DEVELOPING AN APHID DAMAGE HYPERSPECTRAL INDEX FOR DETECTING APHID (HEMIPTERA: APHIDIDAE) DAMAGE LEVELS IN WINTER WHEAT

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ABSTRACT

Aphid (*Hemiptera: Aphididae*) appears in wheat planting area of China almost every year and have had significant economic impacts on wheat yield. As a result, large amounts of insecticides are used to control aphid populations, which may cause environmental pollution. Therefore, remote sensing as a repeatable and rapid method is necessary for monitoring aphid damage level. The study analyzed the hyperspectral characteristics of wheat infested by several aphid damage levels and selected out the sensitive bands to aphid damage levels, and the aphid damage hyperspectral index (ADHI) was developed based on the most sensitive bands to aphid damage levels in the visible, near-infrared and short-wave infrared regions. The results indicated that ADHI exhibited a high correlation with aphid damage levels (R^2=0.839), so it had the potential to detect wheat damage caused by aphid.

Index Terms—Winter wheat, Aphid, Damage Levels, Hyperspectral index, Sensitive Band

1. INTRODUCTION

Aphid (*Hemiptera: Aphididae*) is considered as one of the most destructive insects which appears almost every year in the main planting area of winter wheat in China[1]. Aphid can cause economic damage to plant crops as a result of its direct feeding activity. In high enough densities it can remove plant nutrients which can potentially cause a reduction in the number of heads, the number of gains per head, and a reduced seed weight [2]. Indirect damage can be caused by excretion of honeydew, and as a vector for viruses, most notably two strains of the Luteovirus Barley Yellow Dwarf Virus (BYDV-MAV and BYDV-PAV)[3]. Besides, large amounts of insecticides are used to control aphid populations, which may cause environment pollution. Therefore, monitoring and detecting aphids in a repeatable and rapid method and the subsequent use of this information to facilitate timely avoidance strategies are critical to enhancing wheat yield.

Remote sensing has been proven to have potential for detecting the changes caused by stress. Many researches [4, 5] have reported that plants under stress display a decrease in canopy reflectance in the lower portion of the near-infrared band, a reduced red absorption in the chlorophyll active band, and a consequent shift of the red edge. Besides reflectance, various vegetation indices have also have been used in crop stress detection, such as ratio vegetation index (RVI)[6], atmospherically resistant vegetation index (ARVI)[7], water band index(WBI) [8], yellowness index(YI)[9], and so on. Until now, there have been a large number of studies on aphid infestation. Riedell and Blackmer found that reflectance at wavelengths ranging between 625-635nm, 680-696nm and the normalized total pigment to chlorophyll index, were good indicators of chlorophyll loss and leaf senescence caused by Greenburg infestation [10]. Mirik et al. developed the Aphid index (AI) and damage sensitive spectral index 2 (DSSI2) to quantify Greenburg density and damage to wheat, respectively. However, most of the studies on aphid infestation are conducted in greenhouse and in the initial stage of aphid [11, 12]. Yang et al detect stress in wheat caused by greenbug infestation using ground-based multispectral radiometry, and it was concluded that the band centered at 694nm and the vegetation indices derived from bands centered at 800nm and 694nm were identified as most sensitive to damage due to greenbug infestation [13].

The study aimed to identify spectral characteristics and selected out sensitive bands to stress in wheat induced by aphid infestation at canopy scale in the filling stage of wheat. Furthermore, this study tried to develop an aphid damage hyperspectral index (ADHI) based on sensitive bands for detecting aphid damage levels at wheat canopy scale in the filling stage of wheat.

2. MATERIALS AND METHODS

2.1 Field experiments and field inventory

The field experiment plot is located at Xiaotangshan Precision Agriculture Experiment Base, in Changping District, Beijing (40º10.6'N, 116º26.3'E). The experimental field is about 250 m in length and 80 m in width. The winter wheat of study area was planted approximately on Oct 3, 2009, and harvested on June 25, 2010. Field inventory was conducted on June 7, 2010 when wheat was in the filling stage. 25 ground investigations including different aphid damage levels were collected. Aphid damage levels were surveyed according to the investigation rule [12].

2.2 canopy spectral measurements

In each investigation point, an area ($1m^2$) was selected for canopy spectral reflectance measurement. Canopy spectral reflectance was measured at a high of 1.3m above ground, under clear sky condition 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 350-2500nm spectral region with a sampling interval of 1.4 nm between 350 and 1050 nm, 2nm between 1050 and 2500 nm, and with spectral resolution of 3 nm at 700nm and 10 nm at 1400 nm as well as 2100 nm, A BaSO4 calibration panel (0.4 m × 0.4 m) was used for calculating the black and baseline reflectance. Vegetation reflectance measurements were taken by averaging 20 scans at optimized integration time, with a dark current correction at each spectral measurement. Calibration panel reflectance measurements were taken before and after canopy spectral measurement.

3. RESULTS

3.1 Spectral characteristics of wheat infested with aphid

By comparing the canopy spectral differences between aphid-infested and healthy wheat, it indicated that canopy reflectance gradually decreased in the range from 350 nm to 1750 nm, especially in the near infrared region (Fig.1). The result was not consistent with previous researches [14] that the stressed wheat had higher reflectance in visible bands than the healthy wheat because the photoactive pigments (chlorophylls, anthocyanins, carotenoids) were destroyed. The reason was that aphid occurred in the filling stage of wheat, and the honeydew excreted by aphid absorbed dust or others from surrounding environment and the leaf got dirty and little black, so the absorption in the visible bands became strong but not weak.

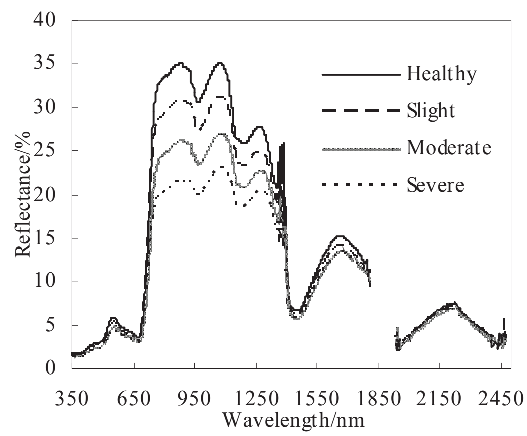

Fig.1. The spectral reflectance of healthy wheat and wheat infested by various aphid damage levels. (Healthy: the average spectra of healthy wheat samples; Slight: the average spectra of aphid damage level 1and 2; Moderate: he average spectra of aphid damage level 3and 4; Severe: he average spectra of aphid damage level 5 and 6)

3.2 Sensitive band selection of aphid infestation

The sensitive bands were selected out by correlation analysis between reflectance and aphid damage levels, which lied in the range from 400 nm to 690 nm, from 700 to 1300 nm and between 1500 and 1800 nm. The most sensitive bands to aphid were 551 nm (R^2=0.741) in the visible region, 823 nm (R^2=0.865) in the near-infrared (NIR) region and 1654 nm in the short-wave infrared (SWIR) region (R^2=0.668), respectively (Fig. 2).

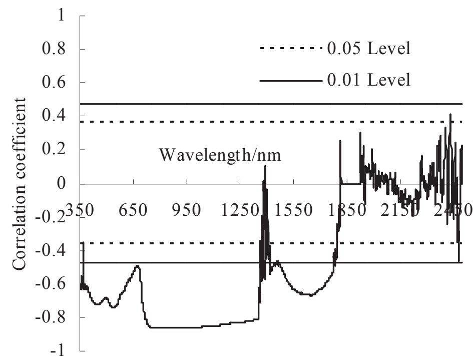

Fig. 2 Correlation coefficient between reflectance and aphid damage levels

3.3 ADHI

ADHI was established based on the most sensitive bands from hyperspectral data in the visible, NIR and SWIR regions and weight coefficients were calculated according to the change rate of reflectance between healthy and aphid-infected wheat, respectively (Fig .3).

$$ADHI = 0.32 \times \frac{R551_{normal} - R551_{infested}}{R551_{normal}} + 0.51 \times \frac{R823_{normal} - R823_{infested}}{R823_{normal}} + 0.17 \times \frac{R1654_{normal} - R1654_{infested}}{R1654_{normal}}$$

where $R551_{normal}$, $R823_{normal}$ and $R1654_{normal}$ are the reflectance at 551nm, 823nm and 1654nm of healthy wheat, $R551_{infested}$, $R823_{infested}$, $R1654_{infested}$ are the reflectance at 551 nm, 823 nm and 1654 nm of aphid-infected wheat, and 0.32, 0.51 and 0.17 are weight coefficients calculated by the contribution to change rates.

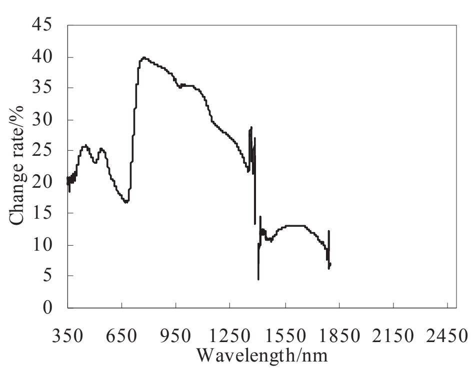

Fig.3 The change rate between healthy wheat and severe damaged wheat by aphid

Further more, the correlation analysis was conducted between ADHI and aphid damage levels from 25 investigation points (Fig. 4). It was concluded that ADHI exhibited a significant correlation with aphid damage levels (R^2=0.839). Therefore, ADHI was a important index to estimate aphid damage levels in winter wheat.

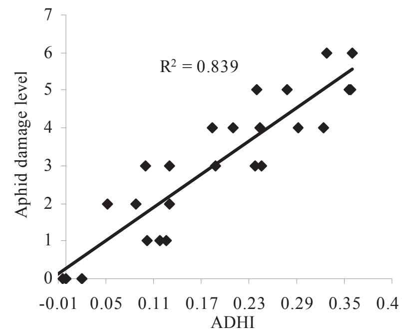

Fig.4 The correlation between ADHI and aphid damage levels

4. CONCLUSION AND DISCUSSION

Hyperspectral remote sensing has undertaken rapid development over the past two decades and there is a trend towards the usage of hyperspectral images in the remote sensing applications for precision agriculture [13]. The study analyzed the spectral characteristics of wheat infested by aphid and selected out the sensitive bands to aphid damage levels, then an ADHI was developed using the most sensitive bands in the visible, NIR and SWIR regions. The result showed that the reflectance of wheat infested by aphid was higher in the visible, NIR and SWIR regions than healthy wheat, and 523nm, 823nm and 1650nm were the most sensitive bands in visible, NIR and SWIR regions, respectively. It was concluded that ADHI was a sensitive index to aphid damage levels, and it could retrieve the aphid damage levels in the filling stage of wheat.

Crop growth is very dynamic, so monitoring the condition of agricultural corps is a complex issue. Therefore, it was possible that wheat damage symptoms caused by aphids and response of canopy reflectance was different in different growth stages. In the study, it was lower for the reflectance of wheat infested by aphid than that of healthy wheat in the filling stage of wheat because of honeydew excreted by aphid was not consistent with previous studies in the early detection of aphid infestation. So, whether the ADHI could retrieve aphid damage levels in other growth stages of wheat should be verified by the further experiments.

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