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HYPERSPECTRAL ESTIMATION MODEL FOR NITROGEN CONTENTS OF SUMMER CORN LEAVES UNDER RAINFED CONDITIONS

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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 study 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 mays* L.) under five nitrogen rates (0, 60, 120, 180 and 240 kg/ha pure nitrogen) were measured at key developmental stages. The accuracy of nitrogen nutrition diagnosis among the single (R) and dual (R_1+R_2) wavelengths spectral reflectance, spectral ratio (SR) in the green, red and near infrared, NDVI, GNDVI and SAVI were compared. Chose the highest determination of coefficient (R^2) model and lowest RMSE and RRMSE at each growth stage, fitted the smaller as the best model. The results showed that $Y = 4.450+0.00X-17.99X^2+10.496X^3$ was the best prediction model for remote estimation of leaf N contents with GNDVI at 10-12 leaf stage followed by $Y = 3.986X^{0.161}$ at silking stage, then $Y = 3.092+1.684X+1.995X^2$ at tasseling stage with R630 nm and $Y = -3.860-12.692X+0.00X^2+7.632X^3$ at early dent stage with R720. The study results indicated that leaf spectral reflectance can be effectively used as nondestructive, quick, and reliable for real time monitoring of corn nitrogen status and important tool for N fertilizer management in precision agriculture.

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 plain of China. 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 & Schepers, 1997).

Warm and humid soil conditions enhance nitrogen supply, whereas dry periods decrease it. Under rainfed conditions both situations can occur, with their relative occurrence varying from year to year (Kolberg *et al*., 1999. This explains its use by agronomists and farmers to make important management decisions at critical stages (e.g., nitrogen supply and pesticide application). Thus, spatially and temporally optimized nitrogen fertilizer application is highly desirable for both economic and ecological reasons (Jaynes *et al*., 2001; Haneklaus & Schnug, 2002; Hatfield & Prueger, 2004; Schmidhalter *et al*., 2006, Khan *et al*., 2012; Shah *et al*., 2012).

Leaf N concentration is an important indicator for diagnosing plant N status (Gerik *et al*., 1994; Bell *et al*., 2003). Traditional measurement methods of crop N status normally depend on plant sampling from the field and analytic assay in the lab (Roth & Fox, 1989; Li *et al*., 2003). 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.

Remote sensing technique has provided a new means for nondestructive and real-time monitoring of crop N status, and is exhibiting a promising prospect in growth monitoring, nutrition diagnosis, and yield estimating in different field crops (Thenkabail *et al*., 2000; Huang *et al*., 2003). 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; Jia *et al*., 2004; Link *et al*., 2005) by temporally N fertilizer application with crop N demand, this new techniques promise help grower to mange N uptake more efficiently.

In this study, we used ground-based hyperspectral remote sensing to determining particular spectral wavelength/combinations of wavelength and spectral vegetation indices 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 of this study were to: (i) determine the seasonal trends of leaf N contents as affected by N fertilizer rates applications (ii) develop functional relationships between leaf N contents and hyperspectral spectral reflectance, SRIs, and SVIs (iii) fitting of linear and nonlinear models to predict plant leaf N status with hyperspectral vegetation indices at five key stages of corn.

Material and Methods

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 to 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 and insect pests were controlled by local standard practices and were kept uniform for all the treatments.

Fields measurements and data collection

Leaf spectral measurements: Spectral reflectance of 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. However, by sampling, the instrument delivers data with 1 nm interval. Gathering spectra at a given location involved optimizing the integration time (set at 217 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 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). The readings were taken on cloud-free days between 10:00 am 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 (Anon., 2005) was used (Table 1).

Chemical analysis: The same plant leaves were selected where the reflectance was measured from each plot immediately 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°C for 30 minutes and then placed at 78°C to constant weight. The dry leaf weighted and grinded and their total N contents were determined by using Kjeltec Auto Analyzer.

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 Range 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 was performed to find sensitive SVIs related to leaf N contents by using SPSS 16.0. In step third, linear or non-linear models were fitted to determine the best-fit determination of coefficients (R^2) for the relationships of leaf N contents to the canopy spectral reflectance of key wavebands and SVIs by using MATLAB 7.1. The performance of the model was estimated by comparing the differences in coefficient of determination (R^2), root meat square error (RMSE). The higher the R^2 and the lower the RMSE values, the higher is the precision and accuracy of model to predict plant N status. The R^2 and RMSE were calculated using Eq. (1) and Eq. (2), respectively.

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

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

Table 1. Definition of commonly used spectral vegetation indices (SVIs) of visible and near infrared reflectance for the estimation of leaf nitrogen contents.

Vegetation index	Abbreviations	Algorithm formula
Reflectance	(ρλ)	
Dual Reflectance	(λ_1, λ_2)	($\rho\lambda_1 + \rho\lambda_2$)
Ratio vegetation index	RVI (λ1, λ_2)	($\rho\lambda_1 / \lambda_2$)
Normalized difference vegetation index	NDVI λ_1, λ_2)	($\rho\lambda_1$ - $\rho\lambda_2$)/ ($\rho\lambda_1 + \rho\lambda_2$)
Green normalized difference vegetation index	GNDVI (λ_1, λ_2)	($\rho\lambda_1$ - $\rho\lambda_2$)/ ($\rho\lambda_1 + \rho\lambda_2$)
Soil adjusted vegetation index	SAVI (λ_1, λ_2)	1.5($\rho\lambda_1$ - $\rho\lambda_2$)/ $\rho\lambda_1 + \rho\lambda_2$+0.5)

λ is the wavelength

Results analysis

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. In the present study, leaf N contents were closely related to the N fertilizer rate and consistently increase with the increasing amount of N fertilizer application throughout the growing season as in the Table 2. Leaf N contents were significantly differed at all N fertilization application during the growing season. The highest N contents was observed at N4 level at 6-8 leaf, 10-12 leaf, tasseling, silking and early dents stages respectively. Maximum leaf N was reached highest at tasseling and silking stages. Leaf N contents changed over growth period and decreased with age. The same results also reported by Gitelson & Merzlvak, 1998; Mubeen, *et al*., 2013) stated that leaf contents changes throughout different stages of plant development and is affected when crop plants are exposed to various kinds of natural and anthropogenic stresses.

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. 1. Nitrogen fertilizer rate mainly affect leaf reflectance in the visible range and in the red edge. Specifically, the leaf reflectance at 550 nm and 680 nm rapidly increased with the decrease in the fertilizer rate. This phenomenon could be clearly seen from the Fig. 1. Several studies have shown that leaf reflectance values around these wavelengths are closely associated with Chl level (Thomas & Gausman, 1977; Blackmer *et al*., 1994). Therefore, N fertilizer rate mainly affect leaf reflectance in the visible range and the red edge feature by the modifying leaf Chl contents. Leaf reflectance around these two wavelengths could be used to detect crop plant N deficiency.

The results of this study showed that strong correlation of leaf N contents with spectral reflectance was existed at different growth stages for the corn crop throughout the growing season. Finding from this study showed that there was strong correlation exist between leaf N and spectral reflectance and highest correlation was found at 10-12 leaf, silking stage and tasseling stage followed by 6-8 leaf stage showed in the figure 2.

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 are presented in the Table 3. Nitrogen fertilizers mainly affected leaf reflectance in the blue, green, red and near infrared regions at 450, 550, 610, 620, 630, 680, 710, 720 nm. These reflectance provided the greatest R^2 with lowest RMSE values with leaf N contents. Among them 450 nm 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 620 nm showed highest R^2 (0.84) at 10-12 leaf stage while 630 nm showed greatest R^2 (0.85) 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 630 nm is the most N sensitivity wavelength followed by 610 nm and 550 nm 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 nm or 610 nm was closely correlated with the corn leaf N contents.

Table 2. Leaf nitrogen contents (%) of corn leaf at different growth stages.

Nitrogen treatments	6-8 Leaf	10-12 Leaf	Tasseling	Silking	Early dent
N0	2.053c	1.872c	1.750c	1.428d	1.321d
N1	2.358bc	1.918bc	2.727b	3.338bc	2.043cd
N2	2.563ab	2.443abc	2.832ab	3.787ab	2.188bc
N3	2.457b	2.622ab	2.855ab	3.810ab	2.450b
N4	2.818a	2.778a	2.915a	3.898a	2.504a

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

Table 3. The relationship between corn leaf N contents and various single wavelengths at different growth stages as measured by R^2 and RMSE.

Stage of the crop	6-8 Leaf		10-12 leaf		Tasseling		Silking		Early dent	
wavelength	R^2	RMSE	R^2	RMSE	R^2	RMSE	R^2	RMSE	R^2	RMSE
450	0.32	2.43	0.71	2.33	0.64	3.52	0.75	3.36	0.29	2.01
550	0.49	2.26	0.78	2.17	0.68	3.40	0.82	2.14	0.28	1.90
610	0.40	2.39	0.84	2.30	0.66	3.50	0.80	2.33	0.25	1.99
620	0.36	2.40	0.84	2.31	0.65	3.51	0.81	2.30	0.25	2.00
630	0.32	2.41	0.85	2.06	0.69	3.39	0.79	2.35	0.30	2.01
680	0.24	2.43	0.84	2.34	0.66	3.53	0.76	2.37	0.32	1.99
710	0.56	2.29	0.72	2.42	0.68	3.44	0.62	2.47	0.39	1.93
720	0.53	2.19	0.51	2.65	0.63	3.60	0.52	3.20	0.42	1.86
810	0.35	1.95	0.33	1.90	0.41	3.08	0.08	2.95	0.25	1.67
900	0.34	1.96	0.35	1.90	0.40	3.07	0.09	2.93	0.56	1.66

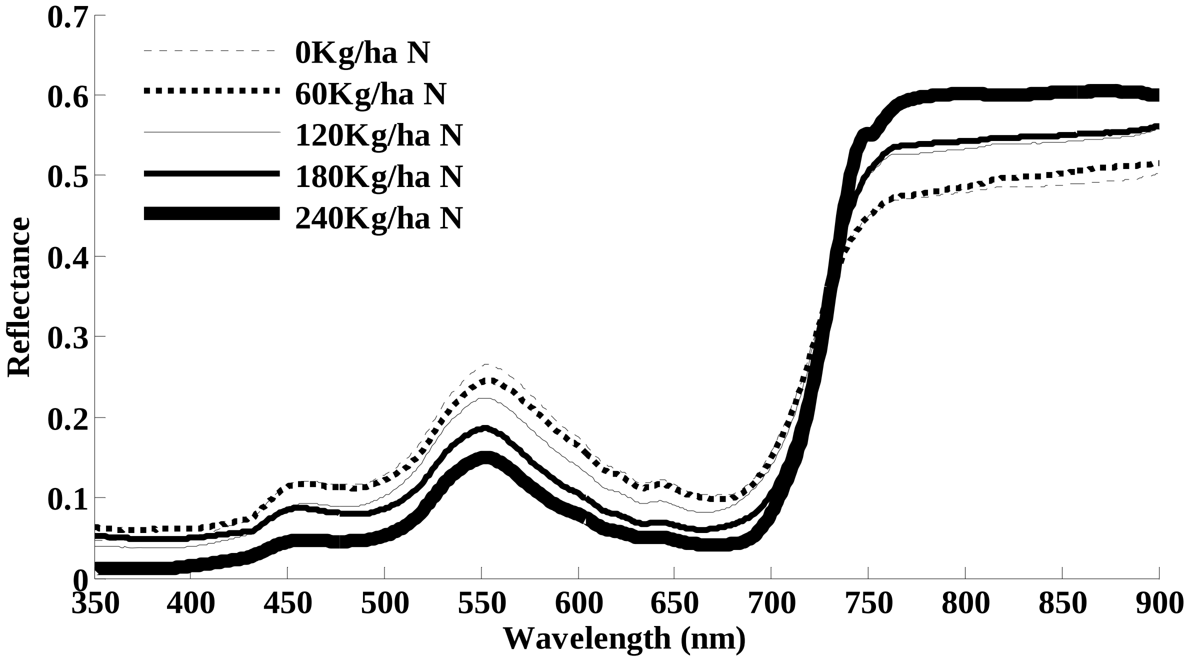

Fig. 1. Change in spectral reflectance under varied leaf N rates.

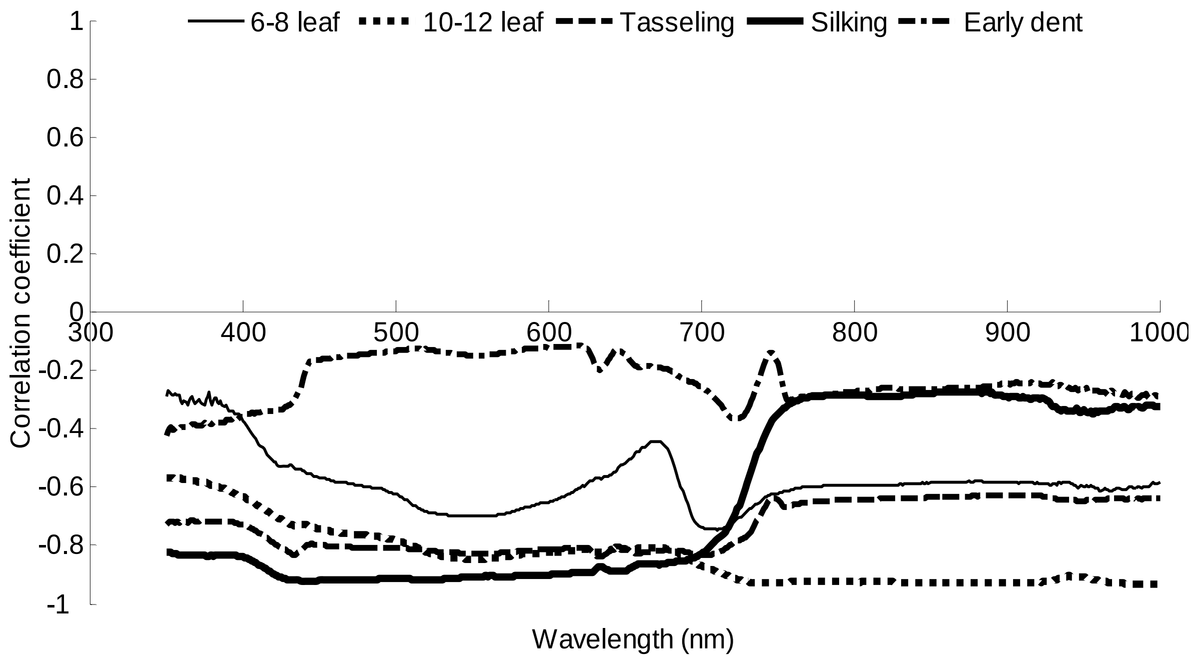

Fig. 2. Correlation curves between leaf N contents and spectral reflectance at different growth stages.

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 4. The dual combinations of spectral were combined with green, red and near infrared waveband regions. The dual wavelength (550+710) showed the highest R^2 value with 0.81, 0.79, 0.70 and 0.53 at 10-12 leaf, silking, tasseling, and 6-8 leaf stages, respectively. The dual wavelength (550+810) showed the greatest R^2 value with 0.68, 0.63, 0.51 at silking, 10-12 leaf and tasseling stages, respectively, whilst combination of dual wavelength (710+810) was lowest among them with highest R^2 value at silking stages, tasseling with values of 0.53, 0.46, respectively. 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 4. The relationship between corn leaf N contents and dual wavelengths at different growth stages as measured by 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	0.81	1.93	0.63	1.67	0.41	1.66
Tasseling	0.70	2.25	0.51	2.61	0.46	2.87
Silking	0.79	2.05	0.68	2.87	0.53	2.83
Early dent	0.34	1.86	0.30	1.48	0.34	1.36

Table 5. The relationship between corn leaf N contents and various spectral vegetation indices at different growth stages as measured by 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	
	R^2	RMSE	R^2	RMSE	R^2	RMSE	R^2	RMSE	R^2	RMSE	R^2	RMSE	R^2	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	0.86	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 6. Leaf N contents prediction models at different growth stages of corn crop with their spectral vegetation indices.

Stage of the crop	SVIs	R^2	F value	Model equation	RMSE	RRMSE
6-8 leaf stage	R710	0.59	25.70	$Y = 4.361e^{-3.060}$	2.287	0.930
10-12 leaf stage	GNDVI	0.90	72.13	$Y=4.450+0.00X-17.99X^2+10.496X^3$	2.023	0.869
Tasseling stage	R630	0.73	22.65	$Y = 3.092+1.684X+1.995X^2$	4.667	1.303
Silking stage	GNDVI	0.81	75.75	$Y = 3.986X^{0.161}$	3.035	0.880
Early dent stage	R720	0.65	13.11	$Y = -3.860-12.692X+0.00X^2+7.632X^3$	2.706	1.322

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 5. An optimal relationship was found in NIR/R, NIR/Green and NIR/NIR at various growth stages. NIR/NIR with 780/700 showed highest R^2 value of 0.80 at 10-12 leaf while 0.58 at silking stage. NIR /Green were highest R^2 value (0.80) at 10-12 leaf stage while 0.77 at silking stage. Among them NIR/R showed the highest R^2 values of 0.86 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 and late in the season with both GNDVI and NDVI. 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 contributed in the soil reflectance.

Leaf N content prediction models: The Table 6 showed different prediction models at different growth stages of the corn crop with their spectral indices as measured by RMSE and RRMSE. The results showed that $Y = 4.450+0.00X-17.99X^2+10.496X^3$ was the best prediction model for remote estimation of leaf N contents at 10-12 leaf stage followed by $Y = 3.986X^{0.161}$ at silking stage with GNDVI and $Y = 3.092+1.684X+1.995X^2$ at tasseling stage with R630 nm. From the current study showed that GNDVI was good indicator for precise determining leaf N contents both at 10-12 leaf stage and at silking stage.

Discussions

The main objective of this study was to identify relationship between spectral reflectance and leaf N at different growth stages and develop strategies for nondestructive measurement of leaf N contents under varied rates of N fertilizer application for field-grown corn. Figure 1 showed different spectral response under the effect of varying N rates. It is likely that variation in spectral reflectance among N treatments also results from changing leaf structure and composition, including pigment concentrations, which altered by N treatment. Near infrared reflectance increased due to increased in vegetation cover, which increased light scattering and reflectance by multiple leaf layers. Therefore, the spectral reflectance is a good indicator for determining different N rate application under field conditions.

Leaf N is a major indicator to characterize the N status in the corn crop. The important reflectance wavelengths for predicting N concentration change with sampling date due to differences in ground cover and growth stage (Osborne *et al*., 2002). The results of this study showed that there was strong correlation existed between leaf N and spectral reflectance and highest correlation was found at 10-12 leaf stage and silking stages was shown in the Fig. 2. Therefore, 10-12 leaf stage and silking stage are more appropriate for accurately estimation of leaf N contents. Bausch & Duke (1996) reported that V11 are the most appropriate stage for estimation of leaf N contents in corn crop under varied nitrogen rates. During early stages, treatment differences were less recognizable because the spectral response of the soil dominated the canopy response due to less soil cover (Colwell 1974; Walburg *et al*., 1981). The later in the season, senescence caused treatment difference to decreased.

The results from the individual wavelength in blue, green, red and infrared waveband are shown in the Table 3. The results from this study showed that the green, red and infrared region or visible region/infrared region had clear difference of different N rate application at different stages of the corn. Analysis of the reflectance spectra from the leaves showed greater reflectance and more distinct separation by N rate at 550 nm wavelength (Fig. 1) in this region of the spectrum, the greatest reflectance consistently occurred with the lowest N rate. This is because N deficiencies traditionally results in decreased amount of leaf chlorophyll, which absorbs less light and therefore results in greater reflectance (Blackmer *et al*., 1994).

In this study, the dual combination of wavelengths showed better performance over single waveband (Table 4). The dual combination of the wavebands showed good indication of leaf N contents with spectral reflectance. The dual wavelength was used in the visible and NIR showed strong relationship over single wavelength in the NIR region and. The highest value of dual wavelength was shown with green and near infrared wavebands R550+R710 (Table 4). The same results also reported by Blackmer *et al*., (1996) stated that combination of wavelengths performed better over single wavelength. The results showed that 10-12 leaf stage and silking stage, tasseling stages and 6-10 leaf stage can have advantage for detection of leaf N contents.

Vegetation index is a simple, effective and experiential measurement of terrestrial vegetation activity, and plays a very important role in qualitative and quantitative remote sensing. Hatifield & Prueger, (2010) stated that multiple vegetation indices to best determining agricultural crop characteristics. So, different spectral vegetation indices were chosen for further analysis. The results showed that NIR/Red with R810/R670 showed highest R^2 values at 10-12 leaf followed by NIR/Green with R810/R550 showed highest R^2 values at silking stage which proved that both NIR/Red and NIR/Green good ratios for determining leaf N contents at 10-12 leaf and silking stages. Daughtry *et al*., (2000) noted that combined near-infrared reflectance and red reflectance (NIR/Red) minimized the contribution of background reflectance. It has been reported that near infrared/red reflectance ratio strongly related to variation of vegetation canopies while insensitive to variation to soil background reflectance. A strong relationship was occurred between leaf N and near infrared/red found even at all stages (Table 5).

SAVI showed good estimation of leaf N at early stage of the crop (Table 5) while the relationship on subsequent stages was poor. This showed that SAVI sensitive to soil background reflectance during early stage of the crop due to less vegetative cover on the ground (Walburg *et al*., 1981; Bausch *et al*., 1993). GNDVI was found most appropriate SVIs for determining leaf N contents at different stages (Table 5) of the field grown corn. GNDVI showed highest R^2 value at 10-12 leaf and silking stages followed by NDVI. GNDVI showed better performance at all the growth stages. Earlier studied reported that the NDVI is the most widely used vegetation index but it became less sensitive when the biochemical and biophysical variables of crops reached high values. Gitelson *et al*., (1996) indicated that green NDVI (GNDVI) was more sensitive than NDVI under these conditions. Osborne *et al*., 2004: Elwadie *et al*., 2005; Mistele & Schmidhalter, 2008, also reported that using green reflectance values such as GNDVI are better suited for grain yield prediction.

The study showed that spectral parameters are more reliable for determining N status of the crop. According to the Thenkabail *et al*., (2000) stated that the direct method of predicting N status using remote sensing is a linear approach by combining spectral reflectance from two or more characteristic wavebands may results in over fitting. To take into account, we tested different models fitting approach to further analysis of these spectral indices that already performed very well under this study. Table 6 also showed that $Y = 4.450+0.00X-17.99X^2+10.496X^3$ was the best prediction model for remote estimation of leaf N contents at 10-12 leaf stage followed by $Y = 3.986X^{0.161}$ at silking stage with GNDVI and $Y = 3.092+1.684X+1.995X^2$ at tasseling stage with R630 nm, respectively.

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, GNDVI was most appropriate spectral indices for estimation of leaf N at most of the stages of the crop while SAVI showed better performance early in the season. $Y = 4.450+0.00X-17.99X^2+10.496X^3$ was the best prediction model for remote estimation of leaf N contents at 10-12 leaf stage followed by $Y = 3.986X^{0.161}$ at silking stage with GNDVI and $Y = 3.092+1.684X+1.995X^2$ at tasseling stage with R630 nm, $Y = -3.860-12.692X+0.00X^2+7.632X^3$ at early dent stage with R720 nm and $Y = 4.361e^{-3.060}$ at 6-8 leaf stage with R710 nm. The study results showed that hyperspectral reflectance can be used for nondestructive, fast, reliable and real time monitoring of leaf N status at different growth stages of field grown corn under different N rate application. Results showed that compared with direct spectral reflectance, spectral vegetation indices may be more reliable in predicting plant N status in corn. This information can be used for optimized nitrogen management and recommendation within growing season.

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