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A comparative analysis of multitemporal MODIS EVI and NDVI data for large-scale rice yield estimation

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ABSTRACT

Rice is one of the most important food crops worldwide, and large-scale rice yield estimation is thus critical for planners to formulate successful strategies to address food security and rice grain export issues. This study performed a comparative analysis of multitemporal Moderate Resolution Imaging Spectroradiometer (MODIS) enhanced vegetation index (EVI) and normalized difference index (NDVI) data for estimating rice crop yields in the Mekong River Delta (MRD), Vietnam. We processed the data for a 10-year period (2002–2011) following three main steps: (1) create a smooth time series of EVI and NDVI data, (2) formulate crop yield models, and (3) validate the model. The comparison results between EVI/NDVI-based estimated yields and the government's yield statistics indicated a significant relationship between the two datasets (p-value < 0.001). The estimated results produced from EVI-based models were slightly more accurate than those from NDVI-based models, with the correlation coefficients (R^2) ranging from 0.62 to 0.71 for spring–winter and 0.4 to 0.56 for summer–autumn rice crops, respectively. The root mean square error (RMSE) and mean absolute error (MAE) used to measure the model accuracy revealed the consistency between EVI-based estimated yields and the government's yield statistics. The RMSE values for winter–spring and summer–autumn crops were, respectively, 6.9–8.1% and 5.4–6.7%, and MAE values were 5.4–6.7% and 6.5–9.5%. There was, however, a significant correlation between the estimated yields obtained from EVI- and NDVI-based models (p-value < 0.001), indicating no significant difference in the estimated yields between these two models. This study demonstrates advantages of using multitemporal MODIS EVI data for large-scale estimation of rice crop yields using the heading date in the MRD prior to the harvest period, and thus the methods could be transferable to other regions.

1. Introduction

Rice is one of the most important food crops for more than half the world's population (FAO, 2004), and rice agriculture plays a critical role in the economy of Southeast Asia countries (Evenson and Rosegrant, 2003; Timmer, 2009), which annually produce approximately 150 million tons of rice grain (or 25% of the world's rice production) (Raitzer et al., 2009). Of this amount, Vietnam produced roughly 40 million tons (GSO, 2010), making this nation the second largest rice exporter worldwide (FAO, 2011). Rice production in Vietnam is mainly from the two deltas, the Red River Delta in the north and Mekong River Delta (MRD) in the south. The terrain of these two deltas is mostly plateaus, and the regions are reported to be among the world's most vulnerable to impacts of climate change (Dasgupta et al., 2009; Ericson et al., 2006; IPCC, 2007; WorldBank, 2010). Climate impacts (e.g., drought, flood, diseases, and salinity intrusion) could undermine rice production (Masutomi et al., 2009; Matthews and Wassmann, 2003; Matthews, 1995; Matthews et al., 1997; Parry et al., 1999), consequently destabilizing rice prices and creating food security issues (Parry et al., 1999; Parry et al., 2005; Rosenzweig and Parry, 1994). A reliable, large-scale 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 and monitoring over the last few decades due to its ability to acquire spatiotemporal data over a large region (Barnett and Thompson, 1983; Groten, 1993; Hamar et al., 1996; Hatfield, 1983; Johnson, 2014). In this study, the Moderate Resolution Imaging Spectroradiometer (MODIS) data were used for rice yield estimation because they have a wide coverage as well as high spectral and temporal resolutions; thus, timely information on yield estimates could be

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achievable before the harvesting period. MODIS data have been successfully used for yield estimation and prediction (Bala and Islam, 2009; Doraiswamy et al., 2004; Huang et al., 2012; Mkhabela et al., 2011; Ren et al., 2008; Shunlin et al., 2004; Son et al., 2013c). In particular, studies have used remotely sensed vegetation indices, such as the normalized difference vegetation index (NDVI) (Kastens et al., 2005; Mkhabela et al., 2011; Mkhabela et al., 2005; Moriondo et al., 2007; Quarmby et al., 1993; Ren et al., 2008), the enhanced vegetation index (EVI) (Bolton and Friedl, 2013; Kyoungdo et al., 2013; Shunlin et al., 2004), and the soil-adjusted vegetation index (SAVI) (Gontia and Tiwari, 2011; Mandal et al., 2007; Noureldin et al., 2013; Panda et al., 2010).

The NDVI using near infrared (NIR) and red bands is the most widely-used vegetation index for crop yield estimation and prediction because it is highly correlated with canopy background variations (Rouse et al., 1974). This index reveals some limitations related to soil background brightness (Bausch, 1993; Elvidge and Lyon, 1985), however, as well as saturation problems at high biomass values (Carlson and Ripley, 1997; Santin-Janin et al., 2009; Stroppiana et al., 2012; Turner et al., 1999). The soil "noise" inherent in NDVI can be overcome by SAVI (Huete, 1988), which uses a soil-adjustment factor to account for first-order, nonlinear, differential NIR and red radiative transfer through a canopy, thus minimizing soil brightness variations and eliminating the need for additional calibration for different soils (Huete and Liu, 1994; Miura et al., 2000).

Crop biomass at different phenological stages has different correlation levels with satellite-based vegetation indices due to phenological variations in plant growth responding to various climatic conditions (Cohen et al., 2003; Davi et al., 2006; Kamthonkiat et al., 2005; Wang et al., 2005). Because the final yield is related to the duration of green biomass during the head-filling stage (Hatfield, 1983), the saturation problem of NDVI during the leaf constant or heading period likely leads to inaccurate estimates of crop yields. The saturation and soil noise problems of NDVI can be overcome by using EVI, which was constructed by decoupling the canopy background signal and reducing atmospheric influences (Chen et al., 2005; Fangping et al., 2007; Fensholt, 2004; Huete et al., 2002; Huete et al., 1997; Miura et al., 2001; Potithep et al., 2013). The 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 (Fangping et al., 2007; Gurung et al., 2009; Potgieter et al., 2007; Wardlow et al., 2007b). 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 (Son et al., 2013c) and the grain filling period (Benedetti and Rossini, 1993; Knudby, 2004; Labus et al., 2002; Shanahan et al., 2001; Shibayama and Akiyama, 1991). Thus, we hypothesized that the temporal accumulation of EVI/NDVI values surrounding the heading date would be significantly correlated with yields of rice crops.

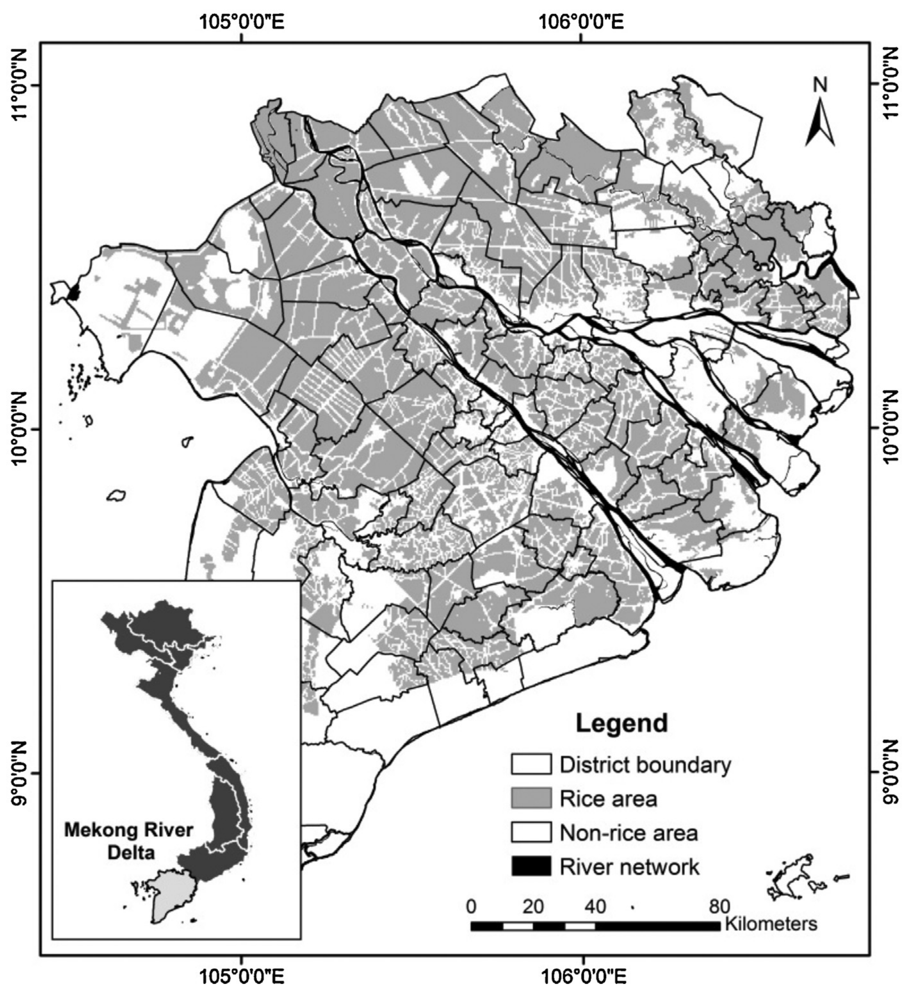

Fig. 1. The study region showing spatiotemporal distributions of three main rice cropping systems, overlaid with administrative district boundaries, with a reference to the national geography of Vietnam.