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CHANGES IN WINTER WHEAT GROWN UNDER IRRIGATED AND RAINFED CONDITIONS

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ABSTRACT

Changes of the canopy spectral reflectance, leaf area index (LAI) and chlorophyll density (CHLD) of winter water in irrigated and dry land at different growth stage were studied to analyze the correlation between hyperspectral vegetation indices and CHLD, and to confirm the optimum vegetation indices for estimating CHLD of winter wheat in irrigated and dry land. The result showed the trend of changes in LAI similar to CHLD in irrigated and dry land, the values increased at first and then decreased, but the maximum value of CHLD and LAI appeared at different growth stages. The changes in canopy reflectance were also similar in irrigated and dry land, canopy reflectance formed an obvious reflection peaks at a waveband (510-680nm), but with the grain filling stage progressed, the reflection peaks gradually became unobvious, and disappeared at maturity. NDVI (780,670) might be better to predict CHLD of winter wheat in irrigated land, with the determination coefficient of 0.9451, but DVI (1200, 670) might be to predict CHLD of winter wheat in dry land, with the determination coefficient of 0.7346.

Key words: Leaf area index; Chlorophyll density; Spectral parameters; Irrigated; Dry land.

INTRODUCTION

Winter wheat (*Triticum aestivum* L.) is planted in about 71% of the cultivated area of Shanxi Province in China, which is the most frequently grown crop in Loess Plateau (Gao *et al*., 2009). Therefore, more study about winter wheat in irrigated and dry land is imperative. Recently, Ma *et al*. (2008) suggested remote sensing is a reliable method for estimating wheat growth (Ma *et al*., 2008)because it is characterized as non-destructive, fast and relatively inexpensive(Darvishzadeh *et al*., 2008), especially for specific vegetation variables, such as leaf area index (LAI)(Ren *et al*., 2010), chlorophyll density (CHLD)(Feng *et al*., 2008; Eitel *et al*., 2009), yield and quality (Wang *et al*., 2011).

CHLD is an index for characterizing photosynthetic capacity and growth condition of many crops because chlorophyll is the major pigment in photosynthesis responsible for absorption and reaction with most of the visible red light (Arunyanark *et al*., 2009). Therefore, field CHLD measurement is important for evaluation of wheat growing environment and condition (Schepers *et al*., 1992; Daughtry *et al*., 2000). With the development of remote sensing, many observed values could be obtained from multi-spectral, multi-azimuth, multi-date, and composite index, which loaded the corresponding waveband information of different crop and vegetation structure.

In field experiment, LAI is also an important dynamic determinant for plant community structure and various of ecosystem processes, such as transpiration, photosynthesis, and nutrient cycling (Brantley and Young, 2007). The crop yield increases along with increasing LAI. However, when the LAI increases to some degree, canopy closure is formed, and results in insufficient light, and decreased photosynthetic efficiency, and finally the crop yield is reduced (Xinyou *et al*., 2011). In addition, study also indicated that nitrogen application could promote crop growth and developmental processes by an increase in LAI to counterbalance decrease in net assimilation rate. Therefore, LAI is an important consideration for high yielding cultivation of wheat plant(XUE *et al*., 2004).

In brief, it is helpful to obtain qualitative and quantitative data for crop production management by studying the relationship between spectrum vegetation index and various agriculture parameters, such as LAI and CHLD. However, up to date, few studies were reported to reflect the changes in CHLD and LAI of winter wheat in irrigated land and dry land through canopy reflectance spectrum. In this study, we comprehensively analyzed the correlation ship between canopy spectral parameter and CHLD and LAI of winter wheat in irrigated land and dry land, and compared the effect of eight spectral parameters on CHLD and LAI of winter wheat in irrigated land and dry land. It is being comprehended to establish the quantitative detection model of CHLD and LAI of winter wheat in irrigated land and dry land, and lay a theoretical and technique basis for monitoring wheat growth by remote sensing.

MATERIALS AND METHODS

Study site: The study site was located in Wenxi county, Shanxi province (longitude110°59′ to 111°37′E, latitude 35°9′3to 35°34′N). Table 1 depicts the villages selected as irrigated and dry land including north to Xi-aodi, west to Chaijiashan and Guojiagou, south to Guojiazhuang and Xiayangzhuang, east to Nanwang and Shangyuan, and the centre of Xiguanzhuang and Shangshaowang. The study area lies in a temperate continental climate zone, with the mean annual temperature of 8-14°C. The winter of study area is cold (averaged of -3.2°C in January) and dry, while the summer is hot (averaged of 26.5°C in July) and rainy. The area have an average annual precipitation of450-600mm and a frost-free period of160-190 days. There is an average of 2461 h sunlight annually, with the most from May to June. The texture of soil was calcareous cinnamon soil with neutral or alkalescent PH, relatively higher mineral matter, organic matter content, humus layer, and fertility.

Canopy spectral measurements: We used a portable multi-spectral radiometer MSR-16R (CROPSCAN Inc, USA) to measure canopy reflectance spectrumat wheat re-greening stage, jointing stage, heading stage, grain filling stage, and maturity, respectively. This spectrometer was fitted with 31.1° field-of-view fiber optics, operating in the 60-1700 nm spectral region, with band positions centered at 460, 500, 550, 600, 650, 670, 730, 780, 800, 850, 950, 1050, 1100, 1200, 1260, and 1460 nm, respectively. The optical head should be held perpendicular to land surface with a distance of 2 m between the plant canopy and the optical head of the spectro-radiometer. Before performing each reflectance measurement, the target measurements were normalized by recording the radiance of a white standard panel coated with $BaSO_4$ and of known reflectivity. To minimize atmospheric perturbations, all spectral measurements were conducted between 10:00 and 14:00 on clear sunny days. In order to suppress the measurement noise, we taken the average value of 15 replicate spectral measurements from each subplot as the final results.

LAI measurements: The LAI measurements and canopy spectral measurements were taken on the same day. Five plants were randomly collected from each plot and five leaves were arranged neatly to measure the total width. And then the middle part of leaves (4 cm) was accurately cut off to measure the partial leaves area(S) and dry weight (W1). The other partial leaves were also dried and obtained the dry weight W2. The total leaf area of the five leaves was calculated according to the following equation: $S_1=S^*(W_1+W_2)/W_2$(Breda, 2003).

Chlorophyll destiny measurements: The chlorophyll destiny measurements and canopy spectral measurements were taken on the same day. All of the upper fully expanded leaves and adjacent lower leaves were collected to determine chlorophyll concentration. Chlorophyll in the sampled leaves were extracted in 25 ml of 80% (v/v) acetone solution and 95% ethanol (1:1), and then kept in dark for 24h before determining chlorophyll using a spectrophotometer (Shimadzu UV-1800 type) with the absorbance at 440nm, 645nm and 663nm, respectively. Chlorophyll destiny was then calculated with the following equations(Arnon, 1949):

Chlorophyll a=$(12.71A663-2.59A645)^*V/W^*1000$

Chlorophyll b=$(22.88A645-4.67A663)\ ^*V/W^*1000$

Total chlorophyll content =$(8.04A663+20.29A645)\ ^*V/W^*1000$

Note: V,10ml; W, 0.05g

Vegetation indices used in this analysis: In this section, we described eight vegetation indices (Table 2) those were examined for their potential to estimate CHLD and optimum spectral wavebands.

RESULTS AND DISCUSSION

Changes in LAI and chlorophyll destiny of irrigated and dry land winter wheat at different growth stages: The LAI is suggested high related to light energy utilization, dry matter production and accumulation, and grain yield. As the major pigment in photosynthesis, the chlorophyll content may reflect the growth condition and production capacity of winter wheat. Therefore, they may directly influence the economic yield of wheat. Results from our study showed a parabola trend in the changes of LAI and chlorophyll destiny of winter wheat in irrigated as well dry land (Figure 1). However, the peak value of them occurred at different stages. Sufficient water supply was present at the whole growth stage in irrigated land, and thus LAI increased from emergence stage and reached the peak value at heading stage (Figure 1A). Due to deficiency water in dry land, the increase of LAI was relatively slower and arrived at the peak value until to grain-filling stage. The LAI showed a rapid decrease after grain-filling stage since the leaves could not carry on the photosynthesis, and senesced and withered subsequently. From Figure 1B, chlorophyll destiny of dry land wheat reached the maximum at jointing stage, but at grain-filling stage in irrigated land. This result may be because that nutrient supply and rainfall were sufficient before jointing stage, and abundant chlorophyll was synthesized to accomplish photosynthesis and make organics to meet the need of vegetative growth and reproductive growth. However, after jointing stage, nutrient gradually decreased due to hot weather and lack of rainfall, and thus chlorophyll synthesis was reduced correspondingly. Identically, sufficient rainfall and nutrient results in the peak value of chlorophyll destiny was at grain-filling stage in irrigated land. Chlorophyll destiny sharply decreased after grain-filling stage because of leaf senescence and abscission.

Our results found the changes trend of LAI and CHLD of winter wheat in irrigated land was consistent with them in dry land, that is, increased first and then declined. However, the peak value of LAI and CHLD of winter wheat arrived at different growth stage in irrigated land and dry land.

Changes in canopy spectrum characteristic of winter wheat in irrigated land and dry land at different growth stage: In this study, we investigated the changes incanopy spectrum characteristic of winter wheat in irrigated land and dry land at two crucial stages, jointing stage and filling stage (Figure 2). The results showed that the canopy spectrum characteristic of winter wheat was similar in irrigated land and dry land. Spectral reflectance gradually increased along with the development of winter wheat in visible waveband (460-730nm), but decreased in infrared waveband (780-1100nm). Two absorption bands were present in visible blue(450nm) and red(670nm) waveband, but a small spectral reflectance peak occurred between these two absorption bands, which lead to the plant green. Spectral reflectance peak disappeared near 540 nm at maturity, therefore the plant became yellow. A absorption valley was present in visible red waveband (680nm). If the absorption valley reduced, the wheat would grow yellow. Spectral reflectance sharply increased from 680 nm visible red waveband and then peaked at 1100 nm infrared waveband.

In addition, spectral reflectance of dry land wheat was significantly higher than that in irrigated land in visible waveband (460-730nm), but lower in infrared waveband (780-1100nm). This indicated that the chlorophyll destiny of winter wheat in dryland was lower than that in irrigated land, which was also in accordance with changes trend observed in Figure 1. In brief, the reflectance varied due to different moisture and nutrient in the same vegetation. Therefore, we could monitor the growth and nutrient status of wheat according to above changes.

Overall, the changes in canopy spectral reflectance of winter wheat were similar in irrigated land and dryland at different growth stage. A spectral reflectance was present in 510-680 nm wave band, but with the development of grain filling, this spectral reflectance peak was gradually unconspicuous and disappeared at maturity. Obvious changes also could be observed in near-infrared waveband (780-1100 nm). Further analysis of jointing stage and grain filling stage indicated that spectral reflectance in dryland was significantly higher than that in irrigated land at visible waveband(460-730 nm), but lower than that in irrigated land at near-infrared waveband(780-1100 nm).

Correlation analysis between CHLD and canopy spectral reflectance at various bands: The results of correlation analysis showed that CHLD of winter wheat in irrigated land was significant and had negative correlation with the spectral reflectance in visible waveband (460-730nm) and near-infrared waveband (1200 nm), but was significant and positive correlated with the spectral reflectance in near-infrared waveband (780-1100 nm) (Figure 3A). The negative correlation between CHLD and spectral reflectance in 1460 nm waveband as well as the positive correlation between CHLD and spectral reflectance in 1260 nm waveband was not statistically significant. However, CHLD of winter wheat in dry land was significant and had negative correlation with the spectral reflectance in visible waveband (460-730nm) and near- infrared waveband (1460 nm), but significant and positive correlated with the spectral reflectance in near-infrared waveband(780-1100 nm) (Figure 3B). The positive correlation between CHLD and spectral reflectance in 1200 nm as well as 1260 nm was not significant.

Further, it can be observed from Figure 3 that correlation coefficient between CHLD and canopy spectral reflectance arrived the peak value at 670 nm waveband, with -0.90 of irrigated land and -0.59 of dry land. Therefore, we drew regression equations by setting spectral reflectance at 670 nm as x and CHLD as y (Table 3). As a result, the regression equation for irrigated land is $y = 12.364e^{-0.3382x}$, with $R^2 = 0.9208$, while the regression equation for dry land is $y= -0.0188x^2 + 0.1998x + 3.3992$, with $R^2 = 0.4057$..

Correlation analysis between CHLD and vegetation index: Eight vegetation index were collected to confirm the correlation analysis between CHLD and vegetation index here (Table 4). Our results showed that eight vegetation index were all significant and correlated with CHLD. And The NDVI was the highest in irrigated land, with correlation coefficient of 0.92, while DVI was the highest in dryland, with correlation coefficient of 0.70. Therefore, NDVI and DVI may be used to estimate the CHLD in irrigated land and dryland, respectively.

In addition, our results indicated that in dryland, TSAVI, PVI, NDVI, SAVI, DVI, OSAVI, and RDVI were significantly and had positive correlation with CHLD in near-infrared waveband (780-1260 nm) and visible waveband (460-730nm), but gave negative correlation with CHLD in near-infrared waveband (1460nm) and visible waveband (460-730nm). However, in irrigated land, PVI was significantly and positive correlation with CHLD in near-infrared waveband (780-1460 nm) and visible waveband (460-730nm). NDVI, OSAVI, TSAVI, SAVI, and RVI were significantly positive correlation with CHLD in near-infrared waveband (780-1260 nm) and visible waveband (460-730nm). Significantly positive correlation was present between NDVI, OSAVI, SAVI and CHLD in 1460 nm waveband and visible waveband (500, 600, 650, 670 nm). But no significantly positive correlation was present between NDVI, OSAVI, SAVI and CHLD in 1460 nm waveband and visible waveband (460, 550 nm). No significantly positive correlation was also observed between TSAVI and CHLD in 1460 nm waveband and visible waveband (460-670nm).

Table1. The geographic location of irrigated and dry land

Treatments	Study sites	
Irrigated land	Xizhang village	Xiangyang village
	Xiaositou village	Jinzhuang village
	Hedi village	Goudong village
	Nanwang village	Renhe village
	Shangyuan village	Xiyangquantou village
	Xinyangzhuang village	Dongzhen
	Dongyu village	Hou village
	Sidi village	Xiguanzhuang village
	Fengjiazhuang village	Daze village
	Jilu village	Xinxizhang village
	Dingdian village	Poshen village
	Xihan village	Shangshaowang village
	Guojiazhuang village	Guodian village
	Xifu village	Yangzhuang village
Dry land	Kengdong village 1	Hutouzhuang1
	Kengdong village 2	Hutouzhuang2
	Zhujiabao village	Bolin village
	Dongdama village	langjiawan
	Beiyuan	Guojiagou
	Xiaodi village	Gaoyu
	Xuedian	Chaijiashan
	Xin village	Qiujiazhuang
	Li village	Zhaojialing
	Xiaozhang village	Dongwang

Table 2. Algorithm and references of different spectral parameters

Spectral parameter	Abbreviation	Algorithm	Reference
Reflectance	R_λ	–	Cropscan (2000)(Inc, 2000)
Ratio vegetation index	RVI	R_{NIR}/R_{Red}	Pearson *et al* (1972)(Pearson and Miller, 1972)
Difference vegetation index	DVI	$R_{NIR}-R_{Red}$	Jordan (1969)(Jordan, 1969)
Normalized difference vegetation index	NDVI	$R_{NIR}-R_{Red}/R_{NIR}+R_{Red}$	Rouse *et al*. (1974)(Rouse, 1974)
Perpendicular vegetation index	PVI	$(R_{NIR}-aR_{Red}-b)/\sqrt{1+a^2}$	Richardson *et al*. (1977)(Richardson and Wiegand, 1977)
Transformed Chlorophyll Absorption ratio Index	TCARI	$3^*[(R700-R670)-0.2^*(R700-R550)(R700/R670)]$	Haboudane *et al*. (2004)(Hu *et al*., 2004)
Transformed soil adjusted vegetation index	TSAVI	$\frac{a(\rho NIR-a\rho Red-b)}{a\rho NIR+\rho Red-ab}$ a=10.489, b=6.604	Baret *et al* (1989)(Baret *et al*., 1989)
Soil adjusted vegetation index	SAVI	$(1+L)\ (R_{NIR}-R_{Red})/\ (R_{NIR}+R_{Red}+L)$ L=0.5	Huete *et al*. (1988)(Huete, 1988)
Optimized soil-adjusted vegetation index	OSAVI	$(1+0.16)\ (R_{800}-R_{670})/\ (R_{800}-R_{670}+0.16)$	Ronddeaux *et al*.(1996)(Rondeaux *et al*., 1996)
Renormalized difference vegetation index	RDVI	$\sqrt{NDVI \times DVI}$	Reujean *et al*. (1995)(Roujean and Breon, 1995)

Table 3. Quantitative relationships between CHLD(y) and canopy reflectance of 670nm(x)in winter wheat

Treatment	Regression equation	Determination coefficient R^2
Irrigated land	$y=12.364e^{-0.3382x}$	0.9208**
Dry land	$y=-0.0188x^2+0.1998x+3.3992$	0.4057**

** indicates P< 0.01.

Table 4. Correlation analysis between CHLD and eight vegetation index

spectral index	Water land	Dry land
	CHLD	CHLD
TSAVI	0.90**	0.68**
NDVI	0.92**	0.65**
OSAVI	0.90**	0.65**
SAVI	0.90**	0.65**
PVI	0.90**	0.62**
RDVI	0.87**	0.67**
DVI	0.84**	0.70**
RVI	0.73**	0.51**

** indicates P < 0.01.

Table 5. Quantitative relationships of CHLD(y) to individual spectral index(x)in water and dry land of winter wheat

Treatment	Spectral parameter(x)	Linear regression equation	R^2
Irrigated land	NDVI(780, 670)	$y=7.1019x^{2.6863}$	0.9451**
	OSAVI(780, 670)	$y=4.8185x^{2.6852}$	0.9449**
	SAVI(780, 670)	$y=2.4735x^{2.6829}$	0.9447**
	TSAVI(780, 670)	$y=4.7808e^{0.4644x}$	0.9332**
Dry land	DVI(1200, 670)	$y=1E\text{-}05x^{4.1715}$	0.7346**
	RDVI(1200, 600)	$y=0.0112x^{5.0458}$	0.7255**
	TSAVI(1200, 600)	$y=60.92e^{0.8726x}$	0.683**
	SAVI(1200, 600)	$y=11.092x^{4.293}$	0.6298**

Establishment of spectrum model based on CHLD: Regression analysis was performed between eight spectrum vegetation index and CHLD of winter wheat in irrigated land and dryland. The results indicated NDVI, OSAVI, SAVI, and TSAVI were better spectral parameters to monitor in irrigated land, but DVI, RDVI, TSAVI, and SAVI were better spectral parameters to monitor in dryland (Table 5). Of them, NDVI (780, 670) could predict the CHLD of winter wheat in irrigated land, with 92.36% precision, but DVI (1200, 670) could predict the CHLD of winter wheat in dryland, with 85.78% precision(Figure 4).

Recent studies have demonstrated that spectrum parameter is associated with LAI and CHLD. For example, vegetation indices, such as NDVI, RDVI, and SAVI, etc were sensitive to changes of chlorophyll concentration and were affected by saturation at high LAI (Haboudane *et al.*, 2004). Bannari *et al* (2007) investigated the correlation between chlorophyll content and a wide range of hyperspectral chlorophyll indices and found that normalized pigments chlorophyll ratio index (NPCI) showed the best results when R^2= 0.84 and root mean squared (RMSE) = 11.0 hyperspectral chlorophyll indices (Bannari *et al.*, 2007). Both of NDVI and MTVI2 indices provided good relationships with LAI (R^2 = 0.70–0.90). And the MTVI2 performed better than the NDVI at full canopy closure. Estimation of LAI using the MTVI2 was underestimated late in the season during the seed-filling period (Smith *et al.*, 2008). Identically, in this study, our results suggested that NDVI(780, 670) was more effective to predict the CHLD of winter wheat in irrigated land, when the determination coefficient (R^2) was 0.9451, but DVI(1200, 670) was for CHLD of winter wheat in dry land, when the determination coefficient (R^2) was 0.7346. The corresponding regression model was $y_{\text{irrigated land}} = 7.1019x_{\text{NDVI (780, 670)}}^{2.6863}$ and $y_{\text{dry land}} = 1E\text{-}05x_{\text{DVI (1200, 670)}}^{4.1715}$, respectively.

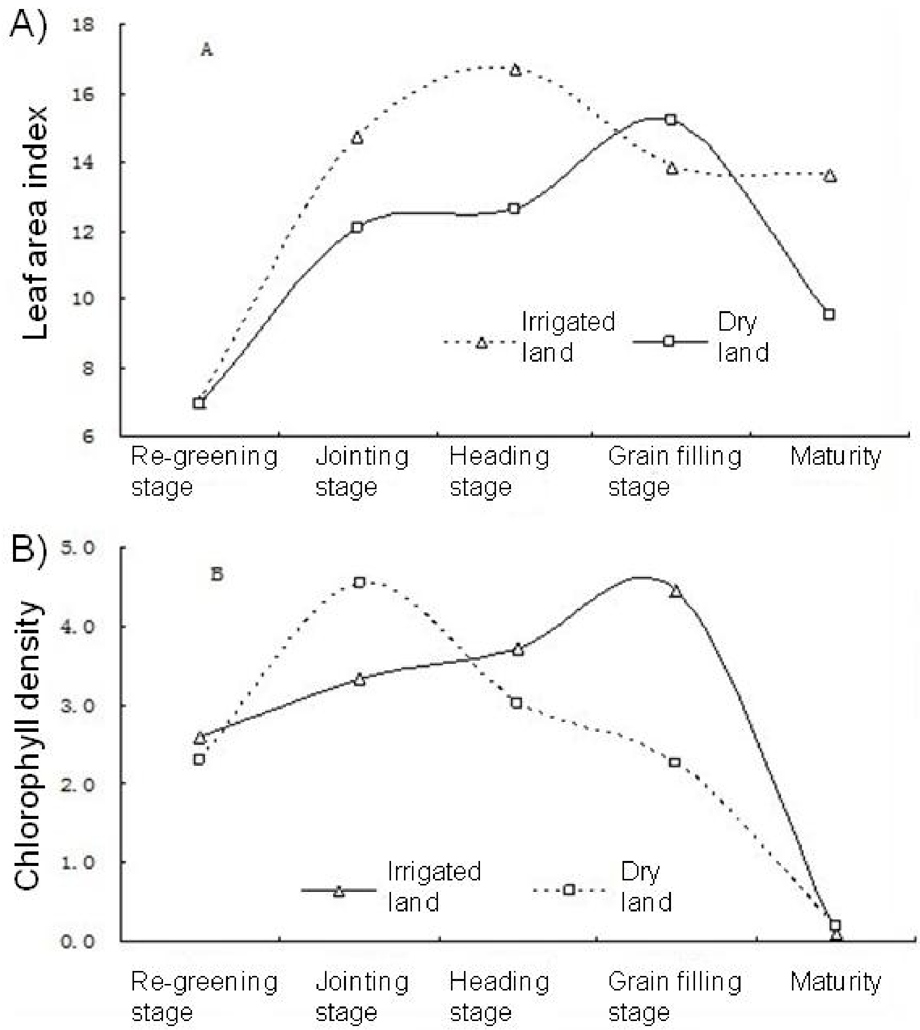

Figure 1.Changes in leaf area index (A) and canopy CHLD (B) of irrigated and dry land wheat at different growth periods.

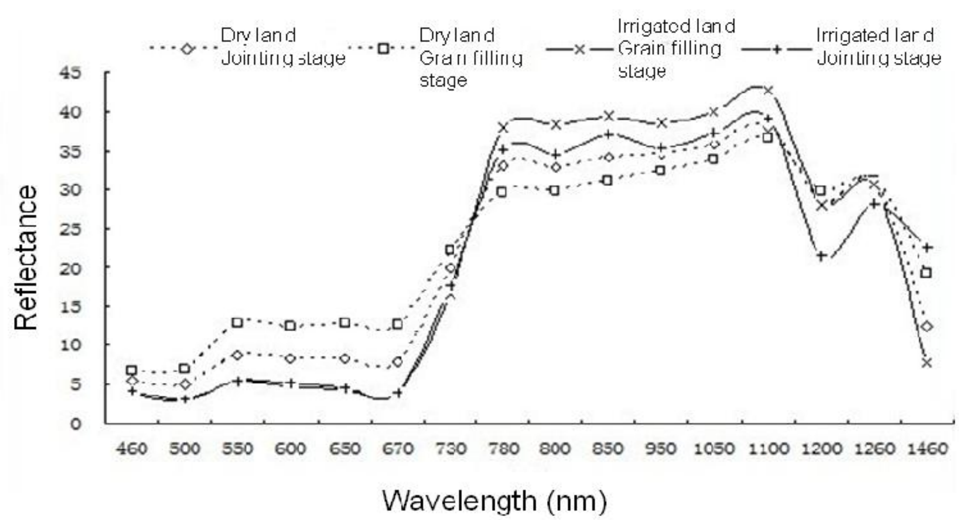

Figure 2.Variation of spectral reflectance of irrigated land and dry land at different growth Stage.

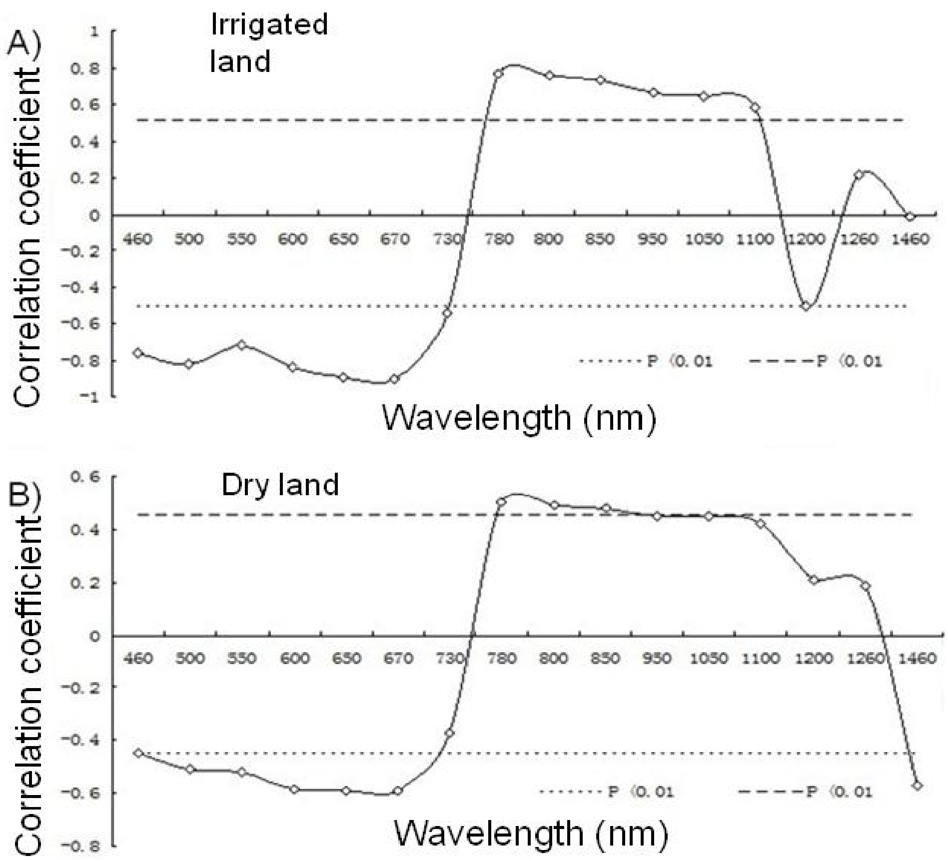

Figure 3.Correlation analysis between chlorophyll density and canopy reflectance at various bands in irrigated (A) and dry land (B).

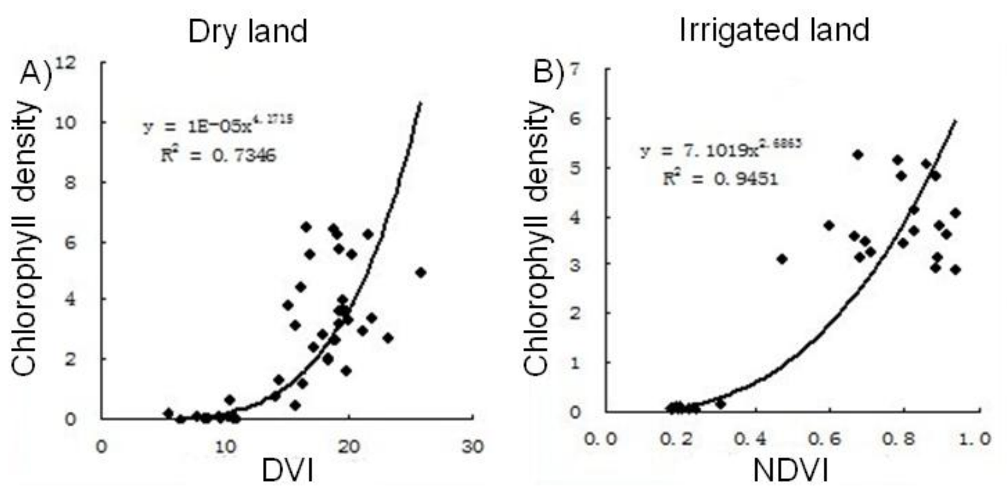

Figure 4.Regression analysis for estimating CHLD of irrigated land (A) and dry land (B) in winter wheat using spectral vegetation index. DVI, difference vegetation index; NDVI, Normalized difference vegetation index.

Conclusion: Our monitor model is demonstrated suitable for field experiment in Yuncheng town. Comprehensive analysis of LAI and CHLD in irrigated and dry land through remote sensing may provide technique for wheat dynamic management in Shanxi Province. However, a difference in canopy reflectance spectrum may be caused by some factors, such as irrigation times, and sampling time, etc. Many years, many regions, and many position experiments are still indispensable to further confirm.

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