DERIVING NITROGEN INDICATORS OF MAIZE USING THE CANOPY CHLOROPHYLL CONTENT INDEX

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ABSTRACT

Many spectral indices have been proposed to derive aerial nitrogen (N) status parameters of crops in recent decades. However, most of red light based spectral indices easily loss sensitivity at moderate-high aboveground biomass. The objective of present study is to assess the performance of red edge based Chlorophyll Canopy Content Index (CCCI) in deriving N concentration and aerial N uptake of maize (*Zea mays L.*). The CCCI was developed based on a two dimensional method with the use of the normalized difference vegetation index (NDVI) accounting for variation in canopy coverage, and the normalized difference red edge (NDRE) accounting for measuring of crop N. Experiments including different N rates in maize were conducted in 2009 and 2010 in Quzhou County of the North China Plain. The spectral indices were derived from simulated GreenSeeker and Crop Circle active crop canopy sensor bands. The results indicated that growth stages had a significantly influences on the relationships between spectral indices and aerial N related indicators. The two-dimensional CCCI were found to be more stable and better predictors than traditional red light based NDVI and RVI in estimating aerial N concentration and the aerial N uptake. For aerial N concentration, values of coefficient of correlation (r) ranged from 0.54 to 0.82. For aerial N uptake, r values ranged from 0.75 to 0.84. The relationship between CCCI and aerial N concentration was better under full maize cover conditions. We concluded that CCCI using the planar domain index approach significantly improved the prediction power of red edge dependent vegetation indices in deriving the aerial N status. The findings from this study are potentially useful to manage N fertilizer application in maize.

Keywords: CCCI, Nitrogen status, Red edge.

INTRODUCTION

In China, the sowing area and total yield of maize are increasing gradually due to the rising price. Maize has become the second staple food crop since its total production exceeded that of wheat in 1998 (China Agricultural Yearbook, 1981-2009). Therefore, maize play an important role in meeting rising demand for food products in pace with Chinese population growth. However, an effective method or tool is absent for in-season nitrogen (N) fertilizer management of maize (Miao et al., 2011). Particularly in small field management of Northern China plain, farmers applied N fertilizer depending on their experiences. The applied N rates vary among different farmers' fields. Traditional soil-plant based N diagnosis and recommend techniques are difficult to meet the demand for field by field recommendation (Chen et al., 2006). As a result, some farmers applied N rate exceeding maize plants requirement. Excessive reactive N load into environment, can not only result in environmental risks but also increase farmers' economically input (Ju et al., 2009)

In recent decades, some commercial active crop canopy sensors, such as GreenSeeker and Crop Circle, were developed to estimate nitrogen (N) status of crop timely and nondestructively. Coupled with corresponding N fertilizer recommendation algorithms, the crop sensor can recommend in season application N rates for crops. Compared with traditional practice, the N fertilizer use efficiency (NUE) was significantly increased using GreenSeeker based N management technique for winter wheat (Raun et al., 2002; Li et al., 2009; Bijay-Singh et al., 2011). Using active crop sensor based variable-N management method, 25-50 $/ha profit was obtained for maize production (Kitchen et al., 2010). Making a general survey of the literatures, the point is that the readings of crop sensor and correspondingly algorithms are sensitive to the N status related indicators of crop. Particularly for corn, the aboveground biomass rapidly increases after V6. Thus, most of red light based spectral indices like NDVI easily loss sensitivity. Therefore, the objective of this study is to assess the performance of red light- and red edge-based vegetation indices derived from simulated active GreenSeeker and Crop Circle crop sensor data to remotely sense plant N concentration and uptake in maize.

MATERIAL AND METHODS

The experiments were conducted at the Quzhou Experimental Station of the China Agricultural University (CAU) in Quzhou County located in the North China Plain. Quzhou County lies in the warm-temperate subhumid-continental monsoon zone and is characterised by cold winters and hot summers. The yearly mean temperature is 13.1°C, with 200 frost-free days. Annual average rainfall is 438 mm (average of 5 years from 2006 to 2010). Only about 80 mm rainfall occurs between regreening of winter wheat at the beginning of March and harvesting at the beginning of June and the temperature is high. So, the climate in this area is hot and dry in winter wheat growing season. Generally, 3-4 times irrigation was applied in this area.

Two experiments involving three cultivars were conducted from June to October in 2009-2010 for two maize seasons at Quzhou experimental station. Experiment 1 was a split-plot design with four replications. The main plot consisted of five N treatments: control (no N was applied), 50% of optimum N rate (Opt), 150% of Opt, Opt, and conventional N rate fertilization (Con), and the subplot consisted of three summer maize cultivars. The Opt was determined based on soil N_{min} test. The conventional N treatment represents local farmer's practice. Experiment 2 is a experiment of N fertilizer applied strategies using different techniques.

Canopy spectral reflectance was measured using the ASD Fieldspec3 optical sensor (Analytical Spectral Devices, Inc., Boulder, CO, USA) from 10 am to 2 pm under cloudless conditions. The reflectance of the target is calculated with the calibration measurements of dark current and a white reference panel with known reflectance properties (ASD User's Guide 2002). Spectral measurements were taken randomly at three sites in each plot and were averaged to represent the canopy reflectance of each plot. Aboveground biomass was collected in each plot following each sensor scanning at V6, V10 and VT. All plant samples were oven dried at 70 ^{o}C to constant weight and then weighed, ground, and their Kjeldahl-N determined. In this study, we selected four vegetation indices NDVI, RVI for simulating GreenSeeker sensor bands and NDRE, CCCI for simulating Crop Ccircle ACS-470 sensor bands. The selected indices were related to plant N concentration and plant N uptake.

RESULTS AND DISCUSSION

Variation in Plant N Concentration and Uptake

Across growth stages, applied N rates, sites and years, plant N concentration of maize ranged between 0.58% and 3.61% with a mean of 2.16%, and plant N uptake varied from 6.4 kg N ha^{-1} to 179.5 kg N ha^{-1} with a mean of 64.7 kg N ha^{-1} (Table 1). With the development of growth stage, coefficients of variation (CV, %) for plant N concentration and uptake increased. Compared with plant N concentration of maize, the variation of plant N uptake is greater, indicating that plant N uptake is more easily predicted by using remote sensing technology.

Table 1 Described statistics of plant N concentration and uptake.

Growth stage	Min.	Max.	Average	SD	CV, %
Plant N concentration (%)					
V6	2.00	3.61	3.07	0.40	13.1
V10	1.49	3.22	2.43	0.45	18.4
VT	0.58	1.86	1.31	0.33	24.9
All data	0.58	3.61	2.16	0.79	36.6
Plant N uptake (kg N ha^{-1})					
V6	6.4	31.9	20.8	6.4	30.8
V10	19.7	104.8	65.1	22.1	34.0
VT	24.5	179.5	96.3	34.0	35.3
All data	6.4	179.5	64.7	37.0	57.2

Relationships between Selected Indices and Agronomic Indicators

In order to evaluate the commercially available active crop canopy sensors and test the sensitivity of red light- and red edge-based spectral indices to plant N status related indicators of maize, we calculated NDVI and RVI using simulated GreenSeeker sensor wavebands, and NDRE, CCCI using simulated Crop Circle ACS-470 sensor wavebands. Calculated spectral indices were related to aboveground biomass, plant N concentration and uptake in growth stages V6-VT. As the values of coefficient of correlation illustrated in Table 2, the red edge based spectral indices using simulated Crop Circle data have stronger correlations with aboveground biomass, plant N concentration and uptake compared to red light based spectral indices in all measured growth stages, regardless of cultivars, sites and years. Particularly in growth stage V10-V12, the leaf area index (LAI) of maize almost reached maximum, red light based NDVI varied only in 0.8-0.9, which lost the sensitivity. The coefficient of correlation corresponding the relationship between NDVI and plant N concentration and uptake is lower than between red edge based indices NDRE, CCCI and plant N concentration and uptake in V10-V12 growth stage. This suggested that GreenSeeker crop sensor should be used for in-season N management of maize before V10-V12 growth stage. When all data in different growth stages were combined, the coefficient of correlation decreased compared with that in single growth stage, indicating that difference in biomass and canopy structure resulted from different growth stages affected the relationships between the spectral indices and plant N concentration and uptake. Better correlations between spectral indices and aerial N uptake were observed at each growth stage.

Table 2 Relationships between selected indices and biomass, plant N concentration, plant N uptake and SPAD values in maize growth stage V6, V10 and VT.

Spectral index	Growth stage	Biomass (t/ha)	Plant N concentration (%)	Plant N uptake (kg/ha)
NDVI	V6-V7	0.447**	0.241	0.423**
	V10-V12	0.613**	0.413**	0.690**
	VT	0.657**	0.744**	0.774**
	Combined	0.003	0.085	0.343**
RVI	V6-V7	0.427**	0.188	0.399**
	V10-V12	0.624**	0.366**	0.682**
	VT	0.646**	0.755**	0.784**
	Combined	0.061	0.130	0.294**
NDRE	V6-V7	0.663**	0.627**	0.737**
	V10-V12	0.676**	0.517**	0.827**
	VT	0.728**	0.721**	0.773**
	Combined	-0.180	0.336**	0.251*
CCCI	V6-V7	0.654**	0.817**	0.802**
	V10-V12	0.672**	0.535**	0.841**
	VT	0.721**	0.691**	0.746**
	Combined	-0.270*	0.459**	0.182*

***Stand for 0.05 significant levels； ** Stand for 0.01 significant levels.**

Model Establishment

To further understand the effects of growth stages on the relationships between calculated spectral indices and plant N concentration and uptake, we performed regression correlations for V6-V10 and V10-VT growth periods. The selected spectral indices significantly related to plant N uptake before V10 growth stage whereas spectral indices significantly related to plant N concentration after V10 growth stage (Data not shown). This probably results from aboveground biomass having a great influence on the relationship between spectral indices and plant N status related parameters (Flowers et al., 2003). Compared with NDVI, CCCI is more sensitive to plant N concentration and uptake under moderate-high aboveground biomass (Fig. 1). Thus, active Crop Circle sensor including red edge waveband is flexible in extracting spectral indices and is more sensitive in estimating maize plant N status compared to GreenSeeker sensor.

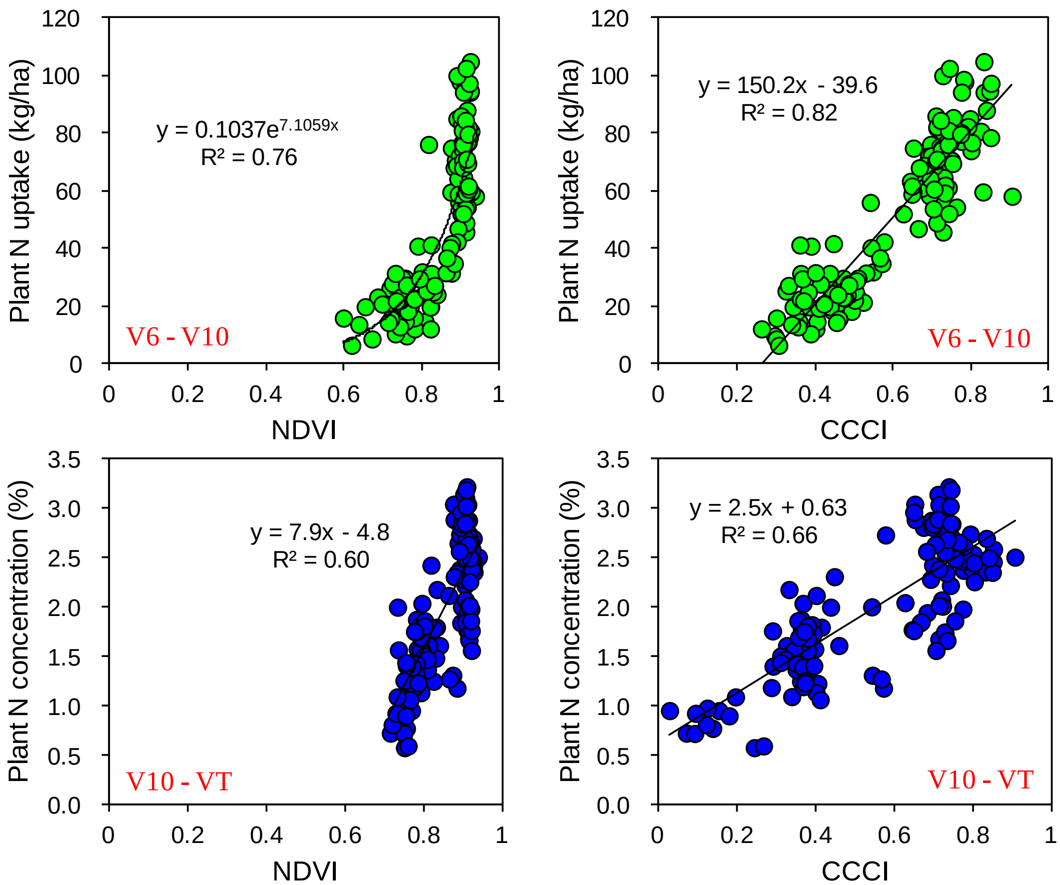

Fig.1 Relationship between NDVI, CCCI and plant N uptake from growth stage V6 to V10 and plant N concentration from growth stage V10 to VT.

CONCLUSION

The red edge based index NDRE , particularly, two-dimensional combined index CCCI calculated using simulated Crop Circle ACS-470 sensor wavebands were relatively stable and powerful indices for deriving plant N uptake before V10 stage and plant N concentration after the V10 stage across cultivars, sites and years. The results also provide useful insight for using commercial active crop sensors to guide producers in managing their N application in the critical growth stages. Further validation and testing will be needed to estimate the stability and transferability of the best performing spectral indices at heterogeneous maize production agro-ecosystems in the future.

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