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 rice crop. With the estimated LAI (leaf area index), growth status of rice crop may be evaluated and yield production at harvest may be assessed. 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\(_{\text{measured}}\) and NDVI\(_{\text{NB}}\) (normalized difference vegetation index calculated from hyperspectral reflectance spectra) from the collected data. Rice plants of different planting densities, in the range of 0.28-2.78 \(\times 10^5\) hills ha\(^{-1}\), were grown in the field in the first and the second cropping seasons of 2006, and LAI was computed as the measured leaf area over unit ground area (m\(^2\) m\(^{-2}\)). A total of thirty-six multi-spectral images of the study area taken by FORMOSAT-2 satellite were also acquired, parts of these images were used to calculate the broadband values of NDVI\(_{\text{BB}}\) for linking with the narrowband values of NDVI\(_{\text{NB}}\) and the rest images were used for model validation. 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 and can provide reasonable estimated values of LAI. Such capability of FORMOSAT-2 spectral images enables their applicability in areas of precision farming.

Media summary

This study used multi-spectral images taken by FORMOSAT-2 satellite and field data to establish algorithms for estimating LAI of rice crop as plants developed.

Keywords

Growth estimation, Site-specific management, Hyperspectral reflectance spectrum, Normalized difference vegetation index, Satellite image

Introduction
Rice is the primary food source for more than three billions people and is also an important staple crop to many countries in Asia. Growth and development of rice crop is controlled by its genetic make-up while production potential is restrained by the environmental factors of its habitat. Conventionally, the progress of a crop is 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 to monitor and facilitate the on-going functioning processes of plant population and thus timely actions may be applied to the targeted areas site-specifically. If rice crop can be attended to its growth status, there will have a greater chance to meet the supply demand and control need achieving the varietal yield potential.

Reflectance of agricultural crops in the visible and infrared regions has been used to assess different crop parameters and growth status. Most green plants exhibit a spectral reflectance profile of higher reflectance in the near-infrared and lower reflectance in visible light in conditions advantageous to photosynthesis. Under inversed conditions, a reverse fashion is observed due to a decrease in plant vigor and canopy coverage and an increase in the reflectance of chlorophyll absorption. 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 be assessed from the canopy spectral characteristics (SCs). Generally a crop with larger vegetation and higher leaf area index (LAI) 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, and be extended to pre-planning many agricultural production processes.

The FORMOSAT-2, a sun synchronous satellite operated by the National Space Organization of Taiwan, was launched on 20 May 2004 and began business operations a year later for the purposes of monitoring, forecasting and managing natural resources and human activities. The satellite equipped with high-spatial and multi-spectral resolution sensors that can generate 2-m panchromatic (450-900 nm) and 8-m multispectral images (blue band, 450-520 nm; green band, 520-600 nm; red band, 630-690 nm; and near-infrared band, 760-900 nm) with 1-day revisit rate. The high quality satellite data acquired from FORMOSAT-2 cover both terrestrial and oceanic regions of the entire earth and are able to resolve both intra- and inter-field variability of crop growth conditions. Attempts were made in this study to use spectral images taken by FORMOSAT-2 satellite to estimate LAI of rice crop as plants developed. The near-ground hyperspectral reflectances of rice canopy were measured periodically on the dates of plant samplings during cropping seasons. The relationship between the measured LAI and the calculated NDVI_{NBB} (normalized difference vegetation index calculated from narrowbands of hyperspectral data) was established and used as the platform to yield the derived values of LAI from the input of NDVI_{BB} (NDVI calculated from broadbands of satellite images).

**Methods**

Seedlings of rice (*Oryza sativa* L. cv. TNG 67) were planted in eight population densities, i.e., \(2.78 \times 10^5\), \(2.22 \times 10^5\), \(1.85 \times 10^5\), \(1.59 \times 10^5\), \(1.39 \times 10^5\), \(1.11 \times 10^5\), \(5.56 \times 10^4\) and \(2.78 \times 10^4\) hills ha\(^{-1}\), and were grown in the experimental farm of Taiwan Agricultural Research Institute (24°45’N, 120°54’E, elevation of 85 m) in both
first and second cropping seasons of 2006. Variations in density produced varied plant growth and hence various values of LAI along plant development. Leaf area (m² hill⁻²) was determined by plant samplings with an area meter (LI-3000A, LI-COR Inc., USA), and LAI_{measured} (m² m⁻²) was calculated as the accumulated apparent leaf area of vegetation divided by ground area. The near-ground canopy spectral reflectance was acquired by an operating system containing a portable spectroradiometer (GER-2600, GER Corp., USA) with a 10 degrees field-of-view lens on time of plant samplings for NDVI measurements. The unit was mounted on a 4 wheel-drive adjustable mobile lift raised 5.8 m vertically above canopy surface in a nadir. Target measurements of radiance spectra were collected immediately after the reference measurements taken from a 99% ‘Spectralon’ panel (Labsphere, Inc., USA) to compute reflectance spectra. All spectral data were collected under near cloud-free conditions between 10:00 to 12:00 to minimize the zenith angle effect.

Three distinct locations of canopy reflectance spectra, i.e., narrowbands at chlorophyll absorption minimum (GREEN) of the green region (490–560 nm), chlorophyll absorption maximum (RED) of the red region (640–740 nm), and peak (NIR) of the near-infrared region (740–1300 nm), were identified dynamically from near-ground hyperspectral data to compute 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 LAI_{measured}-NDVI_{NB} relationship.

A total of thirty-six multispectral images taken by FORMOSAT-2 satellite during both crops were processed by band-to-band coregistration, spectral preserved pan-sharpening, automatic orthorectification, multitemporal imagery matching, radiometric normalization and absolute radiance calibration. Seventeen out of thirty-six spectral images were selected to avoid the interference of atmospheric effects, and were used as broadband database for calculating NDVI_{BB}, which values were then input to the aforementioned LAI_{measured}-NDVI_{NB} relationship to yield LAI_{BB} values from the developed regression equation. The correlations between NDVI_{BB} and NDVI_{NB} and LAI_{BB} and LAI_{measured} were compared.

![Figure 1. Changes of the measured values of leaf area index (LAI_{measured}) in response to the values of NDVI_{NB} from near-ground canopy hyperspectral reflectance data.](image)

**Figure 1.** Changes of the measured values of leaf area index (LAI_{measured}) in response to the values of NDVI_{NB} from near-ground canopy hyperspectral reflectance data.

**Results**

Much research and progress have been made in the areas of crop growth modeling and production estimation using the spectral indices (SIs) incorporating SCs chosen from remote sensing data such as NDVI (Yang and Chen 2004; Rouse et al. 1974). This study measured the hyperspectral reflectance of rice canopies and
identified the SCs in the red (R\text{RED}) and near-infrared (R\text{NIR}) regions to compute NDVI\text{NB}. Plant samplings were made on days of spectral measurements to determine LAI\text{measured}. The exponential relationship between LAI\text{measured} and NDVI\text{NB} was developed (Figure 1) as proposed by Yang and Chen (2004), and the regression equation derived was used as platform to yield LAI\text{BB} by using NDVI\text{BB} as inputs.

In contrast to NDVI\text{NB} computed from reflectance of narrowbands, values of NDVI\text{BB} were calculated from broadband data of red and near-infrared regions extracted from multispectral images taken by FORMOSAT-2 satellite through a series of processing processes, during the cropping seasons. Results indicated that NDVI\text{NB} values from hyper spectral data correlated linearly \((r = 0.793^{***})\) with NDVI\text{BB} values from FORMOSAT-2 images (Figure 2). By correlating values of LAI\text{BB} yielded from LAI\text{measured}xNDVI\text{NB} relationship with values of LAI\text{measured}, the relationship was also a linear function \((r = 0.729^{***})\) (Figure 3).

\begin{figure}[h]
\centering
\includegraphics[width=0.45\textwidth]{figure2.png}
\caption{The correlation between NDVI\text{BB} from spectral images of FORMOSAT-2 satellite and NDVI\text{NB} from near-ground canopy hyperspectral reflectance spectra.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.45\textwidth]{figure3.png}
\caption{The correlation between LAI\text{BB} from spectral images of FORMOSAT-2 satellite and LAI\text{NB} from near-ground canopy hyperspectral reflectance spectra.}
\end{figure}

**Conclusion**

As a result, LAI of rice crop can be reasonably estimated by employing the FORMOST-2 satellite high-temporal and high-spatial imagery. The approach proposed by Yang and Chen (2004) is proved applicable to the integrating of the FORMOSAT-2 observations with a comprehensive dataset containing canopy hyperspectral reflectance and plant samplings collected in the field for such purpose.

**References**
