Utilizing normalized difference vegetation indices (NDVI) and in-season crop and soil variables to estimate corn grain yield.

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ABSTRACT

Enhancing the efficiency of farm inputs without negatively impacting profitability or the environment has been a primary focus of precision agriculture research for quite some time. Quantifying the nitrogen (N) requirements of corn plants is an important component of this research and being able to accurately estimate corn grain yield would allow us to better determine the amounts of N needed for plant growth. Currently research is being conducted using NDVI to quantify the N requirements of corn plants and NDVI has proven to be very effective in determining in-field corn leaf N variability. However, estimating corn yield based on this NDVI measurement has not been as successful. With the goal of determining better corn grain yield estimates we conducted a study to determine if using crop and soil variables in conjunction with NDVI would increase yield correlation over using NDVI alone. To accomplish this we collected NDVI readings from two active hand-held remote sensors (NTech's Red GreenSeeker™, and Holland Scientific's Crop Circle™) at a northern Colorado field site over corn growth stages V8, V10, V12, and V14. At these growth stages ancillary crop and soil data was also collected including corn leaf N content, soil N content, plant height, and SPAD readings. Step-wise multiple regression was conducted to determine what measurements best correlated with grain yield at each corn growth stage. Results show that at the V8, V10, and V12 corn growth stages leaf N content had the highest correlation with grain yield. At the V14 growth stage NDVI had the highest correlation with corn grain yield. However, different sensors, and/or using multiple variables did not increase the correlation with grain yield at any of the growth stages tested.

INTRODUCTION

Enhancing the efficiency of farm inputs without negatively impacting profitability or the environment has been a primary focus of precision agriculture research for quite some time. Quantifying the nitrogen (N) requirements of corn plants is an important component of this research (Khosla et al., 1999) and being able to accurately estimate corn grain yield would allow us to better determine the amounts of N needed for plant growth. Currently research is being conducted using NDVI to quantify the N requirements of corn plants (Scharf & Lory, 2002; Sripada et al, 2005) and NDVI has proven to be very effective in determining in-field corn leaf N variability (Raun et al, 2003, 2004). However estimating corn grain yield based on the NDVI measurement has been challenging (Shanahan et al, 2001; Chang et al, 2003). Accurate grain yield estimation would greatly assist agronomists and farmers in making in-season variable-rate N applications.

With the premise that NDVI readings alone are not accurate estimator of grain yield we decided to conduct a study to determine if additional measurements such as SPAD chlorophyll content, corn leaf N content, soil N content, and corn plant height would in themselves, or in conjunction with one another and NDVI better correlate with corn grain yield than NDVI alone. This was done over four fluid fertilizer N application rates of 0, 50, 100, and 175 lbs N/ac and over four different corn growth stages of V8, V10, V12, and V14, in an effort to determine if the N rate applied to the corn and the timing of these measurements affected the yield correlation.

The objective of this study was to determine what variable or combination of variables including NDVI, SPAD, corn leaf N content, and soil N content best correlate with corn grain yield and therefore may be used to increase the accuracy of corn grain yield estimation and expected grain yield based in-season N recommendations.

MATERIALS AND METHODS

Research Sites and Experimental Design:

This study was conducted at the Colorado State University Agricultural Research Development and Education Center (ARDEC) located north of Fort Collins, CO. This site is a continuous corn field under furrow irrigation and conventional tillage management. A Complete Randomized Block (CRB) design was implemented within the field with subplots of different N rates. There were four N rate treatments (0, 50, 100, and 175 lbs N/ac), and each N rate was replicated four times to account for spatial variability, yielding 16 subplots. 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 Crop Circle™. Each of these units determines NDVI using the equation below:

$$\text{NDVI} = \frac{\text{Near Infrared Band Reflectance} - \text{Visible Band Reflectance}}{\text{Visible Band Reflectance} - \text{Near Infrared Band Reflectance}}$$

The primary difference between the sensors is the visible light wavelength at which each sensor collects reflectance. The NTech™ unit collects light at the 650nm (red) wavelength, and the Crop Circle™ sensor collects light at the 590nm (amber) wavelength. Sensor readings were collected at the V8, V10, V12 and V14 corn growth stages with each unit.

Ancillary Crop and Soil Variables:

At each of the aforementioned growth stages ancillary crop and soil data was also collected within each N rate sub-plot. This included corn flag leaf N content, soil N content (0-8 inch depth), plant height, and SPAD readings of the corn flag leaf. Step-wise multiple regression using SAS proc reg was then conducted to determine what measurement, or combination of measurements, best correlated with grain yield at each corn growth stage.

RESULTS AND DISCUSSION

Results show that each of the commercially available active hand-held sensors used in this study were able to distinguish in-season N variability in corn (Figure 1.). While each sensor yielded different levels of NDVI, the overall trend of the NDVI readings for each sensor generally increased with increasing corn growth stage.

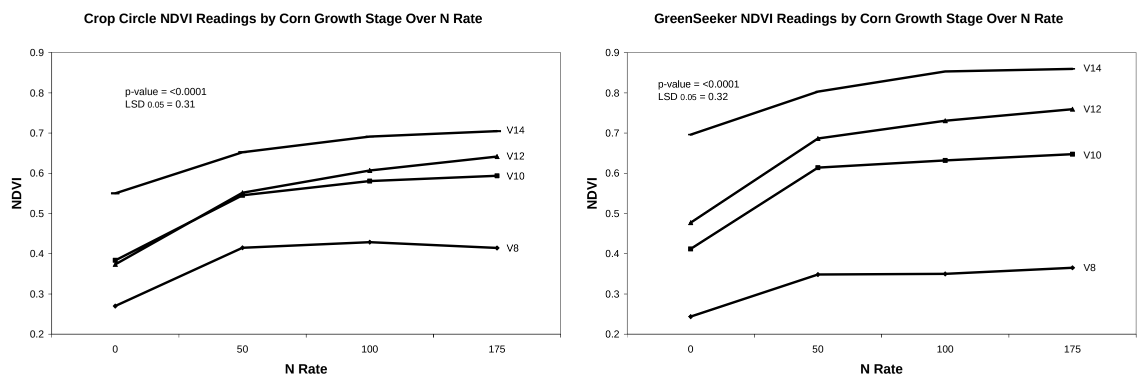

Figure 1. Crop Circle™ and GreenSeeker™ NDVI readings at corn growth stages V8, V10, V12, and V14 as affected by N rate.

Table 1 shows that both sensors were able to account for similar levels of variability when NDVI was regressed on yield. The r-square for each sensor generally increased with each successive crop growth stage. The highest r-square from NDVI readings was collected at the V14 crop growth stage. The Crop Circle™ sensor achieved an r-square of 0.71 and the GreenSeeker™ achieved an r-square of 0.75 at the V14 crop growth stage. These results suggest that both sensors used in this study correlated relatively well with corn grain yield at later (V14) corn growth stages without the aid of any other ancillary crop or soil variables that are often destructive to the plant. However, these correlations still leave a significant hole in determining accurate N requirements. These results show that an increased accuracy is needed for yield estimation. By using other ancillary variables in conjunction with the NDVI readings we may be able to further increase yield correlation and hence the accuracy of yield estimation, which would enable us to better determine how much in-season N is needed by the crop. First we needed to determine whether the measured crop and soil variables responded to different N rates and how well they correlate with corn grain yields.

The analysis for the ancillary crop and soil data are presented in Figure 2. The corn grain yield by applied N is also presented there. The SPAD leaf chlorophyll content, the soil N content, and the corn grain yield were a function of the applied N rate. The leaf N content and plant height were the function of an applied N rate and corn growth stage interaction.

All variables measured responded as expected to applied N rate and corn growth stage except soil N concentration. SPAD leaf chlorophyll content increased with increasing N application rate. The 175 lb/ac rate had the highest SPAD reading, the 50 lb/ac rate had the lowest (except for the check), and the 100 lb/ac rate was intermediate (Figure 2). The soil N content at each N applied rate did not follow this trend as the results appeared to be random. The soil N variable has many other factors contributing to it than just applied N. Residual soil N, organic matter mineralization, and other factors likely contribute to soil N, meaning applied N rate alone may not necessarily be a good indicator of this variable.

Corn Growth Stage	V8	V10	V12	V14
	--------------------	--------R-square--------	--------------------	
Predict Yield by:				
Crop Circle NDVI	0.51	0.59	0.69	0.71
GreenSeeker (Red) NDVI	0.49	0.66	0.66	0.75
SPAD	0.39	0.59	0.57	0.43
Soil N	0.31	0.05	0.10	0.27
Leaf N	0.64	0.74	0.74	0.50
Plant Height	0.45	0.62	0.49	0.61
Multiple Regression	----------	----------	0.84 (Soil N + Leaf N)	----------

Table 1. R-square values for various corn growth stages, corresponding to the sensor and measured soil and crop variables as determined by multiple regressions.

Analysis for corn leaf N content and corn plant height followed the trends of other variables across all corn growth stages tested. Corn leaf N content increased across applied N rates at all growth stages except V8 which increased up to 100 lb/ac and then decreased at 175 lb/ac (Figure 2). It is unclear why this occurred only at the V8 growth stage. Leaf N content also decreased with each successive growth stage, the V8 growth stage had the highest quantities of leaf N content at all N rates with the V10, V12, and V14 growth stages each decreasing in leaf N (Figure 2). Plant height also increased with corn growth stage but not necessarily with applied N rate (Figure 2). At all growth stages there was an increase above the 0 lb/ac rate, but at the V8 and V10 growth stages there was no significant difference in height across N rates. At the V12 growth stage there was a significant difference in plant height at the 175 lb/ac rate when compared to the 50 lb/ac rate, the 100 lb/ac rate was intermediate. At the V14 growth stage there was a significant difference in plant height across all applied N rates. The plant height data shows that it takes some time for N rate differences to take effect with biomass growth. This correlates well to the NDVI data that also becomes more accurate as growth stage increases (Figure 1). This correlation is not unexpected as plant biomass and the amount of light reflected to calculate NDVI is related.

Corn grain yield yields of 166, 135, 110, and 59 bu/ac at the 175, 100, 50, and 0 lb/ac applied N rates respectively (Figure 2) were found and used against the crop, soil, and NDVI variables to test correlation.

The results of the crop and soil variables suggest that all variables tested except the soil N content may be a good indicator of crop yield.

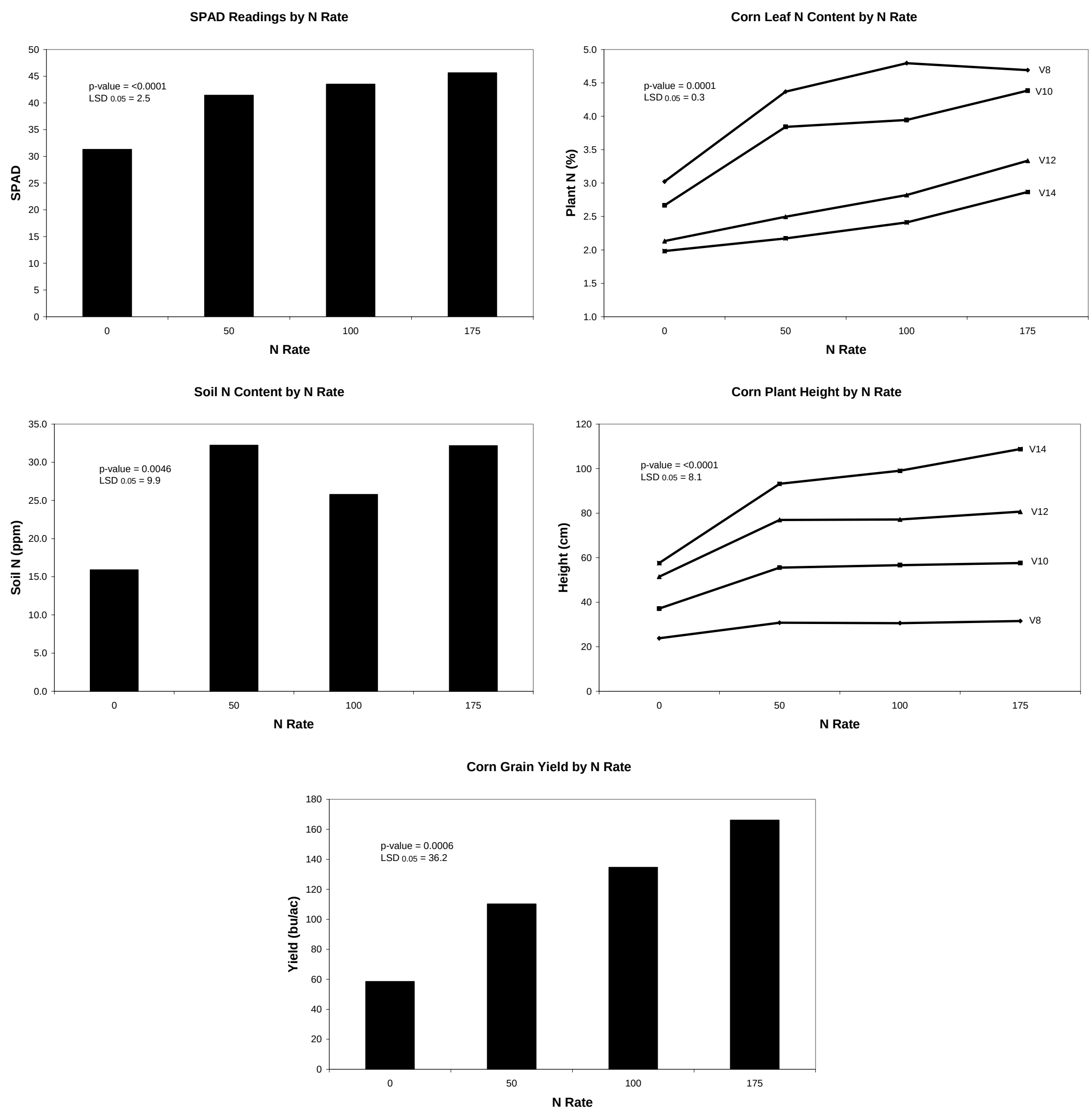

Figure 2. SPAD, plant height, soil N, corn leaf N content, and corn grain yield as affected by N rate.

Table 1 shows the r-square coefficients of each variable and how it correlates to crop yield. The r-square is a good indicator of how much of the variability in yield each tested variable explains. An r-square was calculated for each variable at each corn growth stage. At the V8 growth stage the leaf N content was the best variable for yield correlation with an r-square of 0.64 (Table 1). No other variable had as high of an r-square (including any insignificant multiple regressions) and there were no significant multiple regressions. No combination of the variables used in the stepwise multiple regression increased the r-square found with just the leaf N content alone. Compared to the NDVI r-square the leaf content was better correlated to grain yield with the Crop Circle™ having an r-square of 0.51 and the GreenSeeker™ having an r-square of 0.49. All other variables had r-squares less than 0.50 suggesting they are not highly correlated or good estimates of yield variability.

At the V10 growth stage the corn leaf N content was again the best estimate of yield variability with an r-square of .74 (Table 1). At this corn growth stage the NDVI sensor r-squares increased for both sensors with the Crop Circle™ having an r-square of 0.59 and the GreenSeeker™ having an r-square of 0.66. The increase in r-square at this growth stage correlates to the increase in plant biomass for higher NDVI readings and the more linear leaf N content compared to the V8 growth stage. At the V10 growth stage the SPAD reading and plant height variables had similar r-squares with 0.59 and 0.62 respectively. Again there were no significant multiple regression values and even with the insignificant results there were no r-squares higher than 0.74. These results suggest that at the V10 corn growth stage plant leaf N content is the best indicator of grain yield.

The results at the V12 growth stage were very similar to those found at the V10 growth stage (Table 1). The primary differences between the V12 and V10 growth stages is in plant height where the r-square drops to 0.49, and the V12 growth stage has a significant multiple regression with a combination of soil N and leaf N yielding a r-square of 0.84. However this value is curious considering soil N content did not correlate to N application rate or corn grain yield and the individual soil N r-square is only 0.10. This multiple regression is most likely an artifact of the data and we have to assume that the leaf N content again best explains the corn grain yield variability. The NDVI sensors r-square values continue to increase as growth stage increases due to increased plant biomass and resulting higher and more accurate reflectance values.

The results for the V14 growth stage show that the NDVI sensors best explain corn grain yield variability at this growth stage with the Crop Circle™ having an r-square of 0.71 and the GreenSeeker™ having an r-square of 0.75 (Table 1). As the corn continues to get bigger more light is reflected to the sensor resulting in more accurate NDVI calculations and higher r-square values when explaining yield variability. At this growth stage the leaf N content r-square drops to 0.50 suggesting that the levels of N in the leaf are now too low to accurately equate to yield as N is most likely being distributed to other parts of the plant to prepare for tasseling and subsequent pollination. Again no multiple regressions were significant and all other measured variables had low r-squares.

Overall, flag leaf N content best correlated to grain yield at the V8, V10, and V12 crop growth stages. At the V14 crop growth stage NDVI had the highest correlation to grain yield and was similar for both sensors tested. No combination of variables tested lead to a higher correlation with grain yield than leaf N content and NDVI did alone at the aforementioned crop growth stages. While these variables had relatively high yield correlations they are not good enough for accurate yield estimates and we were not able to increase this correlation using multiple variables. This study does show that NDVI values generally correlate as well or better with grain yield as other methods that are destructive to the crop. This study also underlines the difficulties involved with accurately estimating corn grain yield. While all variables examined except for soil N responded linearly with N application, and all variables are associated with crop health and grain yield, they do not show the entire picture. Variables such as soil moisture, climatic factors, pest pressures, and many others also contribute to corn grain yield. While we did not increase yield correlation in this study the variables tested did help to increase our understanding of how these variables correlate with grain yield and provides valuable information for subsequent attempts to increase yield estimation accuracy.

CONCLUSIONS

This study demonstrated hand-held remote NDVI sensors and other ancillary soil and crop variables such as corn leaf N content, SPAD readings, and plant height measurements generally respond linearly to different rates of applied liquid N fertilizer and correlated with corn grain yield. In the cases of plant leaf N content and plant height these results were also a function of the plant growth stage. It was our hypothesis that a combination of these variables used in conjunction with NDVI in a multiple regression analysis would increase yield correlation over NDVI values alone and therefore may be used to increase the accuracy of yield estimations and in-season N recommendations. However we found no multiple regression that could improve the r-square for leaf N content at the V8, V10, and V12 corn growth stages or the NDVI r-square at the V14 growth stage. The corn leaf N content and NDVI readings explained a significant portion of the variability in corn grain yield but this is most likely not a high enough level to use solely for in-season N requirement estimates. This study demonstrates the complexity and intricacies involved in corn grain yield estimations and provides a good ground work for successive studies to build upon in attempting to achieve this goal while showing the relationship between several soil and crop variables with applied liquid N fertilizers.

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