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Research article

Spatial distribution characteristics and types of salt-affected soils spots developed on alluvial fan complex over old marine sediment, Thailand

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Abstract

Salt-affected soils are universally known as one of the most important problematic soils causing a negative impact on agricultural lands worldwide. Thus, the aims of the current were: 1) to elucidate the spatial distribution of salt-affected soils, 2) to investigate the spatial factors impacting the distribution of salt-affected soils and 3) to classify the types of salt-affected soils. The study sites were located in Kamphaeng Saen district, Nakhon Pathom province, Thailand where the soils have developed under old marine sediment. Orthographic mapping was used to identify the locations of salt-affected soils; subsequently, 38 locations were selected. At these sites, soil samples were collected using a hand auger at four depths (0−20 cm, 30−50 cm, 60−80 cm, 80−120 cm) for analysis of their chemical properties. The ArcGIS software was used to analyze the spatial factors influencing the distribution of salts comprising the irrigation canal system, road construction, elevation and surface slope of the study area. The results indicated that the majority of salt-affected soils appeared where there was a salt crust, bare surface and halophytic plants were present, which all acted as environmental indicators. Generally, these soils were spatially distributed in the north of Kamphaeng Saen district, Nakhon Pathom province; the irrigation canal system, road construction and elevation may be regarded as the spatial factors leading to the occurrence of the salt-affected soils. Furthermore, these salt-affected soils were deep, moderately developed with possessing the ranges of EC_e, SAR and ESP values from 0.20–74.70 dS/m, 2.30–85.09 and 2.74–113.23%, respectively. Thus, our finding indicated that the types of these salt-affected soils could be classified into two groups: 1) saline-sodic soils appearing at 34 study locations and 2) saline soils appearing at 4 study locations.

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Introduction

Salt-affected soils are the principal and imperative problem affecting extensive agricultural and environmental areas in both developed and developing countries (Farifteh, 2007). These soils incorporate considerable concentrations of soluble salts that impose restrictions on plant growth, crop cultivation and food quality (Feng et al., 2003; Chhabra, 2004; Fan et al., 2016). In principle, salt-affected soils can be classified into three groups comprising saline, saline-sodic and sodic soils. According to Brady and Weil (2008), saline soils have electrical conductivity (EC_e) of a saturation extract greater than or equal to 4 dS/m. Their sodium adsorption ratio (SAR) is less than 13. Saline-sodic soils have an EC_e value of a saturation extract and SAR greater than or equal to 4 dS/m and 13, respectively. Sodic soils have an EC_e of the saturation extract less than 4 dS/m and their SAR levels are greater than or equal to 13. The formative areas of salt-affected soils are common in arid or semi-arid zones where the amount of rainfall is inadequate to leach and remove the salts and potential evaporation is higher than atmospheric precipitation (Fullen and Catt, 2004; Luedeling et al., 2005). However, in Thailand, the majority of salt-affected soils occur in three main locations consisting of the Northeast Plateau basin, the Central Plain and the Coastal area with the total area being approximately 2.302 million ha. Furthermore, each location is controlled by different environmental conditions (Takai et al., 1987; Arunin, 1992; Arunin and Pongwichian, 2015).

Observation of salt-affected soils on the Central Plain of Thailand revealed that six provinces (Nakhon Pathom, Suphan Buri, Kanchanaburi, Sing Buri, Ang Thong and Chai Nat) have areas with salt-affected soils (Arunin, 1998). Generally, salt-affected soils in these provinces have developed from marine sediment (Hattori and Takaya, 1989). Therefore, the influence of marine activity in former times seems to be directly consistent with the formation of salt-affected soils in these areas. In particular, areas of Kamphaeng Saen district, Nakhon Pathom province, where the farmers produce many economic crops, are faced with substantial problems due to salt-affected soils (Fakon, 2012). Thus, these soils have a negative impact on the growth and yield of plants as well as the accumulation of salt that reduces the productivity of the soils. Salt-affected soils need intensive management for both the soil and plants to overcome the negative impacts of the salts and to prevent the problem worsening. Knowledge of management strategies for salt-affected soils is essential to address the causes and mechanisms of the pedogenic processes. Hence, the objectives of this study were: 1) to determine the spatial distribution of salt-affected soils, 2) to investigate the spatial factors impacting the distribution of salt-affected soils; and 3) to classify the type of salt-affected soils. This research was conducted in Kamphaeng Saen district, Nakhon Pathom province where the soil has been designated as originating from old marine sediments.

Materials and Methods

Site description and soil sampling

An orthographic map with a scale of 1:4,000 generated and published by the Land Development Department in 2005–2008 was used as a base map to identify the locations of salt-affected soils that commonly presented as bare areas on that map. After exploration of salt-affected soils based on the orthographic map, 38 locations in Kamphaeng Saen district, Nakhon Pathom province, Thailand were chosen as possessing salt-affected soils and subsequently soil samples were collected for the current study (Fig. 1). All the study sites had a tropical savanna climate with a mean annual temperature of 27−30°C. In general, the rainy season is between mid-August and mid-October with average annual precipitation of 903 mm/y (Thai Meteorological Department, 2015). The soils investigated in this research had been formed on an alluvial fan. The parent materials were derived from the alluvium complex mixed with marine sediments. The disturbed soil samples at each location were collected using a hand auger at four depths (0−20 cm, 30−50 cm, 60−80 cm and 80−120 cm) to investigate the chemical properties. Undisturbed soil cores were collected at depths of 0−20 cm and 30−50 cm to determine the soil bulk density (BD) and soil saturated hydraulic conductivity (Ksat). Disturbed soil samples collected using the hand auger were air-dried, gently disaggregated and passed through a 2 mm stainless steel sieve to eliminate gravel, plant debris and plant litter before analysis.

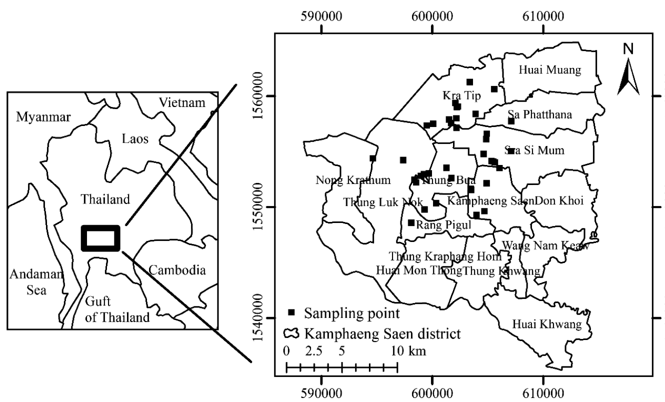

Fig. 1 Sampling locations for salt-affected soils in Kamphaeng Saen district, Nakhon Pathom province, Thailand

Soil preparation and analysis

The physicochemical properties of the whole soil samples were investigated according to standard procedures. The BD was determined using a cold method (Blake and Hartge, 1986). The Ksat was determined using the variable head method (Klute and Dirksen, 1986). The electrical conductivity (EC_e) of a saturation extract at 25°C was measured using an electrical conductivity meter

(U.S. Salinity Laboratory Staff, 1954). The saturation extractions of Ca^{2+}, Mg^{2+} and Na^{+} cations were determined using an atomic absorption spectrophotometer (National Soil Survey Center, 1996) and subsequently, the sodium adsorption ratio (SAR) was calculated by dividing the molar concentration of Na^{+} in the saturation extract by the square root of the molar concentration of Ca^{2+} plus Mg^{2+} divided by two and recorded in centimoles per kilogram (U.S. Salinity Laboratory Staff, 1954). The exchangeable sodium percentage (ESP) was calculated using the exchangeable sodium divided by the exchange capacity determined using the NH_4OAC method (CEC-7) and further multiplied by 100 (U.S. Salinity Laboratory Staff, 1954).

Evaluation of factors controlling distribution of salt-affected soils

The spatial factors influencing the distribution of salts were analyzed using the ArcGIS software version 10.0 (Esri; Redlands, CA, USA). The selected factors applied for this study were irrigation canal system, road construction, elevation and surface slope of the study area.

Results and Discussion

Spatial distribution and characteristic of study sites faced by salt-affected soils

The analysis revealed that a majority of salt-affected soils appeared in the north of Kamphaeng Saen district including the Kra Tip, Thung Luk Nok, Thung Bua, Sra Si Mum, Sa Phatthana, and Kamphaeng Saen sub-districts (Fig. 2A). The orthographic map indicated that the areas with salt-affected soils showed as bare areas characteristically and many plants in these areas had not grown regularly (Fig. 2B). The results from the field survey also revealed that many plants could not grow well in the areas with salt-affected soils. On the other hand, halophytic plants such as *Combertum guadranglaer* Kurz., *Azima sarmentosa* Benth., *Pluchea indica* and *Eleocharis congesta* D. Don were found in the topsoil at these sites which could be assumed as plant indicators for areas with salt-affected soils. In addition, many characteristics of a salt crust appeared in the topsoil of the study area (Fig. 3A–D). These results were similar to those reported in areas with salt-affected soils in Northeast Thailand where both salt crusting and salt tolerant plants were recorded (Wongpokhom, 2007; Wongpokhom et al., 2008).

Spatial factors influencing distribution of salt-affected soils

The irrigation system in Kamphaeng Saen district, consisting of irrigation and drainage canals, is shown in Fig. 4A. Most of the canals were constructed using soil, with no concrete slabs on the bottom. Generally, the direction of water flow is from west to east. On the other hand, used irrigation water from the agricultural area drains from the northern and southern regions to the central region. The results of the analysis revealed that the largest distribution of salt-affected soils was in close proximity to irrigation canals and the level of salt-affected soil distribution decreased further from canals, especially where the distance was greater than 3 km. The elevation in the study area was in the range 6–16 m. However, the salt-affected soils were generally distributed in areas having an elevation range of 8–10 m (Fig. 4B). The surface slope factor analysis showed that most of the study area had a surface slope in the range 0–2%. There was no relationship identified between the surface slope and the distribution of salt-affected soils (Fig. 4C). Nevertheless, salt-affected soil is expected to occur on the side slope from the lower position to the upper position.

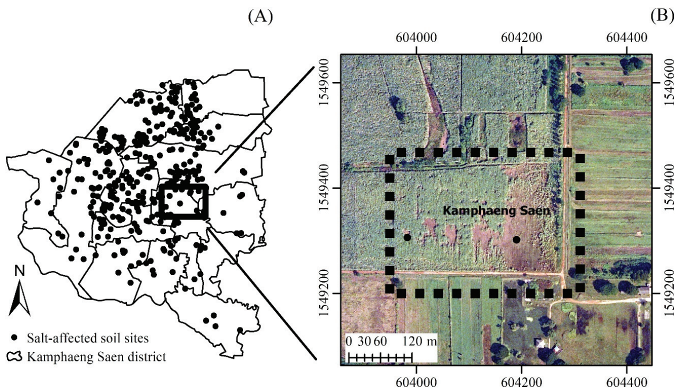

Fig. 2 Salt-affected soils at the study sites: (A) their spatial distribution obtained from orthographic mapping; (B) bare areas and irregular plant growth characteristics inside black dotted rectangle as indicators of salt-affected soil

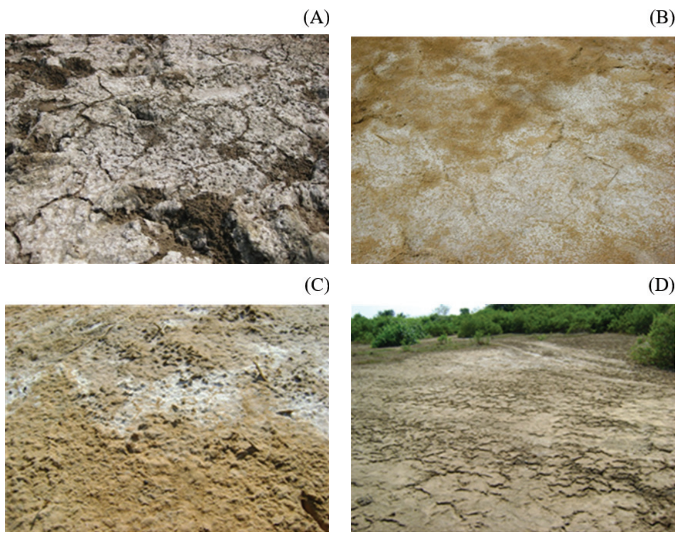

Fig. 3 Characteristics of salt crust found in topsoils in the studied areas demonstrating divergent features among investigated sites (A−D)

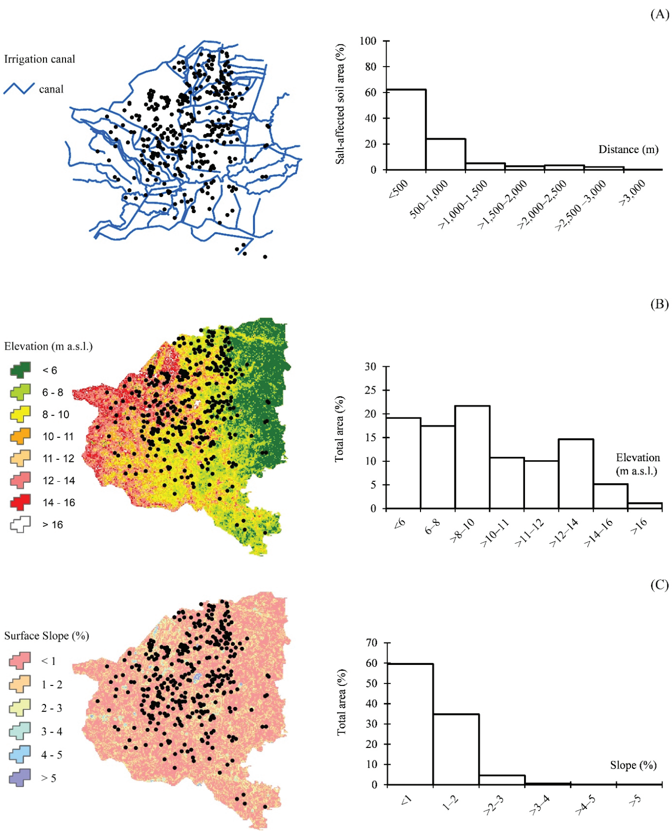

Fig. 4 Relationship between areas with salt-affected soils and following factors influencing salt-affected soil distribution: (A) irrigation canal system; (B) elevation and (C) surface slope, where a.s.l. = above sea level

Properties and types of salt-affected soils

The results indicated that all salt-affected soils were deep and moderately developed. The topsoil (0−20 cm) and subsurface soil (30−50 cm) horizons of these soils had BD values generally higher than 1.6 Mg/m^3 in the range 1.64–2.40 Mg/m^3 (Table 1). Dispersion and flocculation seem to have been the main processes causing the high BD values in the soils encountered, due to small-sized particles, clay and silt particles dispersed in the soil at low salt concentrations and flocculated in soil voids at high salt concentrations (Takai et al., 1987; Arunin, 1992). The Ksat values had a large range between locations of 0.01–14.67 m/d (Table 1) which could be classified as very slow to very rapid (O' Neal, 1952). Furthermore, the trend in the Ksat decreased with depth. However, the Ksat in the major salt-affected soils suggested slow to very slow flow because the high level of sodium ions in these salt-affected soils induced the flocculation of small-sized particles in soil voids (Klute, 1965; Wongpokhom, 2007).

The EC_e values of these soils were in the range 0.20–74.70 dS/m and decreased with depth (Table 2). In addition, some soil horizons at all study sites had EC_e values of more than 4 dS/m, which could be considered as affected by salts (saline soils) (Brady and Weil, 2008). In particular, the topsoil had the highest EC_e values due to the movement of soluble salts from shallow groundwater upward to the soil surface during droughting. The SAR values of these soils varied between 2.30 and 85.09 and decreased with depth (Table 2). Since the SAR is usually associated with the ratio of positive charges in the soil system, especially of sodium, calcium and, magnesium ions, most soils at the study sites having SAR values between intermediate and very high were mainly associated with the extractable Na values. The ESP values of these soils were in the range 2.74–113.23% and tended to increase with increasing SAR values (Table 2). Overall, based on the EC_e, SAR or ESP or all three (Brady and Weil, 2008), the soils in the current study could be classified into two groups: saline-sodic soils at 34 locations and saline soils at 4 locations (Table 2).

In summary, the spatial distribution of the salt-affected soils was clearly observed by applying an orthographic map, demonstrating that most of the salt-affected soils were spatially distributed in the north of Kamphaeng Saen district. The irrigation canal system was reasonably considered as a factor pertaining to the occurrence of the salt-affected soils. In other words, the distribution of salt-affected soils mostly originated near irrigation canals. The classification of salt-affected soils into saline-sodic soils and saline soils was helpful to indicate their development since the salt-affected soils are generally lower developed in the order: saline soils < saline-sodic soils < sodic soils. However, in some cases, saline-sodic soils can individually occur, irrespective of saline soils where an area contains a high Na^+ concentration. For this reason, the origin and alteration of salt-affected soils in the study areas still remain to be elucidated. The current observation suggested that an orthographic map can be applied to rapidly explore the distribution of salt-affected soils. Furthermore, the obtained information can provide beneficial details for agriculturists who are managing or solving further problems regarding salt influences in their arable areas and the information can be used to monitor the changes in the distribution of the salt-affected soils for each region.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Acknowledgements

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Table 1 Bulk density (BD) and saturated hydraulic conductivity (Ksat) of salt-affected soils at each study site

Site	Depth (cm)	Soil property		Site	Depth (cm)	Soil property	
		BD (Mg/m³)	Ksat (m/d)			BD (Mg/m³)	Ksat (m/d)
S01	0−20	1.67	9.07	S20	0−20	1.71	2.50
S01	30−50	1.90	1.89	S20	30−50	1.66	7.52
S01	60−80	1.95	0.45	S21	0−20	2.10	2.87
S01	80−120	1.89	2.59	S21	30−50	2.12	1.34
S03	0−20	1.95	1.80	S22	0−20	2.11	1.22
S03	30−50	1.83	4.84	S22	30−50	2.19	0.55
S04	0−20	2.07	0.15	S23	0−20	1.91	0.39
S04	30−50	1.85	0.66	S23	30−50	2.25	0.04
S05	0−20	1.67	0.02	S24	0−20	1.80	0.20
S05	30−50	1.83	0.75	S24	30−50	2.09	0.05
S06	0−20	1.89	3.13	S25	0−20	1.64	8.39
S06	30−50	2.03	0.92	S25	30−50	2.16	0.60
S07	0−20	1.99	0.02	S26	0−20	1.94	0.24
S07	30−50	2.13	0.02	S26	30−50	2.09	0.07
S08	0−20	1.98	4.04	S27	0−20	2.02	5.78
S08	30−50	2.07	2.86	S27	30−50	2.23	14.67
S09	0−20	1.83	7.45	S28	0−20	2.06	2.97
S09	30−50	2.00	2.30	S28	30−50	1.92	2.33
S10	0−20	2.01	9.16	S29	0−20	1.88	6.68
S10	30−50	1.80	0.08	S29	30−50	2.10	0.70
S11	0−20	1.86	6.68	S30	0−20	2.17	0.06
S11	30−50	2.24	0.12	S30	30−50	2.17	0.02
S12	0−20	1.77	4.07	S31	0−20	2.01	5.11
S12	30−50	1.83	1.83	S31	30−50	2.13	5.26
S13	0−20	1.79	2.69	S32	0−20	1.89	2.70
S13	30−50	1.96	0.44	S32	30−50	2.15	3.33
S14	0−20	2.12	0.05	S33	0−20	2.01	4.06
S14	30−50	2.06	0.50	S33	30−50	2.16	0.46
S15	0−20	1.87	1.12	S34	0−20	2.14	0.06
S15	30−50	2.19	0.02	S34	30−50	2.04	0.01
S16	0−20	2.01	1.12	S35	0−20	2.09	0.12
S16	30−50	1.98	0.17	S35	30−50	2.11	0.09
S17	0−20	1.97	0.02	S36	0−20	1.92	0.24
S17	30−50	2.40	0.10	S36	30−50	2.01	2.89
S18	0−20	1.86	1.29	S37	0−20	1.78	0.30
S18	30−50	2.36	0.29	S37	30−50	1.97	0.09
S19	0−20	2.05	0.55	S38	0−20	2.13	2.87
S19	30−50	2.18	0.05	S38	30−50	2.25	1.64

Table 2 Electrical conductivity (EC_e), sodium adsorption ratio (SAR), exchangeable sodium percentage (ESP) and type of salt-affected soils at each study site

Site	Depth (cm)	Soil properties			Type	Site	Depth (cm)	Soil properties			Type*
		EC_e (dS/m)	SAR	ESP (%)				EC_e (dS/m)	SAR	ESP (%)	
S01	0−20	26.95	22.49	17.68	SSS	S11	0−20	2.51	7.63	113.23	SSS
S01	30−50	8.33	9.07	5.66		S11	30−50	2.66	8.36	39.70	
S01	60−80	9.29	11.69	5.85		S11	60−80	5.05	11.48	4.83	
S01	80−120	8.14	10.76	7.15		S11	80−120	8.47	19.05	24.34	
S02	0−20	34.70	23.80	20.19	SSS	S12	0−20	14.83	19.27	23.87	SSS
S02	30−50	3.98	8.16	3.80		S12	30−50	4.90	8.46	13.61	
S02	60−80	3.38	9.65	6.29		S12	60−80	2.88	5.99	2.74	
S02	80−120	6.40	11.95	21.50		S12	80−120	3.82	6.69	3.70	
S03	0−20	46.20	16.02	38.59	SSS	S13	0−20	10.73	38.38	8.63	SSS
S03	30−50	10.21	14.03	4.50		S13	30−50	2.25	18.92	9.79	
S03	60−80	8.17	11.18	29.06		S13	60−80	1.65	14.95	5.30	
S03	80−120	5.61	8.15	4.40		S13	80−120	0.96	11.74	3.93	
S04	0−20	47.00	11.44	14.16	SS	S14	0−20	50.30	19.33	20.76	SSS
S04	30−50	10.00	16.80	7.12		S14	30−50	16.88	21.07	14.83	
S04	60−80	8.06	15.65	31.46		S14	60−80	16.82	19.34	12.05	
S04	80−120	7.82	15.21	8.50		S14	80−120	15.47	18.55	12.76	
S05	0−20	56.60	31.68	14.61	SSS	S15	0−20	36.90	73.23	101.83	SSS
S05	30−50	9.86	32.73	7.39		S15	30−50	13.43	40.41	97.42	
S05	60−80	5.16	36.12	12.01		S15	60−80	9.13	34.08	30.68	
S05	80−120	6.23	31.95	8.86		S15	80−120	3.76	13.97	6.91	
S06	0−20	52.00	44.43	30.77	SSS	S16	0−20	59.70	13.21	21.15	SSS
S06	30−50	8.42	22.97	5.32		S16	30−50	15.62	15.13	13.14	
S06	60−80	8.66	24.48	7.71		S16	60−80	11.56	14.64	7.86	
S06	80−120	12.08	23.94	42.59		S16	80−120	8.74	15.96	6.51	
S07	0−20	4.05	15.19	2.92	SS	S17	0−20	53.40	65.96	28.74	SSS
S07	30−50	1.83	13.96	15.17		S17	30−50	14.99	18.35	10.02	
S07	60−80	1.45	18.07	3.86		S17	60−80	14.22	16.60	9.65	
S07	80−120	0.20	12.38	3.18		S17	80−120	9.14	17.25	8.99	
S08	0−20	12.54	15.46	5.83	SSS	S18	0−20	32.50	29.46	20.97	SSS
S08	30−50	13.20	18.23	6.96		S18	30−50	12.37	20.73	11.29	
S08	60−80	12.10	20.49	6.95		S18	60−80	13.84	18.37	11.00	
S08	80−120	7.03	21.33	6.75		S18	80−120	11.67	17.69	9.17	
S09	0−20	12.62	5.55	26.27	SSS	S19	0−20	74.70	85.09	21.39	SSS
S09	30−50	10.08	11.93	7.17		S19	30−50	20.47	27.54	10.72	
S09	60−80	9.22	11.29	6.39		S19	60−80	16.11	23.57	15.02	
S09	80−120	5.17	7.46	4.11		S19	80−120	17.01	22.54	26.05	
S10	0−20	6.30	24.90	6.22	SSS	S20	0−20	1.75	2.30	46.48	SSS
S10	30−50	1.05	10.42	2.82		S20	30−50	3.46	3.22	54.43	
S10	60−80	0.82	8.65	3.97		S20	60−80	7.40	7.20	4.92	
S10	80−120	0.70	8.32	3.99		S20	80−120	7.46	8.01	4.05	
S21	0−20	45.70	12.29	25.44	SSS	S30	0−20	36.80	33.11	41.84	SSS
S21	30−50	12.17	14.82	63.28		S30	30−50	11.90	14.89	35.99	
S21	60−80	11.50	20.59	14.91		S30	60−80	12.01	12.57	8.23	

Table 2 Continued

Site	Depth (cm)	Soil properties			Type	Site	Depth (cm)	Soil properties			Type*
		EC_e (dS/m)	SAR	ESP (%)				EC_e (dS/m)	SAR	ESP (%)	
S21	80−120	15.98	13.59	50.01		S30	80−120	13.74	15.69	7.74	
S22	0−20	56.60	11.47	30.84	SSS	S31	0−20	34.40	13.38	35.12	SSS
S22	30−50	20.01	13.69	11.76		S31	30−50	14.20	11.56	27.41	
S22	60−80	16.03	19.12	16.37		S31	60−80	16.26	13.98	49.78	
S22	80−120	17.71	19.39	4.63		S31	80−120	13.65	14.76	26.15	
S23	0−20	24.91	17.56	8.80	SSS	S32	0−20	16.17	15.71	14.48	SSS
S23	30−50	10.90	11.01	4.72		S32	30−50	7.69	10.32	39.02	
S23	60−80	7.01	8.49	4.85		S32	60−80	4.45	10.48	34.02	
S23	80−120	6.48	7.02	6.56		S32	80−120	6.64	10.77	20.84	
S24	0−20	57.20	45.81	18.59	SSS	S33	0−20	31.30	30.48	105.49	SSS
S24	30−50	15.62	13.23	11.13		S33	30−50	3.02	11.42	42.21	
S24	60−80	10.18	10.66	8.78		S33	60−80	2.53	15.03	23.55	
S24	80−120	10.93	11.43	9.95		S33	80−120	3.46	12.16	21.48	
S25	0−20	35.50	16.41	17.07	SSS	S34	0−20	46.10	17.25	21.63	SSS
S25	30−50	11.25	12.07	45.33		S34	30−50	17.38	18.49	24.76	
S25	60−80	11.15	11.73	31.36		S34	60−80	12.42	11.79	22.44	
S25	80−120	12.53	12.08	28.45		S34	80−120	12.19	12.23	21.93	
S26	0−20	70.80	59.96	87.14	SSS	S35	0−20	14.41	17.90	34.39	SSS
S26	30−50	13.03	13.03	15.73		S35	30−50	10.75	14.51	32.82	
S26	60−80	11.45	10.91	19.03		S35	60−80	7.53	19.74	27.54	
S26	80−120	10.95	12.30	30.39		S35	80−120	6.23	17.68	32.04	
S27	0−20	7.38	8.67	7.74	SS	S36	0−20	47.80	42.15	43.16	SSS
S27	30−50	4.96	6.04	4.79		S36	30−50	24.85	22.78	42.56	
S27	60−80	4.96	5.96	11.00		S36	60−80	21.35	22.40	48.38	
S27	80−120	2.69	7.08	19.56		S36	80−120	21.32	23.22	42.19	
S28	0−20	33.00	9.16	30.37	SSS	S37	0−20	26.50	29.88	32.86	SSS
S28	30−50	8.59	10.02	15.14		S37	30−50	7.84	11.59	15.97	
S28	60−80	8.33	11.16	21.96		S37	60−80	7.34	10.65	48.88	
S28	80−120	8.97	10.97	11.27		S37	80−120	10.78	13.87	72.33	
S29	0−20	10.93	6.80	8.38	SS	S38	0−20	16.53	14.68	90.52	SSS
S29	30−50	4.88	7.32	19.23		S38	30−50	4.95	5.52	79.90	
S29	60−80	4.63	8.04	17.30		S38	60−80	6.26	7.11	78.51	
S29	80−120	7.52	7.51	40.32		S38	80−120	4.38	6.02	59.52	

SS = saline soils; SSS = saline- sodic soils

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