

Using Formosat-2 Satellite Data to Estimate Leaf Area Index of Rice Crop

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ABSTRACT

Estimation of plant growth over a large paddy field provides the needed information for site-specific management of crop including rice. With the estimated leaf area index (LAI) as input, growth status of rice crop may be evaluated and yield production at harvest may be assessed through functioning algorithms. This study measured the near-ground hyperspectral reflectance of rice canopy periodically on the dates of plant samplings during crop development, and then established the relationship between LAI_{measured} (i.e. the measured LAI) and $NDVI_{\text{NB}}$ (i.e. normalized difference vegetation index calculated from narrowbands of hyperspectral reflectance) from the collected data. Rice plants of different planting densities, in the range of $0.28\text{-}2.78 \times 10^5$ hills ha^{-1} , were grown in the field to produce varied values ($\text{m}^2 \text{m}^{-2}$) of LAI along plant growth for such purpose in the first and the second cropping seasons of 2006. A total of thirty-six multi-spectral images of the study area taken by Formosat-2 satellite on days of ground samplings were also acquired to calculate the broadband values of NDVI ($NDVI_{\text{BB}}$) and input to the $LAI_{\text{measured}}-NDVI_{\text{NB}}$ relationship to obtain the estimated LAI (LAI_{BB}). Results indicate that the high-temporal and high-spatial-resolution images of Formosat-2 satellite are good source for monitoring plant growth of rice crop by providing reasonable estimated values of LAI. Such a capability of Formosat-2 spectral images enables their applicability in areas of precision farming.

Keywords: Growth estimation, Site-specific management, Hyperspectral reflectance spectrum, Normalized difference vegetation index, Satellite image of Formosat-2

1. Introduction

Rice is the primary food source for more than three billions people (Khush, 2005) and is also an important staple crop to many countries in Asia. Growth and production of rice crop is controlled by not only its own genetic make-up but also the environmental factors of its habitat. The progress of a crop is conventionally evaluated by periodical plant samplings and management practices are adapted to the performance in the field. Nowadays, remote sensing is the preferred technology adopted worldwide for large scale fields to monitor and facilitate the on-going functioning processes of plant population and thus timely actions may be applied to the desired areas precisely as well as site-specifically (Bouman, 1995; Pierce et al., 1999). If rice crop can be attended to its growth status, it is possible to meet the supply demand and control need so as to achieve the varietal

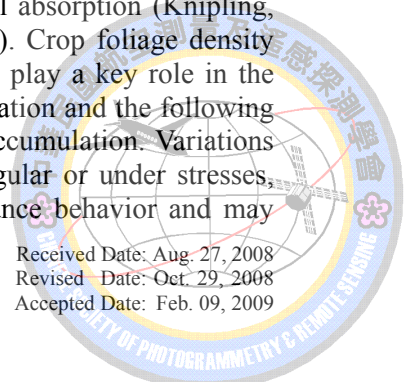
growth and production potential.

Along with the progress of spectral remote sensing technology, reflectance of agricultural crops in the visible and infrared regions has currently being used to assess different crop parameters and growth status (Carter and Knapp, 2001; Clevers, 1988; Lee et al., 2008; Yang and Chen, 2004; Yang et al., 2007a, 2007b). Most green plants exhibit a spectral reflectance profile of higher reflectance in the near-infrared and lower reflectance in visible light when grown in normal conditions (Hall et al., 2002). Under stressed environment, a reverse fashion is observed due to a decrease in plant vigor and canopy coverage and an increase in the reflectance of chlorophyll absorption (Knippling, 1970; Yang et al., 2007a). Crop foliage density and changes in geometry play a key role in the reception of incident radiation and the following biomass formation and accumulation. Variations in crop vegetation, in regular or under stresses, reflect greatly in reflectance behavior and may

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be assessed from the canopy spectral characteristics (SCs) (Carter and Knapp, 2001; Yang and Chen, 2004). Generally a crop with larger vegetation and higher leaf area index (LAI) has an implication in healthy status and obtains a relatively greater photosynthetic capacity and size expansion. Monitoring the progressive changes of LAI can therefore provide qualitative and quantitative information related to plant growth and biomass production available for pre-planning many agricultural management practices (Bouman, 1995; Gilabert et al., 1996; Wiegand et al., 1991).

The objectives of this study were to use spectral images taken by Formosat-2 satellite and a comprehensive field data to establish algorithms for LAI estimation of rice crop as plants developed. The near-ground hyperspectral reflectance spectra of rice canopy were measured periodically on the dates of plant samplings during rice growth. The relationship between the measured LAI ($LAI_{measured}$) and the calculated normalized difference vegetation index from narrowband reflectance ($NDVI_{NB}$) was determined follow the method of Yang and Chen (2004). The relationship was then used as the template to yield the estimated values of LAI (LAI_{BB}) from the input of NDVI calculated from broadband reflectance of satellite images ($NDVI_{BB}$).

2. Materials and Methods

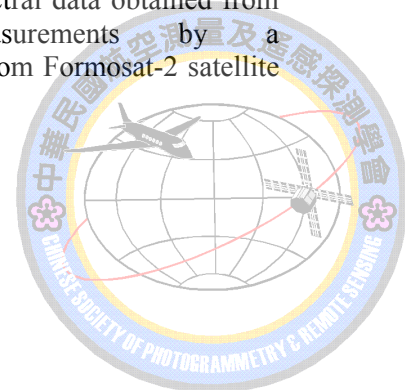
2.1 Rice Cultivation and Spectral Measurements

Rice seedlings (*Oryza sativa* L. cv. TNG 67) were machine transplanted to north-south rows at three- to four-leaf stage and were grown in the experimental farm of Taiwan Agricultural Research Institute (24°45'N, 120°54'E, 85 m above mean sea level) in both first and second cropping seasons of 2006. The experimental field (Figure 1) was divided into three plots as replications, with a size of 50 m by 50 m. Each replicate was divided into eight subplots occupied with eight different population densities aligned in a descending order site by site, i.e., 2.78×10^5 , 2.22×10^5 , 1.85×10^5 , 1.59×10^5 , 1.39×10^5 , 1.11×10^5 , 5.56×10^4 and 2.78×10^4 hills ha^{-1} . Variations in population density produced varied plant growth giving various values of LAI along plant development. Six plants were sampled from each individual planting density

periodically from the targeted region taking the near-ground canopy hyperspectral reflectance during the growing seasons. Leaf area ($m^2 \text{ hill}^{-2}$) was determined with an area meter (LI-3000A, LI-COR Inc., NE, USA), and $LAI_{measured}$ was calculated as the accumulated apparent leaf area of vegetation divided by unit ground area ($m^2 m^{-2}$).

The transplanting dates were on March 1 and August 2 and the harvest dates were on July 4 and November 17 for First Crop and Second Crop of 2006, respectively. The soil was a loam texture classified as Fluvaquentic Dystrochrept with pH of 5.18 and organic matter of $0.0183 \text{ kg kg}^{-1}$. Total nitrogen applied was 120 kg N ha^{-1} which was divided into four separate doses in rates of 40:20:40:20 kg N ha^{-1} . The basal dose was applied in the week of transplanting, and followed by 2 weeks after transplanting (WAT), 4 WAT, and 6 WAT. Plants were prevented from the pest infestations by applying pesticides recommended by Plant Protection Handbook (2001) of local authority.

The canopy reflectance spectra were acquired by a system unit containing a portable spectroradiometer (model GER-2600, Geophysical and Environmental Research Corporation, NY, USA) with a 10 degrees field-of-view (FOV) lens at 2-3 weeks intervals at the time of plant samplings. The unit was mounted on a 4 wheel-drive adjustable mobile lift raised 5.8 m vertically above canopy surface at a nadir resulting in a sampled area 1 m in diameter. Target measurements of radiance spectra were collected immediately after the reference measurements taken from a 99% 'Spectralon' panel (Labsphere, Inc., NH, USA) of known SCs to compute reflectance spectra. Canopy reflectance spectra from ten random spots per subplot were taken and the mean values were used for analyses. All spectral data were collected under near cloud-free conditions between 10:00 to 12:00 local time to reduce the effect of changes in zenith angle. Furthermore, near ground measurements were taken on the days that Formosat-2 satellite flew over the experimental site to minimize the radiance differences between spectral data obtained from near ground measurements by a spectroradiometer and from Formosat-2 satellite acquisitions.



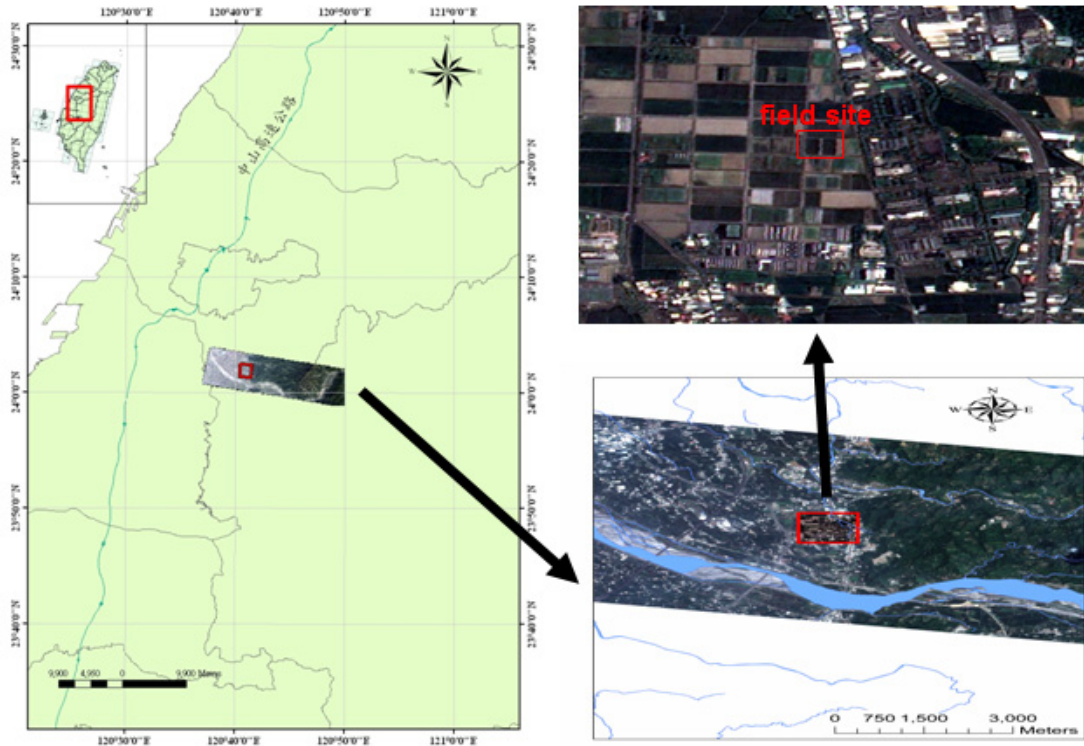


Figure 1 The Formosat-2 image of the experimental field located in the experimental farm of Taiwan Agricultural Research Institute at Wufeng (24°45'N, 120°54'E), Taichung Hsien, Taiwan.

The spectroradiometer contains two spectrometers, with one uses an array of 512 silicon detectors measuring waveband range 330-1050 nm (averagely 1.5-nm resolution) and the other has an array of 128 PbS detectors measuring waveband range 1050-2600 nm (averagely 11.5-nm resolution) (GER-2600 User Manual, 1996). The band centers were rounded off to the nearest whole number, and only reflectance data in the 350-2500 nm range were used to avoid severe noise in both ends of the spectrum reducing spectral channels to 573. Spectral measurements and calibrations are controlled by simple menu-driven software supplied by GER on the connected computer.

2.2 Model Establishments and Image Processing

The NDVI is probably the most well-known spectral index (SI) that has been used in many agricultural applications (Clevers, 1986; Elvidge and Chen, 1995; Rouse et al., 1974; Tucker et al., 1979; Yang and Chen, 2004). Reflectance of two distinct locations of canopy hyperspectral reflectance spectra, i.e., narrowbands at chlorophyll absorption maximum (λ_{RED}) of the red region (640–740 nm) and peak (λ_{NIR}) of the near-infrared region

(740–1300 nm), were identified dynamically along plant development to calculate values of $NDVI_{NB}$, by the formula $(R_{NIR} - R_{RED}) / (R_{NIR} + R_{RED})$. The approach proposed by Yang and Chen (2004) was followed to establish the exponential relationship between $LAI_{measured}$ and $NDVI_{NB}$, which was used as the template to transform the input of $NDVI_{BB}$ into LAI_{BB} output.

A total of thirty-six level-1A or level-2 image products of Formosat-2 taken over the study site during the experimental periods were acquired from NSO of Taiwan. These images were processed by a series of automatic processing algorithms. The purpose of applying these algorithms is briefed as follows. Because the arrangement of CCD arrays onboard Formosat-2 makes the PAN CCD line and each of the MS CCD lines scans the ground sequentially with a slight time lag rather than simultaneously, the band-to-band misregistration is significant and visually evident in the Formosat-2 image. To fix the problem, the algorithm of band-to-band coregistration reported by Liu (2006) was employed. To improve the spatial details yet preserve the spectral properties and produce color composites with sharper spatial details and high spectral fidelity, the algorithm of spectral preserved

