MEASUREMENTS AND MODELLING OF BI-DIRECTIONAL REFLECTANCE OF WHEAT: PROSAIL VALIDATION RESULTS

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ABSTRACT:

In this study, an attempt has been made to define the geometry of sensor and source position to best relate plant biophysical parameters with bidirectional reflectance of wheat varieties varying in canopy architecture and to validate the performance of PROSAIL radiative transfer model. A field experiment was conducted with two wheat cultivars varying in canopy geometry and phenology. The bidirectional measurements between 400-1100 nm at 5nm interval were recorded every week at six view azimuth and four view zenith positions using spectro-radiometer. Canopy biophysical parameters were recorded synchronous to bi-directional reflectance measurements. The broadband reflectances were used to compute the NDVIs which were subsequently related to leaf area index and biomass. Results showed that the bidirectional reflectance increased with the increase in view zenith from 20° to 60° irrespective of the sensor azimuth. The reflectance was observed maximum at 50° view zenith and 150° azimuth (hotspot). The measured bidirectional NDVI had significant logarithmic relationship with LAI and linear relationship with biomass for both the varieties of wheat and maximum correlation of NDVI with LAI and with biomass was obtained at the hotspot position.. The PROSAIL validation results showed that the model simulated well the overall shape of spectra for all combination of view zenith and azimuth position for both wheat varieties with the overall RMSE less then 5 percent. The hotspot and dark spot positions were also well simulated.

Introduction

The reflection of electro-magnetic radiation from natural targets on earth surface is highly anisotropic in nature (Hapke, 1981), which besides being a function of target surface properties is also dependent on source-target-sensor geometry (Verstraete *et al.*, 1988; Chakraborty, 2002). This anisotropic reflectance is characterized as Bi-directional and is mathematically represented as Bi-Directional Reflectance Distribution Function (BRDF) (Hapke, 1981). An understanding of the BRDF of underlying surface is the best way of deriving its properties/parameters from remote sensing systems. In case of vegetation, the Bi-Directional Reflectance characterization has been shown to help in deriving canopy

biophyisical parameters such as leaf area index (LAI), leaf angle distribution (LAD), chlorophyll content, biomass etc (Verhoef and Bunnik, 1981; Kuusk, 1985)

The parameterization of vegetation canopy BRDF can be achieved either by carrying out measurements for a range of source-target-sensor geometries (Verstraete *et al.*, 1988; Chakraborty, 2002) or using a validated canopy reflectance model (Asrar, 1989). The canopy reflectance models are based on the understanding of the physics of interaction between incident radiation and vegetation elements by completely describing the complex processes of radiative transfer within the canopy. These validated models can be inverted to derive the canopy biophysical parameters using reflectance measurements (Goel and Strebel, 1983). The PROSAIL is one such model which is easily invertible and consists of leaf reflectance model PROSPECT and canopy radiative transfer model SAIL.

In the present study, an attempt has been made to (a) define the geometry of sensor and source position to best relate plant biophysical parameters with bi-directional reflectance of wheat varieties varying in canopy architecture and (b) validate the performance of PROSAIL canopy reflectance model for the two wheat varieties.

Materials and Methods

A field experiment was laid in the experimental farm (Block 8C) of Indian Agricultural Research Institute, New Delhi, located at $28^o38'$ 23.89''' N latitude, $77^o09'$ 16.55'' East longitude, altitude of 228.6 m with two cultivars HD-2733 (Erectophile and medium duration) and *Kalyansona* (Planophile and long duration) were grown.. The modified cosine receptor having FOV of $20.16^°$ was used to measure bi-directional reflectance using BaSO$_4$ reference panel and a hemispherical iron frame of 2-meter radius (Fig. 2). The bi-

directional spectral measurements between 400 - 1100 nm at 5nm interval were recorded every week during 60 to 116 days after sowing at six view azimuth (60°, 105°, 150°, 195°, 240° and 330°) and four view zenith (20°, 40°, 50° and 60°) positions. In synchronization biophysical parameters like leaf area index, leaf chlorophyll content, specific leaf area, leaf length, plant height and leaf inclination angle, water thickness, biomass etc were recorded. The five point Newton-cote's integration formula in IDL was used to integrate spectroradiometer reflectance data recorded 5nm interval corresponding to four broad bands of IRS LISS sensor viz. 400 - 520nm (B1), 520 - 590nm (B2), 620 – 680nm (B3), 770 – 860nm (B4). The program written in IDL was used to compute solar zenith and azimuth positions at different time and days of observations. The broad-band reflectances were used to compute the NDVI and were subsequently related to crop biophysical parameters. The PROSAIL model was validated for both the wheat varieties at different growth stages by comparing simulated reflectance with measured values from 400 – 1100 nm at 5nm step for a range of azimuth and zenith positions. The inputs used to running the PROSAIL model at 70 DAS for two wheat varieties are given in table 1.

Results and Discussions

The results showed that the overall pattern of bi-directional reflectance for two wheat varieties is similar but reflectances were varying in magnitude. The bi-directional reflectance increased with the increase in view zenith angle irrespective of the sensor azimuth angle in all the wavelength bands. The figure 3 shows that the maximum reflectance at around 50^0 and 150^0 view zenith and azimuth angles corresponded to the hotspot position in this study and it varied 40 to 60 percent in infrared region (770 – 860 nm) for both the varieties at 70 DAS.

The Normalized Difference Vegetation Index (NDVI) derived for different view zenith and azimuth angles was highly positively correlated with Leaf Area Index (LAI) and biomass. Many other workers have also reported high correlation between plant biophysical parameters and vegetation indices (Asrar *et al.* 1985). The functional form of relation between NDVI and LAI was found to be saturating type that was fitted as logarithmic equation (Sehgal and Sastri, 2005) whereas NDVI was linearly related with biomass. The coefficient of determination (R^2) of logarithmic relation of NDVI with LAI and linear relation of NDVI with biomass for two wheat varieties were observed highest at hotspot position in different view azimuth and zenith angles are given in Table 2. At hotspot position the R^2 value for NDVI *vs.* LAI was 0.91 and 0.98 and of NDVI *vs.* Biomass was 0.71 and 0.84 for HD 2733 and *Kalyansona*, respectively.

The presented PROSAIL validation results pertaining to *Kalyansona* at 70 DAS showed the observed and model simulated spectral reflectance curve between 400 and 1100 nm at constant view azimuth (150^0) and varying view zenith in figure 4 whereas, at constant view zenith (50^0) and varying view azimuth in figure 5.

It is evident from figure 4 that for a fixed azimuth angle, that the error in model simulation between 400 to 700nm is very small at 20° and 60° view zenith angle but it was nearly double at 40° and 50° zenith angle. In case of 700 to 1100 nm, the reverse trend is observed i.e. errors are comparatively lower at 40° and 50° than at 20° and 60° zenith angles, though over whole spectrum the mean error is constant (~2.6 percent) at all zenith angles. In general, the model is overestimating the reflectance at low (20°) and high (60°) view zenith whereas it is underestimating at intermediate view zenith angles throughout the spectrum. Overall, the model performance is much better in simulating reflectance in 400 to 700 nm at different view zenith angle with an average error of 1.1 percent than in 700 to 1100nm having an average error of 4.2 percent.

The figure 5 shows that for a fixed zenith angle, the model in general is underestimating the reflectance at different view azimuth angles throughout the spectrum. The mean RMSE, RMSE1 and RMSE2 are lowest in the dark-spot (330° 50°) and low in hot-spot position (150° 50°) than in other positions. As observed earlier, the model errors are comparatively very small in 400 to 700 nm than between 700 to 1100nm at all view azimuth angles. Both RMSE1 and RMSE2 are also showing decreasing trend with the increase in azimuth angle from 2.2 percent to 0.6 percent and 6.1 percent to 1.8 percent, respectively. The results from figure 4 and 5 shows that the model simulations of crop reflectance are highly sensitive to viewing geometry as observed from the actual measurements.

Conclusions

This study clearly shows that the reflectance from wheat canopy is anisotropic in nature showing a variation with view angles. The overall pattern of bi-directional reflectance of the two wheat varieties, *viz.* HD-2733 and *Kalyansona* having different canopy geometry, is similar but reflectance varies in magnitude. In general, for any fixed azimuth angle the canopy reflectance was increased with increasing zenith angles and it was highest at hot-spot position (150^0 azimuth and 50^0 zenith). In this work, among the different view geometry, hot spot position showed highest coefficient of determination (R^2) for crop biophysical parameters (LAI and Biomass) with vegetation index (NDVI) for both the wheat varieties. These results are in good agreement with the literature. Therefore hot-spot is the critical bi-directional position to extract crop biophysical parameters from canopy reflectance values.

The validation of PROSAIL model shows that the model simulates well the overall

reflectance spectra of wheat varieties at different view geometries including reflectance at hot-spot and dark-spot positions. The future scope to retrieve the biophysical parameters through inversion of PROSAIL model for ground and space based data will be the new horizon in estimation and prediction in agricultural system.

Acknowledgement

References

Asrar, G., Myneni, R. B., Li, Y. and Kanemasu, E. T. (1989). Measuring and modeling spectral characteristics of a tallgrass prairie, *Remote Sens. of Environ.*, **27**(2): 143-155.

Chakraborty, A. (2002). Effect of crop-, sensor- and source geometry on the spectral reflectance of wheat (Triticum aestivum L.). M.Sc. Thesis, Indian Agricultural Research Institute, New Delhi.

Goel, N.S. and Strebel, D.E. (1983). Inversion of vegetation canopy reflectance models for estimating agronomic variables. I. Problem definition and initial results using suits model. *Remote Sens. of Environ.*, **16** : 69-85.

Hapke, B. (1981). Bidirectional reflectance spectroscopy, 1.Theory, J. Geophys. Res. **86**: 3039-3054.

Kuusk, A. (1985). The hotspot effect of a uniform vegetative cover. Soviet Journal of Remote Sensing. **3**: 645-658

Roujen, J. L. (2000). A parametric hot spot model for optical remote sensing application. *Remote Sens. of Environ.*, **71**(2): 197-206.

Sehgal, V.K. and Sastri, C.V.S. (2005). Simulating the effect of nitrogen application on wheat yield by linking remotely sensed measurements with WTGROWS simulation model, *J. Ind Soc. Remote Sens.*, **33**(2): 297-305.

Verhoef, W. and Bunnik, N. J. J.(1981). Influence of crop geometry on multispectral reflectance determined by the use of canopy reflectance models. *Proc.Intl.Colloq. Signatures Remotely Sens. Objects*, Augnon, France, pp-273-290.

Verstraete, M.M.; Pinty, B. and Dichinson, R.E. (1988). A physical model of the bidirectional reflectance of vegetation canopies, 1.Theory. *J. Geo-physical Res.*, **95**(D8): 1755-1765.

PROSAIL Model Input Parameters	HD 2733	*Kalyansona*
isat (Spectroradiomater, 400-1100 nm, 5 nm interval)	0	0
*iho*t (hot-spot parameter)	1	1
Theta_s, Phi_s (sun position)	60.0, 160.0	60.0, 160.0
tl (Mean leaf inclination)	50.0	40.0
l (Leaf Area Index)	3.7	3.2
vai (Leaf Internal Structure)	1.5	1.5
cab (Leaf Chlorophyll content, μgcm^{-2})	50.0	47.0
cw (Equivalent Water Thickness, cm)	0.028	0.03
cm (Leaf dry matter content, gcm^{-2})	0.017	0.015
sl (Leaf size/crop height)	0.48	0.46
vis (Horizontal visibility)	50.0	50.0
na (Theta_v(j), Phi_v(j)) (sensor angle combinations)	24	24

Table 1. Input values used in PROSAIL validation for HD 2733 and *Kalyansona* wheat varieties at 70 DAS.

View Azimuth	View Zenith	R^2 NDVI vs LAI		R^2 NDVI vs Biomass	
		(HD 2733)	(*kalyansona*)	(HD 2733)	(*kalyansona*)
60^0	20^0	0.65	0.93	0.54	0.69
	40^0	0.56	0.93	0.45	0.55
	50^0	0.69	0.87	0.59	0.47
	60^0	0.81	0.42	0.40	0.63
105^0	20^0	0.68	0.95	0.41	0.58
	40^0	0.70	0.87	0.51	0.83
	50^0	0.75	0.85	0.53	0.81
	60^0	0.74	0.47	0.52	0.53
150^0	20^0	0.84	0.87	0.56	0.89
	40^0	0.84	0.97	0.58	0.84
	50^0	0.91	0.98	0.71	0.84
	60^0	0.90	0.82	0.58	0.63
195^0	20^0	0.74	0.78	0.67	0.66
	40^0	0.76	0.75	0.47	0.49
	50^0	0.86	0.89	0.68	0.40
	60^0	0.84	0.67	0.56	0.41
240^0	20^0	0.66	0.92	0.55	0.63
	40^0	0.77	0.76	0.51	0.40
	50^0	0.77	0.84	0.58	0.49
	60^0	0.79	0.53	0.43	0.46
330^0	20^0	0.71	0.70	0.54	0.47
	40^0	0.72	0.64	0.53	0.46
	50^0	0.80	0.63	0.48	0.47
	60^0	0.76	0.71	0.59	0.48

Table2. Coefficient of determination (R^2) of NDVI with Leaf Area Index (LAI) and biomass at different view azimuth and view zenith angles for HD 2733 and *Kalyansona*.

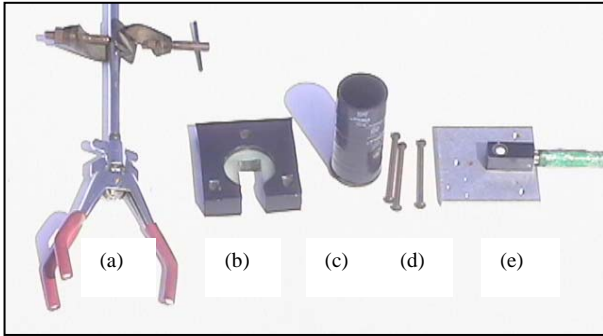Figure1. Perspex assembly: (a) Clamp for holding the modified sensor, (b) Perspex plate for the attachment to the base of the sensor of Spectroradiometer, (c) open ends tube, (d) nut-bolt for firmly attaching the assemble, (e) Steel base with sensor of Spectroradiometer.
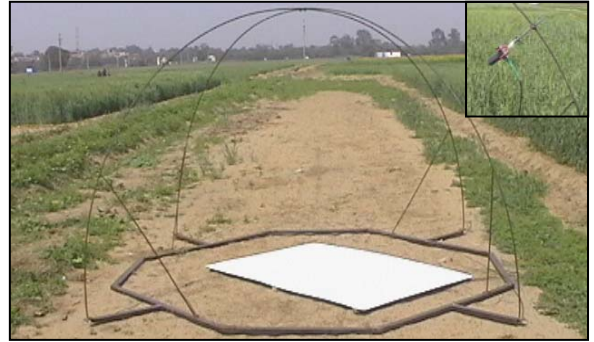

Figure 2. Metallic hemispherical structure to set different view geometries of sensor and barium sulfate reference panel at the centre. Inset shows modified sensor attached to the arc of hemisphere for particular view geometry.
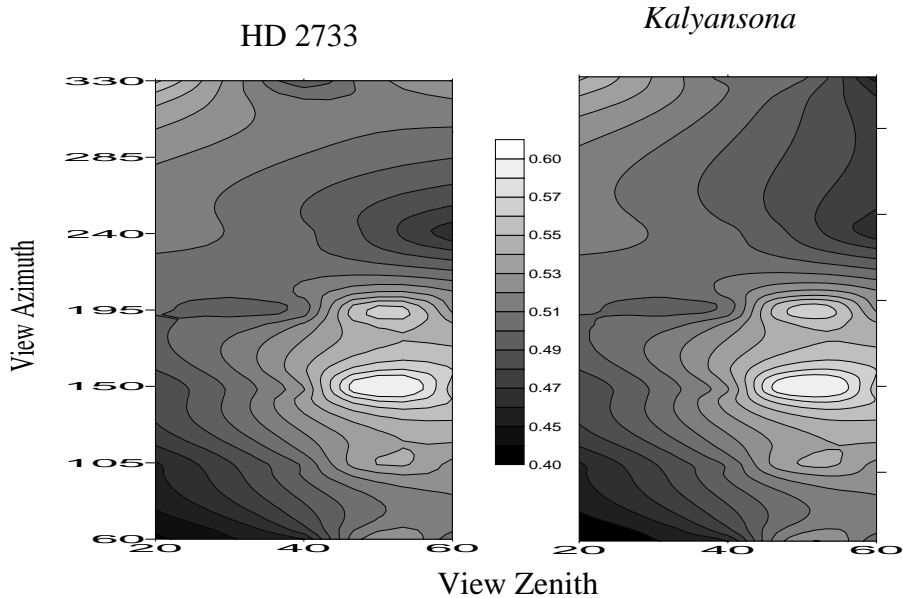

Figure 3. Bi-directional reflectance pattern at different view geometries for HD 2733 and *Kalyansona* at 70 DAS in infrared region.
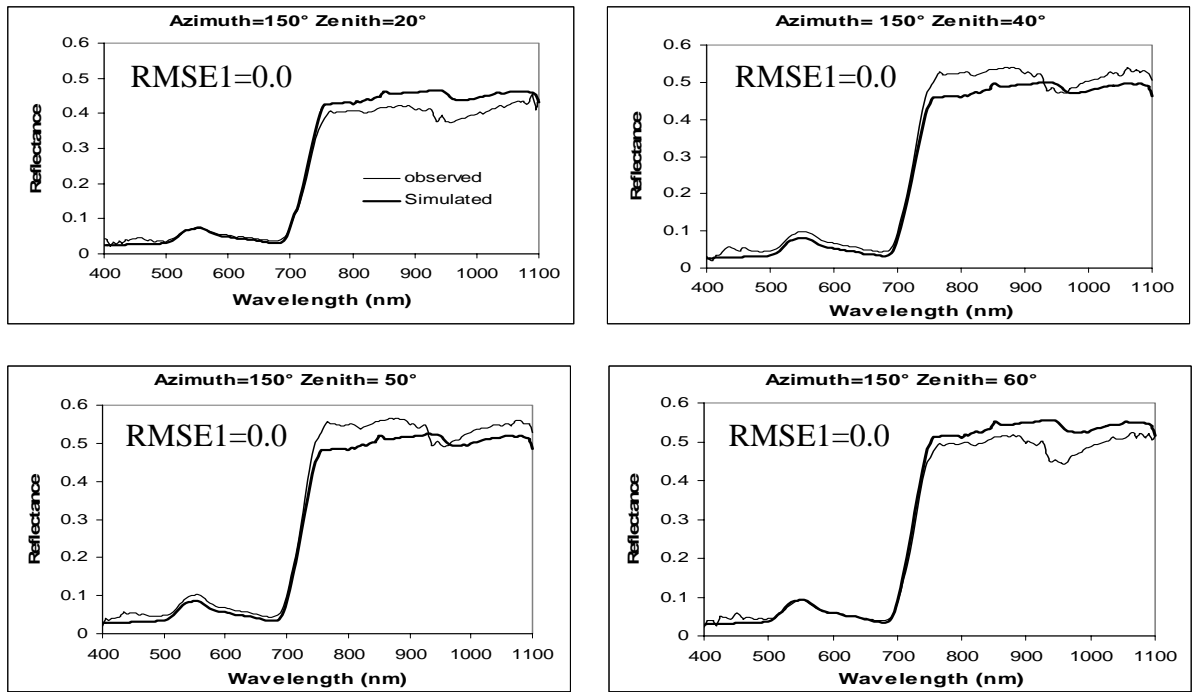
Figure 4. Observed vs. PROSAIL simulated canopy reflectance curve of *Kalyansona* at 150° azimuth and different view zenith angles at 70 DAS and RMSE values in red and infrared regions.
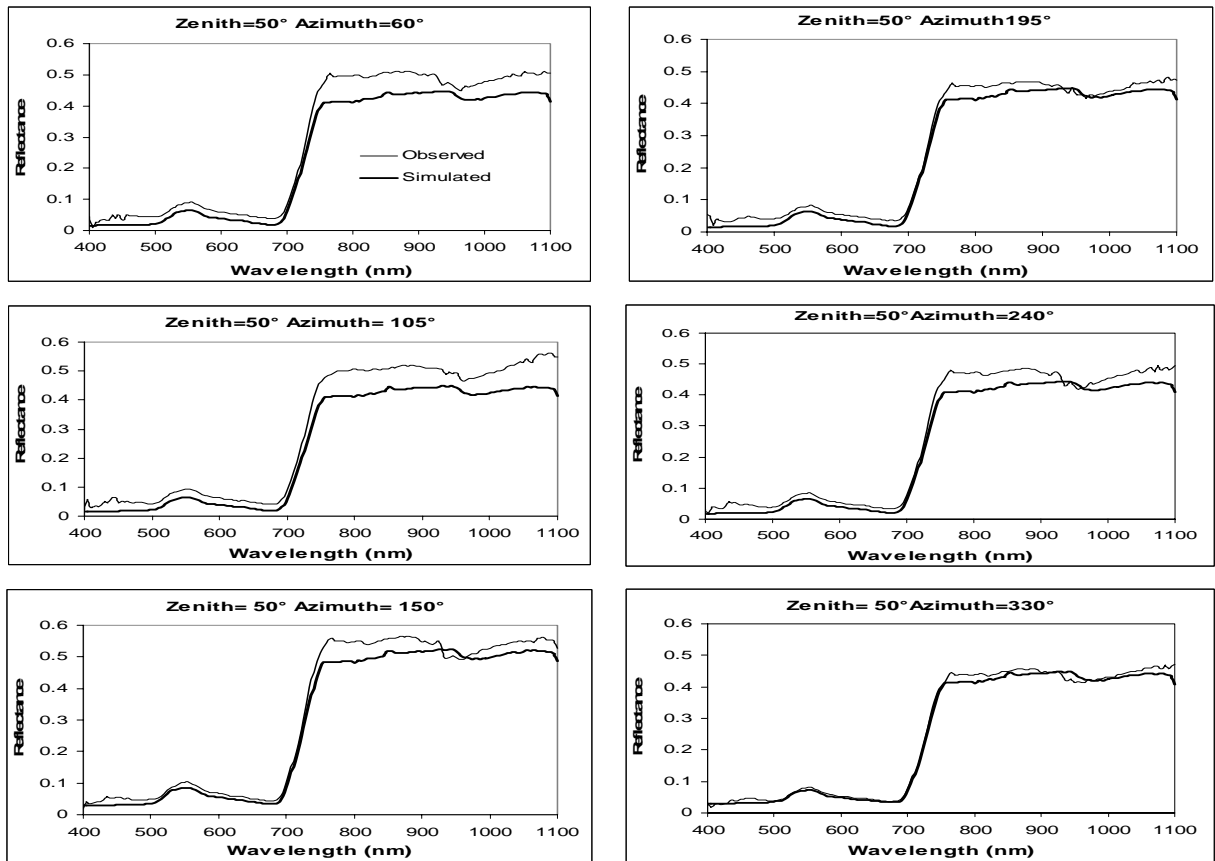

Figure 5. Observed vs. PROSAIL simulated canopy reflectance curve of *Kalyansona* at 50° zenith and different view azimuth angles at 70 DAS and RMSE values in red and infrared region.