Rice yield estimation with satellite data

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ABSTRACT: Information on rice yield is thus critical for agronomic planners to estimate rice production in respect to successful strategies to address food security and rice grain export issues. This study aimed at modelling rice yields based on rice crop phenology with Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data in the Mekong River Delta, Vietnam. The data processed for 2011 comprised of three main steps: (1) constructing the filtered time-series enhanced vegetation index (EVI) data, (2) model rice crop yields, and (3) verify the yield model. The comparison results between the satellite-based estimated yields and government's yield statistics indicated a significant relationship between the two datasets (p-value < 0.001) with the correlation coefficients (R^2) of 0.66 to 0.46 for spring–winter and summer–autumn rice crops, respectively. The RMSE and MAE values for winter–spring and summer–autumn crops were lower than 10%, indicating the consistency between estimated yields and statistics.

1. INTRODUCTION

Rice agriculture plays a critical role in the economy of Vietnam. This country annually produced roughly 40 million tons (GSO, 2010). Climate impacts (e.g., drought, flood, diseases, and salinity intrusion) could undermine rice production, consequently destabilizing rice prices and creating food security issues. A reliable estimate of rice crop yields is thus needed for agronomic planners to devise timely, successful strategies to address food challenges and rice grain exports. Remote sensing has been successfully used for yield estimation. In this study, the Moderate Resolution Imaging Spectroradiometer (MODIS) data were used for rice yield estimation. Because the final yield is related to the duration of green biomass during the head-filling stage (Hatfield, 1983), the enhanced vegetation index (EVI) is thus an effective index in tracking phenological events of crop growth as well as assessing and monitoring seasonal variations of crops and evergreen vegetation. Because the rice crop yield is highly correlated with the maximum biomass during the heading stage (Lam-Dao, 2009), previous studies indicated the highest correlation coefficient between crop yields and vegetation indices during the ripening stage and the grain filling period. Thus, we hypothesized that the temporal accumulation of EVI values surrounding the heading date would be significantly correlated with yields of rice crops.

The main objective of this study was to develop an approach to bridge a research gap between the effectiveness of MODIS EVI data for a large-scale yield estimation of rice crops in the Mekong River Delta, Vietnam.

2. STUDY AREA

The Mekong River Delta covers approximately 40,000 km^2 (Figure 1). The climate is monsoonal tropical with two distinct seasons: rainy season (May–November) and dry season (December–April), more than 80% of the total precipitation occurs in the rainy season. Rice production is dependent on the availability of irrigation. The winter–spring (November–December to February–March) and summer–autumn (April–May to July–August) seasons are the two main rice cropping seasons in the region. The winter–spring crop generally provides higher rice yields than the summer–autumn crop due to more favorable weather and irrigation conditions. The rice cultivars in the region are short-term varieties (90–100 days).

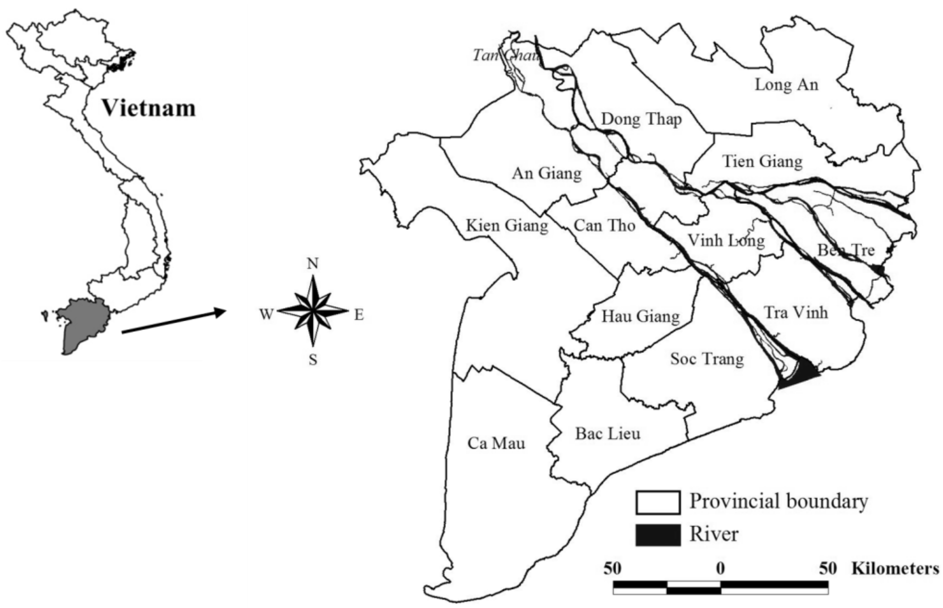

Figure 1. Map of study area shows administrative boundaries of provinces with reference to the national geography.

3. DATA

The MODIS/Terra (MOD09A1) acquired from NASA for 2011 for the rice cropping seasons (Nov 2001 to Dec 2011) were used. The MOD09A1 data have been previously radiometrically corrected. The district-level yield statistics of the two main rice crops (i.e., winter–spring and summer–autumn cropping seasons) in the study region were collected from the Provincial Departments of Statistics for 2011 rice cropping seasons. We also collected the 2002 rice crop map (scale: 1:250,000) to verify the non-rice area masking results.

4. METHODS

The MODIS data, formatted using the sinusoidal projection, were first reprojected to the Universal Transverse Mercator coordinate systems (Zone 48 N); the data were then subset over the study region. The EVI was subsequently calculated using the following equations:

$$EVI = 2.5 \times \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + 6 \times \rho_{red} - 7.5 \times \rho_{blue} + 1}, \quad (1)$$

where ρ_{red} (620–670 nm), ρ_{nir} (841–876 nm), and ρ_{blue} (459–479 nm) are MODIS bands 1, 2, and 3, respectively. To create the time-series data for these two indices for 2011 rice cropping seasons, we first calculated these indices for every 8-day MODIS image. A total of 46 images were consequently created and then stacked into one 8-day composite scene. The time series of EVI data contained some noise were filtered using the empirical mode decomposition (EMD) method (Huang, 1998). Non-rice areas (e.g., orchards/fruit trees, forests, built-up areas, and water bodies/shrimp farms) were masked out if the IMF3 values (derived from EMD processing of the time-series EVI data) were smaller than 0.05.

The rice yields for each crop were modeled using the filtered EVI data and district-level yield statistics. The statistics of crop yields were considered as the dependent variable, determined by an independent variable of EVI. The quadratic regression model used to examine the effectiveness of EVI for estimating rice crop yields in the study region was expressed as follows.

$$\hat{y} = \beta_0 + \beta_1 x + \beta_2 x^2, \quad (2)$$

where, $\hat{y}$ is the estimated yields of rice crops, β_{0-2} are the model parameters, and x is the mean value of EVI data for each district. The heading date was chosen as a basic point to respectively calculate the temporal accumulation of EVI values for five extended points, 1–5 (day of year), surrounding the heading date. Based on the crop phenology analysis, we found that the maximum intensity of EVI (upper bound) during the peak reproductive stage of the winter–spring crop was lower than 0.7, while that of the summer–autumn crop was lower than 0.6. Similarly, during the harvesting period (i.e., approximately four consecutive 8-day periods totaling 32 days after the heading date), the EVI value of the winter–spring and summer–autumn crops were generally higher than 0.3 and 0.2, respectively. Thus, these thresholds were used to establish rice crop yield models. Finally, the spatial mean values were calculated for each district and used for yield modeling. The robustness of yield model performance was evaluated using the root mean square error (RMSE) and mean absolute error (MAE).

5. RESULTS AND DISCUSSIONS

The results obtained from the quadratic regression analysis between rice yield statistics and EVI data using the heading date and its five extended points (DOYs) for the winter–spring and summer–autumn crops showed the variation of correlation coefficients (R^2) throughout the cropping seasons (Figure 2). In general, higher correlation levels were clearly observed for the relationship between EVI data and yield statistics of rice crops during the heading stages for both rice cropping seasons in all years. The summer–autumn crop revealed lower levels of correlation than the winter–spring crop due to larger variations in climatic conditions. By the end of the summer–autumn crop, serious cloud contamination from the onset of the rainy season could affect the vegetation greenness, consequently creating disparities in the values of EVI data. In both cropping seasons, the correlation coefficients began leveling off after the first extended points of heading dates (i.e., H+1). Thus, the results implied that EVI better estimated yields of rice crops using the heading date of rice plant growth, thus allowing agronomic planners to devise more timely rice grain import and export strategies.

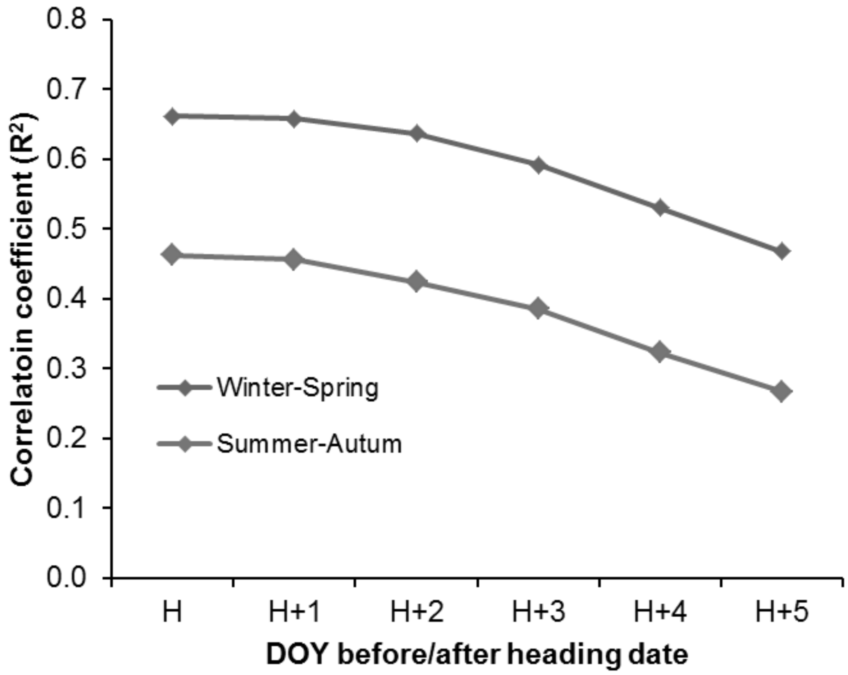

Figure 2. Correlation coefficients obtained from regression analysis using the heading date (H) and its extended points (i.e., H+1 to H+5) for the winter-spring and summer-autumn crops.

The quadratic models of the heading date, which yielded the higher correlation levels between rice crop yield statistics and smooth EVI data, were chosen to estimate rice crop yields in the study region for both winter–spring and summer–autumn crops. The scatterplots between the yield statistics and estimated yields indicated the correlation coefficients achieved for the winter–spring and summer–autumn crops were 0.65 and 0.46, respectively (Figure 3). The RMSE and MAE values between the two datasets for the winter–spring crop were from 6.9% and from 5.4%, respectively; while the values obtained for the summer–autumn crop were from 8.9% and from 7.1%, respectively. These values were lower than 10%, indicating consistency between the yield statistics and estimated yields. Larger errors in yield estimates were observed for the summer–autumn crop owing to various reasons such as cloud cover and heavy monsoon rains that influenced the spectral quality of satellite data.

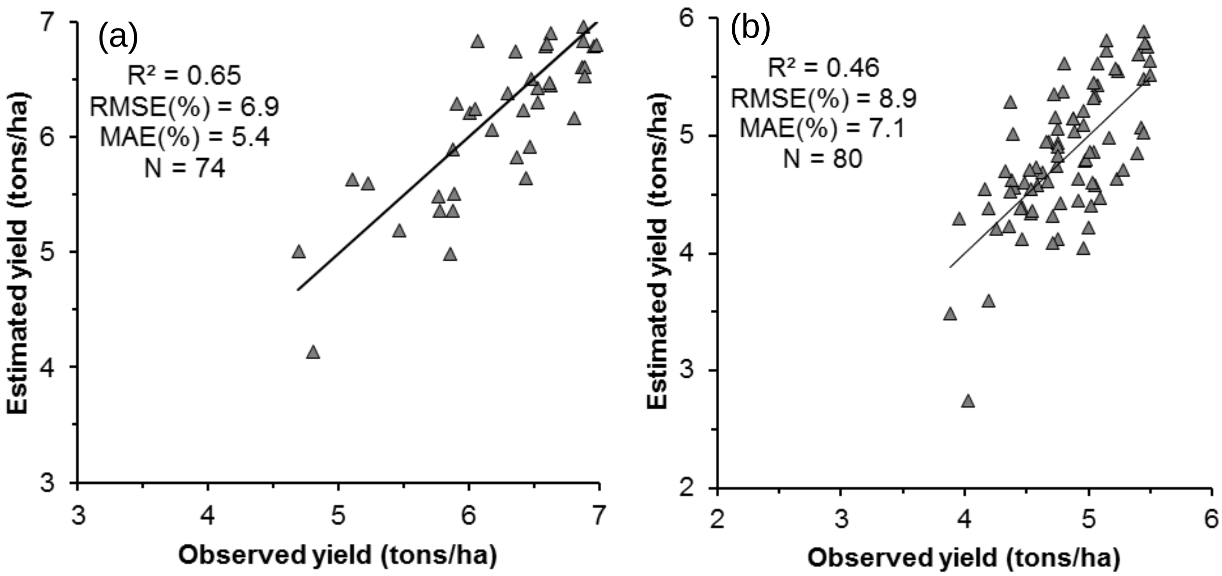

Figure 3. Correlation levels between the enhanced vegetation index (EVI) and rice yield statistics: (a) winter–spring crop, and (b) summer-autumn crop.

6. CONCLUSION

It could be concluded a significant district-level correlation between EVI data and rice yield statistics. The R^2 achieved for the winter–spring and summer–autumn crops during the heading date were 0.66 and 0.46, respectively. The RMSE and MAE used to verify the accuracy of yield models indicated the consistency between the government's rice yield statistics and estimated yields. Because several error sources such as cloud cover, rice diseases, and weather calamities could lower the model accuracy, the findings achieved from this study demonstrated the effectiveness of EVI data for a large-scale yield estimation using the heading date, which would be useful for planners to estimate rice production prior the harvesting period.

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