Winter wheat geometry identification by bidirectional canopy reflected spectrum

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Abstract: Effect of crop leaf angle on canopy reflected spectrum cannot be ignored in the inversion of leaf area index (LAI) and the monitoring of the crop growth condition using remote sensing technology. In this study, experiments on winter wheat (Triticum aestivum L.) were conducted to identify crop leaf angle distribution (LAD) by bidirectional canopy reflected spectrum. Canopy reflected spectrum has significant differences among erectophile, planophile and horizontal geometry varieties at essentially the same LAI value. Canopy reflectance value at near infrared of the erectophile variety was lower than that of the horizontal variety. The effects of LAI and crop LAD on canopy reflectance were studied among erectophile, planophile and horizontal LAD varieties. The Standard Deviation (STDEV) of canopy reflectance at the near infrared bands (800 nm and 1100 nm) was more significant than those of visible bands (450 nm, 550 nm, 680 nm). It indicates that near infrared bands could be used for different LAD wheat varieties identification. The method for identification of crop geometry parameters was by the bidirectional canopy reflectance at different wave bands and view angles. 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. For erectophile varieties, the bidirectional canopy reflectance at near infrared was f45°＞f15°＞f30° (f45°, f15° and f30° mean the canopy reflectance at 45°, 15°, and 30°, respectively), in the visible band it was f45°＞f15° ≈ f30°. For planophile varieties, the bidirectional canopy reflectance in the near infrared and visible band was f15°＞f45°＞f30°. For horizontal varieties, the bidirectional canopy reflectance in the near infrared and visible band was f45°＞f30°＞f15°. So, it is feasible to identify erectophile, planophile and horizontal varieties of wheat by bidirectional canopy reflected spectrum.

Keywords: winter wheat, bidirectional canopy reflectance, crop geometry, leaf orientation value (LOV)
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1 Introduction

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[1]. Canopy geometry affects light interception that controls energy balance and canopy reflectance[2]. Mickelson et al.[3] 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 of a

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considerable research[4]. Pepper et al.[5] 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[6] with canopy radiation permeation ration and Li and Wang[7] by multimedia image approach. 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.[8] 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.[9] proposed a structural scattering index (SSI) and a relative structural scattering index (RSSI) whose derivation is based on BRDF parameters.

The objective of this study was to distinguish erectophile, planophile and horizontal leaf type varieties by bidirectional canopy reflected spectrum.

2 Materials and methods

The experiments were carried out at the China National Experimental Station for Precision Agriculture, located in the 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) [5]:

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

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" (Figure 1).

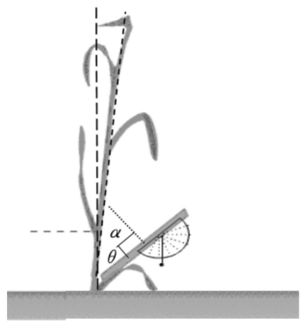

Figure 1 Graph for showing the physical definition of leaf inclination angle

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.

Canopy BRDF reflectance was measured by using the same spectrum instrument as that in measuring the in situ canopy reflected spectrum. The instrument was fixed on rotating bracket multi-angular viewing equipment (Figure 2), which enables BRDF observation of the same object in a short time. The multi-angular viewing equipment was also used by Yan et al.[10] for the bidirectional canopy thermal infrared temperature measurement. The observation plane was the principal plane and the cross-principal plane. The view zenith changes from 0° to 65° at the intervals of 5°.

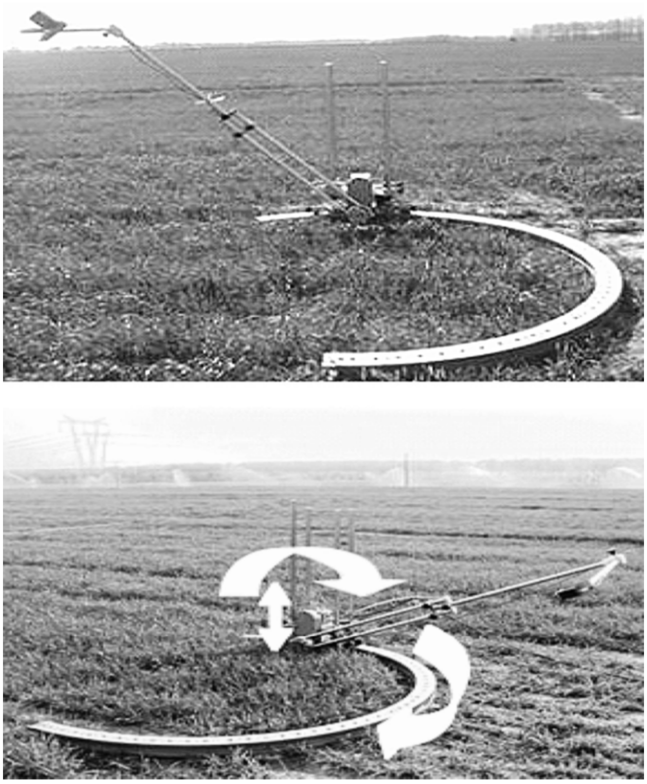

Figure 2 Rotating bracket for observing BRDF canopy reflectance

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 (Figure 3).

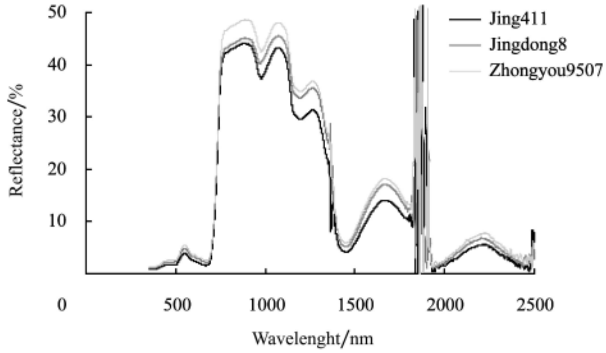

Figure 3 Canopy reflectance of different crop geometry varieties

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.[11] as follows:

$$NDVI = (NIR - R)/(NIR + R) \tag{2}$$

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 identification of different LAD wheat varieties.

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 Identification of 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 4). 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 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.

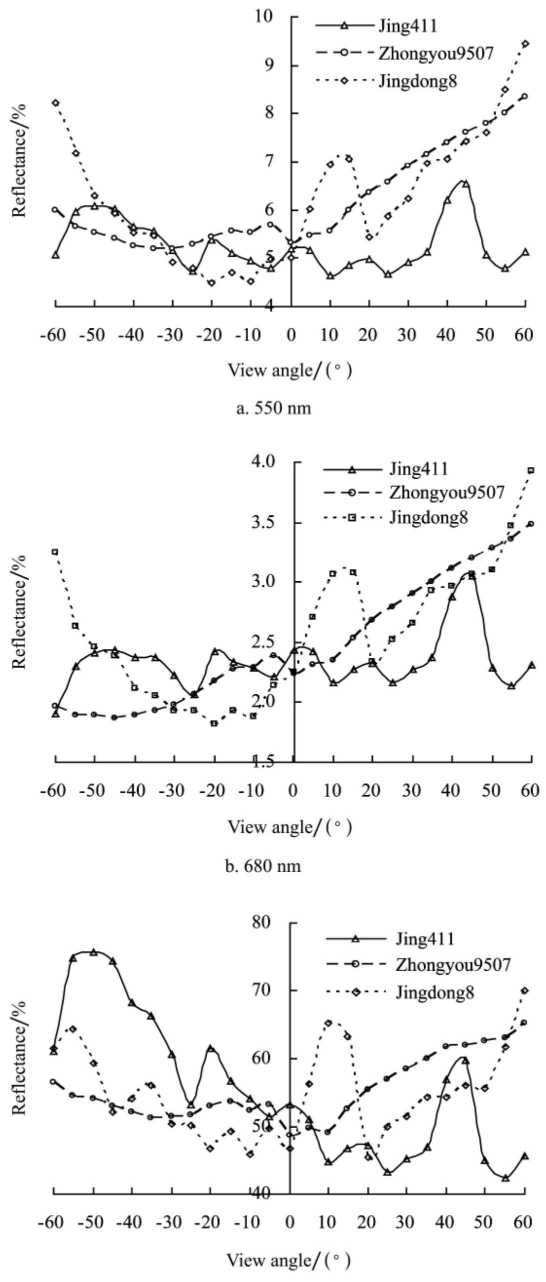

Figure 4 Bidirectional canopy reflectance at 550 nm, 680 nm and 1100 nm for different canopy geometry varieties

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 ground-truth 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.

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