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Spectral Characteristics Comparison of Two Summer Corn Cultivars under Different Fertilization Treatments

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Abstract This study is aimed to explore the spectrum reflection characteristics of summer corn leaves in different fertilization conditions. Using hyperspectral remote sensing technology, the experiments were conducted in fields to collect the hyperspectral images of Denghai 605 (DH605) and Ludan 981 (LD981) in different growth period under five fertilization treatments, and then the reflectance of corn ear leaves was extracted by ENVI software. The five fertilization treatments included the control (CK) with no fertilization, 40 kg and 30 kg of controlled-release fertilizer per 666.67 m^2 as base (K40 and K30), 50 kg and 40 kg of compound fertilizer per 666.67 m^2 as base with 15 kg urea as seed fertilizer (F50 + N and F40 + N). The reflectance spectrums of the two corn cultivars under different fertilization treatments showed the approximately same changing trend with a reflection peak at green band (550 nm) and a higher reflection platform at near infrared band (760 nm – 1050 nm). At the heading to filling stage, the reflectance of DH605 and LD981 was the highest under the CK, followed by the K30 and F40 + N respectively. At the filling to dough stage, the reflectance of DH605 and LD981 was the highest under the treatment K30 and F40 + N respectively, which was obviously higher than that of the other treatments. In the conditions of compound fertilizer, except the late filling stage, LD981 had little higher reflectance than DH605 at the other stages. In the conditions of controlled-release fertilizer and at dough to mature stage, LD981 had obviously higher reflectance compared to the other stages, and also higher than that of DH605; there was not obvious difference in reflectance LD981 and DH605 at the other stages.

Key words Fertilization, Summer corn, Ear leaf, Spectral reflectance, Spectral characteristics

1 Introduction

Corn is an important source of grain crop and feed. In China, corn is the third largest grain crop only second to rice and wheat, and it plays a very important role in promoting China's economic development and ensuring the grain security. Hyperspectral remote sensing is the frontier technology in the field of remote sensing. It uses many narrow (usually less than 10 nm) electromagnetic wave bands to obtain remote sensing data from the object of interest, so that the remote sensing can be expanded in the spectral dimension, and quantitative analysis of weak spectral differences can be directly made on ground objects. It shows great advantages in research and application of vegetation remote sensing[1] and has been widely applied in studies such as extraction of physiological and biochemical parameters of vegetation and the identification of plant types and status[2]. Hyperspectral remote sensing data can accurately reflect the spectral characteristics of field crops, while the spectral characteristics of crop leaves has a direct relationship with its growth[3]. Wang Shuwen *et al.* [4] studied hyperspectral images of corn canopy in frigid regions at different growth stages at different nitrogen levels, and found that there was significant difference in the reflectance of corn canopy in frigid regions at different nitrogen levels. Corn "red edge" had the phenomenon of double peak, the red edge showed redshift; according to corn canopy hyperspectral reflectance and red edge peak values, it was able to qualitatively differentiate serious shortage of nitrogen, normal application of nitrogen, and excessive application of nitrogen. According to studies of Chen Guoqing *et al.* [5], under different nitrogen fertilization treatments, there were significant differences in the canopy hyperspectral characteristics between super-high-yield summer corn and ordinary corn varieties; with the increase in nitrogen fertilizer, there was little change in the canopy hyperspectral reflectance and red edge position of super-high-yield summer corn, while the red edge area and the amplitude of red edge showed gradual increase. The research results of Guo Man *et al.* [6] also showed that there was a significant correlation between nitrogen nutrition level and leaf spectral reflectance in summer corn and it is feasible to use hyperspectral remote sensing data to monitor the nutritional status of summer corn in Guanzhong area. Tan Changwei *et al.* [7] measured the canopy reflectance spectra of field summer corn at different growth stages of two years. The results showed that the canopy reflectance spectra response of summer corn under different conditions showed certain rules; in the near infrared band, the reflectance value increased with the increase in the application of nitrogen fertilizer, especially in 750 nm – 1350 nm wave band, but in the visible light band, the reflectance value declined; with gradual increase in the obser-

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vation probe, the reflectance value dropped; with the increase in the weeds, the reflectance value gradually increased.

In sum, previous researches focus on the effects of different nitrogen treatments on the hyperspectral characteristics of corn leaves or canopy, while there are few reports about the effects of treatments with different controlled-release fertilizers and compound fertilizers on hyperspectral of summer corn leaves. Taking high efficient corn varieties Denghai 605 (DH605) and Ludan 981 (LD981) as experimental materials, we compared the spectral reflectance characteristics of corn ear leaves under different controlled-release fertilizers and compound fertilizer treatments, to provide theoretical support for estimating the fertilizer demand with hyperspectral data of crop and provide references for the next step of reasonable fertilization.

2 Materials and methods

2.1 Experimental materials and sample collection time The experimental summer corn cultivars were Denghai 605 (DH605, nitrogen high efficient) and Ludan 981 (LD981). The data collection time was August 11 (heading stage), August 20 (heading to filling stage), August 31 (late filling stage), September 7 (filling-to-dough stage), and September 17 (dough to mature stage).

2.2 Design of field experiment The experiment was conducted in the Linzi experimental field in Zibo of Shandong Province from June to October 2015. Five treatments were set: CK, control, no fertilization; K40, basal application of 40 kg controlled-release fertilizer per 666.7 m^2 (potassium sulfate, N-P_2O_5-K_2O was 28-5-9, total nutrient ≥42%, the same below); K30, basal application of 30 kg controlled-release fertilizer per 666.7 m^2; F50 + N, basal application of 50 kg compound fertilizer per 666.7 m^2 (N-P_2O_5-K_2O was 28-6-6, total nutrient ≥40%, the same below) and application of 15 kg urea at the time of sowing; F40 + N, basal application of 50 kg compound fertilizer per 666.7 m^2 and application of 15 kg urea at the time of sowing. Corn was planted in the same way of no-tillage direct seeding as the local area, about 4000 corn plants were cultivated in every 666.7 m^2 land. Other management measures were the same as in conventional field.

2.3 Hyperspectral data collection of corn ear leaves Hyperspectral data of corn leaves were measured using SOC710VP visible-near-infrared hyperspectral imaging type spectrometer (American Surface Optics Corporation) in the laboratory with controllable light conditions, the spectral range was 350 nm – 1050 nm, and the spectrum resolution was 4.6875 nm.

Cut about 20 cm of the middle part of ear leaves, wiped the surface clean; placed the single layer of leaves on the black test platform with the reflectance close to zero, pressed both ends with black plates to prevent warping upward; the field angle of spectrometer was 25 degrees, the probe was 0.30 m from the leaf to be measured, the probe should vertically face down to the middle of leaf to be measured. In order to eliminate external disturbances to ensure the accuracy, five ear leaves were taken for each treatment, and the average value was taken as the spectral reflectance of the treated leaves; during the measurement, white board was calibrated in time.

2.4 Preprocessing of hyperspectral data In order to eliminate the influence of disturbing factors in original spectral data on the model, we used SRAnal710 software to firstly calibrate hyperspectral image data obtained by SOC710 in three steps: spectral calibration, black point calibration, spatial and spectral radiation calibration; then, from the calibrated spectral data, we extracted the reflectance, and carried out smooth processing of collected original spectral data using five-point weighted smoothing method.

3 Results and analyses

3.1 Spectral reflectance characteristics of ear leaves of DH605 and LD981 under different fertilization treatments Under different fertilization treatments, the spectral curves of ear leaves at different growth stages were similar in the full wavelength range, and the changes were consistent with changes of spectral curves of typical plants[8,9], namely, the "green peak" with visible light band, red light valley, near-infrared plateau; the difference of spectral reflectance in visible light band was little, while the difference in near-infrared wave band was large (shown in Fig. 1 and Fig. 2). The obvious reflectance peak appeared at the green band (about 550 nm), the blue-violet band absorption peak appeared at the left of this peak (about 402 nm); in the right side, it moved along the long-wave direction and passed a red band absorption valley (about 685 nm); at 680 nm – 750 nm, the spectral reflectance increased sharply, showing steep sharp increase; after 750 nm, the spectral reflectance increased slowly and formed a higher reflection platform in the near-infrared band (>780 nm). In the visible light band, the reflectance of corn leaves mainly depends on the content of chlorophyll; the higher the content of chlorophyll, the higher the absorption rate, and the lower the reflectance; near-infrared spectral reflectance is generally affected by the internal cell structure of leaves, leaves of high chlorophyll content have complex cell structure, thus the reflectance is high. This is consistent with results of previous researches[10]. When the wavelength is greater than 900 nm, the spectral curve of corn is relatively undulating, because the range of this wavelength band is just located in the absorption band of atmospheric moisture, resulting in the decrease and irregularity of changes in the spectral reflectance[11].

At the heading to filling stage (Fig. 1), generally, the spectral reflectance of DH605 ear leaves was higher than LD981 under different treatments; at the filling-dough stage, under CK and K40 treatments, there was little difference in the spectral reflectance between DH605 and LD981 ear leaves; under K30 and F50 + N treatments, the spectral reflectance of DH605 ear leaves was higher than LD981; under F40 + N treatment, the spectral reflectance of DH605 ear leaves was lower than LD981, indicating that at the late stage of corn growth, different fertilization treatments had different effects on nitrogen high efficient and low efficient crops.

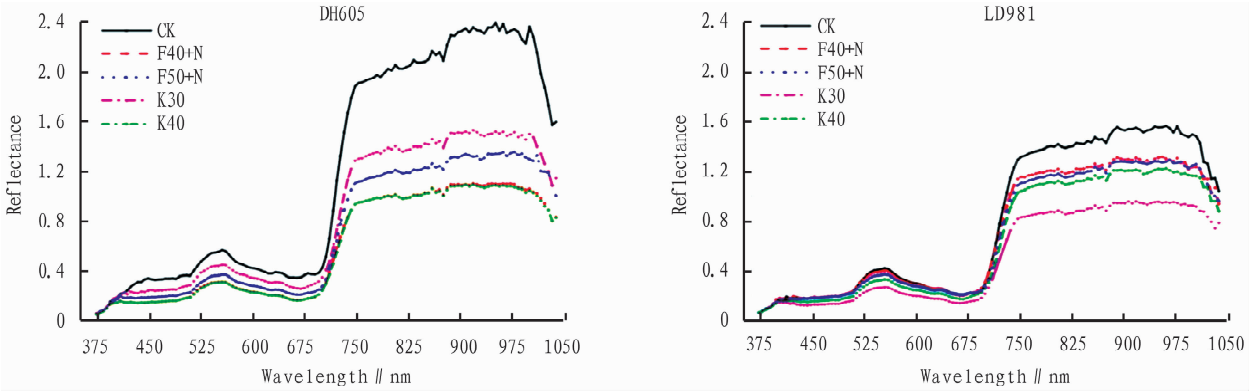

Fig. 1 Spectral reflectance of ear leaves at the heading to filling stage of corn under different fertilization treatments

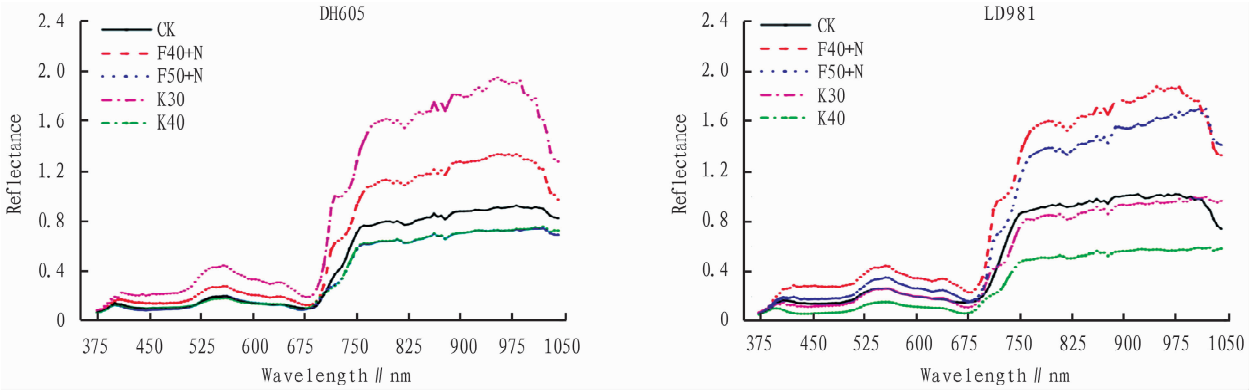

Fig. 2 Spectral reflectance of ear leaves at the filling to dough stage of corn under different fertilization treatments

3.2 Effects of compound fertilizer and controlled-release fertilizer on the hyperspectral reflectance of ear leaves of summer corn cultivars The average values of spectral reflectance of compound fertilizer and controlled-release fertilizer were taken, to analyze the effects of different fertilizers on the hyperspectral reflectance of the leaves of two corn cultivars. As shown in Fig. 3 and Fig. 4, under the compound fertilizer treatment, the spectral reflectance of DH605 was the highest at the dough to mature stage in the near-infrared band (760 nm – 1050 nm), the next was heading to filling stage, filling to dough stage, heading stage, and filling stage; in the visible light band (380 nm – 760 nm), changes in the spectral reflectance were basically consistent with the near-infrared band, but the reflectance at filling to dough stage, heading stage, and late filling stage was coincident in most bands, indicating there was basically no difference between three stages. Under the controlled-release condition, the spectral reflectance of DH605 greatly declined in all bands except at dough to mature stage, and it was significantly lower than other four stages; the changes in spectral reflectance of the rest stages were basically the same as that treated by compound fertilizer.

Under the compound fertilizer treatment, the spectral reflectance of LD981 was the highest at the dough to mature stage in the near-infrared band (760 nm – 1050 nm), it was the lowest at the late filling stage, which was the same as the reflectance of DH605, the next was filling to dough stage, heading to filling stage, and heading stage, slightly different from DH605, possibly because the growth and development time of two corn cultivars was slightly different. Under the controlled-release fertilizer treatment, the spectral reflectance of LD981 at the dough to mature stage was much higher than the same cultivars at other stages, because LD981 belonged to early and medium mature corn cultivars. At the late stage of growth, nutrients mainly supplied corn fruits, leaves became yellow, chlorophyll of leaves dropped, and absorption rate declined, leading to high reflectance. The spectral reflectance of ear leaves of LD981 was much higher than that of DH605 at the dough to mature stage, largely because the mature time of two cultivars was different. DH605 belonged to medium and late mature corn cultivar, LD981 belonged to early and medium mature corn cultivar. At the same growth time node, the chlorophyll content of leaves of DH605 was higher than that of LD981, leading to high reflectance of DH605 leaves and lower spectral reflectance.

4 Conclusions and discussions

(i) The reflectance spectrums of the two corn cultivars under different fertilization treatments showed the approximately same changing trend with a reflection peak at green band (550 nm) and a higher reflection platform at near infrared band (760 nm – 1050 nm). (ii) Under different fertilizer treatment, at the early stage of growth (heading to filling stage), the spectral reflectance of DH605 ear leaves was higher than LD981, it was more obvious after the wavelength of 750 nm; at the late stage of growth (filling to mature stage), there was little difference in the spectral reflectance between DH605 and LD981. (iii) Under the conditions of compound fertilizer, except the late filling stage, LD981 had little higher reflectance

than DH605 at the other stages. In the conditions of controlled-release fertilizer and at dough to mature stage, LD981 had obviously higher reflectance compared to the other stages, and also higher than that of DH605; there was not obvious difference in reflectance LD981 and DH605 at the other stages. The difference between the two cultivars may mainly be related to the difference of the canopy structure and the mature stage. (iv) For the same cultivar, the spectral reflectance of DH605F was obviously higher than that of DH605K, and the spectral reflectance of LD981F and LD981K was slightly different. The experiment showed certain rules, which provide the basis and data for further utilizing the hyperspectral remote sensing data to study the nutritional status of summer corn.

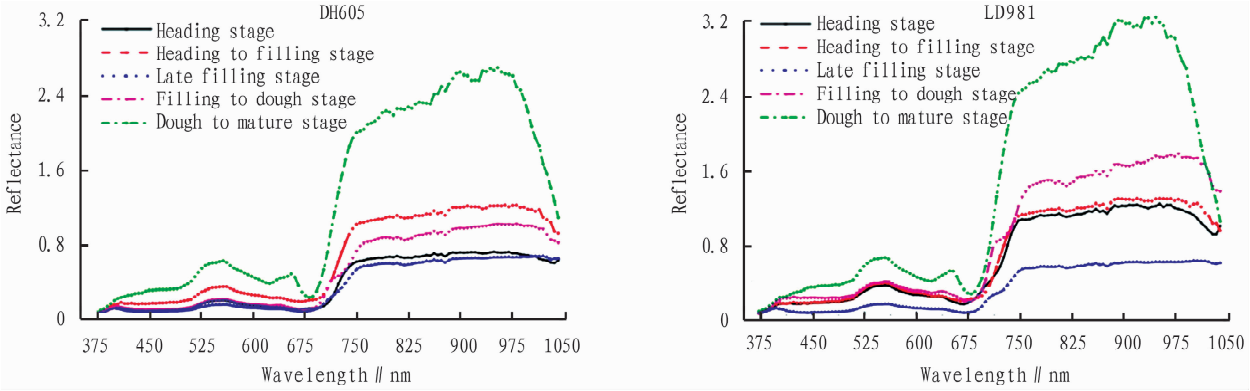

Fig. 3 Spectral reflectance characteristics of DH605 and LD981 at different growth stages under compound fertilizer treatment

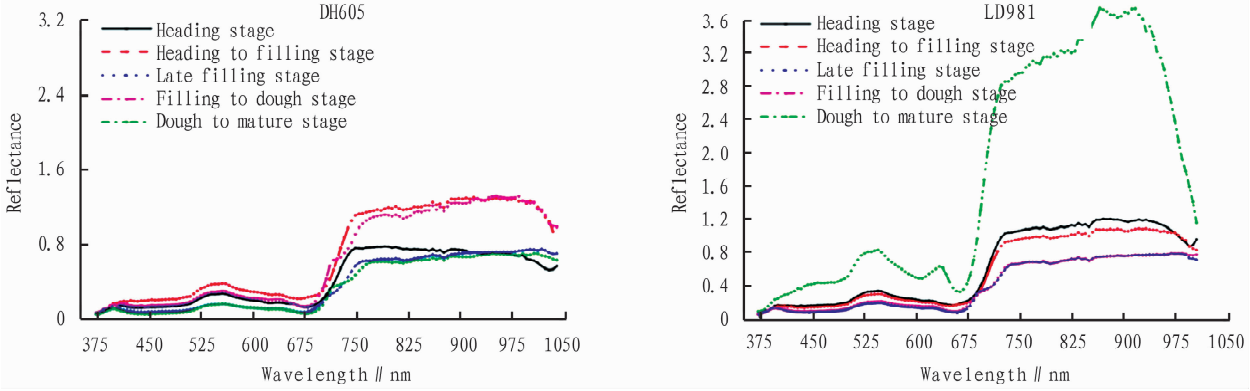

Fig. 4 Spectral reflectance characteristics of DH605 and LD981 at different growth stages under controlled-release fertilizer treatment

However, the conclusions of this study can not fully reveal the mechanism and rules of spectral changes of summer corn under different fertilization levels because of the natural factors such as season, soil and climate, and human factors such as cultivation techniques and management. The spectral information of corn leaves will vary slightly. Therefore, to fully reveal the spectral characteristics of summer corn under different fertilization levels, it is necessary to carry out further researches and verifications.

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