INTRODUCTION

Climate change has been recognized as an adversely crucial predicament encountering the world since it is a large-scale hazard that has a strong effect on various matters such as fluctuation of weather patterns, extreme weather, human health risks as well as wildlife and ecosystem impacts. Earlier studies have reported that climate change has widespread origins on divergent timescales from decades to millions of years, with more recently human activities (for example burning of fossil fuels and clearing of forests) releasing very large quantities of greenhouse gases (GHGs) into the Earth’s atmosphere (Henderson, Reinert, Dekhtyar, & Migdal, 2017). Furthermore, this report indicated that almost 40% of the rise in the concentration of atmospheric carbon dioxide ($\text{CO}_2$) was caused by human activities between 1750 and 2011. The reason for this increase in $\text{CO}_2$ concentration has contributed considerably (approximately 64%) to the total radiative force of all the well-mixed GHGs (IPCC, 2013). In response to this positive radiative force built up by $\text{CO}_2$ and other GHGs, the Earth’s energy budget has risen significantly, resulting in an increase of the global surface temperature (Shukla, Verma, & Misra, 2017). Since the Industrial Revolution, it has been reported that the mean temperature of the Earth has been increasing. During the period of 1880 to 2015, the increment of mean global surface temperatures accounted for 0.9°C was demonstrated (Henderson, Reinert, Dekhtyar, & Migdal, 2017). Moreover, the Intergovernmental Panel on Climate Change or IPCC (2007) estimated that the global surface temperatures on average would be ranged from 2.5-4.7°C higher by 2100 than the pre-industrial degree.

One of the most important impacts of climate change is reflected in a rising sea level, which is
directly consistent with a combination of a number of processes, e.g., thermal expansion, water addition to the oceans by means of melting glaciers, ice caps and polar ice sheets, changes in ocean and atmospheric circulations as well as natural and human-induced changes in groundwater levels (Noone, 2013). The rates of sea level have accelerated since approximately 1870 (Henderson, Reinert, Dekhtyar, & Migdal, 2017) and based on tidal gauges during the 20th century, the rates have shown the average value of 1.7 mm/year, and then have raised to 3.2 mm/year (Church & White, 2011). Additionally, the global change in sea level at the end of the 21st century as estimated by the IPCC will presumably be on the ranges of 0.63-0.98 m (IPCC, 2007). Currently, sea levels are rising and are expected to continue to do so for centuries, although GHGs emissions are halted and the concentrations of those atmospheric gases stabilized (Church & White, 2011). In principle, a sea level rise influences intervening variables in the hydrological cycle that impact the amount of water stored on land (Church, Monselesan, Gregory, & Marzeion, 2013) either as surface water in lakes, rivers, artificial reservoirs, and marshes or as subsurface water, e.g., groundwater, liquid water trapped in soils, and permafrost (Noone, 2013). In addition, a potential rise in the sea level could have variable but crucial consequences, for example on domestic consumption, saltwater contamination of fresh water supplies, aquaculture, coastal flooding, erosion, and increased salinity in agricultural soils (Shukla, Verma, & Misra, 2017).

Salt affected soils can be defined as the accrual of soluble salts in the surface or near-surface soil horizon that imposes worldwide restrictions on plant growth, crop production, and food quality (Chhabra, 2004; Emran et al., 2020). These soils are considered to be pivotal problems affecting extensive agricultural and environmental areas in both developed and developing countries (Farifteh, 2007). Generally, the composition of soluble salt in soils consists of chlorides and sulfates of sodium, calcium, magnesium, and potassium derived from either weathering of rocks and minerals or deposition on soils through rainfall (Brady & Weil, 2008). The formation of salt affected soils can occur worldwide; however, these soils are especially widespread in arid and semi-arid zones (Jafarpooor, Manafi, & Poch, 2021; Zhao et al., 2020) where the amount of precipitation is insufficient for leaching and removing the salts in conjunction with high evaporation that can also increase the salt concentration in soils (Fullen & Catt, 2004). In Thailand, the overall areas of salt affected soils make up approximately 2.302 million hectares which can be separated into three principal locations (the Northeast Plateau basin, the Coastal area, and the Central Plain) where each location is influenced by heterogeneous environmental conditions (Arunin & Pongwichian, 2015; Phankamolsil, Sonsri, Kheoruenromne, Gilkes, & Phankamolsil, 2021).

The rising sea level is currently being examined as a cause of salt affected soils, particularly during freshwater systems and/or soils have been potentially intruded by saltwater which might be caused a secondary salinity. Royal Irrigation Department (2016) disclosed that the Chao Phraya River basin, the significant water resources of Thailand, has been impacted by seawater from the Gulf of Thailand, in particular during spring tides and it has been suggested that a suitable control method, to prevent the above-mentioned problems, is fresh water management to force the seawater returned to the Gulf of Thailand. However, Thailand has been experiencing a drought since 2015 until the summer season in 2016 leading to the amount of available freshwater being inadequate to influence the flow of seawater. Thence, the increase in electrical conductivity (EC$_{w}$) value of this river has possibly occurred, which further resulted in the negative impacts on agricultural regions neighboring the river and/or the areas that directly utilized the water from this river. The agricultural areas of the Lower Central Plain seem to be one of the areas confronted by a sea level rise due to its location in the Chao Phraya River basin which is adverse to the growth and yield of economic crops.

Hence, this research was aimed at monitoring the effects of sea level rise on some soil properties related to salt affected soils in the agricultural areas of the Lower Central Plain, Thailand as well as aiding the understanding of the intensity of salt affected soils during different periods in the study areas.

**MATERIALS AND METHODS**

**Characteristics of Study Areas**

The study locations were in the central region of Thailand covering the Nonthaburi and Pathum Thani provinces which are designated as being
in part of the Lower Central Plain (Fig. 1). These areas are located in the northwest of Bangkok on the Chao Phraya River, making up 622.3 and 1,526 km², respectively, with UTM coordinates from 1530605 to 1548469 N and 47 0654556 to 0664331 E. Land use types in these study sites were mainly tropical fruit orchard, paddy field, and green leafy vegetables. Geologically, the Lower Central Plain of Thailand is characterized as a flat, low-lying area surrounded by mountains to the west, north, and east as well as being connected to the shoreline of the Gulf of Thailand to the south which is a sedimentary basin containing a thick sequence of Quaternary sediments (Songtham, Musika, Mildenhall, Cochran, & Kojevnikova, 2015). The elevation over the study sites ranged from 2 to 3 m above mean sea level. The region's climate is classified as tropical savanna, having an annual mean temperature of 27 to 30°C. For the Central region, the rainy season is from mid-May to mid-October with possessing average yearly precipitation of 903 mm (Meteorological Department, 2015).

Remarks: The satellite image was taken from Google Earth (Google Earth, 2018)

**Fig. 1.** Sampling locations at agricultural areas in Nonthaburi and Pathum Thani provinces on the Lower Central Plain, Thailand
Soil Sampling and Characterization

Eleven soil samples (five locations in Nonthaburi province and six locations in Pathum Thani province) were selected according to the disparate distances from the Chao Phraya River. The investigated period was conducted monthly between March and August 2018. The soils at each study location were classified as Inceptisols according to the USDA soil taxonomy and soil profiles to a depth of 120 cm were described by the genetic horizons based on the standard field methods (Soil Science Division Staff, 2017). At each location, whole soil samples at depths of 0-15, 15-30, 30-60, 60-90 and 90-120 cm were extracted using a hand auger for analysis of the soil properties associated with salt affected soils. Before analysis of soil particle size distribution, electrical conductivity (ECe), and sodium adsorption ratio (SAR), the samples were air-dried, gently pulverized, and passed through a 2 mm stainless steel sieve. The pipette method was performed to determine the soil particle size distribution (Kilmer & Alexander, 1949). Soil moisture (θm) was examined by the gravimetric method (Black, 1965) and was expressed on a percentage weight basis as the ratio of the mass of water present (mw) to the dry weight of the soil sample (ms) as shown in the following formula:

\[ \theta_m = \frac{m_w}{m_s} \] (1)

ECe in saturation paste extracts was measured following the standard method described by the United States Department of Agriculture (USDA, 1954). The SAR was measured based on the saturation of extracted cations Na+, Ca++, and Mg++ using atomic absorption spectrophotometry, and also calculated according to the USDA as shown in the following formula:

\[ \text{SAR} = \frac{[\text{Na}^+]}{\sqrt{[\text{Ca}^{++}]+[\text{Mg}^{++}]}/2} \] (2)

Where: Na+, Ca++, and Mg++ are expressed in meq/L.

Statistical Analysis

The relationships between the soil chemical properties associated with salt affected soils as well as soil moisture were performed according to Pearson’s correlation procedure. An analysis was carried out using IBM SPSS Statistics for Windows version 22.0 (IBM Corp., Armonk, NY, USA).

RESULTS AND DISCUSSION

Soil Morphological Characteristics

The characteristic appearances of soil profiles are shown in Fig. 2, including representative soils from a tropical fruit orchard in Nonthaburi province (N1), a paddy field in Nonthaburi province (N5), a green leafy vegetable crop in Pathum Thani province (P2) and a paddy field in Pathum Thani province (P5). Overall, the soil profiles were generally deep without rocks observed down to 120 cm owing to the possession of deep alluvium at each location. The soil matrix color was very different between sites. However, many of the soil profiles had a low chroma value (≤ 2) and there was mottling in either some or all soil horizons at each investigated area. The low chroma values and mottling demonstrate progressively poor drainage and profile development under water-saturated conditions in a consequence of the annual reduction/oxidation cycles imposed in several years (Prakongkep, Suddhiprakarn, Kheoruenromne, Smirk, & Gilkes, 2008). These soils usually had a fine texture comprising silty clay and clay, leading to poor drainage which affected the soil color and caused mottling. The soil profile development may have had the horizontal arrangement changed by weathering, but there was no distinct evidence of accumulation in subsoil layers, suggesting that these soils had a low level of development. Furthermore, these soils could be taxonomically classified as Inceptisols (Soil Survey Staff, 2014).

Selected Soil Physical Properties

The soil textural triangle classes for the soils in this study are demonstrated in Fig. 3. The information pertaining to soil particle size distribution according to soil depths for each study site in both Nonthaburi and Pathum Thani provinces is shown in Fig. 4. In general, most soils had definitely similar textures at each study site consisting of silty clay and clay that could be referred to as finer-textured soils. The texture groups were consistent with field texture implementation. There was a quite different distribution between locations of sand, silt, and clay particles. Nevertheless, clay seemed to be the dominant particle type for these soils. Moreover, the soil profiles had quite erratic variations in the
clay percentage with depth that was probably related to depositional layers. This phenomenon presumably reflects the possession of sedimentary layers accumulated under a regime where transport conditions became more energetic over time (Wongpokhom, Kheoruenromne, Sudhiprakarn, Smirk, & Gilkes, 2008).

The soil moisture at each study site from March to August 2018 is shown in Fig. 5 and varied between 20.84 and 79.04%. Moreover, the soil moisture was very different among locations, depth levels, and periods of soil sampling. In April, for most sites, the soil moisture seemed to gradually decrease and was lower than in other months (Fig. 5b). On the other hand, between May and June, most sites had clear increases in soil moisture (Fig. 5c and 5d) probably due to the dry and wet seasons (the dry season in April leading to low precipitation and low soil moisture while the wet season in May and June having usually high precipitation resulting in a high level of soil moisture) (Meteorological Department, 2015). Additionally, it was noticed that the soil moisture in these soils mostly increased with soil depth. Nonetheless, in paddy fields such as N4, N5, P4, and P6, the topsoil seemed to have higher soil moisture than the subsoil which may have been the result of irrigation management by the farmers.

Fig. 2. Representative samples of soil morphological characteristics with presence of horizon, color, and texture (SiC = silty clay, C = clay)
Fig. 3. Ternary graph of sand, silt, and clay compositions for the agricultural soils in the study areas

Fig. 4. Soil particle size distribution according to soil depth for agricultural soils in the study areas
Fig. 5. Depth functions showing soil moisture values for agricultural soils in the study areas from March to August 2018.
Soil Chemical Properties Related to Salt Affected Soils

The trends for EC with depth for the soils in agricultural areas of Nonthaburi and Pathum Thani provinces between March and August 2018 are presented in Fig. 6 and Fig. 7, respectively. Commonly, the EC values during the period of soil sampling ranged from 0.21 to 4.42 dS/m which represented considerable variation among locations, depth levels, and periods of soil sampling. In Nonthaburi province, location N4 in April (Fig. 6b) and location N5 in March, July, and August (Fig. 6a, 6e and 6f) had EC values higher than 4 dS/m demonstrating that the investigated soils were affected by salts based on the classification of salt affected soils suggested by Brady & Weil (2008). However, in Pathum Thani province only location P4 in March (Fig. 7a) had EC values of more than 4 dS/m. In addition, during the study period, many locations had EC values greater than 2 dS/m in some soil horizons, which would refer that plant growth would be noticeably affected (Brady & Weil, 2008). In terms of soil depth functions, it was observed that the EC values in most subsoil (30 to 90 cm) samples in Nonthaburi and Pathum Thani provinces tended to increase with depth. However, some locations had EC values in the topsoil (0 to 30 cm) that were greater than in the subsoil, this was probably due to the upward transport of groundwater containing salts under high evaporation (Rose, Konukcu, & Gowing, 2005). Incidentally, the increase of EC values in the paddy field, for instance, locations N5, and P6 might be a result of the irrigation management conducted by agriculturists, which directly used the water from the Chao Phraya River through the branch canal trail in their cultivated areas.

In general, the SAR values of these soils during the periods of soil sampling were rather higher than 13 in either some or all layers of the soil profiles, ranging between 6.80 and 41.89. A SAR value of more than 13 clearly indicates that the soil is impacted by sodium ions (Na+) (Brady & Weil, 2008; Zhang, Yang, Yao, Wang, & Xie, 2020). Additionally, the SAR values of these soils both in Nonthaburi and Pathum Thani provinces were distinctly different among locations, period of soil sampling and also within the soil profiles (Fig. 8 and Fig. 9). In Nonthaburi province, all locations and soil horizons in April and June (Fig. 8b and 8d) had SAR values of more than 13. The SAR values increased with soil depth from 0 to 90 cm in many locations that were probably caused by the high accumulation of Na+ because of either slow mobility of Na+ in the soil system or the adsorption of Na+ by clay minerals, particularly in the soils having clayey-textured characteristics (Sparks, 2002). Overall, considering the intensity of salt affected soils in the study areas, it seemed that Nonthaburi province had greater levels than in Pathum Thani province, presumably because Nonthaburi province is located closer to the Gulf of Thailand than Pathum Thani province (Fig. 1). During the study, many locations, both in Nonthaburi and Pathum Thani provinces, were affected by salts which possibly suggested the soils could be classified as sodic soils in all study locations. Furthermore, at locations N4 in April, N5 in March 2018, July and August, and P4 in March, the EC values exceeded 4 dS/m indicating these were saline-sodic soils (Brady & Weil, 2008). Consequently, during these times, there was likely to have been the major impact of salt, with the changes affected by a sea level rise compared to during May and June when there was high precipitation.
Fig. 6. Trends in $\text{EC}_e$ with soil depth in agricultural areas of Nonthaburi province between March and August 2018 (--- denotes the $\text{EC}_e$ values (4 or 2 dS/m) used to differentiate classes of salt affected soils)
Fig. 7. Trends in $EC_e$ with soil depth in agricultural areas of Pathum Thani province between March and August 2018 (- - - - denotes the $EC_e$ values (4 or 2 $dS/m$) used to differentiate classes of salt affected soils)
Fig. 8. Trends in SAR values with depth for soils in agricultural areas of Nonthaburi province between March and August 2018 (- - - - - denotes the SAR value (13) used to differentiate classes of salt affected soils)
Fig. 9. Trends in SAR values with depth of soils in agricultural areas of Pathum Thani province between March and August 2018 (- - - - - denotes the SAR value (13) used to differentiate classes of salt affected soils)
Table 1. Pearson’s correlation coefficients amongst soil chemical properties associated with salt affected soils and soil moisture between March and April 2018 in agricultural areas on the Lower Central Plain, Thailand

|       | March                      | April                      |
|-------|----------------------------|----------------------------|
|       | ECₜ | SAR | Ca⁺⁺ | Mg⁺⁺ | Na⁺ | θₑ | ECₜ | SAR | Ca⁺⁺ | Mg⁺⁺ | Na⁺ | θₑ |
| ECₜ   | -   | 0.41” | 0.53” | 0.46” | 0.56” | 0.08 | ECₜ   | -   | 0.26 | 0.78” | 0.75” | 0.61” | -0.04 |
| SAR   | 0.41” | -   | -0.12 | 0.26 | 0.67” | 0.29’ | SAR   | 0.26 | -   | -0.04 | 0.14 | 0.70” | -0.15 |
| Ca⁺⁺  | 0.53” | -0.12 | - | 0.56” | 0.30’ | -0.21 | Ca⁺⁺  | 0.78” | -0.04 | - | 0.76” | 0.43” | 0.04 |
| Mg⁺⁺  | 0.46” | 0.26 | 0.56” | - | 0.70” | -0.03 | Mg⁺⁺  | 0.75” | 0.14 | 0.76” | - | 0.57” | 0.24 |
| Na⁺   | 0.56” | 0.67” | 0.30’ | 0.70” | - | 0.17 | Na⁺   | 0.61” | 0.70” | 0.43” | 0.57” | - | 0.14 |
| θₑ    | 0.08 | 0.29’ | -0.21 | -0.03 | 0.17 | - | θₑ    | -0.04 | 0.15 | 0.04 | 0.24 | 0.14 | - |

Remarks: **= the presence of statistical correlation at p<0.01, *= the presence of statistical correlation at p<0.05

Table 2. Pearson’s correlation coefficients amongst soil chemical properties associated with salt affected soils and soil moisture between May and June 2018 in agricultural areas on the Lower Central Plain, Thailand

|       | May                      | June                      |
|-------|--------------------------|---------------------------|
|       | ECₜ | SAR | Ca⁺⁺ | Mg⁺⁺ | Na⁺ | θₑ | ECₜ | SAR | Ca⁺⁺ | Mg⁺⁺ | Na⁺ | θₑ |
| ECₜ   | -   | -0.18 | 0.36” | 0.87” | 0.58” | -0.07 | ECₜ   | -   | -0.14 | 0.03 | 0.87” | 0.56” | 0.21 |
| SAR   | -0.18 | -   | -0.50” | -0.30’ | 0.38” | 0.02 | SAR   | -0.14 | -   | -0.57” | -0.22 | 0.55” | -0.13 |
| Ca⁺⁺  | 0.36” | -0.50” | - | 0.38” | 0.41” | 0.03 | Ca⁺⁺  | 0.03 | -0.57” | - | -0.09 | -0.06 | 0.21 |
| Mg⁺⁺  | 0.87” | -0.30’ | 0.38” | - | 0.54” | 0.06 | Mg⁺⁺  | 0.87” | -0.22 | -0.09 | - | 0.46” | 0.14 |
| Na⁺   | 0.58” | 0.38” | 0.41” | 0.54” | - | -0.01 | Na⁺   | 0.56” | 0.55” | -0.06 | 0.46” | - | -0.01 |
| θₑ    | -0.07 | 0.02 | 0.03 | 0.06 | -0.01 | - | θₑ    | 0.21 | -0.13 | 0.21 | 0.14 | 0.14 | - |

Remarks: **= the presence of statistical correlation at p<0.01, *= the presence of statistical correlation at p<0.05

Table 3. Pearson’s correlation coefficients amongst soil chemical properties associated with salt affected soils and soil moisture between July and August 2018 in agricultural areas on the Lower Central Plain, Thailand

|       | July                      | August                     |
|-------|--------------------------|----------------------------|
|       | ECₜ | SAR | Ca⁺⁺ | Mg⁺⁺ | Na⁺ | θₑ | ECₜ | SAR | Ca⁺⁺ | Mg⁺⁺ | Na⁺ | θₑ |
| ECₜ   | -   | -0.01 | 0.76” | 0.90” | 0.69” | 0.37” | ECₜ   | -   | -0.21 | 0.88” | 0.92” | 0.64” | 0.19 |
| SAR   | -0.01 | -   | -0.14 | -0.19 | 0.57” | -0.02 | SAR   | -0.21 | -   | -0.48” | -0.24 | 0.50” | 0.35” |
| Ca⁺⁺  | 0.76” | -0.14 | - | 0.68” | 0.67” | 0.28” | Ca⁺⁺  | 0.88” | -0.48” | - | 0.85” | 0.39” | 0.06 |
| Mg⁺⁺  | 0.90” | -0.19 | 0.68” | - | 0.49” | 0.24 | Mg⁺⁺  | 0.92” | -0.24 | 0.85” | - | 0.56” | 0.15 |
| Na⁺   | 0.69” | 0.57” | 0.67” | 0.49” | - | 0.23 | Na⁺   | 0.64” | 0.50” | 0.39” | 0.56” | - | 0.35” |
| θₑ    | 0.37” | -0.02 | 0.28” | 0.24 | 0.23 | - | θₑ    | 0.19 | 0.35” | 0.06 | 0.15 | 0.35” | - |

Remarks: **= the presence of statistical correlation at p<0.01, *= the presence of statistical correlation at p<0.05
Relationships of Soil Properties
The statistical analysis of the soil property data for the soils in agricultural areas from March to August 2018 are summarized in Table 1, Table 2 and Table 3. Generally, the EC\textsubscript{e} values had a positive correlation with Na\textsuperscript{+}, Ca\textsuperscript{2+}, and Mg\textsuperscript{2+}, particularly in April, July, and August. However, there was a negative correlation with soil moisture from April to May. The SAR values seemed to have a strong positive correlation with Na\textsuperscript{+}, especially between March and April. In contrast, there was a negative correlation with soil moisture in April, June, and July. In terms of soil moisture, there was mainly a negative correlation with other soil property parameters during the study period. Therefore, soil moisture can be presumably considered as a factor controlling the increase or decrease in soil properties values with regard to salt affected soils. For instance, the EC\textsubscript{e} usually decreases in the wet season, when soil moisture is relatively high, as a consequence of desalinization and salt leaching in relation to the infiltration of rainfall. On the other hand, it generally increases in the dry season, when soil moisture is rather low, owing to the capillary rise of groundwater having soluble salts as a result of the evaporation and poor surface cover (Iwai, Oo, & Topark-ngarm, 2012).

CONCLUSION
The soil property analysis indicated that many locations in both Nonthaburi and Pathum Thani provinces were affected by salts, resulting in the affected soils being classified as sodic soils for all study locations. Therefore, sea level rise seemed to have distinctly affected the concentration of sodium ions (Na\textsuperscript{+}). Moreover, the high salt levels at locations N4 in April, N5 in March, July and August, and P4 in March resulted in these soils being classified as saline-sodic with the substantially increased salt levels likely caused by a rise in the sea level compared to during May and June when there was high precipitation. However, further information on soil and water properties with regard to salinity is required from the continuous investigation.

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Kiattisak Sonsri et al.: Sea Level on Salt Affected Soils

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