields evaluated in this study. In all fields the lower N rate had a lower mean yield but a similar maximum yield to the other N rates; however, the distribution showed a wider dispersion and more variation. As the N rate increased the variation pattern showed reduced dispersion with a higher frequency of values near the mean value (Fig. 5 compared to Fig. 6). In all of the fields we observed that the higher the N rate the less variation in frequency distribution with the same shape of the distribution and the maximum and minimum values across all of the N rates.

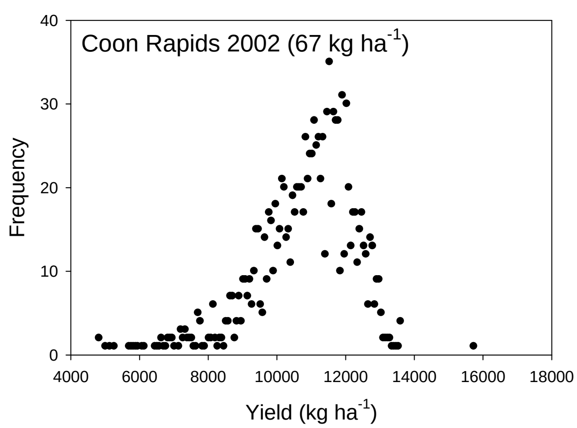


Figure 4. Frequency distribution of corn yields at the 67 kg N $ha^{-1}$ rate for the Coon Rapids field in 2002.

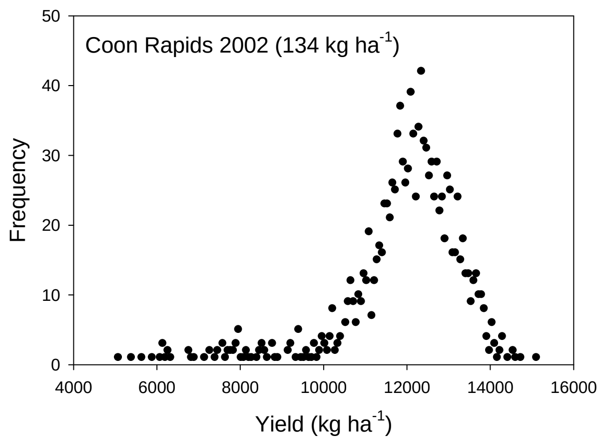


Figure 5. Frequency distribution of corn yields at the 134 kg N ha$^{-1}$ rate for the Coon Rapids field in 2002.

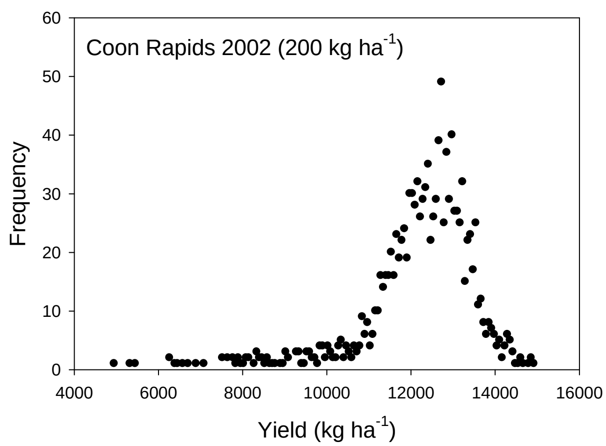


Figure 6. Frequency distribution of corn yields at the 200 kg N ha$^{-1}$ rate for the Coon Rapids field in 2002.

The spatial variation of the yields within fields was significant in their relationship to soil variation within the field. However, when all of the fields were considered in the analysis there was not a single regression model that could be assembled that explained the yield variation. To attempt to understand the variation in the patterns of yield the first relationship was between the red/green vegetative index and yield. There was an inverse relationship between yield and the August red/green index for the fields (Fig. 7). There was a large variation about the regression line for this field and this index showed one of the most significant relationships with yield compared to other vegetative indices.

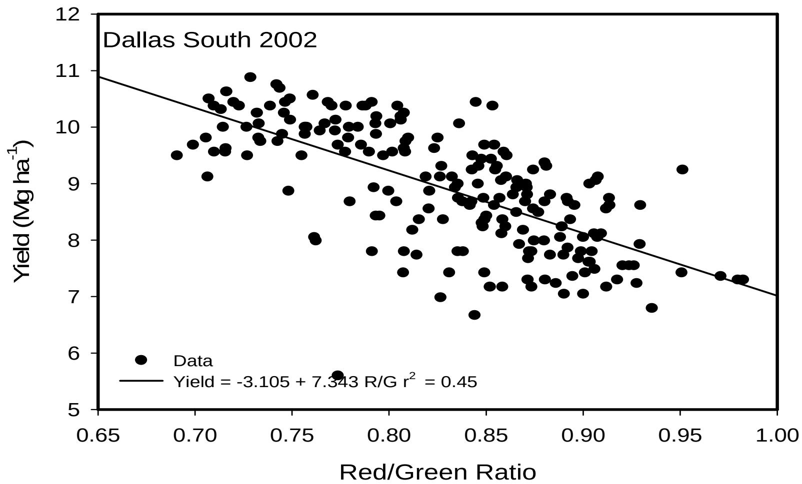


Figure 7. Relationship between corn yield and red/green ratio observed in August with an aircraft scanner for the Dallas South field in 2002.

A more detailed examination of the red/green ratio during the growing season with the observations collected at four times during the growing season. The observations in May were when the crop did not affect the soil background, July to represent maximum vegetative cover, August at a point of mid-grain fill, and September near the point of physiological maturity. At each of these times the frequency distribution was computed for each N rate within the field. There is a seasonal trend in the frequency distributions with a decrease in the variation found in the distribution from the May to the July or August observations and then an increase with the September observations. An interesting part of these observations was that there was no difference among the 67, 134, or 200 kg N ha$^{-1}$ rates for the frequency distributions (Figs. 8, 9, and 10).. The frequency distribution of the August data showed the least variation across the field. We observed in fields that the variation decreased as the crop developed and during the maximum vegetative period and early grain-fill period there was little variation across the fields. As the grain-filling period progresses there was an increasing degree of variation within the field because of the limitation in the amount of available soil water and the affect on the rate of plant senescence.

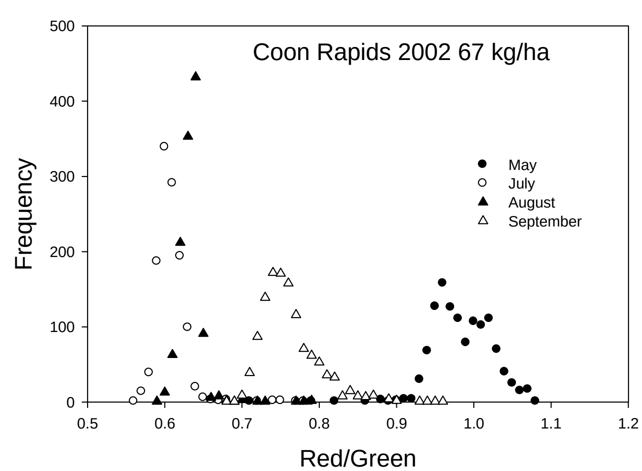

Figure 8. Frequency distribution of red/green ratio for the four observation times during the 2002 growing season for the Coon Rapids field with 67 kg N $ha^{-1}$ rate.

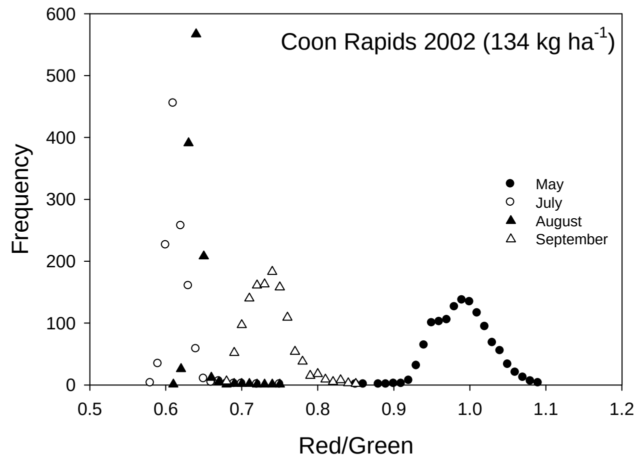


Figure 9. Frequency distribution of red/green ratio for the four observation times during the 2002 growing season for the Coon Rapids field with 134 kg N $ha^{-1}$ rate.

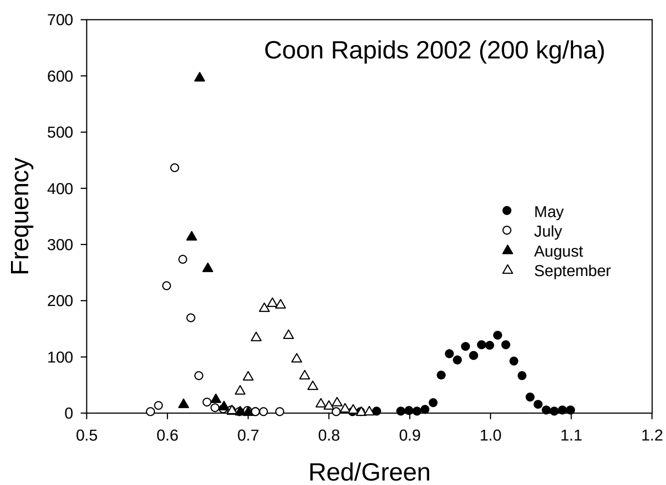


Figure 10. Frequency distribution of red/green ratio for the four observation times during the 2002 growing season for the Coon Rapids field with 200 kg N $ha^{-1}$ rate.

Different vegetative indices exhibited a different response throughout the growing season (Fig. 11). The NDVI and $NDVI_{grn}$ showed little variation about the field mean during the July, August, and September overflights, while the red/green and nir/red ratios showed a greater variation (Fig. 11). These data for the Calhoun field in 2002 was typical of the field response we observed in the study. The relationship between NDVI and $NDVI_{grn}$ and corn yield was nonsignificant across all of the fields we observed in this study. The simple red/green ratio showed the most consistent relationship with corn yield across all of the different fields.

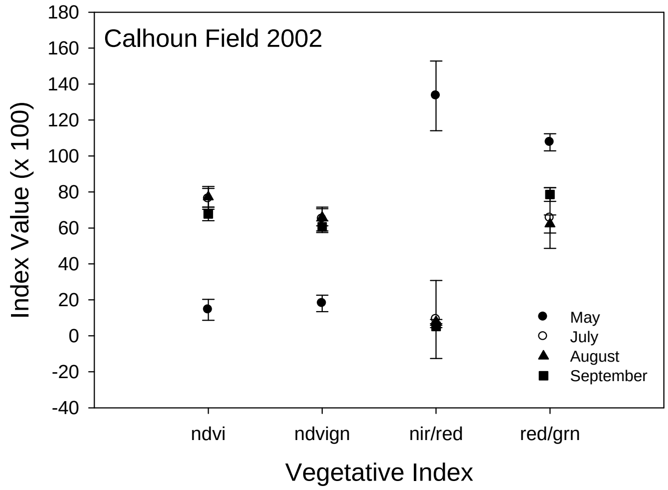

Figure 11. Changes in mean and standard deviation of the vegetative indices obtained from the Calhoun field in 2002 from four different overflights during the growing season.

Spatial relationship of yield and the red/green index across fields was computed using the GS+ version 5.1 software. Autocorrelation values were computed across the field using the field location points as coordinates to compute the range and sill for yield and the red/green index. Spatial variation maps for the Coon Rapids field in 2002 showed the yield variation patterns that indicated evidence of a relationship to N rates at the higher N rate of 155 kg $ha^{-1}$. These strips had higher yields in parts of the field but were not consistent across the entire strip and there was a difference between the west and east end of the field (Fig. 12). However, there was no difference in the soil types that would cause this yield pattern. The presence of the waterway within the field was detectable in the spatial map of the field. The simulated yields did not cover the full width of the strip and the range estimated by the spatial analysis was 150 m.

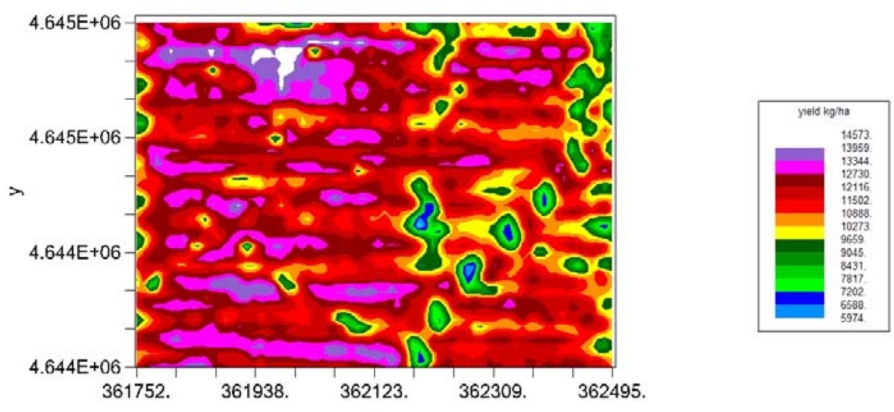

Figure 12. Interpolated yield map from the Coon Rapids field in 2002 using spatial analysis software.

Spatial analysis of the red/green index for the May and August periods during the 2002 growing season showed the effect of the soil differences for the May image with the differences from west to east (Fig. 13). The May spatial analysis image had a correlation with the yield of 0.56 which was significant. The presence of waterway was very evident in this kriged map of the field. The range of the samples was 20 m indicating there were detectable differences over relatively short distances within the field. In other fields the range was considerably longer and on the order of 80 to 100m. This is in contrast with August image in which there is little variation across the field in the red/green ratio (Fig. 14). There is one spot with poor plant growth that is detectable in the field. In this analysis there was no stable range in the data because there was no spatial pattern present in the field. These maps confirm the analysis conducted within each strip and field that showed the July and August periods have the least variation in vegetative indices across the field because the crop growth is uniform.

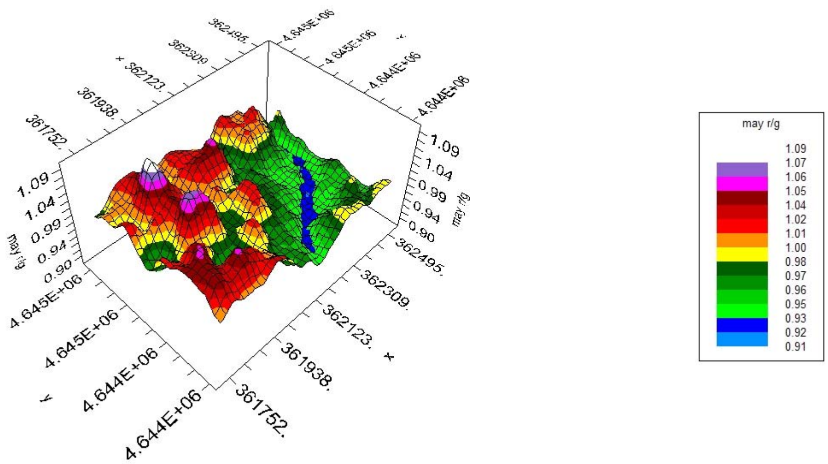


Figure 13. Spatial map of the red/green ratio for the Coon Rapids field in 2002 for the May image.

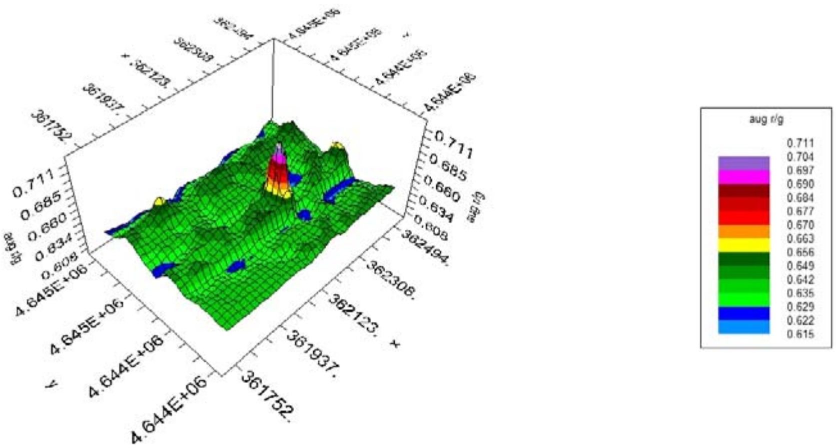


Figure 14. Spatial map of the red/green ratio for the Coon Rapids field in 2002 for the August image.

There was an increase in the variation in the September analysis of the field because soil differences began to emerge as there was differential maturity across the field. This pattern was detectable in the fields we evaluated in this study.

## CONCLUSIONS

Spatial patterns within crop fields provide insights into the crop response to management practices. In this study there was not a significant relationship between yield and N application rate across the 14 fields evaluated over the 3 years. There were fields in which there was a positive response while in others a negative yield response to applied N. There was a large range of N rates within this study that would be expected to create a yield response to N. There was a significant relationship to soil type; however, there was not a soil type by N rate interaction. An examination of the patterns observed within fields provides a reason for the differences in the responses among fields. Spatial analysis of yield across fields showed that frequency distribution was not different among N rates; however, there was a detectable decrease in the variation as the N rate increased. The higher rates of N reduced the dispersion about the mean but didn't change the overall distribution of observed yields.

Analysis of the NDVI either with red or green wavebands or nir/red or red/green ratios during the growing season revealed differences among these indices. The NDVI was not sensitive to N rates or crop yield because this index was saturated during three of the observations during the growing season. Likewise, the $NDVI_{grn}$ showed a similar result to the NDVI. The red/green ratio showed the best relationship to yield and there was a change in the variation in these values during the growing season. The variation in red/green values decreases as the crop develops and then changes as the crop begins to senesce differently across the field because of the water availability in the different soils. Analysis of the spatial patterns within fields explains the seasonal patterns within fields that are due to distribution of soil types rather than N management practices.

Further refinement of our understanding of the spatial patterns within crop production fields and the seasonal changes in remotely sensed vegetative indices will provide more information about dynamics of field-scale responses. This study has helped identify potential approaches to be applied for precision agriculture that can enhance N use efficiency and help guide future research to better methods of field variation.

## ACKNOWLEDGEMENTS

The support of the Risk Management Agency and especially Virginia Guzman and Dave Fulk are greatly acknowledged and this research is under the agreement 07-IA-0831-0210. This effort would not be possible without the capable support of Brooks Engelhardt, Wolf Oesterreich and Bert Swalla in their efforts to collect and process the data from the field experiments and the interactions with Galen Hart for his encouragement and insights. Likewise the support of the producers, Don Ferguson, Mike Hermanson, Nels Leo, Kriss Lightener, Dale Pennington, and David Schroeder who willingly let us use their fields for these studies and the efforts of the Farnhamville Cooperative of Farnhamville, IA (Jeff True, Gabe Tar) for helping identify the producers. The support from CALMIT at the University of Nebraska (Rich Perk and Don Rundquist) to obtain the hyperspectral data is greatly appreciated.

## REFERENCES

Blackmer, T.M. and J.S. Schepers. 1996. Aerial photography to detect nitrogen stress in corn. J. Plant Physiol. 148:440-444.

Blackmer, T.M., J.S. Schepers, and G.E. Varvel. 1994. Light reflectance compared with other nitrogen stress measurements in corn leaves Agron. J. 86:934-938.

Blackmer, T.M., J.S. Schepers, G.E. Varvel, and G.E. Meyer. 1996a. Analysis of aerial photography for nitrogen stress within corn fields. Agron. J. 88:729-733.

Blackmer, T.M., J.S. Schepers, G.E. Varvel, and E.A. Walter-Shea. 1996b. Nitrogen deficiency detection using reflected shortwave radiation from irrigated corn canopies. Agron. J. 88:1-5.

Blackmer, T.M., J.S. Schepers, and M.F. Vigil. 1993. Chlorophyll meter readings in corn as affected by plant spacing. Commun. Soil Sci. Plant Anal. 24:2507-2516.

Brouder, S.M., D.B. Mengel, and B.S. Hoffman. 2000. Diagnostic efficiency of the blacklayer stalk nitrate and grain nitrogen tests for maize. Agron. J. 92:1236-1247.

Hatfield, J.L., and J.H. Prueger. 2001. Increasing nitrogen use efficiency of corn in Midwestern cropping systems. Proceedings of the 2nd International Nitrogen Conference on Science and Policy. TheScientificWorld (2001) 1(S2):682-690.

Inman, D., R. Khosla, R. Reich, and D.G. Westfall. 2008. Normalized difference vegetation index and soil color-based management zones in irrigated maize. Agron. J. 100:60-66.

Lee, Y., C. Yang, K. Chang, and Y. Shen. 2008. A simple spectral index using reflectance of 735 nm to assess nitrogen status of rice canolpy. Agron. J. 100:205-212.

Massey, R.E., D.B. Myers, N.R. Kitchen, and K.A. Sudduth. 2008. Profitability maps as an input for site-specific management decision making. Agron. J. 100:52-59.

Schepers, J.S., T.M. Blackmer, W.W. Wilhelm, and M. Resende. 1996. Transmittance and reflectance measurements of corn leaves from plants with different nitrogen and water supply. J. Plant Physiol. 148:523-529.

Schepers, J.S., D.D. Francis, M. Vigil, and F.E. Below. 1992. Comparison of corn leaf nitrogen concentration and chlorophyll meter readings. Commun. Soil Sci. Plant Anal. 23:2173-2187.