Yearly change in severely salt-damaged areas in paddy fields in Ban Phai in Northeast Thailand

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Abstract:

Future expansion of salt-damaged areas is anticipated in Northeast Thailand. We conducted a field investigation of paddy fields from 2016 to 2019 in Ban Phai district, Khon Kaen province in Northeast Thailand to evaluate yearly changes in the effect of salinity damage on rice production. The investigation area was classified into severely salt-affected areas (2⁶ of 5 classes) based on the definition used in Thailand. Since salinity severely damages rice production, rice cultivation was abandoned in some fields, although some were still planted. The soil electrical conductivity (EC) in the rice-planted paddy fields changed yearly in association with the amount of precipitation. The effect of the difference in EC on rice yield was moderate, suggesting that rice yield was mediated by surface water. Some areas in the abandoned fields did not have any vegetation, and quite high soil EC values were observed. The non-vegetated areas evaluated based on yearly unmanned aerial vehicle (UAV) images changed partly due to the amount of precipitation. However, some non-vegetated areas decreased in contrast to the decrease in precipitation, probably because of the effect of groundwater. Although the continuous expansion of severely salt-damaged areas was not observed, the monitoring of salinity levels is recommended for the future.

KEYWORDS electrical conductivity; rice production; precipitation; non-vegetated area; supervised classification; groundwater

INTRODUCTION

Soil salinity, which affects crop production due to the accumulation of toxic ions and the inhibition of water and nutrient absorption (Maas and Grattan, 1999), is considered a serious global problem in terms of food security (Butcher et al., 2016). Northeast Thailand is a severely salt-affected region; more than 3.3 million ha are estimated to be salt-affected in the area (Thaikla et al., 2010). The soil salinity is derived from underground salt rock in Northeast Thailand (Gardner, 1967). Accordingly, the groundwater has a considerable effect on salinity, further complicating the situation (Seeboonruang, 2013; Yoshida et al., 2021). Some studies have reported the expansion of salt-affected areas (Ratanopad and Kainz, 2006), but the details of these expansions are still unknown.

Rice is a major agricultural product in Northeast Thailand. Rice paddy fields occupy more than half of the agricultural land, but their production levels are both low and unstable (Homma et al., 2007; Sujariya et al., 2020). Since irrigation facilities have not yet been developed, most rice production is conducted under rainfed conditions. Precipitation shows yearly and spatially large variations, frequently causing drought and flooding. Compared with drought and flooding, the salinity problem for rice production is rather localized (Saisema and Pagdee, 2015). However, since some farmers are starting to abandon their paddy fields due to severe salinity, the problem has become one of the major issues affecting rice production in Northeast Thailand (Oo et al., 2013; Thanasilungura et al., 2020).

Based on the situation described above, we conducted field investigations to evaluate salinity conditions in relation to rice production in Ban Phai district, Khon Kaen province in Northeast Thailand, which is one of the most severely salt-affected regions. One accompanying papers in this special issue analyzed soil salt accumulation by simulating soil water movement (Yoshida et al., 2021). We also analyzed spectral reflectance of salinity affected fields to evaluate salinity conditions at a regional scale with satellite remote sensing (Maki et al., 2019). This report focused on yearly changes in rice production and salinity conditions. In particular, the yearly movement of severely salt-damaged areas was analyzed based on yearly unmanned aerial vehicle (UAV) images changing partly due to the amount of precipitation. However, some non-vegetated areas decreased in contrast to the decrease in precipitation, probably because of the effect of groundwater. Although the continuous expansion of severely salt-damaged areas was not observed, the monitoring of salinity levels is recommended for the future.
areas in paddy fields was evaluated on the basis of RGB images taken by unmanned aerial vehicles (UAVs).

**METHODS**

**Research site**

The investigation site (Figure 1) was located in Ban Phai district, Khon Kaen province in Northeast Thailand. The area is classified as having a tropical savanna climate and has 2 seasons (a rainy and a dry season). The rainy season starts in May and ends in October. Precipitation data were collected from the meteorological station in Ban Phai, Meteorological Department, Thailand. Since irrigation facilities have not been developed in the study region, rice was planted only in the rainy season under rainfed conditions.

The soil salinity level was officially classified into 5 classes (class 1 corresponds to very severely salt-affected soils; class 5 corresponds to non-salt-affected soils) by the Land Development Department, Thailand (Wichaidit, 1995; Katawatin and Sukchan, 2012). The investigation site was classified as class 2, comprising severely salt-affected soils. Some farmers continued to plant rice in the study region, but others had abandoned their paddy fields due to the severe salinity conditions.

**Measurements**

Yield measurements were conducted at 29, 34, 19 and 30 points in rice-planted paddy fields in 2016, 2017, 2018 and 2019, respectively (Figure 1). Although the harvested points varied from year to year because some fields were not planted based on the farmers’ decision, the points were selected to represent the rice planted paddy fields in the area. Rice plants were harvested in a 1-m$^2$ circle at each point on November 12, 2016, November 5, 2017, November 6, 2018, and November 8, 2019. The grain was threshed, and its weight was calibrated with its moisture content, which was measured with a grain moisture meter (CD-6E, Shizuoka Seiki). Five hundred ml of plow layer soils were collected uniformly from the surface to 12 cm depth at the 34, 19 and 30 harvested points in 2017, 2018 and 2019, respectively, at the same time that the rice plants were harvested. The soil samples were ground and sieved in 2-mm sieves after being air dried. The soil EC (soil:water = 1:5) was measured using an EC meter (FiveEasy™ Plus EC meter FEP 30, Mettler Toledo).

**Analysis of non-vegetated/vegetated areas**

RGB images were collected at the rice harvest, just after the rainy season ended, by UAVs: a 3DR Solo on November 12, 2016, a DJI Phantom 4 on November 6, 2018, and by a DJI Mavic pro on November 8, 2019. We tried to take RGB images on November 5 and 6, 2017, but failed due to strong winds. The flight height was 50 m at approximately 2 cm/pixel resolution. The images, synthesized by PhotoScan Professional (Agisoft), were georeferenced by QGIS based on Google Maps. A 4.3-ha area, which was common to the images in 2016, 2018 and 2019, was analyzed to evaluate the non-vegetated/vegetated areas with a support vector machine (SVM) in scikit-learn for Python (https://scikit-learn.org/stable/index.html, Pedregosa et al., 2011). One hundred buffers for non-vegetation and 100 buffers for vegetation were selected in each image. The representative non-vegetated/vegetated area was determined with observation and recorded by GPS receiver (eTrex 20x, Garmin). The non-vegetated/vegetated buffers were selected in each representative area with checking the RGB image. The buffer was set at a 1-m $\times$ 1-m square to obtain the minima, maxima, means and medians of R, G and B. Seventy-five percent of buffers were used for training, and the rest were used for validation. The image was divided with 1-m $\times$ 1-m meshes and was then subjected to supervised classification with SVM. The accuracies for the validation buffers were
0.88, 0.98 and 0.98 in 2016, 2018 and 2019, respectively. Soils were sampled uniformly from the surface to 12 cm depth at 10 non-vegetated points and at 10 adjacent vegetated points on October 9, 2019 (Figure 1). The EC (soil:water = 1:5) for the sampled soil was measured using the same method for soils at the rice harvesting points.

**RESULTS AND DISCUSSION**

Precipitation varied from year to year (Figure 2). Rainfall was abundant in 2017 but quite limited in 2018 and 2019. Although the amounts were similar between 2018 and 2019, the patterns were quite different: the precipitation level was high from April to July in 2018 but high in May and August to September in 2019. In 2019, some paddy fields near the investigation area were delayed for rice planting due to inadequate rainfall in June and July and suffered from flooding due to heavy rainfall in August and September. The precipitation level from August to October, which is the most important duration for rice production at the site, was 269 mm in 2018, which was approximately half of the average (515 mm).

Based on a simulated water budget for the area (Yoshida et al., 2021), potential evapotranspiration was 1421 mm per year on average from 2016 to 2019; the differences of precipitation minus potential evapotranspiration were 358 mm in rainy season (from May to October) and −541 mm in dry season (November to April) on average. The precipitation from August to October (e.g. 515 mm on average from 2016 to 2019) ordinary exceeds the potential evapotranspiration (347 mm) but the scarce precipitation in 2018 (269 mm) was less than the potential evapotranspiration (330 mm).

The soil EC in rice-planted paddy fields varied from year to year and seemed to be associated with precipitation, especially from August to October (Figure 3). Although the lowest ranges of soil EC were quite similar from year to year, the highest values differed extensively.

The rice yield showed large variation and many fields showed quite low yield (Figure 4). For example, one fourth of the fields recorded less than 54 g m⁻² of yield in 2018. The average rice yield seemed to be associated with precipitation. Higher rice yield was expected due to higher precipitation in 2017. However, the abundant rainfall caused farmers to plant paddy rice even in salinity fields (Figure 3), which decreased the average yield. The abundant rainfall sometimes caused lodging due to excess stem growth, which also decreased the average yield in 2017. The yearly variation in rice yield was smaller than those in precipitation and soil EC. The effects of precipitation and then soil EC on rice production were probably alleviated by surface water. Our preliminary analysis suggested that the classification of soil ECs (i.e. the EC of the soil saturation extract) clearly categorized the effect of salinity on rice production. A detailed analysis of the relationship between soil salinity and rice production will be described in another report.

The soil EC in the non-vegetated area (2.6 ± 3.5 dS m⁻¹) was significantly higher than that in the vegetated area (0.16 ± 0.11 dS m⁻¹). Salt crusts were clearly observed in RGB images in 2018 and 2019, although the images were taken just at the beginning of the dry season (white areas in Figure 5). The scarce precipitation in October in both years

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**Figure 2.** Precipitation from 2016 to 2019 in Ban Phai. The numbers on the bars indicate precipitation amount between August and October.

**Figure 3.** Box plot of soil EC (1:5, soil:water) of investigated paddy fields from 2017 to 2019. The number of samples was 34, 19 and 30 in 2017, 2018 and 2019, respectively. The number to the right of each symbol is the EC, which exceeded 2.0 dS m⁻¹. Red symbols indicate the EC where the rice yield was 0 g m⁻².

**Figure 4.** Box plot of rice yield of investigated paddy fields from 2016 to 2019. The number of samples was 29, 34, 19 and 30 in 2016, 2017, 2018 and 2019, respectively.
might enhance the appearance of salt crusts earlier in the season. Non-vegetated areas occupied 11.4%, 14.6% and 10.0% of the analyzed area in 2016, 2018 and 2019, respectively. No clear tendency towards expansion of the non-vegetated areas was observed. The non-vegetated areas also did not show clear associations with precipitation or soil EC in rice-planted fields. Some non-vegetated areas expanded from 2016 to 2019, while others were reduced (Figure 6). The reduction of non-vegetated areas may suggest that the soil EC was partly alleviated by non-rice planting. The localized differences in the trend of non-vegetated areas were likely affected by groundwater. EC of groundwater in the area was high and stable (44.8 ± 1.2 dS m$^{-1}$, from July 16, 2017, to October 6, 2018; data retrieved from Yoshida et al., 2021) and shallow (−46 ± 8 cm, from August 1 to October 6, 2017; −196 ± 9 cm from February 1 to April 30, 2018; −75 ± 10 cm from August 1 to October 6, 2018), being the major resource of salinity.

Some studies evaluated salinity-affected areas by utilizing satellite data (Katawatin and Kotrapat, 2005; Shrestha, 2006). The utilization of satellites is quite effective for wider regions, especially for evaluating large and severe salinity-affected areas, such as class-1 areas. However, this study showed that quite small pieces of non-vegetated area changed from year to year, suggesting that the threshold of whether a plant can or cannot grow fluctuates locally and yearly. Accordingly, quite a small change that could be evaluated by UAV may be important for evaluating salinity levels in terms of rice production. The authors tested satellite data to directly evaluate soil EC$_e$, which is quite important for evaluating the effects of salinity on crop production (Richards, 1954; Nguyen et al., 2014). The combination of soil chemical properties based on satellites with vegetation evaluations based on UAVs would be an effective tool to evaluate the effects of salinity on crop production in wider regions.

Yoshida et al. (2021) assessed the climate change impact of soil salt accumulation by simulating soil water content and predicted that soil EC$_e$ would increase in the future. Since this study did not suggest an increasing trend in soil EC or non-vegetated areas, monitoring for longer durations would be necessary. Since the trends of non-vegetated areas differed spatially, the evaluation of groundwater movement is essential for predicting salinity levels at each location. The observation that some areas had vegetation following a lack of vegetation imply that salinity levels can be alleviated by controlling groundwater, such as through reforestation (Miura and Subhasaram, 1991).

**CONCLUSION**

This study conducted field investigation to reveal present conditions in severely salt-affected paddy field areas where some farmers had abandoned their paddy fields due to the severe salinity. The variation in precipitation may be one of the major factors affecting salinity conditions. However, while soil EC in the rice planted fields apparently varied with precipitation, the effects on rice yields were not so obvious. Standing water provably alleviated salinity damage.

Since some fields produced quite low yields, an increase in the abandonment of fields is anticipated in the future. Analysis of non-vegetated/vegetated areas were conducted to evaluate severe salt-damaged areas and to forecast the future availability of areas for rice cultivation. However, increases in non-vegetated area were not explicitly observed because some areas changed from non-vegetated to vegetated. The increase or decrease in non-vegetated area geographically varied, suggesting that groundwater is another factor affecting salinity conditions. Further investigation is recommended to reveal the dynamics of salinity conditions and to contribute to the improvements in rice production.
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