Phenological Response of Rice Crop to Salinity Using Time Series Data

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ABSTRACT: Rice is an important cereal crop and its farming is a major source of livelihood for most people in Eastern India. Despite having 60% area under rice cultivation, the region contributes to less than half of total rice production. Soil salinity is one of the major impediments in optimum growth and high yield of rice. This study aims to assess the impact of salinity on plant growth using the Enhanced Vegetation Index (EVI) from the Moderate resolution imaging spectroradiometer (MODIS). Firstly, duration from start to middle of the season of the rice crop, and secondly, the amplitude of the seasonal photosynthetic activity were assessed. We collected 204 soil samples from 51 rice fields in the coastal region of Odisha at 15 day interval and electrical conductivity (EC) was measured. We used MODIS EVI 250m 8 day composite data from June 2015 to January 2016 for deriving phenological parameters for the kharif season (wet season). We observed that the values of $EC_{1:2}$ decreased with increasing distance from the coast. Our results show that at high levels of salinity ($EC_{1:2}$> 0.8 dS/m) rice crop reaches its middle season late (62 ±6 days) as compared to that of areas with lower salinity levels where the crop reaches middle season relatively earlier (48±5 days) ($p<0.001$). This indicates that the vegetative stage is longer in salinity stressed environments leading to delayed flowering. In addition, salinity also has an effect on the amplitude of the seasonal photosynthetic activity. The value of the amplitude increased as soil salinity decreased ($r=-0.77$). Absence of other stresses and similarity in temperature, precipitation and crop management practices confirms the fact that salinity is the cause of the delayed phenology and reduction in photosynthetic activity of the rice crop. The study has implications on determining salinity stressed rice environments on broad scale by monitoring crop's phenological response.

1. INTRODUCTION

India is the second largest producer of rice in the world. Rice is not just a staple diet for more than half of the population of India but is also an important source of livelihood. More than 60% of the total rice cropped area of India lies in Eastern India (Singh et al., 2012). This region, however, contributes less than half of the total rice production of the country (Serraj et al., 2011). This is because 20 million ha of rice in Eastern India is severely affected by abiotic stresses (GRiSP, 2013).

Coastal soil salinity is one of the abiotic stresses that affect rice productivity in Eastern India. Salinity can lead to substantial yield loss in rice (Asch et al., 2000, Rad et al., 2011). Salinization is a dynamic process and may affect crops at different growth stages so monitoring at regular intervals is needed to avoid crop loss and land degradation. Conventional methods to monitor salinity are time consuming, expensive and even difficult due to non-accessibility of certain areas. Satellite technology offers a cost-effective option due to its synoptic coverage. Both multispectral and hyperspectral satellite data have been extensively used to detect soil salinity (Weng et al., 2008; Satir et al., 2010; Setia et al., 2011; Koshal, 2012). Moderate resolution imaging spectroradiometer (MODIS) has proven to be cost effective and useful in mapping and identifying phenological stages of rice crop over large areas (Sakamoto et al., 2005; Son et al., 2014; Peng et al., 2014). Because of its high temporal resolution, MODIS has potential to capture temporal variability in soil salinization.

Several studies have developed salinity indices to detect salinity from bare soil (Douaoui et al., 2006; Zhang et al., 2011). However, direct detection of soil salinity in kharif rice crop is not feasible due to standing crop. Therefore, performance of rice crop in terms of its phenology can be considered as proxy to measure level of salinity stress (Lobell et al., 2007; Zhang et al., 2015). Enhanced Vegetation Index (EVI) time series data of MODIS is more advantageous over Normalized Difference Vegetation Index (NDVI) due to its high sensitivity at higher levels of biomass (Huete et al., 2002, Xiao et al., 2005).

This study aims to assess the impact of salinity on plant growth using MODIS EVI data by monitoring phenology of rice crop. We focused on two parameters: (1) duration from start of the season to middle season of rice crop and (2) the amplitude of the seasonal photosynthetic activity. The study will contribute to the understanding of the effect of salinity stress on growth of crop which eventually affects rice production.

2. MATERIALS AND METHODS

2.1. Study area

The study area is located in Odisha in the eastern state of India (Figure 1). The area is bounded on the east by the Bay of Bengal. A total of 4 coastal districts of Odisha, namely, Baleshwar, Bhadrak, Kendrapara and Jagatsinghpur comprise the study area, which covers 15% of total geographical area of the state. The region is characterized by tropical climate with three seasons- summer (March to June), monsoon (July-September) and winter (October-February). In the summer, the maximum temperature reaches 40ºC. Winters, on the other hand, are not severe. The average annual rainfall is 1,500 mm resulting mainly from the south west monsoon from July to October. Climate is mostly humid. Soil is mainly alluvial in this region with high level of salt due to salt water intrusion from the sea. Rice is monocropped, mainly grown in the kharif season (July to Nov) and is dependent on the monsoon rains. The coastal area of Odisha has 1.7 million hectares of rice and the total production in this region is estimated at 2.68 million tons (Das, 2012)

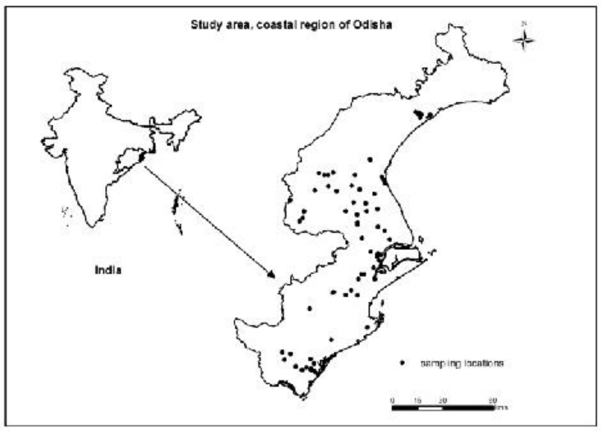


Figure 1. The study area: Coastal region of Odisha.

2.2. Data

We used the EVI band of the 8 day composites of MODIS VI L3 Global 250 m data from Aqua (MOD13Q1) and Terra (MYD13Q1). A total of 80 images from April 2015- Feb 2016 were downloaded for two tiles h25v06 and h26v06 from the Land Processes Distributed Active Archive Centre (LP DAAC, http://lpdaac.usgs.gov).

We collected 204 soil samples from 51 locations using standard procedures for electrical conductivity (EC) measurement. Samples were collected at every 15-20 day interval from August to December 2015. We used 1:2 (V:V) soil: water extract method ($EC_{1:2}$) of United States Salinity Laboratory Staff (1954). Electrical conductivity is a measure of amount of salts. At each soil sample location, data on crop management practices, temperature, precipitation, and occurrence of drought, submergence and biotic stress were collected.

2.3. Data processing and extraction of phenological parameters

All the 80 images were mosaicked to create 40 scenes and reprojected to GCS WGS 84 and cropped to cover only the study area. To reduce noise in the data, Savitzky-Golay filter (Savitzky and Golay, 1964) was used. It is a low pass filter based on least square polynomial function. Once the data was smoothed, the non-rice areas were masked out using the rice area mask generated by Gumma et al. (2015). We extracted phenological parameters of rice crop using the TIMESAT software (Jönsson and Eklundh, 2004). The parameters extracted for 2105 kharif season were start of the season (SoS), end of the season (EoS), middle of the season (MS) and amplitude. SoS represents green up of rice crop at the beginning of the season, EoS is end of senescence of rice crop, and amplitude is the difference between maximum value and the base level.

We categorized EC values into levels of severity: non-saline ($EC_{1:2}$ <0.8 dS/m), low salinity ($EC_{1:2}$: 0.8-1dS/m) medium salinity ($EC_{1:2}$: 1-1.6dS/m) and high salinity ($EC_{1:2}$ >1.6dS/m).

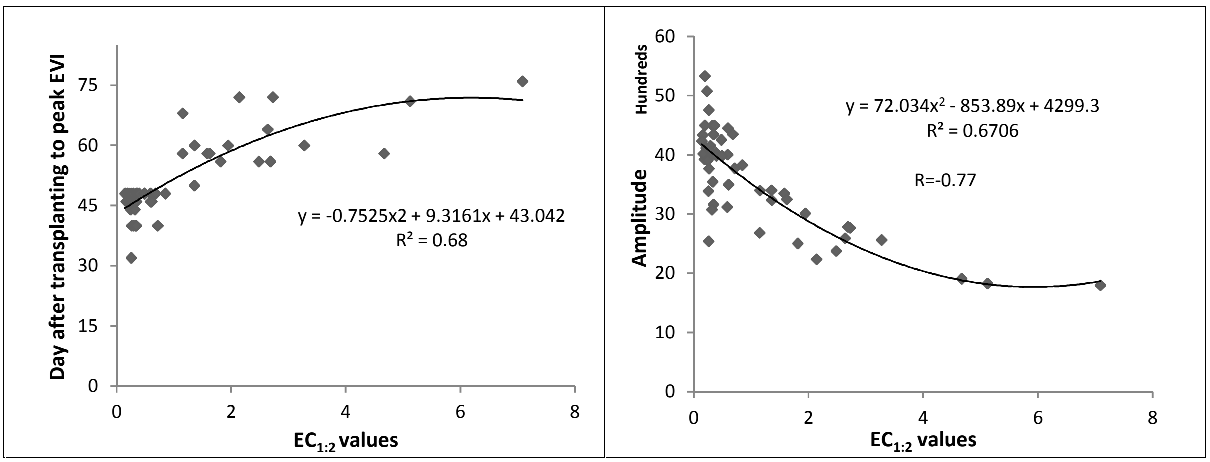
We calculated the mean value of EC and seasonal parameters at each sample location and performed regression analysis to test if there is a significant relationship between mean EC value and each of the seasonal parameters. Regression analysis was also used to test significant relationship of the factors like temperature, precipitation, crop management practices and presence of any other stresses with EC values.

3. RESULTS AND DISCUSSION

3.1. Phenological parameters

We found that rice crops reached its middle season at different times under different levels of salinity. At medium and high levels of salinity ($EC_{1:2}$: 1-1.6dS/m and $EC_{1:2}$ >1.6dS/m), the rice crop reached its middle season late compared to that of areas where salinity levels were low ($EC_{1:2}$: 0.8-1dS/m) or non-saline ($EC_{1:2}$ <0.8 dS/m). At highly saline areas, the duration between the start of the season and the middle season is long (62 ± 6 days), indicating a longer vegetative phase and delayed flowering. In low or non saline areas, on the other hand, this period is shorter (48 ± 5 days, $p<0.001$) (Figure 2a). This finding is consistent with that of Grattan et al. (2002) and Khatun et al. (1995) who observed that flowering is delayed as an effect of salinity in rice plants.

Amplitude decreased with an increase in salinity (r=-0.77) (figure 2b). Salinization reduces the number of tillers, number of spikelet per panicle and photosynthetic leaf area (Munns, 2002, Alam et al., 2004, Hasamuzzaman et al., 2009). As a result, the crop will have less canopy and therefore less overall chlorophyll content which prevents the crop from reaching high EVI values.



(a) (b)

Figure 2. Effect of salinity on (a) duration between transplanting and peak and (b) EVI of rice crop seasonal amplitude of rice crop

We found that as the distance from the coast increased, salinity decreased (r = -0.65) (Figure 3). From Figures 2 and 3, we can conclude that the rice crop near the coast is more vulnerable to high salinity. Due to high level of soil salinity, crops near coast have low values of amplitude and longer duration between transplanting and flowering (stage at which EVI is highest in the crop cycle). Rice crops near the coast have longer vegetative stage hence delayed flowering and do not attain high photosynthetic activity.

One of the constraints of the study lies in its strength. MODIS despite having high temporal resolution one has to compromise on its coarser spatial resolution. Therefore, we had to focus on large homogeneous areas, which is not always possible in the areas where land holding size is small.

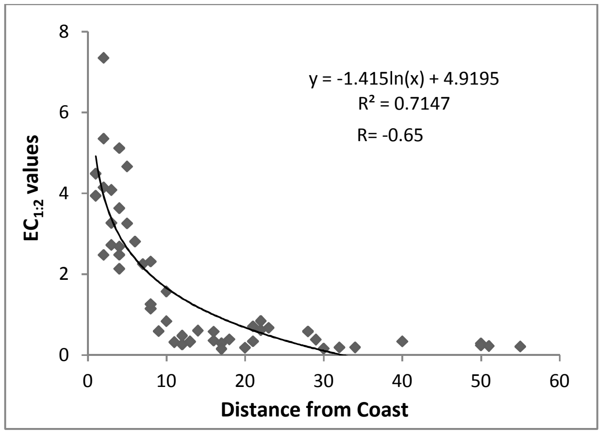


Figure 3. Trend of salinity with varying distance from coast

4. CONCLUSION

The study indicates that satellite remote sensing using MODIS EVI data has potential in detecting the effects of salinity on rice phenology. MODIS is promising in exploring that under saline environment the rice crop reaches its maximum EVI late as compared to the non saline environment. Therefore, suggesting a delayed flowering which corroborated with physiological studies conducted on rice plants. Our results also show that rice crop's phenological parameters estimated from satellite data can also be an effective way to differentiate rice crops between saline and non-saline environments. The study shows the novel approach of detecting delay in phenology and reduction in potential of photosynthetic activity of rice crop under salinity stress using satellite data. Further studies are required to test this approach on larger scale or using satellite data with high spatial and temporal resolution.

Presence of similar conditions in terms of, temperature, precipitation and crop management practices and absence of any other abiotic and biotic stress confirms that salinity is the cause of delayed flowering and reduction in photosynthetic activity. The study has implications on determining salinity stressed rice environments over large areas by monitoring the crop's phenological response.

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