Analyses of the correlation between rice LAI and simulated MODIS vegetation indices, red edge position

Cheng Qian, Huang Jingfeng, Wang Renchao, Tang Yanlin

(*Institute of Agricultural Remote Sensing and Information Application, Zhejiang University, Hangzhou* 310029, *China*)

Abstract: In the present study, analyses of the correlation between rice Leaf Area Index (LAI), hyperspectal data, Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI) and the Red-Edge Position (REP) were studied. Hyperspectral data of hybrid rice and common rice in whole growing stage during 2002 was measured using the ASD FieldSpec UV/VNIR Spectroradiometer with resolution of 3 nm and at the same time the rice LAI was measured. The REP may be defined using the first derivative spectrum. The three bands of the Moderate Resolution Imaging Spectroradimeter (MODIS), band 1(620～670 nm, red), band 2(841～876 nm, NIR) and band 3(459～479 nm, blue) were simulated and MODIS-NDVI and EVI were calculated by averaging the continuous reflectance factor (350～1000 nm) over the spectral range of each band. A strong non-linear correlation was found between LAI of two rice varieties and the REP. The REP, MODIS-EVI and MODIS-NDVI were well related with LAI for the common rice, but the REP and MODIS-EVI were more sensitive than MODIS-NDVI to rice LAI for the hybrid rice. The reasons were that LAI of hybrid rice became greater with growth, and MODIS-NDVI was more affected by saturation, but MODIS-EVI and REP were less affected. This showed that the REP and MODIS-EVI will be more effective in monitoring the rice LAI.

Key words: analyses of correlation; rice LAI; simulated MODIS-NDVI; REP

CLC number: S127 **Document code**: A **Article ID**: 1002-6819(2003)05-00104-05

1 Introduction

Leaf Area Index (LAI), the one-sided area of leaves per unit ground area, is a quantitative measure of the surface area available for the interception of photosynthetically active radiation (PAR) and transpiration, and consequently is the key spatial variable required to drive models of forest ecosystem processes[1]. LAI is also one of the most important variables affecting rice canopy reflectance and therefore there is a realistic possibility of estimating rice LAI from remotely-sensed data.

Vegetation indices (VI) have emerged as important tools in the monitoring, mapping, and resources management of the Earth' terrestrial vegetation. They are radiometric measures of the amount, structure and condition of vegetation, which serve as useful indicators of seasonal and inter-annual variations in vegetation. The recently launched Moderate Resolution Imaging Spectroradimeter (MODIS) onboard the Terra platform offers many improvements for land studies and VI production. These include improved sensitivity to chlorophyll and less contamination by atmospheric water vapor through narrower bandwidths in the red and NIR, respectively. In addition, the finer pixel size (250 m red and NIR bands) provides improved VI monitoring and detection capability.

In fact, different studies have already demonstrated the potential of the optical vegetation indices to monitor the rice growth[2,3]. In relation to the recently launched MODIS, the key instrument onboard the Terra platform, the expectation is that performing the NDVI, a continuity index, as well as the EVI, will result in more precise and accurate measures of the vegetative cover. Whereas, the NDVI is chlorophyll sensitive and responds mostly to red band variations, the EVI is more NIR sensitive and, as results of the penetrating properties of the NIR band, is more responsive to canopy structural variations, including LAI, canopy type, and canopy architecture[4]. Some researchers have analyzed the difference between the MODIS-NDVI and EVI[5], and applied the MODIS vegetation indices in land monitoring and tree growing monitoring, but they have not studied the relationships between the MODIS-VI and LAI[6,7].

Guyot et al. (1992) suggested that the REP is determined by the level of red and near-infrared reflectance, the variation of which is dominated by change in LAI[8]. This suggests that the REP should provide a useful tool for LAI estimation with the advantages of hyperspectral data outline above. In China, many workers have performed to study the relationships between the hyperspectral variables and

---

Received date: 2003-06-20

Foundation item: Project is supported by the National Natural Science Foundation of China (No. 40171065)

Biography: Cheng Qian, associate professor, PhD candidate, majored in remote sensing and GIS application. Zhejiang University, Hangzhou 310029, China. Email: qiancheng525@yahoo.com.cn

LAI, pigments, etc., and they have found the LAI was well correlated with the REP[9~11]. Although the NDVI has been widely used for estimating the LAI of vegetation canopies, it is unlikely to provide reliable estimates of LAI in plants because of the independent variation of canopy cover which affects the index[1], and because of saturation at relatively low LAI values. In close plants, when LAI is greater than 2 or 3, the NDVI will not change with the LAI[12]. Because rice is different from other plants, so the saturation problems between rice LAI and MODIS-VI, the REP should be researched, but few scientific workers have dealt with the problems. Among the MODIS-NDVI, MODIS-EVI and the REP, which indices were strongly correlated with rice LAI, this work became more and more important in monitoring rice growing.

The objectives of this study were (1) to investigate the correlations between the rice LAI and hyperspectral reflectance data, MODIS-NDVI, MODIS-EVI and the REP, and (2) to demonstrate that the REP and MODIS-EVI are more sensitive than MODIS-NDVI to rice LAI.

2 Material and methods

2.1 Field site

The experiment was conducted in a paddy field located at the Zhejiang University experimental farm, Hangzhou, China (30°14′N, 120°10′E) in 2002. The mean annual precipitation was 1320.9 mm and the mean annual temperature was 16.2°C. The rice varieties selected in the study were Xieyou 9308 (XIEY) and Xiushui110 (XIUS). XIEY is hybrid rice, XIUS is common rice. The sandy loam paddy soil had the following properties: pH 5.7, organic matter with 16.5 g/kg and total N with 1.02 g/kg.

2.2 Spectral reflectance measurement

The canopy spectral reflectance of different nitrogen levels were measured by Analytical Spectral Devices (ASD) (Fieldspec®) UV/VNIR (350~2500 nm) Spectroradiometer at different stages. The rice canopy Spectra and LAI were observed on July 12th, 17th, 23rd, 30th, August 5th, 22nd, 31st, September 11th, 20th, 28th, October 3rd, during clear and windless days; and always carried out between 10:00 and 11:45 (Beijing time). The 25° field of view of the sensor was toward the nadir, 1.0 m to the rice canopy. The 10 spectral records were averaged to yield a spectral reflectance for each sample. The absolute reflectance factor was obtained by using a white Spectralon panel with spectral reflectance measurements of the rice canopy beforehand and afterwards.

2.3 Leaf area index measurement

After the spectral reflectance was measured, the LAI was measured using the following way immediately.

$$A/a = W/\omega;\ A = a \times W/\omega$$

Where A is the whole leaf area; a is the partial leaf area; W is the dry weight of whole leaf; ω is the dry weight of partial leaf.

a is calculated using MapInfo Professional 6.0.

2.4 Simulating MODIS-NDVI and MODIS-EVI

The measured spectral region ranged from 350 nm to 2500 nm, at resolution of 3 nm. The spectral region ranged from 350 nm to 1000 nm was selected from the measured spectral region ranged from 350 nm to 2500 nm to decrease the size of data and to mainly consider the relationship between LAI and spectral reflectance from 350 nm to 1000 nm.

Spectral response functions were used to simulate plot reflectance in red waveband, MODIS band-1 (620~670 nm), a near-infrared waveband MODIS band-2 (841~876 nm) and a blue waveband MODIS band-3 (459~479 nm) and to calculate the MODIS-NDVI and MODIS-EVI.

$$NDVI = \frac{\rho_{NIR} - \rho_{\text{Red}}}{\rho_{NIR} + \rho_{\text{Red}}} \tag{1}$$

$$EVI = (1 + L)\frac{\rho_{NIR} - \rho_{\text{Red}}}{\rho_{NIR} + C_1\rho_{\text{Red}} - C_2\rho_{Blue} + L} \tag{2}$$

Where ρ_{NIR}, ρ_{Red} and ρ_{Blue} are the surface reflectance for the respective MODIS bands. L is a canopy background calibration factor that normalizes differential red and NIR extinction through the canopy. C_1 and C_2 are the weighing factors for the aerosol resistance. The coefficients adopted in the EVI algorithm are, $L = 1$, $C_1 = 6$, and $C_2 = 7.5$[13].

2.5 Computing the REP

Laboratory experiments have demonstrated a positive relationship between the wavelength of the red-edge position (REP) and the chlorophyll content of leaf samples[14], but attempts to relate the chlorophyll content of complete canopies to the REP have met with only partial success. It was showed, by modeling, that at the canopy level, movement of the red-edge is controlled by LAI.

The REP may be defined using the first derivative spectrum. The first derivative of spectra may be calculated by the following equation[15].

$$\rho'(\lambda_i) = [\rho(\lambda_{i+1}) - \rho(\lambda_{i-1})]/2\Delta\lambda \tag{3}$$

where ρ' is the first derivative spectrum, λ_i is wavelength and $\Delta\lambda$ is the difference of two wavelengths.

Data analysis concentrated on the relationships between rice LAI, the hyperspectral reflectance data, MODIS-NDVI, MODIS-EVI and REP.

3 Results and discussion

3.1 Correlations between rice LAI and hyperspectral reflectance data

Figure 1 showed that the reflectance was greater in NIR wavelength when rice LAI was greater. Rice LAI varied from 0.3 to 8.3 for XIUS and from 1.29 to 9.7 for XIEY.

A correlation spectrum was calculated to highlight statistically significant correlations between rice LAI and reflectance (Fig. 2). Maximum correlation with LAI was found around 680 nm, in line with previous studies[16, 17]. Figure 2 shows that the coefficient of the correlation between rice LAI and reflectance was significant at the 0.01 significance level in the visible and NIR region, because of the absorption of chlorophyll in 400~500 nm and 630~680 nm regions. The correlation coefficient was lower around 550 nm. Rice LAI was well positive correlated with spectrum between 750~1000 nm, with the correlation coefficient being highly significant. This was caused by multiple reflectance of leaf structure in NIR region.

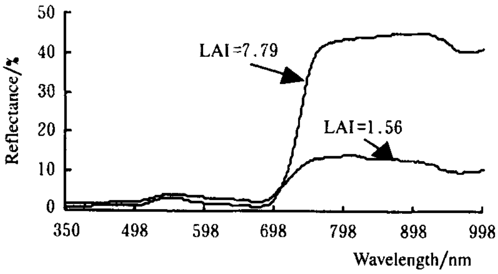

Fig. 1 Reflectance spectrum for two different rice LAI for XIUS

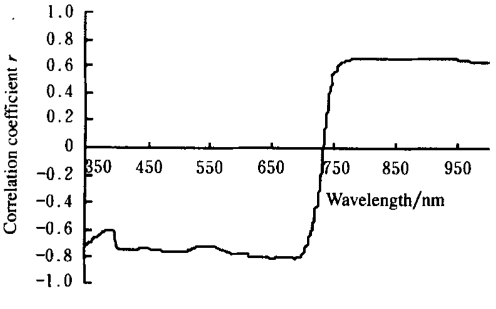

Fig. 2 Correlation spectrum between rice LAI and reflectance in each of the spectro-radiometer wavelengths for XIUS. 99 percent confidence limits shown at $r = 0.38$

3.2 Correlations between rice LAI and MODIS-NDVI

A positive correlation between rice LAI and MODIS-NDVI was observed (Fig. 3). There was no correlation for rice with an LAI greater than 5 because the correlation with red reflectance was low and there was no correlation with near-infrared reflectance. By comparison of XIUS and XIEY, for XIUS, the body of rice LAI is small in whole growth and the coefficient of determination is greater. For XIEY, rice LAI is bigger in whole growth and the coefficient of determination is smaller. For LAI, with the saturation of chlorophyll, NDVI will not change with LAI.

$$NDVI = 0.4992 LAI^{0.3646} \quad R^2 = 0.8237 \tag{4}$$

$$NDVI = 0.0553 LAI + 0.4719 \quad R^2 = 0.3669 \tag{5}$$

Equation (4) and equation (5) show some relationships between NDVI and LAI for XIES and XIEY variety of rice.

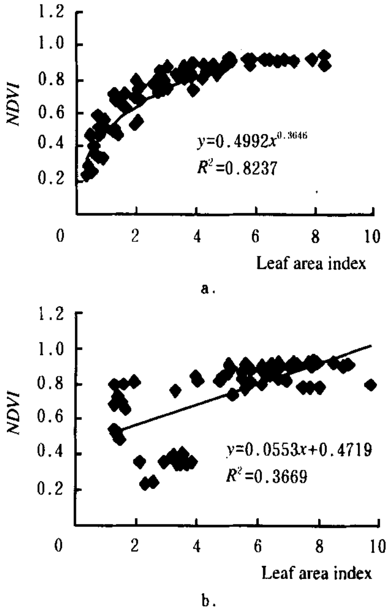

Fig. 3 Relationship between NDVI and LAI with linear and power regression fitted for (A) XIUS and (B) XIEY variety of rice ($n = 68$)

3.3 Correlations between rice LAI and MODIS-EVI

A positive correlation between rice LAI and the MODIS-EVI was observed (Fig. 4). By comparison of Fig. 3 and Fig. 4, the coefficient of determination of EVI and LAI is usually higher than the coefficient of determination of NDVI and LAI for XIUS or XIEY. This demonstrates that EVI can decrease the effects of rice canopy background. There was no correlation for rice with LAI greater than 5 because the correlation with red reflectance was low and there was no correlation with near-infrared reflectance.

$$EVI = 0.2124 LAI^{0.4369} \quad R^2 = 0.7382 \tag{6}$$

$$EVI = 0.2905 LAI^{0.2705} \quad R^2 = 0.4439 \tag{7}$$

Equation (6) and equation (7) show some relationships between EVI and LAI for XIES and

XIEY variety of rice.

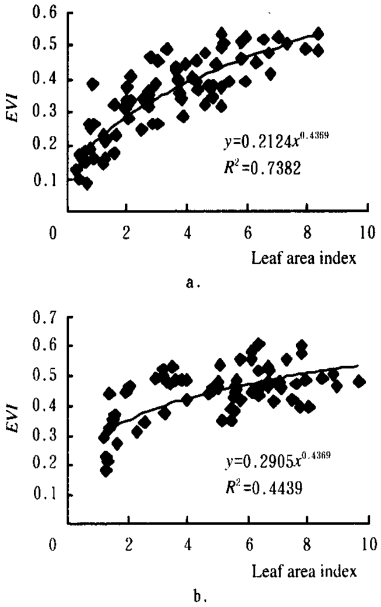

Fig. 4 Relationship between EVI and LAI with power function fitted for (A) XIUS and (B) XIEY variety of rice (n = 68)

3.4 First derivative and red edge position

The first derivative of the spectra was calculated and Fig. 5 showed the variations of the first derivative spectrum in the red edge region. The red edge position was the wavelength corresponding to the maximum value of the first derivative spectrum. In early stage of rice growth, the position of red edge was near shorter wavelength because rice LAI was small. With rice growth the body of rice became greater and rice LAI increased, so the position of red edge shifted to longer wavelength. The shift reached maximum when LAI was greatest in rice booting stage, and after the position of red edge shifted to shorter wavelength in the milking stage with senescence of the leaves below rice canopy. These results were consistent with previous study[18, 19].

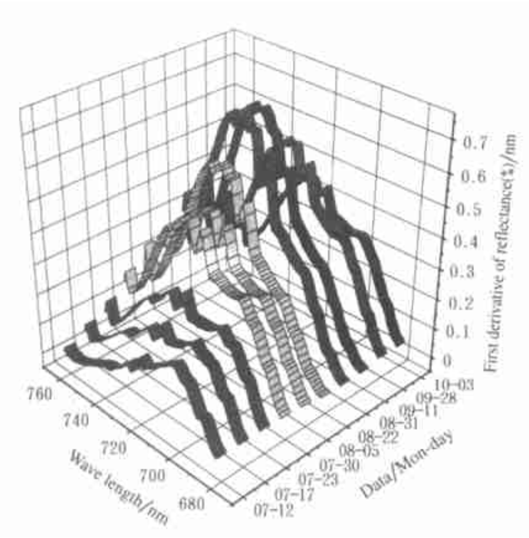

Fig. 5 Variation of first-order derivative spectra with time for XIUS of common rice in 2002

3.5 Correlations between rice LAI and REP

The REP was strongly correlated with rice LAI, this non-linear relationship agreed with the simulations performed by other workers[20], it was considerably strongly than that with the NDVI and reached an asymptote at an LAI of around 5 (Fig. 6).

$$REP = 708.56 LAI^{0.018} \quad R^2 = 0.7085 \tag{8}$$

$$REP = 709.18 LAI^{0.0151} \quad R^2 = 0.587 \tag{9}$$

Equation (8) and equation (9) show some relationships between REP and LAI for XIES and XIEY variety of rice.

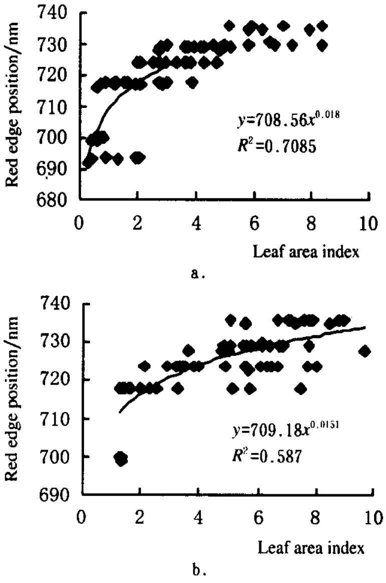

Fig. 6 Relationship between REP and LAI with power function fitted for (A) XIUS and (B) XIEY variety of rice (n = 68)

4 Conclusions

Comparison of MODIS-NDVI, EVI and REP with rice LAI, MODIS-NDVI is unlikely to provide reliable estimates of LAI in different rice variety because of the independent variation of canopy cover which affects the index. The REP and EVI should be less sensitive to change in background reflectance and therefore more reliable at estimation of LAI values. These results have still to be tested in a rice field but in this study, where the rice LAI was consistently high, the REP and MODIS-EVI appear to be more sensitive to LAI than NDVI. These results have implications for work on spectral shifts associated with rice growth, the REP may be controlled by the leaf amount, as measured by LAI, as well as by the chlorophyll content of rice leaf.

[References]

[1] Nemani A R, Pierce L L, Running S W, et al. Forest ecosystem processed at the watershed scale: sensitivity to remotely-sensed leaf area index estimates [J]. Int J Remote Sensing, 1993, 14: 2519～2534.

[2] Shibayama M, Akiyama T. Seasonal visible, near-infrared and mid-infrared spectra of rice canopies in relation LAI and above-ground dry phytonmass [J]. Remote Sens Environ, 1989, 27: 119～127.

[3] Casanova D, Epema G F, Goudriaan J. Monitoring rice reflectance at field level for estimating biomass and LAI [J]. Field Crops Research, 1998, 55: 83～92.

[4] Gao X, Huete A R, Ni W, et al. Optical-biophysical relationships of vegetation spectra without background contamination [J]. Remote Sens Environ, 2000, 74: 609～620.

[5] Huete A R, Didan K, Shimabokuro Y, et al. Regional Amazon Basin and global analysis of MODIS vegetation indices: early results and comparisons with AVHRR [A]. Proceedings of the IGARSS 2000, IEEE International Geoscience and Remote Sensing Symposium [C]. Honolulu, HI, USA, 2000, 536～538.

[6] Tang J M, Zhang S W. Application research of MODIS data in monitoring landuse change [J]. Remote Sensing Technology and Application, 2002, 17: 104～107 (in Chinese).

[7] Qin X L, Yi H R. Monitoring tree growing based on MODIS data [J]. Remote Sensing Technology and Application, 2003, 18: 123～128 (in Chinese).

[8] Guyot G, Baret F, Jacqumemoud S. Imaging spectroscopy for vegetation studies [A]. In Imaging spectroscopy: fundamentals and prospective applications [C]. Edited by F. Toselli and J. Bodechet (Dordrecht: Kluwer). 1992, 145～165.

[9] Wang R C, Chen M Z, Jiang H X. Studies on agronomic mechanism of the rice yield estimation by remote sensing: Ⅱ. the correlation analysis of agronomic parameters and spectral variables [J]. Journal of Zhejiang Agricultural University, 1993, 19 (Sup.): 15～22 (in Chinese).

[10] Wang X Z, Wang R C, Huang J F. Derivative sepectrum remote sensing and its application in measurement of rice agronomic parameters of rice [J]. Transactions of the CSAE, 2002, 18(1): 9～13 (in Chinese).

[11] Tang Y L, Wang X Z, Huang J F, et al. Action of derivative spectra and vegetation indices for rice [J]. Transactions of the CSAE, 2003, 19(1): 145～150 (in Chinese).

[12] Liu Y J, Yang Z D. The principle and arithmetic of MODIS [M]. Beijing: Science Press, 2001, 237～239 (in Chinese).

[13] Huete A R, Justice C, Leeuwen V. "MODIS vegetation index (MOD13)", Version 3. Algorithm Theoretical Basis Document [ED]. 1999. http://modis.gsfc.nasa.gov/data/atbd/land_atbd.html

[14] Horler D N, Dockray M, Barber. The red-edge of plant leaf reflectance [J]. Int J Remote Sensing, 1983, 4: 273～288.

[15] Pu R, Gong P. Hyperspectral remote sensing and its applications [M]. Beijing: Higher Education Press, 2000, 205～206 (in Chinese).

[16] Peterson D L, Spanner M A, Running S S W, et al. Relationships of thematic mapper simulator data to leaf area index of temperate coniferous forests [J]. Remote Sens Environ, 1987, 22: 323～341.

[17] Smith N J, Borstad G A, Hill D A, et al. Using high-resolution airborne spectral data to estimate forest leaf area and stand structure [J]. Canadian Journal of Forest Research, 1991, 21: 1127～1132.

[18] Liu W D, Xiang Y Q, Zheng L F, et al. Relationships between rice LAI, CH. D and hyperspectra data [J]. Journal of Remote Sensing, 2000, 4: 279～283 (in Chinese).

[19] Wang X Z, Huang J F, Li Y M, et al. Relationships between rice agricultural parameters and hyperspectral data [J]. Journal of Zhejiang University (Agric. & Life Sci.), 2002, 28: 283～288 (in Chinese).

[20] Danson F M. Red-edge response to forest leaf area index [J]. Int J Remote Sensing, 1995, 16: 183～188.

水稻叶面积指数与MODIS植被指数、红边位置之间的相关分析

程 乾, 黄敬峰, 王人潮, 唐延林

(浙江大学农业遥感与信息技术研究, 杭州 3210029)

摘 要: 对模拟中分辨率成像光谱仪(MODIS)两个植被指数归一化植被指数(NDVI)、增强植被指数(EVI)以及红边位置(REP)与水稻叶面积指数(LAI)进行了相关研究。利用光谱分辨率为3 nm的ASD FieldSpec UV/VNIR光谱仪获得了2002年两个不同水稻品种——杂交稻和常规稻整个生长期的高光谱数据, 同时对水稻LAI进行了测定。利用一阶微分计算红边位移。模拟了MODIS 3个波段, 波段1(620-670 nm, 红波段), 波段2(841～876 nm, 近红外)和波段3(459～479 nm, 蓝波段), 并用这些波段计算了MODIS-NDVI和EVI。结果表明: 对于常规稻, MODIS-NDVI、EVI和REP与水稻LAI呈现出良好的相关性; 而对于杂交稻, 与水稻LAI相关性来说, MODIS-EVI和REP要比MODIS-NDVI更敏感。分析原因, 主要是因为杂交稻同常规稻相比在生长的中后期LAI比较大, MODIS-NDVI容易饱和; 而MODIS-EVI和REP由于可以消除背景影响, 增强对LAI的敏感性。因此MODIS-EVI和REP可以更有效地监测水稻叶面积指数。

关键词: 相关分析; 水稻叶面积指数; MODIS植被指数; 红边位置