Field monitoring of wheat seedling stage with hyperspectral imaging

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Abstract: Nutrient elements such as chlorophyll, nitrogen and water at the seedling stage are important key factors that could influence growth, development and even the final yield of wheat. In this study, the spectral data of canopy and single wheat plant leaves at seedling stage were acquired in field by using ASD non-imaging hyperspectrometer and imaging spectrometer respectively to establish prediction models for monitoring the growth at the seedling stage of wheat. According to the comparative analysis of models results built through partial least square algorithm (PLS), it was found that the models built using spectral data of canopy based on ASD non-imaging hyperspectrometer and imaging spectrometer both had low precision, which was possibly caused by background such as soil; while the model established from single wheat plant leaves based on the imaging spectrometer had a better effect. At last, the PLS model was established for chlorophyll SPAD value of wheat seedling leaves based on imaging spectrometry and its correlation coefficient R reached 0.8836, and the correlation coefficient R of the relevant model for nitrogen content was 0.8520, suggesting that the superiority of location monitoring of growth at seedling stage of wheat based on hyperspectral imaging is significant.

Keywords: wheat seedling, monitoring, ASD, hyperspectral imaging, partial least squares
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1 Introduction

Nutrient elements such as chlorophyll, nitrogen and water at the seedling stage of wheat are the key factors that influencing wheat growth, development and even the final yield[1]. The deficiency of crop nutrient elements content will be reflected by the spectral characteristics of crop leaves. Therefore, it is necessary to develop a rapid, accurate and non-destructive technology of diagnosis and monitoring for nutrient elements such as nitrogen, chlorophyll and water at the seedling stage of wheat.

A high-resolution field spectrometer can be used to carry out a simple, rapid, non-destructive estimation for biochemical compositions of crop canopy, and it is paid more and more attention by agronomists[2]. Also, significant achievements have been made in the researches on nutrition monitoring of large-area crops[3]. Crop growth trend is greatly related to its nutritional status, which is influenced by the nutrient elements such as nitrogen, chlorophyll, water, etc., and the researches show that the reflectance of many crop leaves or canopy with the visual light wave band is increasing high because of the deficiency of nitrogen. According to the methods of spectroscopic assay and variable operation such as the ratio of near-infrared to infrared (NIR/Red), the wave bands which most sensitive to the change of crop nitrogen

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content are between 500 nm and 560 nm, and different levels of nitrogen are differentiated greatly[4]. After confirming the sensitive wave band of nitrogen in the field crop, to seek the relationships between spectral reflectance and nitrogen content or its biomass, researchers had established many models with a variety of statistical methods[5-7] for estimating the content of nitrogen in the crop. For example, to estimate biochemical concentrations (total chlorophyll, total nitrogen and total phosphorus) of canopy, Pu and Gong[8] used multivariate statistics methods and spectral derivative technology to evaluate the potential and efficiency of the data extracted from small airborne imaging spectrometer. Borge et al.[9] compared the relationship between various spectral indices and chlorophyll density of wheat canopy, and the results suggested that the predictive effect conducted from the model of Lagrange was good on red edge position under the lower density, while there was a better predictive effect with the model of second soil-adjusted vegetation index (SAVI2) under the higher density. To make precise geometric correction and reflectance conversion of total nitrogen content in ground wheat leaves for mapping of total nitrogen content finally, Zhang et al.[10] conducted a study on the estimation of nitrogen content in wheat leaves using aerial hyperspectral remote sensing image acquired from imaging spectrometer (OMIS) at the test base of Xiaotangshan in Beijing, and 43 spectral bands as the characteristic parameters were selected and designed with the methods of red-edge, spectral absorption characteristic analysis and stepwise regression algorithm. Wang et al.[11] established a good linear and positive correlation of the relative content of water in wheat leaves with characteristic absorption peaks reflectance of water near wavelength 1450 nm, which was feasible to quantitatively forecast water content in crop and monitor the condition of water deficiency. With the development of high-resolution remote sensing technology, crop nutrient monitoring based on hyperspectral remote sensing will greatly lead the development of precision agriculture. Wu et al.[12] established a model using hyperspectral data for estimation of chlorophyll density and leaf area index of crop leaves, the result showed that the estimation accuracy of chlorophyll and leaf area index respectively reached 80.6%, 63.0%. Jing et al.[13] studied the physiological reaction characteristics of winter wheat caused by nutrient stress through analyzing the correlation of spectral features and some parameters such as leaf chlorophyll content, leaf area index. So far, monitoring information of crop seedling growth by using remote sensing technology is usually influenced greatly by some factors such as soil background, canopy structure in practical applications, however, these background interference factors can be reduced with some methods, for example, the method of constructing vegetation index.

In this study, a nondestructive monitoring method was provided to predict wheat growth potential and trend of physiological ecology and wheat breeding using spectrum analysis technology and image processing technology through a large number of image blocks contained spectral information of consecutive wavelength. Therefore, through analyzing the correlation between the spectral information and nutritional information of the crop internal quality such as nitrogen, chlorophyll and leaves water content at the seedling stage of wheat, the hyperspectral imaging technology which integrated the image and the spectrum characteristics was used to realize the requirements of the wheat seedling growth monitoring.

2 Materials and methods

2.1 Experimental design

Growth monitoring experiments at the seedling stage of wheat were respectively conducted at Xiaotangshan National Demonstration Base of Precision Agriculture Research (Changping District, Beijing, 40.18°N, 116.45°E) and the experimental farm of Beijing Academy of Agriculture and Forestry Science (Beijing, 40.17°N, 116.533°E) in September 2010. Winter wheats to be tested were planted and managed with normal water and fertilizer method. In November 2011, hyperspectral data of wheat seedling stage were acquired in Xiaotangshan base by using ASD non-imaging field hyper-spectrometer (Analytical Spectral Devices, Inc.

USA). In the meanwhile, imaging hyperspectral data and ASD non-imaging hyperspectral data of group canopy and single wheat plant were acquired in March 2011 in Beijing Academy of Agriculture and Forestry Science. And then, laboratory measurement of physiological and biochemical indexes were conducted to monitor the comprehensive growth trend at the wheat seedling stage.

The experiments in field were carried out from 09:30 am to 15:00 pm on sunny calm days to acquire imaging and non-imaging spectral data. Planar array visible-near infrared imaging spectrometer (VNIR, The MS4100 high-resolution 3-CCD camera, Redlake Inc., San Diego, CA) was used, and it has the characteristics of high spectral resolution (2.8 nm), high spatial resolution (mm level), spectral range 400 nm to 1000 nm and spectral interval 2.4 nm. This VNIR was more portable with a rapid acquisition rate without moving the heavy rail compared to original push broom imaging spectrometer (PIS), which could be operated by a single person to acquire the imaging spectrometer data in field. Also, due to its convenience and rapid operation, it is very suitable for spectral data acquisition of wheat seedling stage in large fields, and the experimental device is shown in Figure 1. The parameters of non-imaging hyperspectrometer ASD included: spectral range was from 350 nm to 2500 nm, spectral resolution was calibrated 3 nm at near 700 nm wave band, 10 nm at both near 1400 nm and 2100 nm wave band respectively. The sample interval was calibrated 1.4 nm at wave range of 350 nm to 1000 nm, 2 nm at wave range of 1000 nm to 2500 nm respectively, and the viewing angle was 25°.

Figure 1 Experimental photos of acquiring spectral data at wheat seedling stage using VNIR

3 Results and discussion

3.1 Spectral Images of canopy and single plant leaves at the wheat seedling stage

Spectral imaging information of canopy and single plant of wheat varieties (Jingdong 12, Laizhou 3279, Zhou 16, CAO 175, Jin 70, Jing 9843, Nongda 3423, Jing 9428, Zhong 175, Jing 411, Nongda 211, Jingdong 17, Yannong 19, I-93, Jingdong 8, Zhongyou 206, Nongda 3291) at the seedling stage were acquired by spectral imaging VNIR, and RGB images under characteristic wavelengths of three primary colors of R, G and B (680 nm, 550 nm and 450 nm) were extracted from the original spectral images to reconstruct and obtain RGB image using remote sensing image processing software EVNI 4.4 (Exelis Visual Information Solutions, Inc. Pearl East Circle Boulder, CO, USA). Hyperspectral imaging effect of canopy and single wheat plant at seedling stage are shown in Figures 2a and 2b respectively, which suggests that spectral imaging could visually reflect the morphological information of wheat growth trend at seedling stage, and also the spectral differences of different leaf layers at different positions in canopy and single wheat plant could be observed from the effect of hyperspectral imaging.

a. Canopy

b. Single wheat plant

Figure 2 Hyperspectral images of canopy and single wheat plant

3.2 Comparative analysis between imaging and non-imaging spectra of canopy and single wheat plant

Wheat growth and development at seedling affect the final yield, quality and safety, and are always concerned by seedling vigor agronomists, breeders and biochemists. Former researchers have conducted a number of researches using ASD, for example, they constructed multiple inversion models at canopy and leaf scales to guide the crop growth situations, nutrients, plant disease, and water, etc.[14] Due to the characteristics of ASD such as high spectral resolution, portability and real time, it has been regarded as one of the standards of ground hyperspectrometer. Hyperspectral data of canopy and single wheat plant at seedling stage were acquired respectively by ASD non-imaging spectrometer and imaging spectrometer, and then to be converted into reflectance with Equation (1):

$$Ref_{object}=Rad_{object}/Rad_{whiteboard}\times Ref_{whiteboard}\times 100\% \quad (1)$$

where, Ref_{object} represents the spectral intensity data of the object obtained by whiteboard reflectance; Rad_{object} represents the radiance of object measured by spectrometer; $Rad_{whiteboard}$ represents the radiance of the whiteboard measured by spectrometer; $Ref_{whiteboard}$ represents the known reflectance ratio of whiteboard.

In addition, non-imaging hyperspectral data were processed by software ASD viewspecpro, imaging hyperspectral data were processed by remote sensing image processing software ENVI 4.4, and the relationships between various types of data were processed by software Origin 8.0 (Origin Lab. Origin Professional drawing software, USA). The processing results suggested that they were both presented a typical vegetation characteristic curve respectively obtained from ASD and imaging spectrometer, which are shown in Figure 3. At the same time, there were some differences among data, for the spectral curve obtained by imaging spectrometer, a significant peak appeared near wavelength 780 nm, and also there were obvious curve fluctuations, which were possibly caused by configuration of the system so that the noise was larger and could not be eliminated. According to comparison of spectral curve at 450 nm to 700 nm, reflectance value of imaging spectra was lower than that of ASD spectral curve. The possible reason was that the plant at the wheat seedling stage was weak, so that soil and other factors of background interference would significantly affect the spectra reflectance of wheat seedling, especially ASD was non-imaging spectrometer that not only acquired spectral information of canopy at the wheat seedling stage, but also acquired soil's spectral information simultaneously as raw data. Therefore, it was possible that spectral reflectance of wheat canopy at the seedling stage acquired by ASD non-imaging spectrometer was higher than that acquired by imaging spectrometer which could select the regions of interest of wheat seedling canopy as the original spectral values.

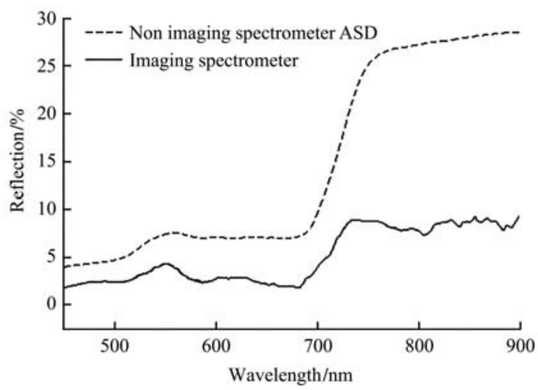

Figure 3 Comparative analysis of imaging and non-imaging spectra of wheat canopy at seedling stage

According to the above analysis results, ASD non-imaging spectrometer was more suitable for wheat later stage growth monitoring after multipoint acquisition. However, its shortcomings included: (1) due to non-imaging, spectral information of wheat canopy acquired was mixed, it would cause large interference of soil background with growth situation at the wheat seedling stage; (2) spectra information provided by ASD belonged to "point" data, which was difficult to analyze nutritional status of various local areas; (3) it could not detect spectral information at different layers of wheat. However, imaging spectrometer could carry out location analysis for canopy at the seedling stage, the result is shown in Figure 4. Therefore, imaging spectrometry was more suitable for data acquisition and processing analysis for growth monitoring at the wheat seedling stage. Subsequently, the relevant models were established by using hyperspectral reflectance of canopy and single wheat plant leaves acquired by ASD and imaging spectrometers VNIR at seedling stage respectively.

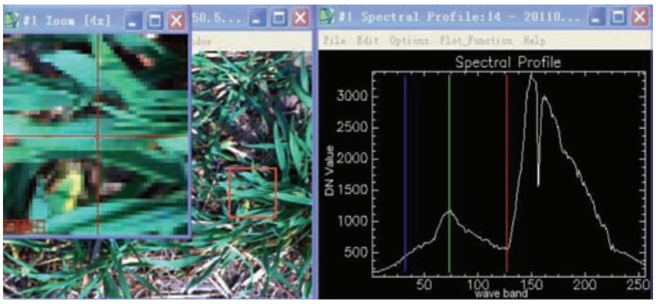

Figure 4 Hyperspectral data of wheat canopy at seedling stage acquired by imaging spectrometry

3.3 Comparative analysis of comprehensive growth monitoring of wheat at seedling stage

ASD hyperspectral data and VNIR imaging spectral data of canopy and single wheat plant leaves at seedling stage were respectively acquired and converted into reflectance. The relevant models were established using partial least square (PLS) algorithm in software Matlab 9.0 (Matrix Laboratory mathematical software, Inc. Math Works, USA) in the range of 450 nm to 900 nm wavelength which were selected based on the empirical method of comparative analysis. Modeling results (which are respectively shown in Table 1, Table 2 and Table 3) suggested that growth monitoring at the wheat seedling stage was disturbed greatly by background factors of soil, etc., and the models for acquired spectral data of canopy based on ASD non-imaging hyperspectrometer and the imaging spectrometer both had low precision, while the model established for single wheat leaves based on the imaging spectrometer had a better effect. Thirdly, correlation coefficient *R* of the PLS model established for chlorophyll SPAD value of single leaves based on imaging spectrometry could reach 0.8836, and correlation coefficient *R* of the relevant model established for nitrogen content was 0.8520.

Table 1 Modeling results of ASD spectra of canopy

Biochemical values	Number of factors	Correlation coefficient *R*	Corrected standard deviation	Predicted standard deviation	Relative percentage/%
SPAD value	1	0.6122	5.5616	1.0934	13.8076
Chlorophyll a	1	0.2433	0.2298	0.9022	13.2875
Chlorophyll b	1	0.2019	0.0843	1.0416	23.0892
Nitrogen content	1	0.2766	0.1795	1.0114	13.3295
Water content	1	0.4370	0.2457	1.2000	30.0407
Total dry weight	1	0.4370	0.4914	1.2000	30.0407

Table 2 Modeling results of imaging spectra of canopy

Biochemical values	Number of factors	Correlation coefficient *R*	Corrected standard deviation	Predicted standard deviation	Relative percentage/%
SPAD value	1	0.3027	6.7866	1.0272	14.4211
Chlorophyll a	1	0.4508	0.2115	0.7211	16.6264
Chlorophyll b	1	0.4452	0.0771	1.2226	19.6707
Nitrogen content	1	0.3147	0.1773	0.9392	14.4503
Water content	1	0.6790	0.2006	1.2522	29.8961
Total dry weight	1	0.6185	0.4239	1.4425	24.9911

Table 3 Modeling results of imaging spectra of single wheat leaves

Biochemical values	Number of factors	Correlation coefficient *R*	Corrected standard deviation	Predicted standard deviation	Relative percentage/%
SPAD value	6	0.8836	3.1955	1.4784	9.0961
Chlorophyll a	3	0.7072	0.1613	0.9877	13.4356
Chlorophyll b	2	0.5258	0.0709	1.0296	23.2844
Nitrogen content	3	0.8520	0.0823	1.1204	11.2820
Water content/	2	0.8510	8.1729	0.1897	11.7434
Total dry weight	2	0.6867	0.3525	1.3893	22.5752

4 Conclusions

In this study, spectral data of canopy and single wheat plant leaves were acquired simultaneously using ASD non-imaging hyperspectrometer and imaging spectrometer respectively to monitor the growth at the wheat seedling stage. For spectral data of canopy and single wheat plant leaves, the raw data were converted into the average spectral reflectance after denoised to establish the relevant model using PLS algorithm.

According to the comparative analysis of model results, it was found that the models of canopy established using spectral data of ASD non-imaging hyperspectrometer and imaging spectrometer both had low effect precision for the growth monitoring of wheat at seedling stage, which disturbed greatly by the background factors of soil, etc.; while the model result based on imaging spectrometer of the single wheat plant leaves had a better effect by using fixing location analysis of regions of interest for realizing the qualitative and positioning analysis. Finally, correlation coefficient *R* of the PLS model established for chlorophyll SPAD value of single wheat plant leaves based on imaging spectrometry could reach 0.8836, and correlation coefficient *R* of the relevant model for nitrogen content was 0.8520, which suggested that the superiority of location monitoring of growth at the wheat seedling stage based on hyperspectral imaging was significant.

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