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Spectral reflectance characteristics, vegetation and leaf area indices for sorghum (*Sorghum bicolor* L.)

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ABSTRACT

A growing number of studies have focused on evaluating the spectral indices in terms of their sensitivity to vegetation biophysical parameters like leaf area index. In this context, different hyperspectral ratios and normalized difference vegetation indices were computed for sorghum based on ground-based spectral data obtained in 350-2500 nm wave length region over the crop growth period of sorghum. The analysis of the hyperspectral data was carried out to compare the performance of vegetation indices (Normalized Difference Vegetation Index [NDVI], Renormalized Difference Vegetation Index [RDVI], Modified Simple Ratio [MSR], Soil-Adjusted Vegetation Index [SAVI], Modified Soil-Adjusted Vegetation Index [MSAVI], and Modified Chlorophyll Absorption Ratio Index [MCARI]) by linearly relating to LAI separately for growth and decline phases. The regression coefficient values were found in the range of 0.79 to 0.87 for growth phase and 0.89 to 0.98 for decline phase. The most significant relationship of LAI was found with MSAVI when growth (R^2 of 0.87) and decline (R^2 of 0.98) phases were analyzed separately.

Key words : Sorghum bicolor, spectral reflectance, vegetation indices, leaf area index

The leaf area index (LAI) is a key variable used by crop physiologist and modelers for estimating foliage cover and forecasting crop growth and yield (Haboudane et.al. 2004). Direct measurement of leaf area index is tedious, time consuming and prone to errors in measurement. Vegetation indices (VIs) derived using the reflectance properties of vegetation from hyperspectral and remote sensing measurements, are therefore commonly used to characterize the growth pattern of cropped surfaces including LAI. VIs are thus used to model vegetation biophysical parameters. In this context, leaf and canopy radiative transfer models are valuable for modeling and understanding the behavior of vegetation. The common and most widely used approach to estimate LAI have been to develop relationships between ground-measured LAI and vegetation indices (Spanner et. al. 1990). Consequently' a large number of relationships have been established, and a wide range of determination coefficients ($0.05<R^2<0.66$) between vegetation indices and LAI were found (Baret and Guyot, 1991; Brown et al.,2000; Chen, 1996).

In practice, LAI prediction from vegetation indices obtained from remotely sensed data faces two major difficulties: (1) vegetation indices approach a saturation level asymptotically when LAI exceeds 2 to 5, depending on the type of vegetation index; (2) there is no unique relationship between LAI and a vegetation index of choice, but rather a family of relationships, each a function of chlorophyll content and/or other canopy characteristics (Baret and Guyot, 1991; Broge and Leblanc, 2000). During recent decades, substantial efforts were expended in improving the Normalized Difference Vegetation Index (NDVI) and in developing new indices aiming to compensate for soil background influences (Bannari et al., 1996; Baret et al., 1989; Huete, 1988; Qi et al., 1994; Rondeaux et al., 1996). A few studies have been carried out to assess and compare various vegetation indices in terms of their stability and their prediction power of LAI (Baret and Guyot, 1991; Broge and Leblanc, 2000). Consequently, some indices have been identified as best estimators of LAI because they are less sensitive to the variation of external parameters affecting the spectral reflectance of the canopy, namely soil optical properties, illumination geometry, and atmospheric conditions. The main purpose of the paper is to suggest a spectral index that is suitable to simply, and yet accurately, determine LAI of crop canopies for agriculture management purposes. Thus the main focus of this study is to reduce variability in LAI estimates due to changes in spectral characteristics of the vegetation. Therefore, in this study set of indices that have proven to be resistant to atmospheric and soil brightness effects were assessed in terms of their prediction power of LAI.

MATERIALS AND METHODS

The study area

The data required for this study were collected from Sorghum (*Sorghum bicolor* L.) field at Water Management Project, MPKV, Rahuri located at $19^0 21'54.32''$N and $74^0 38'43.47''$E during 2012-2013. 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 sorghum field was border-irrigated. The crop was sown in September, 2012 and harvested in February, 2013 and the data were recorded during this period.

Spectral reflectance measurements

Spectroradiometers are widely used to collect spectral data and are designed to match the wavebands of different satellites' sensors (Agapiou et al., 2010). The canopy spectral reflectance was measured using SVC (Spectra Vista Corporation) HR-1024 Spectroradiometer with spectral range from 350 to 2500 nm (1 nm interval).

A reference calibrated spectral on panel with 100% reflectance was used to measure the incoming solar radiation as a reference one, while the measurement over the crops as a target. The reflectance was calculated using the equation, Reflectance = (Target Radiance / Panel Radiance) x calibration factor of the panel. In order to avoid any errors due to significant changes in the prevailing atmospheric conditions, the measurements over the spectralon panel and the target were taken with the shortest time lag. All the measurements have been taken from nadir view, from a height of 0.45 m using a 4^o Field of View (FOV) lens. The reflection of the spectralon panel was recorded for every measurement to ensure reliable data collection. Two specific locations were selected and five measurements were made for measuring spectral reflectance in order to have a representative sample. The same point was visited each time for taking observations over the crop growth period.

Leaf Area Index (LAI) measurements

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 CI-110 uses a fish eye camera, ceptometer and proprietary software to capture and analyze images of canopy data, PAR levels and GPS information. The gap-fraction inversion procedure (Norman and Campbell, 1989) was used to estimate LAI, canopy transmission coefficient and mean leaf angles. The software calculates the solar beam transmission coefficient using a user defined number of zenith and azimuth divisions. The output data is then displayed on the computer screen and can be saved into a file for further analysis. The LAI was estimated by analyzing the image with 5 zenith and azimuth divisions. The threshold contrast level was kept 95 with fish eye camera angle of 180^0.

Spectral vegetation indices selected for the study

The most common vegetation indices (Normalized Difference Vegetation Index [NDVI], Renormalized Difference Vegetation Index [RDVI], Modified Simple Ratio [MSR], Soil-Adjusted Vegetation Index [SAVI], Soil and Atmospherically Resistant Vegetation Index [SARVI], Modified Soil-Adjusted Vegetation Index [MSAVI] and Modified Chlorophyll Absorption Ratio Index [MCARI]) were selected to compare the performance of vegetation indices to estimate LAI that are linearly related to VIs. These are given below.

$NDVI = (R_{800}-R_{670}) / (R_{800}+R_{670})$ (Rouse et al., 1974)

$RDVI= (R_{800}-R_{670}) / (R_{800}+R_{670})^{0.5}$ (Rougean and Breon, 1995)

$MSR=(R_{800}/R_{670}-1)/(R_{800}/R_{670}+1)^{0.5}$ (Chen, 1996)

$SAVI=(1+L)(R_{800}-R_{670})/(R_{800}+R_{670}+L)$ (Huete, 1988)

$MSAVI=1/2[2xR_{800}+1-[(2xR_{800}+1)^2-(8x(R_{800}-R_{670})]^{0.5}$ (Qi et al., 1994)

$MCARI=[(R_{700}-R_{670})-0.2(R_{700}-R_{550})](R_{700}/R_{670})$ (Kim et al., 1994)

The linear relationship was then developed between selected vegetation indices and LAI to compare the performance of different vegetation indices to estimate LAI. The relationships were developed for the growth and decline phases separately.

RESULTS AND DISCUSSIONS

Spectral reflectance of sorghum crop

The multi date spectral reflectances of sorghum crop between the wavelengths of 350 to 2500 nm are shown in Fig.1. It is observed from Fig.1, that in the visible spectrum (400-700 nm) because of the high absorption of light by pigments which occur in leaves (chlorophyll, protochlorophyll, xanthophylls, etc.) the reflectance is less. There is a slight increase in reflectivity around 550 nm

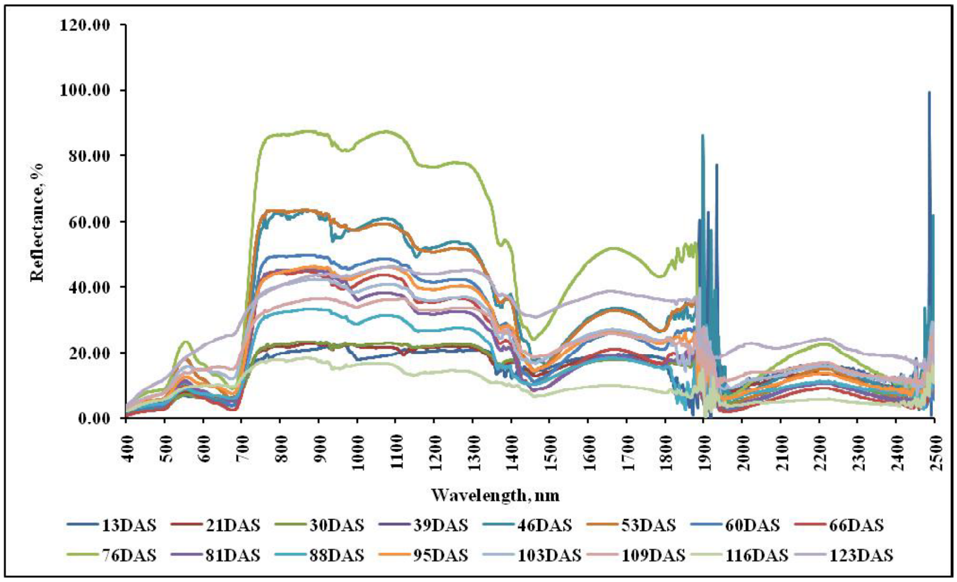

Fig.1: Spectral reflectance of sorghum crop during crop growth period

Table 1: Relationships between vegetation indices and LAI during crop growth period of sorghum

Growth phase		Declining phase	
Relationship	R^2	Relationship	R^2
LAI=7.029NDVI-2.827	0.86	LAI=3.311NDVI-1.232	0.97
LAI=0.547RDVI-0.522	0.85	LAI=0.416RDVI+1.417	0.94
LAI=0.992MSR-0.020	0.82	LAI=0.816MSR+1.864	0.89
LAI=4.622SAVI-2.707	0.86	LAI=2.236SAVI+1.215	0.97
LAI=10.00MSAVI-6.021	0.87	LAI=3.721MSAVI+0.518	0.98
LAI=0.161MCARI+0.480	0.79	LAI=0.179MCARI+1.634	0.94

(visible green) because the pigments are least absorptive there. In the spectral range 700-1300 nm there is no strong absorption, but the plant scatters strongly and reflectance is more. From 1300 to 2500 nm, the absorption by leaf water is more therefore reflectance is less. The same pattern is observed for all the dates of spectral signature acquisition. The multidate spectral signatures collected during the crop growth period of sorghum showed the low reflectance at 13DAS in IR and NIR regions. It was found increased upto 76 DAS. The reflectance was found decreased from 76 DAS to 123 DAS. In general, the multi date spectral signatures collected during the crop growth period of sorghum crop showed the low reflectance at the beginning of the crop development which is increased as crop grows-up till it reached to peak and then started reducing until the crop dried.

Relationships between vegetation indices and LAI

The empirical relationships between LAI and spectral indices were developed. Equations describing these relationships vary in both mathematical forms (linear, exponential, power, inverse of exponential, etc.) and empirical coefficients, depending on the experiments, the indices used, and the vegetation type (Chen et al., 2002; Gilabert et al., 1996; Matsushita and Tamura, 2002; Qi et al., 2000). The common procedure has been used to establish an empirical relationship between a given spectral index and LAI by statistically fitting measured LAI values and corresponding values of the spectral index. In the current study, linear relationships between VIs and LAI were developed for crop growth period of two different phases of sorghum crop viz. growth and decline phases separately.

It is seen from the Table 1, that the R^2 values were found in the range of 0.79 to 0.87 for growth phase and 0.89 to 0.97 for decline phase for selected vegetation indices. The most significant relationship of LAI was found with MSAVI (R^2 in 0.87 and 0.98) when growth and decline phases were analyzed separately. A recent study by Broge and Leblanc (2000) using relative transfer model has also found that MSAVI is the best LAI estimator in terms of sensitivity to canopy effects compared to other indices. It proved to be less affected by variations in canopy parameters as well as soil spectral properties and hence it is the best LAI estimator in dense canopies like sorghum.

CONCLUSIONS

Analysis based on hyperspectral data and ground measured LAI for sorghum crop during crop growth period showed the highly significant linear relationship with the vegetation indices. Significant relationship of LAI (LAI=10.00MSAVI-6.021 with R^2 of 0.87 for growth phase and LAI=3.721MSAVI+0.518 with R^2 of 0.98 for decline phase) was found with MSAVI when growth and decline phases were analyzed independently.

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