

PERFORMANCE OF TWO ACTIVE CANOPY SENSORS FOR ESTIMATING WINTER WHEAT NITROGEN STATUS IN NORTH CHINA PLAIN

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ABSTRACT

Crop canopy sensor-based in-season site-specific nitrogen (N) management is a promising approach to precision N management. GreenSeeker sensor has previously been evaluated in North China Plain (NCP) for improving winter wheat N management, and it was found that NDVI became saturated when winter wheat biomass reached about 3700 kg ha⁻¹. A new active canopy sensor, Crop Circle ACS-470, has 6 wavebands, and has the potential to improve the estimation of crop N status. The objective of this research was to compare these two sensors for estimating winter wheat N status at different growth stages. Four field experiments were conducted in Quzhou Experiment Station of China Agricultural University in 2010. Preliminary analyses indicated that both sensors performed well for estimating winter wheat biomass and N uptake, but several vegetation indices calculated with Crop Circle ACS-470 sensor performed significantly better than GreenSeeker NDVI and RVI for estimating plant N concentration. The Crop Circle sensor has a better potential for in-season site-specific N application in North China Plain, and more researches are needed to develop algorithms for making in-season N recommendations.

Keywords: GreenSeeker, Crop Circle ACS 470, Nitrogen status diagnosis

INTRODUCTION

Over and mis-application of nitrogen fertilizers has been a common problem in China, resulting in low nitrogen use efficiencies and high risk of environmental contamination (Cui et al. 2008a, b; Ju et al. 2006, 2009; Guo et al. 2010; Miao et al. 2011). Precision nitrogen management is promising strategy to solve this problem, considering both spatial and temporal variability of crop nitrogen demand and supply. This precision management requires real-time diagnosis of crop nitrogen status, and recommends nitrogen application rates accordingly.

Recent advances in precision agriculture technology have led to development of ground-based active remote sensors without the need for ambient illumination or flight concerns. The light source simultaneously emits visible and near infrared light (NIR) from a single LED light source. The amount of visible and NIR light that is reflected by the crop canopy is measured and spectral vegetation indices can be calculated. There are few studies that document the performance of different active canopy sensors for estimating nitrogen status. Solari et al. (2004) showed that light conditions and leaf wetness had no effect on NDVI readings using GreenSeeker red and Crop Circle amber sensor. Hong et al. (2007) compared several types of sensors including the GreenSeeker red sensor and a passive version of the Crop Circle and found that both sensors can provide a nondestructive, real-time assessment of apparent plant N status and can be used to guide in-season N management decisions. Shaver et al. (2010) compared two ground-based active crop canopy sensors (Crop Circle amber and GreenSeeker red) across plant growth, wind, crop row spacing, sensor movement speed and N fertilizer rate under greenhouse conditions and found that N rate and growth stage did affect the NDVI of both sensors with NDVI values increasing with increased N rate and advancing growth stage. Shaver et al. (2011) compared the performance of two active sensors (GreenSeeker and Crop Circle ACS-210) by determining each sensor's NDVI relationship with maize N status and concluded that both the GreenSeeker red sensor and the Holland Scientific amber Crop Circle sensors performed well in the determination of N variability in irrigated maize at the V12 and V14 growth stage. Tremblay et al. (2009) compared the performance of two commercial sensors, the Yara N-sensor/FieldScan and the GreenSeeker, for assessing the status of N in spring wheat and corn and concluded that both sensors were capable of describing the N status, but each sensor had its own sensitivity characteristics. The Yara N-sensor/FieldScan can record spectral information from wavebands other than red and near infrared, and more vegetation indices can be derived that might relate better to N status than NDVI.

Review of the literature indicated that there are no studies that have focused on using two commercially available active canopy sensors to study their

comparative effectiveness under field conditions in North China Plain (NCP). The objectives of the study were: (1) to determine the effectiveness of two commercially available active canopy sensors across several winter wheat varieties and growth stages in NCP; (2) to determine the optimum growth stage at which each sensor performed best and evaluate the related spectral vegetation indices derived by different active canopy sensors.

MATERIAL AND METHODS

Field Experiment

Four experiments (Table 1) were conducted in Quzhou Country (36.9°N, 115.0°E) in Hebei Province, located on the NCP. Experiment 1 was a long-term field experiment. Five N treatments, including no N as a control (CK); optimal N rate based on in-season root-zoon N management (Opt.); farmer's N practice (FNP); and 50% and 150% of Opt., were applied in 2007-2012. The Opt. was determined according to an in-season root-zoon N-management strategy (Cui et al., 2008a; Ju et al., 2009). The FNP was set at 300 kg N ha⁻¹ (150 kg N ha⁻¹ applied before planting and 200 kg N ha⁻¹ applied at stage Feekes 6), which is typical for Hebei province. Based on soil P and K test results, all treatments received appropriate amounts of triple superphosphate (150 kg P₂O₅ ha⁻¹) and potassium chloride (120 kg K₂O ha⁻¹) before planting. The N source for all treatments was urea. A widely used winter wheat variety in this region, Liangxing 99, was used in the experiment. Experiment 2 was conducted to evaluate different N management strategies. Several N management strategies. For each strategy, N treatments were replicated four times and arranged in a randomized complete block design. Liangxing 99 was also used in this experiment. Experiment 3 was variety-N experiment. Seven N rates were applied: 0, 60, 120, 180, 240, 300, 360 kg N ha⁻¹. Each N rate was replicated three times in complete randomized block design. Kenong 9204 and Heng 4399 were used in this experiment. Experiment 4 has three N rates, including no N as a control, optimal N rate and conventional N rate, and two winter wheat cultivars: Liangxing 99 and Shimai 18. Each N rate was replicated four times in complete randomized block design.

Active Canopy Sensor Data Collection

Two crop canopy sensors were tested and compared. The first sensor used was GreenSeeker handheld sensor (Trimble Navigation Limited, Sunnyvale, California, USA) which is active optical crop canopy sensor. Sensor readings were collected at different stages (Table 1) in all plots and the sensor path was parallel to the seed rows or the beam of light was perpendicular to the seed row. Another sensor used was the Holland Scientific Crop Circle ACS-470

Multi-Spectral Crop Canopy Sensor. This unit is also active sensor and it operates under similar principles as GreenSeeker sensor, however, the Crop Circle ACS-470 incorporates three optical measurement channels. The spectral characteristics of the Crop Circle ACS-470 are user configurable (440 nm to 800nm) using 12.5 mm interference filters. In this study, a wavelength of 550nm and 730nm in the visible bands and 760 Long Wave Pass (LWP) nm in the NIR band were selected. The data can be easily and quickly recorded to a text file on an SD flash card using the Holland Scientific GeoSCOUT GLS-400 data logger. Sensor readings were collected approximately 0.7 to 0.9 m above winter wheat canopy at a rate of 10 readings per second and walking in the same speed in the each plot, and the average reflectance values were used to represent each plot. Then these reflectance values were used to calculated vegetation index (Table 2).

Plant Sampling and Measurement

Plant samples were taken from stage Feekes 4 (tillering) to Feeker 10.5 (onset of flowing). Details of the sampling times for each experiment site are shown in Table 1. This sampling was done at the same time that sensor readings were collected. At each sampling time, the aboveground biomass was collected by randomly clipping 100 by 30 cm vegetation from scanned plants following sensing in each plot. All plant samples were oven dried at 75°C to constant weight then weighed. Sub sample samples that passed through a 1 mm screen in a sample mill were mineralized using H₂SO₄-H₂O₂, and plant N concentration was determined using the standard Kjeldahl method (Horowitz, 1970). The plant N uptake was determined by multiplying plant N concentration by dry biomass.

Statistical Analysis

Correlation, regression, and analysis of variance (ANOVA) were conducted using STATISTICA 6.0 (StatSoft, Inc., Tulsa, Oklahoma, USA) and MicroSoft Excel (MicroSoft Cooperation, Redmond, Washington, USA).

Table 1. Wheat variety, soil texture, sampling stages and soil chemical properties (0-30 cm soil layer) before winter wheat planting at the 4 experiment in Quzhou Country in North China Plain.

Experiment	Year	Variety	pH	Organic	Total	Olsen-P	NH ₄ OA c-K ⁺	Sampling stages (Feekes scale)
				matter	N			
				----- g kg ⁻¹	-----		----- mg kg ⁻¹	
1	2009/2 010	LX99	8.3	14.9	0.76	9.9	104	4, 5, 6, 9, 10.5
2	2009/2 010	LX99	8.1	14.0	0.75	6.2	97	4, 10.5
3	2009/2 010	KN9204/H 4399	8.3	14.2	0.83	7.2	125	6, 10.5
4	2009/2 010	LX99/SM 18	8.1	14.2	0.67	7.0	110	5, 6, 9

Table 2. Spectral vegetation indices calculated from Crop Circle ACS-470.

Vegetation Index	Definition	References
NDVI_1	$(R_{760}-R_{730})/(R_{760}+R_{730})$	Rouse et al. (1974)
NDVI_2	$(R_{760}-R_{550})/(R_{760}+R_{550})$	
NDVI_3	$(R_{730}-R_{550})/(R_{730}+R_{550})$	
RVI_1	R_{760}/R_{730}	Jordan (1969)
RVI_2	R_{760}/R_{550}	
RVI_3	R_{730}/R_{550}	
DVI_1	$R_{760}-R_{730}$	
DVI_2	$R_{760}-R_{550}$	
DVI_3	$R_{730}-R_{550}$	
OSAVI_1	$(1+0.16)(R_{760}-R_{730})/(R_{760}+R_{730}+0.16)$	Rondeaux et al. (1996)
OSAVI_2	$(1+0.16)(R_{760}-R_{550})/(R_{760}+R_{550}+0.16)$	
OSAVI_3	$(1+0.16)(R_{730}-R_{550})/(R_{730}+R_{550}+0.16)$	
RDVI_1	$(R_{760}-R_{730})/\text{SQRT}(R_{760}+R_{730})$	Rougean et al. (1995)
RDVI_2	$(R_{760}-R_{550})/\text{SQRT}(R_{760}+R_{550})$	
RDVI_3	$(R_{730}-R_{550})/\text{SQRT}(R_{730}+R_{550})$	
MSR_1	$(R_{760}/R_{730}-1)/\text{SQRT}(R_{760}/R_{730}+1)$	Chen (1996)
MSR_2	$(R_{760}/R_{550}-1)/\text{SQRT}(R_{760}/R_{550}+1)$	
MSR_3	$(R_{730}/R_{550}-1)/\text{SQRT}(R_{730}/R_{550}+1)$	

MSAVI_1	$0.5 \times [2 \times R_{760} + 1 - \text{SQRT}((2 \times R_{760} + 1)^2 - 8 \times (R_{760} - R_{730}))]$	Qi et al.(1994)
MSAVI_2	$0.5 \times [2 \times R_{760} + 1 - \text{SQRT}((2 \times R_{760} + 1)^2 - 8 \times (R_{760} - R_{550}))]$	
MSAVI_3	$0.5 \times [2 \times R_{730} + 1 - \text{SQRT}((2 \times R_{730} + 1)^2 - 8 \times (R_{730} - R_{550}))]$	
MCARI	$[(R_{760} - R_{730}) - 0.2 \times (R_{760} - R_{550})] (R_{760} / R_{730})$	Daughtry et al. (2000)
TCARI	$3 \times [(R_{760} - R_{730}) - 0.2 \times (R_{760} - R_{550})] (R_{760} / R_{730})$]	Haboudane et al. (2002)
TVI	$0.5 \times [120 \times (R_{760} - R_{550}) - 200 \times (R_{730} - R_{550})]$	Broge et al. (2002)
MTVI	$1.2 \times [1.2 \times (R_{760} - R_{550}) - 2.5 \times (R_{730} - R_{550})]$	Haboudane et al. (2004)
TCARI/OSAV L_1	TCARI/OSAVI	Haboudane et al. (2002)
TCARI/OSAV L_2	TCARI/OSAVI	
TCARI/OSAV L_3	TCARI/OSAVI	
MCARI/OSA VI_1	TCARI/OSAVI	Zarco-Tejada et al. (2003)
MCARI/OSA VI_2	TCARI/OSAVI	
MCARI/OSA VI_3	TCARI/OSAVI	

RESULTS AND DISCUSSION

Variation of Agronomic Variables

The agronomic parameters varied greatly across different growth stages, N treatment and winter wheat varieties (Table 3). The greatest differences occurred at Feekes growth stage 4-6 where above ground biomass ranged from 0.1 to 3.8 t ha⁻¹. The coefficient of variation (CV) of above ground biomass and N uptake were larger than N concentration. This result indicated that above ground biomass and N uptake would be easier to be estimated by remote sensing than N concentration.

Table 3. Descriptive statistics of winter wheat above ground biomass, plant N concentration and N uptake.

Statistic	Biomass		N Concentration		N Uptake	
	F†4-6	F9-10.5	F4-6	F9-10.5	F4-6	F9-10.5
	--- t ha ⁻¹ ---		--- % ---		--- kg ha ⁻¹ ---	
Valid N	176	133	176	133	176	133
Mean	1.7	5.0	3.2	1.8	50.1	93.8
Median	1.4	5.2	3.1	1.9	51.4	96.9
Min.	0.1	1.3	1.3	0.8	5.1	16.3
Max.	3.8	7.7	4.9	2.8	114.7	165.4
Std.Dev.	1.0	1.4	0.8	0.4	29.1	35.5
CV(%)	60.5	29.0	24.0	22.1	58.1	37.8

† F, Feekes growth stage.

Relationship between Spectral Indices and Agronomic Variables

The correlation coefficients between spectral indices and agronomic parameters are shown in Table 4. All correlations between above ground biomass and vegetation indices, except DVI_2 at Feekes growth stages 4-6 and OSAVI_3 at Feekes growth stages 9-10.5, were similarly significant. Better relationships were observed at Feekes growth stages 4-6 than Feekes 9-10.5. In contrast, the relationship between spectral vegetation indices and plant N concentration at Feekes 9-10.5 was better than at Feekes 4-6. The results indicated that the vegetation indices derived by Crop Circle ACS-470 were highly correlated with plant N concentration compared with GreenSeeker NDVI and RVI. The relationships between GreenSeeker NDVI and plant N concentration were greatly affected by growth stages, with the relationships between plant N concentration and GS_NDVI and GS_RVI being relatively stronger at higher above ground biomass conditions. However, some indices derived by Crop Circle ACS-470 were more stable, without being significantly affected by growth stages.

Table 4. Correlation coefficient between above ground biomass, plant N concentration, plant N uptake and several vegetation indexes at different growth stage (Significant at the 0.01 probability level).

Index	Above Ground			Plant N			Plant N Uptake		
	F†4 N=1	F9-1 N=1	All N=3	F4- N=1	F9-1 N=1	All N=3	F4- N=1	F9-1 N=1	All N=3
GreenSeeker									
NDVI	0.94	0.83	0.83	-0.2	0.59	-0.3	0.91	0.84	0.90
RVI	0.90	0.71	0.80	-0.2	0.49	-0.3	0.83	0.73	0.83
Crop Circle									
NDVI_1	0.94	0.83	0.83	-0.2	0.64	-0.3	0.92	0.88	0.91
NDVI_2	0.93	0.82	0.78	-0.2	0.65	-0.3	0.91	0.87	0.89
NDVI_3	0.88	0.75	0.59	-0.2	0.66		0.85	0.84	0.77
RVI_1	0.93	0.82	0.84	-0.2	0.64	-0.3	0.91	0.88	0.92
RVI_2	0.92	0.79	0.78	-0.2	0.65	-0.3	0.89	0.87	0.89
RVI_3	0.88	0.73	0.57	-0.2	0.66		0.85	0.83	0.75
DVI_1	0.83	0.69	0.52		0.79		0.87	0.87	0.76
DVI_2		0.47	-0.3	0.55	0.82	0.76	0.32	0.75	
DVI_3	-0.8	-0.59	-0.8	0.58		0.75	-0.7	-0.34	-0.7
OSAVI_1	0.93	0.81	0.79	-0.2	0.69	-0.3	0.92	0.89	0.90
OSAVI_2	0.90	0.76	0.64		0.75		0.91	0.88	0.84
OSAVI_3	0.25		-0.5	0.41	0.73	0.77	0.40	0.51	-0.2
RDVI_1	0.90	0.77	0.71		0.73	-0.2	0.91	0.89	0.87
RDVI_2	0.74	0.67	0.31		0.80	0.30	0.82	0.86	0.61
RDVI_3	-0.7	-0.24	-0.8	0.65	0.47	0.83	-0.6		-0.6
MSR_1	0.94	0.84	0.87	-0.2	0.61	-0.4	0.90	0.87	0.92
MSR_2	0.93	0.81	0.82	-0.2	0.62	-0.3	0.89	0.86	0.90
MSR_3	0.91	0.77	0.71	-0.3	0.61	-0.3	0.86	0.83	0.82
MSAVI_1	0.90	0.76	0.71		0.74	-0.1	0.91	0.89	0.87
MSAVI_2	0.79	0.64	0.34		0.80	0.25	0.86	0.84	0.65
MSAVI_3	-0.7	-0.45	-0.8	0.63	0.28	0.81	-0.6		-0.6
MCARI	0.88	0.72	0.69		0.74	-0.2	0.89	0.87	0.85
TCARI	0.86	0.73	0.60		0.76	-0.1	0.88	0.86	0.78
TVI	0.91	0.78	0.74	-0.2	0.72	-0.3	0.90	0.89	0.85
MTVI	0.92	0.81	0.79	-0.3	0.66	-0.4	0.89	0.88	0.85
TCARI/OSA	0.67	0.74	0.52		0.74	-0.2	0.69	0.87	0.64
TCARI/OSA	0.89	0.76	0.72		0.73	-0.2	0.90	0.89	0.87
TCARI/OSA	0.90	0.77	0.78		0.70	-0.2	0.90	0.89	0.90
MCARI/OSA	-0.6	-0.73	-0.5	0.20	-0.42	0.36	-0.6	-0.68	-0.6
MCARI/OSA	-0.9	-0.82	-0.8	0.36	-0.41	0.56	-0.8	-0.74	-0.8
MCARI_1/O	-0.9	-0.71	-0.8	0.50		0.70	-0.7	-0.52	-0.7

†F, Feekes growth stage.

CONCLUSION

Results of this study showed superior performance of Crop Circle ACS-470 compared to the GreenSeeker to estimate agronomic variables, especially for estimating plant N concentration. Unlike GreenSeeker, the Crop Circle ACS-470 can record spectral information from wavebands other than red and near infrared, and more vegetation indices can be derived that have better relationships between spectral vegetation indices and agronomic parameters than NDVI and RVI derived by GreenSeeker. The Crop Circle sensor has a better potential for in-season site-specific N application in North China Plain, and more researches are needed to develop algorithms for making in-season N recommendations.

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REFERENCES

- Broge, N. H., and Mortensen, J. V. 2002. Deriving green crop area index and canopy chlorophyll density of winter wheat from spectral reflectance data. *Remote Sens. Environ.* 81: 45-57.
- Cui, Z., Chen, X., Miao, Y., Zhang, F., Schrode, J., Zhang, H.. 2008a. On-farm evaluation of the improved soil Nmin-based nitrogen management for summer maize in North China Plain. *Agronomy Journal*, 100, 517–525.
- Cui, Z., Zhang, F., Chen, X., Miao, Y., Li, J., Shi, L., Xu, J., Ye Y., Liu, C., Yang, Z., Zhang, Q., Huang, S., and Bao, D.. 2008. On-farm evaluation of an in-season nitrogen management strategy based on soil Nmin test. *Field Crops Research*, 105, 48–55.
- Daughtry, C. S. T., Walthall, C. L., Kim, M. S., Brown, D., Colstoun, E., and McMurtrey, J. E. 2000. Estimating corn leaf chlorophyll concentration from leaf and canopy reflectance. *Remote Sens. Environ.* 74: 229-239.
- Haboudane, D., Miller, J. R., Tremblay, N., Zarco-Tejada, P. J., and Dextraze, L. 2002. Integrated narrow-band vegetation indices for prediction of crop chlorophyll content for application to precision agriculture. *Remote Sens. Environ.* 81: 416-426.
- Haboudane, D., Miller, J. R., Elizabeth Pattey, Zarco-Tejada, Pablo J., Strachan,

- Ian B. 2004. Hyperspectral vegetation indices and novel algorithms for predicting green LAI of crop canopies: Modeling and validation in the context of precision agriculture. *Remote Sens. Environ.* 90: 337-352.
- Horowitz, W. (1970). *Official methods of analysis*. 11th ed. p. 17-18. AOAC, Washington, DC.
- Jordan, C. F., 1969. Derivation of leaf area index from quality of light on the forest floor. *Ecology* 50: 663-666.
- Ju, X. T., Kou, C. L., Zhang, F. S., & Christie, P.. 2006. Nitrogen balance and groundwater nitrate contamination: Comparison among three intensive cropping systems on the North China Plain. *Environmental Pollution*, 143, 117–125.
- Ju, X. T., Xing, G. X., Chen, X. P., Zhang, S. L., Zhang, L. J., Liu, X. J., Cui, Z. L., Yin, B., Christie, P., Zhu, Z. L. and Zhang, F. S.. 2009. Reducing environmental risk by improving N management in intensive Chinese agricultural systems. *Proceedings of National Academy of Sciences USA (PNAS)*, 106, 3041–3046.
- Miao, Y., Stewart, B. A., & Zhang, F. 2011. Long-term experiments for sustainable nutrient management in China. A review. *Agronomy for Sustainable Development*, 31, 397–414.
- Rondeaux, G., Steven, M., and Baret, F. 1996. Optimization of Soil-Adjusted Vegetation Indices. *Remote Sens. Environ.* 55: 95-107.
- Roujean, J. L., and Breon, F. M. 1995. Estimating PAR absorbed by vegetation from bidirectional reflectance measurements. *Remote Sens. Environ.* 51: 375-384.
- Rouse, J.W., Has, R.H., Schell, J.A., Deering, D.W., 1974. Monitoring vegetation systems in the great plains with ERTS. *Third ERTS Symposium, NASA SP-351, Vol. 1. NASA, Washington, DC.* 309-317.
- Shaver, T. M., Khosla, R., Westfall, D. G. 2010. Evaluation of two ground-based active crop canopy sensors in maize: growth stage, row spacing, and sensor movement speed. *Soil Science Society of America Journal*, 74, 2101-2108.
- Shaver, T. M., Khosla, R., Westfall, D. G. 2011. Evaluation of two crop canopy sensors for nitrogen variability determination in irrigated maize. *Precision Agriculture*, 12, 892-904.
- Tremblay, N., Wang, Z. J., Ma B. L., Belec, C., Vigneault, P. 2009. A comparison of crop data measured by two commercial sensors for variable-rate nitrogen application. *Precision Agriculture*, 10, 145-161.
- Zarco-Tejada, P. J., Pushnik, J. C., Dobrowski, S., and Ustin, S. L. 2003. Steady-state chlorophyll a fluorescence detection from canopy derivative reflectance and double-peak red-edge effects. *Remote Sens. Environ.* 84(2): 283-294.