Research article

Development of a Biological Salt Utilization System for Management of Salt-affected Agricultural Fields in Khon Kaen, Thailand

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Received 28 December 2023 Accepted 31 October 2024 (*Corresponding Author)

Abstract Approximately 1.5 million hectares (ha) of agricultural land across the world are salinized each year. Khon Kaen province in northeast Thailand, is located in the low-lying Korat Plain where famous for its soil salinization problem. The Ban Phai district in Khon Kaen province was selected as the study site, related to its challenges managing salinized soil which has failed to improve. In Ban Phai, the average farmer's landholding is approximately 2-4 ha. The farmland parcels are not well developed, and the flat topographical slope makes it difficult to construct a network of drainage channels to facilitate salt removal. In this study, we developed a biological salt utilization system that promotes salt management and utilization within each farmer's farmland, without reliance on drainage channel networks. The system was implemented in June 2019, and data was obtained related to soil salinization and farmers' cash income including the sale of salt removed in traditional salt production and in cultivating and selling *Sesbania rostrata,* a salt-tolerant crop. Three years after the system was installed, the electrical conductivity of the soil decreased from 1,403 mS/m to 991 mS/m. It was also evident that the use of vermicompost improved the growth of *Sesbania rostrata* compared to conventional cultivation. The system's downstream component of traditional salt production using discharged salt, was effective with produced salt sold for approximately 20 baht per kilogram, which contributed to improved cash income for farmers. To promote this system, it is necessary to identify applicable land conditions including soil, hydrology, salinity, and related and to demonstrate the economic benefits to farmers.

Keywords soil salinization, drainage, salt utilization, vermicompost, salt-tolerant crops, traditional salt production

INTRODUCTION

Multiple soil salinization studies in agricultural fields have been conducted including measurement of soil salinity, appropriate irrigation and drainage methods (Tanji and Yaron, 1994), improvement of saline soils (Chhabra, 1996), wide area mapping of saline fields by satellite remote sensing (Metternicht, 2003), and saline soils management methods (Vargas et al., 2018). The current main research in the San Joaquin Valley (SJV), California State, USA, is wastewater management and quantitative load reduction and drain water reuse (Chang and Silva, 2014). Despite these many studies, saline soil remains throughout the world with a further loss of 1.5 million ha per year.

The Ban Phai district in Khon Kaen province, the selected study site, includes a large area of salt-affected farmland (Aung et al., 2013). Local farmers in the district own farmland with an average size of approximately 2 to 4 ha. The farmland parcels are not well developed, they are not dependent on drainage channel networks, and the flat topographic slope makes it difficult to construct drainage networks that would facilitate salt removal, all of which result in a large amount of salt-affected farmland. Due to the topographical problems and the cost of constructing drainage channel networks, it is considered necessary and beneficial to conduct research on the use of farmland desalinization with the aid of a system in which salts are removed in a cascade-type (Fujiwara, 2012), step-by-step manner. Thus, in this study, we developed and implemented a cascade-type system including a biological salt utilization system consisting primarily of salt removal through leaching and drainage channels within the field that are not drainage network, cultivation of salt-tolerant crops with different treatments, and traditional salt production. The most significant difference between conventional salt management and this method is the use of salt in saline soils as a resource for traditional salt production in the Khon Kaen province.

OBJECTIVE

The objectives of this study are to apply biological salt utilization systems in the field and to determine 1) the effect of drainage improvement on salt removal from soil layers, 2) differences in growth of salt-tolerant crop cultivars due to various treatments, and 3) traditional salt production methods and market prices.

METHODOLOGY

Location of Research Field and Outline of the Biological Salt Utilization System

The study was conducted in a 0.6ha research field in Ban Phai District, Khon Kaen Province, Thailand, where the soil and shallow groundwater are salinized (i.e., groundwater EC ranged from 8.4 to 35.2 dS/m). The source of salt in this area is halite found in the Mahasarakham Formation, which generally occurs at depths of 200 m and is exposed at or near the surface due to the angle of dip of the strata or by development of salt domes (Wongsomsak, 1986). The biological salt utilization system consists of a reservoir, drainage channels, and an evaporation pond (Fig.1). The system promotes drainage from upstream to downstream for salt removal and cultivation of sesbania (*Sesbania rostrata*), a moderately sensitive to the salts for the yield (Tanji and Kielen, 2002), and salt production is carried out using the highly saline wastewater removed at the downstream end of the system. To reduce soil salinity, drainage channel and ditches, as shown in Fig. 1, were excavated during April and May of 2019. Salt is discharged from upstream to downstream, and table salt is produced by traditional methods using concentrated brine at the evaporation pond. Reservoir water is used to grow sesbania. In this way, the system aims to increase the cash income of farmers through salt

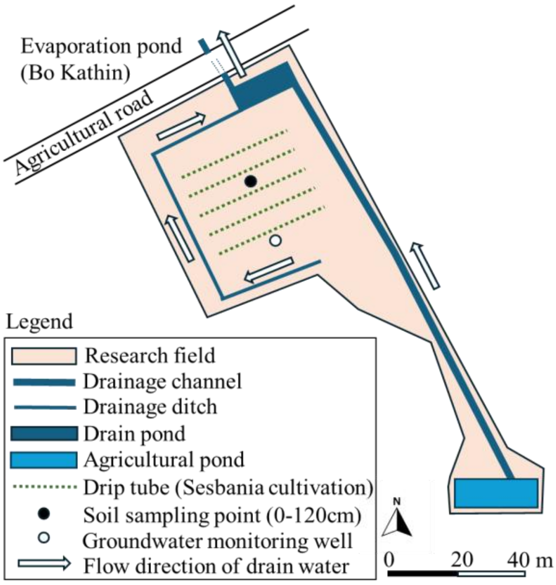

Fig. 1 Outline of the research field for the Biological Salt Utilization System

removal by drainage channels, salt production using the removed salt, and cultivation of salt-tolerant crops.

Field Observation and Measurement Data

Before and after excavation of the drainage channels, indirect soil electrical conductivity (EC_a) measurements using EM38 and $EC_{1:5}$, pH measurements with soil samples, as well as cation and anion concentration measurements of extracted solutions were performed using ion chromatography. The EC_a values were analyzed using QGIS together with the x-y coordinates from GPS to map the spatial distribution. Contour maps of EC_a were created by the Inverse Distance Weighting (IDW) method. Precipitation was measured with a tipping basin rain gauge, and groundwater depth was measured with a pressure water level gauge. Crop height was measured for different soil treatments during crop cultivation from November 2019 to January 2020. The traditional salt production method in the area was investigated, and the sales price of salt was determined through interviews.

RESULTS AND DISCUSSION

Effect of Drainage Channels on $EC_{1:5}$ and pH Changes in Soil Profiles

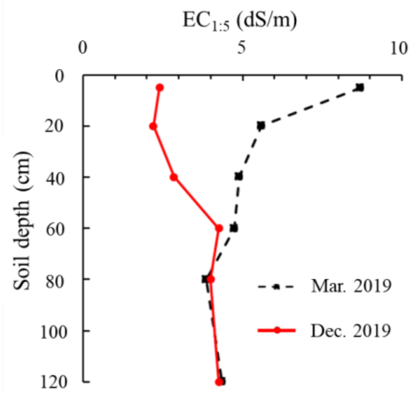

Fig. 2 Changes in $EC_{1:5}$ before and after the excavation of drainage channel

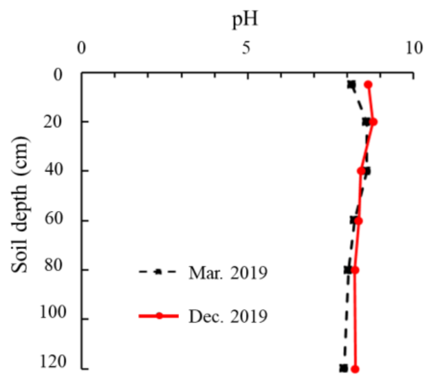

Fig. 3 Changes in pH before and after the excavation of drainage channel

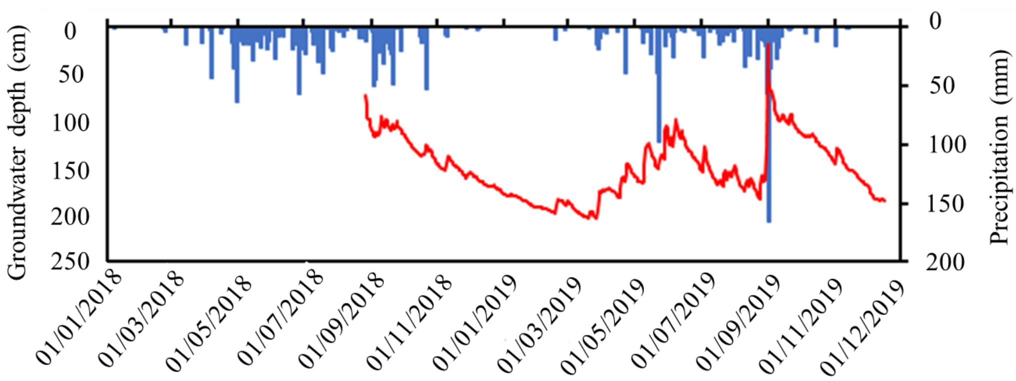

Fig. 4 Data of groundwater depth (red line) and precipitation (blue bar) from January 2018 to December 2019 in the research field

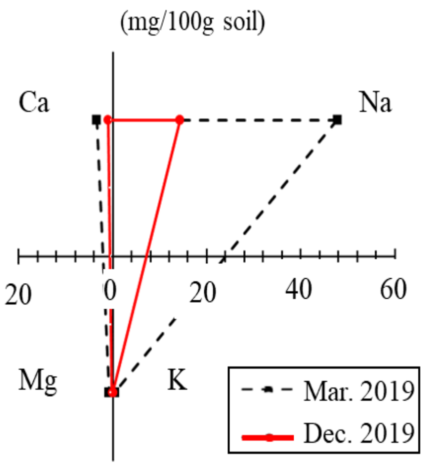

Fig. 5 Changes in cations before and after the excavation of drainage

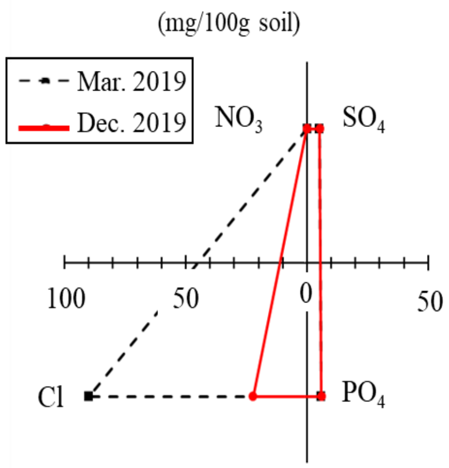

Fig. 6 Changes in anions before and after the excavation of drainage channel

The $EC_{1:5}$ of the soil decreased from the surface to a depth of 40 cm in December 2019 compared to March 2019. In particular, the soil surface $EC_{1:5}$ decreased from 8.6 dS/m to 2.4 dS/m, as shown in Fig.2. No difference was found in soil pH during the period (Fig.3). The reason for the decrease in $EC_{1:5}$ in the surface layer is attributed to the heavy rainfall in September 2019, shown in Fig. 4, which washed away salts of the surface layer. The decrease in $EC_{1:5}$ from the surface to a depth of 40 cm may be due to the leaching and drainage of salt facilitated by the heavy rainfall and excavation of drainage channels in the same September 2019. The slope of the groundwater decline from September 2018 to May 2019 was smaller than after the drainage channel was excavated. However, after the excavation of drainage channels, the slope of the

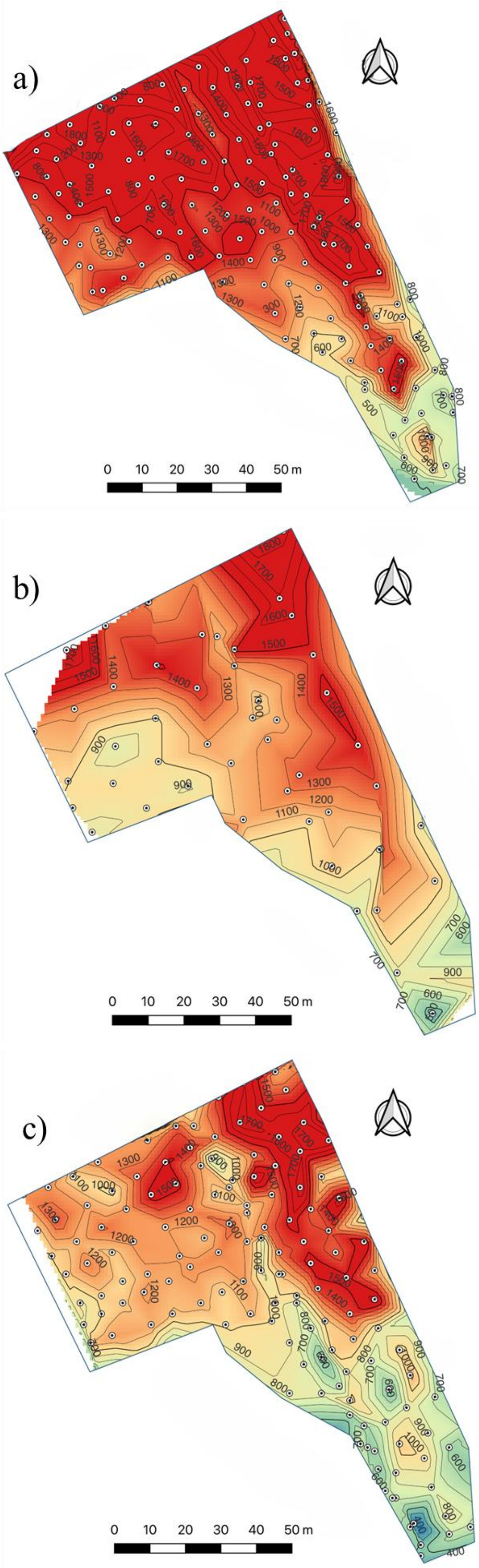

Fig. 7 Spatial distribution of EC_a at the research field in a) August 2018, b) August 2019 and c) August 2021

groundwater decline became steeper after rainfall, indicating that drainage channels are functioning.

Composition of Soluble salts in Soil

Water-soluble salts in this field were mainly NaCl, which was dissolved in rainfall water and ionized and discharged from the soil layer into the drainage channels. As shown in Fig. 5 and Fig. 6, the soluble Na and Cl contents in the soil were much lower in December (2019) than in March (2019). Soil pH showed almost the same values (Fig. 3). This is thought to be because most of the water-soluble salts are NaCl, which has low adsorption to the soil, but Ca^{2+} and Mg^{2+} might be adsorbed to the soil in large amounts as exchangeable cations.

Changes in Spatial Distribution of EC_a

The results of the spatial distribution of EC_a values in the field decreased as shown in Fig.7 in September 2019 and October 2021 compared to August 2018. The same results in dry season were shown after drainage channel excavation (Nohara et al., 2020). The mean values of EC_a at the three time periods, August 2018, August 2019 and August 2021, shown in the figure are 1,403 mS/m (SD = 376), 1,154 mS/m (SD = 311) and 991 mS//m (SD = 395), respectively, indicating that EC_a values have decreased since June 2019, after two months of drainage channel excavation. EC_a in 2018 showed an almost general trend of higher EC_a, with the exception of some areas upstream of the drainage channel. In contrast, in 2019 and 2021, EC_a showed a distribution of higher EC_a from the left side of the figure with the drainage ditch to the drainage channel. In particular, in 2021, there was a large decrease in salinity from upstream to midstream of the drainage channel. This may be a result of rainfall in the rainy season (June through September) and improved drainage promoting salt removal, as well as $EC_{1:5}$ values from soil samples shown in Fig.3.

Effect of Various Treatments on Crop Growth in Saline Soils

Figure 8 shows the height of sesbania cultivated in the study field and the changes in salinity in each treatment (Fig. 9) (T1: Control =No treatment, T2: Vermicompost (Pengkam et al., 2019), T3: Coconut coir, T4: Biochar from rice husk, T5: T2+T3+T4 (1:1:1)). Soil salinity was high on November 23 at sites T1 and T2 and on December 7 at site T1, and low on January 26 at site T2. The values at T5 were always higher than the others during the growing period. Sesbania growth was tallest at T2 when grown with Vermicompost. Next was T5 with three soil amendments. Coconut core and rice husk biochar were applied at T3 and T4, followed by the lowest sesbania height values at T1, which was grown in saline soil only. These results indicate that sesbania cultivation in the study field showed the best growth in the treatment plot with Vermicompost. However, we need to be careful to note the growth of T5 sesbania grown at sites with the highest soil salinity. The height of sesbania at T2 was 38.8 cm and at T5 was 35.0 cm on December 28, 2019. If T2 and T5 had the same salinity, sesbania might have grown better in T5 than in T2.

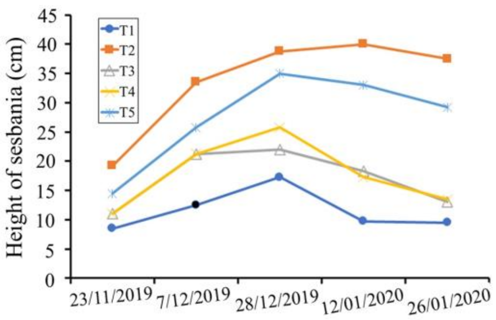

Fig. 8 Plant height in each plot with five different treatments

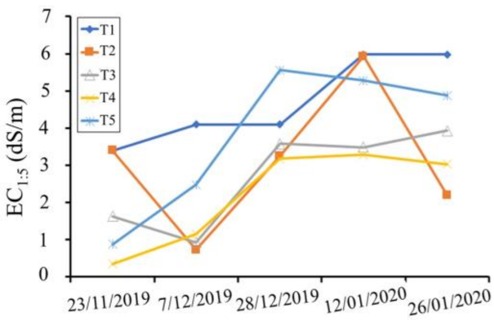

Fig. 9 $EC_{1:5}$ in each plot with five different treatments

Traditional Salt Production at the Evaporation Pond

The traditional salt production process is as follows; 1) collect high-salinity surface soil, 2) place the soil in a mud boat using straw as a filter, 3) pour high-salinity groundwater over the mud boat to wash out soil salt and extract brine with increased concentration, 4) pour the extracted brine in an iron pan and set over a fire to evaporate the water to obtain salt. The water evaporates to obtain salt. Salt is produced through these manual processes. The salt is then distributed and sold at local markets or wholesale to middlemen. Currently, salt is sold by producers to middlemen at 20 baht per kilogram. Production depends on the time of year and the farmer's situation, but between December and April, more than 1,000 kg can be produced. This is an important means of cash income for farmers. The salt produced is also used in the production of food and bath salts. The application of the former king Bhumibol's new theory (The Chaipattana Foundation, 2017) may be more acceptable to farmers as a way to secure land to realize salt production, and it may work well if the land owned by farmers is divided into a certain ratio of reservoirs, agricultural field, and salt-affected field for salt production.

CONCLUSION

This study is an empirical study to develop a biological salt utilization system that promotes salt removal from salinized field while cultivating salt-tolerant crops and using high-salinity groundwater and soil to produce salt in the downstream areas where salt is discharged. The systematization and implementation of salt removal, salt-tolerant crop cultivation, and salt production on farmland owned by farmers has proven to be an opportunity for farmers to earn cash in salinized fields, which had previously been considered barren.

ACKNOWLEDGEMENTS

This research was supported by the JSPS Grant-in-Aid for Scientific Research (21H0369). The authors would like to acknowledge the support from LDD Khon Kaen branch.

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