Rice Science, 2007, 14(3): 195-203

New Vegetation Index and Its Application in Estimating Leaf Area Index of Rice

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Abstract: Leaf area index (LAI) is an important characteristic of land surface vegetation system, and is also a key parameter for the models of global water balancing and carbon circulation. By using the reflectance values of Landsat-5 blue, green and red channels simulated from rice reflectance spectrum, the sensitivities of the bands to LAI were analyzed, and the response and capability to estimate LAI of various NDVIs (normalized difference vegetation indices), which were established by substituting the red band of general NDVI with all possible combinations of red, green and blue bands, were assessed. Finally, the conclusion was tested by rice data at different conditions. The sensitivities of red, green and blue bands to LAI were different under various conditions. When LAI was less than 3, red and blue bands were more sensitive to LAI. Though green band in the circumstances was less sensitive to LAI than red and blue bands, it was sensitive to LAI in a wider range. When the vegetation indices were constituted by all kinds of combinations of red, green and blue bands, the premise for making the sensitivity of these vegetation indices to LAI be meaningful was that the value of one of the combinations was greater than 0.024, i.e. visible reflectance (VIS)>0.024. Otherwise, the vegetation indices would be saturated, resulting in lower estimation accuracy of LAI. Comparison on the capabilities of the vegetation indices derived from all kinds of combinations of red, green and blue bands to LAI estimation showed that GNDVI (Green NDVI) and GBNDVI (Green-Blue NDVI) had the best relations with LAI. The capabilities of GNDVI and GBNDVI to LAI estimation were tested under different circumstances, and the same result was acquired. It suggested that GNDVI and GBNDVI performed better to predict LAI than the conventional NDVI.
Key words: vegetation index; rice; leaf area index; reflectance spectrum; remote sensing

Leaf area index is a significant characteristic of land surface vegetation system, which not only can be used to infer land surface processes such as photosynthesis, evaporation, transpiration and to estimate terrestrial ecosystem net primary production, but also is a key parameter in models of hydrology and carbon-circling [1]. The measurement of LAI is important for improving the performance of these models [2]. In addition, the LAI of rice is well correlated to the biomass and production of rice. Traditional measurement of LAI is destructive and time-consuming. The technique of optical remote sensing provides a simple, precise and nondestructive way to retrieve LAI from regional to global scales.

There are primarily two approaches to estimate vegetation parameters such as LAI. The first approach is to establish an empirical relationship between vegetation indices and LAI. The second one involves using bidirectional reflectance distribution function (BRDF) models. It inverts a BRDF model with radiometric measurements to estimate LAI using an optimization procedure [5]. Though the two approaches both have advantages and limitations, the first one is widely used due to simple computation [6-8]. The normalized difference vegetation index (NDVI) is one of the most extensively applied vegetation indices related to LAI, but it was criticized for the following reasons: 1) Differences between the 'true' NDVI, as would be measured at the surface, and that actually determined from space are sensitive to attenuation by the atmosphere and by aerosols. 2) The sensitivity of NDVI to LAI becomes increasingly weak with increasing LAI beyond a threshold, which is typically between 2 and 3. And 3) Variations in soil brightness may produce large variations in NDVI from an image to the next [9]. Thus, many researchers commit

Received: 19 December 2006; **Accepted:** 5 March 2007
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This paper was translated from its Chinese version in *Chinese Journal of Rice Science*, Vol. 21, No. 2, 2007, Pages 159-166.

themselves to solving the problems. On the one hand, new vegetation indices were developed to minimize the effects of atmosphere [10] and soil brightness on NDVI [11-12]. On the other hand, from the point of the reason of NDVI saturation, some other new vegetation indices such as green NDVI (GNDVI) [13], visible atmospherically resistant index (VARI) [14] were also propounded. However, compared to the study on the effect of atmosphere and soil, that of NDVI saturation is not enough.

NDVI is the function of reflectance of red and near infrared (NIR) bands, which are the most extensively used bands. Because of the high chlorophyll absorption in the red and high reflectance in NIR of live plant tissue [15-16], the two bands contain much of vegetation information. However, some researchers tend to pay attention to the absorption characteristic of red band, and to neglect the easily saturated property and the use of green and blue bands. Many studies indicated that green band was well correlated to vegetation parameters. Yoder et al [18] used the green channel in a vegetation index and found that it had a better correlation with photosynthetic activity of miniature Douglas-fir trees than a red channel. Gitelson et al [19] analyzed the sensitivity of visible reflectance to chlorophyll and pointed out that the green channel was more sensitive to chlorophyll than the red channel, and thus the GNDVI was developed. Gitelson et al [20] also used a green channel to estimate vegetation cover and achieved satisfactory precision. Though the blue channel also contains vegetation information, it has seldom been applied in remote sensing of vegetation. The objective of this study is to try to replace the red band of NDVI with the combination of visible red, green and blue bands to create new vegetation indices, and to evaluate the abilities of all these vegetation indices to estimate LAI of rice.

MATERIALS AND METHODS

Rice materials

A japonica rice variety Xiushui 110 was used to construct the regression equation in 2002. The characteristics of Xiushui 110 was as following: 145 days of growth duration, dark green, short and erect leaves with slippery surface, not lodging at high doses of nitrogen fertilizer, compact canopy structure, tolerances to chilliness and weak-light, weak resistance to blast, wide adaptability, and not easily shattered grains. An indica rice variety Jiazao 324 with 100-105 days of growth duration, and an indica hybrid rice Xieyou 9308 with 140-145 days of growth duration were used for validation in 2002. In addition, Xiushui 110 planted in 2003 was also used for validation.

Experimental site

The study was conducted at the Experiment Farm of Zhejiang University, Hangzhou, China (30°14′ N, 120°10′ E), and arranged in a completely randomized design with four repeats. Each plot was 4.76 m × 4.68 m, and the rice was planted at a row spacing of 17 cm × 13 cm. The physical and chemical properties of paddy soil were as the followings: sandy loam texture; organic matter, 9.96 g/kg; total nitrogen content, 1.15 g/kg; available nitrogen content, 188.5 mg/kg; total phosphorus content, 1.21 g/kg; total potassium content, 72.7 mg/kg.

Measurement

Spectroradiometer

The measurement instrument was the ASD FieldSpe Pro FR^{TM}, which was manufactured by Analytical Spectral Devices. The spectral range of the spectroradiometer was 350 nm to 2500 nm with the spectral sampling interval and resolution of 1.4 nm and 3 nm in the range of 350–1000 nm, and 2 nm and 10 nm in the range of 1000–2500 nm, respectively.

Reflectance of rice canopy

The reflectances of rice canopy were collected on 7 July, 23 July, 30 July, 5 August, 22 August, 31 August, 20 September, 3 October in 2002. Single readings were always taken horizontally to the canopy between 10:00 and 14:00 with a field of view of 25°. There were no wind effects on leaf angle leading to different spectral responses during the period of measurement. Before each measurement, a dark current

Table 1. Computation formulae of various VNDVI.

Index	Formula	Resource
NDVI	NDVI=(NIR-Red)/(NIR+Red)	Rouse et al (1974)
Green NDVI	GNDVI=(NIR-Green)/(NIR+Green)	Gitelson et al (1996) [13]
Blue NDVI	BNDVI=(NIR-Blue)/(NIR+Blue)	This paper
Green-Red NDVI	GRNDVI=[NIR-(Green+Red)]/ [NIR+(Green+Red)]	This paper
Green-Blue NDVI	GBNDVI=[NIR-(Green+Blue)]/ [NIR+(Green+Blue)]	This paper
Red-Blue NDVI	RBNDVI=[NIR-(Red+Blue)]/ [NIR+(Red+Blue)]	This paper
Pan NDVI	PNDVI=[NIR-(Green+Red+Blue)]/[NIR+(Green+Red+Blue)]	This paper

NIR, Green, Red and Blue denote the reflectances of near infrared, green, red and blue channels.

and a white-panel correction were performed. Ten readings were collected for each measurement sample, and then the average reflectance was acted as the reflectance of the corresponding sampling point.

LAI measurement

After the spectral measurement, the corresponding rice samples were taken to laboratory for LAI measurement. The single area of rice leaf is obtained through multiplication of length and width of leaf multiplied by corrected coefficient, as following formula: Single leaf area=Length×Width×Corrected coefficient; And then the whole leaf area of the rice sample was computed from all the single leaf areas. At last the LAI was obtained. Due to special characteristics of rice leaf at different stages, the corrected coefficients for the seedling stage and maturity stage are 75%, and other stages are 83%.

Selection of simulated bands

Landsat-5 satellite has served for more than 20 years since the launch in 1984, and has accumulated lots of data on the each observation. To validate the result of experimental plots from the satellite images, the spectral range of the blue channel (450-520 nm), green channel (520-600 nm), red channel (630-690 nm) and NIR channel (760-900 nm) of Landsat-5 TM were selected for simulation. The average reflectance was taken as the simulation reflectance of the corresponding channel.

Calculation of all kinds of NDVIs

To fully explore the useful information in visible spectral range, the red band reflectances of NDVI were replaced by all the combinations of red, green and blue reflectances, including green, blue, red reflectances, the sum of green and red reflectances, the sum of green and blue reflectances, the sum of red and blue reflectances and the sum of all the three band reflectances. All the formulae are listed in Table 1.

The general formula is as follows:

Visible NDVI=VNDVI=(NIR-VIS)/ (NIR+VIS); (1)

Where, NIR is near infrared reflectance, VIS is the visible reflectance, which is either a single band reflectance of red, green, blue bands, or the combinations of them. In the following of the paper, VNDVI is taken as the general name of NDVI, GNDVI, BNDVI, GRNDVI, GBNDVI, RBNDVI and PNDVI.

Computation of coefficient of variation

Coefficient of variation (*CV*) is calculated as the standard error divided by the mean ($\bar{x}$), which is used to analyze the deviation of data. The greater the *CV*, the more scattered the data.

RESULTS

Correlation analysis

Correlation between the reflectances of the visible bands

All VNDVI in Table 1 are consisted of various combinations of the four band reflectances, which are blue, green, red and NIR reflectances. From Table 2, it could be seen that the reflectances of visible bands were highly positively correlated with each other (correlation coefficients were all over 0.95), of which the reflectances of red and green bands were the most

Table 2. Coefficients of correlations between reflectances of different bands.

Band	Blue	Green	Red	NIR
Blue	1.000000	0.964080	0.981766	-0.382550
Green	0.964080	1.000000	0.973484	-0.308250
Red	0.981766	0.973484	1.000000	-0.428050
NIR	-0.382550	-0.308250	-0.428050	1.000000

highly correlated with the correlation coefficient of 0.981766; the correlation between the reflectances of red and green bands was in the next place with the correlation coefficient of 0.973484; and that between the reflectances of green and blue bands was less highly correlated with a correlation coefficient of 0.96408. The high correlation meant that the two bands contained more redundancy information. On the contrary, less correlation indicated that two bands had more independent information. Therefore, more information was included between green and blue bands. Despite of this, the R^2 of the fitted regression linear equation between the two band reflectances was up to 0.9295. However, the reflectance of NIR band was less negatively correlated with that of the visible bands, indicating that in general the reflectance of visible band decreased with the increasing of the reflectance of NIR band.

Correlation between all kinds of VNDVI

Since the reflectance of single bands was highly correlated with each other, the combinations of them must be also highly correlated. The correlation analysis showed that all the correlation coefficients were greater than 0.97 between the VNDVIs (Table 3). The greater correlation coefficients indicated that the two vegetation indices were similar, while the less ones showed that the two vegetation indices had more differences, which come from the integrated effect of differences in bands and the form of NDVI equation. The coefficients of correlation between BNDVI and GRNDVI or PNDVI were relatively less, which was attributed to the relatively great differences among reflectances of the blue band, green band and sum of red, green and blue bands. The coefficients of correlation of the others were larger than 0.99, which indicated the two vegetation indices were well linearly correlated and the similar precision might be achieved as estimating LAI by using them.

Sensitivity analysis

The sensitivity of red, green and blue reflectances to LAI and the comparisons of the vegetation indices derived from them

The premise of reliably and accurately estimating environmental variable from remotely sensed data is to inspect if this variable is a state variable of radiation problem and if it significantly affects the measurements. In other words, it must be assumed that a change of the radiation variable of interest will result in a significant variation of the spectral measurements. This, in turn, implies that the point representative of the system under study in spectral space will be displaced when the property of interest changes [21]. LAI obviously belongs to the variables that can cause radiation variations. Though the reflectance of rice canopy is affected by multiple factors such as reflectance and transmission of single leaf, soil background, leaf angle, the geometry of sun and sensor angles, LAI and so on, the effect of LAI is significant (Fig. 1).

Before analyzing the relationships between all kinds of VNDVIs and LAI, the relations between each

Table 3. Coefficients of correlations between all kinds of VNDVIs.

VNDVI	BNDVI	GNDVI	NDVI	GBNDVI	RBNDVI	GRNDVI	PNDVI
BNDVI	1.000000	0.981412	0.986607	0.985854	0.991225	0.976548	0.976641
GNDVI	0.981412	1.000000	0.989467	0.998583	0.994491	0.997938	0.996915
NDVI	0.986607	0.989467	1.000000	0.989107	0.996799	0.991181	0.987807
GBNDVI	0.985854	0.998583	0.989107	1.000000	0.996643	0.997488	0.998166
RBNDVI	0.991225	0.994491	0.996799	0.996643	1.000000	0.995384	0.994833
GRNDVI	0.976548	0.997938	0.991181	0.997488	0.995384	1.000000	0.999257
PNDVI	0.976641	0.996915	0.987807	0.998166	0.994833	0.999257	1.000000

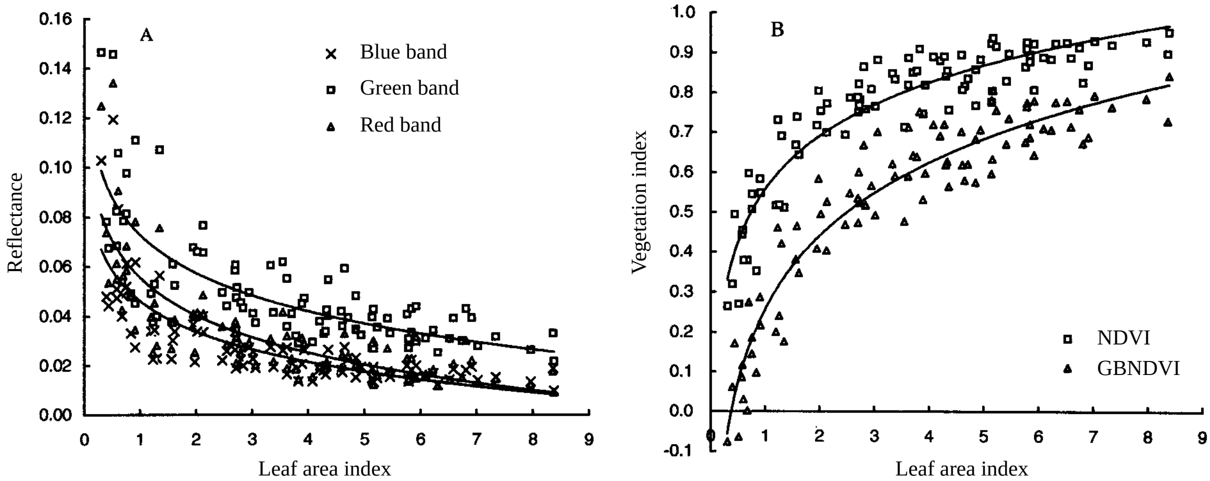

Fig. 1. Relationship between LAI and the reflectances of three bands (red, green and blue bands) and two vegetation indices (NDVI and GBNDVI).

VNDVI (NDVI, GNDVI, BNDVI, GRNDVI, RBNDVI, GBNDVI and PNDVI) and LAI were studied. Fig. 1-A presented that there existed the relations between the LAI of rice and the reflectances of blue, green and red bands, the reflectances of red, green and blue bands decreased with the increasing of LAI, being quickly decreased at LAI within 2, at which the reflectance was sensitive to LAI variation. For the red and blue bands, the reflectances stopped decreasing as LAI increased up to 3 or 4, which had decreased to 2-2.5%, while at LAI over 6, the reflectances of the two bands reached an asymptote. Therefore, vegetation indices constructed from the red and blue reflectances were sensitive to LAI as LAI was less than 3. However, the green reflectance didn't obviously reach an asymptote even LAI was beyond 5 or 6. Compared to vegetation indices constructed from the red and blue reflectances, the vegetation index from the green reflectance was less sensitive to LAI when LAI was within 3. It could be seen that the sensitivity of reflectance of spectral bands to LAI was associated with the range of LAI, the vegetation indices constructed from single red (blue) or green band all had limitations, thus it was reasonable to take into account the combination of these bands to construct vegetation indices. Fig 1-B showed the relations between the vegetation indices constituted from combinations of different bands and LAI. There existed better exponential relationship between LAI and NDVI or GBNDVI. NDVI values reached an asymptote as LAI was at about 3, while GBNDVI values couldn't obviously reach a saturation level even LAI was about 4 or 5. This indicated that LAI could not be accurately estimated only from the use of red band when LAI was greater than 3, and if the green and blue bands were taken into account, the more accurate estimation should be expected.

The sensitivity of visible band reflectance to LAI and its effect on the estimation of LAI from all kinds of VNDVIs

The above analysis was limited to the general response of the single band and the vegetation indices to LAI. The following would analyze the sensitivity of the bands to LAI and the relation between vegetation indices and LAI from another point of view, which was the coefficient of variation in reflectances of spectral bands.

All the VNDVIs (NDVI, GNDVI, BNDVI, GRNDVI, RBNDVI, GBNDVI and PNDVI) were the functions of visible and NIR band reflectances. The value of vegetation index was determined by the reflectance value of spectral band and the form of the formula. Thus, the following analysis on the sensitivity of all kinds of VNDVIs to LAI was performed from two different perspectives: one is the standard deviation, coefficient of variation (*CV*) of spectral reflectance due to the variation of LAI, the other is the requirement for VIS of VNDVI formula under the conditions of saturation.

The sensitivity analysis of vegetation index based on standard deviation and coefficient of variation

Due to the common use of NIR band reflectance in all kinds of VNDVIs, only the VIS part of equation 1 is analyzed hereinafter. Fig. 2 presented the means, standard deviations and coefficients of spectral reflectance under LAI ranged from 0-8.38 (A), 3-8.38 (B) and 0-3 (C). It could be seen from Fig. 2 that the variation trends of mean and standard deviation of spectral reflectance were similar in different LAI ranges with the only difference in quantity. The coefficient of variation behaved differently in short wave region. The coefficient of variation was smaller at LAI ranged from 3 to 8.38, while it was larger under the two other conditions.

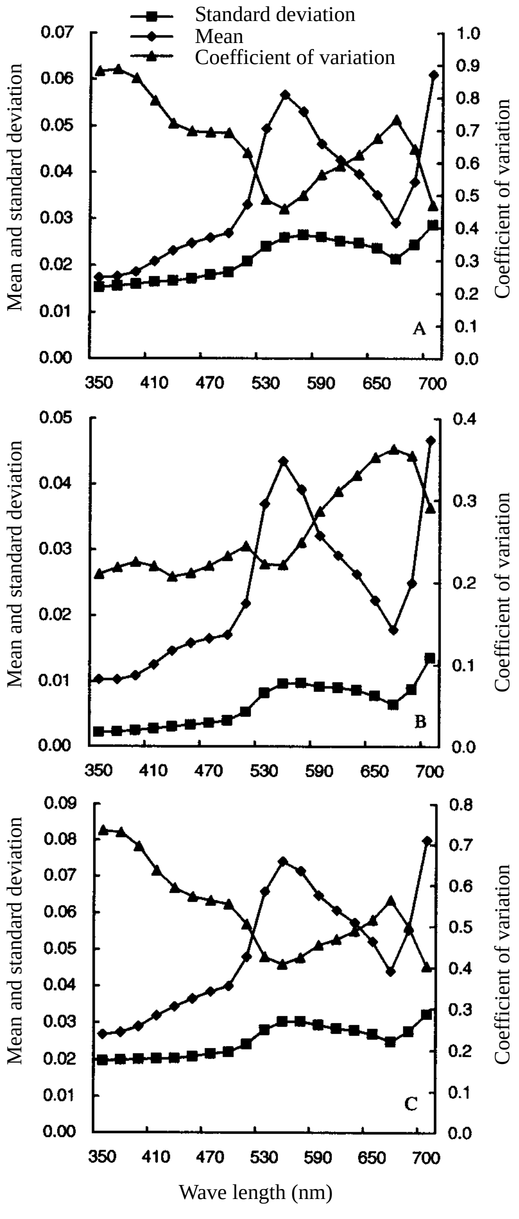

Fig. 2. Mean, coefficient of variation, and standard deviation of spectral reflectance under different LAI ranges.
A. 0≤LAI≤8.38; B. 3≤LAI≤8.38; C. 0≤LAI<3.

The coefficient of variation denotes the relative degree of variation in reflectance, which reflects the relative sensitivity of reflectance of spectral bands to LAI, while the standard deviation of reflectance indicates the absolute degree of variation in reflectance, which presents the absolute sensitivity of reflectance of spectral bands to LAI. Both of them should be considered when estimating LAI from vegetation indices. If they all are relative large, the corresponding spectral band must be one of the optimal bands. However, they often behave differently. From Fig. 2-B, the coefficient of variation and the standard deviation of reflectance in the blue spectral region were small compared to those in the red and green spectral regions, so those in the blue spectral region must be less sensitive to LAI variation. However, it could be seen from Fig. 2-A and C that the coefficient of variation and the standard deviation of reflectance behaved differently, so it was difficult to determine which was better for LAI estimation. Therefore, further study should be given to the problem.

The requirement for VIS of VNDVI equation under the conditions of saturation threshold

It was difficult to determine which band was better for LAI estimation only through the above analysis. When the vegetation indices were created, not only the combination of relative and absolute sensitivity but also the form of the VNDVI formula should be taken into account. In general, VNDVI reaches a saturation point at the value of 0.9 even 0.8. Here, the value of 0.9 was supposed to be the saturation point of vegetation indices, and then they had not reached their saturation point when they were less than 0.9. It could be expressed by following equation:

$$VNDVI= (NIR-VIS)/(NIR+VIS) < 0.9 \rightarrow NIR/VIS; \quad (2)$$

Usually, the NIR reflectance could reach 0.4-0.5 in the period of the most vigorous stage, and the mean value is 0.45. Take this to the equation 2, and then the result is: VIS > 0.024.

The conclusion of above expressions is that as the VIS value is beyond 0.024, the relative greater coefficient of variation denotes that not only the corresponding reflectance band is sensitive to LAI, but also the VNDVI will not be saturated. That is to say that the sensitivity expressed by coefficient of variation is more effective than that by standard deviation. On the contrary, if only the coefficient of variation is relative large and VIS is less than 0.024, the relative large coefficient of variation is meaningless due to the saturation of VNDVI. Therefore, the absolute sensitivity expressed by standard deviation could be taken as the criterion of band selection for LAI estimation

The sensitivity analysis based on the combination of the above two conditions

It could be seen from Fig. 2-B that when LAI was greater than 3, though the coefficients of variation of the red and blue reflectances were relative large, the vegetation indices derived from the red and blue bands had no obvious response to LAI variation because the red and blue reflectances were less than 0.024. On the contrary to the red and blue bands, the green band reflectance was above 0.024. Therefore, the vegetation indices derived from the green band reflectance might have high correlation with LAI. But the relative sensitivity of the green band was less than that of the red band. When LAI is less than 3, the mean reflectance of red and blue bands were greater than 0.024 (Fig. 2-C), so the larger coefficients of variation in reflectances of red and blue bands had direct effects on the vegetation indices constructed from these two bands, and further on LAI. Compared to the red and blue spectral bands, the sensitivity of green spectral band was less despite the reflectance of the green band was above 0.024. In Fig. 2-A, though the reflectances of red and blue bands were above 0.024 and the relative sensitivities of red and blue reflectances were greater than that of the green band reflectance for a wide LAI range, this implied the saturation of the reflectances of red and blue bands as LAI was less than 3. Thus, the vegetation indices constructed from the red and blue band reflectances were moderately correlated with LAI, while those from the green band reflectance had high correlation with LAI. But the relative sensitivity was attenuated due to the less coefficient of variation. Therefore, in the red, green and blue spectral bands, it seems that the reflectance of green spectral band had more sensitive response to LAI variation in wide range. If the sensitivity of the red and blue spectral bands in LAI<3 range had been taken into account, it was reasonable to integrate the reflectances of red or blue band with the green band to construct vegetation indices for estimate LAI in a wide range.

Model and validation

Models for LAI estimation based on VNDVI

According to the relationship between VNDVIs and LAI, all kinds of models to estimate LAI using VNDVIs were established. In general, there was an exponential relationship between LAI and those vegetation indices. After comparing the fitted regression equations, it was true that the optimal regression form was exponent for the whole developmental stage.

From Fig. 3, the relation between LAI and VNDVIs was well fitted, the difference did exist, in which GBNDVI produced the best fitted regression equation with R^2 of 0.8858. GNDVI, GRNDVI, RBNDVI and PNDVI were in the next place, with R^2 of fitted equations all above 0.87. There were a relative worse fitness for BNDVI and NDVI, with R^2 of 0.8698 and 0.8563, respectively. Despite the R^2 of fitted equations were of little difference, it was reflected that the vegetation indices by replacing the red band reflectance of NDVI with the combination of visible band reflectance, especially the green band reflectance and the combination of green and blue band reflectances, were highly correlated with LAI. The conclusion was consistent to the preceding analysis.

Validation of LAI estimation using the vegetation indices

Unlike the validation commonly using the root mean squared error (RMSE) as criteria, the validation in this study was from the view of whether the vegetation indices constructed from the green band reflectance and combination of green and blue band reflectances were vigorous for more other conditions. The data from the different varieties in the same

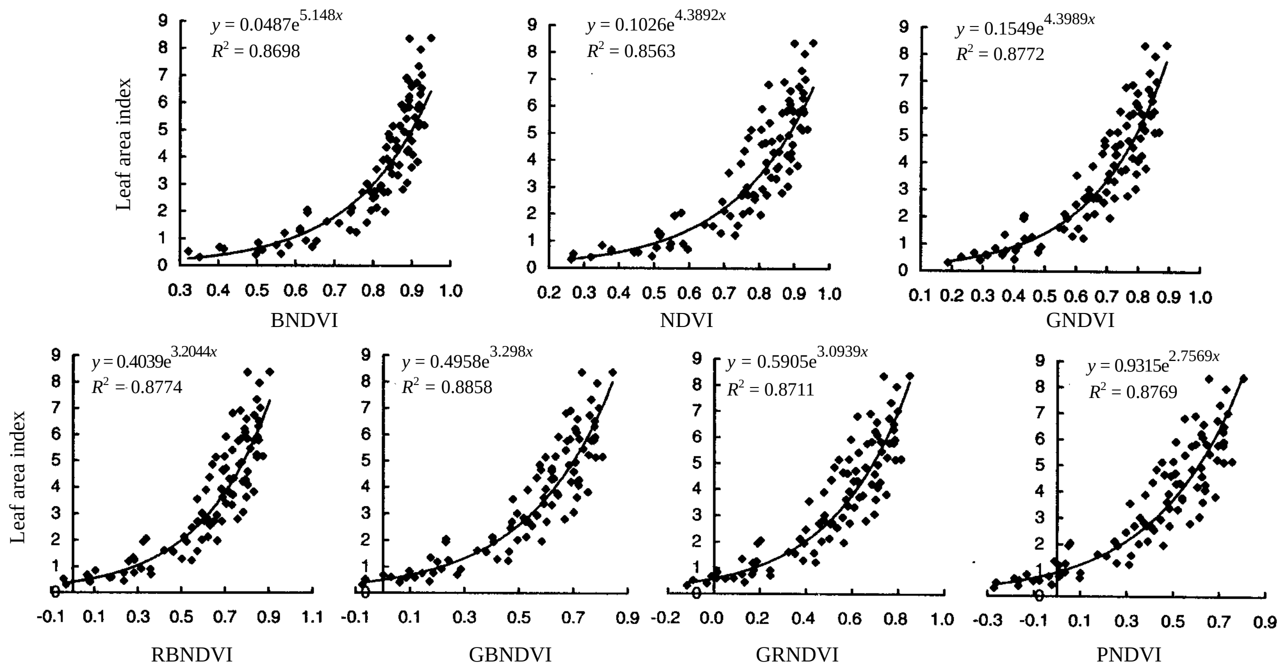

Fig. 3. The best fitted regression equitation between LAI and all kinds of VNDVIs.

growth period and the same variety in different growth periods had been used for validation. The varieties of rice planted in 2002 for validation were Jiazao 324, with the whole growth duration being 100-105 days, and Xieyou 9308, with the whole growth duration of 140-145 days. In addition, Xiushui 110 planted in 2003 was also used for validation. The results indicated that the vegetation indices constructed from the green band reflectance or the combination of green and blue band reflectances in the two conditions always showed better relation with LAI. The R^2 of the best fitted equations was presented in Table 4. The equations with the first two maximum R^2 were always fitted between LAI and GNDVI or GBNDVI. Although the values of R^2 were relatively low, they present the trend of variation. Therefore, it was concluded that the degree of fit in the fitted equation between LAI and GNDVI or GBNDVI was superior to other vegetation indices.

DISCUSSION AND CONCLUSION

The LAI of rice is correlated to the use of solar energy, dry biomass production and accumulation and the final production, and can be inputted some models as one of the significant parameters such as the SAIL (Scattering by Arbitrarily Inclined Leaves) model. The LAI estimation using remote sensing is superior to the traditional method. In this study, the vegetation indices constructed from replacing the red band reflectance of NDVI with the all combinations of the visible band reflectances were used to estimate LAI of rice. The results indicated that the sensitivities of the red, green and blue band reflectances to LAI varied with different ranges of LAI. When LAI was less than 3, the red and green band reflectances were more sensitive than the green band reflectance, but the green band reflectance was sensitive to LAI in a wide

Table 4. R^2 of the best fitted regression equation under different conditions.

Variety (Year)	NDVI	GNDVI	BNDVI	GBNDVI	GRNDVI	RBNDVI	PNDVI
Jiazao 324 (2002)	0.4261	**0.5799**	0.5493	**0.5761**	0.5142	0.4878	0.5283
Xieyou 9308 (2002)	0.3053	**0.5268**	0.4754	**0.5137**	0.4327	0.3833	0.4461
Xiushui 110 (2003)	0.4295	**0.6718**	0.6482	**0.6636**	0.5618	0.5264	0.5819

range. When LAI was greater than 3, GNDVI and GBNDVI constituted from the green band reflectance or combination of green and blue band reflectances were superior to other vegetation indices (NDVI, BNDVI, GRNDVI, RBNDVI and PNDVI) for LAI estimation, which was determined by the sensitivities of the green band reflectance and combination of the green and blue band reflectances to LAI and the form of VNDVI equation. This study found that when the VIS of VNDVI was greater than 0.024, the high sensitivity of spectral band reflectance to LAI would result in changes in vegetation indices, which caused good relation between these vegetation indices and LAI. When VIS was less than 0.024, the high sensitivity of spectral band reflectance was meaningless because the saturation point of vegetation indices was reached. However, the value of 0.024 was a primarily result, more studies under different conditions should be performed to validate it. At last, the result was validated from two different data sets. It was verified again that a better relation existed between LAI and GNDVI or GBNDVI. Of course, the conclusion should be tested by more and further experiments.

It was to be noted that the results of this study were acquired from the simulation of Landsat-5 channel. The band reflectance in the study is the reflectance from earth surface. However, if satellite images were used, the effect of atmosphere should be taken into account. Though the blue band is more easily affected by atmosphere, the accurate surface reflectance could be acquired with the development of the theory and models in atmosphere correction. Therefore, GBNDVI and GNDVI could be used to estimate LAI of rice.

ACKNOWLEDGEMENTS

This study was supported by the National Natural Science Foundation of China (Grant No. 40571115) and the Sci & Tech Basic Work Program, the Ministry of Science and Technology, China (Grant No. 2003DEA2C010-13).

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