MODEL FOR REMOTE ESTIMATION OF NITROGEN CONTENTS OF CORN LEAF USING HYPERSPECTRAL REFLECTANCE UNDER SEMI- ARID CONDITION

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ABSTRACT

Accuracy and precision of nitrogen estimation can be improved by hyperspectral remote sensing that leads effective management of nitrogen application in precision agriculture. The objectives of this experiment were to identify N sensitive spectral wavelengths, their combinations and spectral vegetation indices (SVIs) that are indicative of nitrogen nutritional condition and to analyze the accuracy of different spectral parameters for remote estimation of nitrogen status temporally. A study was conducted during 2010 at Northwest A & F University, China, to determine the relationship between leaf hyperspectral reflectance (350-1075 nm) and leaf N contents in the field-grown corn (Zea maize L) under five nitrogen rates (0, 60, 120, 180, and 240 kg/ha pure nitrogen) were measured at key developmental stages. The fitting of liner and nonlinear regressions models between leaves total nitrogen and the spectral of original reflectance. The accuracy of nitrogen nutrition diagnosis among the single (R) and dual (R1+R2) spectral reflectance, first order differential transform, spectral ratio (SR), NDVI, GNDVI, and SAVI were compared. Chose 2-3 high coefficient and F value model to verification RMSE and RRMSE at each stage, take the smaller as the best model. The results showed that there was best fitting between nitrogen contents and their spectral parameters of R710, SDr, R550 (SDr-SDb)/(SDr+SDb), D(R630）at 10-12 leaf, silking, tasseling, and early dent stages. Spectral ratios with R810/R670 showed highest R^2 at 10-12 leaf stage, silking and tasseling stages respectively, followed by R810/R670. SAVI was the best indicator of nitrogen contents at 6-8, leaf stages. GNDVI showed the highest R^2 (0.88) at 10-

12 leaf stage and at silking stage (0.74) followed by NDVI. The results showed that leaf nitrogen status can be best predicted at 10-12 leaf, silking and tasseling stages by using spectral vegetation indices with GNDVI. The study results indicated that leaf hyperspectral reflectance can be used for real time monitoring of corn nitrogen status and important tool for N fertilizer management in precision agriculture.

Key words: Hyperspectral remote sensing, nitrogen content, spectral vegetation indices, corn.

INTRODUCTION

Nitrogen (N) is the most limiting factor for growing crops and its availability an important in determining crop growth and productivity (van Keulen et al., 1989). Profitable corn (*Zea mays* L.) production systems require of large quantities of N inputs in Northwestern China plain. Its instantaneous and accurate estimation in crops is a key to precision N management. Nitrogen demand of crops varies spatially across fields and can lead to local differences in plant growth (LaRuffa et al., 2001; Auerswald et al., 1997). Hence, nitrogen management is primary consideration in site-specific management (Mulla and Schepers, 1997). Spatially variable N management according to local soil conditions promises to increase crop productivity and decreasing the risk potential for environmental pollution (Hatfield and Prueger, 2004).

Traditional measurement methods of crop N status normally depend on plant sampling from the field and analytic assay in the lab (Roth and Fox, 1989; Li et al., 2003; Chen et al., 2004, 2006; (Gao et al., 2008).). The results from this protocol is relatively reliable, but is weak in temporal and spatial scale to meet the needs of real-time, fast and non-destructive monitoring and diagnosis of plant N status. Since existing methods of soil and plant analysis have proven to be too costly and time-consuming (Long et al., 1998) to fulfill this requirement, the focus is shifting from map-based variable rate application to approaches using hyperspectral remote sensing technologies.

Ground-based remote sensing for variables-rate N management relies on real-time, sensor-based spectral measurement of crop to in season, plant nitrogen assessment and management (Filella et al., 1995; Daughtry et al., 2000; Zarco-Tejada et al., 2000a, 2000b; Afanasyev et al., 2001; Raun et al., 2002; Link et al. 2005; Jia et al., 2004) by temporally N fertilizer application with crop N demand, this new techniques promise to help grower mange N uptake more efficiently. Several studies have assessed N status and other physiological parameters of field crops using leaf or canopy spectral reflectance parameters (Gausman, 1982; Chappelle et al., 1992; Blackmer et al., 1994; Thomas and Gausman1977; Pen˜ Pen uelas and Filella, 1998; Pen˜ uelas and Inoue, 2000; Zhao et al., 2003).

In this study, we use ground-based hyperspectral remote sensing to determining particular spectral wavelength/combinations of wavelength and spectral vegetation indices ratios may be used to rapidly estimate leaf N contents of field-grown corn at different growth stages during growing season across a wide range of N fertilization rates. The specific objectives were to: (i) determine the seasonal trends of leaf N contents as affected by N fertilizer rates applications and (ii) develop functional relationships between leaf hyperspectral reflectance and spectral reflectance ratios and leaf N contents in corn (iii) fitting of linear, nonlinear and exponential models to predict plant leaf N status with spectral vegetation indices.

MATERIAL AND METHODS

2.1 Site description and detail of experiments

The study was performed during 2010 at NWSUAF Agriculture Experimental Station, A & F University, China (Latitude 34.283 N and Longitude 108.063 E) with an elevation of more than 500 m. According FAO Taxonomy soil classification system, soil in this experiment is sandy clay loam type. The experiment was laid out in randomized complete block design (RCBD) with hybrid corn (*Zea mays* L.) cultivar (Zhengdan 958) and five nitrogen fertilizer rates (0, 60, 120, 180, and 240 kg/ha pure nitrogen) were measured at five key developmental stages of the corn. There were four replications and net plot size was 10 m x 3 m with row-to-row spacing of 50 cm, having six rows per plot. All other management practices such as weeding, pesticides were controlled by local standard practices and were kept uniform for all the treatments.

FIELDS MEASUREMENTS AND DATA COLLECTION

Leaf spectral measurements

Spectral reflectance corn leaf was measured using spectroradiometer ASD Hand-Held Fieldspec 2 (Analytical Spectral Devices, Inc., Boulder, CO). This hyperspectral device measures the visible (VIS) and near infrared (NIR) spectrum with 512 channels in the 325–1075 nm wavelength domain. The instrument acquired hyperspectral data at the spectral resolution of 3 nm. But by sampling, the instrument delivers data with 1 nm interval. Gathering spectra at a given location involved optimizing the integration time (typically set at 17 ms) providing foreoptic information, recording dark current, collecting white reference reflectance and obtaining the target reflectance. The target reflectance is the ratio of energy reflected off the target (e.g. crop) to energy incident on the target measured using BaSO4 white reference (Jackson et al., 1992). Since the dark current varies with time and temperature, it was gathered for each integration time (virtually new for each plot). Reflectance measurements were made about 1 m above the crop, middle and lower leaves with the sensor facing the target and oriented normal to the plant. The reflectance measurements were collected for the corn crop using 7.5 °-field-of-view (FOV). This FOV was selected, so that at least 10 cm diameter crop region will be covered when the instrument is kept 1 m above leaves. The readings were taken on cloud-free days between 10:00am to 14:00 p.m. while taking the observations care was taken not to cast shadow over the area being scanned. To minimize the atmospheric effects under field conditions, spectral measurements were taken at three sites in each plot and were averaged to represent the leaf reflectance of each plot. A viewing, analyzing and exporting the spectral data, window-based software View Spec Pro (ASD User's Guide 2005) was used.

Chemical analysis

The same plant was selected where the reflectance was measured from each plot taken to the laboratory for chemical analysis. The midribs of the leaf samples were removed from the leaf blades and weighted them. The leaf samples were oven-dried at 105^{o}C for 30 minutes and then placed at 78^{o}C to constant weight. The dry leaf weighted and grinded by using mortel and pastel and their total N was determined by using TruSpec N1 analyzer (Leco, 2006).

Calculations and statistical analysis

The effects of different N application on corn leaf N were analyzed statistically at five different growth stages by comparing the means of each treatment using Duncan's multiple tests at a 0.05 probability by using SPSS 16.0 (SPSS Inc.2007). In step one; linear correlation analysis was performed by using MATLAB 7.1 (The Math Works, Inc., 2005) between the individual spectral reflectance and leaf N contents at all five stages. Then sensitive spectral ranges (key wavebands) related to leaf nitrogen contents were identified. In second step, different SVIs of the key wavebands were calculated from the original reflectance data and linear correlation analysis to find sensitive SVIs related to leaf N contents by using Microsoft Excel program (Microsoft cooperation 2003). In step third, first order differential characteristics were performed based on position (Db, Dy, Dr) based on area (SDb, SDy, SDr) and vegetation indices (NDVI) were tested (SDr/SDb; SDr/Sdy; Rg/Ro; (SDr - SDb) / (SDr + SDb); (SDr - SDy) / (SDr + SDy); (Rg - Ro) / (Rg + Ro). In the fourth step, the selected model fit include: simple linear function: y = a + bx, logarithmic function: y = a + b * ln(x); parabolic: y = a + bx + cx2; 3 function: y = a + bx + cx2+DX3; exponential function: y = a * ebx; exponential function: y = axb. In the above: the Y-fitting around the nitrogen content; X-spectral variables; a, b, c, d - constant.

The performance of the model was estimated by linear and non-linear modeling approaches, including, selected model fit include: simple linear function: y = a + bx, logarithmic function: y = a + b * ln(x); parabolic: y = a + bx + cx2; 3 function: y = a + bx + cx2+DX3; exponential function: y = a * ebx; exponential function: y = axb. In the above: the Y-fitting around the nitrogen content; X-spectral variables; a, b, c, d - constant. The performance was estimated by comparing the differences in coefficient of determination (R^2), root meat square error (RMSE), and relative root meat square error (RRMSE) in prediction. The higher the R^2 and the lower the RMSE and RRMSE, the higher the precision and accuracy of model to predict plant N status. The RMSE and RRMSE were calculated using Eq. (1) and Eq. (2), respectively.

$$RMSE = [\frac{1}{n}\sum_{i=1}^{n}(Si - Mi)^2]^{\frac{1}{2}} \quad (1) \qquad RRMSE = \frac{[\frac{1}{n}\sum_{i=1}^{n}(Si - Mi)^2]^{\frac{1}{2}}}{\frac{1}{n}\sum_{i=1}^{n}Mi} \quad (2)$$

RESULTS AND DISCUSSION

Leaf nitrogen contents under different N rates

Leaf nitrogen contents significantly differed among different N treatment levels across five growth stages throughout the growing season. Table 3.1 showed that control treatment showed significant N deficiency and leaf N contents decrease over time. Maximum leaf N was reached highest at tasseling and silking stages. These results are coincided with Alley et al., (2009) showed that maximum nitrogen available to the corn plant at tasseling and silking stages. Leaf N contents change over growth period and decrease with age. The highest N contents was observed at N4 level with 2.81, 2.77, 2.91 3.89, 3.62 and 2.50 from 6-8 leaf stage to early dent stages, respectively**.**

Table 3.1. Leaf nitrogen contents of corn leaf at different growth stages under five fertilizer rates.

Nitrogen Treatments	*6-8 Leaf*	*10-12 Leaf*	*Tasseling*	*Silking*	*Early dent*
N0	2.053c	1.872c	1.750c	1.428d	1.32d
N1	2.358bc	1.918bc	2.727b	3.338bc	2.04cd
N2	2.563ab	2.443abc	2.832ab	3.787ab	2.18bc
N3	2.457b	2.622ab	2.855ab	3.810ab	2.45b
N4	2.818a	2.778a	2.915a	3.898a	2.50a

Means within each column followed by different letter indicate significant difference at 0.050 probability level by Duncan’s Multiple Range test.

3.2 Leaf Hyperspectral Reflectance spectra under different N rates

Reflectance spectra, measured at 10-12 leaf stage of corn grown with varying rate of N fertilizer application are shown in Fig. 3.1. Similar responses were observed on other stages during the growing season. The effects of varying nutrition were exhibited across the entire wavelength interval measured. Reflectance decreased in the visible and middle infrared wavelength regions with increasing N fertilizer application, while in the near infrared wavelength region reflectance was increased. Similar changes in the visible and near infrared reflectance has previously been reported by Colwell, 1974; Knippling 1970). It is likely that variation in spectral reflectance among N treatments are resulted from changes in leaf structure and composition, including pigment concentration, which are altered by N treatment (Vesk et al., 1966).

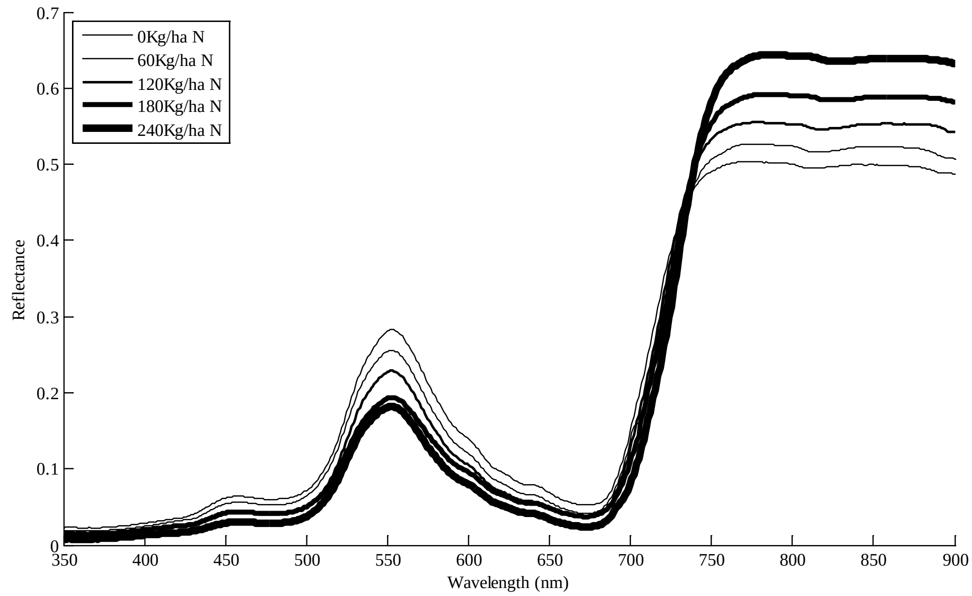

Fig. 3.1. Reflectance spectra of different nitrogen contents under five nitrogen rate fertilizer

Relationship between leaf nitrogen contents and reflectance of single wavelength

Coefficients of determination (R^2) and root mean square error (RMSE) for leaf N contents with leaf reflectance at each single wavelength (data was not are presented here). Nitrogen fertilizer mainly affected leaf reflectance in the blue, green, red and infrared regions at 450, 550, 610, 620, 630, 680, 710, 720 nm. These eight reflectance provided the greatest R^2 with lowest RMSE values with leaf N contents. Among them 450nm showed highest R^2 (0.75) at silking stage while 550 nm showed highest N sensitivity at silking stage with highest R^2 (0.82) value. Both 610 and 620nm showed highest R^2 (0.87) at 10-12 leaf stage while 630nm showed greatest R^2 (0.88) at the same stage. The 710 nm also showed highest R^2 (0.72) value at 10-12 leaf stage while 720 nm showed greatest R^2 (0.63) at tasseling stage. The results showed that 630nm is the most N sensitivity wavelength followed by 610nm and 550nm with the lowest RMSE values. The results of our finding closely match with (Blackmer et al., 1994; Blackmer et al., 1996) reported that in the green region, the reflectance around 550 or 610 was closely correlated with the corn leaf N contents. Leaf N contents was closely related to reflectance at 450, 550,610, 620, 630, 680, 710, 720 from 350-1074nm in this study. However, using the single wavelength vales at any of these seven wavelengths could be used for estimation of leaf N contents.

Relationship of leaf N contents to leaf spectral reflectance of dual wavelength

Relationship of leaf N contents and leaf reflectance spectra of dual wavelength was shown in the Table 3.2. The dual combination of spectral was combined with green, red and infrared waveband regions. The dual wavelength (550+710) showed the highest R^2 value .with 0.76, 0.75, 0.70 and 0.65 at 10-12 leaf, silking, tasseling, early dent and 6-8 leaf stages, respectively. The dual wavelength (550+810) showed the greatest R^2 value whilst combination of dual wavelength (710+810) was lowest among them. The results of this study showed the combination of dual wavelength in green, red and infrared improved the estimation of leaf N contents as compared to the single wavelength, especially in the red region of the wavelength.

Table 3.2.The relationship between corn leaf nitrogen contents and dual wavelengths at different growth stages as measured by coefficients of determination (R^2) and RMSE.

Stage of the crop	*550+710*		*550+810*		*710+810*	
	R^2	RMSE	R^2	RMSE	R^2	RMSE
6-8 Leaf	0.53	2.07	0.43	1.74	0.42	1.67
10-12 leaf	0.76	1.93	0.55	1.67	0.41	1.66
Tasseling	0.70	2.25	0.51	2.61	0.46	2.87
Silking	0.75	2.05	0.59	2.87	0.53	2.83
Early dent	0.34	1.86	0.30	1.48	0..34	1.36

3.5. Relationship of leaf N contents to spectral vegetation indices (SVIs)

A comparison of near infrared, red and green reflectance based SVIs for corn leaf N contents prediction varied at different growth stages presented in the Table 3.3. An optimal relationship was found in NIR/R, NIR/Green and NIR/NIR, and at silking, 10-12 leaf and tasseling stages. NIR/NIR with 780/700 showed highest R^2 value of 0.80 at 10-12 leaf while NIR /Green were highest R^2 value at 10-12 leaf stage. Among them NIR/R showed the highest R^2 values of 0.88 at 10-12 leaf stage and 0.74 at silking stage. A poor relationship was occurred in NIR/NIR region with 780/740. GNDVI showed strongest relationship at 10-12 leaf and silking stage with R^2 values of 0.88 and 0.80, respectively both over NDVI and SAVI. NDVI showed highest R^2 value at 10-12 leaf stage and silking stages with values of 0.80 and 0.74, respectively. A weak relationship was found early in the season both with GNDVI and NDVI. Poor relationship early in the season attributed to the fact that SVIs early in the season do not represents the canopy photosynthetic size to attain maximum LAI that constitutes in yield attribution (Wiegand et al., 1990; Wiegand and Richardson, 1990).

But SAVI perform better early in the season with the highest R^2 value of 0.54 at 6-8 leaf stage. It showed that SAVI is a good estimator for detection of leaf N contents early in the season (Bausch et al., 1996) by giving the reason that during early stage of the growth (V6), canopy is not fully developed and soil also contributed in the soil reflectance. Compared with single reflectance, SVIs improved R2 vales at most wavelengths measured and GNDVI showed the best linear relationship (R2 = 0.88) with leaf N contents. The results indicated that SVIs are the most suitable remote estimation indices of leaf N contents of corn in real time at several growth stages during the growing season. Earlier studied of Elwadie et al., (2005) and Mistele and Schmidhalter, (2008) also showed that the use of SVIs can improve the precision and accuracy of predicting corn leaf N contents compared with single reflectance.

Table 3.3. The relationship between corn leaf N contents at various spectral vegetation indices through out the growing season as measured by coefficients of determination (R^2) and RMSE.

Stage of the crop	*NIR/NIR (R780/R740)*		*NIR/NIR (R780/R700)*		*NIR/Green (R7810/R550)*		*NIR/R (R810/R670)*		*NDVI*		*GNDVI*		*SAVI*	
	R2	RMSE	R2	RMSE	R2	RMSE	R2	RMSE	R2	RMSE	R2	RMSE	R2	RMSE
6-8 Leaf	0.17	1.34	0.04	5.36	0.03	0.50	0.03	16.24	0.01	1.16	0.02	2.05	0.54	1.81
10-12 leaf	0.45	1.35	0.80	3.16	0.80	0.81	0.88	3.12	0.80	1.60	0.88	2.02	0.02	1.54
Tasseling	0.21	2.43	0.43	4.40	0.52	0.93	0.45	4.38	0.49	2.85	0.52	3.15	0.01	2.99
Silking	0.39	2.26	0.58	4.10	0.77	1.04	0.74	4.10	0.74	2.71	0.80	3.04	0.23	2.86
Early dent	0.16	0.99	0.26	2.89	0.18	1.19	0.29	4.75	0.20	1.51	0.18	1.65	0.01	1.62

Table 3.4. Regression model between leaf total nitrogen content and spectral parameters of summer corn cultivar Zhengdan958 in different growth stages

Growth parameters and spectral characteristics		Model Fitting equations	Coefficient of determination (R^2)	F value
6-8 leaf	R720	Y=6.336e-3.121x	0.798	71.116
	DR720	Y=4.354e-40.858x	0.439	14.075
	Rg	Y=4.937e-2.798x	0.407	12.378
10-12 leaf stage	R720	Y=3.629+0.526x-19.795x2	0.795	32.934
	DR720	Y=5.283-252.909x	0.674	37.231
	SDr	Y=5.195-5.493x	0.614	28.609
Tasseling stage	Db	Y=4.623e-70.965x	0.831	88.215
	SDb	Y=4.070-2.304x-52.177x2	0.854	49.778
	SDy	Y=4.495e4.564x	0.771	60.694
Silking stage	DR550	Y=-0.468-0.528lnx	0.647	17.516
	Dy	Y=4.475e-428.603x	0.676	31.758
	SDb	Y=3.616+5.415x-141.639x2	0.554	10.557
Late dent stage	R550	Y=2.162x-0.226	0.767	59.099
	R720	Y=4.571e-1.432x	0.799	71.381
	DR550	Y=-2.390-0.793lnx	0.780	63.789

CONCLUSIONS

A comprehensive studied was performed to identify different spectral vegetation indices for real-time monitoring of leaf N status of corn crop at different growth stages under field-grown corn. From this study, several indices showed good precision for non-destructive estimation of leaf N status. The results showed that there was best fitting between nitrogen contents and their spectral parameters of R710, SDr, R550 (SDr-SDb)/(SDr+SDb), D(R630） at 10-12 leaf, silking, tasseling, and early dent stages. Spectral ratios with R810/R670 showed highest R^2 at 10-12 leaf stage, silking and tasseling stages respectively, followed by R810/R670. SAVI was the best indicator of nitrogen contents at 6-8, leaf stages. GNDVI showed the highest R^2 (0.88) at 10-12 leaf stage and at silking stage (0.74) followed by NDVI. The results showed that leaf nitrogen status can be best predicted at 10-12 leaf, silking and tasseling stages by using spectral vegetation indices with GNDVI. The study results indicated that leaf hyperspectral reflectance can be used for real time monitoring of corn nitrogen status and important tool for N fertilizer management in precision agriculture.

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