Research article

Effect of Excavated Small Drainage Channels on Desalinization in Northeastern Thailand

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Abstract Salt-affected soil is a serious problem in Thailand, and most of this soil is found in the northeastern part of Thailand. The total area of saline land in Northeast Thailand is 2.85 million ha, which accounts for about 17% of this area (Land Development Department,2011). The objective of this study is to evaluate the effect of desalinization by digging drainage channels in salt-affected fields during rainfall. The study was conducted on a high salinity field in Khon Kaen, Thailand. In April 2019, the main drainage channel of a depth of 1 m, was excavated across the center of the field in the south-to-north direction. Additionally, side ditches were installed along the circumference of the west part of the field. We constructed drainage channels to promote field drainage and effectively induce salt leaching with rainfall. Field observations were conducted eight times, especially in the rainy season, from August 2018 to September 2019. Soil apparent electricity conductivity (EC_a) was measured using an electromagnetic induction meter in three distinct depth ranges, i.e., 0.375 m, 0.75 m, and 1.5 m, from the soil surface. Soil salinity was represented as contour maps based on spatially interpolated data and spatial distribution and temporal changes were analyzed. The soil EC_a in the field gradually increased from upstream to downstream. Moreover, it was higher near the surface and lower deep underground. By comparing the soil salinity observed in the later part of the rainy season in both the years, EC_a was observed to have decreased by 20% from August 2018 to September 2019. The EC_a values at depths of 0.375 m and 0.75 m in the west part of the field, which had side ditches, were significantly lower than those in the east part of the field two months after the drainage channels were constructed. However, a contrary result was obtained after a heavy flood. These results indicate that drainage channels contribute to salt leaching with rainfall. Our results suggested that excavating drainage channels could effectively reduce soil salinity during the rainy season under good drainage conditions.

Keywords saline soil, desalinization, leaching, drainage, electric conductivity

INTRODUCTION

Soil salinization is a major global problem limiting crop productivity. Urgency exists to prevent and improve soil salinization for sustainable agriculture. Salt-affected soils are found in more than 100 countries and typically occur in arid and semi-arid regions (Rengasamy, 2006). The Food and Agriculture Organization (FAO) estimated that globally the total area of salt-affected soils is 831 million ha. Salt-affected soils have also been developing in monsoon zones in South and Southeast Asia. Thailand is one of the countries where improving saline soil is an urgent need.

Salt-affected soil is a serious problem in Thailand, and most of this soil is found in the northeastern part of Thailand. The total area of saline land in Northeast Thailand is 2.85 million ha, which accounts for about 17% of this area (Land Development Department,2011). The potential source of salt in this area is halite in the Maha Sarakham Formation (Wongsomsak, 1986). Apart from its geographical environment, human activities such as deforestation associated with agricultural development and traditional salt making have contributed to accelerating soil salinization (Arunin et al., 2015; Löffler et al., 1988). People in this area are impoverished because of low agricultural productivity resulting from infertile land and salt-affected soil. To combat this problem, the mechanism of reducing soil salinization was elucidated, and studies using various approaches to mitigate soil salinity have been attempted from more than 30 years (Miura et al., 1991; Patcharapreecha et al., 1990). However, the people in this area are still suffering from salt-affected soil. In other words, these desalinization approaches do not have widespread application. Some farmers abandoned their farmlands and gave up farming because with salt-affected soil being formed opportunities to expand farmlands did not exist. To enhance agricultural development and encourage the agricultural community, ameliorating salt-affected soil and develop them for farmlands are necessary.

One of the common strategies for combating salt-affected soil is leaching salts from upper to lower soil depths (Qadir et al., 2000). To effectively facilitate the leaching process, an open or subsurface drainage system is commonly adopted (Ritzema, 2016). This approach is generally considered to decrease the saline groundwater table and removes leaching water from the soil profile. However, installing a drainage system to control salinity is a costly proposition (Datta et al., 2000) and raises concerns about high salinity drainage water. In this study, a conceptual model of the Cascading Salt Using System (CSUS) (Kume et al., 2019a, 2019b) has been considered. This model focuses on water and salt flow and proposes to reconsider salt as a useful resource. In this system, different types of crop cultivation are practiced considering feasible salinity levels. For instance, rice paddies can be cultivated upstream and halophilic crops can be cultivated downstream where the salt concentration is higher. Moreover, table salt can be made from high salinity discharge water that is observed at the lowest downstream level. Production of halophilic crops and salt are expected to raise farmers' income.

This study is the first step of the CSUS project to decrease soil salinity in a large salt-affected field by excavating small drainage channels. Open drainage channels that are currently installed in the field considered in this study are not aimed towards completely removing salts from the field and mitigating soil salinity for low salt-affected levels. These drainage channels are not large; therefore, they are inexpensive and easy to install for farmers. The objective of this study is to evaluate the effect of desalinization by digging small drainage channels.

METHODOLOGY

Study Area

The study was conducted in a high saline soil field in Ban Phai district (16°03′ N, 102°69′ E), Khon Kaen (Fig. 1). This area experiences a tropical savanna climate (Köppen climate classification *Aw*) with marked alternation of the rainy season (from May to October) and dry season (from November to April). The range of annual precipitation is from 1,100 mm to 1,500 mm, and the mean annual temperature is 27°C. The overview of the field under consideration in this study is shown in Fig. 2. This field with an area of approximately 0.8 ha has no vegetation because of high soil salinity; however, the upper area of the field is used for rice cultivation in the rainy season. For improving the saline soil in the field, a strategy to install small drainage channels was adopted by the Land Development Department. The drainage channels are expected to promote field drainage and induce salt leaching with rainfall. In April 2019, a main drainage channel with a 1-m depth was excavated across the center of the field in the south-to-north direction. Additionally, side ditches with a depth of 1 m were installed along the circumference of the west part of the field. The gradient of the drainage channels was approximately 2.5 / 1000. The water flow is in the direction of the arrow in Fig. 2. The drainage ultimately runs downstream through the hume pipe under the road lying on the north side of the field. Daily precipitation data (Fig.3) in the urban area in Khon Kaen was obtained from the Japan Meteorological Agency website.

Field Survey

Soil salinity was measured using an electromagnetic induction meter, EM38-MK2 (Geonics Limited), which measured apparent soil electrical conductivity (EC_a) in units of millisiemens per meter (mS/m). This instrument has two receiver coils, each of which, are separated by 1 m and 0.5 m from the transmitter providing data from effective depth ranges of 1.5 m and 0.75 m, respectively, when positioned in the vertical dipole orientation, and 0.75 m and 0.375 m respectively, when positioned in the horizontal dipole orientation. We measured soil salinity in vertical and horizontal dipole orientation in 1-m intercoil spacing as well as in horizontal dipole orientation in 0.5-m intercoil spacing, thereby obtaining three distinct depth ranges of data, i.e., 0.375 m, 0.75 m and 1.5 m, from the soil surface. The measurement interval was about 10 m. Field observations were conducted eight times, especially in the rainy season, from August 2018 to September 2019 and three times in the dry season, i.e., February, March, and December 2019.

Fig. 1 Location of the study area

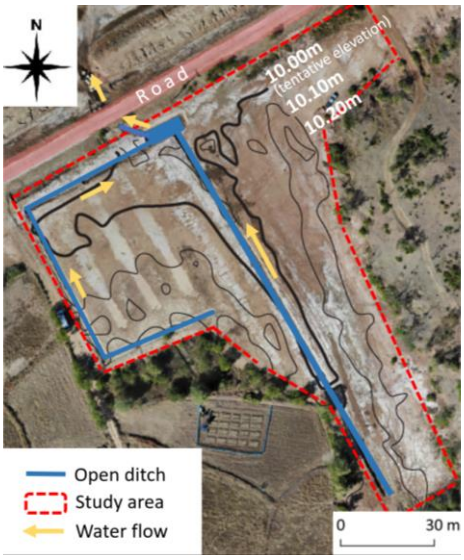

Fig. 2 Overview of the study area

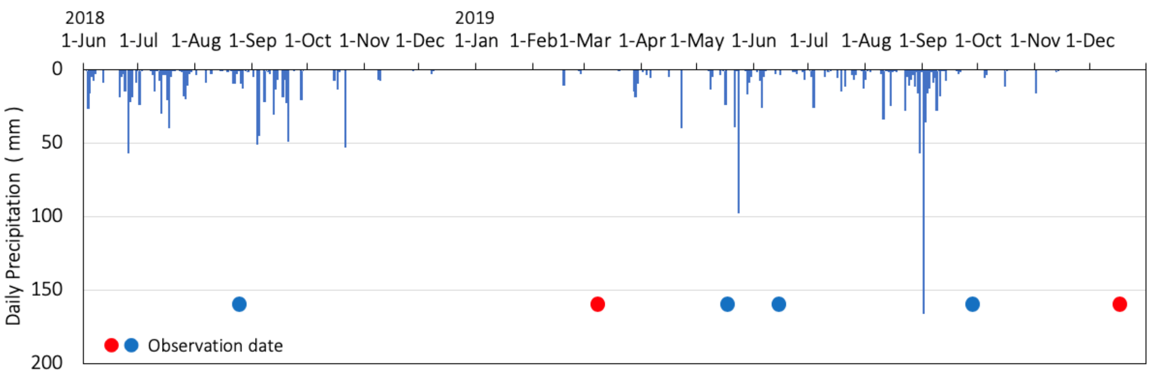

Fig. 3 Daily precipitation in Khon Kaen

Data Analysis

The soil EC_a data obtained from EM38-MK2 in the field were used as a database for mapping the distribution of the field soil salinity. They were interpolated using the Inverse Distance Weighted method with 1-m intervals and represented as contour maps to analyze spatial and temporal distributions. Because EC_a measured using EM38-MK2 affects soil moisture, data under similar groundwater level conditions were used for comparing soil salinity changes. The observation dates of the data used for this analysis are shown in Fig. 3 in blue (in the rainy season) and red (in the dry season) dots. Moreover, averages of field EC_a were calculated based on the interpolated data.

RESULTS AND DISCUSSION

Spatial Distribution and Temporal Changes of Soil Salinity in the Field

Soil salinity in the field was represented as contour maps. Fig. 4 shows field soil salinity at a depth range of 0.75 m in August 2018 as well as September 2019 before and after excavating the drainage channels. The soil EC_a gradually increased from upstream to downstream in the field associated with water flow. Identical results were obtained at the other measurement dates as well as the other two depths, i.e., 0.375 m and 1.5 m. Comparison of both the figures showed that the soil EC_a in September 2019 was lower than that in August 2018 in the entire field. Table 1 shows the average EC_a in the field at three different depth under similar groundwater level conditions in the rainy season. The soil EC_a has a tendency to be higher near the soil surface and lower deep underground. In the rainy season in 2019, the soil EC_a gradually decreased from the early part of the rainy season in May to the end of the rainy season September. The specific decrease was from 1398 mS/m to1290 mS/m, 1367 mS/m to 1205 mS/m, and from 1106 mS/m to 944 mS/m at the depths of 0.375 m, 0.75 m, and 1.5 m, respectively. The total rainfall in this period was 655.4 mm. Leaching is considered to have progressed during rainfall.

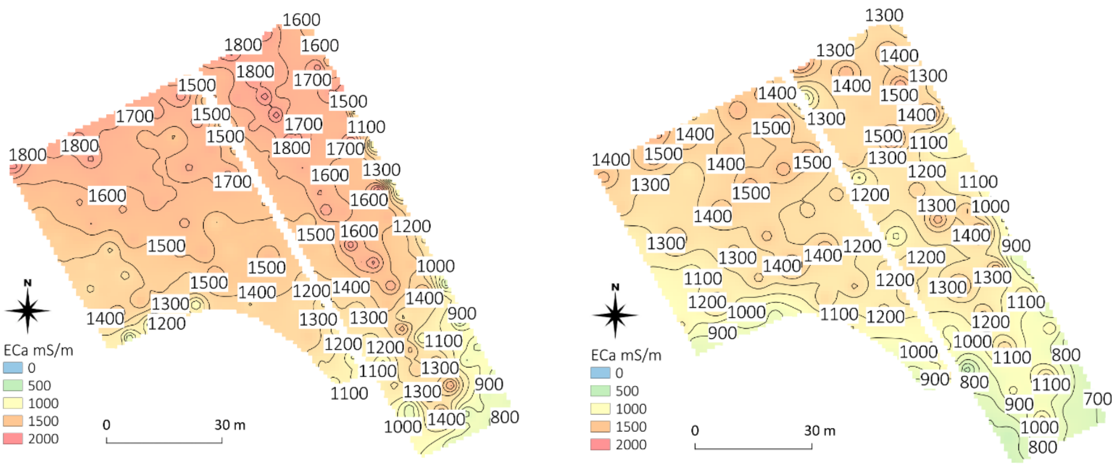

Fig. 4 Distribution of soil salinity in the field at a depth of 0.75 m before the installation of drainage (left) and after the installation of drainage (right) in the rainy season

Moreover, the soil EC_a decreased after excavated drainage channels. The soil EC_a in September 2019 was 20% lower than that in August 2018, even though both these periods were the later part of the rainy season. This result indicates that installing drainage channels promotes salt leaching by rainfall in the rainy season.

Additionally, soil salinity was compared before and after excavating drainage channels in the dry season. Fig.5 shows field soil salinity at a depth range of 0.75 m in March 2019 as well as December 2019 before and after excavating the drainage channels. The averages of the soil EC_a in the dry season are also shown in Table 1. After installing drainage, the soil EC_a in December 2019 was lower than that in March 2019, before installing drainage. Additionally, Fig. 5 clearly shows that the soil EC_a decreases after excavating the drainage channels. Miura, K., and Subhasaram, T. (1991) indicated that accumulation of salt on the soil surface in the dry season was associated with the elevation of the groundwater table to a critical level at the end of the rainy season and continuity of capillary pores above the groundwater level. In this study, comparing the soil EC_a under similar groundwater level conditions, this continuity of capillary pores should be prevented due to the groundwater level after excavating the drainage channels was relatively lower than before that. This result agrees with the earlier result in the rainy season and supports the assumption that drainage channels effectively function as a desalinization method.

Table 1 Averages of field EC_a (mS/m) at three depths

Depth (m)	Rainy season				Dry season	
	August 2018	May 2019	June 2019	September 2019	March 2019	December 2019
0.375	-	1398	1277	1290	1133	944
0.75	1470	1367	1286	1205	1109	954
1.5	1155	1106	1077	944	947	840

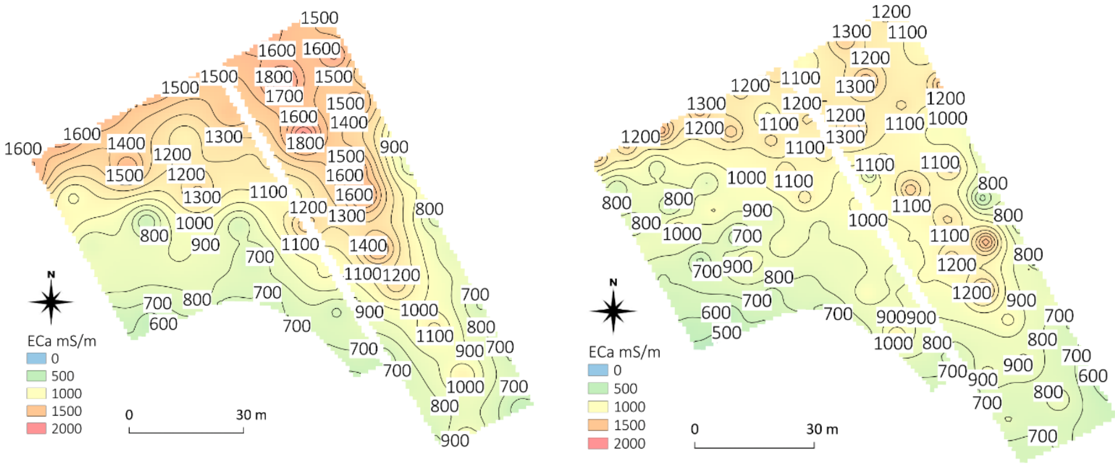

Fig. 5 Distribution of soil salinity in the field at a depth of 0.75 m before installing drainage (left) and after installing drainage (right) in the dry season

Comparison of Salinity Changes under Different Drainage Intensity

In the field under consideration in this study, the intention of drainage channels is different between the west and east parts of the field. The west part of the field is surrounded by a side ditch; therefore, drainage and leaching efficiency in the west part are expected to be better than those in the east part of the field. To compare the desalinization effect on both the sides, we compared the soil EC_a in the west part to that in the east part of the field. Fig. 6 shows the average soil EC_a at a depth of 0.75 m in the west and east parts of the field. The error bars show the standard deviation. The average of the soil EC_a before the introduction of drainage was higher in the west part of the field than that in the east part of the field, i.e., 1498 mS/m and 1442 mS/m, respectively. However, the soil EC_a was lower in the west part than that in the east part of the field two months after the drainage installation, i.e., June 2019. The average field EC_a was 1205 mS/m and 1340 mS/m in the west and the east part of the field, respectively. Moreover, significant difference (Mann-Whitney U test; p <0.01) with the same result was obtained at a depth of 0.375 m, while no significant difference between the west and the east parts of the field was observed at a depth of 1.5 m. This result indicates that intensive drainage enhanced salt leaching in the west part of the field. However, in September 2019, the soil EC_a in the west part was higher than in the east part of the field. Before measurement in September 2019, this area experienced heavy flooding, and some parts of the drainage system were broken; therefore, excess water in the field could not be immediately removed. This may have caused higher salinity in the west part of the field in September 2019. In December 2019 after the flood, the same tendency was observed as that before the flood even though it was the dry season.

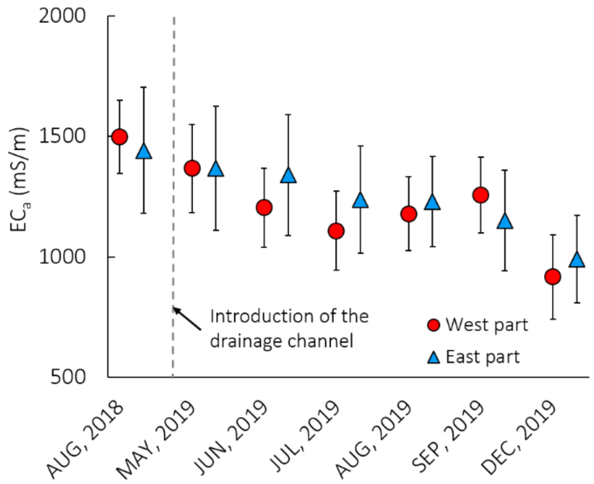

Fig. 6 Averages of the soil EC_a in the west and the east part of the field at a depth of 0.75 m

Fig. 7 Divided five areas depend on the distance from drainage channels

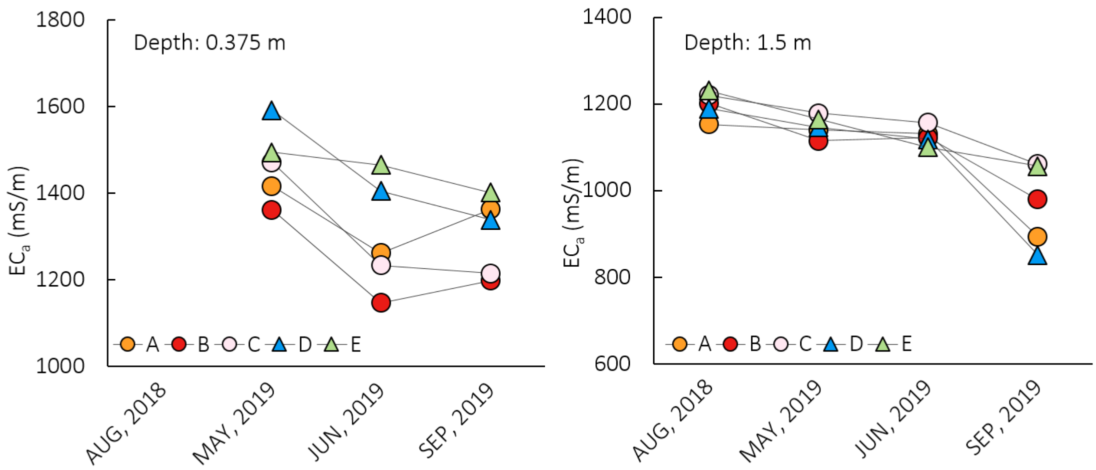

Fig. 8 Changes of the average EC_a in five areas in the rainy season

Subsequently, we compared the soil EC_a near the drainage channels and far from them to conduct a detailed examination of the field salinity changes. The field was divided into five areas (Fig. 7) based on the distance from the drainage channels, i.e., the area 0-10 m from the main drainage channel in the west part of the field (area A), the area 0-10 m from the side ditch in the west part of the field (area B), the middle area of the west part of the field (area C), the area 0-10 m from the main drainage channel in the east part of the filed (area D), and the area 10-25 m from the main drainage channel in the east part of the field (area E). We compared the values of the soil EC_a in the five areas at three depths during the rainy season under a similar groundwater level condition. Fig. 8 shows the average soil EC_a in each of the five areas at depths of 0.375 m and 1.5 m as an example. The soil EC_a generally decreased in all the areas and at all the depths from August 2018 to June 2019. However, in September 2019, after the flood, the soil EC_a suddenly increased in areas A and B at a depth of 0.375 m, while it slightly decreased in area C, which was surrounded by A and B,. This result indicates that salt was supplied from the soil surface layer in C to the A and B areas. Alternatively, this may suggest that salt reaccumulated from the drainage water after the flood. Conversely, at a depth of 1.5 m, the soil EC_a in areas A, B, and D near the drainage channel, considerably decreased in September 2019 in contrast with small changes before that. The drainage and leaching effect was considered to be less at a depth of 1.5 m because the groundwater level was over 1.5 m in the ordinarily rainy season, but the depth of the excavated drainage channels was 1.0 m. However, the groundwater level in the field was low in July and August 2019 because low rainfall was experience during this period. Therefore, a large amount of rainfall caused by the flood infiltrated deep underground in an instant and this made the salt leach away, especially from near the drainage channel and deep underground. These results indicate that drainage channels contribute to salt leaching during rainfall and drainage systems operating in a satisfactory manner are important for desalinization.

CONCLUSION

We evaluated the effect of small drainage channels during rainfall on desalinization in the high salinity field in Khon Kaen, Thailand by measuring field soil EC_a using an electromagnetic induction meter. After analyzing the spatial distribution and temporal changes of the field soil salinity, we found the following results. The soil EC_a gradually increased in the field from upstream to downstream. The soil EC_a was higher near the surface and lower deep underground. In 2019, the soil EC_a gradually decreased from the early part rainy season to the end of the rainy season. By comparing the soil salinity before and after excavating the drainage channels in the same season, the soil EC_a was observed to have decreased after drainage installation. Moreover, the soil EC_a in the west part of the field, where drainage was more intensive, was significantly lower than that in the east part of the field two months after the drainage channels were constructed. However, later in the rainy season in 2019, the value of the soil EC_a in the west part of the field was higher than that in the east part of the field. The drainage channels were considered to have not worked well after the heavy flood. The same holds true of the result obtained by comparing the EC_a changes based on the distance of the drainage channels. Our results suggest that the excavated drainage channels can effectively reduce soil salinity during the rainy season. Overall, the desalinization effect could be observed in the field soil EC_a throughout the year. Additionally, desalinization is assumed to continue to progress by repairing the drainage channels.

It was estimated that heavy flood in September 2019 would be equivalent to once in 50 years scale from local interviews. Due to such heavy flood, several collapses of the channel slope, sedimentation in the channel, and damage to the Hume concrete pipe at the most downstream point occurred. In order to restore the drainage function and leaching effect, it is necessary to repair them urgently.

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