Estimating leaf area index considering the crop geometry effection

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ABSTRACT

The quantitative effect of crop canopy reflected spectrum by leaf area index (LAI) and average leaf angle (ALA) was studied. Effect of ALA on canopy reflected spectrum can not be ignored with inversion of LAI and monitoring of crop growth condition by remote sensing technology. It indicated that canopy reflected spectrum has significant difference between erective and horizontal cultivars by radiative transfer model and measured experiment data. Investigations have been made on identification of erective and horizontal cultivars by bidirectional canopy reflected spectrum. The bidirectional reflectance of visible and near infrared bands at 15°, 30°and 45°field of view for the main viewing plane could be used for identification of plant structural types based on bidirectional data. For erective varieties, the bidirectional canopy reflectance at near infrared was f45°>f15°> f30°, at visible band was f45°>f15°≈f30°; For middle varieties, the bidirectional canopy reflectance at near infrared and visible band was f15°>f45°> f30°; For loose varieties, the bidirectional canopy reflectance at near infrared and visible band was f45°>f30°> f15°. So, it is feasible to identify loose, middle and erective varieties of wheat by bidirectional canopy reflected spectrum. The result indicates that the application of EVI is affected by LAD, so LAD should be considered when retrieve LAI using enhanced vegetation index (EVI).

Keywords: Winter wheat, Leaf area index (LAI), Enhanced vegetation index (EVI), Leaf area distribution (LAD), Radiative transfer model

1 INTRODUCTION

Leaf area index (LAI) is defined as one half the total green leaf area per unit horizontal ground surface area, and it is an important structural property of vegetation canopy. Generally, LAI can be measured directly by using TRAC (Xu et al, 2003) and LAI-2000 (Fang et al, 2003). Though these methods are difficult for some objects like crop, and it was time-consuming and difficult to make for wide regional and global studies. It's highly desirable to develop new techniques to overcome the limitations of traditional field sampling method. With the development of remote sensing technology, it is possible to estimate LAI nondestructively on a large area in time. Estimating LAI by remote sensing usually has three approaches: statistical methods, physical methods, and hybrid methods (Liang, 2004). In statistical methods, it is often to estimate LAI by establishing functional relationships between various vegetation indices (e.g. NDVI, SR, WDVI, SAVI et al) and LAI (Baret and Guyot, 1991; Carlson and Ripley, 1998; Liang, 2004).

In this study, we analyzed the effects of chlorophyll content, LAI, leaf angle distribution, observation/illumination angle, soil background on EVI using model PROSAIL, and eliminated the effect of sun zenith angle for measured spectrum data caused by difference of measured times through PROSAIL, then, used the corrected data to compute EVI, estimated LAI by the statistical relationship between LAI and EVI. With the rapid development of remote sensing technology, the application of remote sensing has extended from single view angle to multi-view angles. It was not enough to monitor and forecast the crop dynamic and geometry information only by the single view angle and single temporal information. Multi-angle remote sensing information is necessary for crop dynamical and geometry information extraction. Remote sensing has been shown to be a valuable tool in mapping and quantifying within-field biophysical variations for use in research and management (Moran,1997). Canopy geometry affects light interception that controls energy balance and canopy reflectance (Roberts,2004). Mickelson et al (2002) suggested that a number of heritable traits including leaf amount, leaf angle, leaf orientation, and tassel size determine heritable differences among genotypes for light interception. So the canopy structure should be taken into consideration when using remote sensing techniques to monitor crop growth status. The relationship between canopy structure and reflectance has been the focus

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of a considerable research (Hall,1995). Pepper et al.(1977) concluded that leaf orientation value (LOV) can reflect the leaf inclination angle and position. The research on extracting crop leaf angle distribution (LAD) has been performed by Bonhomme(1970) with canopy radiation permeation ration. However, for identification of crop geometry in large scale, the method based on canopy spectrum characteristics would be the ideal selection. Many techniques have been employed to utilize the spectral, angular, and temporal information content of the data in order to improve the accuracy of land surface parameters retrieved from satellite data. The bidirectional reflectance distribution function (BRDF) model establishes a relationship between the bidirectional reflectance and these spectral and structural features. It is possible to obtain structural information by retrieving biophysical parameters from a physical BRDF model and a number of bidirectional observations. Sandmeier et al.(1998) proposed the anisotropy factor (ANIF) and anisotropy index (ANIX), which are based on reflectance ratios at different viewing or illumination geometries. Obvious differences were found between an erectophile grass lawn and a planophile watercress canopy. The parameters of physical BRDF models are related to the biophysical structural information. Gao et al.(2003) proposed a structural scattering index (SSI) and a relative structural scattering index (RSSI) whose derivation is based on BRDF parameters.

2 MATERIALS AND METHODS

The experiments were carried out at the China National Experimental Station for Precision Agriculture, located in Changping district of Beijing (40°11′ N, 116°27′ E), P. R. China from 2003 to 2004. The nutrient contents of the soil (0-0.2 m) were: organic matter 14.2-14.8 g/kg, total N 0.81-1.00 g/kg, available phosphorus 20.1-55.4 mg/kg and available potassium 117.6-129.1 mg/kg.

Crop canopy geometry was classified by crop leaf orientation value (LOV), and was calculated as equation (1) :

$$LOV = \sum_{i=1}^{n} \left[a(h/L)_i / n \right] \tag{1}$$

Where a is the leaf inclination angle, $a = 90^\circ - \theta$; θ is the angle between leaf tangent and the stem; h is the distance from leaf base point to the zenith of the leaf; L is Leaf length; n is the number of leaves. The units of a and θ is the degree of angle "°", the units of h and L is "cm".

The wheat varieties with LOV≥45° are treated as erectophile leaf type varieties, with 25° < LOV < 45° are treated as planophile leaf type varieties, and with LOV≤25° are treated as horizontal leaf type varieties. Eighteen winter wheat varieties, including erectophile leaf type variety Jing411; planophile leaf type variety Jingdong8, and horizontal leaf type variety Zhongyou 9507 were studied.

A 1 m × 1 m area of each sample was selected to measure canopy reflectance and to analyze leaf area index (LAI) by LAI 2000 instrument (LI-COR Company, Lincoln, Nebraska, U.S.A). Canopy reflectance was measured at a height of 1.3 m, under clear sky conditions between 10:00 and 14:00, using an ASD FieldSpec Pro spectrometer (Analytical Spectral Devices, Boulder, CO, USA) fitted with a 25° field of view fiber optic adaptor and operated in the 350-2500 nm spectral range. A 0.4 m × 0.4 m $BaSO_4$ calibration panel was used for calculating the black and baseline reflectance. Vegetation reflectance measurements were taken by averaging 20 scans at optimized integration times. Calibration panel reflectance measurements were taken before and after the vegetation measurements.

3 RESULTS AND DISCUSSION

3.1 Effect of crop geometry on canopy reflected spectrum

Canopy reflected spectrum has significant differences between erectophile, planophile and horizontal geometry varieties at almost the same LAI value (Table 1). LAI value was measured by the LAI 2000 instrument. Canopy reflectance at near infrared of the erectophile variety was less than that of horizontal geometry variety. The effects of LAI and crop LAD on canopy reflectance were studied among erectophile, planophile and horizontal LAD varieties. We studied the canopy reflected spectrum at the 450 nm (blue), 550 nm (green), 680 nm (red), 800 nm and 1100 nm bands (NIR), these bands almost represented the canopy reflected spectrum characteristics in the visible and near infrared bands.

The most common vegetation index was the normalized difference vegetation index (NDVI). It was defined by Rouse et al (1974) as follows:

$$NDVI = (NIR - R)/(NIR + R) \qquad (2)$$

The canopy reflectance (%) at 450, 550, 680, 800 and 1100 nm, and the NDVI value for different LAD (erectophile, planophile and horizontal) varieties were different at almost the same LAI values (Table 1). The LAI value was measured by the LAI 2000 instrument. The Standard deviation (STDEV) of canopy reflectance in the near infrared bands (800 nm and 1100 nm) was more significant than those of the visible bands (450 nm, 550 nm, 680 nm). It indicates that near infrared bands could be used for different LAD wheat varieties identification.

Table 1 Reflectance and NDVI for different LAD varieties under essentially the same LAI

Mean LAI	Crop geometry	Variety	LAI	450 nm	550 nm	680 nm	800 nm	1100 nm	NDVI
LAI≈4.1	ELT	Jing411	4.42	1.72	3.91	1.69	42.75	42.35	0.89
	PLT	Jingdong8	4.14	2.25	4.86	2.27	43.59	44.75	0.90
	HLT	Zhongyou9507	4.10	2.50	5.44	2.61	47.05	47.34	0.91
	STDEV		0.06	0.40	0.77	0.46	2.28	2.50	0.01
	VAR		0.00	0.16	0.59	0.22	5.20	6.24	0.00
	MV		4.15	2.16	4.74	2.19	44.46	44.81	0.90
	CV		1.47	18.44	16.24	21.23	5.13	5.58	0.78

Note: 1) ELT: Erectophile LAD varieties; PLT: Planophile LAD varieties; HLT: Horizontal LAD varieties; 2) STDEV: Standard deviation; VAR: Variance; CV: Coefficient of Variation; MV: Mean value.

3.2 Effect of leaf angle distribution, sun zenith, and observation zenith on LAI estimation

Assumed that the sun zenith varies from -80° to 80° with 10° interval, and the sun azimuth, observation zenith, observation azimuth all equal 0°. There have an evident hot spot when sun zenith is 0° in Figure1, because of 0° observation zenith; also the influence of LAI for EVI is bigger at the 0° zenith. Assumed that the observation zenith varies from -70° to 70° with 10° interval, and the sun azimuth, sun zenith, observation azimuth all equal 0°. The result in figure 2 indicated that the change of EVI with observation zenith is obvious, and the maximum influence of LAI is around the -40° zenith. Assumed that LAD varies from 15° to 85° with 10° interval. The result in Figure 3 indicated that EVI decrease when LAD increase, and this exhibition is more clear when LAD > 65°, though the influence of LAI is bigger around the 55° LAD.

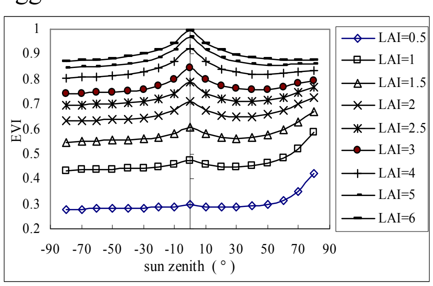

Figure 1. Effect of sun zenith on EVI.

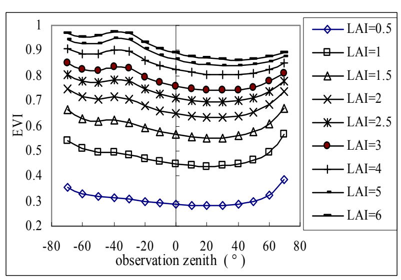

Figure 2. Effect of observation zenith on EVI.

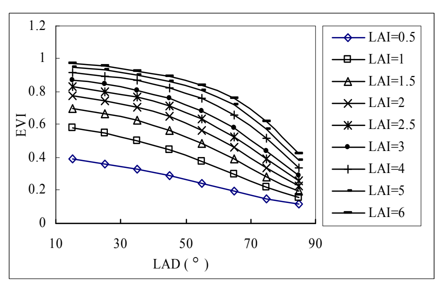

Figure 3. Effect of LAD on EVI.

3. 3 Relationship between LAI and EVI based measured data

We assumed LAI from 0.5 to 7 by PROSAIL model with every 0.5 step, and simulated the canopy spectrum. The relationship between LAI and EVI was an exponential form; and when LAI > 4, the change of EVI was small. Establish the statistical expression for LAI and EVI using measured data, the result is shown in figure 4 and in figure 5. We used PROSAIL model to correct the influence of different sun zenith; simulated canopy reflectance in measured sun zenith and in 0° zenith, used their ratio to correct measured data to a uniform sun zenith 0°. It see that the corrected data is more sensitive to LAI, the R^2 is 0.6921 and the root mean square error (RMSE) is 0.7620, which is 0.6542 and 0.8308 respectively using the original data. The result indicates that the application of EVI is affected by LAD, incoming radiation conditions, observation conditions et al., so these factors should be considered when retrieve LAI using EVI. From the analysis we can see that the effect of LAD is very apparent, EVI varies > 55% when LAD from 15° to 85°, this will achieve 72% -73% when LAI is 1-1.5. So we estimated LAI using EVI based model corrected measurement data, the result has be shown better than using original data.

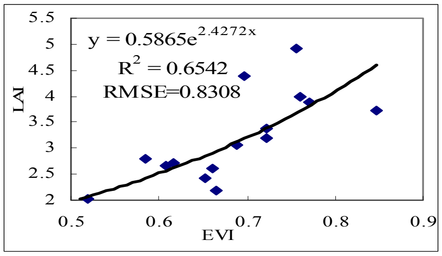

Figure 4. Relationship between LAI and EVI using measured data.

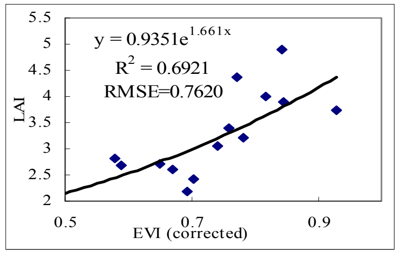

Figure 5. Relationship between LAI and EVI using model corrected data.

3.4 Identification crop geometry by field bidirectional canopy reflected spectrum

The bidirectional reflectance of visible (550 nm and 680 nm) and near infrared band (1100 nm) at 15°, 30°and 45° field of view for the main viewing plane, could be used for identification of erectophile, planophile and horizontal varieties of wheat, based on bidirectional data (Figure 6).

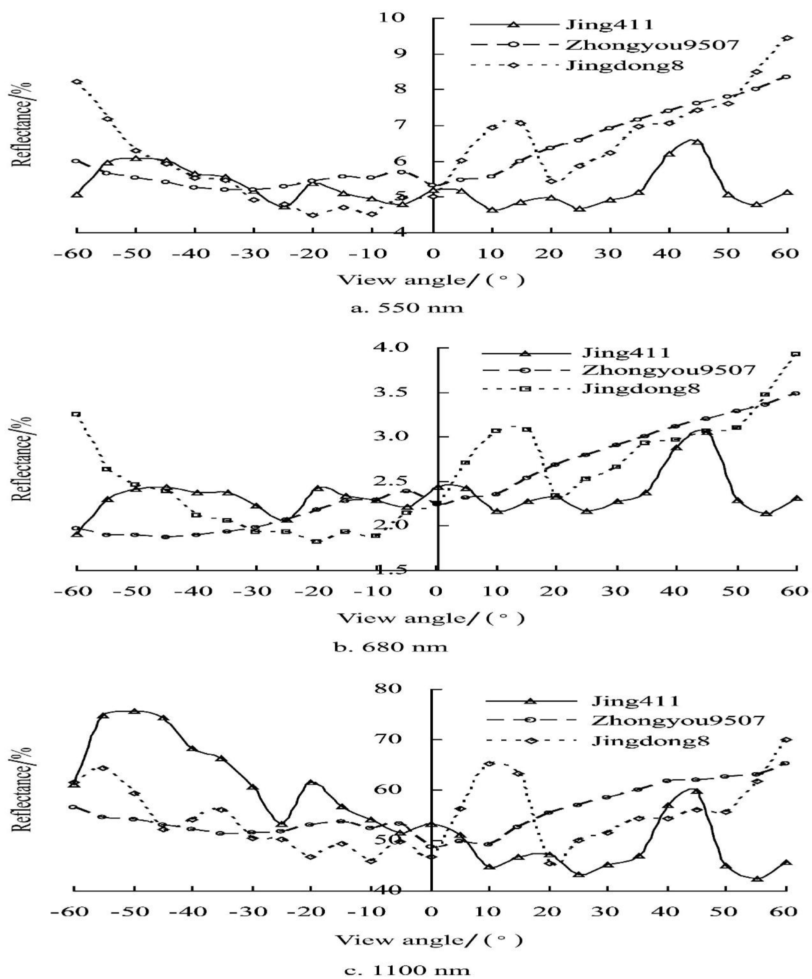

Figure 6 Bidirectional canopy reflectance at 550 nm, 680 nm and 1100 nm for different canopy geometry varieties

For the erectophile variety, the bidirectional canopy reflectance at near infrared was f45° > f15° > f30° (f45° means the canopy reflectance at the observation angle of 45°, the same meaning as other observation angles), in the visible band was f45° > f15° ≈ f30°. For planophile variety, the bidirectional canopy and 1100 nm for different canopy geometry varieties reflectance at near infrared and in the visible band was f15° > f45° > f30°; For horizontal variety, the bidirectional canopy reflectance at near infrared and in the visible band was f45° > f30° > f15. Because wheat LAD and LAI have a similar effect on the crop reflected spectrum, the effect of LAD was ignored in the traditional remote sensing inversion method of LAI among erectophile, planophile and horizontal LAD varieties. The results in this paper allow an on-site and non-sampling mode of crop geometry identification, which is useful in improving the inversion precision of LAI value using remote sensing for crop growth monitoring, fertilizing, and water management without a priori knowledge. Moreover, a careful analysis should be carried out to investigate the effects of soil background, shadow, band width and view angles. Further studies are needed to confirm and improve the results mentioned in this study, such as how to define the effect parameters among erectophile, planophile and horizontal LAD varieties. Therefore, this technique will assist the application of precision decision-making on nitrogen fertilizer management. In order to avoid lodging and yield reduction, management practice on controlling wheat plant growth should be performed in over-luxuriant winter field. To improve the estimation accuracy of the vegetation information, prior knowledge of groundtruth information was needed. In other words, information on the spectral data and canopy structure should be obtained as much as possible when using remote sensing method to monitor crop management.

4 CONCLUSIONS

The canopy reflectance has significant differences between erectophile, planophile and horizontal geometry varieties at essentially the same LAI value. Canopy reflectance at near infrared bands could be used for different LAD wheat varieties identification. The bidirectional reflectance of visible and near infrared bands at 15°, 30° and 45° field of view for the main viewing plane could be used for identification of erectophile, planophile and horizontal LAD varieties based on bidirectional data. The result indicates that the application of EVI is affected by LAD, so LAD should be considered when retrieve LAI using EVI. From the analysis we can see that the effect of LAD is very apparent, EVI varies > 55% when LAD from 15° to 85°, this will achieve 72% -73% when LAI is 1-1.5. The hot spot of EVI is evident with the change of sun zenith when LAI is more than 3. The higher observation zenith, the greater EVI when observation zenith from 0° to 70°; though EVI firstly increase and decrease later, when observation zenith from -70° to 0°. So we estimated LAI using EVI based model corrected measurement data, the result has be shown better than using original data with considering the LAD effect.

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