Applications of Ground-Based Remote Sensing for Precision Agriculture

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Abstract

Leaf color and plant vigor are key indicators of crop health. These visual plant attributes are frequently used by greenhouse managers, producers, and consultants to make water, nutrient, and disease management decisions. Remote sensing techniques can quickly quantify soil and plant attributes, but it requires humans to translate such data into meaningful information. Over time, scientists have used reflectance data from individual wavebands to develop a series of indices that attempt to quantify things like soil organic matter content, leaf chlorophyll concentration, leaf area index, vegetative cover, amount of living biomass, and grain yield. The recent introduction of active sensors that function independent of natural light has greatly expanded the capabilities of scientists and managers to obtain useful information. Characteristics and limitations of active sensors need to be understood to optimize their use for making improved management decisions. Pot experiments involving sand culture were conducted in 2003 and 2004 in a green house to evaluate corn and red pepper biomass. The rNDVI, gNDVI and aNDVI by ground-based remote sensors were used for evaluation of corn and red pepper biomass. The result obtained from the case study was shown that ground remote sensing as a non-destructive real-time assessment of plant nitrogen status was thought to be a useful tool for in season crop nitrogen management providing both spatial and temporal information.

Introduction

Remote sensing in agriculture has largely focused on the spectral and spatial properties of soil and plants. These technologies provide the capability for rapid collection of vast quantities of spatial data that can be analyzed quickly for use in charting a course of action. It follows that the potential exists for scientists, consultants, and managers to use remote sensing to assess their crops and make more intelligent in-season

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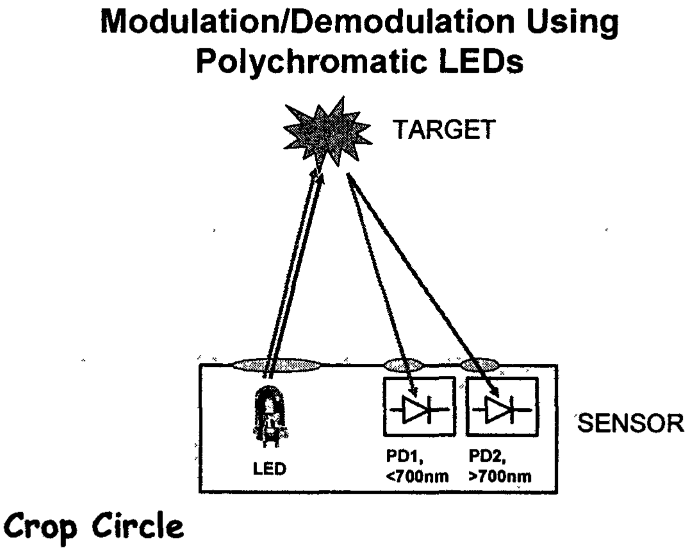
management decisions. Much of the power of remote sensing lies in the fact that physical entities like soil, roads, and water do not perturb the incoming light before it is reflected. In contrast, biological systems like plants transform the energy of certain wavebands (predominately blue and red) into structural and non-structural materials (i.e., photosynthesis). Also, the composition of certain components of living vegetation affects the amount of near infrared (NIR) radiation that is reflected. These simple relationships make it possible to extract considerable amounts of information from an image or reflectance data.

Conventional remote sensing techniques rely on natural light to serve as the source of energy for light that is reflected. Sunlight is very powerful and penetrates deep into canopies, but it is also distorted as it passes through the atmosphere. Early on, scientists learned that normalizing the reflectance of individual wavebands to one another removed much of the distortion because the atmosphere tends to affect visible and NIR wavebands similarly. However, normalizing reflectance data, as with the normalized difference vegetation index (NDVI), does not totally correct for differing amounts of light reaching the earth's surface as could be caused by clouds (additional details are provided later in this paper). The ever-changing intensity of natural light that reaches a plant places severe limitations on what can be accomplished with aircraft or satellite imagery. Ground-based sensors were developed to overcome some of these problems by sequentially or even simultaneously measuring incoming and reflected light. Sun angle, light intensity, and shadows remain a problem for all types of remote sensing that relies on natural lighting.

Experimental versions of active sensors using mechanically modulated light, analog electronic circuits, and mini-computers were documented in the mid 1970s, but these systems were bulky, required large amounts of well-regulated power, and were not very feasible. As digital electronics developed, so did new devices with specialized optics to accommodate the desire for real-time management. Modern active sensors tend to be a combination of older and more innovative optical and electronic designs. As new sensors become available, the challenge is to understand their limitations and applications.

Past research has shown that a change in canopy reflectance may not be unique for a given stress. Also, other agents may have effects on canopy reflectance similar to those of the stress in question. The detection of stress mainly relies on being able to determine and detect deviations from normal function (Murtha, 1982). Some changes, such as those associated with developmental growth, are normal. Only after we understand what is normal for a crop at a given point in time can we look for and identify reflectance patterns that may indicate a stress. For the assessment of crop N status, field reference strips are one technique that can be used as an aide in determining what is or isn't normal (Francis et al., 1991).

Active Sensor Characteristics



Various approaches, including satellite and aircraft platforms and ground-based sensors have been developed and tested for measuring crop canopy reflectance. All have their distinct advantages and disadvantages. Mobile, ground-based sensors offer excellent spatial resolution and can be integrated with material delivery systems to facilitate real-time applications. As noted above, the problem with most remote sensing tools is that they rely on natural radiation to generate the reflectance that is measured by a sensor. As, such, light intensity, viewing angle, time of day, shadows, atmospheric interferences, crop growth stage, and weather conditions are all factors that must be considered. To overcome some of these limitations, technologies that provided auxiliary lighting were introduced and later refined to employ modulated or pulsed light to differentiate between reflectance attributed to natural radiation and that coming from the auxiliary light. Improvements in these technologies have led to development of active sensors such as the GreenSeeker by NTech Industries (see www.Ntechindustries.com) and the Crop Circle sensor by Holland Scientific (see www.Hollandscientific.com)[3]. Design of the optics and electronics gives each a unique set of operational characteristics. For example, the polychromatic bank of diodes in the

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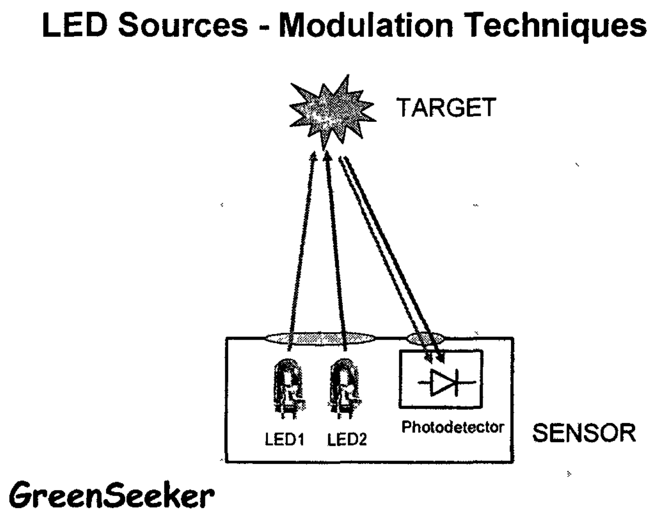
[3] Mention of products does not imply endorsement by the USDA-Agricultural Research Service.

Crop Circle sensor emits light in two wavebands simultaneously, so the illumination provided by each diode covers the same area for each waveband. Because both wavebands are emitted simultaneously, two detectors are required (one for visible light and another for NIR light). This requirement is actually good in that the sensitivity of photo-detectors decreases as the wavelength decreases, so the detector output can be tuned for each waveband. A double detector system eliminates any chance for hysteresis in sensor output and thereby greatly adds to the stability of the sensor readings. Additional advantages of this design are that a special type of lens can be used to uniformly disperse the zones of illumination across the field of view. The optical design of the Crop Circle sensor provides about 90% uniformity in both amber and NIR reflectance as a 5-cm wide leaf is moved across the long dimension of the field of view (~10 x 50 cm at a distance of 60 cm).



Cautions to be considered when using an active sensor that employs single-waveband diodes to generate the two wavebands of light are that the illumination characteristics of the two banks of diodes are almost certain to be different. This typically results in a different field of view for each waveband. It is not be possible for humans to compare differences in the field of view if one of the wavebands is NIR without special waveband-blocking filters and the use of color infrared photography. The GreenSeeker uses a masking technique to collimate the light in one dimension (0.5-cm wide) that reaches the target, but in the other dimension (~60-cm long) the intensity decays outward from the center of the field of view according to the cosine law because of the optical system that is used. As such, uniform illumination across the field of view is not possible, which makes positioning of the sensor over row crops like corn or individual plants critical. In the case of the GreenSeeker, about 75% of the energy is concentrated in the center 25 cm. A unique consequence of the masking technique used in the GreenSeeker is that the field of view is relatively constant (~0.5 x 60 cm). Sensors with a single photo-detector are especially prone to hysteresis problems in that the electronics must alternately respond to high levels of NIR reflectance and low levels of visible light reflectance.

Active sensors work by using diodes to generate modulated light (pulsed at ~2000 Hz) in specific wavebands that are sensitive to plant properties of interest (e.g., chlorophyll, biomass, etc.). Readings are typically collected ten times per second, so each recorded value is the average of about 200 readings. Natural light is not modulated, so with adequately sophisticated electronics, the photo-detector circuitry of the sensors is able to differentiate between the radiance (reflectance) generated by the natural and modulated light. One of the primary limitations of active sensors is that low-energy radiance is generated by the diodes, and as such, the sensors are only effective in the near proximity of the target (0.3 to 2.5 m for the Crop Circle). The range of the GreenSeeker is even more restrictive because of the optical design and sensitivity of the electronics (NDVI values are relatively stable between 0.7 and 1.1 m). Along with this limitation comes the rapid dissipation of light with distance (intensity decreases with the square of the distance). Therefore, active sensors operating close to the target are very sensitive to changes in distance. This situation can probably be both good and bad, depending on how well the sensor distance above the soil surface is controlled. Studies on winter wheat (average height ~5 cm) in 2005 showed that both GreenSeeker and Crop Circle sensors performed comparably at 75, 100, and 125 cm above the soil.

Vegetation Indices

Various vegetation indices, based on passive solar reflectance, have been developed to diagnose and evaluate plant health. These indices involve reflectance data from several wavebands and are generally preferred over single wavelengths because they compensated for short- and long- term changes in solar irradiance and atmospheric conditions (Patience and Klemas, 1993). The most common vegetation index is NDVI:

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

Where, NIR represents reflectance from the near infrared portion of the electromagnetic spectrum (760-900 nm) and is most sensitive to living plant tissue. Reflectance from the red portion of the spectrum (630-

690 nm), like much of the visual portion of the electromagnetic spectrum, is sensitive to chlorophyll. Both GreenSeeker and Crop Circle software provide NDVI output. Active sensors essentially eliminate the need to deal with temporal changes in solar irradiance and atmospheric conditions. Therefore, the use of multi-waveband vegetation indices like NDVI may be sacrificing some of the differentiating power of single wavebands. However, if sensor height above the soil is not well controlled, some type of normalized vegetation index is recommended to correct for the strong sensitivity of active sensor output to distance from the target (especially <60 cm).

The NDVI was originally developed to correlate leaf area index of trees with reflectance patterns. Since then, it has been widely used to quantify the amount of living biomass of many targets. As noted above, the effectiveness of NDVI is questionable for canopies containing high levels of chlorophyll because red reflectance remains consistently low. Other indices (Gitelson and Merzlyak, 2004) have been proposed to estimate specific parameters such as:

Vegetative cover: (Green – Red) / (Green + Red – Blue)

Chlorophyll: (NIR-Green) / (Green)

Sensor Measurements

Active sensors are not strictly calibrated in the same manner as passive sensors. Radiance values collected by passive sensors are typically converted to percent reflectance by using a white standard (such as barium sulfate or a Spectralon panel) whose radiance (reflectance) value is assumed to be100%. When using a passive sensor, reflectance measurements from a white standard are typically taken before or after each plant or soil measurement. The alternative is to use an up-dwelling sensor to record and electronically correct for any changes in solar irradiance after first calibrating to the white standard. Active sensors have the benefit of having a close, stable light source so frequent calibration is not required. However, the trade-off is that great care must go into knowing the distance relationship between the sensor and target with active sensors if individual waveband data are used. Distance concerns are minimized when using normalized vegetation index values to make management decisions.

Active crop sensors have only been available to researchers for 4 to 5 years. Recent studies indicate that the concepts developed using passive sensors and aerial photography need to be re-evaluated when using active sensors. Both commercially available active sensors (Crop Circle and GreenSeeker) provide NDVI and visible/NIR values as output. Recall that these indices were developed from years of passive sensor research. It wasn't until the active Crop Circle sensor entered the scene in 2002 that researchers had access to NIR and visible waveband reflectance values (commercial versions of the GreenSeeker do not provide data for the individual wavebands).

Canopies like turf are typically well manicured and thus the distance between the sensor and canopy surface are generally well characterized. As such, differences in sensor readings are primarily indicative of spatial variability in biomass. A similar situation exists when sensors are used to map soil color (i.e., brightness), provided that sensor height above the soil surface is consistent. Irregular canopies like corn present a unique challenge because the large arcing leaves at various levels in the canopy generate a wide range of distances between the reflective surface and sensor. This variability in distance exists between rows and between plants so positioning of the sensor above the crop relative to the field of view is important. Other canopies like wheat present an intermediate situation in that the leaves are smaller and more numerous than corn, the distance between plants is less, and the distance between upper and lower leaves (depth of field) in wheat is less than corn.

Normalized vegetation indices remove the effect of distance between the sensors and canopy because distance affects all bands similarly. However, important distance relationships still remain when one refers to the individual band data. For example, the response of the NIR band for an active sensor is indicative of (1 changes in biomass density if the distance between the sensor and canopy is constant (as with turf), 2) variation in sensor height if the field of view remains the same, or 3) variation in height or density of living biomass if the sensor height above the soil remains constant. Considering these possibilities, it is important to know about other sensor limitations such as uniformity of the modulated radiation within the field of view, size and shape of the field of view, and electronic noise.

In applying precision agriculture to wheat production, Oklahoma State University developed a system that integrates data acquired by the GreenSeeker sensor with a decision aid and variable-rate technology. This system has shown that it can optimize farm profits while minimizing environmental impact by reducing N fertilizer inputs and applying those inputs only to N responsive sites (Raun et al., 2002).

An unexpected relationship between NIR and red reflectance for active sensors was first recognized with turf where visible reflectance remained consistently low with the active red sensor (i.e., turf absorbed all of the red light) while NIR reflectance was variable. Height of the sensor above the turf was controlled so changes in distance between the target and sensor could not account for changes in NIR reflectance. Even for passive sensors, the relationship between NIR and red reflectance changes once the leaf area index (LAI) of the crop reaches about 2.0 because there is adequate vegetation to absorb all of the available red light (Gitelson and Merzlyak, 1997). This is also why NDVI is not very sensitive to leaf chlorophyll status once the crop canopy closes and why one version of the Crop Circle sensor uses amber light (595 nm) instead of red light. The amber version of the sensor is not quite as sensitive as the red version for low vegetation situations, but the amber version does not saturate as quickly as vegetation amount increases.

■ A Case Study

(Comparison of Ground-Based Remote Sensors for Evaluation of Crop Biomass Affected by Nitrogen Stress)

Material and methods

<General procedure>

Pot experiments involving sand culture were conducted in 2003 and 2004 in a green house to evaluate corn and red pepper biomass. Sand was placed in large (28-cm dia x 26-cm depth) free-draining polyvinyl chloride (PVC) pots. Each pot was put in plastic container (40-cm width x 50-cm long x 30-cm depth) covered with Styrofoam to exclude light and inhibit algae growth. Corn was sown on 1 March, 2003 with Pioneer brand hybrid 3417. And red pepper was sown on 3 May, 2004 with Korea brand Eutheum and was cultivated until the maturing stage, the 120th day after planting. Pots with plants were arranged in a randomized complete block design with four replications. Six levels of N in Hoagland's nutrient solution ranging from 40% to 140% (20% intervals) were used for nitrogen stress of corn and red pepper.

<Sensors estimated>

Plant measurements were made using 1) chlorophyll meter (Minolta, SPAD 502), 2) Fieldscout™ (Spectrum Technologies, CM1000), 3) GreenSeeker™ (Ntech Industries), 4) Crop Circle™ (Holland Scientific), and 5) spectroradiometers (Ocean Optics S2000 and USB2000 in 2003 and LICOR Inc. LI-1800 in 2004). The SPAD meter uses two light-emitting diodes (650 and 940 nm) to determine the amount of light transmitted through a 2x3-mm leaf section. The Fieldscout^{TM} chlorophyll meter commercialized by Spectrum Technologies, Inc. uses ambient and reflected light at 700 and 840 nm to estimate chlorophyll content. The GreenSeeker^{TM} as commercialized by Ntech Industries Inc. was the only active sensor used in this study and measures red and near infrared (NIR) reflectance to generate rNDVI. The field of view for this sensor is 1 x 60 cm with an effective depth of field from 80 to 120 cm (32 to 48 inches) from the target. The Crop Circle^{TM} sensor made by Holland Scientific is a multi-waveband sensor designed for measuring light reflecting from crop canopies. Crop Circle^{TM} is a passive sensor with a conical field of view (20 degree) that measures four-band reflectance; green (550nm), amber (600nm), red (680nm), and near infrared (NIR, 820nm) allowing the calculation of red NDVI, green NDVI, and amber NDVI. And spectroradiometer can measure reflectance from visible to near infrared wavebands; 350~1025 nm (0.3-nm interval) for Ocean Optics S2000 in 2003, 400~996nm (2-nm interval) for Ocean Optics USB2000 in 2003, and 340~1100 nm (2-nm interval) for LI-1800 in 2004. Consequently, a wide variety of vegetation indices can be calculated.

<Reflectance measurement>

Canopy reflectance measurements with the GreenSeeker^{TM} and Crop Circle^{TM} sensors and spectroradiometers (Ocean optics S2000, USB2000, and LI-1800) were made on the same date as the SPAD and CM1000 measurements. All leaf reflectance measurements were made during midday under incident solar radiation from an angle perpendicular to the canopy. To minimize the background effect on reflectance measured with GreenSeeker^{TM}, Crop Circle^{TM}, and spectroradiometers, a black board was installed on the surface of each pot. In case of GreenSeeker^{TM} measurement, sensor was slowly scanned over the corn and red pepper canopy of each pot keeping about 100 cm distances from top canopy to the sensor head. For the outdoor measurement of Crop Circle^{TM}, the sensor was installed above the fixed pot position having 80~90 cm distance from the sensor head to top canopy. The rNDVI, gNDVI and aNDVI were used for evaluation of corn and red pepper biomass. After collecting canopy reflectance measurements, two leaf discs were taken from the upper-most expanded leaf using a cork borer (1-cm dia.) for determination of chlorophyll content. Leaf disc samples were homogenized in 80% acetone solution and the mixture was centrifuged at 2000 rpm for 2 minutes. Thereafter, the optical density of supernatant was measured at 645 and 663 nm. Chlorophyll content was calculated using the Arnon method (1949).

Results and discussion

<Dry weight>

Dry weight of corn, as affected by nitrogen stress, were greatly different at the flowering stage, ranged from 8.3 to 101.7 g plant^{-1} for 2003. Variations of corn dry matter showed the big difference among treatments having 46.3% of coefficient of variation, respectively. And dry weight and nitrogen uptake of red pepper, as affected by nitrogen stress, were greatly different at the 120th day after planting, ranged from 48.2 to 196 6 g plant^{-1} and from 824 to 3399 mg N plant^{-1}, respectively. Variations of dry matter and nitrogen uptake at the 120th day after planting showed the big difference among treatments having 27.8% and 34 0% of coefficient of variation, respectively. This variation was used to compare the sensitivity of reflectance indexes by different sensors for evaluation of corn and red pepper biomass affected by nitrogen stress.

<Correlation between Crop Biomass and Reflectance Indices>

The SPAD chlorophyll meter showed good correlation with chlorophyll content. From the relationship between chlorophyll reading and chlorophyll content, it was assumed that the SPAD reading could be used for the calibration standard of chlorophyll if there is no data of chlorophyll content. Others have also found that the SPAD 502 chlorophyll meter readings correlate linearly with extractable chlorophyll concentrations for a wide variety of crops, including rice (Takebe et al., 1990), soybean (Ma et al., 1995) and corn (Blackmer and Schepers, 1995). Schepers (2001) found that within a corn hybrid, there is usually a strong positive correlation between leaf chlorophyll content and nitrogen concentration and there is also a strong relationship between SPAD readings and both chlorophyll and nitrogen concentrations.

Correlation coefficients between dry weight of corn tissue and vegetation indices derived from reflectance measurements are shown in Tables 1 for the 2003 experiments. Relationships between dry weight of corn and several vegetation indexes showed the good correlation coefficient. All the vegetation indexes by GreenSeeker™ and Crop Circle™ were identified to be good predictor for evaluation of corn biomass at the V_6, $V_{7\sim8}$, and flowering growth stage, respectively, whereas all the indexes by spectroradiometer showed the lower correlation coefficient. Especially rNDVI and gNDVI by Crop Circle™ were the best indexes for evaluation of corn biomass at all growth stages showing correlation coefficient of more than 0 8

Table 1. Correlation coefficient between dry weight of corn and several vegetation indexes for 2003 experiment (n=24).

Measurement	Index	Dry weight		
		V_6 stage	$V_{7\sim8}$ stage	Flowering
Arnon's method	Chlorophyll a+b	0.65**	0.50*	
Chlorophyll meter	SPAD reading	0.73**	0.83**	0.59**
GreenSeeker^{TM}	rNDVI	0.68**	0.70**	
GreenSeeker^{TM}	Red/NIR	-0.66**	-0.69**	
Crop Circle^{TM}	rNDVI	0.87**	0.83**	0.88**
Crop Circle^{TM}	gNDVI	0.80**	0.82**	0.86**
Crop Circle^{TM}	Vegetative Cover	0.69**	0.73**	0.84**
Crop Circle^{TM}	Red/NIR	-0.86**	-0.82**	-0.87**
Spectroradiometer, S2000	rNDVI	0.38	0.42*	
Spectroradiometer, S2000	gNDVI	0.43*	0.59**	
Spectroradiometer, S2000	Vegetative Cover	0.27	0.25	
Spectroradiometer, S2000	Red/NIR	-0.36	-0.41*	
Spectroradiometer, USB2000	rNDVI	0.54**	0.65**	
Spectroradiometer, USB2000	gNDVI	0.47*	0.21	
Spectroradiometer, USB2000	Vegetative Cover	0.53**	0.58**	
Spectroradiometer, USB2000	Red/NIR	-0.54**	-0.65**	

Table 2. Correlation coefficient between dry weight of red pepper and reflectance indexes at the 78th day after planting (n=12)

Sensor	Index	Fresh weight	Dry weight	Yield of pepper	N-uptake by leaves
Chlorophyll meter	SPAD reading	0.49	0.52	0.36	0.67*
GreenSeeker^{TM}	rNDVI	0.61*	0.64*	0.32	0.70*
Crop Circle^{TM}	rNDVI	0.86**	0.84**	0.66*	0.83**
Crop Circle^{TM}	gNDVI	0.86**	0.84**	0.66*	0.88**
Crop Circle^{TM}	aNDVI	0.85**	0.78**	0.58*	0.79**
Spectroradiometer	rNDVI	0.61*	0.70*	0.48	0.82**
Spectroradiometer	aNDVI	0.38	0.52	0.34	0.66*

*Significant at the 0.05 level

**Significant at the 0.01 level

Correlation coefficients between dry weight and nitrogen uptake of red pepper tissue and vegetation indices derived from reflectance measurements are shown in Tables 2 for the growth stages at the 78th day after planting. Especially reflectance indices by Crop Circle^{TM} were the best for evaluation of dry weight and nitrogen uptake at every growth stages measured. From the above results, vegetation indexes such as rNDVI, aNDVI, and gNDVI by Crop Circle^{TM} were found to be available tool for predicting corn biomass and to be able to use for making management decision such as recommendation of nitrogen fertilizer.

<Prediction of crop biomass by reflectance indices>

The vegetation indexes such as rNDVI and gNDVI by Crop Circle^{TM} at the different growth stage were compared for evaluation of dry weight of corn at the flowering stage as shown in table 3. The indexes at the V_6 and $V_{7\sim8}$ growth stage considered as the critical season were significantly correlated with dry weight of corn at the flowering stage. This result suggested that Crop Circle^{TM} measurement at the critical season of corn might be used for evaluation of corn yield or further more recommendation of nitrogen fertilization.

Table 3. Correlation coefficient between dry weight at the flowering stage and Crop Circle indexes at the different growth stage for 2003 experiment.

Growth stage	Index by Crop Circle^{TM}	Dry weight at the flowering stage
V_6 stage	NDVI	0.72**
	GNDVI	0.66**
	VC	0.71**
$V_{7\sim8}$ stage	NDVI	0.82**
	GNDVI	0.81**
	VC	0.71**
Flowering stage	NDVI	0.88**
	GNDVI	0.86**
	VC	0.84**

The vegetation indices such as rNDVI and aNDVI by Crop Circle^{TM} at the different growth stage were compared for evaluation of green pepper yield, dry weight, and nitrogen uptake of red pepper at the 120th day after planting as shown in table 8. The indices such as rNDVI and aNDVI by Crop Circle^{TM} measured at the 40th, 50th, and 78th day after planting were significantly correlated with pepper yield, dry weight, and nitrogen uptake of red pepper at the 120th day after planting. This result suggested that Crop Circle^{TM} measurement at the critical season of red pepper might be used for evaluation of red pepper yield or further more recommendation of nitrogen fertilization.

Table 4 Correlation coefficient between yield and amount of N-uptake by leaves of red pepper and reflectance indexes at the different growth stage

Day after planting (DAP)	Index	at the 120th day after planting		
		Yield	Dry weight	N-uptake by leaves
40th DAP	SPAD	0.49*	0.63**	0.64**
	CM(40)	0.40	0.58**	0.62**
	rNDVI by GreenSeeker	0.50*	0.59**	0.64**
	rNDVI by Crop Circle	0.67**	0.73**	0.73**
	aNDVI by Crop Circle	0.73**	0.71**	0.75**
	rNDVI by Spectroradiometer	0.77**	0.82**	0.86**
78th DAP	SPAD	0.50*	0.68**	0.81**
	rNDVI by GreenSeeker	0.57**	0.70**	0.68**
	rNDVI by Crop Circle	0.77**	0.85**	0.87**
	aNDVI by Crop Circle	0.80**	0.89**	0.91**
	rNDVI by Spectroradiometer	0.55**	0.59**	0.72**
	aNDVI by Spectroradiometer	0.57**	0.63**	0.74**

*Significant at the 0.05 level
**Significant at the 0.01 level

Summary

As noted above, the weak energy source used in active sensors does not penetrate very deep into canopies with horizontal leaves and the farther the leaves are from the sensor, the lower the reading. Therefore, once a crop like corn, and perhaps wheat, develops several layers of leaves it is likely that the NIR reflectance values will reach a plateau. When this occurs, any changes in NIR reflectance will be due to distance between the sensor and the canopy. If sensor height above the soil is constant and multiple layers of leaves are in the field of view, an increase in NIR reflectance likely means that the bulk of the vegetation is closer to the sensor. The take-home-lessons are that 1) the distance relationship between active sensors and the target is critical, 2) the reliability of the relationship between sensor data and any chemical or physical plant parameter depends on the ability to acquire representative samples of each, and 3) data for individual reflectance bands from active sensors can enhance the information obtained and increase the utility of the technology. Ground-based remote sensors were compared for evaluation of crop biomass affected by nitrogen stress. The result obtained from the case study was shown that ground remote sensing as a non-destructive real-time assessment of plant nitrogen status was thought to be a useful tool for in season crop nitrogen management providing both spatial and temporal information.

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