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Effects of Previous Rice Cropping History on Salt Accumulation of Surface Soils in the Middle Nile Delta, Egypt

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Agriculture in Egypt mostly depends on crop production in the Nile Delta, but problems of salinization in the surface soil become obvious due to development of Aswan High dam and irrigation agriculture. In this situation, rice cultivation is considered as a salt leaching method because it uses larger amounts of water than field crops. The present study was conducted to investigate the effects of previous rice cropping history on salt accumulation of surface soils on 15 farms in the middle Nile Delta. These surface soil samples were collected from the Agriculture Research Center (ARC) near Sakha and 14 private farms near ARC, and categorized by the record of previous rice cropping history. In addition, farmers were asked about the field conditions, such as fertilization and subsurface drainage. Irrigation water was also sampled in each area.

As results of soil analysis, there were little differences in pH, total carbon (T-C), total nitrogen (T-N), and cation exchange capacity (CEC) of the soil samples, showing the basic properties of soils were similar. However, exchangeable bases showed some differences, and electrical conductivity (EC) and exchangeable Na^{+} revealed correlations, but these differences were not related to previous rice cropping history. Ion concentrations in irrigation water were also different among areas. Based on statistical results, there were significant differences in salt accumulation of surface soils depending on area and especially in the conditions of subsurface drainage. However, previous rice cropping was seen to have had little effect on salt accumulation in the surface soils. These results show that other factors, such as subsurface drainage conditions or quality of irrigation water, affect soil salinity in these study sites rather than rice cultivation.

Key words: rice cultivation, salinization, salt leaching, Nile Delta, Vertisols

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1. Introduction

Salt accumulation of surface soils due to irrigation agriculture is a common phenomenon in arid regions. It has occurred in the Nile Delta since 1965 with the development of irrigation agriculture following the construction of the Aswan High Dam (Kitamura, 1994). Historical practices of irrigation agriculture in Egypt have favored wet-field rice cultivation as the best solution for controlling soil salinization (Kotb *et al*., 2000). In the Senegal Delta, where soil type is similar to the Nile Delta, a positive effect of desalinization with rice cultivation was also shown, probably due to salt leaching by irrigation water (Ceuppens and Wopereis, 1999). In the Nile Delta, irrigation water for wet-field rice was supplied 4 days and stopped 4 days (Watanabe *et al*., 1994). On the other hand, farmers irrigated their field every 12–15 days for field crop cultivation, such as corn (Agricultural Research Center, 2012). These data show that larger amounts of water were used for rice cultivation than for field crop cultivation. If the same amount of water

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was supplied during each irrigation time, the total amount of irrigation water in wet-field rice cultivation is roughly three to four times larger than in corn cultivation. However, another study showed re-salinization after rice cultivation, probably due to saline irrigation water (Boivin *et al*., 2002). Moreover, a study in the Nile Delta suggesting salt leaching by rice cultivation (El Guindy and Risseeuw, 1987) included some exceptional cases. In addition, all of the studies focused on differences in soil salinity before and after cultivation on experimental farms, but no previous study has observed the relationships between concentration of salts and rice cropping history. If more salts are leached by rice cultivation with larger amounts of water than other crops, more rice cultivation practices could lower concentrations of salts in surface soils. Therefore, the present study was conducted to assess whether the positive effects of frequency of previous rice cropping were shown in salt concentrations of surface soils in private farms.

2. Material and methods

2.1 Study sites

The Nile Delta has a dry climate: annual mean temperature at Cairo is 21.8℃, while annual precipitation is 26.7 mm, with 0 mm in August and 7.3 mm in December (Japanese Chronological Science Tables, 2009). In the Nile Delta, farmers practice summer and winter double cropping. In the summer season, roughly from May to September, the main crops are cotton, maize and wet-field rice. In the winter season, roughly from October to April, the main crops are wheat, sugar beet and Egyptian clover. As for water resources, agriculture in Egypt is entirely dependent on irrigation from the Nile, and most famers use perennial and basin irrigation for cultivation (El Guindy and Risseeuw, 1987). Irrigation canals and drainage canals are constructed separately throughout the Nile Delta, so little drainage water is mixed with irrigation water. However, the drainage water from industries or households is mixed into the irrigation canals (Kotb *et al*., 2000).

Fifteen study sites in the middle Nile Delta, which has heavy clay soils classified as Haplic Vertisols according to the WRB classification system (Orii, 2010), were selected, one from an experimental farm and 14 from private household farm fields. The experimental farm was in the Agriculture Research Center (ARC) (N 31° 5′ 31.0″, E 30° 56′ 0.3″), Sakha, Kafr El-Sheikh, Egypt (Fig. 1), and the private farms were situated in four areas north, south, east and west of the ARC and were within 5 km of the ARC. Farmers in each area used different branches of irrigation canals, but there was no difference in their cultivation methods. Soil samples were collected from

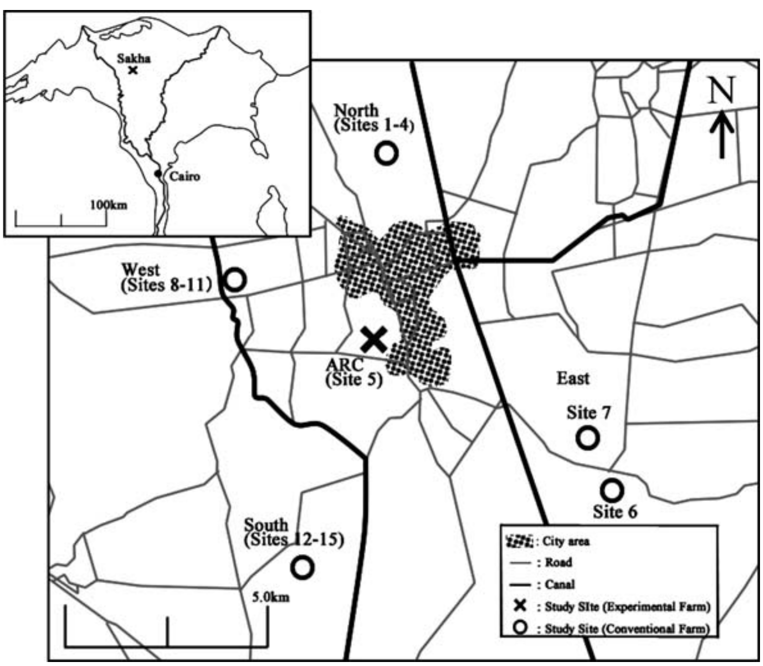

Fig. 1. Location of study sites

study sites in each area that had received different intensities of rice cropping over the past two years.

2.2 Samples

Samples of soils and bulk irrigation water were taken on 20th～26th May, 2010. There was no precipitation from March to November in 2010 (Sakha Research Station, 2012). In addition farmers were asked about their actual field practices during the past two years and the irrigation conditions, including drainage systems. Surface soil (0～20 cm) was taken from 5 sampling points on each farm representing the 4 corners plus the center point. The 5 sub-samples from a farm were well mixed, and a laboratory sample for analysis of about 500 g was taken to eliminate heterogeneity. Irrigation water was also taken from a nearby irrigation canal in each area. It was stored in 250 ml plastic bottles and kept in a refrigerator at 4℃ until analysis.

2.3 Analytical Methods

2.3.1 Physicochemical analyses of soil samples

Particle size distributions were determined by the pipette method (Nakai 1997). To remove the carbonates in soils, samples were washed and centrifuged twice with HCl (pH: 3.5), shaking for 15 minutes after H_2O_2 treatment. The pHs of H_2O and pHs of KCl were measured with a glass electrode pH meter (HM-30R, TOA Electronics Ltd., Tokyo) (Kamewada 1997a). Electrical conductivity ($EC_{1:5}$) was determined in an ultra-pure water suspension (water: soil weight ratio is 5:1), and measured with a conductivity meter (CM-30R, TOA Electronics Ltd., Tokyo) (Kamewada 1997b). Water-soluble ions were determined by ion chromatography (Prominence Series, SHIMADZU, Kyoto) (Kamewada 1997c) on the same water suspension used for electrical conductivity. Total carbon (T-C) and nitrogen (T-N) were determined with a NC-analyzer (SUMIGRAPH NC-900, Sumica Bunseki Center, Co., Ltd., Tokyo). Cation exchangeable capacity (CEC) was measured by the batch method, and NH_4^+ was determined using a semi-micro distillation method. Exchangeable bases were determined on the same extracts as CEC, and analyzed by atomic absorption spectrophotometer (AA-6200, Shimadzu Co., Kyoto).

2.3.2 Chemical analysis of irrigation water

Ions and EC of irrigation water were measured respectively by ion chromatography and with a conductivity meter as above. All the data except particle size distribution and T-C and T-N in all figures and tables are the average values of duplicate analyses.

2.3.3 Statistical analysis of data

Welch's test in SPSS (IBM) was used for statistical analyses because the standard deviations of each group were high and homoscedasticity among each group is not assumed with a F-test.

3. Results

3.1 Interview results for farmers on actual field practices

From interviews with the farmers of each sampled farm plot, we obtained information on previous rice cropping and subsurface drainage conditions (Table 1). The 15 soil samples were divided into 3 categories according to the extent of previous rice cropping history: 1) undergone no rice cultivation in the past two years, 2) cultivated once in 2008 or 2009, and 3) cultivated in both 2008 and 2009. Subsurface drainage conditions were also variable in the four studied areas. The ARC experimental farm did not have a drainage system. For the other sites, the conditions of subsurface drainage on two sites in the east and one site (no. 11) in the west of ARC were bad. On four sites in the west and one site (no. 11) west of ARC, the farmers closed subsurface drainage during rice cultivation. There were also variations between sampling sites during the period since the last irrigation or fertilization.

3.2 Physicochemical properties of surface soil

Figure 2 shows the particle size distributions of surface soils from each site. Study sites are arranged in the order of the times of previous rice cropping history in the past two years. All of the sites contained more than 40% clay, from south to north there was a gradual increase in clay content and decrease in sand content of the surface soils.

Little differences were found in pH, T-C, T-N and CEC between the soil samples (Table 2), showing that the basic properties of soils were similar; pH (8.05 to 8.67), T-C (18.42 to 29.77 g kg^{-1}), T-N (1.41 to 2.38 g kg^{-1}), and CEC (35.48 to 48.80 $cmol_c$ kg^{-1}). Exchangeable bases increased slightly from south to north (Fig. 3), but there was no trend related to previous rice cropping history in any area, so the differences in exchangeable bases were not attributable to rice cultivation. Among study sites, as compared with Ca^{2+}

Table 1. Site information about previous rice cropping history and subsurface drainage conditions

Area	North				Center (ARC)	East		West				South			
Site number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Rice cultivation in the past two years (times)	0	1	1	2	1	1	2	0	0	1	2	0	1	1	2
Subsurface drainage conditions	good	good	good	good	no drainage system	bad	bad	good	good	good	bad	good	good	good	good
Subsurface drainage conditions (during rice cultivation)	closed	closed	closed	closed	similar to closed conditions	open	open	open	open	open	closed	open	open	open	open

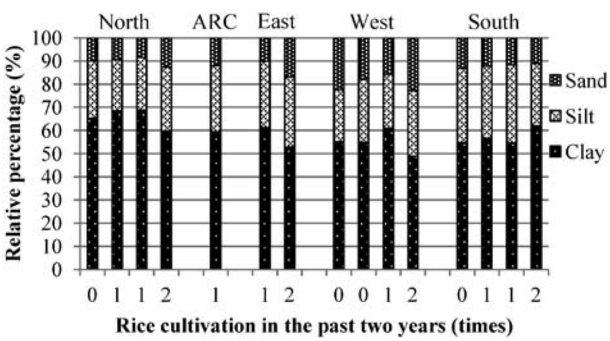

Fig. 2. Soil particle size distributions in soil samples of each study site

(45.6 to 55.1 $cmol_c$ kg^{-1}), ions of Mg^{2+}, K^+ and Na^+ varied from 12.3 to 26.5, 0.50 to 2.09, and 1.36 to 11.0 $cmol_c$ kg^{-1}. Electrical conductivity (EC) and exchangeable Na^+ revealed a correlation ($R=0.857$, $P<0.001$) (Fig. 3 and Table 2). As for water-soluble ions, Na^+, Cl^- and SO_4^{2-} differed among the study sites. Exceptionally high values were obtained at study sites n° 2 and 11.

The results of statistical analysis are shown in Table 3. There were no significant differences (all probabilities $>5\%$) among the three different groups of sites arranged by the times of previous rice cropping history (Table 3a). However, when we divided the sites by area; North and others, where there are differences such in clay content of soils and quality of water (described below), there were significant differences in total exchangeable cations and exchangeable Mg^{2+} with probabilities $<1\%$ and $<5\%$, respectively (Table 3b). Furthermore, significant differences with a probability of $<1\%$ were found for total exchangeable cations and exchangeable Mg^{2+} and a probability of $<5\%$ found for exchangeable Na^+ between the different subsurface drainage conditions during rice cultivation (Table 3c).

3.3 *Irrigation water quality*

As shown in Table 4, EC and the concentrations of ions in irrigation water were variable among sampling areas. However, they appeared to increase across the area from south to north. Although the value of EC for general irrigation water around ARC was 0.32 dS m^{-1} (Abou El-Hassan *et al*., 2009), the value in the northern area was 6 times higher than normal.

4. Discussion

This study showed that differences in the extent of previous rice cropping history did not affect the salt concentrations of surface soils (Fig. 3 and Table 3a). Therefore, the present study could not demonstrate desalinization or re-salinization effects of rice cultivation. However, El Guindy and Risseeuw (1987) showed the salt leaching is affected by rice cultivation, but included some results showing no effects by rice cultivation because of a lack of irrigation water. Furthermore, after irrigation, soil particles in Vertisols swell immediately and close the pores, resulting in a

Table 2. The pH, total carbon, total nitrogen, CEC, water-soluble ions and EC of soil samples from each site

Area	Study site number	Rice cultivation during past two years (times)	pH		T-C	T-N	CEC ($cmol_c$ kg^{-1})	Water-soluble cations				Water-soluble anions				EC
			H_2O	KCl	(g kg-1)			Ca^{2+}	Mg^{2+}	K^+	Na^+	F^-	Cl^-	NO_3^-	SO_4^{2-}	(dS m^{-1})
								($cmol_c$ kg^{-1})				($cmol_c$ kg^{-1})				
North	1	0	8.48	7.07	20.84	1.82	46.44	0.27	0.43	0.03	1.33	0.09	0.15	0.16	0.50	0.36
	2	1	8.28	7.27	18.42	1.42	48.80	0.83	0.92	0.03	5.38	0.11	1.80	0.13	4.34	1.43
	3	1	8.40	7.16	19.11	1.67	46.30	0.27	0.40	0.04	1.36	0.05	0.25	0.36	0.41	0.43
	4	2	8.36	7.15	23.08	1.97	45.44	0.28	0.38	0.04	1.52	0.11	0.31	0.20	0.67	0.43
ARC	5	1	8.28	7.15	19.33	1.53	48.67	0.37	0.56	0.10	1.37	0.05	0.48	0.36	0.85	0.49
East	6	1	8.44	7.18	19.81	1.41	39.98	0.26	0.43	0.07	1.01	0.05	0.20	0.04	0.33	0.31
	7	2	8.67	7.24	19.08	1.36	40.06	0.41	0.54	0.07	1.63	0.13	0.16	0.13	0.58	0.44
West	8	0	8.23	7.05	18.82	1.70	35.48	0.25	0.55	0.05	0.69	0.08	0.11	0.20	0.32	0.28
	9	0	8.38	7.22	20.83	1.91	38.98	0.25	0.51	0.06	1.06	0.06	0.30	0.36	0.42	0.38
	10	1	8.05	7.22	23.43	2.38	38.18	0.63	1.18	0.08	1.36	0.03	0.16	2.18	0.38	0.70
	11	2	8.10	7.34	29.77	2.72	38.18	0.79	1.04	0.19	4.07	0.06	2.00	0.68	2.46	1.23
South	12	0	8.41	7.16	19.70	1.68	41.63	0.24	0.51	0.05	0.59	0.05	0.03	0.10	0.37	0.25
	13	1	8.14	7.10	26.22	2.38	45.19	0.33	0.70	0.09	1.26	0.06	0.70	0.63	0.34	0.51
	14	1	8.29	7.15	21.84	1.70	40.39	0.30	0.38	0.12	1.21	0.08	0.28	0.10	0.59	0.45
	15	2	8.31	7.10	26.02	2.30	44.76	0.26	0.51	0.06	0.64	0.07	0.10	0.25	0.22	0.27

T-C: Total carbon, T-N: Total nitrogen, EC: Electrical conductivity, CEC: Cation exchange capacity

Table 3. Statistical results of Welch test

	(a) Effect of rice cultivation					(b) Comparison of area					(c) Influence of subsurface drainage				
	Rice cultivation in the past two years (times)	Numbers of sites	Mean	S.D.	Significance probability	Area	Numbers of sites	Mean	S.D.	Significance probability	Subsurface drainage conditions (during rice cultivation)	Numbers of sites	Mean	S.D.	Significance Probability
Total exchangeable cations	0	4	71.00	7.47											
	1	7	74.75	7.43	0.721	North	4	82.09	4.68	0.009**	closed	6	80.01	4.87	0.002**
	2	4	74.41	4.23		others	11	70.59	3.7		open	9	69.42	2.92	
Exchangeable Na	0	4	2.64	1.39											
	1	7	4.23	3.05	0.304	North	4	6.01	3.31	0.180	closed	6	5.69	2.78	0.046*
	2	4	4.57	2.03		others	11	3.13	1.6		open	9	2.7	1.22	
Exchangeable Mg	0	4	15.17	4.07											
	1	7	18.35	4.47	0.509	North	4	22.09	3.1	0.017*	closed	6	20.95	3	0.003**
	2	4	17.76	1.86		others	11	15.62	2.35		open	9	14.95	2.01	
EC	0	4	0.32	0.06											
	1	7	0.62	0.38	0.165	North	4	0.66	0.51	0.545	closed	6	0.73	0.47	0.152
	2	4	0.59	0.43		others	11	0.48	0.28		open	9	0.4	0.15	

(a) Between previous rice cropping history
(b) Between area (North and others)
(c) Between subsurface drainage conditions during rice cultivation.
(* $P<0.05$, ** $P<0.01$)

decreased infiltration rate. The use of low quality water for irrigation of rice, results in the EC of surface soils gradually increasing during the cultivation period (Boivin, 2002).

We found negative effects by closing the subsurface drainage during rice cultivation (Table 3c). However, El Guindy and Risseeu (1987) showed that 7.6 ton/ha of salts were lost in 1977 by the end of rice cultivation with the closure of subsurface drainage systems, and 1.8 ton/ha of salts were added in a field with an open system. These results may be related to differences in the amount of irrigation and surface drainage water.

The increase in salt accumulation toward the northern area was probably related to an increase in clay content (Fig. 2), the quality of irrigation water (Table 4) and closed drainage conditions during the rice season in the north area. However, since there was significant differences in exchangeable Na^+ between the subsurface drainage conditions during rice cultivation (Table 3c), these effects were larger.. Based on the data shown in Table 4, salt concentrations of irrigation water increase towards the north. Moreover, the higher amounts of Na^+, Cl^- and SO_4^{2-} in irrigation water indicate that drainage water may be mixed with irrigation water in the Northern area. Therefore, soils include more exchangeable cations further downstream in the Nile Delta.

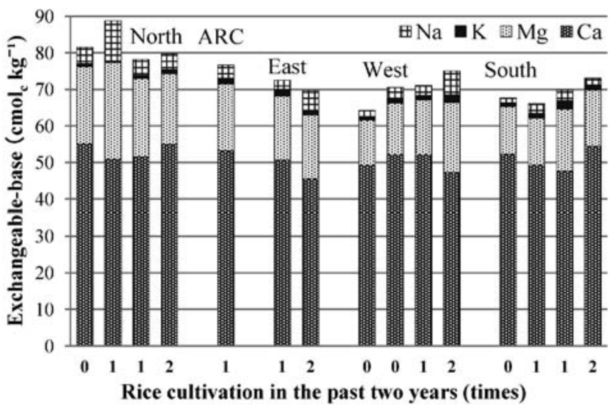

Fig. 3. Exchangeable bases in each study site

5. Conclusion

Actual field agricultural conditions in private farmlands of the middle Nile Delta were variable. The present study suggested no significant effect of rice cultivation on salt accumulation of surface soils, probably due to the confounding influence of a combination of other factors. However, this study indicates a significant effect of subsurface drainage systems on salt leaching from surface soils in agricultural fields.

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Table 4. Irrigation water quality

Area	Concentrations of ions in irrigation water							EC of irrigation water
	Na^+	Mg^{2+}	Ca^{2+}	F^-	Cl^-	NO_3^-	SO_4^{2-}	
	($cmol_c\ kg^{-1}$)							($dS\ m^{-1}$)
North (sites 1–4)	1.35	0.41	0.62	0.01	0.57	0.01	0.95	2.03
East (site 6)	0.14	0.07	0.22	0.00	0.06	0.00	0.05	0.38
East (site 7)	0.27	0.12	0.26	0.01	0.12	0.01	0.12	0.61
West (sites 8–11)	0.20	0.08	0.25	0.01	0.09	0.00	0.06	0.41
South (sites 12–15)	0.14	0.09	0.24	0.01	0.05	0.00	0.04	0.40

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