Study on spectral indices for crop growth monitoring

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Abstract: The objective of this paper is to determine the suitable spectral bands for monitoring growth status change during a long period. The long-term ground-level reflectance spectra as well as LAI and biomass were obtained in xiaotangshan area, Beijing, 2001. The narrow-band NDVI type spectral indices by all possible two bands were calculated their correlation coefficients R^2 with biomass and LAI. The best NDVIs must have higher R^2 with both biomass and LAI. The reasonable band centers and band widths were determined by a systematically increasing bandwidth centered over a wavelength. In addition, the first 19 bands of MODIS were simulated and investigated. Each developed spectral indices was then validated by the biomass and LAI time series using the generalized vector angle. It turned out that six new NDVI type indices within 750-1400nm were developed. NDVI(811_10,957_10) and NDVI(962_10,802_10) performed best. No satisfactory conventional NDVI formed by red and NIR bands were found effective. MODIS_NDVI(band19, band17) and MODIS_NDVI(band19, band2) were much better than MODIS_NDVI(band2,band1) for growth monitoring.

Keywords: spectral indices, growth monitoring, optimal band, MODIS

1. Introduction

Recent researches on the field spectroradiometers and airborne hyperspectral sensor data have shown that the narrow bands may be crucial for providing additional information with significant improvements over broad bands in quantifying biophysical characteristics of agricultural crops. Many spectral indices have been developed and proved to be diagnostic for the dynamic change of biochemical or biophysical parameters during crop growth season. For example, R_{NIR}/R_{700} and R_{NIR}/R_{500} (here R_{NIR} represents reflectance of near infrared platform, R_{500} represents reflectance at 500nm, the same below.) have significant relationships with chlorophyll content of two kinds of broadleaf trees[1] ; R_{680}-R_{500} is sensible to the photosynthesis pigment change during the leaf senescence stage[2]; R707/R589 performs fairly well in monitoring nitrogen concentration[3]; LAI and coverage fragment are both correlated highly with narrow bands ratios of the near infrared platform and with the red edge[4]; . However, most of the present analysis about spectral indices tends to be static and constrained to a certain stage or moment, while dynamic analysis is not thorough enough, especially short of an effective evaluation to the spectral indices in tracking dynamic change of crop growth.

So the main goal of this study is to develop some spectral indices which will be suitable for hyperspectral remote sensing and sensible to crop growth change during a long period or a growth season. In aid of these spectral indices, applications of hyperspectral remote sensing in the fields such as agriculture, environment surveying will be promoted effectively.

2. Data and measurements

The study site is a located in Xiaotangshan Precision Agriculture Demonstration Area, Beijing, in which the wheat plantation is about 100-ha. The whole site is flat and cultivated orderly. During the period April 4 to May 17, 2001, wheat spectra and the best growth indicators, biomass and LAI (Thenkabail P.S. 1995, Fassnacht K.S. 1997), were measured every five to ten days on the 45 even-distributed plots and abnormal plots which had accurate differential GPS data with them. The instrument was ASD Fieldspec FR2500 field spectrometer, which could acquire 2151 bands within 350~2500nm spectral range with sampling interval of 1.4nm in 350~1000nm range and 2nm in 1000~2500nm range respectively. Spectra measurements were performed between 10：00a.m.～14：00p.m. under clear weather and no wind or slow wind. For each sample, ten times of measurements were acquired and got the average as the final representative spectrum in order to avoid random error.

While the field spectra were being measured, plant sample above the ground of a 0.6×0.4 m^2 area near to the spectra measurement spot was taken synchronously and sent to lab nearby for LAI and dry biomass analysis rapidly. LAI was obtained by the dry weight method. Firstly, 50~100 leaves were chosen and measured their areas, oven-dried and weighed on a simple weighing machine. Then LAI was determined according to the dry weight and corrected by CI-203 laser leaf area meter. The corresponding dry biomass was weighed by the weighing machine after all the leaves of one sample were dried for 15 minutes by an oven. In the end, 140 sets of spectrum, biomass and LAI were acquired totally in 2001.

3. Methods

1) Developing spectral index by correlation analysis

The ideal NDVI type spectral indices should be sensible to wheat growth change during a long time period, namely these indices should be not only sensible to LAI change but also to biomass change. However, they will not be constrained to the red and NIR bands. In fact, all the useful bands within 350~2500nm range was take into consideration in our study. Due to the severe noise of water vapor absorption bands of 1.4μm and 1.94μm as well as of the end of the spectrum (2.5μm), these bad bands were excluded and only 1639 bands were considered. All possible two-band NDVI combinations were calculated their determinate coefficients (R^2) with LAI and biomass. Fig.1 showed the R^2 >0.4 distribution. It was obvious that R^2 between NDVI and biomass (over the diagonal) was higher than that between NDVI and LAI(under the diagonal), especially in the ranges of 750～1100nm and 1100~1350nm, the R^2 with biomass were all higher than 0.6, even up to 0.8. While most of the higher R^2 between NDVI and LAI were centered between 0.4 and 0.6, and R^2 of 0.5-0.6 occurred in the ranges of 1000～1150nm and 750-900nm. It also showed that the narrow-band NDVI（818nm,960nm） was most sensible to the two wheat growth indicators change（with the largest sum of the two corresponding R^2）. Further analysis indicated that the NDVI combinations of 746-812nm and 1132-1358nm, 759-811nm and 949-1029nm, 864-917nm and 1007-1047nm, 812-889nm and 942-976nm, 796-861nm and 1128-1164nm, 812-861nm and 985-1039nm had higher R^2 with both biomass (> 0.6) and LAI(>0.4) . Therefore a thorough analysis was made on these range combinations so as to find the optimal central wavelengths and band widths. For each range combination, all possible adjacent 10nm～30nm width bands (step was 5nm) were averaged and the corresponding NDVIs, accordingly R^2 with LAI and biomass were calculated. The NDVI with the largest sum of the two R^2 was the optimal one. It turned out, all R^2 of the optimal NDVIs decreased as bandwidth increased. Table 1 listed the optimal NDVIs of 10nm bandwidth.

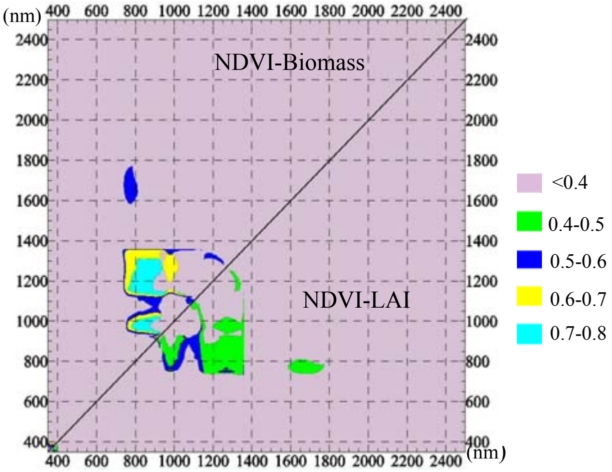

Fig.1 Plot of R^2 over 0.4 between NDVI and biomass (over the diagonal) and between NDVI and LAI (under the diagonal) .

Tab.1 NDVIs most sensible to wheat growth change (n=140)

NDVI		R^2 with biomass	R^2 with LAI
Band1 (nm)	band2 (nm)		
957_10*	812_10	0.7389	0.4738
962_10	802_10	0.7342	0.4773
1137_10	813_10	0.707	0.491
1139_10	803_10	0.7029	0.4933
992_10	812_10	0.7353	0.4582
1007_10	864_10	0.728	0.4586
MODIS－NDVI		R^2 with biomass	R^2 with LAI
915-965(band19)	890-920(band17)	0.7393	0.4412
915-965(band19)	841-876(band2)	0.6327	0.4978

* 957_10 represents band with 957nm as beginning wavelength and 10nm width，the same for other bands except MODIS bands.

In addition, we also used the field spectrum to simulate the first 19 bands of MODIS (covering 405～2135nm spectral range).l It showed that the conventional NDVI by band1(red band) and band2(NIR band) had the lower R^2(0.2717 for LAI and 0.2931 for biomass), while NDVI(b19,b17) and NDVI(b19,b2) gave the highest R^2 (see table 1).

3.2 Validation of NDVIs for tracking wheat growth change

The generalized vector angle was chosen to avaluate the efficiency of the new NDVI spectral index in tracking wheat growth change. Samples with multi-temporal measurements (here five or four times of measurements) were selected to form the NDVI and LAI(or biomass) time series vectors. The generalized vector angle algorithm was applied on these vectors to compare the shape similarity between the NDVI temporal vector and the growth variable vectors. The generalized vector angle could be calculated by the following equations：

$$\theta = \cos^{-1} \frac{G \bullet VN}{\|G\| \times \|VN\|} \tag{1}$$

namely,

$$\theta = \cos^{-1} \frac{\sum_{i=1}^{n} g_i \times NDVI_i}{\sqrt{\sum_{i=1}^{n} g_i^2} \sqrt{\sum_{i=1}^{n} NDVI_i^2}} \quad \theta \in [0°, 90°] \tag{2}$$

where $G = (g_1, g_2, \ldots.. g_n)$ and $VN = (NDVI_1, NDVI_2 \ldots.. NDVI_n)$ represent growth variable vector and its NDVI temporal vector (where subscript 1~n represents serial number of the measurement time). The smaller is the angle θ, the greater similarity between the two vectors is. So the NDVI that has the smallest angle between the NDVI and growth variable time series (or vectors) will be the optimal spectral index for growth tracking..

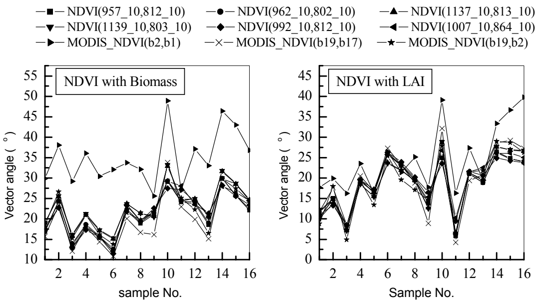

Fig. 2 Vector angle of every sample between each NDVI time series and its Biomass time series (left) and between NDVI time series and its LAI time series (right).

As shown in Fig.2, MODIS_NDVI(b1,b2) were always larger than the other indices, meaning that the conventional NDVI by the red and the NIR waveband performed not very well in diagnosing growth change during a long period. On the contrary, as was expected, the newly developed indices could track the growth change fairly well by giving smaller vector angles. Statistics of these angles showed that NDVI(957_10,812_10) and NDVI(962_10,802_10) formed the smallest vector angles with both LAI and biomass, and MODIS_NDVI(b19,b17) took the second place. All the larger angles were generally larger in this study, which should be attributed to the fact that the temporal resolution of this time series was not enough.

4. Summary and Conclusion

This research chose biomass and LAI as the best indicators of crop growing conditions. Based on a long term field wheat measurements, some wavelength portions of interest and thereby some optimal NDVI type narrow band spectral indices were determined, which had remarkably strong relationship with both LAI and biomass. Six 10nm-width optimal NDVI type spectral indices were determined within 750-1400nm. Furthermore, by simulating the first 19 bands of MODIS sensor, the two NDVIs formed by band19 and band17, band19 and band2 had much more significant linear correlationship with the both growth indicators than the traditional NDVI by red and NIR band combinations. By using generalized vector angle as the measure, the 9 spectral indices were validated for their efficientcy of tracking crop growth change. NDVI(957_10,812_10) and NDVI(962_10,802_10) were most sensible to the changes of both LAI and biomass, and MODIS_NDVI(b19,b17) took the second place. These results demonstrate that the widely used red and NIR band combinations are not necessarily the best of NDVI type indices for vegetation growth change monitoring.

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