Chapter 1
Applying Rice Husk Biochar to Revitalise Saline Sodic Soil in Khorat Plateau Area – A Case Study for Food Security Purposes

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Abstract Salt-affected soils occur in the areas where excess dissolved mineral salts accumulate in the root zone that crop yields are adversely affected from the salts released by weathering of rock or those initially present in the soil-forming materials. In addition, evaporation and transpiration processes, due to high temperatures and droughts, can cause salt movement with capillary action inducing its accumulation in surface soil. Excess amounts of salts cause adverse effects on the physical and chemical properties of soil, microbiological processes and food security. Biochar produced from rice husk (RH) under the pyrolysis condition (400–500 °C) from a retort designed to produce laboratory quality biochar that is easy for farmers to use in order to promote self- sustaining biochar production. This study aimed to explore the use of rice husk biochar as a soil amendment in order to solve the salt-affected soil problems. The study area was Bung O sub- district, Kham Thale So district where the critical of salt-affected soil and drought area in Nakhon Ratchasima, Thailand. The results indicated that adding RH biochar with organic fertilizer into soil can improve both physical and chemical properties in every parameter. Particularly, the soil became less alkalinity. The results also showed an increased ion exchange capacity, higher amount of major and minor soil nutrients and the reduced amount of all sodium in the soil in every parameter. This included the absorption rate of sodium in the soil, the conductance of the soil, all of the amount of sodium in the soil, and the increasing amount of exchangeable magnesium and the amount of exchangeable calcium. The two elements contained positive ions which could replace the sodium ions in the salty soil making the soil less salty.

Keywords Salt-affected soil · Saline sodic soil · Biochar · Rice husk · Food security purposes

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1.1 Introduction

Salt-affected soils become one of the global issues that adversely affect soil resources in various areas (Martinez-Beltran and Manzur 2005). Even though saline soils occur naturally on Earth's crust (Rengasamy 2006) human activities and inappropriate land use have contributed to the acceleration of the saline soil problems both in terms of its severity and an expansion of the affected areas (Shahbaz and Ashraf 2013; Brinck and Frost 2009; Martinez-Beltran and Manzur 2005; Metternicht and Zinck 2003). The human activities included overgrazing, the use of chemical fertilizers and deforestation (Lakhdar et al. 2009). Climate change and soil degradation problems contribute to an expansion of soil salinity. The adverse impact in the next 25 years is expected to be 30% loss of land (Wang et al. 2003). For agricultural countries, these problems possess significant threats to agriculture, land use and food security especially in rural farming areas. High salt concentration negatively affects soil microbial activities as well as soil chemical and physical properties causing a decline in soil productivity (Amini et al. 2015; Wong et al. 2009; Yuwaniyama 2004). Moreover, salt- affected soil also causes physiological drought and its expansion to nearby areas also negatively affects the ecosystems and resource utilization. Soil salinization is complex and highly interrelated with specific conditions in the area.

In general, salt- affected soil mostly occurs in arid and semiarid regions of the world. Despite its location in the tropics, Thailand has long been suffering from salt- affected soil due to physical characteristics of the location. In recent years, the problems have become more severe and the surrounding environment and the people's quality of life are affected. The north-eastern part of Thailand (14° 14′ to 18° 27′ N and 101° 0′ and 105° 35′ E) is a vast area covering 1700,000 sq km, of which 17% is salt affected soil area with different levels of concentration. The majority of the areas are located in Nakhon Ratchasima province, especially in Kham Thale So district where the impacts are severe that patches of salt stains are visible on the surface (Wijitkosum 2018). Isaan Catchment Hydrogeological and Agricultural model was used to predict that, without an appropriate management plan for salt-affected soil in the Kham Thale So area, the severity of the problems and the distribution of salt-affected soil areas would increase by 21% in the next 30 years (Yuwaniyama 2004).

There are many possible solutions to mitigate soil salinity problems including physical, chemical and biological methods. The biological solutions are such as using salt tolerant plants (Grover et al. 2003; Manchanda and Garg 2008; Schubert et al. 2009), cover cropping, planting soil enhancement plants, shifting the crop calendars (Venkateswarlu and Shanker 2009) or mixing the saline soil with soil amelioration substances such as cow manure or chemical fertilizers (Qadir and Oster 2002). Using soil amelioration substances, either natural or chemical, is the most popular method among farmers. This method allows the soil amelioration and the agricultural processes to proceed simultaneously. However, using chemical substance for soil amelioration is a costly method and may lead to long-term effects on the ecosystem (Qadir and Oster 2002). Therefore, using environmental friendly soil amelioration substance is a more sustainable choice as it is beneficial to the ecosystem as well as farmers'quality of life (Venkateswarlu and Shanker 2009; Chaganti et al. 2015; Sun et al. 2016).

Biochar, a carbonaceous organic material, is a soil ameliorating substance that can be obtained from various types of biomass. The types of biomass or raw materials and the pyrolysis process play significant roles in the final products as the biochar's characteristics are highly depending on the types of raw materials and the pyrolysis processes it was obtained from (Sriburi and Wijitkosum 2016; Lehmann and Joseph 2009; Sohi et al. 2009; Yamato et al. 2006). This exclusive characteristic allows biochar researchers to design and produce the substance to best suit specific agricultural purposes. Furthermore, biochar has been widely researched and accepted as an efficient soil amendment substance that improves soil quality in various conditions including acid soils (Martinsen et al. 2015; Obia et al. 2015; Slavich et al. 2013; Yuan et al. 2011; Chan et al. 2007; Lehmann et al. 2003; Glaser et al. 2002), hard soils (Herath et al. 2013; Uzoma et al. 2011; Laird et al. 2010), infertile soils (Wijitkosum and Kallayasiri 2015; Rajakovich et al. 2012; Laird et al. 2010), sandy soil (Uzoma et al. 2011), alkaline soil (Sun et al. 2016; Abrishamkesh et al. 2015; Wu et al. 2014) as well as preventing soil erosion (Wang and Xu 2013; Chaganti et al. 2015). However, studies on salt-affected soils are limited to laboratory research or in column study (ex. Schultz et al. 2017; Chaganti et al. 2015; Wu et al. 2014) but not in field research. There is some research found that biochar is like organic matter that can effectively reduce the absorption of crops to Na^+ and reduce the salinity stress to crops (Thomas et al. 2013, Yang et al. 2014). There are a limited number of reports describing the effects of biochar on rice grown in saline-sodic paddy soil. Moreover, biochar research in Thailand and the effects of biochar on salted soil is still scant. This study aims to explore the use of biochar as a soil amendment in order to solve the salt- affected soil problems. Biochar used in this study was obtained from a retort designed to produce laboratory quality biochar that is easy for farmers to use in order to promote self-sustaining biochar production.

1.2 Salt Layers Underneath the Khorat Plateau: The Source of Salt Affected Soil in Nakhon Ratchasima Province

Beneath the Khorat Plateau lies multilayers of various clastic sedimentary rocks in the Khorat group including conglomerate, sandstone, siltstone, shale and mudstone (Division of Mineral Resources Conservation and Management 2015). As for Maha Sarakham formation, the layers of rock salt underneath the soil surface contributes directly to the saline soil on the top surface. The formation covers approximately 34.18% of the whole region (Department of Mineral Resource 1982; Thai- Australia Tung Kula Ronghai Project 1983). Moreover, the depths of rock salts differ from one area to another. In some areas, the depths can exceed hundreds of meters or only

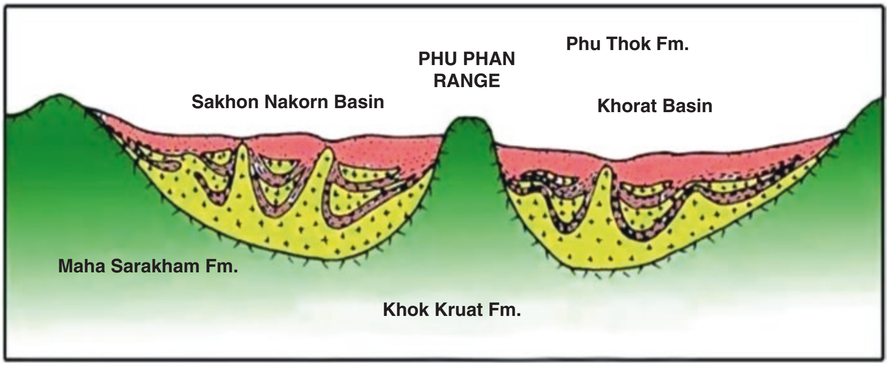


Fig. 1.1 Salt-affected areas in the north-eastern part of the country and its natural geographical cause. (Source Suwanich 1986)
A model showing the elevated Phu Phan Range that divides north-eastern part of Thailand into Sakhon Nakorn Basin and Khorat Basin resulting curved underground salt layers. These salt layers emerged near the surface causing salt-affected soils in the region

up to 20–25 m deep in Nakhon Ratchasima. The rock salts located closer to the surface affect evaporation and brings saline solution up to the surface through the capillary force (Fig. 1.1).

The dissolution of rock salts and its dispersion in groundwater are the main causes of salt-affected soil problems in Nakhon Ratchasima. Moreover, necessary shortcuts and catalysts are crucial for the saline soil to widely spread over the plateau. Salt domes act as shortcuts that allow the source of salt to emerge closer to the surface while faults act as pathways to facilitate the upward movement of saline groundwater (Fig. 1.1). Being dissolved by the groundwater, capillary force in the formerly salt domes acts as a catalyst to pull the brine to the surface against the gravity. At this point, water evaporates from the soils and only salt remains. This process happens continuously in dry weather conditions where the groundwater table is less than four feet and the top soil is sandy (Division of Mineral Resources Conservation and Management 2015).

Research indicated that the altitude of the area influences the level of ground water that contributed to the distribution of salt-affected soil in the area. The concentration of salinity was varied depending on soil horizon (Kovda et al. 1973) and seasons (Blaylock 1994). The level of saltiness was varied greatly (Leksungnoen 2006) and was influenced by the saltiness of ground water (Japan International Cooperation Agency 1991). Moreover, heavy deforestation in the past and land use changes had direct impacts on the distribution of salt- affected soil (Williamson et al. 1989). In monsoon seasons, the salt stains washed off and retained in the soil. However, in dry season or in draught period, the water retained in the soil will evaporate and make the salt stains visible on the surface (Yuvaniyama 2003; Manchanda and Garg 2008). In this relatively dry area the farmers faced severe water scarcity problems during the dry season and lost a considerable amount of production land due to soil salinization.

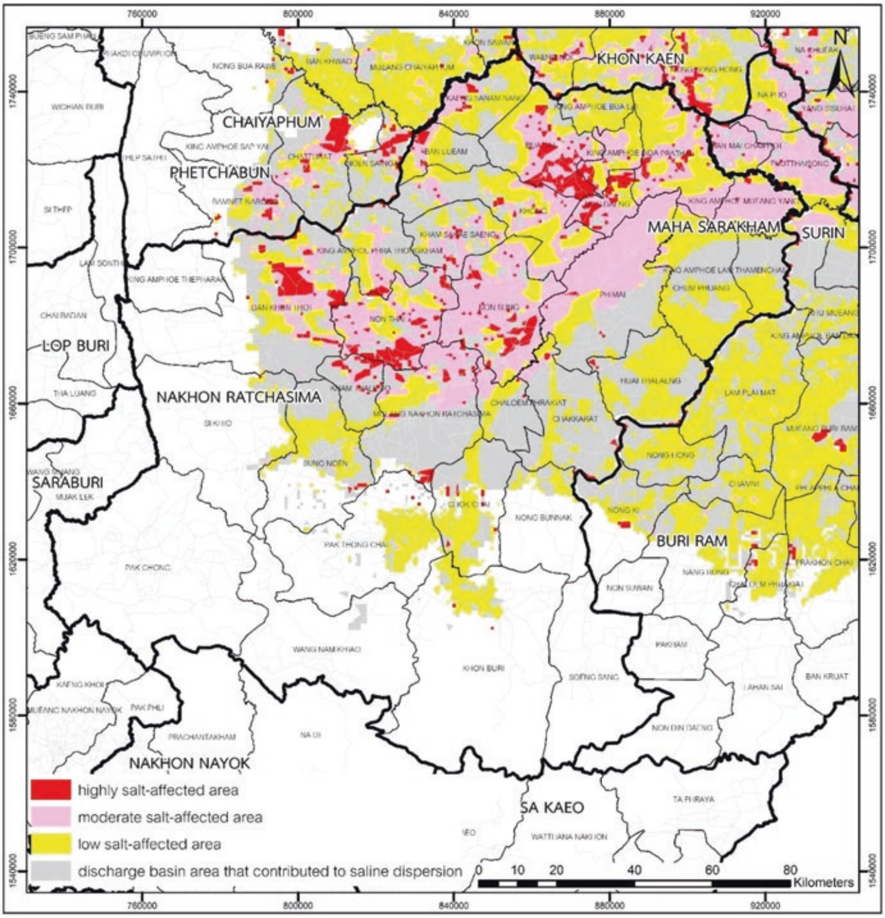


Fig. 1.2 A map showing saline-affected areas in Nakhon Ratchasima province

Nakhon Ratchasima province covers an area of approximately 20,493.96 sq km. 92.13% of Nakhon Ratchasima is land area and only 38.86% of the area is not affected by salt deposits. The saline soil area comprises lowland area (53.33%), high land area (46.66%) and salt farms (0.02%). Four different concentration levels of salt were found scattered in the lowland area: low level (less than 1% of salt stains), moderate level (1–10%), high level (10–50%) and heavy level (more than 50%). The majority of the area was affected at a low level (30.33%), followed by a moderate level (20.42%), a high level (1.61%) and a heavy level (0.97%) (Fig. 1.2). However, Nakhon Ratchasima possesses the largest salt-affected areas and suffers the most from the problems in comparison to the whole north-eastern region. The salt- affected area in Nakhon Ratchasima covers 4809.58 sq km and 5866.48 sq km is prone to saline distribution. Of all affected area, 2.33% suffered salinity at an extreme, 3.85% at a high level, 49.02% at a moderate level and 44.79% suffered a mild level. Moreover, 3.75% of the total area is uncultivable. Moderate to fair saline- affected areas, where rice was cultivated, were 15.63% and discharge basin area that contributed to saline dispersion was 17.19%.

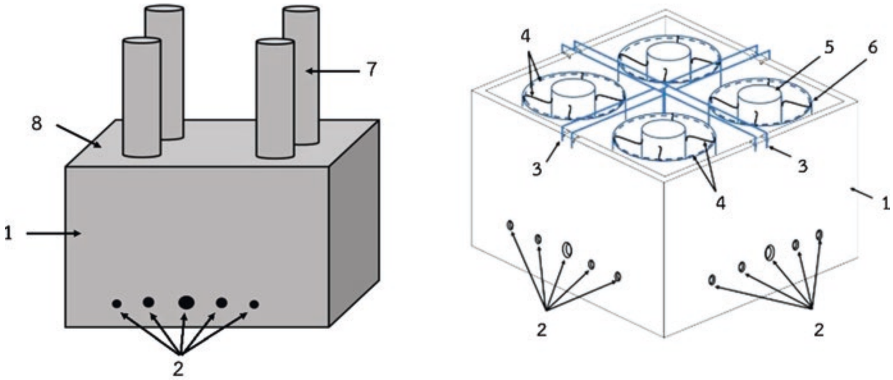
Nakhon Ratchasima province was severely affected by salinization that patches of salt stains were visible on the surface. The rapid dispersion of saline soil had compromised quality of life for many people and caused many problems to the province's economy, society and environment.

1.3 The Production of Rice Husk Biochar and Its Properties

The biochar used in this study was rice husk biochar (RH biochar) obtained from paddy husks that were locally available in the area. The paddy husks were produced into biochar using the slow pyrolysis process in a 4 × 200 litters Retort for Rice Husk Biochar Production (patent number: 1601001281) at a controlled temperature between 400–500 degree Celsius (Fig. 1.3). The temperature was at an appropriate range for producing biochar according to the Food and Agriculture Organization of the United Nations (FAO 2009). The retort is cost- efficient and can be built easily using locally available materials and in addition can use locally available biomass as feedstock.

The biochar sampling method used in this study was adapted from the Standardized Product Definition and Product Testing Guidelines for Biochar that is used in Soil (IBI 2014). The samples were randomly selected from ground biochar and analyzed for specific characteristics including surface area, total pore volume and average pore diameter using the Brunauer- Emmett- Teller method of analysis of the nitrogen adsorption isotherms. Moreover, pH (pH meter with 1:2 (v/v) char: water), electrical conductivity (EC; EC meter with 1:5 (v/v) char: water), cation exchange capacity (CEC; leaching method), organic matter (OM; Walkley and Black method), total carbon (total C; Shimadzu TOC Tcvh), total nitrogen (total N; Kjeldahl method), phosphorus (P_2O_5; Vanadomolybdophosphoric acid colorimetric method), potassium (K_2O; AAS) and water holding capacity (WHC) were analysed. The carbon (C), hydrogen (H), nitrogen (N) and sulfur (S) atom contents (wt.%) were measured using a Carbon, Hydrogen Nitrogen and Sulfur/ Oxygen Analyzer (Leco CHN628 model).

According to the physical and chemical analysis of RH biochar, the results indicated a specific surface area of 41.43 m^2/g and total pore volume of 0.034 cm^3/g. The results were higher than those of the feedstock (rice husk) that had 2.06 m^2/g of specific surface area and 0.0038 cm^3/g of total pore volume. The majority of RH biochar composites were cellulose, hemicellulose and lignin. Moreover, the RH biochar had many pores in the structure (Fig. 1.4 bottom left and bottom right) which showed an average pore diameter of 32.73 Å. The X-ray elemental mapping with a magnification of 1000× revealed that biochar contained various elements on its surface. The proportion of oxygen was the highest followed by silicon, phosphorus, potassium and magnesium, respectively. The main elements on the surface of



a. Model of the rice husk biochar retort (outside)

b. Model of the rice husk biochar retort (inside)

1 Outside concrete retort

2 Air intake holes

3 Outside removable steel lid support rebar

4 Heat exchanger support

5 Heat exchangers

6 200 litter steel drum

7 Smoke chimney

8 Outside removable steel lid

Fig. 1.3 The 4 × 200 litters Retort for Rice Husk Biochar Production (patent number: 1601001281) at a controlled temperature

RH biochar were oxygen (44%) and silica (20%). Nwajiaku et al. (2018a) and Mahmoud et al. (2011) found that silicon increased with an increase in pyrolysis temperature which was a result of the change in the form of silica relative to the time of charring. It is reported that the amorphous form of silica changed into crystalline form when heat was applied (Todkar et al. 2016; Parry and Smithson 1964; Nwajiaku et al. 2018b).

This study concluded that the two elements on the surface were in the form of silicon dioxide (SiO_2), which was consistent with a study conducted by Nwajiaku et al. (2018a), Mahmoud et al. (2011) and Mansaray and Ghaly (1997) who studied elements of rice husk in oxide forms. The study indicated that SiO_2 was the major element, accounting for more than 90%, along with other elements existing in oxide forms such as K_2O, P_2O_5 and MgO. The result was in accordance with the analysis conducted by Scanning Electron Microscope and Energy Dispersive X-ray Spectrometer (SEM-EDS (IT300)) that nutrients such as potassium, phosphorus and magnesium were crucial for crop growth. Therefore, this study concluded that RH biochar was an effective accelerator of crop growth.

RH biochar had weak alkalinity (pH 7.9), EC of 0.35 dS/m and CEC of 17.34 cmol/kg. The results from Elemental Analyzer (CHNS) indicated that RH biochar's composites comprised 45.68 wt% C, 0.93 wt% N and 2.22 wt% H. Its H/C molar was 0.27 and C/N molar was 49.50, which reflected the stability of the biochar (IBI

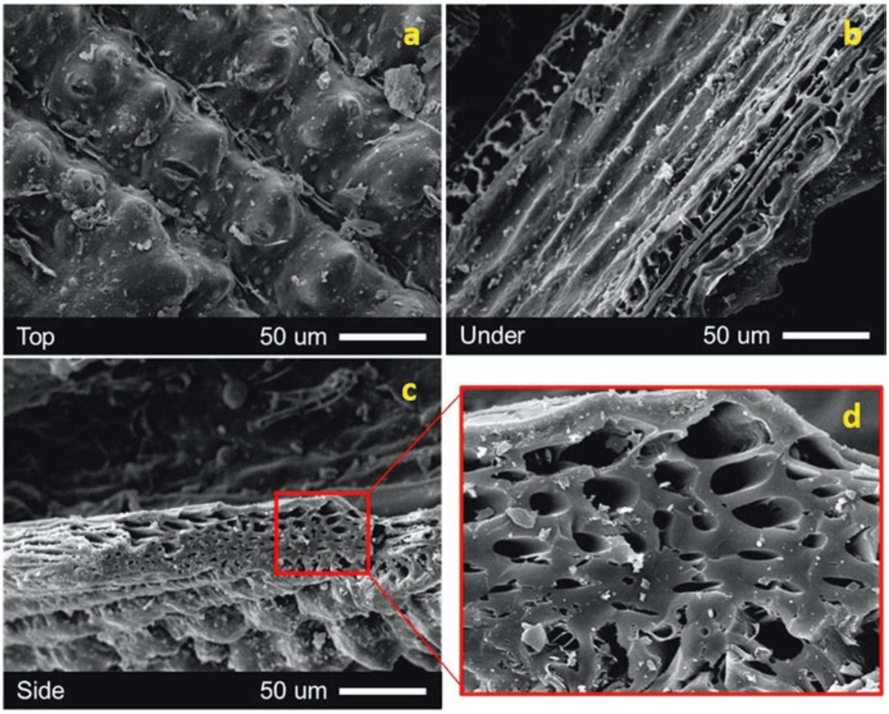


Fig. 1.4 Physical characteristics of rice husk biochar from multipoint BET method and scanning electron microscopy (SEM) at a magnification of 500× (**a** and **b**) and the porous structure of rice husk biochar (**c** and **d**)

2015; Downie et al. 2009; Lehmann et al. 2009). This property made the carbon in RH biochar very stable (Kim et al. 2012; Sohi et al. 2009; Downie et al. 2009), created a highly porous carbon structure (Chen et al. 2012; Sohi et al. 2009) which made it suitable for use as a soil amendment and soil carbon storage. In terms of its nutritional value, RH biochar had macro-nutrients: total N content of 0.51%, with Total P_2O_5 of 0.29% and K_2O of 1.02 wt.%. Moreover, RH biochar also had a high OM (13.06 wt%), which contributed to an increased OM level in the soil and improved the soil fertility. The pyrolysis of RH biochar at an appropriate temperature (400–500 °C) also increased the porosity on biochar's surface which led to an increased number of ions on its surface (Sohi et al. 2009; Sun et al. 2014). This study concluded that RH biochar produced from the retort had superior physical characteristic, which was consistent with a study of Mathurasa and Damrongsiri (2017) who found that pyrolysis of rice husks at 500 °C for 2 h increased its surface area, total pore volume, pore diameter, and CEC value of the biochar product. The surface of RHB had a greater fraction of silica than of the unprocessed rice husk. As a result, the RH biochar had high capacity to adsorb and retain organic carbon and non- organic matters within the soil. In addition, it also contributed to nutrient adsorption or covalent interaction on a large surface area (Schmidt and Noack 2000;

Amonette and Joseph 2009; Downie et al. 2009; Atkinson et al. 2010; Wijitkosum and Kallayasiri 2015). This helped with aeration and reduced soil density (Jones et al. 2010; Bhogal et al. 2009; Novak et al. 2009; Hati et al. 2007). Before applying RH biochar, the biochar was soaked in liquid fertilizer for three minutes and was left to dry on the grille. Liquid fertilizer was alkaline (pH 6.8), with EC of 0.82 dS/m, OM of 0.02 wt.%, total K of 0.04 wt.%, total N of 20.16 mg/ L and total P of 44.07 mg/L. RH biochar soaked in the liquid fertilizer yielded in even more alkalinity (pH 8.9), higher EC of 0.49 dS/m, higher specific surface area (98.49 m^2/g) and higher total pore volume (0.069 m^3/g). The structure of RH biochar showed an average pore diameter of 28.17 Å, with water holding capacity of 138.30%. Due to its large surface area and high porosity, biochar is able to adsorb and retain nutrients from the liquid fertilizer. This resulted in higher nutrient contents and a better structure as a soil amelioration substance. Biochar characteristics after being soaked in the liquid fertilizer contained 0.54% of total N, 0.35% of total P_2O_5, 1.10% of total K_2O and 7.78% of silicon.

1.4 Using Biochar as a Soil Amendment for Salt-Affected Soil: A Pilot Study in Kham Thale So District, Nakhon Ratchasima Province

The study area is located in Bung O sub- district, Kham Thale So district, Nakhon Ratchasima province. The study area covers approximately 203.60 sq km (14°57′ 39″ N101°56′ 51″ E). The area is inclined from the west towards the east and its altitude is 178–247 m above mean sea level. The soil is sandy soil and loamy sand of low fertility and high permeability (Fig. 1.5). The three most affected areas in Kham Thale So are Phan Dung, Nong Sruang and Bung O sub-districts which is the most affected area among the three. The study area is located in a plain area, far from natural water sources and with an annual average precipitation date of 54 days/year.

Soil analysis obtained from the study area indicated that the soil was strongly alkaline (pH 8.5–10.20) and electrical conductivity of the saturated extract (ECe) of 14.36–57.80 dS/m. The soil texture was loamy sand and silt loam with CEC of 2.40–6.20 cmol/kg. The soil had a very low level of primary macronutrients (total N of 17.50–297.50 mg/kg, available phosphorus (avail. P) of 2.00–17.00 mg/kg, and exchangeable potassium (exch. K) of 3.00–31.00 mg/kg and very low level of secondary macronutrients (exchangeable calcium (exch. Ca) of 1221.44–1279.63 mg/kg, and exchangeable magnesium (exch. Mg) of 22.50–23.22 mg/kg). The soil had very low fertility with 0.03–0.48% of OM. The results from the analysis of soil salinity parameters were: 0.03–0.54% of total sodium (total Na), 2425.50 mg/ kg of extractable sodium (extrac. Na), 283.60–4745.00 mg/kg of extractable chloride (extrac. Cl) and 34.35–1158 of Sodium Adsorption Ratio (SAR).

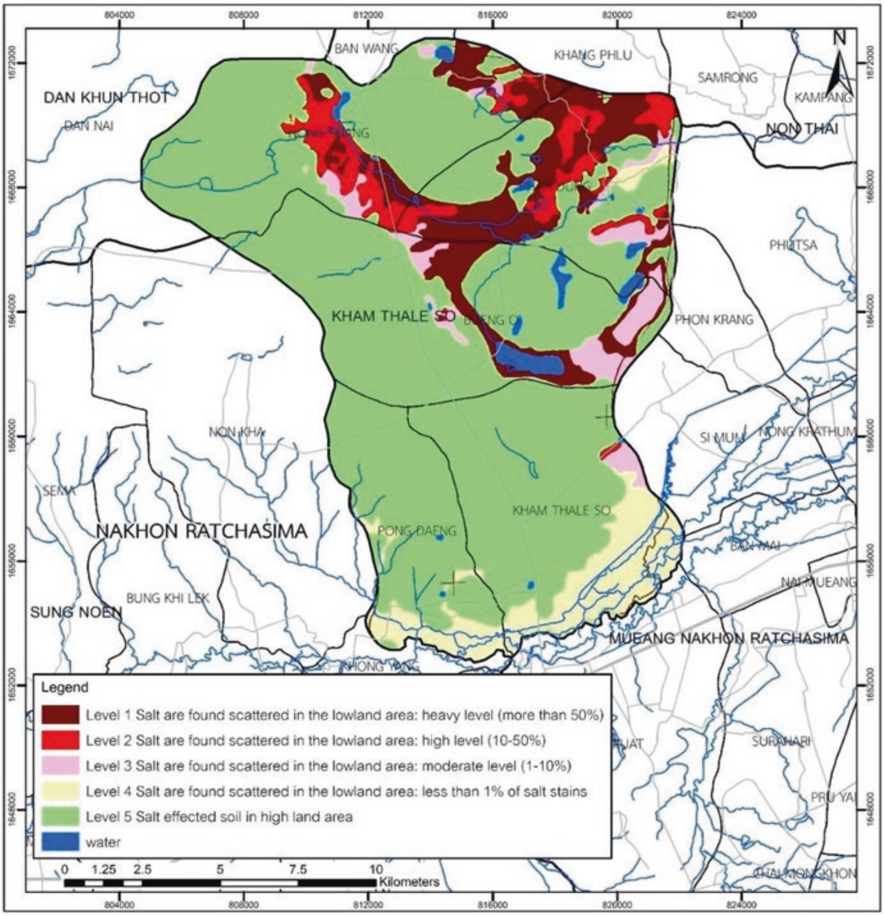


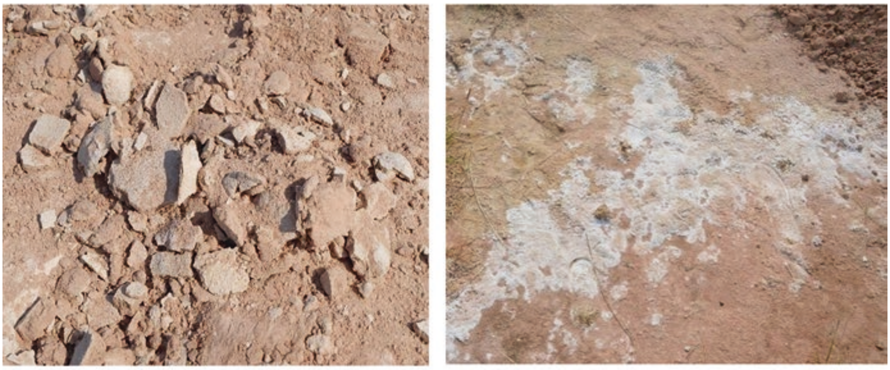
Fig. 1.5 The critical area affected by salt-affected soil in Kham Thale So, Nakhon Ratchasima

The soil properties indicated that the soil in the area was saline sodic soil. The soil analysis revealed both salinity and sodicity problems and characteristics of both types. The saline sodic soil was referred to the soil of which ECe of saturated paste extract was greater than 4 dS/m, its SAR was greater than 13, its exchangeable sodium percentage (ESP) was greater than 15 and its pH value was usually between 8.5 and 10. (U. S. Salinity Laboratory Staff 1954; FAO 1988; Richard 1954; Eynard et al. 2006; Hinrich et al. 2001; Rengasamy 2010).

Considering the ECe and SAR values to predict the quantity of salt and its impacts on plant growth, the results revealed that the soil in the pilot study area was of extremely high salinity. The soil was not suitable for regular plants but were suitable for halophytes or other plants with efficient salt-tolerance mechanisms (ECe greater than 16 dS/m) (El-Zanaty et al. 2006; Flowers et al. 1986). The high salinity made the area uncultivable and was left barren. There was no vegetative cover

Surface cracks from evaporation

Soil surface texture



Cracked and dusty top soil

Visible salt stains

Fig. 1.6 The pictures of saline sodic soils and salt stains

excepts halophytes and salt-tolerant plants (El-zanaty et al. 2006; Flower et al. 1986) such as Acacias ampliceps and Sesbania (Sesbania rostrate L.) rostrate that local farmers grew to battle soil salinity in the area.

The salinity and sodicity of the soil properties caused a declined vegetation growth (Chen et al. 2007; Mathur et al. 2006; Shi and Wang 2005; Raul et al. 2003) from salt toxicity (Bacilio et al. 2004; Munns 2005; Orcutt and Nilsen 2000), high osmotic suction (Kaymakanova et al. 2008; Sheldon et al. 2004), nutrient deficiency (Lakhdar et al. 2009; Yuwaniyama 2004), high pH, surface crust and degraded soil structure. A field survey revealed visible salt stains scattered on the soil surface and no vegetative cover was present. In relation to the findings, Wijitkosum (2018) also reported that the area in Kham Thale So district, Lam Ta Kong watershed was also critically affected by salinity, especially in the northern parts where dense salt crusts (>50%) were distributed widely on the soil surface (Fig. 1.6).

The salt-affected soil problems in Kham Thale So district were the results of groundwater flows that spread more saline water into the recharge area. This process accelerated the local flow system allowing more groundwater with rock salt solution to be brought up to the soil surface (Williamson et al. 1989; Yuwaniyama 2004). Moreover, Wijitkosum (2018) found that the study area was facing the highest risk of drought due to its location which was further from the water sources together with a very low precipitation volume of only 931 mm/year. Additionally, the salt- affected soil also caused physiological drought. The situation was at its peak during drought season when water evaporated from the soil leaving behind salt stains which appeared on the soil surface (Yuvaniyama 2003; Manchanda and Garg 2008). The expansion of saline soil to nearby areas also had an effect on ecosystems and resource utilization. These problems greatly and adversely affected agricultural areas.

1.5 Application of Rice Husk Biochar on Saline Sodic Soil in Rice Paddy Fields

In this study, soil samples in the experimental plots were collected both pre- cultivation and post- cultivation to analyse their physical and chemical characteristics including pH, soil texture, ECe, CEC, OM, total N, total Na, avail. P, exch. K, exch. Mg, exch. Ca and SAR. Soil in the experimental plots was classified as strongly alkaline loamy sand (%sand = 72, %silt = 20, %clay = 8) with a pH of 10.20 and CEC of 5.79 cmolc/kg. The salt-affected soils had a high value of ECe with 48.47 dS/m and SAR of 1158. It had a high concentration of dissolved mineral salt, exch. Mg of 22.50 mg/kg, exch. Ca of 1279.63 mg/kg and total Na of 0.329%. Moreover, the affected area had very low soil fertility with 0.103% of OM, 0.004% of total N, 14.50 mg/kg of exch. K and 3.88 mg/kg of avail. P. Based on their ECe, SAR and pH, the soil in the experimental plots was saline sodic soil. The study was a field experimental design aimed to explore the impacts of biochar as soil amelioration substance on the salt-affected areas under the influences of actual natural factors such as weather conditions, temperature and precipitation. The experimental plots located at UTM 193.051605–193.370087 and 196.0820153–200.17691. The study was carried out using randomized complete block design (RCBD). The size of each experimental plot was 3.0 m in width, 4.0 m in length and 0.3 m in depth. There were 20 experimental plots in total which were divided into five treatments, each with four replicates. The five treatment conditions included soil plus 1.25 kg/ sq m organic fertilizer for control untreated treatment (TM) representing regular farming activity. The other four treatments were soil plus 1.25 kg/sq m organic fertilizer with different amounts of added biochar at 2.0 kg/sq (T-MBR2), 3.0 kg/sq (T-MBR3), 4.0 kg/sq (T- MBR4) and 5.0 kg/sq (T-MBR5). There were two equal applications of organic fertilizer for all treatment: once at two weeks before rice planting and subsequently at booting stage.

The organic fertilizer was produced from the composting of soybean stems and its characteristics were in accordance with all the parameters the Organic Fertilizer Standard of the Thai Department of Agriculture in 2005. The characteristics of organic fertilizer were: pH 8.3, EC of 3.50 dS/m, 40.30 wt.% OM, 23.43 wt.% total organic carbon (TOC), 1.70 wt.% total N, 0.87 wt.% total P,3.54 wt.% total K and a 13.75 C/N ratio. Jasmine rice 105 (Oryza sativa L.), namely Khao Dawk Mali (KDML105) or Thai Hom Mali 105″, was planted in the experimental plots. After mixing the soils according to the given ratio, the treatments were left in the sun to dry for 14 days prior to adding water to each plot. Each plot was irrigated with 10 cm of water in depth. A day after irrigation, the rice was transplanted into the experimental plots.

1.6 Effects of RH Biochar on Physiochemical Properties of Saline Sodic Soil

After harvesting, the soil samples form all experimental plots were randomly selected in the amount of 1000 g/plot at a depth of 30 cm from soil surface. All soil samples were analyzed for physical and chemical properties. The results revealed changes in soil properties after applying RH biochar (Table 1.1). Soil pH decreased in every experimental plot to pH 9.50–9.80. The change of pH was not statistically significant in comparison with the soil before the cultivation. On the other hand, ECe was significantly decreased in all treatment relative to pre-treatment. ECe decreased in every treatment from 46.47 to 6.78–7.00 and the ECe values were higher in treatments without biochar (TM). The CEC value in all biochar- treated treatments showed statistically significant decreases in comparison with the pre-cultivation soil. The highest amount of biochar added (T-MBR5) had the highest CEC increase (8.34 cmol/kg). The soil fertility value rose in every treatment with biochar (0.180–0.260) and the result was statistically significant whereas the fertility values declined in all non- biochar treatments (0.060%). The OM value increased the most in the treatment with the highest amount of biochar. The primary macronutrients in soil underwent certain changes after the rice cultivation. In the treatment without biochar (TM), the total N value decreased to the point that it could no longer be measured. In the treatments with biochar, the total N values were maintained: 0.004% in T-MBR3 and 0.011% in T-MBR4 which was the highest increase in the total N value. The result from the T-MBR4 treatment was the only treatment that the increase of total N showed statistically significant difference (Table 1.1).

Moreover, avail. P and exch. K values increased in every treatment whereas avail. P and exch. K values were the lowest in TM treatments. In other words, there was 10.00 mg/kg of avail. P and 38.00 mg/kg of exch. K in treatment with organic fertilizer (TM). The avail. P value and exch. K value were the highest values in the T-MBR5 treatment with the highest volume of biochar (22.00 mg/kg and 191.00 mg/kg, respectively), of which the values of avail. P and exch. K increased by 5.67 and 13.17 times, respectively. As for the treatments with lowest volume of biochar (T-MBR2), the avail. P and exch. K values increased by 3.61 and 6.90 times, respectively. In the treatment without biochar (TM), the avail. P and exch. K values only

Table 1.1 Characteristics of the soil from pre- and post-treatments

Parameter	Units	Pre-treatment	Post-treatment				
			TM	T-MBR2	T-MBR3	T-MBR4	T-MBR5
pH	–	**10.20 ± 0.18**	9.80 ± 0.24^{a}	9.50 ± 0.57^{a}	9.70 ± 0.22^{a}	9.50 ± 0.51^{a}	9.60 ± 0.27^{a}
ECe	dS/m	**46.47 ± 21.97**	7.00 ± 0.73^{a,*}	6.90 ± 0.26^{a,*}	6.83 ± 0.32^{a,*}	6.78 ± 0.35^{a,*}	6.86 ± 0.26^{a,*}
CEC	cmol/kg	**5.79 ± 0.76**	6.93 ± 1.07^{a}	7.66 ± 0.99^{a,*}	8.03 ± 0.46^{a,*}	8.25 ± 0.81^{a,*}	8.34 ± 0.69^{a,*}
OM	%	**0.103 ± 0.036**	0.060 ± 0.022^{b}	0.210 ± 0.077^{a,*}	0.180 ± 0.014^{a,*}	0.230 ± 0.067^{a,*}	0.260 ± 0.064^{a,*}
Total N	%	**0.004 ± 0.003**	nd	0.007 ± 0.004 ^{ab}	0.004 ± 0.001^{b}	0.011 ± 0.002^{a,*}	0.007 ± 0.002^{ab}
Avail. P	mg/kg	**3.88 ± 1.25**	10.00 ± 2.83^{c,*}	14.00 ± 3.27^{bc,*}	18.00 ± 3.27 ^{ab,*}	19.00 ± 4.55^{ab,*}	22.00 ± 3.65^{a,*}
Exch. K	mg/kg	**14.50 ± 2.61**	38.00 ± 5.89^{c,*}	100.0 ± 13.37^{b,*}	100.00 ± 14.24^{b,*}	173.00 ± 28.61^{a,*}	191.00 ± 14.63^{a,*}
Exch. Ca	mg/kg	**1279.63 ± 341.25**	1479.00 ± 319.89^{a,*}	1446.00 ± 327.20^{a,*}	1451.25 ± 345.74^{a,*}	1551.75 ± 302.50^{a,*}	1548.50 ± 337.99^{a,*}
Exch. Mg	mg/kg	**22.50 ± 5.02**	46.00 ± 11.05^{a,*}	63.00 ± 10.61^{a,*}	49.00 ± 10.58 ^{a,*}	58.00 ± 13.19^{a,*}	55.00 ± 4.08^{a,*}
Total Na	%	**0.329 ± 0.113**	0.196 ± 0.065^{a}	0.167 ± 0.049^{a,*}	0.153 ± 0.052^{a,*}	0.147 ± 0.040 ^{a,*}	0.152 ± 0.064^{a,*}
Extrac. Na	mg/kg	**2425.50 ± 801.02**	1520.00 ± 271.34^{a}	1360.00 ± 331.96^{a,*}	1226.00 ± 319.78^{a,*}	1163.00 ± 228.57^{a,*}	1080.00 ± 238.95^{a,*}
SAR	–	**1158 ± 853.92**	12.45 ± 2.90^{a,*}	10.86 ± 2.57^{a,*}	11.61 ± 2.10^{a,*}	11.29 ± 1.86^{a,*}	10.36 ± 1.97^{a,*}
C/N ratio	–	**2.463 ± 1.646**	nd	0.060 ± 0.019^{ab}	0.030 ± 0.012^{b}	0.080 ± 0.036^{a}	0.050 ± 0.022^{ab}

Note: Data are shown as the mean ± 1SD

$^{a, b, ab, c}$ means a significantly different betweeen treatments at the 0.05 level

*mean a differenct pre and post-soil are significantly differenct at the 0.05 level ($p < 0.05$)

increased by 2.58 and 2.62 times, respectively. Comparing the amount of avail. P and exch. K in soil, all treatments after the cultivation revealed results that were statistically significant difference in comparison with treatments prior to the cultivation.

After rice cultivation, the amount of micronutrients such as exch. Ca and exch. Mg increased in all treatment. Exch. Ca value increased in every treatment. The treatment with the highest increase of exch. Ca value was TM (1479.00 mg/kg). The exch. Mg increased in every treatment with the value of 46–63 mg/kg with was statistical significance. The amount of exch. Mg was higher in the soil after rice cultivation in the biochar treated treatments (49.00–63.00 mg/kg) than the one without biochar treated (46.00 mg/kg). The highest amount of exch. Mg was found in the treatment with the lowest volume of biochar (T-MBR2).

The parameter illustrating soil salinity revealed that certain changes occurred in every treatment (Table 1.1). After the cultivation, the total Na value decreased the most in the T-MBR4 treatment at 0.147%. The extrac. Na value and the SAR value decreased the most in the TMBR-5 at 1080 mg/kg and 10.36, respectively. The value of extrac. Na in TMBR-5 decreased by 2.25 times and the SAR value decreased by 111.78 times in comparison to the soil prior to the cultivation. However, in the TMBR-4 treatment, the amount of total Na decreased by 2.24 times in comparison to the pre-cultivated soil. As for treatments with only fertilizer, the amount of total Na, extrac. Na and SAR decreased by 1.68, 1.60 and 93.01 times, respectively, in comparison to the pre-cultivated soil. Meanwhile, treatments with the least of biochar rate- treated, the amount of total Na, extrac. Na and SAR decreased by 1.97, 1.78 and 106.63 times, respectively, in comparison to the pre-cultivated soil. Even though the soil salinity parameter in the post-cultivation treatments indicated reduced amount to total Na, extrac. Na and SAR, the treatments incorporated with biochar revealed a better decreased rate than the non-biochar incorporated treatments.

1.7 Rice Yields from the Saline Sodic Soil Area

In this study, Jasmine Rice 105 was cultivated in five experimental plots each with four replicates which totalled 20 plots. Each plot measured 12 sq m (3 × 4 sq m). Three rice saplings were placed in each of the plots (three saplings in a clump) (Fig. 1.7a, b). On average, there were eight clumps per square metre (Fig. 1.7c, d). At the time of harvesting, it was apparent that out of the five experimental fields, there were merely three treatments that produced harvestable yields, of which only one treatment yielded top quality rice crops (Fig. 1.7e, f). However, rice seedlings in other plots grew up to a vegetative stage but failed to mature or ripe which made it unable to harvest (Fig. 1.7g). Some seedlings died at an early stage and some died off soon after. The rice turned yellow and withered away (Fig. 1.7h). The three experimental plots that were successfully grown were those with biochar-treated

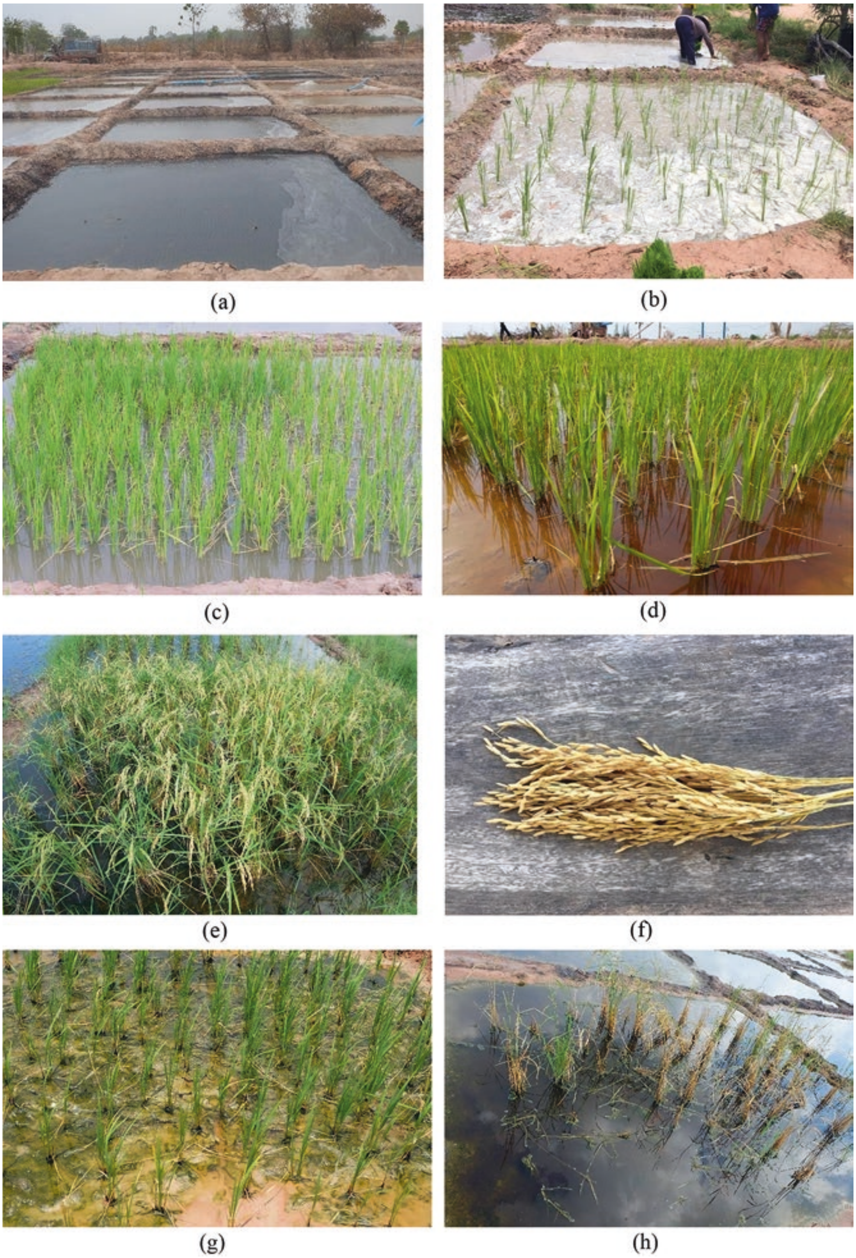


Fig. 1.7 The transplanting of Jasmine Rice 105 in experimental plots with saline sodic soil. (**a**) The preparation of the experimental plots. (**b**) Rice saplings. (**c**) Rice saplings after transplanting. (**d**) Rice saplings in plot T-MBR2 after transplanting. (**e**) Rice at the maturing stage in plot T-MBR2 (**f**) Yield from plot T-MBR2. (**g**) Rice saplings in plot T-MBR5 – a month after transplanting. (**h**) Dead rice in an irrigated TM plot

Table 1.2 Yields of Jasmine Rice 105

Treatments	Ears per area (ears/m^2)	Numbers of ears per clump (ears/clump)	Whole grain rice yields (g/m^2)	White rice yields (g/m^2)
T-MBR2	100.00	12.50	142.14	80.82
T-MBR3	27.00	3.38	38.38	21.82
T-MBR4	43.33	5.42	61.60	35.02

treatments at 2.0 kg/m^2 (T-MBR2); 3.0 kg/m^2 (T-MBR3) and 4.0 kg/m^2 (T-MBR4), respectively.

The experimental plot with the least amount of biochar (2.0 kg/m^2) yielded of jasmine rice with the maximum number of ears of paddy per area and ears of paddy per clump. The results followed by the plot with RH biochar of 4.0 kg/m^2 and of 3.0 kg/m^2, respectively. The details are provided in Table 1.2.

Even though the results from the 6-month cultivation period were not promising, there was an apparent improvement on the quality of soil. The change allowed the rice saplings to grow in the current saline sodic soil experimental plots and yielded acceptable crops. The changes that were influenced by biochar application were pH, ECe and CEC (Wijitkosum and Jiwnok 2019; Wijitkosum and Kallayasiri 2015; Yooyen et al. 2015; Laird et al. 2010). It also improved ion exchange ability (Schultz et al. 2017), better microbials activities as well as absoption ability of the roots (Akhtar et al. 2015a; Yooyen et al. 2015; Wang et al. 2014).

Biochar has an ability to adsorb salt from saline soil (Melas et al. 2017; Schultz et al. 2017; Chaganti and Crohn 2015; Akhtar et al. 2015a; Novak et al. 2009) and many studies revealed that adding salt into salt-affected soil reduced sodium ion accumulation in different parts of rice plant. Moreover, biochar addition reduced plant sodium uptake under salt stress soil by transient Na^+ binding due to its high adsorption capacity and by releasing mineral nutrients (particularly K^+, Ca^{2+}, Mg^{2+}) into the soil solution (Melas et al. 2017; Akhtar et al. 2015b). Feng et al. (2018) showed that the sodium ion accumulation significantly decreased and reduced sodium ion toxicity for better rice growth and yield formation after biochar applied in saline- sodic paddy soil. Moreover, biochar increased root biomass which accelerated plant growth (Alcívar et al. 2018; Wijitkosum and Jiwnok 2019; Yooyen et al. 2015) which was the result from biochar's ability to exclude salts from root system (Akhtar et al. 2015a). Biochar also able to induce exudation of organic compounds produced by the plant microbiota, which positively affects root development (Arjumend et al. 2015; Kammann et al. 2011). Similar results were also found by Akhtar et al. (2015a) biochar positively affects plant root growth under saline conditions, due to its high adsorption capacity, which might lead to reduce Na^+ uptake or enhanced Na^+ exclusion or both from roots. This indicated the overall improvement of the soil and its fertility as well as the reduced soil salinity enabling the rice to grow in the previously barren land. However, the improvement of saline sodic soil is a longitudinal and continuous process. Such outstanding revelation included the improvement of the salt- affected soil quality by adding soil organic carbon released from the RH biochar. The rice cultivation also required an adequate amount of water throughout the process. The sufficient amount of water aided the movement of salt from underground to the surface. Moreover, the betterment of the salt-affected soil required the right amount of time to further enhance the soil property. It contributes to a higher volume of products. This finding was in accordance with a number of research attempts indicating that in order to effectively improve soil with biochar, one needed to dedicate the right amount of time to make the biochar mechanism work as effectively as possible.

1.8 Rice Husk Biochar as an Organic Soil Amendment for Reclamation of Saline Sodic Soil

RH biochar is a highly stable substance rich in nutrients. It was produced by the slow pyrolysis of rice husk in a retort controlled temperature between 400–500 °C. The results indicated that the soil properties showed a better improcement when the soil was incorporated with both biochar and organic fertilizer than the treatment with fertilizer alone. Moreover, the improved quality of the soil enabled rice growth in saline soil within the 6-month application period. This experiment also indicated that, adding RH biochar into saline sodic soil improved all soil properties and providing better results than adding fertilizer alone. The results are shown below.

1.9 pH Value and Potential to Reduce Alkalinity

Research indicated that applying organic amendments into the salt-affected soil reduced soil pH (Wong et al. 2009; Makoi and Ndakidemi 2007). The results from this study showed that RH biochar added into soil decreased the soil pH. Even though the results did not show statistically significant difference between treatments, the biochar treated treatments yielded lower pH than the non-treated treatments (Fig. 1.8).

This was possible due to the fact that RH biochar had lower alkalinity (pH 6.8) than the soil (pH 10.20). Many studies reported that most biochar are alkaline and soil pH increases due to biochar application (Wijitkosum and Kallayasiri 2015; Martinsen et al. 2015; Obia et al. 2015; Yuan et al. 2011; Laird et al. 2010; Glaser et al. 2002). All of these studies were conducted on acidic soils with pH lower than biochar. On the other hand, studies in alkaline soil indicated that biochar application into the soil can decreases soil pH (Wijitkosum and Jiwnok 2019; Sun et al. 2016; Wu et al. 2014; Liu and Zhang 2012; Yamato et al. 2006), especially in saline sodic soils and sodic soils (Abrishamkesh et al. 2015; Liu and Zhang 2012).

High pH values of saline sodic soils and sodic soils are primarily associated with high exchangeable sodium percentage (ESP) (Shaygan et al. 2017), a reduction in soil ESP of those incorporated with biochar can be concluded as one of a possible mechanisms responsible for the decrease in soil pH (Lashari et al. 2015). Furthermore,

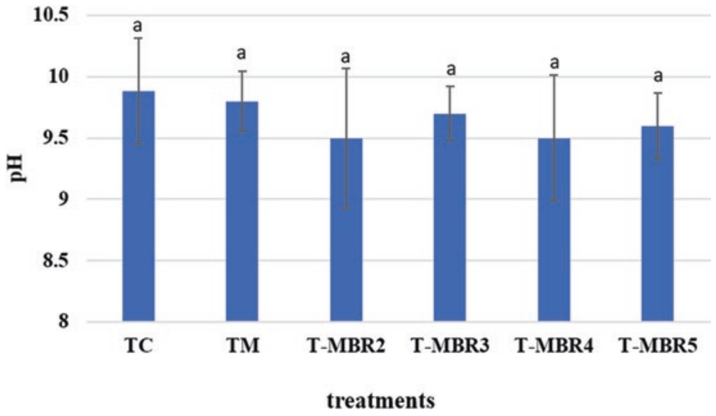


Fig. 1.8 Soil pH after the soil amelioration treatment (post-cultivation)

as for the biochar induced reduction in ESP, the initial pH of biochar may play a significant role in the pH changes of salt-affected soils (Sun et al. 2016; Amini et al. 2015; Liu and Zhang 2012). The pH of biochar depends on the types of feedstock and the pyrolysis condition as reported by Yuan et al. (2011), Chen et al. (2008), Yamato et al. (2006) and Glaser et al. (2002). The alkalinity of biochar results from their ash content releasing base cations and alkaline properties of organic functional groups (Yuan and Xu 2012). Many studies found that, not only the pH of biochar, the pH of soil also impacted the final pH of the biochar-soil mixture (Saifullah et al. 2018; Wijitkosum and Kallayasiri 2015). In this study, soil pH from all biochar- treated treatments were lower than the treatments with solely added fertilizer. The pH level in the soil changed due to its ability to exchange cations in the soil solution. Adding biochar into the soil enabled chemical activities that triggered the ion exchange which led to a higher level of soil pH (Warnock et al. 2007; Chan et al. 2008; Yuan et al. 2011) while biochar pH decreases (Amelong et al. 1997; Wijitkosum and Kallayasiri 2015). Hinsinger et al. (2003) explained that the decreased pH in biochar-treated treatments was due to the high amount of biochar's CEC which promoted the plant's uptake of cation (e.g. K^+, Ca^{2+}, and Mg^{2+}), resulting in H^+ being released from roots to balance the charges. The change of the pH occurred from oxidations between functional groups of biochar and soil solution (Cheng et al. 2006). Moreover, application of biochar also stimulates microbial activities. Biochar's highly porous structure and large surface area provides "shelter" for soil microorganisms such as microbes which live in the plants' rhizosphere and increase macro-nutrient availability, soil aeration and soil hydrology (Sriburi and Wijitkosum 2016; Hardie et al. 2014; Downie et al. 2012; Lehmann and Joseph 2009). Thus, the carbon dioxide partial pressure increases during the decomposition of organic matters in the soil and causes the development of pH-reducing conditions. Biochar effectively adjusts the pH of the soil in agricultural areas as shown in Wijitkosum and Kallayasiri (2015) which the results indicated that biochar obtained from wood scraps improved soil pH in the agricultural area from pH 6.70 to pH 7.51. The study took into account the suitable amount of biochar applied per area and the types of biomass that were made into biochar. Liu and Zhang (2012) reported that biochar produced a decreasing pH trend, which can reduce the effect of high pH on the growth and development of rice and soil nutrient availability. It was necessary for the biomass types to be appropriate for the nature of the soil as buffering capacity of the soil may hamper its ability to improve the pH (Collins 2008; Yuan and Xu 2010). It was also reported that biochar's capability for reducing salt-affected soil pH was mainly influenced by the types of raw materials (Schultz et al. 2017). Biochar was able to lower soil acidity in accordance with the amount of biochar being mixed within the soil. The ability to lower soil acidity increased in accordance with the amount of added biochar (Yuan et al. 2011; Jien and Wang 2013). However, the decreasing trends of soil pH and its relation the amount of added biochar were not conclusive and did not reveal apparent differences.

1.10 Soil CEC and Levels of Base Cations with Biochar Addition

Soil CEC was increased in all treatments but there was a significant difference between the pre and post cultivation in only the biochar-treated treatment. Moreover, CEC results in all biochar-treated treatments were higher than the treatments without biochar treated (Fig. 1.9). The results corroborated Wijitkosum and Jiwnok (2019), Wijitkosum and Kallayasiri (2015), Yooyen et al. (2015), Abdullaeva (2014) and Laird et al. (2010) which observed that CEC in various types of soil were increased after the addition of biochar from agricultural residues.

Adding RH biochar into the soil helped increase soil CEC significantly, but the significant difference on soil CEC among the biochar-treated treatments were not detected (Fig. 1.9). This result was similar to previous studies that also reported the increases in soil CEC after application different types of soil amendments such as composts (Aggelides and Londra 2000; Ouédraogo et al. 2001), biochar (Laird et al. 2010; Cheng et al. 2008; Liang et al. 2006). Furthermore, the high CEC value, increased due to biochar application, had a tendency to control the soil salinization process in agricultural lands (Liu and Zhang 2012).

The value of soil CEC increased after adding RH biochar was due to an effect of biochar's structure. Ions from the biomass that was made into biochar helped enhance cation exchange capacity within the soil (Chan et al. 2008; Lehmann et al. 2003). After the pyrolysis process, the structure of biochar was formed by aromatic compound (Schmidt and Noack 2000) and carboxyl groups were created on its surface which led to high ion exchange capacity (Joseph et al. 2009; Lehmann et al. 2007; Cheng et al. 2006). CEC is the quantification of the capacity of a material to bind positive charged ion or molecule on negatively charged surfaces like clays and soil organic matter (Brady and Weil 2008). Biochar has large surface areas and a large number of ions per area resulting in a higher rate of ion exchange within the

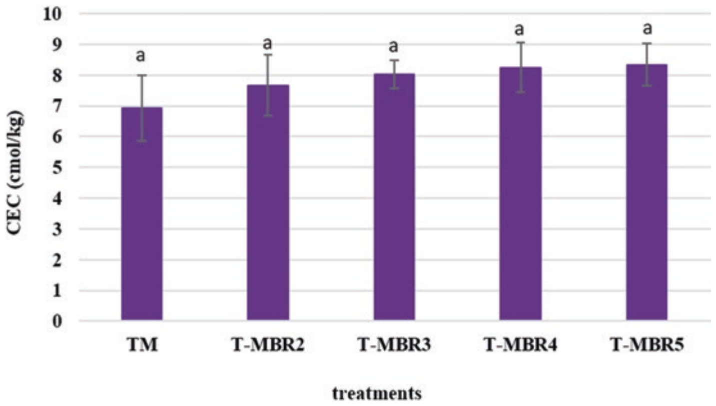


Fig. 1.9 CEC values at post treatment and post cultivation stage

soil (Liang et al. 2006). However, the amount of biochar added to the soil has an influence on the ion exchange capacity. This study concluded that the more biochar added, the better the ion exchange performance became (Fig. 1.10). The results were in accordance with Zhang et al. (2019); Chintala et al. (2014); Liang et al. (2006) in both laboratory and field researches. Chintala et al. (2014) incubated sodic soil with biochar made from corn stover (Zea mays L.) in different ratios (0, 52, 104, and 156 Mg ha^{-1}) over the period of 165 days. The results indicated that the increase in soil CEC values was significantly higher in treatments with corn stover biochar at all application rates. The CEC values increased in accordance with the increased amount of incorporated biochar. The CEC values were 14.71 for 52 Mg ha^{-1}, 17.33 for 104 Mg ha^{-1} and 19.04 for 156 cmolc kg^{-1}. As for the field research, Nigussie et al. (2012) conducted an experiment on lettuces (*Lactuca sativa*) by incorporating biochar produced from maize stalk at the rates of 0, 5 and 10 t/ha on soils (pH = 5.23; sand:silt:clay = 20%:40%:40%). The results indicated that CEC values at the post-cultivation stage were 27.22, 31.61 and 33.69 meq/100 g. However, Abdullaeva (2014) founded that the CEC in soil were not depending on the rate of biochar-treated applied. The results revealed that the amount of CEC increased in accordance with the amount of biochar added to the treatments. Moreover, the CEC amount also increased even higher the longer the biochar was incorporated within the soils (Zhang et al. 2019).

The increase of CEC is possible from the exchange of ions between soil solution and biochar through cation exchange which is a reversable process that occurs constantly. The process allows plants to utilise the nutrients continuously. Therefore, the increase in the amount of exchangeable cations in the amended soils suggested an improvement in soil fertility and nutrient retention, which may be attributed to the high specific surface area and a number of carboxylic groups of the biochar (Cheng et al. 2006; Metson 1961).

1.11 Biochar Impact on Soil ECe and SAR of Saline Sodic Soils

Even though the post-treatment results of soil ECe were not significantly different from one treatment to another, the results still showed a significant difference between the ECe of the pre- and pos- treatment results (Fig. 1.10). The decrease of ECe was apparent in one crop cycle. However, Lashari et al. (2013) indicated that the decrease of ECe was detectable in the 2-year field experiment under the combined application of biochar and poultry manure compost compared to non-treated soil. In contrast, Alcívar et al. (2018) found that soil amendment applications resulted in a significant reduction in soil ECe except in the biochar treatment. However, Usman et al. (2016) showed that biochar addition at higher rates increased ECe values due to the concentration of soluble salts in the ash.

However, the slight decreases of ECe among the treatments might be due to the high amount of salt accumulated in plants' roots. The experimental fields were high in temperature, effected by direct and strong sunlight and retained little amount of freshwater. On the other hand, saline solution in groundwater was similar to that of surface water which contributed to a high level of evapotranspiration which bring a large amount of salt to the surface. Therefore, washing away the salt from the surface was limited. The comparison between ECe results among the pre- and the post-treatments were taken from the cultivation in the experiment. Each plot was irrigated with water at 10 cm in depth (Williamson et al. 1989; Qadir and Oster 2004; Manchanda and Garg 2008; Yuvaniyama 2003). The reduction of ECe in saline sodic soil was attributed to the biochar-induced improvement in soil porosity and hydraulic conductivity that accelerated leaching of salts. ECe reduction in biochar-treated soil was be attributed to the adsorption of some soluble ions by functional groups existing at the biochar surface.

The SAR of all treatments were significantly decreased in post-cultivation, but the SAR among post- treatments were not significant different. However, the SAR of saline sodic soil in all biochar-treated treatments were lower than the fertilizer-treated treatment alone. However, Alcívar et al. (2018) indicated that soil incorporated with humic substances yielded a smaller decrease in SAR soil incorporated with humic substances alone.

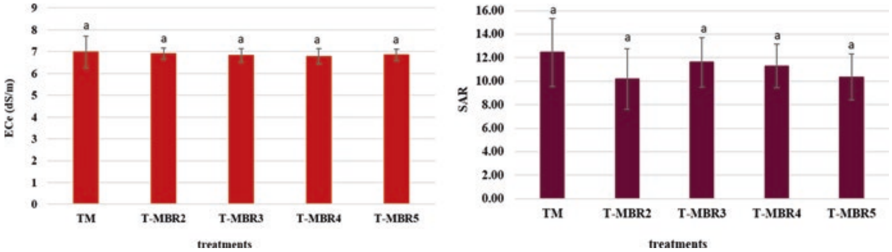


Fig. 1.10 ECe and SAR values of the post-cultivation stage

Adding RH biochar into the saline sodic soil as a soil amendment increased salt leaching which was facilitated by soil aggregation. In addition, Kim et al. (2016) discussed the changes of SAR values within the soil that there was an apparent relationship between Na^+ and Ca^{2+} proportions in the soil solution. The content of Na and Ca varied depending on biochar types. The rate and types of biochar applied into the soil are the two most important factors controlling the impact of biochar on SAR of saline sodic soils. In contrast, the result from this study found that the SAR values in saline sodic soils were not depending on the rate of biochar-treated applied (Fig. 1.10). The decreases in soil EC and SAR in this study were similar to the findings of Lashari et al. (2015), Hammer et al. (2015) and Akhtar et al. (2015a).

1.12 Effects of Biochar on Na^+, Mg^{2+}, Ca^{2+} of Saline Sodic Soil

Post-cultivation soil analysis revealed non-significant differences among treatments with the control having higher soil total Na and extrac. Na^+ than soils that received biochar amendments (Fig. 1.11). The results of this study were similar the Chaganti et al. (2015) of which the application of biochar helped reduce highest amount of extra. Na^+ by 80% in comparison to the control treatment.

This study found that adding RH biochar into the soil significantly decreased total Na and extrac. Na^+, but the significant difference on soil total Na and extrac. Na^+ of the addition of various amount of RH biochar was not detected (Fig. 1.11). The findings corroborated Lashari et al. (2013) who reported that there was a significant decrease in soil pH and salt and sodium contents with the application of a biochar. Alcívar et al. (2018) reported that adding biochar alone and biochar incorporated with humic substance significantly reduced extrac. Na^+ in soil. There are many studies (ex. Alcívar et al. 2018; Major et al. 2010; Lehmann et al. 2003) reported that the incorporation of biochar into soil successfully reduced Na^+ concentrations. Moreover, application of RH biochar into the soil can significantly increase soil $Mg^{2+}$and Ca^{2+}. The ions were being absorbed onto biochar surfaces

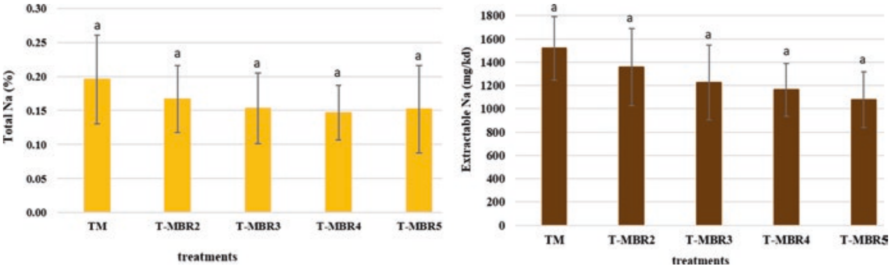


Fig. 1.11 Total Na and extractable Na at the post-cultivation stage

which increased K^+, Ca^{2+}, Mg^{2+} concentrations (Alcívar et al. 2018; Lashari et al. 2015; Hammer et al. 2015; Akhtar et al. 2015a, b; Major et al. 2010).

The reclamation of saline sodic soils requires the removal of sodium from the soil exchange sites into soil colloids by divalent cation to promote soil flocculation (Jalali 2008). This is a key point for a successful reclamation of saline–sodic soil. Soil incorporated with organic amendments, such as fertilizer and biochar, has an increased amount of soil CEC that attracts Ca^{2+} instead of Na^+ from the soil solution. The results of this research study was similar to the findings of Hammer et al. (2015), Rajakovich et al. (2012), Tsai et al. (2012) and Laird et al. (2010) who reported that biochar was rich in nutrients such as Ca^{2+} and Mg^{2+} and enhanced their availability in the soil when added as soil amendments.

This was due to the pyrolysis condition of biochar. Feedstocks that underwent the pyrolysis process contained a higher amount of P, Mg and Ca (Cao and Harris 2010). Therefore, saline sodic soils benefit from biochar application in various ways including an increased content of soil organic carbon and nutrients, especially cationic ones (eg. K^+, Ca^{2+}, Mg^{2+}), increased CEC, more stable soil structure, enhanced physical properties by balancing water contain and air porosity as well as the replacement of Na^+ from exchange sites by providing Ca^{2+} in soil solution (Zheng et al. 2018; Usman et al. 2016; Yue et al. 2016; Rajakovich et al. 2012).

Many studies also indicated that the reclamation process was a lengthy process. Lashari et al. (2013) reported no significant differences in total N between plots applied with biochar manure compost in combination with pyroligneous solution and untreated plots in the first year of the experiment. However, there was a 69% increase in total N in the second year. Biochar amendment had significant effects on soil Ca in Year 1, but this did not persist the following year. Amended soils' P, K, or Mg levels were not significantly different than those of the control soils in either year though their concentrations decreased at the end of the study. The decrease in base cation concentrations by the end of the second growing season was due to crop uptake and leaching losses in this sandy and saline-sodic soil.

1.13 Conclusion and Recommendation

The application of RH biochar into saline sodic soils has great potential for reducing soil salinity, improving soils fertility and promoting rice growth. Therefore, this study concluded that adding RH biochar into the experimental fields of Jasmine rice 105 in one crop cycle significantly improved the quality of the soil both physically and chemically and the results were statistically different. Main parameters indicated a decrease in soil salinity were the reductions of ECe, extrac. Na, total Na and SAR and the increase of exch. Mg and exch. Ca. Moreover, the soil became more fertile and the agricultural areas transformed from uncultivable bare lands into cultivable soils even though the products were not of top quality. The study indicated that treatments of soil with biochar induced changes in soil that are favourable, but long- term studies are required to monitor the extent of these effects. Moreover, one of the crucial factors for saline sodic soil amelioration was also maintaining the irrigation level in the rice fields to prevent transportation of salt to the soil surface. Therefore, using RH biochar to revitalise saline sodic soil should maintain the irrigation level in the plots.

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