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Identification of Wheat Canopy Structure Using Hyperspectral Data

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Abstract

Some winter wheat varieties were selected in this experiment. The results were as follows: 1) Leaf orientation value (LOV) and leaf area index (LAI) of wheat had different contributions to canopy spectral reflectance (CSR). For example, LOV affected greatly canopy spectra more than LAI did in jointing stage, but LAI had a greater effect on CSR than LOV did after the ground was near to be covered completely. 2) Twenty treatments including different varieties and densities were arranged in this experiment, and the result of cluster analysis showed that all these treatments can be parted into four clusters according to LAI and LOV: varieties with erect leaves and low LAI (denoted as A), varieties with erect leaves and high LAI (denoted as B), varieties with horizontal leaves and low LAI (denoted as C), varieties with horizontal leaves and high LAI (denoted as D). Their CSR had difference in 400-700 nm and 700-1 150 nm at jointing stage, especially in different plant types. 3) There was obvious distribution difference among different clusters in scatter plot (X=ΔR890, Y=R890), ΔR890 was the reflectance increment from jointing to booting stage. It was seen from the Y-axis direction that R890 of horizontal varieties were higher than the erect ones, and seen from the X-axis direction that the greater ΔR890 was, the lower LAI one within the same plant type varieties, which indicted that the combination of plant-type and the population magnitude can be initially identified by this method.

Key words: Winter wheat, Plant type, Canopy structure, Hyperspectral

INTRODUCTION

Researches in the past decades have shown that remote sensing technology offers a practical alternative to the complicated, slow and expensive chemical method for estimating foliar chemical concentration[1-3]. However, canopy spectral reflectance (CSR) measured by remote sensing technology are influenced by many factors such as leaf area index (LAI) and leaf orientation value(LOV)[4-6], which also affect population photosynthesis efficiency and crop yield[7-10]. It is very difficult to abstract the interested information from CSR and describe them quantificationally for the influences of canopy structure. However, There have been few studies on identifying wheat canopy structure (especially plant type) by hyperspectral remote sensing.

In this paper, the correlations between canopy spectral characteristic parameters and LAI, LOV were analyzed, and the CSR in different LAI and LOV were also discussed. The results of this study provide theoretic support for crop canopy structure information acquisition in large area by aviation and spaceflight remote sensing. Furthermore, it is useful for heightening the precision of plant chemical parameters accessing.

MATERIALS AND METHODS

Design of experiments

The experiment was conducted in the Experimental Sta-

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tion of the Institute of Crop Science, Chinese Academy of Agricultural Sciences (39° 57'55" N, 116° 19'46" E). The soil type was characterized as a silt clay loam with organic matter content 0.72%, alkali-hydrolysis nitrogen 36.7 μg mL^{-1}, rapidly available phosphorus 103.1 μg mL^{-1} and rapidly available potassium 145.9 μg mL^{-1} in 20 cm depth, which were determined by ASI method[11]. Moreover, 150 kg ha^{-1} pure nitrogen was also applied at jointing. The selected cultivars in this experiment were some winter wheat varieties with different plant types and approximate growing period, for example, CA0015, CA0045, CA9554, H3276, P7, J411 are with erect leaves, and ZY9507, ZY9844 are with horizontal leaves. The densities of those cultivars are 300 ten thousand plants per ha. Besides, J9428, JD8, DF9801 were arranged by 4 density levels for producing different populations, and they are 90, 180, 270, 360 ten thousand plants per ha, which denoted as J9428-1, J9428-2, J9428-3, J9428-4, JD8-1, JD8-2, JD8-3, JD8-4, DF9801-1, DF9801-2, DF9801-3 and DF9801-4, respectively. Plot area was 6 m × 2 m with two repeats.

Leaf orientation value measurement

Leaf orientation value (LOV) were measured with ruler and protractor and calculated by the Pepper formula as follows:

$$LOV = \sum_{i=1}^{n}\left[Q\left(l_f / l\right)\right] / n$$

In the formula, Q denoted the angle between leaf orientation and horizontal line (°), lf denoted the length from the highest point to basal point of leaf (cm), l denoted the whole leaf length (cm), and n was the measured leaf number.

Leaf area index measurement

Leaf area index (LAI) was measured by the dry weight method. Twenty leaves in one treatment were selected and cut 3 cm from the position where width of the leaf are consistent. Ranked 20 leaf segments with one line and measured the whole length, then calculated leaf area and measured dry weight, and finally, the whole area was calculated by combining with dry weight of all the leaves in a treatment.

Clustering analysis

Euclidean square method were selected in clustering analysis with SPSS statistical analysis software.

Spectral reflectance measurements

Spectral reflectance measurements was taken under clear sky conditions from 10:00 to 14:00 (Beijing local time) using an ASD-2500 spectrometer (Analytical Spectral Devices, Boulder, CO, USA) fitted with a 258 field of view fiber optics, operating in the 350-2 500 nm spectral region with a sampling interval of 1.4 nm between 350 and 1 050 nm, and 2 nm between 1 050 and 2 500 nm, and with spectral resolution of 3 nm at 700 nm, 10 nm at 1 400 nm. The reflected radiances measurement was taken by averaging 10 scans at an optimized integration time, with a dark current correction at every spectral measurement. A standard panel radiance measurement was taken with 25° field of view before and after the vegetation measurement by two scans each time. CSR was measured by the method that the sensor probe of the spectrometer was taken vertically from a height of 0.5 m above plants.

Spectral indices calculation

Spectral indices were calculated as the following formulas:

NDVI(1,2)=|(R1-R2)|/(R1+R2)

DVI(1,2) =|(R1-R2)|

In the formulas, R1 and R2 denoted the spectral reflectance in 1 and 2 band respectively.

RESULTS

Correlation analysis between spectral parameters and LOV, LAI

The correlation coefficients between spectral parameters and LOV, LAI were listed in the Table. Reflectance of 680 nm and normalized difference vegetation index NDVI [670,890] had significant correlation with LOV at initial jointing stage (8 April) in wheat, and the correlativity became weaken when the field was near to be covered completely (20 April). However, the correlation between spectral parameters and LAI became

Table Correlative coefficient between LOV, LAI and spectral characteristic parameters at different stages in wheat

Date	Canopy index	Spectral parameters						
		R550	R680	NDVI[670,890]	NDVI[890,980]	NDVI[920,980]	DVI[560-670]	DVI[560-450]
8 April	LOV	0.4830*	0.5999**	-0.5816**	-0.3616	-0.3423	-0.0546	0.3293
	LAI	-0.5516*	-0.5544*	0.3820	0.5396*	0.5262*	-0.1533	-0.4293
20 April	LOV	-0.1762	-0.0669	0.1992	-0.0175	0.0689	-0.2558	-0.2592
	LAI	-0.3672	-0.3755	0.3431	0.3283	0.3449	-0.3346	-0.3126
5 May	LOV	0.1685	0.1420	0.0622	0.1798	0.1252	0.1563	0.0835
	LAI	-0.5699*	-0.6061**	0.5348*	0.5058*	0.5224*	-0.4000	-0.3808

* and **denoted as significance at 0.05 and 0.01 level respectively.

stronger with the population expanding. LAI had significant correlativity with R550, R680, NDVI[670,890], NDVI[890,980] and NDVI[920,980] after tasselling out (5 May), but LOV was on the contrary, which indicated that LAI as well as LOV had different contribution to canopy spectra in different growing stages. The main reason was that the field vegetation cover degree was low and variously different in two kinds of plant types at jointing, which made LOV influence canopy spectra more variously. But, with the population expanding, LAI had more contribution to canopy spectra.

Clustering analysis of wheat canopy structure at jointing stage

By clustering analysis in terms of LAI and LOV at wheat jointing stage, 20 treatments could be divided into four groups when the different coefficient was 0.75. Four groups were respectively A-erect type and low LAI, B-erect type and high LAI, C-horizontal type and low LAI and D-horizontal type and high LAI (Fig.1). The vegetation coverage had obvious difference among treatments with different LAI and LOV before the field was not covered completely, which was the basis to identify plant type using canopy spectral reflectance.

Comparison of CSR in different canopy structures

It was shown in Fig.2 that CSR had obvious difference among different treatments. The CSR of cluster A with low LAI and erect leaves were obviously higher than that of other clusters in the range of 400-700 nm, and the trend of other three clusters was as follows: cluster B with high LAI and erect leaves>cluster C with low LAI and horizontal leaves>cluster D with high LAI and horizontal leaves. The range of 400-700 nm included the chlorophyll absorbed band, and the CSR related to canopy chlorophyll content (chlorophyll content per unit ground area). When their LAI were approximate, there was higher chlorophyll content per unit ground area in

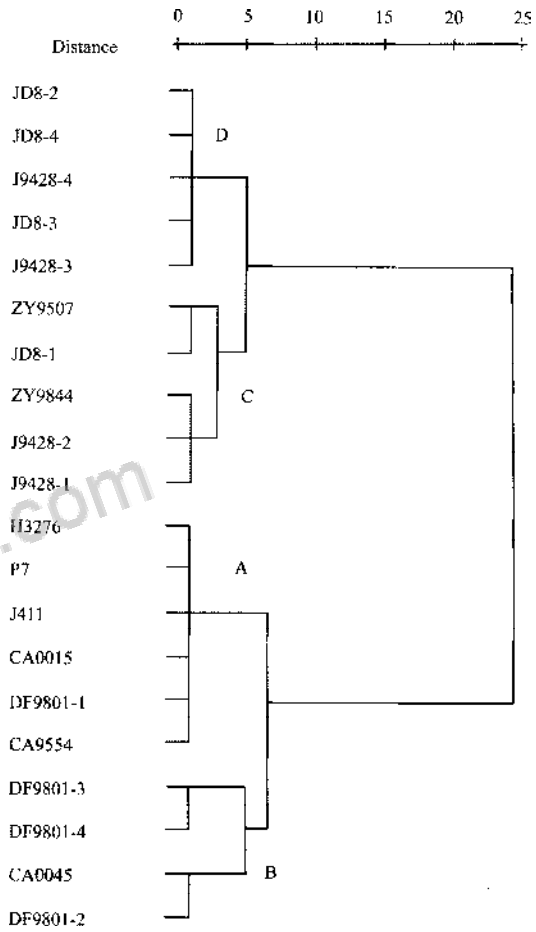

Fig. 1 Clustering analysis of wheat varieties with different LOV and LAI

varieties with horizontal leaves for their larger vegetation coverage, which resulted in absorbing more light and reflecting less light. The CSR orders of the four clusters in 700-1 150 nm region showed contrary to that in visible light region (400-700 nm). Varieties with high LAI and horizontal leaves had the highest CSR, but varieties with low LAI and erect leaves had the lowest CSR among the four clusters.

Identifying population canopy structure in wheat using CSR

Different population canopy structure of wheat could

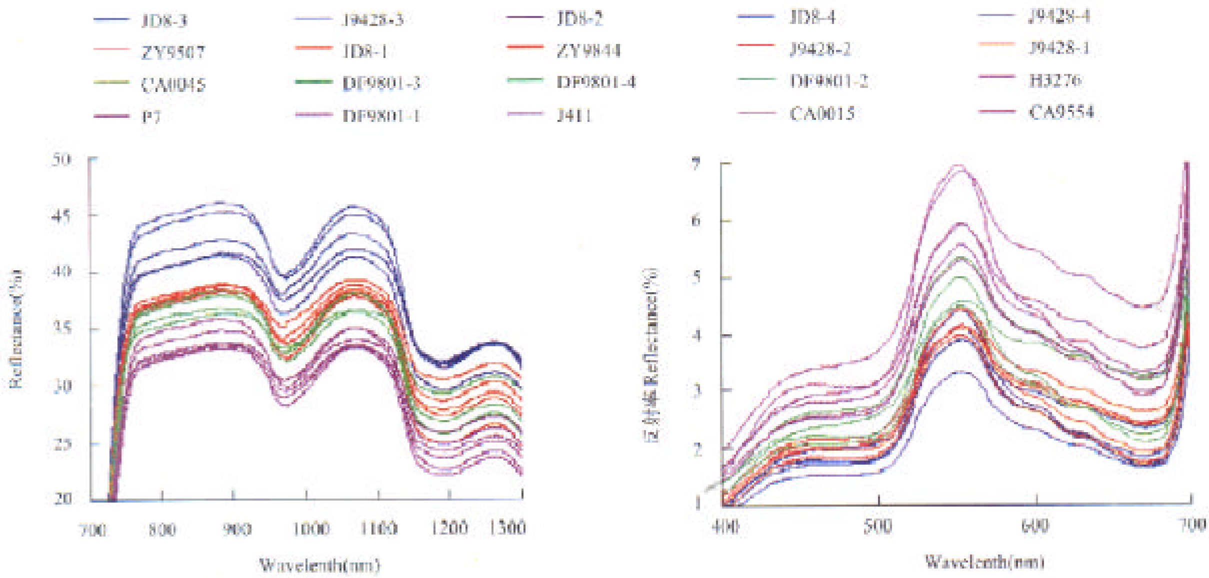

Fig. 2 Comparison of spectral reflectivity among different canopy-type treatments at jointing

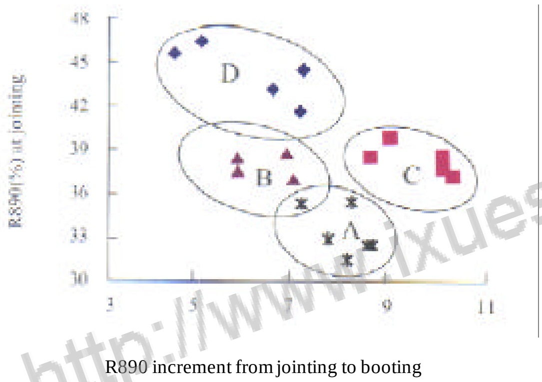

Fig. 3 Reflectance scatter distribution of different canopy types in wheat

be identified using CSR of different growing stage. The reflectance dispersion (ΔR890) denoted the increment of CSR from jointing stage to booting stage, which reflected the increasing speed of CSR in different plant-type varieties. Spectral reflectance at 890 nm (R890) of near infrared region was selected to make graph, in which R890 at jointing stage was Y-coordinate and the increment (ΔR890) was X-coordinate (Fig.3). Seen from Fig.3, there was obviously different distribution of the scatter points in different clusters. For example, seen from vertical orientation, R890 of horizontal varieties (changing from 38 to 46%) were higher than that of erect varieties (changing from 33 to 38%). Of the four clusters, R890 of cluster D with high LAI and horizontal leaves was the highest, and followed by cluster C, cluster B and cluster A. Seen from horizontal orientation, there was obvious difference in those clusters who had the same plant type but different population magnitude. When plant types were same, the clusters with low LAI had higher ΔR890 than that with high LAI. For example, the increment was 5.8-6.7% from jointing to booting stage in varieties with high LAI and erect leaves but 7.4-8.3% in varieties with low LAI and erect leaves. ΔR890 increased 7.9-8.9% in varieties with low LAI and horizontal leaves. The results indicated that varieties with low LAI had more advantages to expand vegetation coverage, so R890 of them increased fast. Besides, compared with erect varieties, cluster C with horizontal leaves showed the traits of horizontal variety, that was to say, their coverage increased faster than that of erect varieties when LAI was similar, which was the main reason for their high spectral reflectance at jointing stage. However, varieties with high LAI and horizontal leaves (cluster D) had low increments (only 4.3-6.3%), which related to their high vegetation coverage at jointing stage .

DISCUSSION

Hyperspectral remote sensing has been used widely in many fields such as recognizing and classifying vegetable type, measuring plant chemical components and so on[5]. However, canopy spectral reflectance measured by remote sensing technology are influenced by many factors, of which canopy structure is one of the main factors in estimating canopy physical and chemical parameters. Furthermore, leaf area and its extension orientation are two important parameters of canopy structure[12,13], which affect intercepting of photosynthetically active radiation and further influence on photosynthesis and yield. That acquiring crop canopy structure information timely is not only significant to such subjects as physiology, cultivation and breeding, but also important to heighten the precision of measuring plant chemical ingredients. Up to now, no report have existed on recognising wheat canopy structure using CSR combined with clustering analysis in terms of LAI and LOV. There was obvious difference between two plant types at jointing stage in winter wheat. So we arranged 20 treatments including different plant types and different densities and classified them through clustering analysis. The correlation between canopy spectral parameters and LOV, LAI was also discussed respectively. Before the field vegetation was near to be covered completely, the difference of vegetation coverage resulted in obvious difference of CSR. As for wheat, field was not covered completely and soil background produced more serious disturbance to CSR at jointing stage than at later stage. It indicated that jointing stage was also the best stage to identify plant type. Using CSR from jointing to booting stages, the different plant types and population magnitudes of the same plant type were initially realized. So the plant type disturbance was avoided and the precision was heightened when measuring crop physical and chemical parameters using ground-based, aviation or spaceflight remote sensing.

CONCLUSIONS

LOV as well as LAI had an effect in varying degrees on CSR at different growing stages. LOV had more contribution to CSR than LAI did for the obvious difference of vegetation coverage resulted from the difference of plant types. But with the population expanding, LAI had more great effect on CSR than LOV did, and the best stage to identify plant type was jointing stage when field was not near to be covered completely in wheat.

CSR was significantly different among varieties with different canopy structures. The CSR of the clusters with erect leaves was obviously higher than that with horizontal leaves in 400-700 nm region, but it was on the contrary in 700-1 150 nm region.

The different canopy structure varieties can be initially realized by using the canopy spectral reflectance from jointing to booting stage. In this paper, R890 at jointing stage and ΔR890 from jointing to booting stages showed difference in the scatter plot, which can be used to recognize different plant types and population magnitude of the same plant type.

Acknowledgements

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