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Derivation of rice crop calendar and evaluation of crop phenometrics and latitudinal relationship for major south and south-east Asian countries: A remote sensing approach

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ABSTRACT

The crop calendar varies considerably with climatic and socio-economic factors as well as farming practices of the region. In present paper we demonstrate the application of remote sensing data to derive a geospatial database for rice crop calendar for major south and south-east Asian countries. The cultural type-wise variability of rice crop calendar and crop phenometrices-latitudinal relationship was also studied.

A crop growth profile equation was used to simplify the parameterization necessary for identification of rice crop phenological matrices. A curve fitting approach was adapted for fitting the spectral Normalized Difference Vegetation Index (NDVI) growth profiles for rice derived from multi-date, multi-temporal SPOT VGT NDVI data and phenometrics viz. sowing/transplantation day, crop maturity/harvest day and total duration of rice crop were derived. The global distribution of the rice along the different latitudes is due to the adaptability of the rice to the regional conditions, which should reflect in the crop calendar. As latitude is one of the controlling factors of the climate, here we investigate the existence of relation between rice crop calendar and latitude. The strength of correlation between the rice crop phenometrics and the latitude was determined by two-tailed Pearson correlation coefficient analysis and Spearman's rank correlation across a latitudinal gradient which indicates an inverse relationship, with the ($P < 0.01$) level of significance for Pearson linear correlation and (rho $\leqslant 0$) for Spearman's rank correlation.

The high temporal NDVI data enabled characterizing the rice crop phenology effectively. The crop calendar derived in this study solely relies on the remote sensing data and can be used for of methane emission assessment from different rice cultural types.

1. Introduction

A crop calendar is a chronological representation of a sequential occurrence of different phenological stages in crop growth cycle. Rice is among the important cereal crop in South and Southeast Asia and significant due to its adaptability to the variety of environmental, ecological and climatic conditions and thus farming scenario in major rice growing countries varies considerably. The ecological conditions, unique paddy farming methods, farming type (irrigated, rainfed, deepwater), crop management (single crop, multi-crop), and seasonality (wet season, dry season) are few of the many parameters which contribute to crop calendar variability (www.fao.org). A crop calendar can serve as a tool in planning and management of activities related to seed and crop simulation models.

Presently the available resources for rice crop calendar are very limited, few to list are: (i) country specific rice crop calendars, mainly based upon inputs from local farmers, (ii) month wise rice crop calendar which represent the planting, harvest and bulk harvest period for major rice growing countries (WRS, 2008), (iii) FAO rice crop calendars representing the *early*, *bulk* and *late* dates for sowing and harvest for a rice crop (FAO, 1984). The FAO rice crop calendar is derived by compilation of the calendar dates from different sources and vary year to year (Matthews et al., 1999), (iv) season wise rice crop calendar maps at 5′ and 0.5° resolutions given by (SAGE) Centre for Sustainability and Global Environment, Nelson Institute of Environmental Studies, Madison (http://www.

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sage.wisc.edu) is the most recent in this list. SAGE rice crop calendar is mainly based upon compilation of crop planting and harvesting dates from six different sources and hence the values are extrapolated in the regions with less number of observations. Moreover as listed by Sacks et al. (2010), few deficiencies exist in presently available crop calendar databases, such as: (i) they generally present only national-level averages, and (ii) the data is in graphical format, making direct input into a global crop model impossible. Considering this gap, apart from rice area database, the need for development of rice crop calendar database has been emphasized by researchers (Twine et al., 2004; Sharpley and Williams, 1990).

The particular sequence of crop growth stages throughout its life cycle decides the spectral response of the crop which is its unique signature. Due to which the change in spectral reflectance over a time is observed as an impression of the developmental stages through which a crop progresses in the course of it's growth cycle. Characterization of temporal-spectral profile plays a major role in derivation of a crop calendar. Hence temporal information from satellite derived data has been used to derive crop calendar for few agricultural crops (Ramankutty et al., 2008; Muratova and Terekhov, 2004; Murthy et al., 1998; Panigrahy et al., 2005). A remote sensing based approach for deriving a crop calendar provides a cost and time-effective solution, providing near-real-time information. In past the relationship between crop growth and climatic parameters such as temperature, rainfall has also been explored by researchers to predict a crop planting and sowing dates (Bondeau et al., 2007). The objective of present study is to derive a rice crop calendar for major rice growing countries of South and Southeast Asia. Earlier the cultural type wise rice area map was derived for South and Southeast Asia using a multidate, multi temporal SPOT VGT NDVI data (Manjunath et al., 2015). This paper demonstrate the use of spatial rice crop maps derived in previous study (Manjunath et al., 2015) as a major input to derive the cultural type wise rice crop calendar for the study region. Emphasis is given only on crop calendar derivation for the cultural type wise rice crop pixels mapped over south and south east Asian region using SPOT VGT NDVI data, the rice crop mapping is not discussed here.

NDVI is a common vegetation index widely applied for crop classification studies using remote sensing data. The rate of rise and decline of NDVI is closely related to the rate of plant growth. Research conducted by Kristijono (1999) using NOAA - AVHRR shows the usefulness of NDVI curve to detect growing stages of rice crop cycle. The crop growth profile modelling approach was adapted for fitting the temporal NDVI growth profiles of rice clusters under different rice cultural types. The NDVI graph depicts the seasonality and crop growth phases of the rice crop. Assuming that crops follow a pattern similar to natural vegetation, planting dates can be estimated. The important phenometrics viz. sowing/transplantation day, crop maturity day and total duration of rice crop were studied. Finally the spatial variability of crop calendar and distinct growth pattern of rice over different countries were studied.

In tropical and subtropical countries rice is such a dominant crop and can be cropped up to three times per year, due to fewer prohibitions by water and other resources for cultivation. Water availability is a major factor which affects the rice crop calendar in these regions. But still as stated by Hogan et al. (1991) and Baker et al. (1992), in tropical regions, the temperature increase due to the climate change is probably near or above the optimum temperature range for the physiological activities of rice. In high latitude regions, atmospheric warming may also increase the duration of the rice growing season. Thus temperature is also likely to have substantial effects on the rice crop calendar (Yoshida, 1973; Spencer, 1977). Though within the tropics and subtropics minor variation is observed in rice crop calendar due to temperature, there has been little investigation of the localized or detailed aspect. In this study we have also explored a relationship between latitude and crop phenometrics to analyse a variation of rice crop calendar in different regions in same generalized latitude.

2. Study area

The study area extends between 10°S to 35°N latitude and 61°E to 142°E longitude and includes major rice producing countries of South and Southeast Asian countries namely: India, Pakistan, Nepal, Sri Lanka, Bangladesh, Myanmar, Thailand, Laos PDR, Cambodia, Vietnam, Malaysia, Indonesia, and Philippines.

3. Data

3.1. Remote sensing data

The NDVI data derived from SPOT VGT S-10 (10 day NDVI composites) for the period two years (total 72 NDVI datasets; 2008–2009 for Bangladesh and 2009–2010 for rest of the countries) was used in this study. The data was downloaded from SPOT website (www.free.vgt.vito.be) as an atmospherically corrected, 10 day MVC product and has advantages of wide swath (2250 km), high temporal resolution and cost free availability.

3.2. Ancillary data

3.2.1. Rice cultural types maps

The rice cultural type maps derived for South and Southeast Asia using SPOT VGT NDVI data, by Manjunath et al. (2015) were used as the key input in this study to derive the rice crop calendar of the region. Those rice area maps were derived using multi-temporal SPOT VGT NDVI images for the period of two years by masking of agriculture and non-agriculture area and NDVI threshold technique. Parameters such as rainfall, irrigation, and elevation specify the suitability of land for different rice ecosystems. Ancillary data sets viz. interpolated rainfall maps, irrigation maps, DEMs, and flood maps – were used for rice cultural type mapping. The information from ancillary map inputs was coded by different ranges of values by considering country-wise physiographic and climatic conditions and rice lands were categorized into irrigated wet, upland, flood-prone, drought-prone, and deep-water cultural types. The detailed methodology of rice cultural type map derivation and validation can be referred from Manjunath et al. (2015).

3.2.2. Reference rice crop calendar

i. SAGE rice crop calendar-The rice crop calendar from Centre for Sustainability and Global Environment (SAGE) was used as the reference for accuracy assessment. The SAGE rice crop calendar provides main season and second season rice crop calendar at 0.5° resolution; dataset is prepared by digitizing and georeferencing existing observations of crop planting and harvesting dates by priority wise compilation of rice crop calendar information from about 6 sources for different countries (www.sage.wisc.edu).
ii. GIEWS- Global Information and Early Warning system on food and agriculture, gives the month-wise range for planting and harvesting of rice. The monthly crop calendar for all the countries was compiled (source: http://www.fao.org/giews/countrybrief/).
iii. Philippines province wise rice crop calendar: The Philippines the rice crop calendar data is available by province and for the wet and dry seasons, as well as for the third crop where available (source: http://irri.org/our-work/research/policy-and-markets/mapping- rice-in-the-philippines-when).