Red and amber normalized difference vegetation index (NDVI) ground-based active remote sensors for nitrogen management in irrigated corn.

T.M. Shaver, R. Khosla, and D.G. Westfall
Department of Soil and Crop Sciences,
Colorado State University, Fort Collins, Colorado, USA.
tshaver@lamar.colostate.edu

ABSTRACT

A great deal of precision agriculture research has been directed towards quantifying in-field and in-season crop and soil variability for enhancing the efficiency of inputs such as nitrogen (N). Studies have shown that remotely sensed imagery (particularly normalized difference vegetation indices, or NDVI) can provide valuable information about in-field variability in corn. Several research institutions in the U.S. are already using NDVI based algorithms for N application in corn using commercially available sensors. While this is the end goal for Colorado as well, it was determined that our first course of action should be to conduct a study to investigate which of the two most prominent commercially available ground-based sensors (NTech's GreenSeeker™ and Holland Scientific's Crop Cricle™) performed best in our region before beginning the development of an algorithm. The sensors were tested for two site years, each having subplots of 4 different N rates (0, 50, 100, and 175 kg N/ha). Sensor readings were collected at the V8, V10, V12 and V14 corn growth stages. Overall this study showed that the NTech GreenSeeker™ red unit and the Holland Scientific amber Crop Circle™ both perform very well in determining the N variability in irrigated corn in Colorado at the V12 and V14 corn growth stages and could therefore serve as very important tools for reducing potential economic loss and environmental degradation through the over and under application of N fertilizers.

INTRODUCTION

A great deal of precision agriculture research has been directed towards enhancing the efficiency of inputs such as nitrogen (N) by quantifying in-field variability. Several methods of quantifying this variability have proven successful for enhancing N management (Cox and Gerard, 2007, Derby et al., 2007, Flowers et al., 2005, Chang et al., 2004, Fleming et al, 2004, Raun et al., 2002, Khosla et al., 2002 and 1999, Johnson et al., 2003, Franzen et al., 2002,), N use efficiency (Raun et al., 2002), and economic return (Koch et al., 2004). The majority of techniques reported in literature employ some form of remote sensing to quantify in-field variability. Studies have shown that remotely sensed imagery (particularly normalized difference vegetation indices, or NDVI) can provide valuable information about in-field and in-season variability in corn (Shanahan et al, 2001; Scharf & Lory, 2002; Chang et al, 2003; Sripada et al, 2005). However, airborne or satellite remotely sensed imagery has limitations including cost, timeliness and cloud free cover in which imagery can be acquired. One way these limitations can be overcome is to use ground-based hand-held active remote sensing devices that compute NDVI. Active sensor devices allow for measuring NDVI at specific times and locations throughout the growing season without having weather or flight concerns. Numerous studies specific to ground-based NDVI sensors have shown that NDVI readings adequately quantify corn N content (Raun et al., 2005) and correlate well with many variables that affect corn growth and yield (Martin et al., 2007, Freeman et al., 2007, Teal et al., 2006, Thomason et al., 2007, Inman et al., 2007). Overall these sensors allow for the timely quantification of crop N variability. This in turn allows producers an opportunity to variably manage in-season N based on spatial and temporal crop needs leading to more efficient utilization of environmentally sensible N. Such an N management strategy can decrease potential economic loss and environmental degradation by limiting over and under application of N.

Several research institutions in the U.S. are already using NDVI based algorithms for N application in corn using commercially available sensors. While this is the end goal for Colorado as well, it was determined that our first course of action should be to conduct a study to investigate which of the two most prominent commercially available ground-based sensors (NTech's GreenSeeker™ and Holland Scientific's Crop Cricle™) performed best in our region before beginning the development of an algorithm. We also wanted to determine the corn growth stages at which each sensor performs best. Significant testing of ground-based sensors in corn has been conducted, however, these sensors have not been tested in Colorado and a baseline study was warranted to determine how these sensors would perform under our specific climatic conditions and management practices. The two sensors in this study operate under the same set of scientific principles. A detailed description of the GreenSeeker™ sensor operation is available in Inman et al., (2005). Essentially they differ by the wavelength of light used for canopy reflectance and NDVI determination. The GreenSeeker™ sensor uses a red visible light and the Crop Circle™ uses an amber visible light. Although these sensors operate similarly we do not know if the performance of one sensor may vary compared to the other sensor in terms of NDVI measurements. It is also important to determine at which corn growth stage these sensors perform best so that the most accurate decisions based on NDVI values can be made.

MATERIALS AND METHODS

Research Sites and Experimental Design:

This study was conducted on two locations at the Colorado State University Agricultural Research Development and Education Center (ARDEC) located north of Fort Collins, CO. The study site was a continuous corn field under furrow irrigation and conventional tillage management. A complete randomized block (CRB) design was implemented at each site having subplots of different N rates. The 2 study sites at ARDEC will hereby be referred to as Site year 1 and Site year 2. There were four N rate treatments for each site year (0, 50, 100, and 175 kg N/ha), and each N rate was replicated four times to account for spatial variability, thereby yielding 16 subplots each. All subplots consisted of four corn rows that were 50ft in length.

Sensor Readings:

Two commercially available active hand-held sensors were used for this study; NTech's GreenSeeker™ red unit and Holland Scientific's amber Crop Circle™. Both devices compute NDVI using the equation presented below:

$$\text{NDVI} = (\text{NIR} - \text{VIS}) / (\text{NIR} + \text{VIS})$$

Where: NIR = near infrared and VIS = visible light wavelength

The primary difference between the sensors is the visible light wavelength employed by each sensor to collect reflectance data. The NTech™ device collects reflectance values at the 650nm (red) wavelength, and the Crop Circle™ sensor collects reflectance values at the 590nm (amber) wavelength. Sensor readings were collected at the V8, V10, V12 and V14 corn growth stages with the two devices.

RESULTS AND DISCUSSION

Corn Grain Yield:

Our study demonstrated a significant yield response ($P < 0.05$) to applied fluid N fertilizer across both site years (Figure 1). Site year 1 had the highest yields at the 175 and 100 kg N/ha application rates and were not significantly different. This suggests that for site year 1, the 100 kg N/ha rate supplied sufficient N for attaining maximum yield in this study. The grain yield at the 100 kg N/ha rate was not significantly higher than that of the 50 kg N/ha rate, however the yield at the 175 kg N/ha rate was higher than of the 50 kg N/ha rate. All applied N rates produced significantly higher grain yield than that of the check (0 kg N/ha) treatment. For site year 2 grain yields were similar to those of site year 1 with the 175 and 100 kg N/ha rates showing no significant differences however, the grain yields were significantly higher than that of the 50 and 0 kg N/ha rates. This again suggests that the N sufficiency level was reached at the 100 kg N/ha rate.

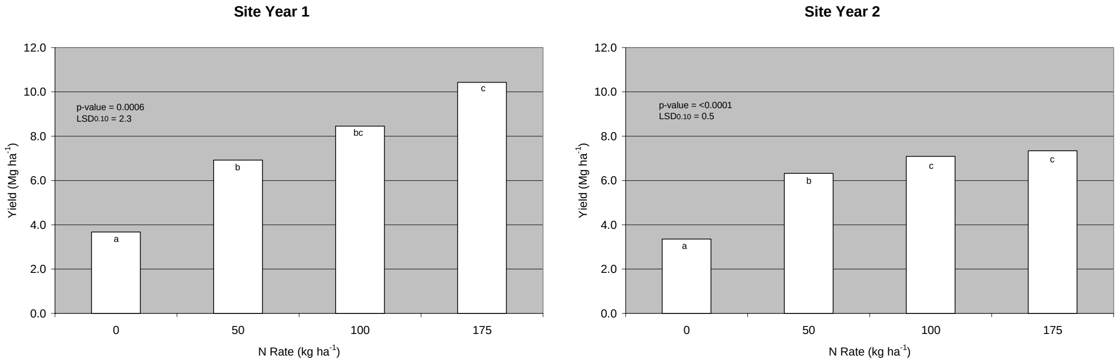

Figure 1. Corn grain yield across 4 fluid Nitrogen application rates at site year 1 and site year 2.

The observed differences in yield indicate that there are sufficient differences in the corn growth at site years 1 and 2 to adequately test the amber and red NDVI sensors. These sensors should be able to distinguish the different applied N rates based on the different biomass and N concentrations that each N treatment created within the corn plants. The treatments that yielded higher should logically have higher NDVI values and vice versa as greater plant biomass and N content are directly related to applied N and directly affect corn grain yield. If these sensors are performing properly we would expect to see the NDVI readings increase across the 0, 50 and 100 kg N/ha application rates and then reach a plateau across the 100 and 175 kg N/ha rates. This would be synchronous to our observations across both site years, where N sufficiency was reached at the 100 kg N/ha rate.

Site Year 1 NDVI:

Site year 1 NDVI readings across the 0, 50, 100, and 175 kg/ha fluid N application rates and V8, V10, V12 and V14 corn growth stages for both the amber and red sensors are shown in Figure 2. The amber and red sensors showed very similar results across all N treatments and corn growth stages. The primary difference between the sensors is in the range in which the NDVI is reported. The red sensor reported NDVI readings ranging from approximately 0.250 to 0.860 whereas the amber sensor's NDVI range was smaller at approximately 0.270 to 0.700. While this difference was observed it did not appear to affect the correlation of NDVI with applied N rate with either sensor.

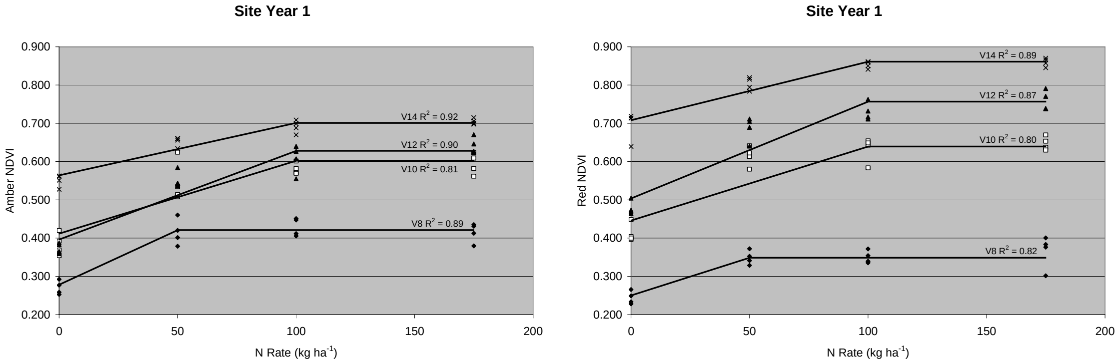

Figure 2. Amber and red NDVI correlation with 4 fluid Nitrogen application rates at site year 1.

At the V8 corn growth stage an increase in NDVI was observed between the 0 and 50 kg N/ha treatments for both sensors. At this point the NDVI readings reach a plateau across the 50, 100 and 175 kg N/ha rates. The plateau observed with each sensor could be attributed to early crop growth stage when plants have not yet accumulated appreciable biomass to be differentiated across fertilized treatment except when compared to the check treatment. Hence, the NDVI values are not significantly different across the 50, 100 and 175 kg N/ha rates. Since the biomass accumulation reached a plateau, the NDVI values should also reach a plateau, and this must be taken into account when performing correlation regression. Therefore a segmented regression was performed so as to account for the plateau and its influence on the correlation or R^2 of the NDVI and N rate. Using this method high correlations for both sensors were observed between NDVI and N rate with the amber sensor having an R^2 of 0.89 and the red sensor showing an R^2 of 0.82.

At the V10, V12 and V14 corn growth stages each sensor showed increasing NDVI readings across the 0, 50 and 100 kg/ha applied N rates and then showed a plateau between the 100 and 175 kg/ha N treatments. As discussed previously there were no yield differences between the 100 and 175 treatments meaning there was little difference in plant growth, which would logically lead to the similarities in NDVI readings at these N application levels. Using segmented regression across the 100 and 175 kg/ha N rates to account for the biomass and yield similarities high correlations were again found between NDVI and N rate at each corn growth stage with each sensor. The amber sensor had slightly higher R^2 values across each growth stage than did the red sensor. The highest correlations for each sensor were observed at the V14 growth stage with the amber sensor having an R^2 of 0.92 and the red sensor having an R^2 of 0.89. Similar correlations were observed at the V12 corn growth with R^2 values of 0.90 and 0.87 for the amber and red sensors respectively. At the V10 growth stage the correlations fall to the 0.80 level for each sensor. This is still relatively high but not as high as the V12 or V14 growth stages.

For site year 1 each sensor's NDVI readings correlated equally well with applied fluid N rate. The only real difference between sensors occurred at the V10 and V12 corn growth stages. The amber sensor did not significantly distinguish these two growth stages while the red sensor did. Figure 1 shows that the regression lines are right on top of each other for V10 and V12 for the amber sensor while the red sensor regression correlations are quite spread out and are significantly different. This did not however affect the correlations with N rate with the amber sensor and the R^2 for the amber sensor are still slightly greater than those observed with the red sensor.

Site Year 2 NDVI :

The results for site year 2 follow those of site year 1 very closely (Figure 2). The amber sensor again had a tighter NDVI range than the red sensor but both performed very well within their range. At corn growth stage V8 we again observed an increase in NDVI from the 0 to 50 kg N/ha rates and then a plateau across all other rates.

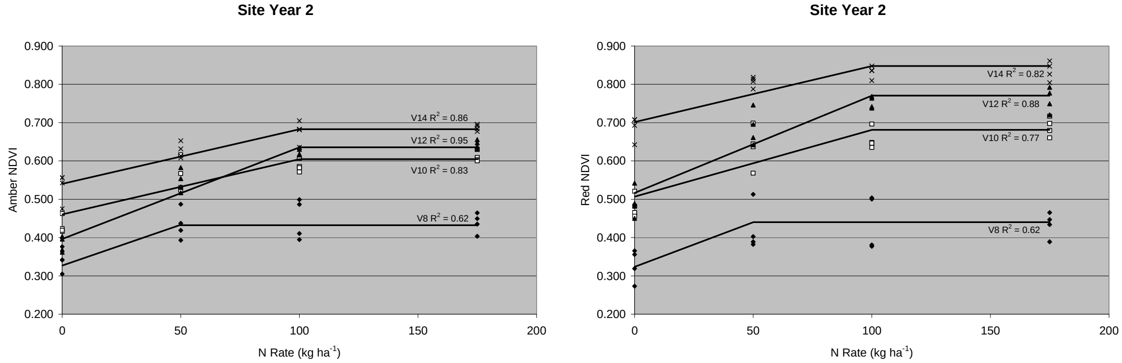

Figure 3. Amber and red NDVI correlation with 4 fluid Nitrogen application rates at site year 2.

However at site year 2 the correlation of NDVI to applied fluid N rate is much lower for each sensor with R^2 values of 0.62 for each sensor at the V8 growth stage. In-season field observations indicate that at site year 2 there was more variability in the corn sizes at the V8 growth stage than at site year 1 leading to a much higher range of NDVI values and lower correlations. The furrow irrigated site year 2 was further away from the water source as compared to that of site year 1 which may be the reason for the variability in plant size early in the growing season. Results were also very similar at the V8, V10 and V12 growth stages when comparing site years 1 and 2. Figure 2 shows that NDVI increased for each sensor across the 0, 50 and 100 kg/ha fluid N application rates and then reached a plateau across the 100 and 175 kg/ha N treatments. As with site year 1, site year 2 also reached N sufficiency at the 100 kg/ha N application rate and corn grain yields did not increase with increased N. Therefore we would expect the NDVI values to plateau across the upper two N rates just as the yields did.

The highest correlation of NDVI to applied N rate for site year 2 was observed at the V12 corn growth stage with R^2 values of 0.95 and 0.88 for the amber and red sensors respectively. The 0.95 R^2 observed with the amber sensor at the V12 growth stage is the highest correlation observed in this study. Correlations were also very high at the V14 corn growth stage with R^2 values of 0.86 and 0.82 for the amber and red sensors respectively. Correlations dropped off at the V10 growth stage just as they did in site year 1 with R^2 values of 0.83 for the amber sensor and 0.77 for the red sensor. As with site year 1 the amber sensor did not significantly differentiate the V10 and V12 corn growth stages but this did not affect the correlation of the NDVI with applied fluid N rate.

Overall site year 2 had lower NDVI values than those observed in site year 1. Such an observation could be attributed to site year 1 having higher yields than site year 2 (Figure 1). The higher yields suggest that the corn biomass and N content were also greater which would lead to greater NDVI values. However, the correlations of NDVI with N rate ranged from the mid-eighties to mid-nineties for both site years at corn growth stages V12 and V14. The correlations observed at these corn growth stages are high enough with each sensor to suggest that V12 to V14 should be the growth stage range in which management decisions based on NDVI readings should be made in Colorado under our specific set of management practices.

CONCLUSIONS

The overall objective of this study was to determine which of the two most prominently used and accepted hand-held active remote NDVI sensors performed best in Colorado under our unique set of environmental and management conditions. We also wanted to determine at what corn growth stage each sensor performed best so that the sensor could be used at the most appropriate time to make the best and most accurate management decisions possible. The amber NDVI sensor had slightly higher correlations with applied fluid N application rate than the red NDVI sensor. However the difference between sensors was not great enough to suggest that one performed better than the other. Each sensor had very high NDVI to applied N rate correlations ($R^2 > 0.89$) and both sensors were able to determine corn N variability across 2 site years. Either sensor would perform adequately in the determination of N variability in corn grown under irrigated conditions in Colorado and either would be a good basis for an N application algorithm. The highest correlations were observed at the V14 corn growth stage for site year 1 and the V12 corn growth stage for site year 2. However, the V12 and V14 NDVI correlations with N rate were very similar and high for both site years. This suggests that the time to take NDVI readings in Colorado is in the V12 to V14 corn growth stage range for the most accurate determination of N variability. Overall this study has shown that the NTech GreenSeeker™ red unit and the Holland Scientific amber Crop Circle™ both perform equally well in the determination of N variability in irrigated corn in Colorado and could be very important tools for reducing potential economic loss and environmental degradation through over and under application of N fertilizers.

REFERENCES

Chang, J., D.E. Clay, C.G. Carlson, C.L. Reese, S.A. Clay, and M.M. Ellsbury. 2004. Defining yield goals and management zones to minimize yield and nitrogen and phosphorus fertilizer recommendation errors. Agron J. 96:825-831.

Chang, J., D.E. Clay, K. Dalsted, S. Clay, and M. O'Neill. 2003. Corn (Zea mays L.) yield prediction using multispectral and multidate reflectance. 2003. Agron. J. 95:1447-1453.

Cox, M.S, and P.D. Gerard. 2007. Soil management zone determination by yield stability analysis and classification. Agron. J. 99:1357-1365.

Derby, N.E., F.X.M. Casey, and D.W. Franzen. 2007. Comparison of nitrogen management zone delineation methods for corn grain yield. Agron. J. 99:405-414.

Fleming, K.L., D.F. Heermann, and D.G. Westfall. 2004. Evaluating soil color with farmer input an apparent soil electrical conductivity for management zone delineation. Agron. J. 96:1581-1587.

Flowers, M., R. Weisz, and J.G. White. 2005. Yield-based management zones and grid sampling strategies: Describing soil test and nutrient variability. Agron. J. 97:968-982.

Franzen, D.W., D.H. Hopkins, M.D. Sweeney, M.K. Ulmer, and A.D. Halvorson. 2002. Evaluation of soil survey scale for zone development of site-specific nitrogen management. Agron. J. 94:381-389.

Freeman, K.W., K. Girma, D.B. Arnall, R.W. Mullen, K. L. Martin, R.K. Teal, and W.R. Raun. 2007. By-plant prediction of corn forage biomass and nitrogen uptake at

Inman, D., R. Khosla, R.M. Reich, and D.G. Westfall. 2007. Active remote sensing and grain yield in irrigated maize. Precision Agric. 8:241-252.

Inman, D., R. Khosla, and T. Mayfield. 2005. On-the-go active remote sensing for efficient crop nitrogen management. Sensor Rev. 25(3):209-216.

Johnson, C.K., D.A. Mortensen, B.J. Wienhold, J.F. Shanahan, and J. W. Doran. 2003. Site-specific management zones based on soil electrical conductivity in a semiarid cropping system. Agron. J. 95:303-315.

Khosla, R., K. Fleming, J.A. Delgado, T.M. Shaver, and D.G. Westfall. 2002. Use of site-specific management zones to improve nitrogen management for precision agriculture. J. of Soil Water Conserv. 57(6):513-518.

Khosla, R., and M.M. Alley. 1999. Soil-specific nitrogen management on mid-atlantic coastal plain soils. Better Crops 83(3): 6-7.

Koch, B., R. Khosla, W.M. Frasier, D.G. Westfall, and D. Inman. Economic feasibility of variable-rate nitrogen application utilizing site-specific management zones. Agron. J. 96:1572-1580.

Martin, K.L., K. Girma, K.W. Freeman, R.K. Teal, B. Tubana, D.B. Arnall, B. Chung, O. Walsh, J.B. Solie, M/L. Stone, and W. R. Raun. 2007. Expression of variability in corn as influenced by growth stage using optical sensor measurements. Agron. J. 99:384-389.

Raun, W.R., J. B. Solie, K.L. Martin, K.W. Freeman, M.L. Stone, G.V. Johnson, and R.W. Mullen. 2005(a). Growth stage, development, and spatial variability in corn evaluated using optical sensor readings. J. Plant Nutr. 28:173-182.

Raun, W.R., J.B. Solie, G.V. Johnson, M.L. Stone, R.W. Mullen, K.W. Freeman, W.E. Thomason, and E.V. Lukina. 2002. Improving nitrogen use efficiency in cereal grain production with optical sensing and variable rate application. Agron. J. 94:815-820.

Scharf, P.C. and J.A. Lory. 2002. Calibrating corn color from aerial photographs to predict sidedress nitrogen need. Agron. J. 94:397-404.

Shanahan, J.F., J.S. Schepers, D.D. Francis, G.E. Varvel, W.W. Wilhelm, J.M. Tringe, M.R. Schlemmer, and D.J. Major. 2001. Use of remote-sensing imagery to estimate corn grain yield. Agron. J. 96:583-589.

Sripada, R.P., R.W. Heiniger, J.G. White, and R. Weisz. 2005. Aerial color infrared photography for determining late-season nitrogen requirements in corn. Agron. J. 97:1443-1451.

Teal, R.K., B. Tubana, K. Girma, K.W. Freeman, D.B. Arnall, O. Walsh, and W.R. Raun. 2006. In-season prediction of corn grain yield potential using normalized difference vegetation index. Agron. J. 98:1488-1494.

Thomason, W.E., S.B. Phillips, and F.D. Raymond. 2007. Defining useful limits for spectral reflectance measures in corn. J. Plant Nutr. 30:1263-1277.