Optimal Time Period for Using NDVI and LAI to Estimate Rice Yield

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Abstract: This study was to monitor changes of leaf area index (LAI) and normalized difference vegetation index (NDVI), calculated from ground-based remotely sensed high resolution reflectance spectra, during rice (*Oryza sativa* L. cv. TNG 67) growth so as to determine their relationships and the optimum time period to use these parameters for yield prediction. Field experiments were conducted at the experimental farm of TARI to obtain various scales of grain yield and values of LAI and NDVI in the first and the second cropping seasons of 2001-2002. It was found that LAI and NDVI can be mutually estimated through an exponential relationship, and hence plant growth information and spectral remote sensing data become complementary counterparts through this linkage. Correlation between yield and LAI was best fitted to a nonlinear function since about 7 weeks after transplanting (WAT). The accumulated and the mean values of LAI from 15 days before heading (DBH) to 15 days after heading (DAH) were the optimum time period to predict rice yield for First Crops, while values calculated from 15 DBH to 10 DAH were the optimal timing for Second Crops.

Keywords: Rice, Yield prediction, Optimum timing, LAI, NDVI.

1. Introduction

During the past decades knowledge about canopy reflectance in the visible and near-infrared wavebands has greatly improved, and the applications of spectral data to vary aspects of agricultural production processes have been extensively explored. Much research and progress have been made in the areas of crop growth modeling and yield estimation and prediction using the spectral indices with multiple wavebands to summarize into a single value to interpret reflectance data. The NDVI, which is calculated by the reflectance values in red and near infrared wavebands, is the most commonly used spectral index developed to characterize the green vegetation [4]. Many researchers have related NDVI to plant vigor, biomass, moisture stress, LAI, or yield [1,3,5]. However, values of NDVI may be affected by background noise such as soil water content, chemical use, and tillage condition [2] and therefore limit its applications.

The present study was conducted to measure ground-based canopy spectral reflectance of high resolution and to monitor rice crop status under different levels of nitrogen fertilizer applications during the growing seasons in 2001-2002. The relationship between LAI and NDVI was developed and correlation of LAI and grain yield was investigated to evaluate the possibility of for using these relationships to predict rice yield in the growing seasons. The optimum time period to predict rice yield using LAI was also determined for different cropping seasons.

2. Materials and Methods

Field experiments were conducted at the experimental farm of TARI (24º45’N, 120º54’E, elevation of 60 m), Wufeng, Taiwan to obtain LAI and to take canopy reflectance measurements of rice plants during the first and the second cropping seasons of 2001 and 2002. Different levels of nitrogen fertilizer were assigned to different subplots to produce variety of LAI, reflectance spectra and grain yield. Six plants were collected from each subplot on each sampling to determine leaf area on the dates of canopy reflectance measurements. The LAI was calculated as the total green leaf area (m^2) per unit land area (1 m^2). To determine the optimum timing for predicting rice yield with LAI, changes of LAI from subplots of different nitrogen levels were monitored. The quantitative relationships between grain yield and LAI were analyzed and the determining factors (R^2) were determined by regression analyses. Two 10-m^2 rice plants were harvested per subplot to determine grain yields at maturity.

Ground-based remotely sensed reflectance measurements began from ca. 4 WAT, and were made in 2 to 3-week intervals until harvest. Spectral measurements were taken on clear or near cloudiness moments of the measuring days with a field portable spectroradiometer (model GER-2600, Geophysical &

Environmental Research Corp., Millbrook, NY, USA). The 537-channel radiometer measures the 350-2500 nm spectral domain and has a 10-degree field of view (FOV) lens, and is connected to a notebook computer for built-in program operation. The sensor head of GER-2600 was held at nadir from a height of about 5.8 m above rice canopy surface to result in a sampled round area of ca. 1 m in diameter. Each reading was divided by the reading from a spectral reference panel ('Spectralon', Labsphere Inc., North Sutton, NH, USA) of known spectral characteristics to compute reflectance spectrum. Target and reference scans were made successively to yield corrected reflectance spectra. Fifteen random spots per subplot were selected for spectral measurements. Reflectance values at 2 distinct locations, reflectance at red light minimum (RED) and reflectance at near-infrared maximum (NIR), of every reflectance spectrum were identified and used for the computations of NDVI, calculated by the equation $(R_{NIR}-R_{RED})/(R_{NIR}+R_{RED})$.

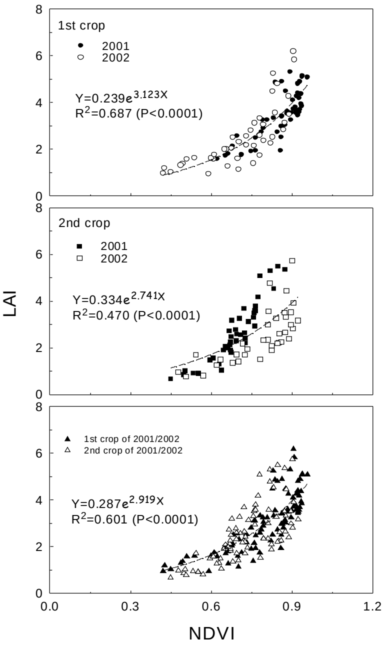

Fig. 1.Correlation between LAI (leaf area index) and NDVI (normalized difference vegetation index) for rice grown in the cropping seasons of 2001-2002.

3. Results and Discussion

Seasonal changes of LAI and NDVI were non-linearly distributed during rice growth and were affected by the amounts of nitrogen fertilizer applied to the field. Higher amounts of nitrogen fertilizer produced higher values of LAI and NDVI and generally plants grown in Second Crops expressed lower values of LAI and NDVI than that of plants grown in First Crops. By plotting the relation of LAI and NDVI, it indicated that relationship was fitted to an exponential function (R^2>0.470) in both crops (Fig.1), similar to that reported by Yang and Su (1999). As there was no significant difference between cropping seasons, data were pooled to reconstruct a generalized formula (R^2>0.601) suitable for both crops. Both parameters can then be mutually estimated through the exponential relationship, and plant growth information and spectral remote sensing data become complementary counterparts through this linkage.

When analyzing the relations of grain yield and LAI, it showed that yield and LAI were closely correlated from ca. 7 WAT to near harvest, with the R^2 greater than 0.72 (Fig.2). For a general application purpose, the accumulated LAI and the mean LAI calculated from various durations of plant growth, from 30 DBH to 30 DAH, were to compare their relationships with yields (Table 1). Results indicated that the accumulated and the mean values of LAI from 15 DBH to 15 DAH provided the best prediction of rice yield for First Crops, while values calculated from 15 DBH to 10 DAH were the most adequate duration to predict yield for Second Crops. The accumulated and the mean values of LAI calculated from the optimum timing were able to account for more than 84% of the variation in yield.

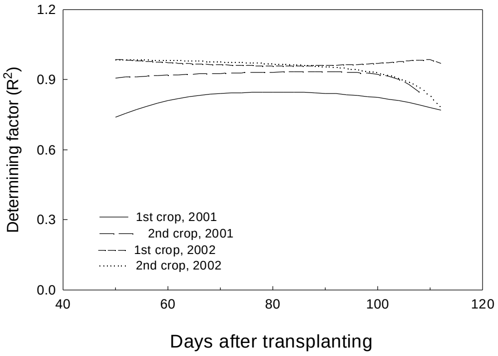

Fig. 2.Changes in determining factor (R^2), calculated from the relationships between grain yield and LAI (leaf area index), during the growing periods for rice grown in the cropping seasons of 2001-2002.

In conclusion, this study has proved the feasibility of LAI-yield relationship to predict rice yield and the potential of NDVI as a substitute for LAI in providing non-destructive real time information. This opens up the possibility for assessment of grain yield in heterogeneous rice populations planted in different dates and varied locations. Such an advantage enables in-growing-season agronomic decisions to improve crop growth. In any case, more experiments conducted in different years and locations need to be carried out to test the yield-LAI-NDVI relationships more thoroughly in the future. The wide variations in field productivity and climatic conditions across different regions may affect the accuracy of yield prediction and the optimum duration for using LAI as a predictor.

5. Acknowledgments

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6. References

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Table 1.Changes in correlation of the accumulated LAI (leaf area) and the mean LAI to gain yield in different growth durations of rice grown in the cropping seasons of 2001-2002.

Days before heading	Days after heading	Duration (day)	$R^2_{\text{Accumulated LAI}}$				$R^2_{\text{Mean LAI}}$			
			1st crop		2nd crop		1st crop		2nd crop	
			2001	2002	2001	2002	2001	2002	2001	2002
15	5	20	0.84	0.96	0.92	0.98	0.84	0.96	0.93	0.98
10	10	20	0.85	0.96	0.93	0.98	0.84	0.95	0.94	0.97
5	15	20	0.84	0.96	0.93	0.97	0.82	0.97	0.94	0.98
20	5	25	0.84	0.96	0.92	0.98	0.84	0.95	0.90	0.98
15	10	25	0.85	0.96	0.93	0.98	0.85	0.95	0.93	0.99
10	15	25	0.84	0.96	0.93	0.98	0.84	0.95	0.90	0.98
5	20	25	0.84	0.96	0.93	0.97	0.85	0.96	0.93	0.97
20	10	30	0.84	0.96	0.92	0.98	0.85	0.95	0.90	0.98
15	15	30	0.84	0.96	0.93	0.98	0.85	0.97	0.90	0.99
10	20	30	0.84	0.96	0.93	0.97	0.85	0.96	0.91	0.97
5	25	30	0.83	0.96	0.93	0.97	0.83	0.95	0.91	0.97
30	5	35	0.84	0.97	0.92	0.98	0.84	0.97	0.92	0.97
25	10	35	0.84	0.96	0.92	0.98	0.84	0.97	0.93	0.99
20	15	35	0.84	0.96	0.92	0.98	0.85	0.97	0.91	0.97
15	20	35	0.84	0.96	0.93	0.98	0.82	0.96	0.93	0.97
10	25	35	0.84	0.96	0.93	0.97	0.83	0.96	0.91	0.98
5	30	35	0.83	0.97	0.93	0.97	0.80	0.98	0.93	0.95