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Short Comminucation

Assessing leaf area index of wheat (*Triticum astvium* L.) crop with hyperspectral field reflectance measurements

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Hyperspectral crop reflectance data are useful for several remote sensing applications in agriculture, but there is still a need for studies to define optimal wavebands to estimate crop biophysical parameters and spectral response of crops. The monitoring of agricultural crops during the development cycle is important to food security. Monitoring can be done observ-ing the biophysical variables. One of these biophysical variables that deserve attention is the leaf area index (LAI), that is related with crop evapotranspiration and crop yield (Sellers *et al.,* 1997; Xavier *et al.,* 2006). One way to estimate these biophysical parameters is by vegeta-tion indices (VI). VI's are mathematical functions of reflected radiant flux in different spectral bands of re-mote sensing data (Jensen, 2007). The Normalized Difference Vegetation Index veg-etation index (NDVI), is the most frequently used vegeta-tion index, and usually correlated with LAI and crop yield (Galvao *et al.,* 2009; Raun *et al.,* 2008). Hyperspectral remote sensing data has the poten-tial to detect more variations on vegetation than multi-spectral data, because it uses narrow spectral channels of less than 10 nm (Stagakis *et al.,* 2010). Therefore, wheat spectral reflectance measurements were analyzed in terms of NDVI to estimate LAI during crop growth cycle for wheat crop.

The data required for this study were collected from Wheat (*Triticum astvium* L.) field at located at $19^0 19'19.494''$ and $74^0 39'16.873''$E during *rabi* season of 2012-2013. Climatically the study area falls under the semi-arid and sub tropical zone with average annual rainfall of 566.5 mm. The average elevation of study area is 657m above the mean sea level. The prominent soil type is clay. The seed plot was selected for the study because all the standard cultivation practices were adopted during the crop growth period and the crop is maintained in unstressed condition. The wheat field was border-irrigated. The crop was sown in 27 November, 2012 and harvested in 26 March, 2013 and the data were recorded during this period.

Field reflectance measurements were performed over wheat field with the SVC HR-1024 spectroradiometer during the crop growth periods at an interval of seven days. The five spectral reflectance measurements from the most central part of each plot were taken with the spectroradiometer over the spectral range 350-2500 nm. The radiometric measurements were collected under clear-sky conditions between 12:00 hrs and 14:00 hrs, at 60 to 80 cm above crop canopy, with the 25° field-of-view (FOV) optic fiber allowing 0.13 to 0.18 m spatial resolutions for each spectral measurement and all the measurements were taken from nadir view. The same point was visited each time for taking observations over the crop growth period. These measurements were then used to simulate the narrow-bands and broad-bands from the spectral bands. Due to atmospheric radiation absorption, some bands in the spectral ranges 1350-1440 nm; 1790-1990 nm; and 2360-2500 nm were disconsidered.

LAI is commonly used for monitoring crop growth. Instead of the traditional, direct and labor-consuming method of physically measuring the plant with a ruler (direct method), an optical instrument, Plant Canopy Imager CI-110 (CID Bio- Science Inc., USA) was used (indirect method).

The NDVI was calculated by using the equation proposed by Rouse *et al.* (1974).

$$NDVI = \frac{NIR - IR}{NIR + IR}$$

The linear, exponential, logarithmic and power type regression relationships were developed between LAI and NDVI. The best fit regression relationship was found out based on the coefficient of determination (R^2), Root Mean Square Error (RMSE), Chi-square (**$Ç^2$**) and Percent Error Modulus (PEM) values

The stagewise spectral reflectances of wheat crop between the wavelengths of 350 to 2500 nm (Fig.1) shows significant variations among the curves which are mainly

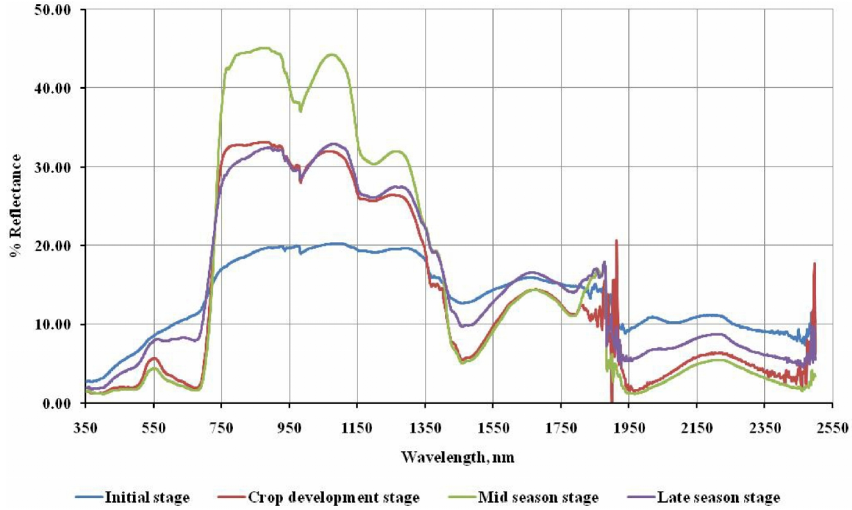

Fig. 1 : Spectral reflectance of wheat at distinct growth stages

Table 1 : Results of regression analysis of LAI with NDVI for wheat over (a) whole crop growth period, (b) growth phase and (c) decline phase of LAI

Regression relationship	Slope 'a'	Intercept 'b'	R^2	RMSE	Ç^2	PEM
(a) Whole crop growth period						
Linear	4.513	-0.288	0.474	—	—	—
Exponential	0.740	1.727	0.340	—	—	—
Logarithmic	2.491	3.945	0.381	—	—	—
Power	3.716	0.929	0.260	—	—	—
(b) Growth phase						
Linear	10.08	-5.729	0.938	3.605	1.617	3.075
Exponential	0.026	5.306	0.995	0.823	0.021	0.786
Logarithmic	7.594	4.174	0.902	3.536	7.017	13.024
Power	4.863	4.077	0.997	0.825	0.030	0.795
(c) Decline phase						
Linear	4.339	0.505	0.975	2.945	0.075	0.028
Exponential	1.340	1.321	0.988	0.389	0.003	0.002
Logarithmic	2.512	4.627	0.915	2.854	0.279	0.085
Power	4.725	0.777	0.957	0.393	0.016	0.038

due to differences in crop growth stages. Lowest reflectance values in near infrared wavelengths (NIR: 700-1300 nm) were observed for the initial stage, where biomass is low and reflectance is influenced mainly by soil. Maximum reflectance in the NIR was observed for the crop development stage followed by mid-season stage, which is coincident with highest values of green leaf area index, consequently low reflectance of solar radiation in red wavelengths and high scattering of solar radiation in NIR (Moreira et al., 1999). At late-season stage, reflectance in visible (VIS:350-700 nm) and NIR regions increase and decrease, respectively, when compared to the previous growth stages, which is mainly caused by the increase of senescent leaves. The visible region shows maximum reflectance at approximately 550 nm

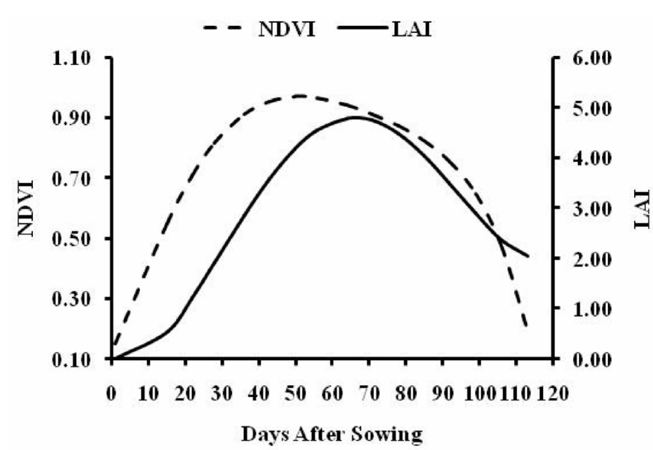

Fig. 2 : LAI and NDVI profile for wheat during crop growth period

region at 680 nm. In general the spectral signatures of wheat crop shows low reflectance in visible and red region and the high reflectance in near infrared region.

Fig. 2 shows the profile of variation of NDVI and LAI during the crop growth period of wheat. The regression analysis between leaf area index (LAI) and Normalized Difference Vegetation Index (NDVI) was carried out over the crop growth period (CGC) for wheat to develop the relationship between LAI and NDVI. The LAI-NDVI relationships developed are presented in Table 1 (a, b, c). The R^2 values were found poor in 0.26-0.47 range for wheat when total crop growth period is considered. In general, R^2 values were not significant, as temporal profile of LAI and NDVI were nonlinear. The regression relationships could be improved if growth and decline phases be analysed separately (Gupta *et al.* 2006). The R^2 values were in 0.90-0.99 range and 0.91-0.98 range for growth and decline phase respectively.

It is observed from Table 1(b) that, the exponential relationships developed for wheat crop during growth phase and decline phase indicated the goodness of fit as per the lower value of $Ç^2$. It is observed that the value of coefficient of determination is maximum, RMSE and PEM are minimum for exponential relationship. Hence, the exponential relationships were found best suitable for the estimation of the LAI from NDVI during growth ($LAI=0.026e^{5.306\,(NDVI)}$) and decline ($LAI=1.340e^{1.321\,(NDVI)}$) phases for wheat. The developed exponential relationships could be used for the assessment of wheat LAI based on NDVI and in the crop evapotranspiration estimation algorithms applying remotely sensed observations.

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