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Research article

Spatial Variability of Soil Salinity and its Influence on Rice Yield in Salt-Affected Areas using Remote Sensing Techniques

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Abstract Soil salinity has become one of the major constraints to sustain crop production in Myanmar, especially in the dry zone areas. Salinity stress and its spatial distribution has been a useful for crop monitoring. Unevenness in early crop growth stage can support to identify yield-limiting factors such as soil salinity, nutrient availability, and soil moisture. Remote sensing techniques have been used to collect reflectance numbers from crop canopies and to analyze the vegetative index (VI). VI has been related with percentage of ground cover, chlorophyll content of plant, and nitrogen use efficiency. This study aims to monitor the influence of salinity stress on the growth, yield and chlorophyll content of rice by using remote sensing techniques. This study was conducted in the salt-affected soils at Myittha Township, the central dry zone of Myanmar during the rainy season of 2019. Electrical conductivity (EC) and chlorophyll content in rice plant were collected at early growth and tillering stages of rice. Sentinel-2 satellite imagery was used in the analysis for those two growth stages. Total grain yield of rice was also measured. The acquired images analysis was implemented with ArcGIS 10.7 software to calculate vegetative indices. The results showed that significant relationships were found between plant chlorophyll content and the normalized difference vegetation index (NDVI) values under different salinity levels. A relationship was also observed between NDVI and rice grain yield. Identifying the spatial distribution of salinity stress using the spectral vegetation indices would be effective for increasing rice yield in the salt-affected areas.

Keywords salinity stress, Sentinel-2 satellite imagery, vegetation index

INTRODUCTION

Rice (*Oryza sativa* L.) is the most important food crop for more than half of the population of the world. It is cultivated over 167 million hectares with the production of 780 million tones (FAO STAT, 2017). It is grown under various environmental situations in both upland and lowland rainfed ecosystem. Crop production in Myanmar is affected by many factors such as soil salinization, drought, and low soil fertility (Oo et al., 2017). Among them, soil salinization is an increasingly severe problem in rainfed rice production.

In Myanmar, salt-affected soils are found in coastal and inland regions. Coastal salinity is affected by seawater intrusion/ infiltration during flood resulting salt accumulation in the top soil in the summer season. It is commonly occurred in Ayeyarwady, Yangon, Yakhaing and Taninthari regions. Inland salinity is commonly happened in dry zone areas of the central Myanmar such as Mandalay, Magway and Sagaing regions. Salinization in central dry zone is becoming a prominent abiotic problem declining rice production which little or lack of attention was paid in the past (Swe and Ando, 2017). They reported that sodic/saline soils have been settled in certain areas, because of the excessive

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application irrigation for several years continuously. The excessive applications of irrigation water elevated the ground water level sufficiently to increase salts concentration through evaporation. It is related principally to the presence of sodium carbonate and sodium bicarbonate in these specific areas. Inland salinity or irrigation salinity is due to over-watering, seepage from irrigation channel, impaired natural drainage and high water table. In the low land soil from those salt affected areas, high rate of evaporation and evapotranspiration of rice crop increase the capillary transport of water and solutes from the groundwater to the root zone. When there is a condition of no or negligible leaching of these salts, the soils will be affected with salts within a few years.

The nutritional monitoring of plants using remote sensing is a vital component of precision agriculture (Liaghat and Balasundram, 2010). Remote sensing has received increased interest as a non-destructive tool for determining the nutrient status of growing crops due to the time and expense involved with traditional soil and plant analysis. Remote sensor can estimate chlorophyll content and nitrogen status by their reflectance in the visible region of the electromagnetic spectrum (Thomas and Gausman, 1977). By using remote sensing images, normalized difference vegetation index (NDVI) is essential parameter for the vegetation growth of crops as well as assessing plant nitrogen content.

The concept of precision agriculture is based on the fact that crop productivity varies spatially and temporally within a field, depending on soil, environment and operational activities. One direction in precision agriculture research is to identify the correct management plot based on the variability in yield limiting factors within a field, and to implement optimal management practices for each plot. The effects of salinity stress on crops are complex and it is difficult to interpret the results if investigates are not designed carefully and if suitable measurements are not made (Negrao et al., 2017). Therefore, classifying the soil salinity variability and its influence to crop yield are essential for farmers to reclaim the salt-affected soils.

OBJECTIVE

This study was to determine the influence of salinity stress on the growth, yield and chlorophyll content of rice by using remote sensing techniques.

MATERIALS AND METHODS

Study Area

In order to determine the influences of salinity stress on the growth and yield of rice, the experiment was conducted in the salt-affected area at Hteinkangyi village in Myittha Township, Mandalay Division where is situated in the dry zone area of Myanmar during the rainy season of 2019. Geographical coordinates are between 21°14’16.36” N latitudes and 96°8’23.88” E longitudes. Its elevation is 106-111 m above sea level. The total area of the study site is 40 hectares. The study site has been affected by salinity for 20 years. The study location map is shown in Fig. 1.

Field Data Collection

The field data was collected during the rainfed rice growing season of 2019. Apparent electrical conductivity was collected by using a portable electrical conductivity meter (Field Scout (FS) direct soil EC meter) before the rice cultivation. Electrical conductivity (EC_e) in saturated paste extracts was calculated by using the formula (2.7FS+0.8).

Chlorophyll content was measured randomly from three mature leaves in each sampling point using a Minolta SPAD-502 leaf chlorophyll meter at the early growth and tillering stages of rice. Rice grain yield was recorded at harvesting. Pawsan and manawthuka varieties were cultivated in the study area.

Vegetation Index (VI) Calculation

The multispectral images from Sentinel-2A Satellite were used in this study. Sentinel-2A has four bands, namely red (R), green (G), and blue (B) and near-infrared (NIR) at 10 meter spatial resolution. The Sentinel-2 image was acquired at the time of early growth and tillering stages of rice. The normalized difference vegetation index (NDVI) was calculated for those two growth stages of rice. This index is widely used for measuring crop health - a healthy plant will absorb visible light (especially blue and red), while the fortified leaf structure will reflect a high amount of NIR. NDVI calculation is simply (NIR–red)/(NIR+red), returning values between -1 and 1, ranging from non-vegetated (water or barren) to healthy plants (Rouse et al., 1974; Tucker, 1979).

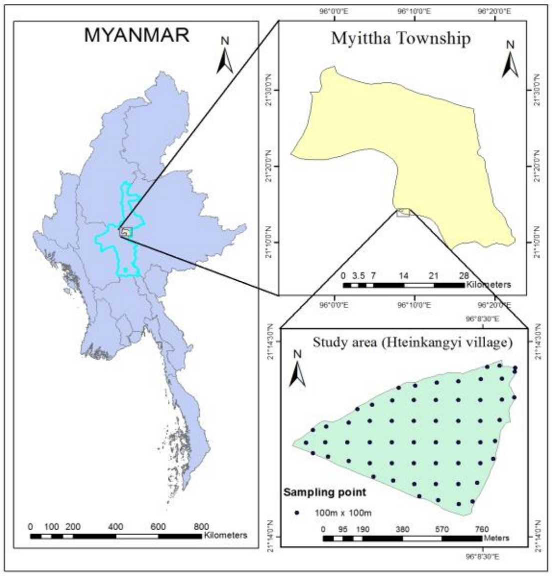

Fig. 1 Map of study area (Hteinkangyi Village)

Data Analysis

The collected data were examined by descriptive statistics to attain the minimum and maximum values, mean, standard deviation (SD), coefficient of variation (CV) of each parameter. All statistical analyses were implemented using Statistix 8.0 software and Excel program (2010). The spatial distribution maps of soil electrical conductivity, SPAD values and rice grain yield were accomplished by ArcGIS 10.7 software.

RESULTS AND DISCUSSION

Spatial Variability of Soil Salinity and Rice Grain Yield

The spatial variability of soil salinity is presented in Fig. 2. Soil salinity was found at three levels as 2.0-3.9 dSm^{-1} (low salinity), 4.0-6.0 dSm^{-1} (moderately salinity) and 6.1-7.6 dSm^{-1} (high salinity). This distribution map can help the farmers to manage or remediate their salt-affected soils accordingly to soil EC level.

Rice grain yield can be varied as affected by soil salinity. The result showed that rice grain yield ranged from 3.00 to 4.83 ton ha^{-1} with the mean value of 4.11 ton ha^{-1} (SD=0.39) and CV of 9.46%. Spatial variability of rice grain yield in the study area was obvious (Fig. 2). This might be due to differences in soil salinity become limiting. Previous study (Oo et al., 2019) reported that salinity stress on the growth of tested rice varieties was found seriously in 7.5 dSm^{-1} when compare with 3.7 and 5.7 dSm^{-1} salinity values in the Hteinkangyi Village.

Chlorophyll Content of Rice Plant

Interpolated maps of chlorophyll meter (SPAD) values at the early growth stage and tillering stage of rice in the salt-affected soils are presented in Fig. 3. The results of this study showed that chlorophyll content was observed relatively large variation within a farmland at the early growth stage (Fig. 3a). It ranged from 23.50 to 38.90 SPAD reading. At the tillering stage, it ranged from 28 to 43 (Fig. 3b). The distribution maps of SPAD values showed that soil salinity affected the chlorophyll content in plant. The plant under low salinity level had the highest chlorophyll content indicating that it may not be affected by salinity. In contrast, the rice plant under the high salinity level produced the low chlorophyll content which was due to limitations of chlorophyll synthesis (Santos, 2004) and it resulted in increased reflectance of active light for plant photosynthetic (Clay et al., 2006) and decreased reflectance in the near-infrared light (Cui et al., 2009; Yoder and Pettigrew-Crosby, 1995).

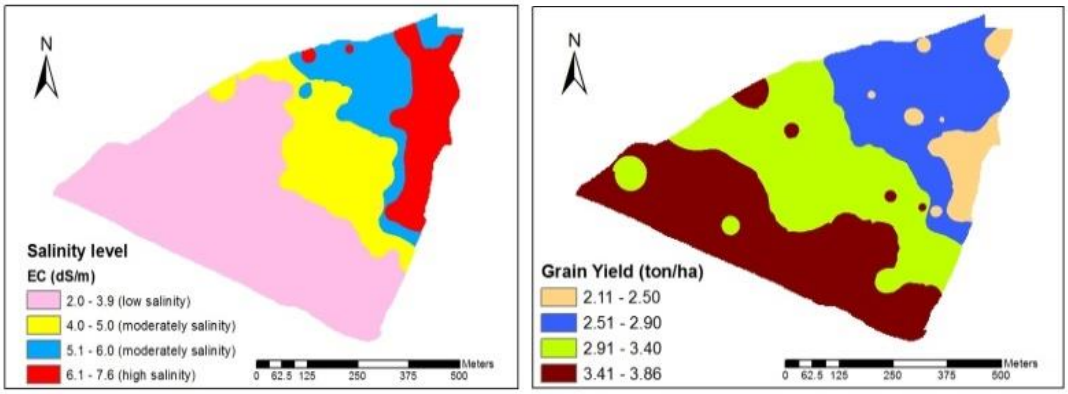

Fig. 2 Interpolated maps of salinity level and rice grain yield in the study area

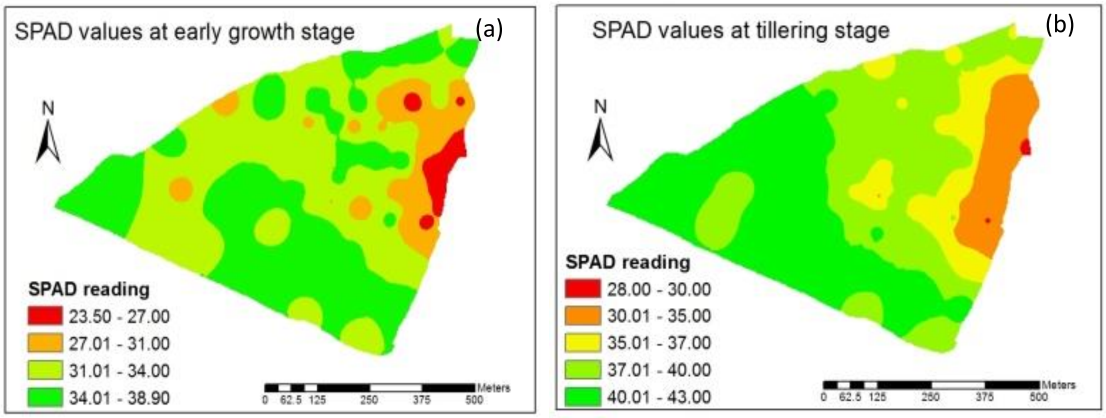

Fig. 3 Interpolated maps of chlorophyll meter (SPAD) readings in the salt-affected soils of Hteinkangyi Village (a) early growth stage and (b) tillering stage

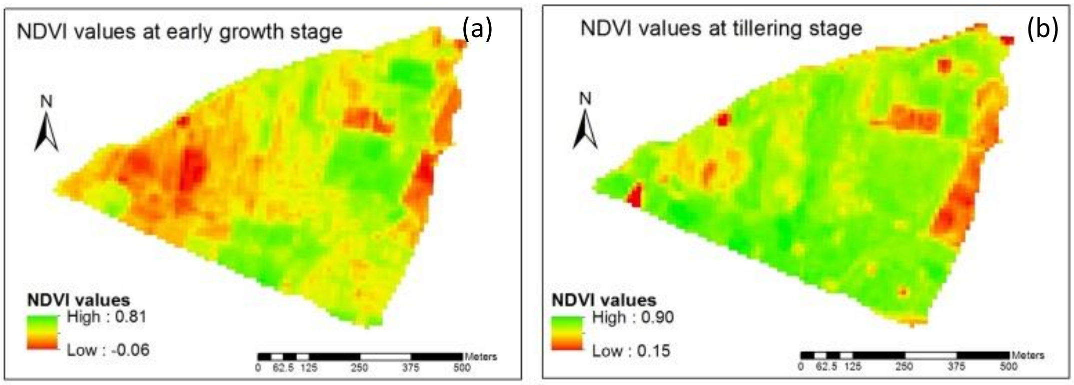

Fig. 4 NDVI maps for Sential-2 spatial resolutions at (a) early growth stage and (b) tillering stage of rice in the salt-affected soils of Hteinkangyi Village

Vegetation Index (VI)

The VI maps were produced at the early growth stage and tillering stage of rice using Sentinel-2 satellite imagery. The maps are shown in Fig 4. The NDVI map demonstrated the vast variation at early growth stage (Fig. 4a). The decreasing NDVI values at early growth stage may be attributed to decrease in the number of rice leaves. The NDVI values largely rise up at tillering stage (Fig. 4b). The high NDVI values (0.90) were observed in the tillering of rice when compared with the early growth stage. Scattered vegetation or death of rice plant was found under high salinity soils, indicating that the effect of salinity stress on rice is the shrinkage of leaf size, which leads to damage of the leaf, and lastly the death of the plant (Volkmar et al., 1998).

Relationships among EC_e, NDVI, SPAD Values and Rice Yield

In this study, there was negatively significant relationship EC_e and NDVI values for both growth stages (Table 1), indicating the higher the EC_e the lower chlorophyll meter in rice plant. EC_e values was negatively significantly correlated with rice yield ($p<0.000$), indicating the higher the EC_e the lower rice yield. The SPAD value was positively associated with the NDVI values for both growth stages. Rice yield was positively associated with the NDVI values and SPAD values for both growth stages. These results showed that NDVI and SPAD value was a strong predictor of rice grain yield. The results of this study can be useable information for the farmers in the study area.

Table 1 Relationships among EC_e, NDVI, SPAD values and rice yield at two different growth stages in Hteinkangyi Village during the rice growing season of 2019

Variable		Regression equation	R^2	*p*-value	Acquired growth stage
EC_e	NDVI values	Y = -0.0547x + 0.7347	0.342	0.000	Early growth
	NDVI values	Y = -0.043x + 0.9014	0.452	0.000	Tillering
	Yield	Y = -0.2308x + 4.1096	0.679	0.000	Harvesting
SPAD	NDVI values	Y = 0.0251x - 0.152	0.237	0.000	Early growth
	NDVI values	Y = 0.0294x - 0.2964	0.255	0.000	Tillering
Yield	NDVI values	Y = 1.5546x + 2.3764	0.267	0.000	Early growth
	NDVI values	Y = 2.5674x + 1.28	0.245	0.000	Tillering
	SPAD values	Y = 0.0458x + 1.4948	0.140	0.003	Early growth
	SPAD values	Y = 0.097x - 0.6633	0.453	0.000	Tillering

CONCLUSION

This research evaluated the salinity and its influence on rice in the salt-affected areas in Hteinkangyi village, Myittha township, Myanmar employing with remote sensing technique and geographic information system (GIS). The maps created by ArcMap 10.7 presented virtual concept of salinity management system which could be useful for the farmers in the study area. The vast variability of soil salinity was found. Soil salinity was affected on the vegetation development and yield of rice under the high salinity area.

Sensor values and rice grain yields had positively significant relationships at all growth stages. The distribution maps are very applicable to farmers for reclaiming the salinity level to their farmlands. The results showed that vegetative index could be useful in detecting the salinity stress in salt-affected area. Based on this study, it could be suggested that the Sentinel-2 satellite imagery would be beneficial for monitoring crop development and managing the salt-affected soils.

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