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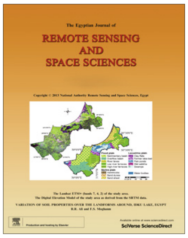

RESEARCH PAPER

Rice yield forecasting models using satellite imagery in Egypt

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Abstract Ability to make yield prediction before harvest using satellite remote sensing is important in many aspects of agricultural decision-making. In this study, canopy reflectance band and different band ratios in form of vegetation indices (VI) with leaf area index (LAI) were used to generate remotely sensed pre-harvest empirical rice yield prediction models. LAI measurements, spectral data derived from two SPOT data acquired on August 24, 2008 and August 23, 2009 and observed rice yield were used as main inputs for rice yield modeling. Each remotely sensed factor was used separately and in combination with LAI to generate the models. The results showed that green spectral band, middle infra-red spectral band and green vegetation index (GVI) did not show sufficient capability as rice yield estimators while other inputs such as red spectral band, near infrared spectral band and vegetation indices that are algebraic ratios from these two spectral bands when used separately or in combined with leaf area index (LAI) produced high accurate rice yield estimation models. The validation process was carried out using two statistical tests; standard error of estimate and the correlation coefficient between modeled and predicted yield. The validation results indicated that using normalized difference vegetation index (NDVI) combined with leaf area index (LAI) produced the model with highest accuracy and stability during the two rice seasons. The generated models are applicable 90 days after planting in any similar environmental conditions and agricultural practices.

1. Introduction

Crop yield forecasts a few months before harvest can be of paramount importance for timely initiating food trade secure the national demand and timely organize food transport within countries (Bastiaanssen and Ali, 2003). Forecasting enables planners and decision makers to determine how much to import (in shortfall case) or optionally, to export (in surplus

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case). Traditionally, crop yield estimation depended upon data collection technique from ground-based field visits. Such technique is often subjective, costly and is prone to large errors, leading to poor crop assessment and crop area estimation (Reynolds et al., 2000). Also, the obtained data may become available too late for appropriate action to be taken to avert food shortage. At the same time, no yield prediction models unless developed or tested locally are suitable for local use (Shresthan and Naikaset, 2003); this view may be due to soil attributes variation, climatic conditions, plant species varieties and agricultural practices from one area to another. Recently, with successful launching of various satellites, a lot of efforts are made to use remote sensing for yield forecasting. Whereas, remote sensing data have the potential to provide timely, systematically high quality spatial and accurate information about land features including environmental impacts on crop growth (Liu and Kogan, 2002). So, the temporal dynamics of remote sensing data and their close relation with plant characteristics could play a crucial role in establishing an effective pre-harvest yield estimation method.

The most multi spectral satellite systems measure varies spectral bands within the visible to mid-infra red region of the electro magnetic spectrum (Shwetank and Bhatia, 2010). The spectral absorption normally occurs from 670 to 780 nm wave length range of the electro magnetic spectrum (Kempeneers et al., 2004). In this concern, leaf chlorophyll has a strong absorption at 0.45 μm and 0.67 μm, and a high reflectance at near infrared (0.7–0.9 μm). Near infrared is very useful for vegetation surveys and mapping because such a steep gradient at 0.7–0.9 μm is produced only by vegetation (Murai, 1996). Moreover, healthy plants have a high normalized difference vegetation index (NDVI) value because of their high reflectance of infrared light, and relatively low reflectance of red spectrum (Moore and Holden, 2003). The modeling process is based on vegetation indices (VI) which could be observed and collected from remote sensing satellite data as well as remotely sensed ground observation tools. Vegetation indices are optical measures of vegetation canopy "greenness". They give a direct measure of photosynthetic potential resulting from the composite property of total leaf chlorophyll, leaf area, canopy cover, and structure. In this concern, (NDVI) was linked to many plant parameters, which are closely related to crop yield. It has a direct correlation with LAI, biomass and vegetation cover (Wiegand et al., 1990, 1992; Tucker, 1979; Holben et al., 1980; Ahlrichs and Bauer, 1983; Nemani and Running, 1989). These driving parameters are largely influenced by variations in soil fertility (Hinzman and Bauer, 1986) soil moisture (Daughtry et al., 1980; Tucker et al., 1980; Teng, 1990, planting date (Crist, 1984) and crop density (Aase and Siddoway, 1981). Most studies have observed a correlation between NDVI and green biomass yield, therefore NDVI can be used to estimate yield before harvesting (Rasmussen, 1997). The other key for the proposed modeling process is leaf area index (LAI) as a biophysical and major parameter for determining crop growth. It gives a measure of the density of foliage and is closely linked to the photosynthetic and evapotranspiration capacities of plants. It can be regarded as the principle morphological parameter of the vegetation canopy linking the satellite-derived vegetation index and photosynthesis (Bach, 1998). Moreover, VI and LAI have a strong correlation with plant physiological conditions and crop productivity under a different dimension and growth stage with multi-source remote sensing data.

2. Materials and methods

2.1. Field experiment

Yield prediction modeling of rice crop was carried out using the collected data from Sakha experiment station, Agriculture Researcher Center, Ministry of Agriculture, Egypt. The experimental field was situated in the rice belt region which includes Kafr El-Sheikh Governorate. It is located between 31° 06′ 40″ and 31° 06′ 0″ North and 30° 54′ 30″ and 30° 55′ 60″ East (Fig. 1). The total area of rice observation site was 2.4 ha during the growing seasons of 2008 and 2009, cultivated by the variety Sakha 104. The region that includes the study area is defined as Pro-Deltaic Alluvial Plain. This Pro-Delta is characterized by clayey soil of high clay fraction and high water saturation percentages. These clayey soils are characterized as Vertisols of Typic Haplotonerts, fine, and thermic (Afify et al., 2011). Rice was sown in May 24th and 23rd in the 1st and 2nd seasons, respectively. At 90 days from sowing (maximum vegetative growth stage), sixty measurements were collected from sixty parcels of the rice field in each season based on the grid system (Fig. 2). Each parcel covers 400 m^2 (20×20 m) that represents a single SPOT pixel that was fixed as one plot of measurements. The location of the center square meter of each plot was recorded using global positioning system (GPS). Out of this number, fifty random samples were selected for the modeling process and ten samples were selected for validation. Three types of data were used as inputs for generating rice yield prediction models: the direct spectral data collected from SPOT imagery (reflectance values of green, red and near infrared bands), six calculated vegetation indices values, as well as the values of observed rice yield and LAI.

2.2. Satellite data

Four spectral reflectance data were released from the different SPOT bands: green (0.50–0.59 lm), red (0.61–0.68 lm), near infrared (0.78–0.89 lm) and middle infrared (1.58–1.75 lm) acquired during the rice seasons in August of 2008 and 2009. In this respect, two satellite imageries of SPOT4 were acquired to cover rice field within the same indexed projection of K111/J287 including multispectral data. The acquisition dates of these images were in August 24, 2008 and August 23, 2009. The images were geometrically, radiometrically and atmospherically corrected. FLAASH model under ENVI software was used for atmospheric correction. It provides accurate, physics-based derivation of apparent surface reflectance through derivation of atmospheric properties such as surface albedo, surface altitude, water vapor column, aerosol and cloud optical depths, surface and atmospheric temperatures from HSI data. FLAASH operates in the 0.4–2.5 μm spectral range. First, MODTRAN simulations of spectral radiance are performed for various atmospheric, water vapor, and viewing conditions (solar angles) over a range of surface reflectance to establish lookup tables for the atmospheric parameters of column water vapor, aerosol type, and visibility for subsequent