EVALUATION OF WAVELENGTH FROM GROUND-BASED ACTIVE OPTICAL SENSORS FOR CORN YIELD PREDICTION IN NORTH DAKOTA

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Abstract

Ground-based active-optical (GBAO) crop sensors have been used successfully to predict crop yield when used during early growth stages. The objective of this study was to evaluate two GBAO sensors wavelengths regarding their usefulness under North Dakota corn (*Zea mays*, L.) growing conditions. Thirty experimental sites were used in North Dakota to conduct N rate trials on corn during 2011 and 2012. All sites were designed as randomized complete blocks with four replications and six nitrogen (N) treatments; check (no added N), 40, 80, 120, 160 and 200 lb N/acre as ammonium nitrate applied by hand preplant within a week of planting. Results were analyzed for all sites, then the sites were segregated into high clay and medium textured soils as well as no-till and conventional tillage. The GreenSeeker™ and Holland Crop Circle-470™, were used to gather NDVI readings from each plot at both the V6 and V12 stages. One interior row from plot was hand harvested and the yield was related with sensor measurements to build algorithms for in-season estimate of yield (INSEY). Four wavelengths 656, 670, 730, and 760 nm, were used to measure the red NDVI and red edge NDVI. The red NDVI from the GreenSeeker™ and the Holland Crop Circle Sensor™ provided similar relationships to yield as the red edge NDVI from the Holland Crop Circle Sensor™ at V6 stage. The red edge NDVI was generally more highly related to yield compared to red NDVI across the models, soil cropping system, and soil textures at the V12 stage.

Introduction

Corn (*Zea mays*, L.) is an important crop in North Dakota used as livestock feed and ethanol production, with over 4 million acres estimated planted in 2013. The recommended N rate for corn in North Dakota is currently determined using yield potential, and it is reduced by subtracting soil test nitrate to two feet in depth, and N credit for certain previous crops. The efficient use of N for corn production increases the economic return and minimizes N losses from leaching or denitrification. Because of large potential losses in early spring due to heavy rainfall, it is logical to develop fertilization practices that can improve fertilizer N efficiency while maintaining corn yield.

Previous studies have shown that crop available N is spatially variable at small distances. Present nitrate zone soil sampling helps explain from thirty to fifty percent of the yield variability in fields (Franzen et al., 1998). It is impossible, however, for zone soil sampling to aid in small-scale variability within the field, particularly if variability is caused by local leaching or denitrification in the field following planting. To avoid the early season loss of a large portion of applied preplant N, one possible strategy is to delay some of the N until V6 to V10. The use of ground-based active-optical (GBAO) sensors is one method to direct such a side-dress N treatment for corn. GBAO crop sensors can be used at any pre-flowering growth stage of crop with small interference from clouds and changes in ambient light. The red light based GBAO sensors measure the health of plant from two-dimensional plant ground coverage (Araus, 1996). Sensors that are based on red edge NDVI tend to 'see' green tints, similar to what a human eye perceives. The objective of our study was to evaluate the GreenSeeker™ and Holland Crop Circle™ NDVI readings and the Holland Crop Circle red edge NDVI readings for their relationship to corn yield over a range of soils and tillage systems.

Methods and Materials

Experimental Sites and Treatments

Thirty sites within farmer cooperator fields in southeastern North Dakota were used to conduct N rate trials on field corn in 2011 and 2012. Six sites were located in Sargent County, eleven in Richland County and thirteen in Cass County. The experimental area did not receive supplemental N from the cooperator, but were planted by the cooperator and received herbicide applications at their discretion along with the rest of the field. Each field was planted with a corn variety chosen by the farmer for the entire field, so no two sites were planted to the same corn variety. The experimental design at each site was a randomized complete block with four replications and six treatments; control (no added N), 40, 80, 120, 160 and 200 pounds N per acre, applied as ammonium nitrate by hand preplant within a week of planting. Previous multiple regression analysis of surface soil textures and tillage practices indicated that analysis be grouped by high clay vs medium textured soils, and within the medium textured soils, conventional tillage and long-term no-till sites (those in no-till for longer than six consecutive years).

Soil Properties and Crop Management

Eight soil sample cores were obtained from each site prior to field work using a one-inch diameter hand probe to a six-inch depth for phosphorous (P), potassium (K), zinc (Zn), pH, and organic matter and two feet in depth for residual nitrate. Phosphorus, K, Zn not applied by the cooperator was applied according to Franzen (2010) if the soil test indicated a probable response from its application. After obtaining soil samples, they were air-dried, ground to pass through a 2 mm screen, and thoroughly mixed, before analysis for soil pH, available P, K, Zn, and organic matter. Soil pH was measured in a 1:1 soil: deionized H2O solution method (Watson and Brown 1998) and, P by the Olsen method (Olsen et al., 1954), Potassium was analyzed using the 1-N ammonium acetate method (Thomas 1982). DTPA method (Lindsay and Norvell 1978) was used for determination of for Zn and organic matter was measured using the loss following ignition method (Schulte and Hopkins 1996).

Sensor Descriptions and Use

GBAO sensors measure crop density by generating modified light on crop plants. The sensors use diodes to generate modified light (pulsed at~40,000Hz) in wavebands that are absorbed by plant tissues (chlorophyll and biomass). Two handheld GBAO sensors were utilized in this study: GreenSeeker™ (GS) (Trimble, Sunnyvale, CA) and Holland Scientific Crop Circle (CC) Sensor™ ACS 470 (Holland Scientific, Lincoln, NE). The CC sensor simultaneously emits three bands (visible, red edge and NIR). This sensor emits light from an array of LEDs and the reflected light collects by companion detectors of 670 (red), 730 (red edge) and 760 (near infrared) nm. The sensor was calibrated using software developed by Holland Scientific.

Absorption measurements can be collected at a rate of 1 per second to 20 per second. Both red NDVI and red edge NDVI measurements were collected from the CC sensor.

The GS that was used in the studies absorb two wavebands of light; 660 ± 15nm (red) and 770 ± 15 nm (near infrared). Light is emitted from diodes in alternate bursts: the visible source pulses for 1 msec and NIR diode source pulses for 1 msec at 40,000 Hz. Each burst from diodes amounts to ~40 pulses before pausing for the other diode to emit its radiation (another 40 pulses). The illuminated area (footprint) is approximately 60 by 1 cm (2 feet by 0.4 inches), with the long dimension positioned perpendicular to the direction of sensor movement (across the row). The field of view is relatively constant for sensor heights between two feet and four feet above the canopy. Output from the sensor is red normalized difference vegetative index (red NDVI) (Chung et al., 2008).

Both GS readings and CC readings were obtained when the corn was about V6 stage and again about 10 days to 2 weeks later when the corn reached V12 leaf stage. Readings were taken over the top of the corn whirls on the identical interior row of each plot from which harvest was taken later.

The GS and CC readings consisted of a mean of between 30-50 individual readings from each plot. Means within a treatment were determined using in-house programs for GS and CC raw data developed for Excel by Franzen (2012). Means for each N treatment of sensor readings and yield were calculated using SAS 9.1 for windows.

Yield Measurement

An interior row (20 feet in length) was hand harvested, dried to about 10 per cent moisture and then shelled using an Almaco® corn sheller in 2011. Moisture at shelling was determined on a grain subsample using a Dickey-John GAC 500 XT moisture-test weight instrument. In 2012, a newer model Almaco® corn sheller was used that allowed complete shelling of wet corn, so corn was shelled directly out of the field without a need for drying. Moisture was measured on shelled grain using the same instrument as in 2011.

Regression analyses was conducted on INSEY (in-season estimate of yield, defined as sensor reading divided by growing degree days from planting date) versus yield, with yield as dependent variable, INSEY was determined at V6 and V12 as the independent variable to evaluate the relationship between yield and INSEY ion terms of different wavelengths. To assess the relationship, linear, quadratic, square root, logarithmic, and exponential models were considered. The result of ANOVA of relationships was that the exponential model tended to be most consistent in the INSEY relationship to corn yield. Regression analyses were conducted on data from no-till sites, conventional till medium texture and conventional till high clay sites.

The determination coefficient (r^2) value was used to evaluate the relationship of crop yield and sensor reading at V6 and V12. SAS procedures using SAS for Windows V9.2 (SAS Institute, Cary, NC) were used to calculate the r^2 and evaluate the linear, quadratic, square root, and logarithmic models.

Results and Discussion

The GS and CC red INSEY and the CC red edge INSEY relationships with corn yield using all sites were significant within years and in combined years (Table 4). However, using categories of medium texture, high clay and no-till sites often increased the r^2 value of a relationship. The CC red NDVI, GS red NDVI and red edge NDVI INSEY relationships with yield were highly significant at V6 in medium textured soils managed with conventional tillage (Table 1). However, in medium textured soils with conventional tillage at V12, only the CC red edge NDVI INSEY relationship with yield was consistently highly significant within years and in combined years.

In the high clay category, all sensors and wavelength INSEY relationships with yield were highly significant except in 2011 with the CC red and red edge INSEY at V6, where the relationship was not significant.

Under no till sites, both the GS and CC red NDVI and the CC red edge performed well at V12 stage during 2011, but not at V6. In 2011, neither GS nor CC INSEY was related to corn yield at either V6 or V12. Slow early growth under no-till conditions in both 2011 and 2012 probably contributed to lack of a relationship of V6 INSEY with yield. INSEY measurements at V12 in 2012 were probably due to lack of N response at any no-till site in 2012.

The difference in red and red edge INSEY relationships with yield between the V6 stage and the V12 stage is due to the properties being sensed at each stage. The red edge NDVI INSEY was often superior to the red NDVI INSEY at V12 because many red NDVI readings are restricted to values approaching 1.0 because the corn canopy is closed and two-dimensional biomass coverage is nearly complete. Red edge NDVI reads more tint of color than two-dimensional biomass, so the range of readings possible at a canopy-closed condition are larger, which results in more detectable differences (Martin et al., 2007; Raun et al., 2005). Several studies have indicated that early growth stages, between V6 and V10, are optimum for sensing the corn for practical reasons, despite improved relationships that result with red edge NDVI at later growth stages (Raun et al. 2005; Kitchen 2006).

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Table 1: Relationship (r^2) of INSEY (in-season estimate of yield) using the GreenSeeker™ (GS) sensor or the Holland Crop Circle™ (CC) sensor at V6 and V12 growth stages with corn yield in all sites in 2011 and 2012. INSEY is the sensor reading divided by growing degree days from planting date. Regression model is exponential.

		2011		**2012**		**2011 & 2012**	
		INSEY		**INSEY**		**INSEY**	
Growth stage	**Sensor/Wavelength**	**r^2**	**Sig†**	**r^2**	**Sig**	**r^2**	**Sig**
V6	GS	0.20	***	0.26	***	0.25	***
	CC red edge	0.15	***	0.51	***	0.40	***
	CC red	0.15	***	0.49	***	0.34	***
V12	GS	0.31	***	0.21	***	0.26	***
	CC red edge	0.47	***	0.25	***	0.46	***
	CC red	0.29	***	0.19	***	0.27	***

† *** denotes significance at 0.001.

Table 2. Relationship (r^2) of INSEY (in-season estimate of yield) using the GreenSeeker™ (GS) sensor or the Holland Crop Circle™ (CC) sensor at V6 and V12 growth stages with corn yield in medium textured soils under conventional tillage in 2011 and 2012. INSEY is the sensor reading divided by growing degree days from planting date. Regression model compared was exponential.

		2011		**2012**		**2011 & 2012**	
		INSEY		**INSEY**		**INSEY**	
Growth stage	**Sensor/Wavelength**	**r^2**	**Sig†**	**r^2**	**Sig**	**r^2**	**Sig**
V6	GS	0.49	***	0.46	***	0.53	***
	CC red edge	0.65	***	0.51	***	0.63	***
	CC red	0.61	***	0.55	***	0.63	***
V12	GS	0.17	*	0.12	*	0.13	**
	CC red edge	0.35	***	0.33	***	0.36	***
	CC red	0.10	NS	0.35	***	0.24	***

† *** denotes significance at 0.001; ** denotes significance at 0.01; * denotes significance at 0.05

Table 3. Relationship (r^2) of INSEY (in-season estimate of yield) using the GreenSeeker™ (GS) sensor or the Holland Crop Circle™ (CC) sensor at V6 and V12 growth stages with corn yield in high clay soils in 2011 and 2012. INSEY is the sensor reading divided by growing degree days from planting date. Regression model displayed is exponential.

		2011		**2012**		**2011 & 2012**	
		INSEY		**INSEY**		**INSEY**	
Growth stage	**Sensor/Wavelength**	**r^2**	**Sig†**	**r^2**	**Sig**	**r^2**	**Sig**
V6	GS	0.40	***	0.60	***	0.53	***
	CC red edge	0.01	NS	0.82	***	0.40	***
	CC red	0.06	NS	0.80	***	0.48	***
V12	GS	0.55	***	0.57	***	0.59	***
	CC red edge	0.73	***	0.73	***	0.69	***
	CC red	0.59	***	0.66	***	0.70	***

† *** denotes significance at 0.001.

Table 4. Relationship (r^2) of INSEY (in-season estimate of yield) using the GreenSeeker™ (GS) sensor or the Holland Crop Circle™ (CC) sensor at V6 and V12 growth stages with corn yield in no-till sites in 2011 and 2012. INSEY is the sensor reading divided by growing degree days from planting date. The model used is exponential.

		2011		**2012**	
		INSEY		**INSEY**	
Growth stage	**Sensor/Wavelength**	**r^2**	**Sig†**	**r^2**	**Sig**
V6	GS	0.05	NS	0.08	NS
	CC red edge	0.18	NS	0.33	NS
	CC red	0.08	NS	0.36	*
V12	GS	0.68	***	0.02	NS
	CC red edge	0.80	***	0.006	NS
	CC red	0.62	***	0.01	NS

† *** denotes significance at 0.001; * denotes significance at 0.05

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