Differences in Growth Estimation and Yield Prediction of Rice Crop Using Satellites Data Simulated from Near Ground Hyperspectral Reflectance

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ABSTRACT

The simulated broadband data of satellites SPOT 5 and FORMOSAT-2 were mimicked from canopy high-resolution reflectance spectra measured near ground, by a field-portable spectroradiometer, and these spectral data were then used to compare the differences in growth estimation and yield prediction of rice crop relative to those of ground measurements. Reflectance of broadband sensors was acquired by using the mean value of reflectance averaging over the respective waveband regions of hyperspectral data. Results indicated that the calculated values of normalized difference vegetation index (NDVIs) from hyperspectral (i.e. NDVI\textsubscript{NB}) and simulated satellites data (i.e., NDVI\textsubscript{SPOT 5} and NDVI\textsubscript{FORMOSAT-2}) were all nonlinearly distributed during the first and second cropping seasons of rice. The curves were nearly parallel to each other, but values of NDVI\textsubscript{SPOT 5} and NDVI\textsubscript{FORMOSAT-2} were lower than those of NDVI\textsubscript{NB}. The relationship between the measured leaf area index (LAI\textsubscript{measured}) and NDVI\textsubscript{NB} was best fitted to an exponential growth function, by which the estimated values of LAI\textsubscript{NB}, LAI\textsubscript{SPOT 5} and LAI\textsubscript{FORMOSAT-2} were obtained using the respective NDVIs as inputs. Values of LAI\textsubscript{NB} were found higher than those of LAI\textsubscript{SPOT 5} and LAI\textsubscript{FORMOSAT-2} on the same sampling dates yet all the estimates were lower than the corresponding values of LAI\textsubscript{measured} after ca. 55 days after transplanting. As the simulated satellites data obtained lower values of NDVI and LAI than those of NDVI\textsubscript{NB} and LAI\textsubscript{NB} counterparts, yields predicted from satellites data were less than yield predicted from ground-based hyperspectral data. These predicted yields were all lower than the measured yields.

Key Words: Rice growth, Yield prediction, FORMOSAT-2, SPOT 5, Hyperspectral data.

1. Introduction

The nondestructive nature and capabilities of large scale observation and on-site monitoring makes remote sensing (RS) techniques an ideal means used for implementing practices in agricultural production processes and the current precision agriculture system. With the techniques applied in data acquiring, timely information on the growth and development of a crop in the field can be provided as commanded, and farmland biotic and abiotic controls and resources management become a daily routine. Since details of spectral characteristics (SCs) from the target surface are detectable and discernible from the high

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radiometric and visual resolution data, it opens up many new applications in areas such as agriculture, forestry, ecology, and land cover classifications. However, correlation between SCs and related biophysical properties of crop canopy should be identified and established before any practical application to be taken in production processes (Goetz, 2002).

Many internal and external factors may impose significant influence on the correlation between biophysical traits and spectral attributes, and thus limit its applications. The spectral components are sensitive to atmospheric effect when detected from higher altitude (Liu and Huete, 1995), and may be affected by interference from soil background and surrounding shadows when obtained from lower elevation (Wiegand et al., 1990; Richardson et al., 1992; Wiegand et al., 1992; Maas, 2000). Growth status of vegetation with contributions from nutrient supply and environmental impact also play a role (Myneni et al., 1989; Barrett and Curtis, 1992; Asner, 1998; Goel, 1988). Therefore, cautions should be made in acquiring the radiometric data for the development of spectral models and in interpreting the assessment results to minimize over-fitting problem.

In this regard, as well as for improving the linkage of SCs with biophysical parameters, a number of spectral indices (SIs) which calculated by two or three SCs have been developed (Huete, 1988). Growth traits, such as fractional vegetation cover, leaf area index (LAI) and biomass, were connected with varied indices to estimate growth and predict yield. Further extended the uses of spectral indices for evaluating stress environment, discriminating treatment levels, and assessing constraints of individual practices can be found in the literature (Kanemasu et al., 1985; Masoni et al., 1996; Clarke, 1997; Fassio and Cozzolino, 2003). Among SIs, normalized difference vegetation index (NDVI), which is defined by the spectral reflectance averaged over wavebands in red and near-infrared regions, is probably the most well known (Rouse and Haas, 1973; Rouse et al., 1974). Change of NDVI to LAI is commonly used to estimate and monitor plant growth (Yang and Chen, 2004), and has also been extended to predict yield (Chen and Yang, 2005). When values of LAI are beyond certain threshold level, however, the LAI-NDVI relationship becomes less sensitive (Yang and Chen, 2004). Soil brightness may produce large variation in NDVI at lower end of LAI (Liu and Huete, 1995), while leaves overlapping along vertical layers of canopy may change both canopy reflectance behavior and LAI-NDVI relationship at higher boundary of LAI (Curran, 1983; Carlson et al., 1990; Carlson and Ripley 1997). At both ends of the relationship changes in NDVI with LAI become irregular and the LAI may not be precisely assessed from NDVI.

The sun synchronous satellite FORMOSAT-2 equipped with high spatial and spectral resolution broadband sensors that can generate 2-m panchromatic (520-820 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 multispectral images acquired by SPOT Earth observation satellites are also source of information for studying, monitoring, forecasting and managing natural resources and human activities. The multispectral wavebands of SPOT 5 are in green (500-590 nm), red (610-680 nm), near-infrared (780-890 nm) and mid-infrared (1580-1750 nm) regions. These high resolution satellite data are useful inputs for data analysis and decision making in the applications of environmental and agricultural issues.
The geometrical and radiometric resolutions are able to resolve both intra- and inter-field variability of crop conditions. By detecting within-field spatial and temporal variability of biophysical traits, a precision farm management becomes possible and may result in an increase in canopy uniformity for a better crop yield and quality (Barnes et al., 1997; Garcia et al., 2001; Johnson et al., 2001). Proper application of fertilizers can also reduce detrimental effects on public health and ecosystems (Buersh et al., 1993; Mashima et al., 1999).

The objective was to evaluate the feasibility and compare the variability of growth estimation and yield prediction with the simulated FORMOSAT-2 and SPOT 5 spectral data mimicked from canopy high-resolution reflectance spectra measured near ground, relative to those obtained from narrow-band data and ground measurements.

2. Materials and Methods

2.1 Cultivation Practices

The cultivation scheme of this study was similar to that reported by Chen and Yang (2005). There were two field experiments conducted in the experimental farm of Taiwan Agricultural Research Institute (24°45′N, 120°54′E, elevation of 85 m) at Wufeng, Taiwan. The experiment one, carried out in the cropping seasons of 2000 to 2002, was to collect the required growth data and near ground canopy high-resolution reflectance spectra used for models’ establishment in growth estimation and yield prediction. The experimental field was divided into 20 plots with ca. 0.5 ha each. Seedlings of rice (Oryza sativa L. cv. Tainung 67) were machine transplanted to north-south rows with a density of approximately 185,000 hills ha⁻¹ (plant distance 0.18 m and row spacing 0.3 m), on 18 February 2000 and 27 February 2002 for first crops and 5 August 2000 and 3 August 2001 for second crops. Data obtained from the first crop of 2001 were not used because the spectroradiometer was in repairing and no near-ground spectral data were collected. Leaf areas were measured periodically to calculate changes in LAI along plant development. Yields were harvested at maturity to correlate with the variation of LAI. Harvest occurred on 16 June 2000 and 25 June 2002 for first crops and 6 December 2000 and 26 November 2001 for second crops.

The pH of loamy soil (Fluvaquentic Dystrochrept) was in rage of 4.5 to 5.7 with organic matter of 0.011-0.021 kg kg⁻¹. Three to five days after transplanting (DAT), a composite fertilizer (N:P:K₂O = 36:24:30 kg ha⁻¹) was applied as basal dose. On 10 DAT (second crops) or 14 DAT (first crops), another composite fertilizer (N:P:K = 20:2.2:8.3 kg ha⁻¹) was applied as the second dose. The third dose (N:P:K = 40:4.4:16.6 kg ha⁻¹) was applied on 21 DAT (second crops) or 28 DAT (first crops). The last dose was applied (25.2 kg N ha⁻¹) about 20 days before heading (6–8 weeks after transplanting). Herbicide butachlor (5% granule, 1.5 kg a.i. ha⁻¹) and bentazon (44.1% solution, 200×, 1.3 L a.i. ha⁻¹) were applied before 7 and 21 DAT, respectively, to minimize the infestations of weeds. Rice brown planthopper (Nilaparvata lugens (Stal)) and leaffolder (Cnaphalocrocis medinalis (Guenee)) were managed with carbofuran (40% WP, 800×, 0.48 L a.i. ha⁻¹) and stem borer (Rupella spp.) was controlled by cartap (6% granule, 1.8 kg a.i. ha⁻¹). Validamycin A (50% S, 1000×, 0.5 L a.i. ha⁻¹) was used to protect from the infection of sheath blight (caused by Rhizoctonia solani Kühn).

The experiment two, conducted in both first and second crops of 2001 and 2002, was to collect data for model validation. A separate experimental field
with pH of 5.60 from TARI Experimental Farm was selected. The field was applied with similar cultivation practices, but was treated with different levels of nitrogen (N) fertilizer, in form of ammonium sulfate, to produce various scales of plant growth and yield production. In first crop of 2002 and second crops of 2001 and 2002, there were six levels of N fertilizer, i.e., 0, 30, 60, 90, 120 and 150 kg N ha\(^{-1}\). Each quantity was divided into 3 equal dressings, sprayed on the week of transplanting, 28 DAT (second crops) or 42 DAT (first crop) after transplanting, and 21 days before heading, respectively. An extra field plot was added and treated with 180 kg N ha\(^{-1}\) in the first crop of 2001. Rice seedlings were transplanted on 27 February 2001 and 27 February 2002 for first crops and on 6 August 2001 and 8 August 2002 for second crops. Yield was harvested at various dates as a consequence of applying different levels of N fertilizer.

2.2 Growth and Spectral Measurements

Leaf area was determined by harvesting six hills of rice plants from the target region of each field plots on each sampling, using an area meter (LI-3000A, Li-Cor Inc., Lincoln, NE, USA). Leaf area index was calculated by the accumulated apparent green leaf area (m\(^2\)) per unit ground area (1 m\(^2\)). Two 10-m\(^2\) areas rice were harvested per field plot for the determination of yield production of each plot.

Measurements of canopy reflectance spectrum were taken at the dates of plant samplings, every two to three weeks from about 1 month after transplanting to harvest. Most parts of the reflectance spectrum were found not affected by background interference when rice crop reached more than 70% of land cover, at about 4 weeks after transplanting. The NDVI calculations were made after that stage. Two SCs, narrow bands at red light minimum (R\(_{\text{RED}}\)), the chlorophyll absorption maximum in photosynthetic reaction, and at near-infrared peak (R\(_{\text{NIR}}\)), near the red-edge right end in response to vegetation covering percentage, were identified dynamically from canopy hyperspectral data during growing periods and used for the calculations of NDV\(_{\text{INR}}\) by the equation: 

\[
\frac{(R_{\text{NIR}}-R_{\text{RED}})}{(R_{\text{NIR}}+R_{\text{RED}})}
\]

The mean values of reflectance over 630-690 nm and 760-900 nm regions were computed for simulating the reflectance values of red and near-infrared regions of FORMOSAT-2 broadband sensors, while mean values averaged over 610-680 nm and 780-890 nm were to simulate broadband reflectance of SPOT 5 satellite. Both narrow-band and broadband data were used to compare the differences in growth estimation and yield prediction relative to those of ground measurements.

A portable spectroradiometer (model GER-2600, Geophysical and Environmental Research Corp., Millbrook, NY) with 10° field-of-view (FOV) lens was used to measure the reflected radiance of target regions in a range from 330 to 2600 nm. The radiometer has two spectrometers, one measuring waveband range of 330 to 1050 nm with 1.5-nm resolution and the other measuring waveband range of 1050 to 2600 nm with 11.5-nm resolution. The band centers were rounded off to the nearest whole number in applications, and only radiance data in the 350 nm to 2400 nm range were used because of severe noise in both ends of the spectrum. A notebook computer, driven by software supplied by GER, was connected to the radiometer unit to automatically record the readings from all 537 channels. The software is able to control spectral measurements and display radiance, percentage reflectance, and other
modes for data interpretation.

The radiometer unit was mounted 5.8 m above the rice canopy surface in a nadir viewing on an adjustable mobile lift to result a sampled area 1 m in diameter. On each targeted area, a setup of four consecutive full spectral range scans was made to compute an averaged radiance spectrum, which was then divided by the radiance spectrum from a spectral reference panel (‘Spectralon’, Labsphere, Inc., North Sutton, NH, USA) of known spectral characteristics to obtain reflectance spectrum. Target measurements were collected immediately after the reference measurements for reflectance spectrum calculation. About 15 spectra were obtained from random target regions on each field or plot each measuring day. A single mean reflectance spectrum was produced from all the spectra collected from each field or plot and used in the statistical analyses. Such practices were intended to compensate for the effects of narrow sensor FOV (10°) and low sensor height (5.8 m) so that the radiance measurements were more analogous to those obtained from the sensor at satellite altitude. All reflectance data were collected under near cloud-free conditions between 10:00 to 13:00 local time.

2.3 Growth Estimation and Yield Prediction

The relationship between LAI and NDVI was analyzed with paired values of LAI_{measured} and NDVI_{NB}. All the computed NDVIs were plotted against the measured LAIs to obtain the regression equation, from which the estimates of LAI_{NB} were extracted from the fitting regression function using NDVIs as inputs. The analyses was then conducted for calculating values of NDVI_{FORMOSAT-2} and NDVI_{SPOT 5}, which were computed from mean reflectance values of near-infrared and red regions as those of broadband sensors of satellites FORMOSAT-2 and SPOT 5, respectively. Values of NDVI_{NB}, NDVI_{FORMOSAT-2}, and NDVI_{SPOT 5} were used as inputs for the previous LAI_{measured} – NDVI_{NB} relationship to obtain the estimates of LAI_{NB}, LAI_{FORMOSAT-2} and LAI_{SPOT 5}, respectively.

Correlation between grain yield and LAI_{measured} was analyzed from 50 DAT to harvest. The determination coefficients (R²) from regression analyses were plotted to determine the optimal timing for predicting yield with LAI_{measured}. Furthermore, the quantitative relationships between the accumulated values of LAI_{measured}, computed from different periods during rice growth, and yields, produced under different levels of N applications, were analyzed to obtain the optimal period that may improve yield prediction with the cumulative LAI_{measured}. The LAI_{measured} was replaced by either LAI_{NB}, LAI_{FORMOSAT-2}, or LAI_{SPOT 5} to accumulate the values in the optimal periods for producing respective predicted yields, and the differences between predicted yields and measured yield were then compared.

2.4 STATISTICS

The statistics were carried out by using Statistical Analysis System (SAS) version 8.1 (SAS Institute, 1998) and Sigmaplot 2000 (SPSS ASC BV, the Netherlands). The dummy-variable test was used to compare differences in spectral data between different years of the same cropping season as well as between cropping seasons. Data from two years or two seasons were pooled for statistical analyses if the tests were non-significant. The root mean square error (RMSE) was calculated as \( \text{RMSE} = \sqrt{\frac{1}{n} \sum (\hat{X}_{i} - \hat{X})^2} \), and was used to compare the precision of estimation between the measured values (\( X_{i} \)) and the estimated values (\( \hat{X}_{i} \)).
3. Results and Analyses

A typical high-resolution reflectance spectrum of rice canopy/vegetation was plotted in Fig. 1, in which generally reflectance was low in the visible region (400-740 nm) while reflectance was high and vary significantly in the infrared region (740-2400 nm). As figure shown, characteristic narrow-bands at red light minimum (RED) and near-infrared peak (NIR) can be identified from the spectrum. During the cropping seasons, both SCs appeared dynamically along the wavelength axis of reflectance spectrum, and their reflectances (R<sub>RED</sub> and R<sub>NIR</sub>) were used for the calculations of NDVI of narrow bands (NDVI<sub>NB</sub>). To compare the relative locations between these two narrow-bands and the corresponding broadband sensors of satellites SPOT 5 (RED: 610-680 nm; NIR: 780-890 nm) and FORMOSAT-2 (RED: 630-690 nm; NIR: 760-900 nm), the specified broadband regions were also identified in Fig. 1.

Temporal changes in NDVIs from narrow-band and broadband spectral data along plant development as the representatives of vegetation expansion were graphed in Fig. 2. The calculated values of NDVI<sub>NB</sub>, NDVI<sub>SPOT 5</sub>, and NDVI<sub>FORMOSAT-2</sub> were curvilinearly distributed during the first and the second cropping seasons, increased to near heading and then decreased toward maturity. Changes in NDVI<sub>SPOT 5</sub> and NDVI<sub>FORMOSAT-2</sub> were nearly parallel to changes in NDVI<sub>NB</sub>, but with a lesser extent, indicating that values of NDVIs from the mimicked satellites broadband data were lower than those from near-ground hyperspectral data on the same sampling dates. By using the ratio-based SIs such as NDVI to correlate with biophysical traits, though in a non-linear trend, the measure can minimize the interference by both internal geometry noise and external radiation influence (Elvidge and Chen, 1995; Gilabert et al., 1996).

![Fig. 1. A typical high-resolution reflectance spectrum of rice (Oryza sativa L. cv. TNG 67) canopy/vegetation and the identified spectral characteristics at red light minimum (RED) and near-infrared peak (NIR). The corresponding locations of red and near-infrared regions to the broadband sensors of satellites SPOT 5 and FORMOSAT-2 are also identified.](image)

![Fig. 2. Temporal changes in NDVI<sub>NB</sub>, NDVI<sub>SPOT 5</sub> and NDVI<sub>FORMOSAT-2</sub> after transplanting for rice plants (Oryza sativa L. cv. TNG 67) grown in first crops of 2000 and 2002 and second crops of 2000 and 2001.](image)
Differences in Growth Estimation and Yield Prediction of Rice Crop Using Satellites Data Simulated from Near Ground Hyperspectral Reflectance

Information contained in satellite images and radiometric data may be extracted to the qualitative and quantitative evaluation of biophysical traits of a crop canopy in field, regional or global scale. Within growth indicators LAI is probably the most commonly used, not only in describing growth behavior of vegetation directly but also in assessing growth status upon environmental impact in many growth models indirectly (Bonan, 1993; Liu et al., 1997; Running et al., 1999). Therefore, the relationship between LAI and SIs derived from remote sensing data is often the subject of interest (Nemani et al., 1993; Chen and Cihlar 1996; Fassnacht et al., 1997; Su and Yang 1999; Chen and Yang 2002; Yang and Chen 2004). The feasibility of using the simulated SPOT 5 and FORMOSAT-2 spectral data in estimating rice growth was examined by the intensity of the LAI-NDVI relationship. The ground truth relationship was analyzed with paired values of LAImeasured and NDVINB, and was found fitted to an exponential growth function (Fig. 3), similar to that reported by Su and Yang (1999) and Yang and Chen (2004). As that changes of LAI as a function of NDVI show a positive correlation with a fairly high coefficient of determination (R² > 0.53), results suggest that LAI can be considered a good indicator for NDVI while NDVI may be a good parameter to estimate LAI. The relationship appears adequate for estimating and monitoring rice growth during the growing periods. However, with the exponential function, change of LAI to NDVI was less sensitive at the lower end of NDVI, a further increase in LAI results in only small and asymptotic increase in NDVI, and may exhibit ‘over-fitting’ problem due to the saturation of reflectance scale at the upper end of NDVI, a rapid increase in LAI with a little variation in NDVI (Gilabert et al., 1996; Yang and Su, 1998; Yang and Chen, 2004).

Additionally, large scatter was observed by the pooling of heterogeneous data of the same cropping season from different years, indicating that there may have a high internal heterogeneity over canopy between years due to variation in environmental factors. Differences in the patterns of LAI-NDVI relationship between cropping seasons also implied that model developed in first crops may not suitable for model developed in second crops. Nevertheless, such variations in LAI suggest that there is a space for precision management by which data of LAI variation may be incorporated as inputs (Yang and Chen, 2005). Management strategies or recommendations can then be formulated and field spots with low LAIs could be potentially improved through a differential site-specific treatment, especially during the early stages of growth. With the
high spatial and radiometric resolution satellites data such as FORMOST2 and SPOT 5, a more precise LAI-NDVI relationship should be retrieved, relative to those of low resolution imageries mixing with several land cover classes in a pixel (Chen and Cihlar, 1996). The scatter effect caused by a mixture of different land covers on the spectral data is therefore greatly reduced.

By using the established LAI-NDVI relationships (Fig. 3), the estimates of LAI\textsubscript{NB}, LAI\textsubscript{SPOT 5}, and LAI\textsubscript{FORMOSAT-2} may be computed by the input of the respective values of NDVI\textsubscript{NB}, NDVI\textsubscript{SPOT 5}, and NDVI\textsubscript{FORMOSAT-2}. Accordingly temporal distributions in LAIs can be plotted for comparisons (Fig. 4). As shown, changes in values of LAI\textsubscript{measured}, LAI\textsubscript{NB}, LAI\textsubscript{SPOT 5}, and LAI\textsubscript{FORMOSAT-2} were all quadratic distributed during rice growth. Values of LAI\textsubscript{NB} were higher than the corresponding values of LAI\textsubscript{SPOT 5} and LAI\textsubscript{FORMOSAT-2}, but the estimated LAIs were lower than the values of LAI\textsubscript{measured} after approximately 55 DAT in both fist and second crops. By inspecting the temporal patterns graphed in Fig. 2, the lower values of the estimated LAIs may be attributed to the lower values of the corresponding NDVIs. Although the simulated satellites spectral data are proved feasible in estimating rice growth in terms of LAI, the estimates of LAIs appeared to be under-estimated with the use of reflectance of larger bandwidths as of SPOT 5 and FORMOSAT-2. With the necessary adjustment algorithms, however, these estimates of LAI can then be re-adjusted to derive the LAI-NDVI relationship applicable for the satellites data and extended for growth monitoring and evaluation (Chen and Cihlar, 1996; Colombo et al., 2003).

As proposed by Chen and Yang (2005) that the accumulated values of LAI\textsubscript{measured} collected from the optimal time period, from 15 days before heading (DBH) to 15 days after heading (DAH) for first crops and from 15 DBH to 10 DAH for second crops, were suitable for predicting grain yield of rice through the pre-established algorithms. This study adopted the method and also substituted the values of LAI\textsubscript{measured} with the values of LAI\textsubscript{NB}, LAI\textsubscript{SPOT 5}, and LAI\textsubscript{FORMOSAT-2} to predict yields from varied satellites (Fig. 5). Results showed that the relationships between the estimated and the measured yields were closely related in both first and second crops. However, yields predicted from the simulated satellites spectral data obtained a lower value than the yield predicted from the near-ground hyperspectral data, and all the predicted yields were lower than the measured yields. Since values of NDVI\textsubscript{FORMOSAT-2}
and NDVISON逊and SPOT 5 were smaller than values of NDVISON逊 on the same sampling dates after transplanting and obtained a lower value of estimates of LAI FORMOSAT-2 and LAI SPOT 5, under the same optimal periods to predict yields, yields predicted from LAIs of satellites would be expected to lower than yields predicted from LAI NB of hyperspectral data. As pointed out by Murata (1975) and Yoshida (1981) that LAI plays the key role in determining source capacity and biomass accumulation, keeping larger values of LAI during heading and grain-filling periods will provide a positive effect to yield production (Shieh, 1978). Thus, with lower cumulative values of LAI, yields predicted from simulated satellites data would result in yield underestimation.

4. Discussion

As a result, this study confirms the potential for using NDVI calculated from canopy high-resolution reflectance data to reasonably estimate growth and predict yield by transforming NDVI into LAI based on the established LAI-NDVI relationship. The approach remains feasible by using the simulated satellites broadband spectral data mimicked from ground-based canopy hyperspectral data. Since values of NDVIFORMOSAT-2 and NDVISON逊SPOT 5 were lower than values of NDVISON逊NB on the same sampling dates after transplanting, lower values of the estimated LAI FORMOSAT-2 and LAI SPOT 5 were obtained, and thus output a lower level of predicted yields. Given that the nature of broadband sensors in providing under-estimated values of NDVI and LAI is tolerable and adjustable, the advantages of using satellites data such as FORMOSAT-2 and SPOT 5 in providing non-destructive real time information of plant growth status are still a promising means to be employed in precision farming system. With the yield predicted a month before harvest, suitable cultivation practices may be applied prior to harvesting for a substantial yield improvement.

In any case, before practical applications of the results yielded from this study, there still has a far step to go. The radiometric distortion caused by geometric and atmospheric effects must be considered and the linkage between satellite data and ground truth should be made. Whether the models examined and validated in the experiments are applicable to real satellite data need also to be clarified.

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References


由近地面高解析光譜模擬之不同衛星光譜資料對水稻生長估測及產量預測產量上之差異

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摘要

Values of LAI_{NB} were found higher than those of LAI_{SPOT 5} and LAI_{FORMOSAT-2} on the same sampling dates yet all the estimates were lower than the corresponding values of LAI_{measured} after ca. 55 days after transplanting. As the simulated satellites data obtained lower values of NDVI and LAI than those of NDVI_{NB} and LAI_{NB} counterparts, yields predicted from satellites data were less than yield predicted from ground-based hyperspectral data. 本研究以近地面量測之水稻植被窄頻高解析光譜模擬法國史波特五號(SPORT 5)及臺灣福衛二號(FORMOSAT-2)之寬頻光譜資料, 俾利用於比較其等對水稻生長估測與產量預測上相對於近地面側值之差異。近地面植被高解析反射比光譜(reflectance spectrum)係由田間可攜式光譜儀(field-portable spectroradiometer)量測之, 寬頻波段之反射比則以同波段各窄頻側值累加之平均值估算。根據試驗結果, 由高解析光譜計算之標準化差植被指數(normalized difference vegetation index,  NDVI_{NB})及模擬衛星光譜計算之標準化差植被指數(NDVI_{SPOT 5} 及 NDVI_{FORMOSAT-2})均於一、二期稻作生育過程中呈現非線性分佈, 且分佈曲線之間幾近平行變化, 模擬衛星光譜資料之 NDVI_{SPOT 5} 與 NDVI_{FORMOSAT-2} 低於高解析光譜之 NDVI_{NB}。地面實測葉面積計算之葉面積指數(LAI_{measured})與 NDVI_{NB} 之間係適用於指數生長型函數, 據此將不同計算方式得到之 NDVIs 輸入以獲得相對估測之葉面積指數(LAI_{NB}, LAI_{SPOT 5} 及 LAI_{FORMOSAT-2})結果發現的自移植後 55 天起, 在同一取樣日之 LAI_{NB} 估測值高於於 LAI_{SPOT 5} 及 LAI_{FORMOSAT-2} 估測, 惟這些葉面積指數估測值低於相對地面實測 LAI_{measured} 值。由於利用模擬衛星光譜資料獲得之 NDVI 及 LAI 估測值低於近地面高解析光譜資料估測之相 NDVI_{NB} 及 LAI_{NB}，因此以模擬衛星光譜資料預測之水稻產量低於近地面光譜資料預測之產量，且均低於實測產量。

關鍵詞: 水稻生長、產量預測、福衛二號衛星、史波特五號衛星、高解析光譜

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