Inversion of Biochemical Parameters by Selection of Proper Vegetation Index in Winter Wheat

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Abstract

Recent studies have demonstrated the application of vegetation indices from canopy reflected spectrum for inversion of chlorophyll concentration. Some indices are both response to variations of vegetation and environmental factors. Canopy chlorophyll concentration, an indicator of photosynthesis activity, is related to nitrogen concentration in green vegetation and serves as an indicator of the crop response to soil nitrogen fertilizer application. The combination of normalized difference vegetation index (NDVI) and photochemical reflectance index (PRI) can reduce the effect of leaf area index (LAI) and soil background. The canopy chlorophyll inversion index (CCII) was proved to be sensitive to chlorophyll concentration and very resistant to the other variations. This paper introduced the ratio of TCARI/OSAVI to make accurate predictions of winter wheat chlorophyll concentration under different cultivars. It indicated that canopy chlorophyll concentration could be evaluated by some combined vegetation indices.

Key words: Winter wheat,Canopy reflected spectrum,Structure Insensitive Vegetation Index,Chlorophyll concentration

Introduction

Farmers, agricultural managers and grain processing enterprises are interested in measuring and assessing soil and crop status in order to apply adequate fertilizer quantities to crop growth, and thereafter, for health monitoring, yield and grain quality forecasting during an advanced development stage of crop. Inversion of crop growth dynamic information in canopy by traditional field sampling method is time-consuming and difficult to make for wide regional and global studies. It's highly desirable to develop new techniques to overcome the limitations of traditional field sampling methods. For this purpose hyperspectral remote sensing can play a vital role in providing time-specific and time-critical information for precision farming, due to their capabilities in measuring canopy nitrogen variability. The application of remote sensing techniques to study

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and/or evaluate canopy chlorophyll concentration is a better way (Card et al[1]).

The winter wheat canopy reflected spectrum are the mixed spectrum in view of the sensor, which are affected by wheat canopy (leaf area index and leaf angle distribution, leaf water content, mineral deficiencies, parasitic attacks, and so on), soil (soil properties, soil illumination), weeds (weed species, amounts), environment and their interactions. When we studied the canopy chlorophyll concentration by canopy reflected spectrum, we should try to minimize the effects of the other effective factors by proper methods.

Leaf area index (LAI) plays an important role in canopy reflected spectrum, the dynamical change of LAI can be used to assess crop growth state and environment stress. But as we all know that the dynamical change of LAI was lagged compared with chlorophyll concentration. When the LAI was sharply descended by the environmental stress, the effective remediation measures are feeble. On the other hand,there hane a lot of reasons for, decline of LAI i.e.,the ecological environmental factors (drought, waterlogging), fertilizer deficiency (nitrogen, phosphorus, potassium fertilizer), disease infection and insect pest immigration could result in LAI decline. So it is more important to monitor canopy chlorophyll concentration dynamical change than that of LAI.

Several methods for estimating canopy chlorophyll concentration with remote sensing are being investigated. These methods, including empirical equations and empirical models, relate spectral reflectance measurements to chlorophyll concentration. Models describing at the canopy level have demonstrated nonlinear mixing effects canopy reflected spectrum (Borel and Gerstl[3]). Many studies have suggested that empirical estimates of canopy chlorophyll concentration based on remote spectroscopic measurements may be possible (e.g.,Card et al[1], Curran[2]). These studies used stepwise multiple linear regressions to predict canopy chlorophyll concentration from derivative reflected spectrum. Different studies and experiments demonstrated the usefulness and feasibility to estimate canopy chlorophyll concentration using empirical regression equations (Fourty et al.[4],Ganapol[5] et al.,Borel and Gerstl[3]). A number of studies have also demonstrated relationships between canopy chlorophyll concentration and ratios of narrow-band reflectance in the visible and “red-edge” wave bands (Penuelas et al[6].1995). However, these studies have mostly focused on the chlorophylls (Yoder et al[7], Blackburn[8,9] , Daughtry et al[10]). Some approaches applied spectral reflectance measurements with different nitrogen treatments in corn and wheat (Blackmer et al[11]).

As stated above, the inversion accuracy of canopy chlorophyll concentration from canopy reflected spectrum is not goodenough. When we study canopy chlorophyll concentration by canopy reflected spectrum, the influence of LAI should to be eliminated, in order to improve the inversion accuracy.

Materials and Methods

Experiment design

Experimental site The experiment was conducted at Beijing Xiaotangshan Precision Agriculture Experimental Base, in Changping district, Beijing (40° 10.6N,116°26.3´E) from the year of 2001 - 2002 and 2002 - 2003. The site is at the worm temperate zone with a mean annual rainfall of 507.7 mm and a mean annual temperate of 13¡æ.

Soils Wheat was planted in a silt clay loam soil, the nutrients in 0-0.30 m soil depth were as follows: the organic matter 1.42-1.48%, total nitrogen 0.08-0.10%, alkali-hydrolysis nitrogen 58.6-68.0 mg kg^{-1}, available phosphorus 20.1-55.4 mg kg^{-1}, and rapidly available potassium 117.6-129.1 mg kg^{-1}.

Cultivar Three tested cultivars of selected winter wheat were Zhongyou9507, Jing9428 and Jingdong8, which are the main cultivars in

North China.

Treatments The three tested cultivars were under different irrigation and soil nitrogen treatments; all the 48 plots were situated in a big and flat cropland. For each cultivar, there are 4 levels of irrigation treatments and 4 levels of fertilizer nitrogen treatments. The 4 levels water irrigation treatments were W0 without any irrigation, W1 with 0.023 m^3 m^{-2}(scanty irrigated), W2 with 0.046 m^3 m^{-2} (rationally irrigated), W3 with 0.069 m^3 m^{-2} (excessively irrigated). The 4 levels ferti-lizer nitrogen treatments were N0 with no nitrogen fertilization, N1 with 5 g m^{-2} (scanty fertilized), N2 with 20 g m^{-2} (rationally fertilized), N3 with 35 g m^{-2} (excessively fertilized) at reviving stage and booting stage respectively.

Modeling and validation Experimental data of year 2002 were used for establishing the calibration models, the data of year 2003 were used for the validation of the established models.

Measured item and methods

Canopy reflected spectrum All canopy reflected spectrum were taken from a height of 1.30 m above ground, under clear blue sky between 11:00 and 14:00 in Beijing Local Time, using an ASD FieldSpec Pro spectrometer (Analytical Spectral Devices, Boulder, CO, USA) fitted with 25° field of view fiber optics, which functions in the 350-2 500 nm spectral region with spectral resolution of 3 nm at 700 nm, 10 nm at 1 400 and 2 100nm, and with a sampling interval of 1.4 nm between 350 and 1 050 nm, and 2 nm between 1 050 and 2 500 nm. Reflected spectrum from a 0.40 m × 0.40 m $BaSO_4$ calibration panel were used for calculation of canopy reflected spectrum. Vegetation and panel radiance measurements were taken by averaging 20 scans at optimized integration time with due care for dark current correction at every spectral measurement.

Chlorophyll concentration and total nitrogen concentration After measuring the canopy spectrum, data were collected for chlorophyll concentration and total nitrogen concentration etl. Leaf samples and the stem samples were dried separately in a forced drought oven at 70¡æ and weighted. Total nitrogen concentration were separated by Kjeldahl method.

Quantitative wheat density The quantitative wheat density was carried out in 1 m^2 area (1 m × 1 m) of symmetrical wheat colony. The number of all stems in the 1 m^2 areawas accounted first,to obtain, a total stem number (TSM, LAI 100), then fotlowed by thinning 10% of the TSM equably for 10 times. After each thinning, the residual stems in the 1 m^2 area was 90, 80, 70, 60, 50, 40, 30, 20, 10% and 0% of the TSM, it was also named as LAI 100(TSM), LAI 90, LAI 80, LAI 70, LAI 60, LAI 50, LAI 40, LAI 30, LAI 20, LAI 10 and LAI 0. Canopy reflected spectrum under different stem densities were measured by the same standard as mentioned above.Then were.

Results

Combination of NDVI and PRI for distinguish from different canopy closures

The most common vegetation index was normalized difference vegetation index (NDVI), it was defined by Rouse et al.as follows:

$$NDVI = (NIR - R)/(NIR + R)$$

In this paper, near infrared (NIR) at 830 nm, red (R) at 675 nm were chosen. $NDVI = (R_{830} - R_{675})/(R_{830} + R_{675})$.It can be used to evaluate crop growth state.

The photochemical reflectance index (PRI) was defined by Penuelas et al. follows:

$$PRI = (R_{531} - R_{570})/(R_{531} + R_{570})$$

where R_{531} and R_{570} are in correspondence with reflectance at the wave band considered. Leaf pigments of the xanthophylls cycle play a major role in light absorption at 531 and 570 nm, which wene used to reduce the chloroplast movements. It provides a quick and non-destructive assessment of foliar physiologi cal properties (Peñuelas et al.[12]).

The three cultivars under rationally water irrigated (W2) and rationally nitrogen fertilized (N2) conditions were selected and studied at five different growth stages (erecting stage, elongation stage, heading stage, anthesis stage and grain filling stage) in 2002 and 2003. As shown in Fis.1 and Figs 2, the combination of NDVI and PRI shows the different coordinate locations under different densities, the different canopy closures can be distinguished very easily both in two years, the result of two years are almost the same. When canopy closures was on the small side, the values of NDVI and PRI are located in the small value area, as canopy closures increased in the small side canopy closures less than 30% of TSM), the NDVI value increased sharply. When canopy closures increased in the large side (canopy closures more than 40% of TSM), the NDVI value in

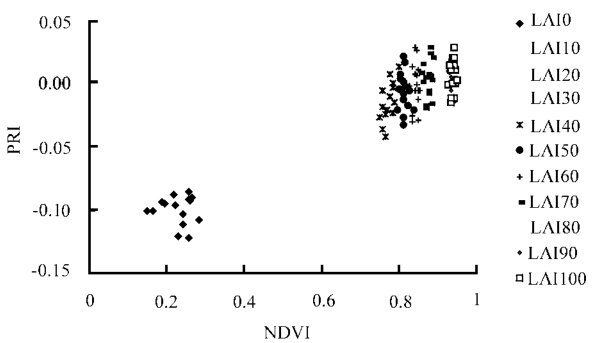

Fig. 1 Combination of NDVI and PRI for distinguish from different canopy closures in year 2002

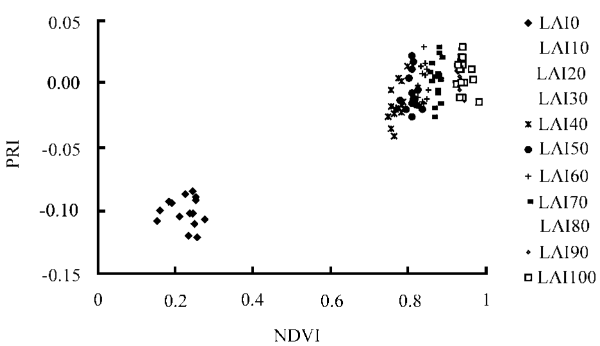

Fig. 2 Combination of NDVI and PRI for distinguish from different canopy closures in year 2003

creased laggardly, so the combination of NDVI and PRI can be used for distinguish the canopy closure and leaf area index, itworks better especially under low canopy closures conditions.

Application of CCII for estimating chlorophyll concentration by minimizing LAI and soil background effect

Some researchers indicated that LAI plays an important role in canopy reflected spectrum, the LAI dominated the near infrared spectrum characteristics of canopy reflected spectrum. When we try to inverse canopy chlorophyll concentration, the effect of LAI on canopy reflected spectrum should be eliminatedas itis possibk. Chlorophyll concentration is an indicator of photosynthesis activity, which is related to the nitrogen concentration in green vegetation and serves as a measure of crop response to nitrogen application. Driss et al.[13] presented a combined modeling and indices for predicting chlorophyll concentration from canopy reflected spectrum while minimizing LAI influence and underlying soil background effects. The index was defined as transformed chlorophyll absorption reflectance index/optimized soil-adjusted vegetation index (TCARI/OSAVI). In this paper, it was named as canopy chlorophyll inversion index (CCII). It was defined as follows:

$$CCII = TCARI/OSAVI$$

$$TCARI = 3[(R_{700} - R_{670}) - 0.2(R_{700} - R_{550})(R_{700}/R_{670})]$$

$$OSAVI = (1 + 0.16)(R_{800} - R_{670})/(R_{800} - R_{670} + 0.16)$$

Where TCARI is ameliorated from modified chlorophyll absorption in reflectance index (MCARI), which was proposed by Daughtry et al.[10] as a variant of the chlorophyll absorption in reflectance index (CARI) developed by Kim et al.[14] TCARI is resistant to non-green biomass effects, but it is still sensitive to the underlying soil reflectance properties, particularly for low LAI (Rondeaux et al.[15]). In order to overcome this problem, Daughtry et al.[10] pro posed the MCARI be combined with a soil line vegetation index like optimized soil-adjusted vegetation index(OSAVI, Rondeaux et al.[15]). OSAVI belongs to the soil-adjusted vegetation index (SAVI Huete[16],). This index (CCII) was proved to be sensitive to chlorophyll concentration and very resistant to the canopy closure variations. This paper introduced the use of CCII to make accurate predictions of winter wheat chlorophyll concentration for different cultivars, different treatments and different years.

All the 48 plots of three cultivars under 4 levels of water irrigated and 4 levels of nitrogen fertilized conditions were selected to be was studied at five different growth stages (erecting stage, elongation stage, heading stage, anthesis stage and grain filling stage) in 2002 and 2003. Data in year 2002 were used to establish the models between chlorophyll concentration and CCII, data in year 2003 were used to calibrate the established models.

As shown in Fig 3, correlation equation was established between measured chlorophyll concentration (in laboratory) and CCII derived from canopy reflected spectrum. Canopy reflected spectrum and chlorophyll concentration were acquired for about 70 days intervals, which covered the different five growth stages. These relationships were determined for LAI values ranging from 1 to 5 and chlorophyll concentration varying from 0 to 90 μg cm^{-2}. It reveals a very good agreement between laboratory measured chlorophyll concentration and CCII, with a coefficient of determination $R^2 = 0.8395 (n = 240)$, it reached very significant positive level ($r_{(0.01,240)} = 0.181$). The established model between chlorophyll concentration and CCII was used for validation the data used in year 2003. As shown in Fig 4, the coefficient of determination between simulated and the measured chlorophyll concentration in year 2003 is 0.9433, which is extremely significant. So CCII can be used to minimize the effects of LAI and non-photosynthetic materials on retrieval of canopy chlorophyll concentration.

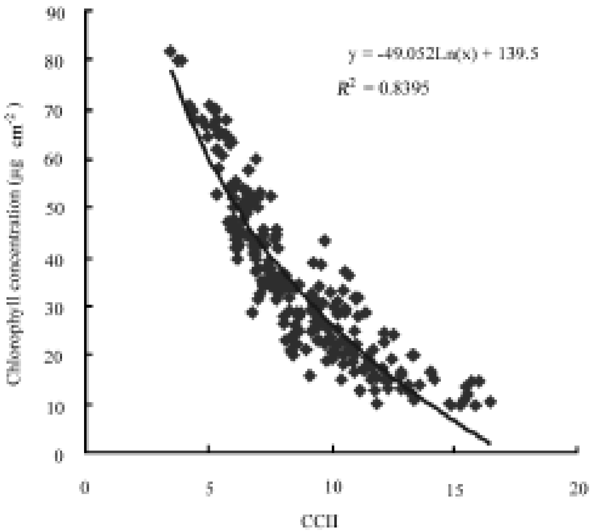

Fig. 3 Relationship between measured chlorophyll concentration and CCII in 2002

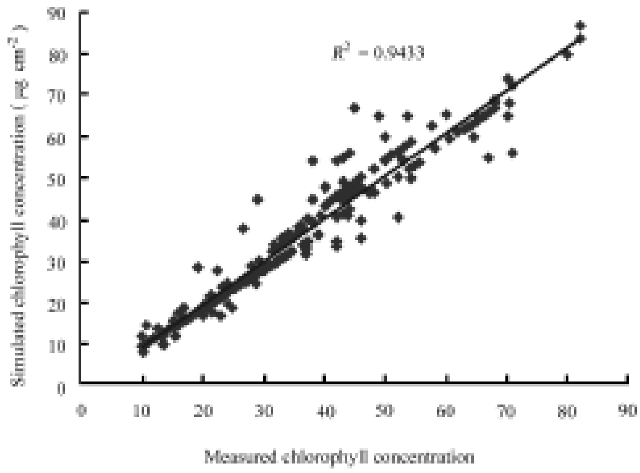

Fig. 4 Relationship between measured and simulated chlorophyll concentration in 2003

Application of SIPI for inversion of a ratio of canopy carotenoid to chlorophyll

Some physiological reflectance indices such as photochemical reflectance index (PRI) and structure insensitive pigment index (SIPI)were proposed to predict pigment concentration. SIPI was proposed by Peñuelas et al.as follows:

$$SIPI = (R_{800} - R_{445})/(R_{800} - R_{680})$$

The 445 nm and 680 nm are the absorption apexes of the carotenoid (including the carotenes and the xanthophylls) and chlorophyll a. When the crop was under nutrition deficiency,especially nitrogen deficiency, the carotenoid concentration will increase while the chlorophyll a concentration will decrease, so the ratio of carotenoid to chlorophyll a can be used to differentiate the nitrogen deficiency.

As shown in Fig 5, the relation between measured carotenoid to chlorophyll a ratio and SIPI of 3 cultivars under different irrigation and soil nitrogen treatments, the ratio of carotenoid to chlorophyll for 240 samples were measured in the laboratory with plot field sampling. It reveals a very good agreement between the measured carotenoid to chlorophyll a value and SIPI, with a coefficient of determination $R^2 = 0.9216$ (n = 240), it reached very significant positive level ($r_{(0.01,240)} = 0.181$). The established model between the ratio of carotenoid to chlorophyll a and SIPI was used for validation the data used in year 2003. As shown in Fig 6, the coefficient of determination between simulated and the measured chlorophyll concentration in year 2003 is 0.9425,which is extremely significant.Itshowed that the ratio of carotenoid to chlorophyll a could be predicted by the index of SIPI.

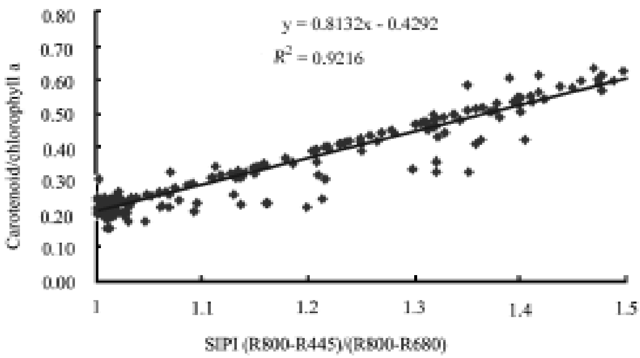

Fig.5 Relationship between the ratio of carotenoid to chlorophyll a and SIPI in 2002

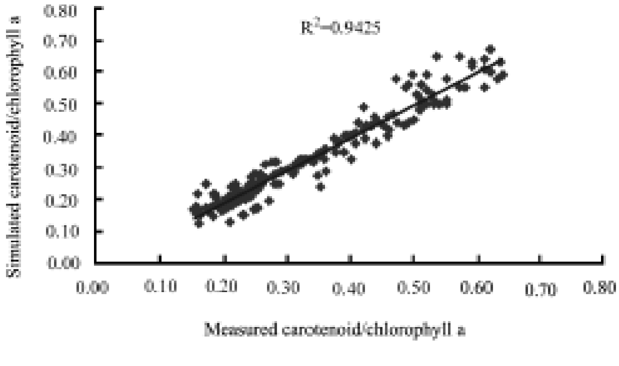

Fig.6 Relationship between measured and simulated carotenoid to chlorophylla in 2003

Relationship between the ratio of carotenoid to chlorophyll a and total nitrogen concentration

Relationship between total nitrogen concentration and grain quality indicators (such as grain protein content) has been studied by wang [17], and regression equations between total nitrogen concentration and grain protein content has been established.So relationship between total nitrogen concentration and pigment concentration should be established. As shown in Fig 7, the measured total nitrogen concentration shows good relation to the ratio of carotenoid to chlorophyll a, all of them wene the measured values in laboratory for the data of year 2002, with a coefficient of determination $R^2 = 0.7347$(n = 240), it reached very significant positive level

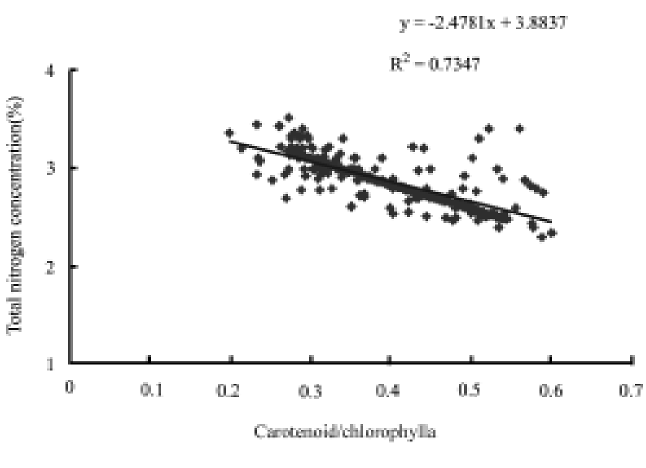

Fig.7 Canopy total nitrogen concentration and carotenoid / chlorophyll a in 2002

($r_{(0.01,240)}$ = 0.181). The established model between the ratio of carotenoid to chlorophyll a and total nitrogen concentration was used for validation the data used in year 2003. As shown in Fig 8, the coefficient of determination between simulated and the measured chlorophyll concentration in year 2003 is 0.8715, which is extremely significant. It showed that total nitrogen concentration could be predicted by the ratio of carotenoid to chlorophyll a.

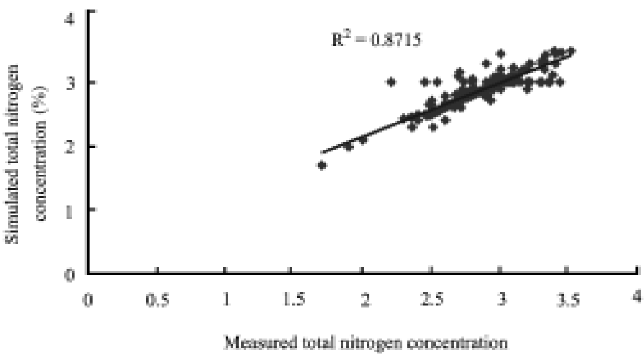

Fig. 8 Measured and simulated carotenoid / chlorophyll a in 2003

Discussion

Uncertainties in winter wheat canopy reflected spectrum is a mixed one in view of the sensor, which are affected by wheat canopy (leaf area index and leaf angle distribution, leaf water content, mineral deficiencies, parasitic attacks, and so on), soil (soil properties, soil illumination), weeds (weed species, amounts), environment and their interactions. When we studied the canopy chlorophyll concentration by canopy reflected spectrum, we should try to minimize the effects of the other effective factors by proper methods.

Depending on these results in this paper, we are developing some simple instruments with selected sensitive bands. For example, optical camera lens and sensors focusing on 800,680 and 445 nm or focusing on 800, 700 and 670 nm could be fixed on the agricultural machine traveling in the field. Such simple instruments can diagnose crop canopy chlorophyll concentration status by the acquired canopy reflected spectrum. Moreover, a careful analysis should be carried out to investigate the effects of these characteristics: band width, sensor height above the ground and so on. So some further study are needed to confirm and to improve the results mentioned in this study.

Conclusion

The combination vegetation indices such as canopy chlorophyll inversion index (CCII) and structure insensitive pigment index (SIPI)proposed in this paper hold a strong potential for “operational” use in the application of agricultural production management. It allows the on-site and non-sampling mode of crop growth monitoring, fertilizing and water guiding, and canopy chlorophyll concentration forecasting without a priori knowledge of it. The combination of normalized difference vegetation index (NDVI) and photochemical reflectance index (PRI) can reduce the effect of leaf area index(LAI) and soil background. The index (CCII) was proved to be sensitive to chlorophyll concentration and very resistant to the other variations. The ratio of TCARI/OSAVI can be used to make accurate predictions of winter wheat chlorophyll concentration under different cultivars. It indicated that canopy chlorophyll concentration could be evaluated by some combined vegetation indices.

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