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Rice Production in Farmer Fields in Soil Salinity Classified Areas in Khon Kaen, Northeast Thailand

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Abstract: Northeast Thailand is the largest rice cultivation region in Thailand, but the rice yield there is quite low. Soil salinity is one of the major yield restricted factors, is derived from underground rock salt, and is predicted to expand in the future. This study focused on evaluating rice productivity related to salinity conditions in Khon Kaen Province, Northeast Thailand. The field investigations were conducted from 2017 to 2019 in farmer fields in severe, moderate, and slight soil salinity classes determined by the Land Development Department of Thailand. The soil salinity on the basis of the electric conductivity of saturated soil extract (ECe) varied year to year, which seemed to be associated with precipitation. The difference in soil salinity between classes was obvious only in the drought year 2018, and reflected in the rice yield, although severe drought devastated rice yield in some fields. Plenty of rainfall may have alleviated soil salinity and rice yield reduction in other years, causing differences in rice yield that were not significant among soil salinity classes. However, salinity level evaluation by the USDA based on ECe showed that rice yield was damaged depending on the level. This study indicates that ECe-based evaluation is recommended for soil salinity in relation to rice productivity. The spatial and temporal evaluation for rice production may benefit farmers. The results in this study also showed rice production largely varied even in similar salinity levels, implying that salinity damage can be alleviated by farmer management.

Keywords: rice yield; dynamic soil salinity; salinity level at harvest; soil moisture content; rainfall

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1. Introduction

Soil salinity is a major agricultural problem in global crop production [1], and it has accounted for approximately 20% of the world's cultivated area [2]. Furthermore, soil salinity is expected to increase because of climate change in the future, and some researchers have reported that serious salinization may increase up to 50% of all arable land by 2050 [3]. Most salinity-affected soil areas are located in Africa and Asia, especially in southeastern Asia [4]. For example, in Northeast Thailand, approximately 17% of the land is affected by salt [5]. The resource of salinity is an underground salt rock in Northeastern Thailand [6]. Moreover, soil salinity has accumulated from human activities, such as irrigation, deforestation, and salt manufacture [7]. To evaluate the soil salinity situation in Northeast Thailand, the Land Development Department (LDD) classified soil salinity into four classes according to the salty crust in the dry season: class 1 "very severely" (salt crust > 50%), class 2 "severely" (salt crust 10–50%), class 3 "moderately" (salt crust 1–10%), and class 4 "slightly" (salt crust < 1%).

Rice is the most important crop in Northeast Thailand [8]. The cultivated area occupies more than 50% of the total rice cultivated area in Thailand, but the yield per hectare is the lowest among regions [9]. Although poor soil fertility and low water availability are the major constraints of production with extensive management [10], soil salinity has caused serious problems in some areas [11].

Rice is highly sensitive to salinity compared with other crops [12]. The responses to salinity are often represented by indicators such as NaCl concentration and electric conductivity (EC) [13,14]. The electric conductivity of saturated soil extract (ECe) is one of the representative indicators and is used to describe salinity levels by the USDA [15]. Maas and Grattan [16] pointed out that rice yield is significantly reduced by soil salinity over 3 dS m^{-1} ECe. However, the above-mentioned soil salinity classes classified by LDD do not correspond to ECe and rice productivity. The soil salinity conditions in relation to rice production have also been insufficiently reported [17]. Therefore, we conducted field investigations to evaluate salinity conditions and rice production in salt-affected areas in Khon Kaen province, Northeast Thailand. We selected the study area based on the soil salinity classification by LDD. The salinity condition was evaluated on the basis of ECe. Based on the analysis of the relationship between salinity condition and rice production, we discussed the classification method of salinity level and further strategies to alleviate salinity damage.

2. Materials and Methods

2.1. Study Area

The study area (Figure 1), located in Khon Kaen, Northeast Thailand, is characterized as having a tropical savanna climate with two seasons (rainy and dry seasons) with an average annual precipitation of approximately 1100 mm. In this area, jasmine rice (KDML 105), is widely cultivated. Farmers plant rice once a year in the rainy season, sow rice in June or July, and harvest in early or mid-November. We conducted field investigations from August to November every year from 2017 to 2019.

Precipitation data were obtained from the meteorological station in the Banphai, Meteorological Department, which is the nearest meteorological station to the study area. Precipitation in the investigated period varied from year to year (Figure 2). The amounts in 2018 and 2019 were less than half of that in 2017. The amounts were similar between 2018 and 2019, but the patterns were different: the rainfall level was high in June and July in 2018 but high in August and September in 2019.

2.2. Field Investigations

Field investigations were conducted in classes 2 and 3 in 2017 and 2018. The areas followed the classification of the LDD [18]. Since farmers in class 3 did not plant rice in 2019, due to the drought in June and July 2019 following crop failure in 2018, we conducted an investigation in class 4. The investigations were divided into 2 measurements: one was the weekly measurement of soil salinity, and the other was rice yield measurement. The weekly measurement of soil salinity was conducted at 14 and 6 points in 7 and 3 fields in class 2 and class 3 in 2017, 10 and 10 points in 5 and 5 fields in class 2 and class 3 in 2018, and 5 and 5 points in 5 and 5 fields in class 2 and class 4 in 2019, respectively (Figure 1). The points were selected to represent the classification area. We tried to investigate the same fields for 3 years but failed because some fields were not planted. The measurement was conducted from 29 August to 5 November, from 11 September to 6 November, and from 8 October to 13 November in 2017, 2018, and 2019, respectively. The rice yield measurement was conducted at 34 and 14 points in class 2 and class 3, 19 and 19 points in class 2 and class 3, and 30 and 26 points in class 2 and class 4, respectively, which included the points of the weekly measurement of soil salinity. The points were selected to compensate for the weekly measurement points. The rice was harvested for measurement on 5 November in 2017, 6 November in 2018, 8 November in class 4, and 13 November in class 2 in 2019, respectively.

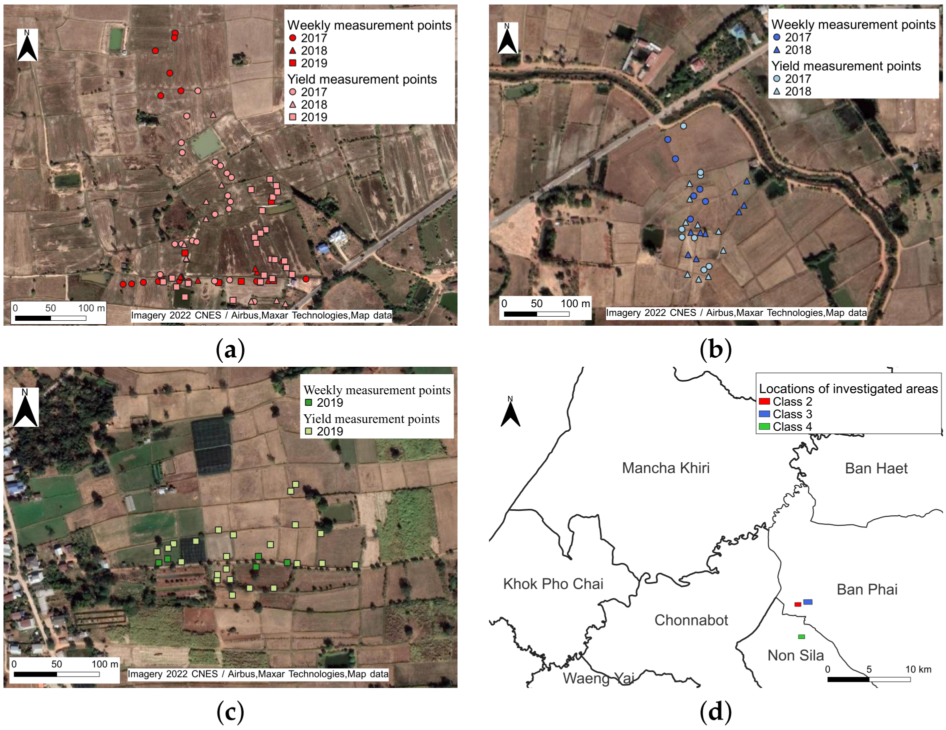


Figure 1. The investigated fields and locations on Google Maps. (**a**) Class 2. (**b**) Class 3. (**c**) Class 4. (**d**) Locations of study areas in Khon Kaen. Lines are the boundaries of the districts.

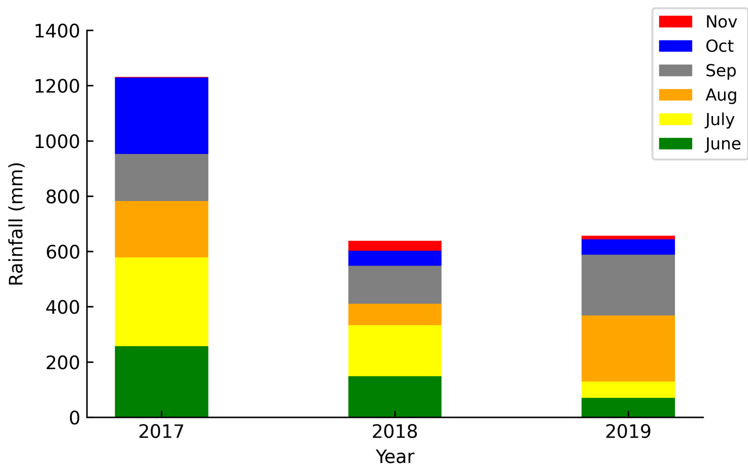


Figure 2. Rainfall during the investigated period from 2017 to 2019. The data were obtained from the meteorological station in Banphai.

2.2.1. Weekly Measurement of Soil Salinity

A soil solution sampler (DIK-301B, Daiki Rika Kogyo Co., Ltd., Saitama, Japan) was installed at 10 cm depth at each weekly measurement point to collect soil solution. A total of 10 mL of soil solution was collected weekly for EC measurement (ECs). When the soil solution was not extracted due to drought, 450 g of soil sample was collected from the surface to 12 cm depth around the weekly measurement point (within a radius of 1 m). The soil was subjected to EC 1:5, ECe, and moisture content measurements.

2.2.2. Rice Yield Measurement

Rice plants were harvested in a circle with an area of 1 m^2 at each point. The yield was determined with rough grain calibrated with a moisture content of 14%. A total of 450 g of soil sample was collected from surface to 12 cm depth and subjected to EC 1:5 and ECe measurements. Soil salinity level was classified by ECe based on US Salinity Laboratory

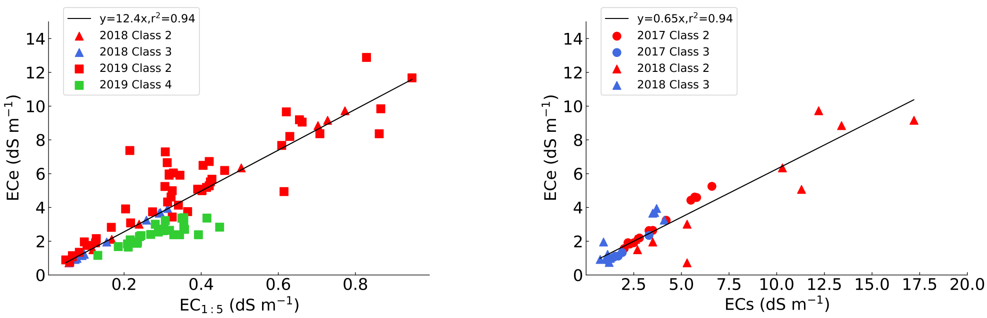
Staff [15]: NS (none saline): 0–2 dS m^{-1}; LS (low salinity): 2–4 dS m^{-1}; MS (mild salinity): 4–8 dS m^{-1}; HS (high salinity): 8–16 dS m^{-1}; SS (severe salinity): >16 dS m^{-1}.

2.2.3. Soil Measurement

The moisture content of soil samples was determined by the ratio of the soil weight before drying and after drying. Air-dried soil samples were passed through a 2 mm sieve. EC of saturated paste (ECe) was determined using the methods outlined by the USDA [15]. The saturated paste was prepared by adding distilled water to 350 g soil samples and stirred until saturation. The saturated paste was left for 24 h for equilibration. The saturated paste extracts were obtained by using a Bucher Funner and applying suction. A 1:5 soil–water suspension was prepared to determine EC 1:5 by adding 50 g of distilled water to 10 g of air-dried soil. ECe, EC 1:5, and soil solution EC (ECs) were determined by an EC meter (FiveEasyTM Plus EC meter FEP30, Mettler Toledo, Greifensee, Switzerland).

2.3. Conversion of Soil Solution EC and EC 1:5 to ECe

ECe had strong linear relationships with soil EC 1:5 and ECs (Figure 3). Although EC 1:5 in class 4 in 2019 had a lower ECe, and the regression lines with 0 intercepts were applied to convert EC 1:5 and ECs to ECe in this study.



(**a**) (**b**)

Figure 3. Comparison between ECe, EC 1:5, and ECs. (**a**) The relationship between soil ECe and EC 1:5. (**b**) The relationship between soil ECe and ECs.

3. Results

3.1. Dynamics of Soil ECe and SMC among Classes from 2017 to 2019

The dynamics of soil ECe varied among years (Figure 4). A higher ECe was observed in the drought year 2018. ECe was rather stable in 2017 and 2019. The average ECe in class 2 was higher than that in class 3, but ECe in class 2 was not always higher than that in class 3 in some fields. Class 4 showed a relatively higher ECe than class 2, especially on 8 and 14 October 2019. Soil moisture content (SMC) was obviously lower in class 3 than in class 2 in 2018. An SMC decrease, which was unable to extract soil solution, rarely occurred in 2017 and 2019. Although the relationship was not clear, ECe tended to increase under low SMC after 10 October 2018.

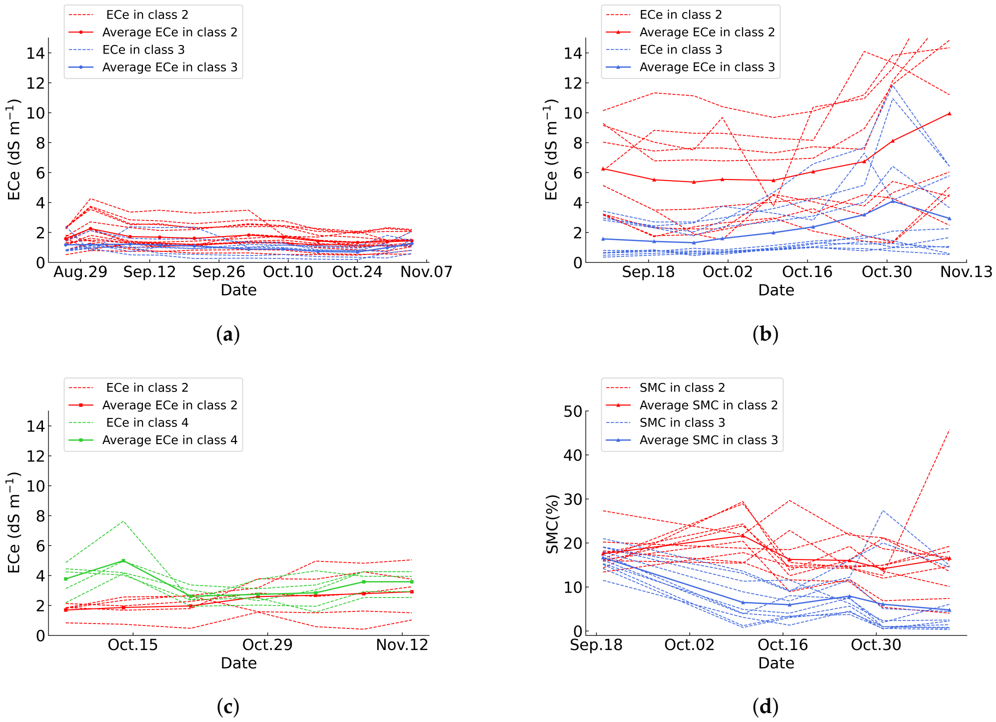


Figure 4. Dynamics of soil ECe in 2017 (**a**), 2018 (**b**), 2019 (**c**), and dynamics of soil moisture content (SMC) in 2018 (**d**).

The average ECe of the weekly measurement at each measurement point showed large variation only in 2018 (Figure 5). The ECe in class 2 was significantly higher than that in class 3 in 2018. However, a significant difference was not observed between class 2 and class 3 in 2017, or between class 2 and class 4 in 2019.

Soil ECe at harvest has a linear positive relationship with average ECe of weekly measurement (Figure 6). Accordingly, the soil ECe at harvest was used to classify the soil salinity level in the following analysis.

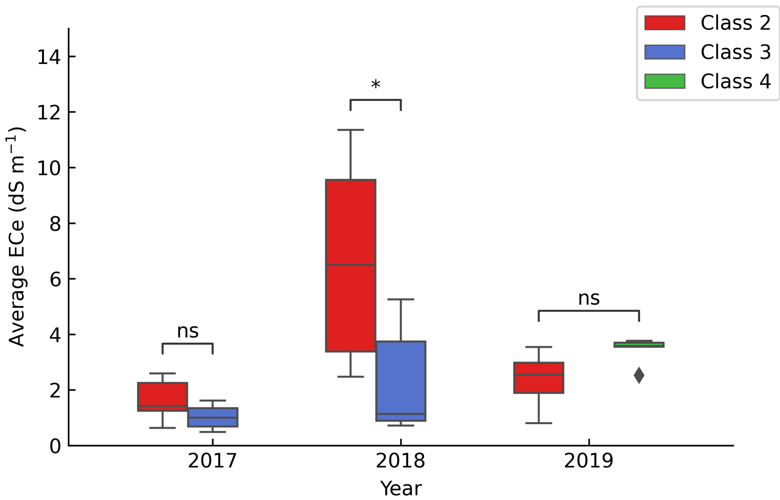


Figure 5. Box plot of average ECe of soil samples in the investigated period from 2017 to 2019. Diamond-shaped markers are outliers. The number of samples was 14 and 16 in class 2, class 3 in 2017; 10 and 10 in class 2, class 3 in 2018; 5 and 5 in class 2, class 4 in 2019, respectively. * significant at a probability level of 0.05 by the Mann–Whitney U test.

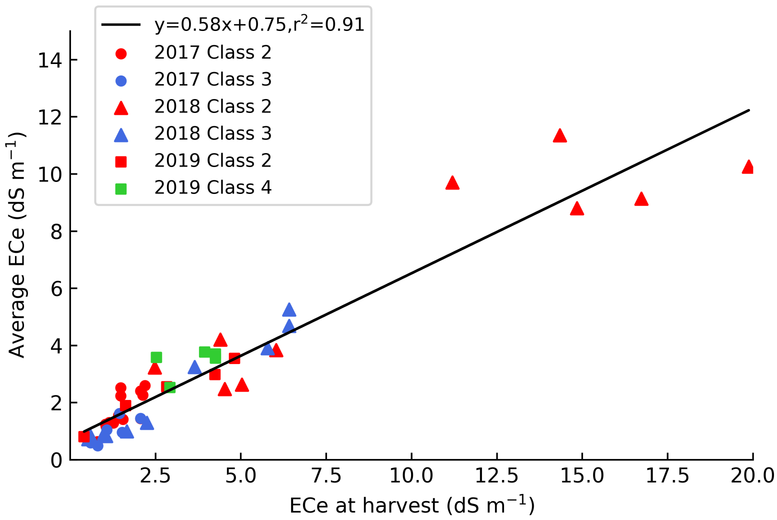


Figure 6. The relationship between average ECe of soil samples during the investigated period and ECe at harvest from 2017 to 2019.

3.2. Effect of Soil ECe and Moisture on Rice Yield

Figure 7 shows the relationship between rice yield and ECe at harvest. An extremely low rice yield (<100 g m^{-2}) was observed where ECe was higher than 10 dS m^{-1} in class 2 in 2018. The extremely low rice yield was also observed where ECe was lower than 6 dS m^{-1} in class 3 in 2018. The fields that showed low rice yield in class 3 in 2018 corresponded to those that had a low SMC (Figure 4). Except for the extremely low rice yield, rice yield varied among points and did not show any tendency against ECe.

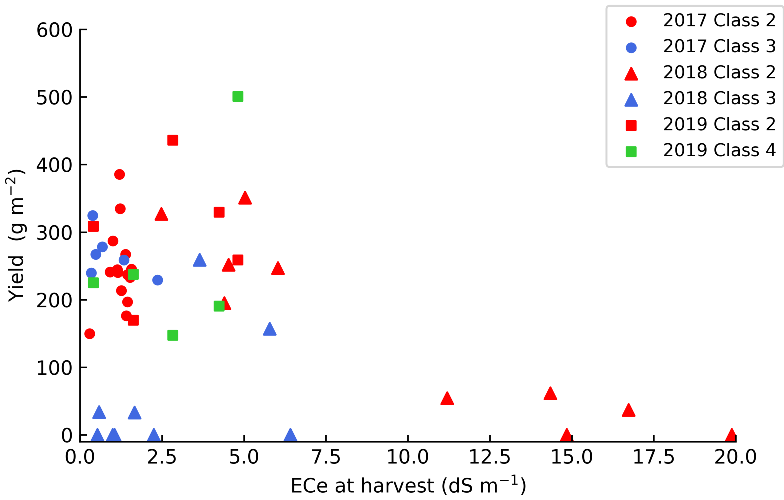


Figure 7. The relationship between rice yield and ECe at harvest from 2017 to 2019.

3.3. Rice Yield Based on Salinity Level at Harvest

The rice yield measurement showed that yield reduced only in class 3 in 2018, and was not significantly different between classes in 2017 and 2019 (Figure 8). The lower yield in class 3 in 2018 might have been caused by the low SMC (Figure 4). Rice yield varied in a large range even at the none saline and low soil salinity level (Figure 9). However, the median yield tended to decrease with increasing salinity levels. Analysis of covariance showed that the effects of salinity levels and year were significant but that of class was not significant (Table 1).

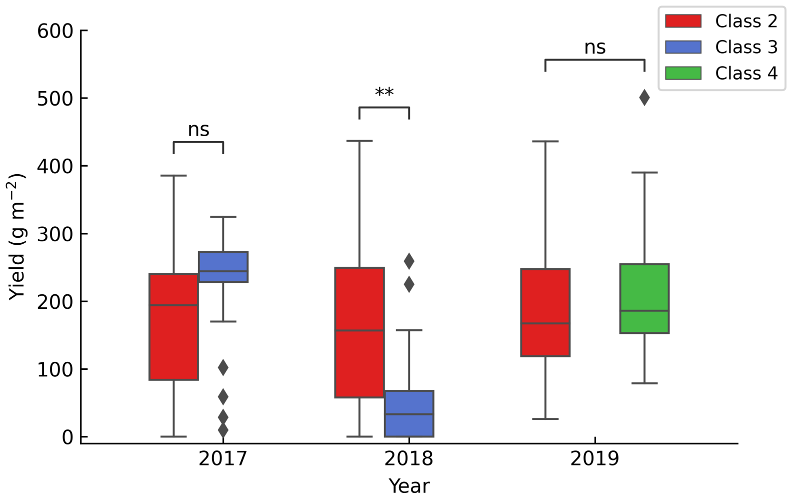


Figure 8. Box plot of rice yield among classes from 2017 to 2019. Diamond-shaped markers are outliers. ** significant at a probability level of 0.01 by the Mann–Whitney U test.

Table 1. ANCOVA result for rice yield by year, salinity, and class.

Source	F Value	*p* Value
Year	6.41	0.002 **
Salinity level	10.41	0.002 **
Class	1.74	0.189

** Significant at a probability level of 0.01.

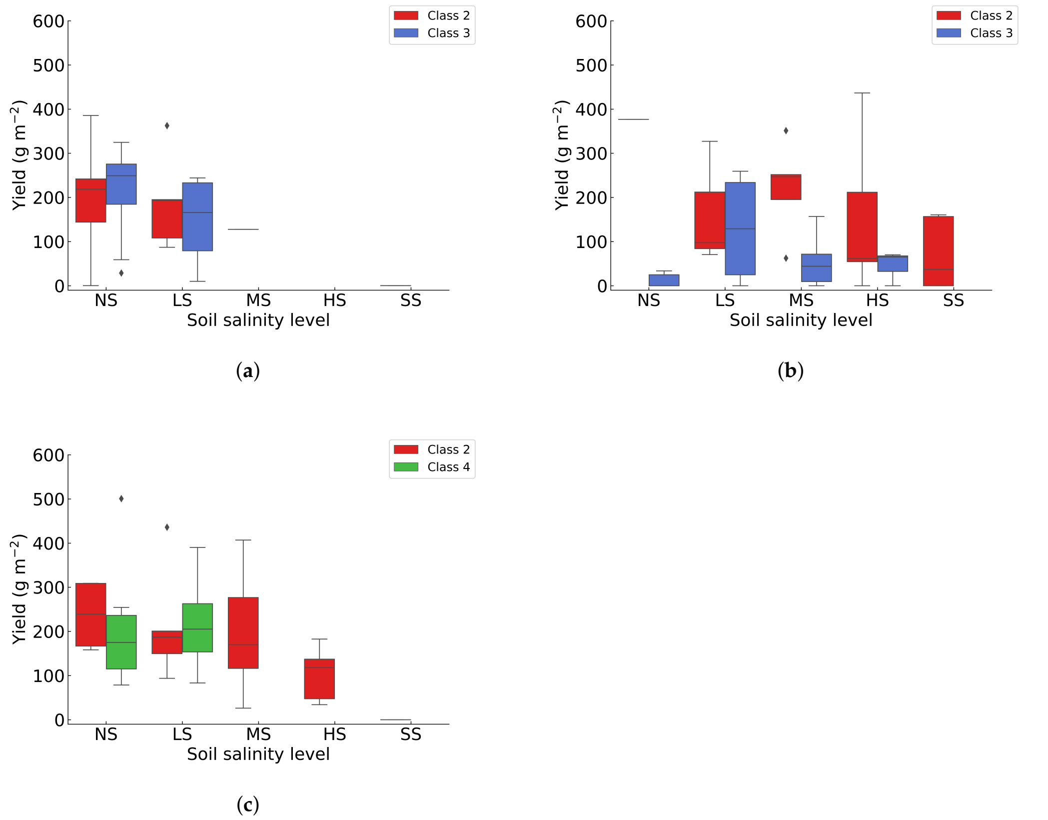


Figure 9. Box plots of rice yield based on salinity level among classes in 2017 (**a**); 2018 (**b**); 2019 (**c**). Diamond-shaped markers are outliers. NS (no saline): 0–2 dS m^{-1}; LS (low salinity): 2–4 dS m^{-1}; MS (mild salinity): 4–8 dS m^{-1}; HS (high salinity): 8–16 dS m^{-1}; SS (severe salinity): >16 dS m^{-1}.

4. Discussion

Soil salinity varied from year to year, which seemed to be associated with precipitation. The low precipitation in August and September of 2018 decreased SMC and increased ECe, which caused significant differences in ECe between classes 2 and 3. However, abundant rainfall alleviated ECe, which resulted in no significant difference among classes. The LDD defined classes based on salt crust in the dry season, but the results in this study suggest that another classification is required for rice production in the rainy season. Precipitation is generally more than potential evapotranspiration in the rainy season, but in 2018 it was less [19]. Including climate data is necessary for the classification. Yang et al. [20] reported that no vegetation areas due to severe salt damage were partly distributed in class 2. The detailed mapping of soil salinity is also required [21].

The soil salinity level based on soil ECe suggested that rice yield was damaged by soil salinity (Figure 9). ECe could be a candidate indicator of soil salinity mapping for rice production if the value was predictable in the rainy season. However, rice yield varied in a large range even at the same salinity level, obscuring the relation between rice yield and ECe (Figure 4). This fact, on the contrary, implies that farmer management could alleviate salinity damage. Farmers can obtain higher yields even at high and severe salinity levels. Since farmers partly applied irrigation water with a small water pump, effective irrigation may directly reduce the salinity level in addition to drought. Cost and water availability are the major limiting factors in the region [22,23]. Development of salinity level management with water-saving culture is recommended. The salinity level of irrigation water also needs to be checked [24]. Since the attainable rice yield of KDML 105 is 450 g m^{-2} [25,26], the yield can be improved. Proper nutrient management may be necessary because low soil fertility due to light-textured soil is generally considered a yield constraint [27]. The authors also observed severe lodging in some locations due to excess stem growth. Control of rice growth is also recommended. Homma et al. [10] suggested that optimization of fertilizer application produces higher productivity by reducing fertilizer at the earlier planted field and increasing fertilizer at the later planted field. Nutrient management based on leaf color may be effective [28].

Although the expansion of severely salt-damaged areas was not observed [20], increases in soil ECe are predicted in the study area in the future [19]. Higher potential evaporation under global warming conditions may produce more severer salinity conditions [29,30]. Several attempts were tested to alleviate soil salinity [31,32]. Since deforestation is one of the major causes that enhances the salinity problem in the region, ecological management is also considered for the countermeasures [33,34]. One of the major countermeasures is reducing the groundwater level in the dry season by tree planting. The lower groundwater level is expected to prevent salinity movement from the deep soil layer to the surface. However, a strategy has not been developed to reach a solution. Under this situation, the spatial and temporal evaluation of salinity conditions is primarily recommended. The evaluation may provide a local solution to continue rice production in the salinity classified area.

5. Conclusions

This study conducted field investigations to evaluate rice production in relation to salinity conditions, where the LDD classified soil salinity. Soil salinity in terms of ECe was affected by the precipitation amount and was not always consistent with the classes by LDD. The salinity level based on ECe was a more suitable indicator to evaluate the salinity damage of rice. These results suggest that the spatial and temporal evaluation of salinity conditions based on ECe is required for rice production. Large yield variation even at high and severe salinity levels suggests that rice yield can be improved by farmer management. Since deterioration of salinity conditions is anticipated under future climate change, further investigation is recommended to alleviate salinity damage for rice production.

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Abbreviations

LDD	Land Development Department
EC	Electricity Conductivity
ECe	Electricity Conductivity of Saturated Soil Extract
ECs	Electricity Conductivity of Soil Solution
SMC	Soil Moisture Content

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