

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

Chwen-Ming Yang¹ Cheng-Chien Liu² Yi-Wen Wang³

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 $0.28-2.78 \times 10^5$ hills ha^{-1} , were grown in the field to produce varied values ($m^2 m^{-2}$) 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

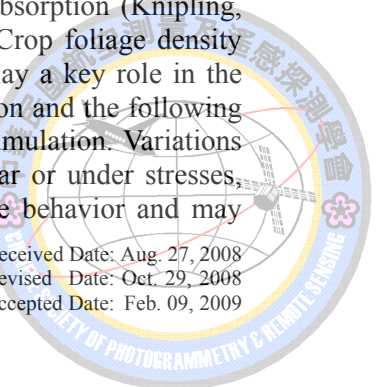
growth and production potential.

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

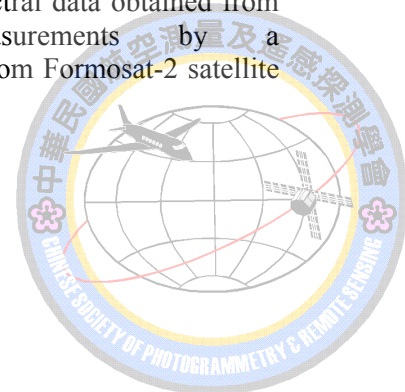
2.1 Rice Cultivation and Spectral Measurements

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.



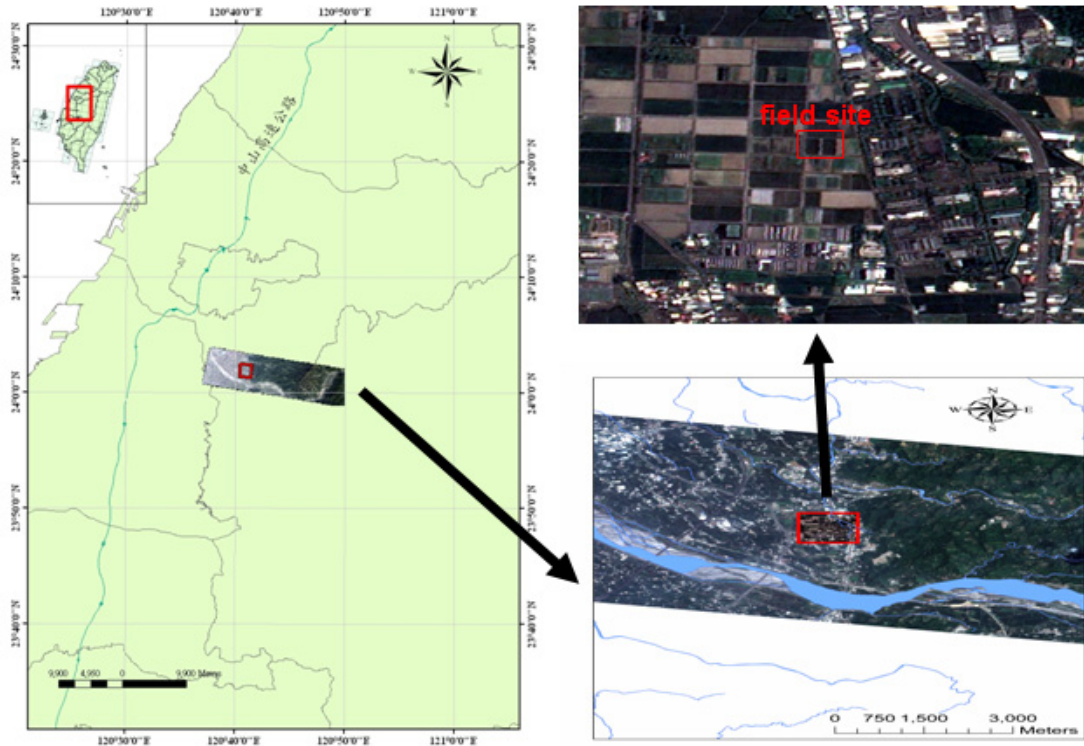


Figure 1 The Formosat-2 image of the experimental field located in the experimental farm of Taiwan Agricultural Research Institute at Wufeng (24°45'N, 120°54'E), Taichung Hsien, Taiwan.

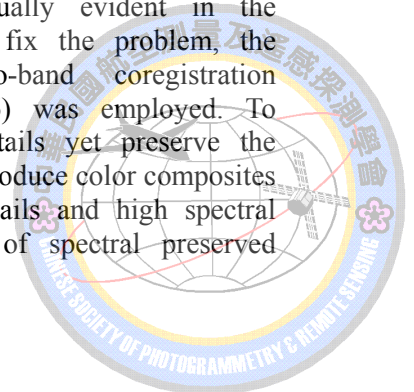
The spectroradiometer contains two spectrometers, with one uses an array of 512 silicon detectors measuring waveband range 330-1050 nm (averagely 1.5-nm resolution) and the other has an array of 128 PbS detectors measuring waveband range 1050-2600 nm (averagely 11.5-nm resolution) (GER-2600 User Manual, 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



pan-sharpening developed by Liu et al. (2007) was adopted. To georeference the high-spatiotemporal Formosat-2 imagery, the algorithm of automatic orthorectification described in Liu and Chen (2008) was used. Accurate spatial registration between multitemporal imagery is necessary if pixel-level changes are to be detected (Coulter et al., 2003; Dai and Khorram, 1998). Even with the rigorous orthorectification of multitemporal Formosat-2 imagery, the change artifacts are significant and visible if change detection is performed directly with this type of imagery. Therefore, the procedures of Liu (2006) were followed to conduct the multitemporal imagery geometrical registration. Finally, the procedure of radiometric normalization set up by Liu et al. (2008) was applied to normalize the radiances among the multitemporal images of the same area, and then assume a parabolic relationship of NDVI exists during the growing season to eliminate the radiance differences caused by different imaging time between the spectroradiometer and Formosat-2. Detailed description of the processes can be referred to (Wang, 2007).

To avoid the interference of atmospheric effects, seventeen out of thirty-six satellite images were selected and used as broadband database for extracting broadband radiance and calculating $NDVI_{BB}$. The values of $NDVI_{BB}$ were then input to the aforementioned $LAI_{measured}$ — $NDVI_{NB}$ relationship to derive LAI of broadband values (i.e. LAI_{BB}) as outputs.

2.3 Data Analyses and Statistics

Spectral and plant data collected from this study were analyzed and graphed by using the software packages Statistical Analysis System version 8.1 (SAS Institute, 1998) and Sigmaplot 2001 (SPSS ASC BV, the Netherlands). The correlation analyses were conducted between $NDVI_{BB}$ and $NDVI_{NB}$ and LAI_{BB} and $LAI_{measured}$. Root mean square error (RMSE) was calculated by the followed formula for accuracy assessment,

$$RMSE = \sqrt{\frac{1}{k} \sum_{i=1}^k (\hat{X}_i - X_i)^2}$$

where \hat{X}_i is the estimated values and X_i is the measured values.

3. Results and Discussion

Much research and progress have been

made in the areas of crop growth modeling and production estimation using the SIs incorporating SCs chosen from remote sensing data such as NDVI (Rouse et al. 1974; Yang and Chen 2004). This study measured the near-ground hyperspectral reflectance of rice canopy along plants development and identified the SCs in the red (R_{RED}) and near-infrared (R_{NIR}) regions to compute $NDVI_{NB}$. Plant samplings were made on days of spectral measurements to determine $LAI_{measured}$. The exponential relationship between $LAI_{measured}$ and $NDVI_{NB}$ was developed (Figure 2) as that proposed by Yang and Chen (2004), and the regression equation derived was used as template to produce output values of LAI_{BB} by using $NDVI_{BB}$ as inputs.

Change of LAI to NDVI is the most common relationship used to link growth parameter with the spectral data for growth monitoring and yield prediction (Aman et al., 1992; Price, 1992; Rajapakse et al., 2000). The exponential relationship implies that soil brightness produces large variation in NDVI at lower end of LAI when young plants are distributed sparingly.

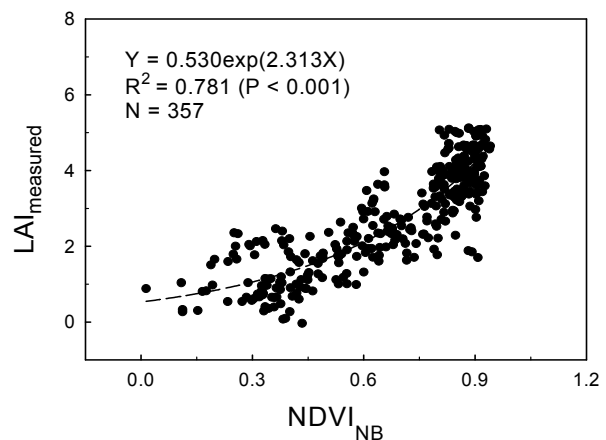


Figure 2 Changes of the measured values of leaf area index ($LAI_{measured}$) in response to the values of $NDVI_{NB}$ from near-ground canopy hyperspectral reflectance data for rice plants (*Oryza sativa* L. cv. TNG 67) grown in the first and the second cropping seasons of 2006.

On the other hand, leaves overlapping along vertical layers of canopy may change reflectance behavior with small NDVI variation at higher end of LAI when maturing plants toward the plateau of growth. Of the most importance, an input of NDVI is able to be transformed into a corresponding value of LAI with the regression equation ($R^2 = 0.781$, $P <$

0.001), and hence, spectral variable (NDVI) obtained from remote sensing is interchangeable with growth parameter (LAI) as plants develop (Gong et al., 1995). However, many papers indicated that the relationship between LAI and NDVI is species dependent and may be affected by environmental factors (Baret and Guyot, 1991; Best and Harlan, 1985; Wanjura and Hatfield, 1987). Accordingly, the locational effects should be taken into consideration for a practical application and adjustments need to be made by considering the specific local conditions.

In contrast to $NDVI_{NB}$ computed from narrowband reflectance of hyperspectral spectra, values of $NDVI_{BB}$ were calculated from broadband data of red and near-infrared regions of multispectral images taken by Formosat-2 satellite during the experimental periods of rice growth. By comparing the paired values of $NDVI_{BB}$ and $NDVI_{NB}$ obtained from the same measuring days, it showed that $NDVI_{BB}$ values from Formosat-2 images correlated linearly ($r = 0.793^{***}$) with $NDVI_{NB}$ values from hyperspectral reflectance (Figure 3). The positive correlation suggests that changes of $NDVI_{BB}$ follow the variation of $NDVI_{NB}$ positively. Results also support the fact that spectral data of Formosat-2 are closely linked to spectral changes on the ground so that images taken by the satellite may be compiled and interpreted with ground truth.

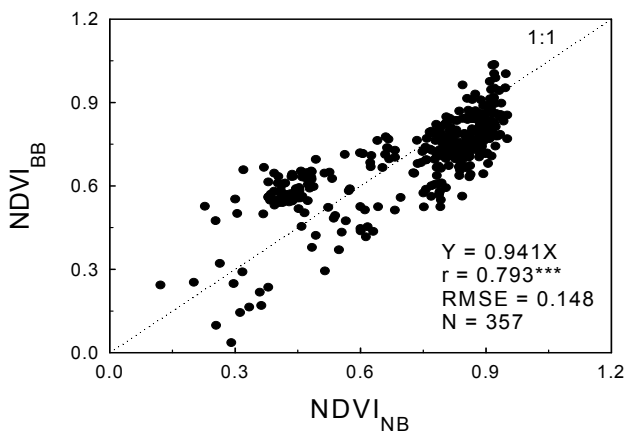


Figure 3 The correlation between $NDVI_{BB}$ from spectral images of FORMOSAT-2 satellite and $NDVI_{NB}$ from near-ground canopy hyperspectral reflectance spectra for rice plants (*Oryza sativa* L. cv. TNG 67) grown in the first and the second cropping seasons of 2006.

By the inputs of $NDVI_{BB}$ to the previously developed $LAI_{measured} - NDVI_{NB}$ relationship

(Figure 2), values of LAI_{BB} were derived as outputs. The correlation between paired values of LAI_{BB} and $LAI_{measured}$ was also linear statistically ($r = 0.729^{***}$) (Figure 4). However, as in general $NDVI_{BB}$ values were lower than $NDVI_{NB}$ values on the same measuring dates, the estimated value of LAI_{BB} was smaller relative to that of the measured value of $LAI_{measured}$. A calibration should be made to compensate for this indigenous difference following the processing algorithms if an accurate estimation is needed.

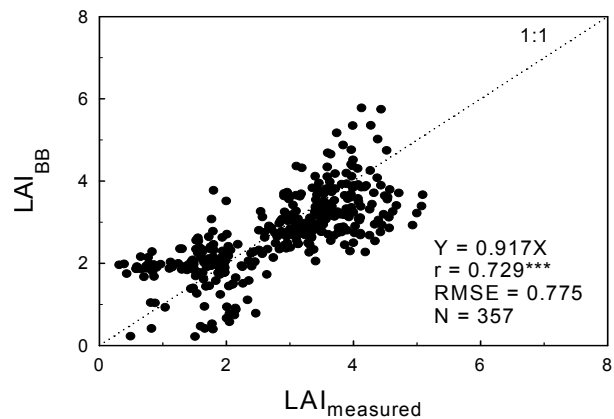


Figure 4 The correlation between LAI_{BB} estimated from spectral images of Formosat-2 satellite and $LAI_{measured}$ from plant samplings for rice plants (*Oryza sativa* L. cv. TNG 67) grown in the first and the second cropping seasons of 2006.

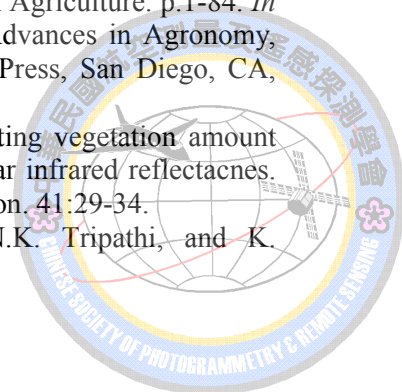
4. Conclusions

As a result, the correlation of LAI and NDVI is high in rice crop so that 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. However, there is still much can be done to improve the image processing algorithms for bettering $NDVI_{BB}$ acquisitions and LAI_{BB} estimation.



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利用福衛二號衛星資料估測水稻族群葉面積指數

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摘 要

在稻作生育期間定期針對大面積水田稻株進行生長估測，以提供稻株生長狀態之即時資訊，乃實施稻作精準管理所必需，俾達到水稻各特定地點之差異性操作。將葉面積指數(leaf area index; LAI)估測值輸入預先研擬之作業決策模組，不僅可以評估稻作之生長狀態，亦可同時預測收穫產量。本研究旨在稻作生育過程中定期同步取樣水稻族群 LAI 及量測植被高解析反射光譜，據以建立實測 LAI (即 LAImeasured) 與高光譜窄波段標準差植被指數(即 NDVINB)之數學關係。試驗係於 2006 年一、二期稻作期間實施，將水稻植株以 8 種不同栽植密度栽種於田間，族群密度介於 $0.28-2.78 \times 10^5$ hills ha⁻¹ 之間，再於生育季節中定期測定 LAI (m² m⁻²)及量測光譜。兩期稻作合計收集 36 幅福衛二號衛星資料(影像及光譜)，經幾何與輻射校正後計算得到多頻譜寬波段標準差植被指數(即 NDVIBB)，將其輸入前述建立之 LAImeasured—NDVINB 數學關係式以獲得 LAI 估值(即 LAIBB)。試驗結果顯示，具有高時間、高空間解析力特性之福衛二號衛星資料能夠提供合理 LAI 估值，因此適合作為追蹤水稻族群生長狀態之資訊來源，此一能力亦使得福衛二號衛星資料具有應用於稻作精準管理之潛力。

關鍵詞：生長估測、特定地點精準管理、高解析反射比光譜、標準差植被指數(正規化植生指數)、福衛二號衛星影像

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