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RESEARCH ARTICLE

The Preliminary Study on Spectral Response of Different Stresses in Winter Wheat

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The aim of this study was to discuss the spectral response of the wheat to different stresses between *in-situ* canopy reflectance and multiband satellite image reflectance. In the three critical growing stages of winter wheat, the field investigations and spectral measurements were conducted and the Landsat 5 TM images were also acquired synchronously to monitor winter wheat under conditions of stripe rust stress and water stress and normal condition. By the comparison of the reflectance between *in-situ* canopy and images within three treatments, it was concluded that the spectral response of stressed wheat and healthy wheat was consistent in field and satellite remote sensing among the three critical growing stages. The study will lay a theoretical basis on monitoring and identifying the stressed wheat in the large area.

Keywords: Spectral Response, Stress, Field Remote Sensing, Satellite Remote Sensing.

1. INTRODUCTION

Winter wheat (*Triticum aestivum L.*) is one of the most important crops in China, and it is planted in about ten provinces, such as He Bei, He Nan, Shan Xi, Gan Su, and so on.[1]

Stress is environmental condition which deviates from adaptive growth conditions greatly and can give rise of many changes and reactions in plant physiological level,[2] and the stresses can lead to the lose of the yield. So to identify the different stresses of wheat in real time was also of great importance for agricultural management and decision making. Fortunately, remote sensing technology provides a possible way to detect different stresses according to spectral characteristics. When the wheat suffered stresses, for example, drought stress, nutrition stress, pests and diseases stress, and so on, the cell viability, water content and [1]chlorophyll content of plants could all change and the spectra of wheat would be different.[3] It was reported that the healthy, vigorously growing plant leaves generally have three characteristics as following: (1) low reflectance at visible wavelengths (400–700 nm) owing to strong absorption by photoactive pigments (chloropgylls, anthocyanins, carotenoids); (2) high reflectance in the near infrared (700–1200 nm) because of multiple scattering at the air-cell interfaces in the leaf's internal tissue; (3) low reflectance in wide wavebands in the short-wave infrared (1200–2400 nm) because of absorption by water, proteins, and other carbon constituents.[4,5] So we can develop monitoring and distinguishing from stresses by remote sensing according to the spectral differences between healthy and stressed wheat.

In particular, a number of successful studies had focused on the detection and identification yellow rust by means of spectral measurements and analysis.[6–10] Yellow rust (*biotroph Puccinia striifoemis*) is a fungal disease of this crop that produces leaf lesion (pustules) that are yellow in color and tend to be grouped in patches. Huang et al. discovered that PRI respond sensitively to the physiological change of winter wheat plant caused by yellow rust. The results showed rather high estimated accuracy of Disease Index (DI) for both ground measurements by spectrometer and airborne hyperspectral images and the coefficient of determination (R^2) reached 0.97 and 0.91 respectively.[11] Disease spectral index which monitor wheat stripe rust was also developed successfully by analyzing multi-times hyperspectral aerial images and the spectral characteristics differences form diseased and health wheat.[12] Besides,

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the experience which compared spectral characteristics of wheat infected by stripe rust obtained from near-ground and fire-balloon was developed, and the result found that the reflectance data from fire-balloon were distinctively high than that from near-ground.[13] Luo et al. identified and separated yellow rust from the mixed types of stress via the feature space that constituted by Normalized difference vegetation index (NDVI) and Physiological reflectance index (PRI), and the accuracy was more than 70%.[14] Besides, the satellite imagery also showed great potential in monitoring winter wheat diseases like powdery mildew and other stresses.[15] However, it was slim and necessary to study the spectral response laws and characteristics of wheat under different stresses by field remote sensing platform and satellite remote sensing platform.

In the study, the healthy wheat and the wheat stressed by stripe rust, water was also monitored synchronously by hyper spectral and satellite remote sensing respectively in three different growth period of wheat. The study will be helpful to monitor and distinguish the stressed wheat by satellite remote sensing in a large scale.

2. MATERIALS AND METHODS

2.1. Experiment Field

The experiment field of the study was chosen in Tongzhou and Shunyi district of Beijing. By ground investigation constant, it concluded that the wheat of SY09 (mark which was the nine plot in Shunyi) was stressed by water; the wheat of TZ14 (mark which was the 14th plot in Tongzhou) was infected by stripe rust; and the wheat of TZ09 (mark which was the nine plot in Tongzhou) was healthy and growing well. The three plots which were managed using the same way were chosen as the representative plots in the study (Table I). In addition, each plot had a continuous wheat planted area of no less than 3 hm^2, which would guarantee the corresponding pixel was only constitute of winter wheat.

2.2. Satellite Remote Sensing Imagery Acquisition and Preprocessing

Three scenes TM images were acquired on the 10th April, the 26th April and the 12th May, 2007, corresponding to the jointing stage, booting stage and heading stage respectively, to monitor the different stresses of the winter wheat. Then, the images was developed a series of preprocess, including cutting, atmospheric correction and geometry correction. In making geometry correction, the photographic map of 1:10000 was used as base map to correct the image of the 10th April, and GPS measured was used as control point to ensure the precision of geometric correction within 1 pixel. Others images were corrected by the 10th April image as the base map.

The bands DN of Landsat TM were transformed as reflectance of images by the algorithms and parameters of Landsat user handbook. And the bands' reflectance of sampling point was obtained from reflectivity images.

Table I. Bhe basic information of the study plots.

ID	Description	Latitude	Longitude
SY09	Water stress	40° 7′	116° 44′
TZ09	Disease stress	39° 43′	116° 47′
TZ14	Healthy	39° 52′	116° 37′

2.3. Field Spectral Data Acquisition

In-situ canopy spectral reflectance measurements of the stressed plots, including SY09, TZ09 and TZ14, were acquired at the same time as the satellite remote sensing was carried out on the 10th, 26th April and the 12th May, respectively. Spectral reflectance measurements were recorded at a height of 1.6 m above ground by an ASD FieldSpec Pro spectrometer (Analytical Spectral Devices, Boulder, CO, USA) fitted with a 25° field of view fore-optic. Spectral acquired in the 350–2500 nm spectral region with a sampling interval of 1.4 nm between 350 nm and 1050 nm, and 2 nm between 1050 nm and 2500 nm. Measured irradiance was converted into reflectance by recording irradiance spectra also from a 0.4 m∗0.4 m $BaSO_4$ calibration panel. All irradiance measurements were recorded as an average of 20 individual measurements at an optimized integration time. All measurements were made under clear blue sky conditions between 10:00 h and 14:00 h (Bejing Local Time).

3. RESULTS

3.1. The Response of Field Hyperspectral of Stressed and Healthy Wheat

The *in-situ* canopy spectral reflectance curves of SY09, TZ14 and TZ09 were obtained in three different growth periods (Figs. 1(a–c)).

The spectral characteristics of SY10 had obvious differences during others which the reflectance was highest in the visible region and short wavelength infrared region while it was lowest in near infrared region than others, because population density of SY10 stressed by water was smaller than others (Figs. 1(a–c)). TZ14 had minor change compared with the control area (TZ09) in the first and second period while the reflectance in near infrared region was significantly lower and higher in visible region than the TZ09 in the third period when the wheat stripe rust was more serious. The result showed that the reflectance of control area was lower in visible region and higher in near infrared region than the wheat stressed by not only stripe rust but also water, it was because that the wheat stressed by water and stripe rust had significant changes in the

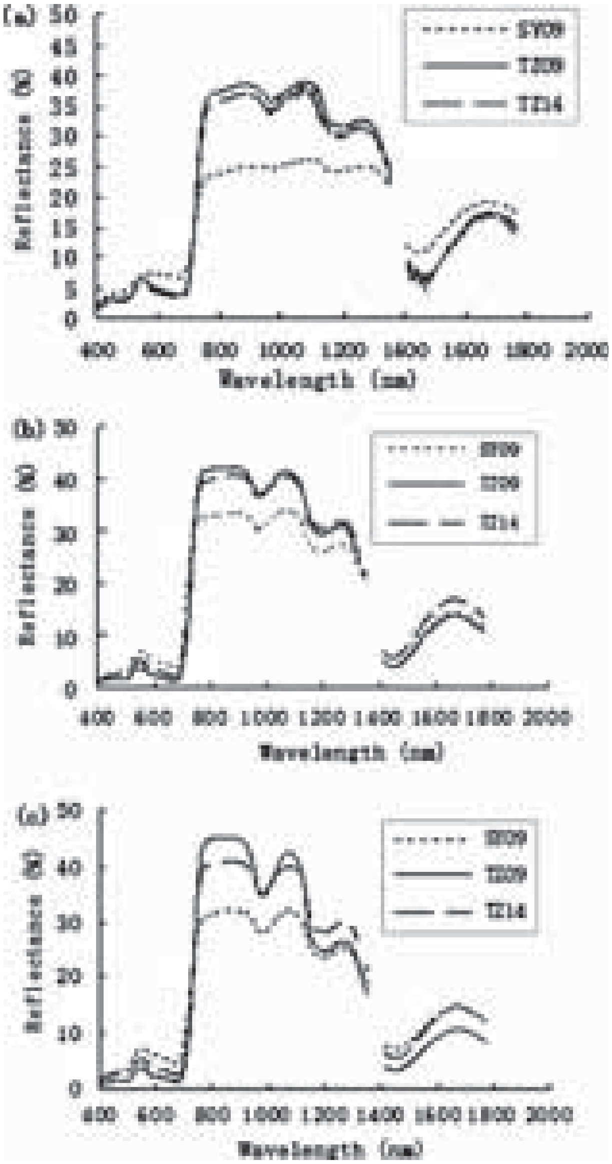

Fig. 1. The canopy reflectance spectrum in 3 study plots among different growth stages. ((a) April 10th; (b) April 26th, (c) May 12th.)

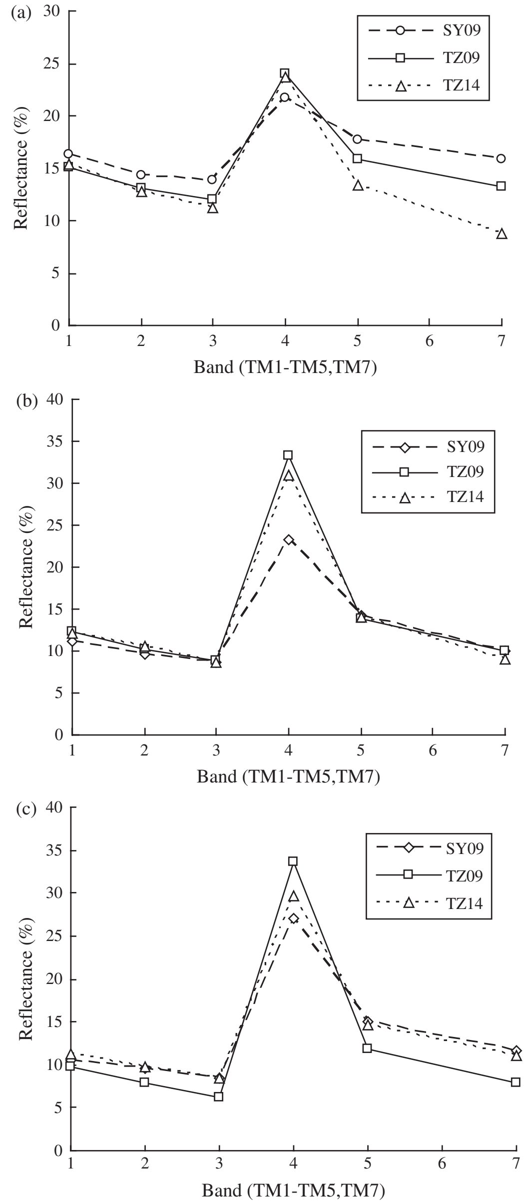

Fig. 2. The band reflectance of Landsat TM images in 3 study plots among different growth stages. ((a) April 10th; (b) April 26th, (c) May 12th.)

physiological and biochemical parameters compared with the control area, such as leaves became narrow and leaf area became small, chlorophyll content dropped, the proportion of leaf pigment content was changed, leaf sponge structure was damaged, and so on. Result, two absorption valleys had become not obvious in visible region, and peak had become low in near infrared region. In short, the spectral reflectance curve was leveled.

3.2. The Response of Satellite Remote Sensing of Stressed and Healthy Wheat

The Landsat TM image reflectances in different bands of SY09, TZ14 and TZ09 were obtained in three different growth period (Figs. 2(a–c)). Comparison with synchronous field spectral, the conclusions were as follows:

(1) The study had found that the aerial spectral reflectance was higher than field spectral reflectance in visible region,[10] Result showed that the spectral reflectance of satellite image was higher than field spectral reflectance in visible region while the result was opposite in near infrared region.

(2) In visible region (TM1, TM2, TM3), the image reflectance of healthy wheat was slightly less than stressed wheat while the image reflectance of healthy wheat was significant higher than the stressed wheat in near infrared region (band 4), which was consistent with the field hyperspectral response results.

Table II. Bands difference comparison between stressed wheat and healthy wheat in Landsat TM.

	DV					
Time	April 10th 2007		April 26th 2007		May 12th 2007	
Band	TZ09-SY09	TZ09-TZ14	TZ09-SY09	TZ09-TZ14	TZ09-SY09	TZ09-TZ14
TM1	−1	0	1	0	−1	−2
TM2	−1	0	1	0	−2	−2
TM3	−2	1	0	0	−2	−2
TM4	4	2	10	2	7	4
TM5	−2	3	0	0	−3	−3
TM7	−3	4	0	1	−4	−3

*DV = difference value.

(3) In three growth stages of winter wheat, the differences of Landsat TM image reflectance in six bands respectively between wheat stressed by water and stripe rust and healthy wheat were compared separately (Table II). Result showed that TM4 was the most sensitive band to stresses in Landsat 5 TM.

4. CONCLUSION

The study monitored the healthy wheat, stressed wheat by water and stripe rust synchronously by the field hyperspectral and satellite remote sensing in three difference growth stages. The aim was to research the spectral responses of stressed wheat in field platform and satellite platform. The result showed that the spectral responses characteristics of stressed wheat and healthy wheat in field were consistent with the satellite image in visible region and near infrared region. So the spectral data from satellite image could be used to identify the stressed wheat in large area combining with ground survey, which was of great significance to manage effectively the wheat planting areas and improve the quality and yield of wheat.

In three growth stages, the study found that the TM4 had the most significant change and was the most sensitive to stresses in winter wheat, so TM4 could be seen as the best band to identify and analyze the stressed wheat. Besides, result showed also that the reflectance of healthy wheat, wheat stressed by stripe rust and water decreased in order in near infrared region of field spectral as well as satellite image in three different stages. However, the study could not identify the wheat stressed by stripe and water quantitatively and qualitatively by satellite image because of lacking enough sampling. So it will be further research to identify the wheat stress by stripe rust and water by satellite remote sensing.

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