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Spatial and Temporal Variation of Soil Salinity During Dry and Wet Seasons in the Southern Coastal Area of Laizhou Bay, China

Liu Wenquan[1,2], Lu Fang[2,3]*, Xu Xingyong[1,2]**, Chen Guangquan[1,2], Fu Tengfei[1,2] & Su Qiao[1,2]

[1]Key Laboratory of Marine Sedimentology and Environmental Geology, First Institute of Oceanography, SOA, Qingdao, 266061, China

[2]Laboratory for Marine Geology, Qingdao National Laboratory for Marine Science and Technology, Qingdao, 266061, China

[3]Shandong Provincial Key Laboratory of Marine Environment and Geological Engineering, College of Environmental Science and Engineering, Ocean University of China, Qingdao, 266100, China

*[E-mail: fang_lu1130@163.com; **xuxingyong@fio.org.cn]

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The southern coastal area of Laizhou Bay is subjected to severe soil salinization due to saline groundwater. The degree of spatial variability is strongly affected by seasonal changes during an annual cycle. In this paper, the spatio-temporal variability of soil salinity in Laizhou Bay, China, was examined to ascertain the current situation of soil salinization in the study area and to reveal the characteristics of seasonal variation of soil salinity. The classical statistical methods and geostatistical methods were applied to soil salinity data collected from four soil layers, i.e., 0-30, 30-60, 60-90, and 0-100 cm, during summer and autumn in 2014. The results indicated that the variation of soil salinity of all the soil layers in summer and autumn was moderate. The soil salinity in the 0-30 cm layer showed a moderate spatial autocorrelation, whereas the spatial autocorrelations of soil salinity in other layers were strong. The overall spatial distribution of soil salinity showed a clear banding distribution and the degree of salinization in the eastern area was lower than that in the western and northern regions.A high ratio of evaporation/precipitation is one of the important reasons for the soil salinity in July is significantly higher than that in November. The rank of soil salinity under different land-use types was: salt pan > orchard > weeds > soybean > woods > cotton > maize > ginger > sweet potato. The research findings can provide theoretical guidance for accurate assessment and soil partition management of regional soil salinization.

[**Keywords:** Dry and wet seasons; Geostatistics; Laizhou Bay; Soil salinity; Spatial variability]

Introduction

Soil salinization is one of the keylimiting factors foragriculture production and sustainable development across the world[1,2]. It influences crop growth, soil quality, microorganisms and ultimately result in soil erosion and desertification[3-6]. In recent years, with the development of precision agriculture, studies regarding the spatio-temporal variability of soil salinization in coastal areas have become one of the key focuses of soil science research. At present, the main research regions in China include Liaodong Bay[7], Tianjin coastal region[8], Yellow River Delta[9], Laizhou Bay[10], and surrounding areas of the Yangtze River Delta[11]. Combination of geostatistics and GIS has been proved to be an effective method to study spatial variation of soil attributes and to quantify the variations of another farmland features[12-15]. Geostatistics derives from multivariate statistics and provides a theoretical framework for interpolation of spatial data and uncertainty analysis[16]. By using original data and the structure of semi-variance function, the kriging method can be applied to implement interpolation for unsampled sites using an unbiased optimal estimation of the regionalized variables[17]. Since the middle of 1980s, geostatistics and the kriging method have been gradually introduced into research on the spatial variation of soil salinity, promoting the development of the discipline[18-20].

Currently, the studies pertaining to spatio-temporal variation of soil salinity in coastal regions mainly focused on field scale[21], which cannot ascertain the dynamic changes of soil salinity at the regional scale. The large-scale studies that have been carried out predominately focused on topsoil and the monitoring relies on remote sensing (RS) technology[22-25]. However, most remote sensors can only record the soil salinity in surface layers[26-28]and are unable to respond to the salinity variation in the crop roots layer thathas a significant influence on crop development and yield. Li and Shi[29] stated that the saline groundwater within the depth of 3m can rise up to the soil surface by capillary movement and accumulating salts in the surface soil, leading to significant vertical salinity variations. Therefore, it is necessary to analyze the soil salinity in deeper layers to ascertain the characteristics of spatio-temporal variations in soil salinity.

The southern coast of Laizhou Bay, China, located near the shore of Bohai Sea, underwent three large transgressions in history and high-salinity brine exists in the underground phreatic stratum[30,31]. In recent decades, excessive underground brine pumping for solar salt has led to the formation of underground depression cones, introducing large-scale seawater intrusion, and as a result, soil salinization has become a serious problem in thearea[10]. The spatial variability of salinity is one of the major natural attributes of saline soil, and the degrees of spatial variation are strongly influenced by seasonal changes during one annual cycle. Between the wet season with concentrated precipitation and the dry season with infrequent rainfall, great differences are observed in the salt content and the distribution of salinity in the soil profile. Therefore, monitoring and analyzing the spatio-temporal distribution and variability of soil salinization subsequently reveal the laws that govern the spatio-temporal variation, are of great importance for the treatment of saline soil and promoting agricultural production as well as regional sustainable development.

The aim of this study is to: a) ascertain the spatio-temporal variability of soil salinity in various layers during dryand wet seasons; b) analyze the environmental factors affecting soil salinity; and c) to study influence of land-use types on salinity distribution.

Materials and Methods

Study area

The study area is located in the northern coastal plain of Weifang, and the area extends from Xiaoqing River in the west, to Jiaolai River in the east (Fig. 1). The study area is a piedmont clinoplain with an altitude below 20 m and covers about 3056 km^2. This region belongs to warm temperate and monsoon climate zone and has the characteristics of both marine and continental climates. The average precipitation is about 600 mm, of which approximately 60% occurs during summer, and the proportion of precipitation during winter and spring is relatively low. The average evaporation is about 1900 mm, which is more than three times the annual precipitation. Cotton is the main crop in the northern region, and the crops in the southern region are mainly wheat, corn, soybean, and sorghum. The predominant soil type is salinized flavor-aquic soil. Because this area has historically suffered from high-salinity underground water, a large amount of soluble salts has accumulated in the soil, and consequently high soluble salt content has become the major factor restricting local agricultural production and development[32].

With the application of hydraulic engineering structures for retaining and recharging in recent decades, most of the atmospheric precipitation and surface runoff enters into the groundwater system. The local government transfers water from reservoirs for irrigation in every April. However, the fields near the coast of Laizhou Bay are far away from reservoirs, thus could not obtain enough fresh water for irrigation. Moreover, a small quantity of precipitation is not sufficient for salt leaching. As a result, the dynamic process of "desalination-salification" is generated in the soil in the study area.

Soil sampling

To accurately reflect the actual situation of the study area, based on the situation of the local agriculture, most of the sampling sites were set in farmlands, and other sites were in the salt wasteland, forest land or grassland (Table 1). The ArcGIS 9.3 software was used to vectorize the administrative map of Weifang City, and the built-in function "fishnet" was applied to lay out the sampling sites at an interval of 6 km (Fig. 1). The samples were collected during early July 2014 (summer) and late November 2014 (autumn). Soil samples were collected according to the five-points sampling method at each site, i.e., four soil samples were taken from the four corners of 1 × 1 m square and one sample was collected from the

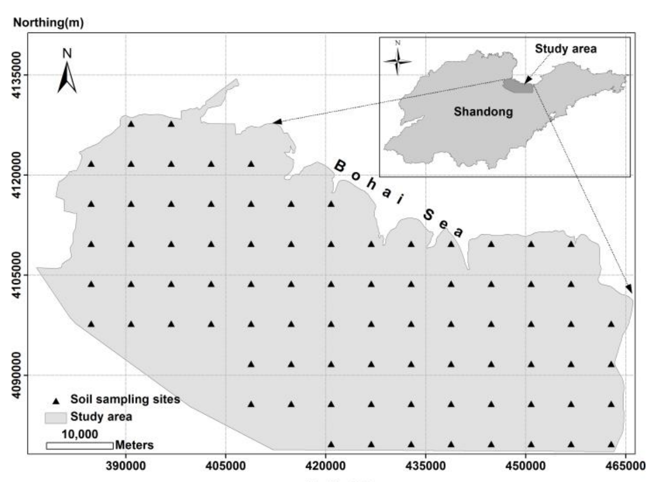

Fig. 1 —Geographical location of the study area and soil sampling sites

Table 1 — Statistical table of sampling quantity of each land use type

Time	Types of land use (n)									
	Soybean	Ginger	Sweet potato	Orchard	Woods	Cotton	Salt pan	Maize	Weeds	Total
July	6	4	5	4	11	14	11	22	5	82
November	6	4	5	4	11	12	7	22	5	76

centre of respective square. Five soil samples form a composite sample. The sampling layers at each site were 0-30, 30-60 and 60-90 cm. The total number of soil samples was 246 in summer and 228 in autumn, respectively. Finally, one-half of the soil samples from3 layers at each site were mixed to form the sample for the 0-100 cm layer.

Soil analysis

All collected samples were sealed and labeled on site. The samples were air-dried naturally indoor and then triturated with a wooden stick. Subsequently, all soil samples were passed through a 2 mm sieve prior to lab analyses. Soil salinity was determined using $EC_{1:5}$ (electrical conductivity of 1:5 soil/water paste extract). The soil salinity of each soil sample was measured according to the procedure given by U.S. Salinity Laboratory Staff[33].

Data processing and analysis

The Origin Pro 9.0 was used to summarize and analyze all the soil attributes data. One-way ANOVA method was applied to analyze whether the soil salinity was significantly different between samples collected in different layers, during different periods, and under different land-use types. The GS^+9.0 was applied to perform the geostatistical analysis of soil salinity data and select the optimal fitting model of the spatial distribution of soil salinity. The ordinary kriging method and the geostatistical analysis module built-in the Arc GIS 9.3 were implemented to generate the spatial distribution maps and partition maps of soil salinity in different layers during wet and dry seasons.

Validation

In order to evaluate the accuracy of the predictive model, this study randomly selected soil conductivity data from each layer from 15 sampling sites, for a total of 120 samples in dry and wet seasons. The mean error (ME), root mean squared error (RMSE), and coefficients of determination (R^2) were used to compare the predicted and observed values at each site[34,35].The equations of the three criteria were as follows:

mean error:

$$ME = \frac{1}{n}\sum_{i=1}^{n}\left[\hat{Z}(s_i) - Z(s_i)\right] \quad \ldots (1)$$

root-mean-square-error:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[\hat{Z}(s_i) - Z(s_i)\right]^2} \quad \ldots (2)$$

the coefficient of determination:

$$R^2 = \left[\frac{\sum_{i=1}^{n}(Z(s_i) - Z(s_i)_{ave})(\hat{Z}(s_i) - \hat{Z}(s_i)_{ave})}{\sqrt{\sum_{i=1}^{n}(Z(s_i) - Z(s_i)_{ave})^2 + \sum_{i=1}^{n}(\hat{Z}(s_i) - \hat{Z}(s_i)_{ave})^2}}\right]^2 \quad \ldots (3)$$

where $\hat{Z}(s_i)$ denoted predicted values, $Z(s_i)$ denoted observed values, $\hat{Z}(s_i)_{ave}$ and $Z(s_i)_{ave}$ denote the average of predicted values and observed values, respectively, and n denotes the sample size. The optimal predictive model should have an $R^2$of approximately1, ME close to 0, and RMSE as small as possible.

Results

Descriptive statistical analyses of total salt content in the soil

The classical statistical analysis was implemented on the soil salinity of layers 0-30, 30-60, 60-90, and 0-100 cm, and the results are shown in Table 2. In order to avoid the scale effect, data applied in the calculation of the semi-variance function should conform to the normal distribution[36]. The normality test of data ($p< 0.05$, 2-tailed) using single sample K-S (Kolmogorov–Smirnov)method showed that the soil salinity in all the layers did not coincide with the normal distribution. The logarithmic transformation of the data was performed and obtained an approximately normal distribution. Thus, the calculation of the semi-variance function was conducted with the data after the logarithmic transformation.

As shown in Table 2, evident differences were observed in the characteristic parameters of soil salinity among different soil layers during the same period. Additionally, the characteristic parameters of the soil salinity of the same soil layer during different periods also showed a remarkable variation. According to the amplitude of variation of soil salinity in different layers, the maximum value of soil salinity was observed in the

Table 2 — Summary statistics of soil salinity in summer and autumn

Sampling time	Soil layers(cm)	Min($dS\cdot m^{-1}$)	Max($dS\cdot m^{-1}$)	Mean($dS\cdot m^{-1}$)	SD	CV(%)	C_s	C_k	*K-Sp*
Summer	0~30	2.47	19.50	5.96	3.38	56.64	2.22	5.30	0.15
	30~60	2.68	53.61	7.02	6.98	99.43	4.54	5.97	0.23
	60~90	2.45	55.72	8.30	7.74	93.17	3.63	4.87	0.23
	0~100	2.69	41.76	7.10	5.59	78.77	3.93	6.79	0.07
Autumn	0~30	2.13	19.33	5.39	3.31	61.40	2.13	3.88	0.13
	30~60	2.20	27.12	5.87	4.29	73.11	2.60	4.42	0.16
	60~90	2.26	46.13	7.10	6.75	95.05	3.48	5.79	0.14
	0~100	2.34	23.92	6.20	4.58	73.89	2.33	5.44	0.09

'Min' is the minimum, Maxis the maximum, 'SD' is the standard deviation, 'CV' is the coefficient of variation, 'Cs' is theSkewness, 'Ck' is theKurtosis, 'K-S' p is the significance (two-tailed) ofone-sample Kolmogorov–Smirnov test.

60-90 cm layer in summer and was 22.7 times higher than its minimum value, with a difference of $53.27dS\cdot m^{-1}$ between the two values. In addition, except the 0-30 cm layer, the amplitudes of variation of soil salinity in other layers were all greater than 15 times during summer. During autumn, the amplitudes of variation of total salt content in the 60-90 cm layer were 20.4 times, while the amplitudes of variation of other layers were around 10 times. The minimum soil salinity of each soil layer during the two periods was basically consistent and the variation was not obvious. However, the maximum values of each layer during summer are apparently higher than that of the corresponding layers during autumn. This is probably because the southern coastal area of Laizhou Bay is characterized by relatively low rainfall and high evaporation capacity, and the soil sampling was carried out during July, which is not yet the rainy season in the area. Therefore, the evaporation of soil water is high and hence higher salt accumulation in the soil. On the contrary, the soil salinity was influenced to a certain degree by a small-scale rainfall occurred before the sampling in November.

As seen in Table 2, that the variation range of the mean soil salinity of each layer falls in the range of $5.39dS\cdot m^{-1}$ to $8.30dS\cdot m^{-1}$. This indicated that the high soil salinity is a major factor restricting the local agricultural production. Furthermore, no apparent variation was observed between the mean soil salinity data of different layers during summer and autumn, which indicated a small vertical variation of the average soil salinity between different layers. The above results showed that the salinization during both periods have a homogeneous pattern along the depth, and the tendency of surface accumulation and bottom accumulation was unobvious.

Table 2 shows that the coefficients of variation of soil salinity in the soil layers were relatively high, which was consistent with research in other coastal regions[20,37,38]. The coefficient of variation of soil salinity ranged from 56.64% to 99.43%, which fell within the range of 0.1 to 1.0 and belonged to moderate variation[39].The coefficients of variation of 0-30 cm soil layer in summer and autumn were smaller than those of other layers in the same period and constantly increased with depth, which indicated that the horizontal variation of soil salinity increased along with the depth. This can be ascribed to the variation of local micro-geomorphology, different land-use types, and the management measures in the study area.

Validation of soil salinity

Figure 2 shows the relationship between the observed and verified values of soil conductivity from each soil layer, and Table 3 shows a summary of cross-validated results. As shown in Figure 2, the R^2range of predicted and measured soil conductivity from each layer was within 0.889-0.955.

Table 3 shows that the ME range was within 0.210-0.442, and the RMSE range was within 0.282-0.473. Validated results showed that R^2 was approximately 1, ME was close to 0, and the RMSE was small, which indicated that the accuracy of the predictive model was relatively high and had strong explanatory value when simulating the distribution of soil conductivity in the vertical profiles. Given these results, the geo statistical method could be adopted to predict the spatial distribution characteristics of soil salinity.

Analyses of spatial variability of soil salinity

The kriging method of geo statistics was used to analyze the spatial variation of soil salinity in different soil layers during summer and autumn. The semi-variance model performance was examined by the determination coefficient (R^2) and the residual sum of squares (RSS). The model with the R^2 close to 1 and the lowest RSS value was selected as the optimal fitting model. The fitting parameters of the

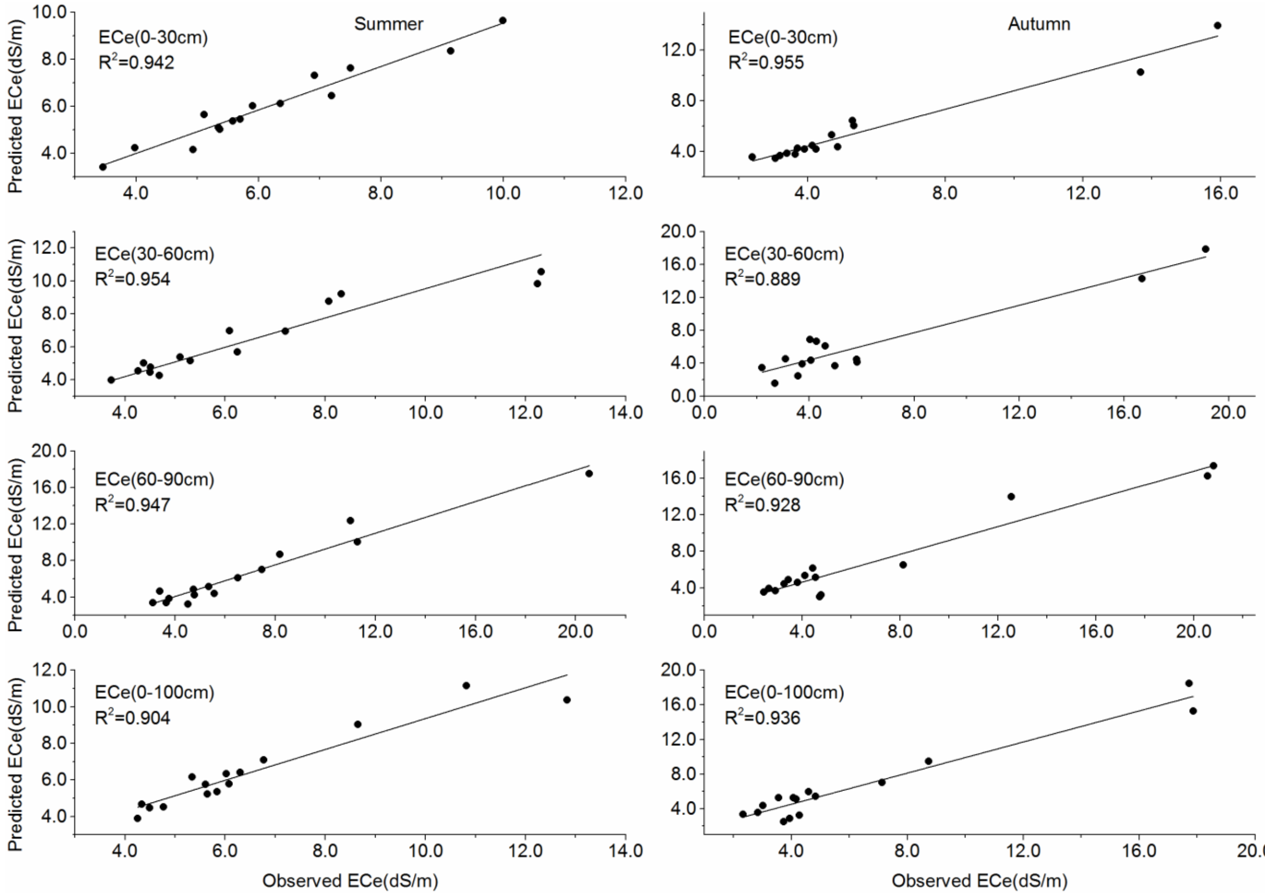

Fig. 2 — Scatter plots of observed and validated values

Table 3— Cross-validated results of soil conductivity at each layer

Time	Items	N	R^2	ME	RMSE
Summer	$ECe_{(0\text{-}30cm)}$ (dS m^{-1})	15	0.942	0.363	0.412
	$ECe_{(30\text{-}60cm)}$ (dS m^{-1})	15	0.954	0.254	0.282
	$ECe_{(60\text{-}90cm)}$ (dS m^{-1})	15	0.947	0.306	0.337
	$ECe_{(0\text{-}100cm)}$ (dS m^{-1})	15	0.904	0.371	0.394
Autumn	$ECe_{(0\text{-}30cm)}$ (dS m^{-1})	15	0.955	0.210	0.248
	$ECe_{(30\text{-}60cm)}$ (dS m^{-1})	15	0.889	0.442	0.473
	$ECe_{(60\text{-}90cm)}$ (dS m^{-1})	15	0.928	0.309	0.342
	$ECe_{(0\text{-}100cm)}$ (dS m^{-1})	15	0.936	0.293	0.319

semi-variance theoretical models of soil salinity in different layers were listed in Table 4.

Table 4 shows that the spatial distribution of soil salinity in the 0-30 cm layer during summer and autumn could be best described by the spherical model, and that of other layers were best fitted by the exponential model. This indicated a consistent spatial distribution of soil salinity of each soil layer during the two periods. According to the grading standard of the spatial correlation of the regionalized variable[40], the spatial autocorrelation is strong if the Co/C ratio is lower than 25%, moderate with the Co/C ratio between 25% and 75%,and weak when the Co/C ratio is higher than 75%. As given in Table 4, the Co/C ratio of soil salinity in the 0-30 cm layer in summer and autumn were 36.36% and 45.00%, respectively. These values fell into the range of moderate spatial autocorrelation and indicated that the spatial distribution of soil salinity was jointly and almost equivalently affected by both natural factors (e.g., climate, parent material, and micro-geomorphology) and human factors (e.g., land-use, tillage measure, and irrigation)[41]. The Co/C ratios of soil salinity in the 30-60 cm and 60-90 cm layers during summer and autumn were all less than 25%, indicating strong spatial autocorrelation and the spatial distribution of soil salinity in the layer beneath the tilth soil was mainly affected by natural factors. In the whole soil profile (0-100 cm), the Co/C ratios of soil salinity during both summer and autumn were 28.00%and 27.86%, which indicated a moderate spatial autocorrelation. This proved that the spatial distribution of the salinity of the whole soil profile was jointly affected by both natural and human

Table 4 — Parameters of semi-variance theoretical models of soil salinity

time	Soil layers (cm)	Model	Co(dS^2/m^2)	C(dS^2/m^2)	Co/C(%)	Ao(m)	R^2	RSS
Summer	0~30	Spherical	0.08	0.22	36.36	17010	0.77	0.005
	30~60	Exponential	0.04	0.21	19.04	11640	0.82	0.003
	60~90	Exponential	0.13	0.59	22.03	15627	0.78	0.002
	0~100	Exponential	0.07	0.25	28.00	17640	0.73	0.001
Autumn	0~30	Spherical	0.18	0.40	45.00	18213	0.82	0.009
	30~60	Exponential	0.11	0.46	23.91	56730	0.76	0.002
	60~90	Exponential	0.13	0.53	24.52	36930	0.88	0.003
	0~100	Exponential	0.17	0.61	27.86	48990	0.78	0.002

Co is the nugget variance, C is the sill value, Co/C is the nugget-to-sill ratio, 'Ao' is the lag size,'R^2' is the coefficient of determination and RSS is the residual sum of squares.

factors. By comparing the results of the two periods, it can be concluded that the 0-30 cm layer is tilth soil, which was frequently affected by human activities. A decrease inhuman impacts was observed in the lower layers. Thus, the spatial distribution characteristics of the soil salinity were consistent with the actual situation. Additionally, as also given in Table 4, the model performances were quite satisfactory for all soil layers, since the determination coefficients of the fitted models for the spatial distribution of soil salinity were significant at the level of $p < 0.05$ and the RSS values were relatively low. The obtained semi-variogram parameters in Table 4were then used in the ordinary kriging to generate the spatial distribution of soil salinity.

Spatial distribution of soil salinity

The kriging method was employed to analyze the spatial distribution of soil salinity. Figures 3 and 4 show the spatial distribution of soil salinity of 0-30, 30-60, 60-90, and 0-100 cm soil layers during summer and autumn in the study area.

As presented in Figure 3, an obvious difference was observed in the spatial distribution of soil salinity between each layer during summer. Yet, an overall banding distribution was presented in the study area. The soil salinity gradually decreased along the direction of the ocean to the continent, and the soil salinity in the eastern area was evidently lower than that of the western and northern areas. The aggravation of soil salinity in the northern area was probably due to the long-term seawater intrusion and high level of groundwater in the area, and the underground salinity rises to the surface through capillary action. Soil salinity in the eastern area was lower on account of the fresh groundwater supply from Jiaolai River.

According to the spatial distribution of the soil salinity in each layer during summer (Fig. 3), the variation of the soil salinity in 0-30 cm layer was relatively large, which possibly arose from the disturbance of human activities in the tilth soil layer (e.g., fertilization and other management measures) during the growing season of crops. Except for the 0-30 cm layer, the spatial distributions of soil salinity of other layers were similar.

Figure 4 shows a similar and regular spatial distribution of the soil salinity in all the layers during autumn. The slight variation of soil salinity in autumn was probably because human activities generally ceased in the field during this period and the migration of soil salinity mainly depended on natural factors. The soil salinity decreased along the direction of the ocean to the continent, which was consistent with that in summer. However, the soil salinity in the eastern area was remarkably higher than that in the same region during summer. This is mainly because the Jiaolai River is a seasonal stream. Concretely, the river is recharged by precipitation and the volume of runoff is large in summer, which could restrain the salinization effectively; whereas the atmospheric precipitation basically terminates in autumn and soil salinity in groundwater gradually rises to the surface through soil capillarity, and consequently salinization aggravates in the soil.

Discussion

Effect of precipitation and evaporation on soil salinity

Climate change, especially the changes of precipitation and evaporation, is an important driving factor for soil salt migration in coastal areas[42,43]. Under natural conditions, salts in the soil rises with evaporation and results in salt accumulation in the upper layers of soil. The effect of soil salt accumulation is stronger under high evaporation process, the salt in the soil dissolve in water and move downward as the rain water permeates into the

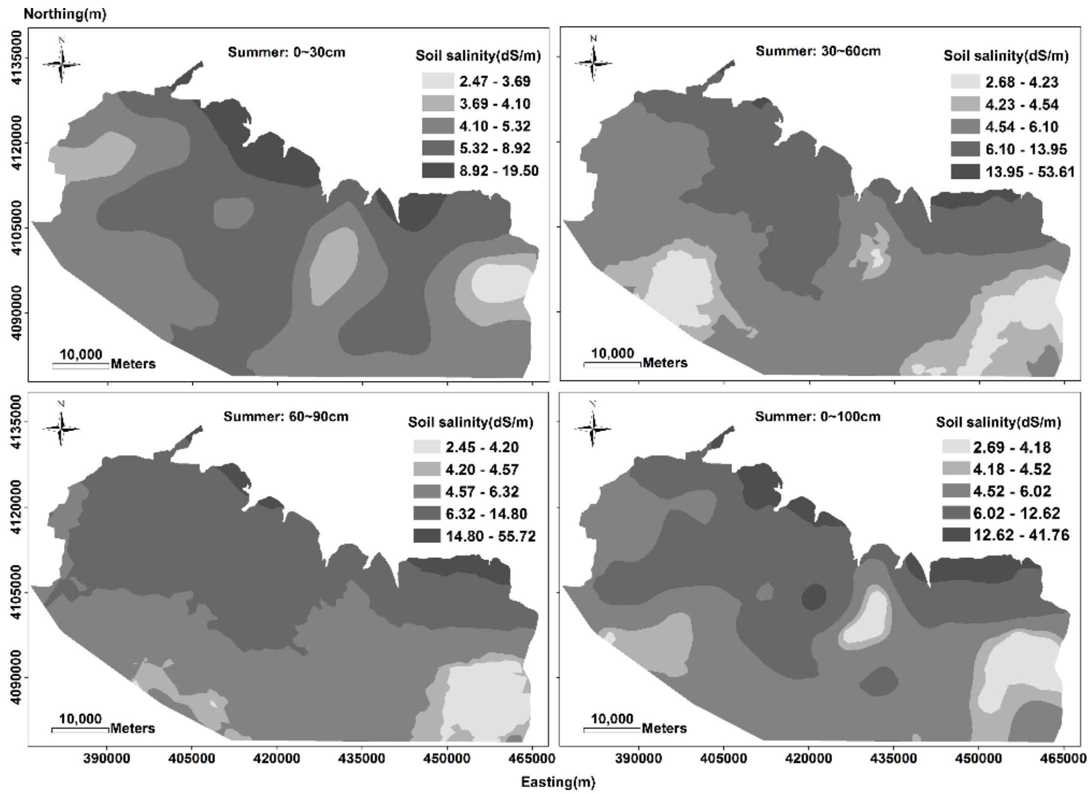

Fig. 3 — Spatial distribution of soil salinity in each layer during summer

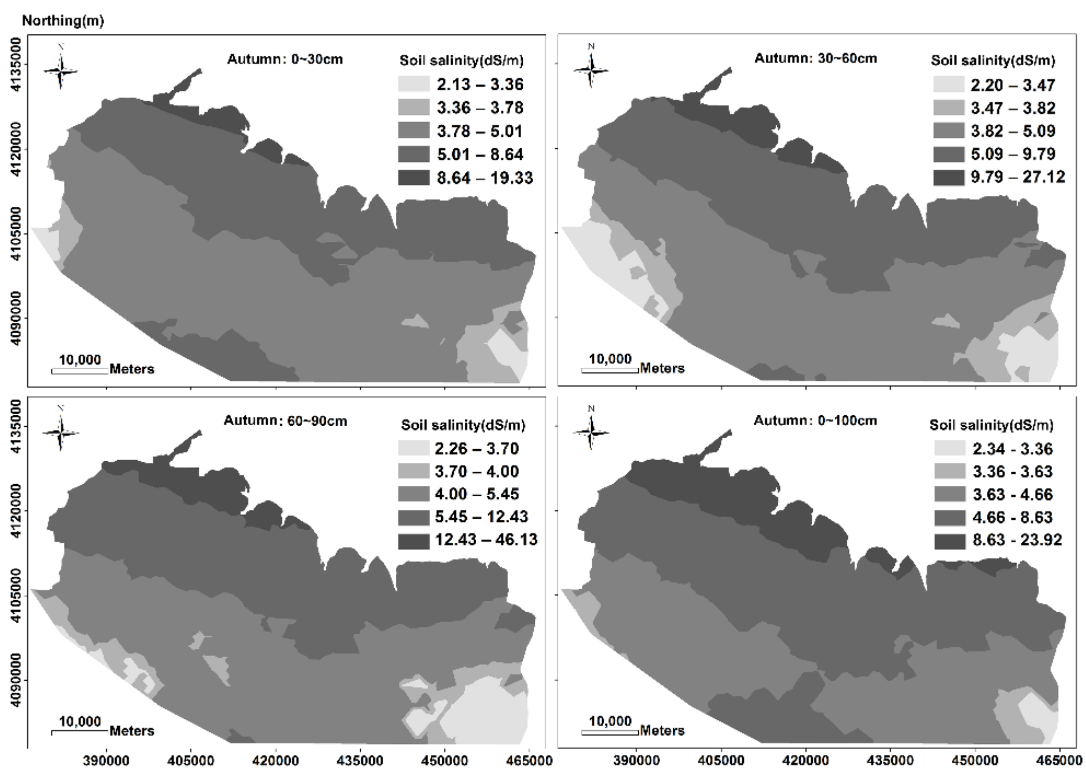

Fig. 4 — Spatial distribution of soil salinity in each layer during autumn

soil and moves down. Meanwhile, the rainwater infiltration recharges groundwater and causes a high groundwater level. The shallow groundwater level may lift above the evaporation critical surface thus lead to obvious salt accumulation in the sub-surface layers of soil in dry seasons[44].

In this paper, the sampling time of the present research was in July and November 2014, and the weather was sunny. As shown in Figure 5, precipitation and evaporation in July were much higher than that in November. Although July was the local rainy season, the soil salt content in July was significantly higher than that in November. This was because the local weather was sunny one week before the sampling time and had a large quantity of evaporation, the average ratio of evaporation/precipitation was about three times of that in November. A high ratio of evaporation/precipitation causes rising of salt from the bottom of the soil up to the root layer. Therefore, the soil salinity in the moist season (July) was higher than that in the dry season (November).

However, climate change is a slow and long-term process, as well as its impact on soil salinity. Therefore, the research on the influence of the ratio of evaporation/precipitation on soil salinity needs further processing and analysis of the relevant data, so as to obtain more accurate results.

Soil salinity variation under different land-use types

Numerous studies have shown that different land-use types can influence the trends and extents of changes of soil environment[45,46]. Different land-use types may result in obvious changes of soil attributes and physicochemical properties[47]. Figure 6 presents that soil salinity under different land-use types varied

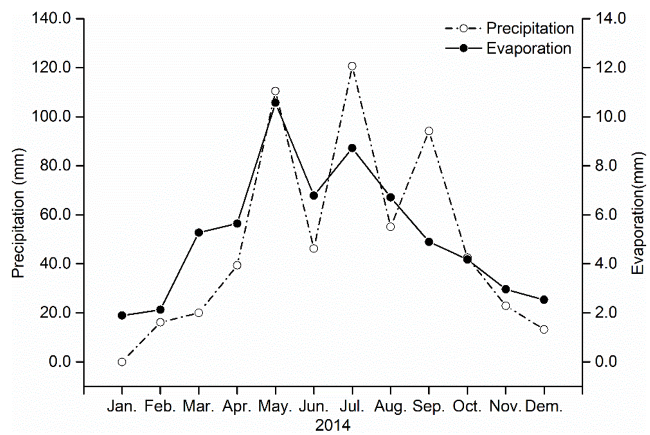

Fig. 5 — Average monthly precipitation and evaporation of study area in 2014

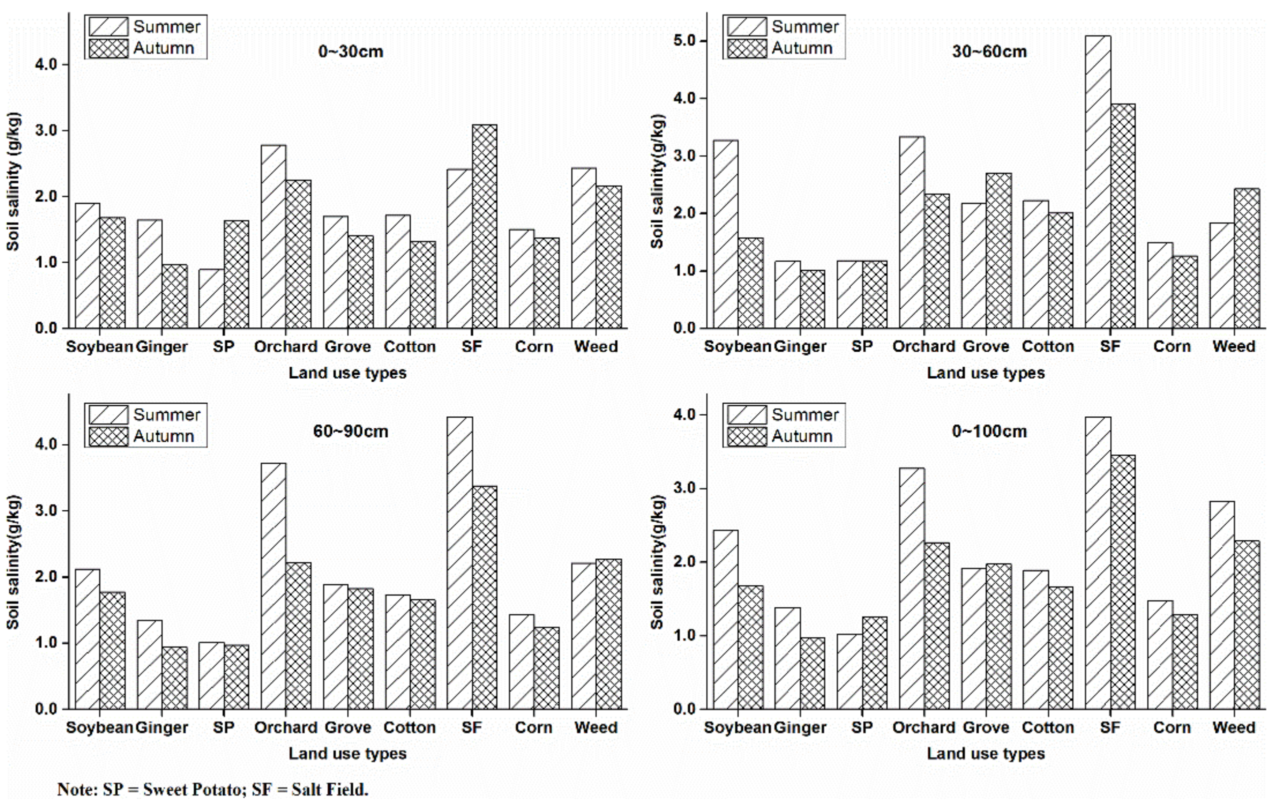

Fig. 6 — Multiple comparisons of soil salinity content in different land use types

significantly with soil depth and sampling time. The soil salinity values under different land-use types in summer were higher than that in autumn in all soil layers. Moreover, the soil salinity clearly increased with depth. In the 0-30 cm layer, the soil salinity of three land-use types was relatively high, i.e., salt pan, orchard, and weeds, whereas those of other types were basically similar. In the 30-60 cm layer, soil salinity under the types of salt pan and orchard were relatively high, while thatof the ginger field was lower. Similarly, the soil salinity of salt pan and orchard land-use types were substantially higher than those of other types in the layers of 60-90 cm and 0-100 cm. Above all, the ranking of soil salinity under different land-use types can be concluded as salt pan > orchard > weeds > soybean > woods > cotton > maize > ginger > sweet potato, which basically coincided with the salt tolerance of crops[48,49].

Conclusion

Soil salinization is a major limiting factor on agricultural production and development in the southern coastal area of Laizhou Bay, China. In this paper, the spatio-temporal variation of soil salinity, the influence of climate change and the different land-use types on soil salinity in the study area were analyzed through the soil salinity data collected from four layers (0-30, 30-60, 60-90, and 0-100 cm) during summer and autumn in 2014. Besides, the spatial distributions of soil salinity during summer and autumn were presented.

The research results showed large variational amplitudes of soil salinity in different layers and the soil salinity increased with depth. The validation result showed that geostatistical method is suitable for assessing soil salinity distribution in the study area. The spatial distribution of soil salinity in 0-30 cm layer during summer and autumn accorded with the spherical model and had moderate spatial autocorrelation. The spatial distributions of other soil layers could be best described by the exponential model and the spatial autocorrelations were strong. Results of kriging interpolation showed a banding spatial distribution of soil salinity and the salinization degree gradually decreased from the ocean to the continent on account of factors such as seawater intrusion. Furthermore, the salinization degree in the eastern part of the study area was clearly lower than that of the western area due to ground-water recharge from the Jiaolai River in the east of the study area. A high ratio of evaporation/precipitation is one of the important reasons for the soil salinity in July is significantly higher than that in November. Different land-use types will change the accumulation of substances in soil. Soil salinity distribution also has obvious accumulation characteristics. Soil salinity under different land-use types in each soil layer is significantly higher in summer than in autumn, and the soil salinity increased as the augment of depth. In terms of different land use types, the salinity of soil was higher under the following three types: salt pan, orchard, and weeds. The ranking of soil salinity under different land-use types was as follows: salt pan > orchard > weeds > soybean > woods > cotton > maize > ginger > sweet potato, which conformed to the salt-tolerance capacity of crops. Therefore, improving and rationally utilizing mild and moderate saline soil is of great importance for increasing regional crop yield and promoting the sustainable development of local agriculture.

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References

1 Douaik, A., Meirvenne, M. V. & Tóth, T., Soil salinity mapping using spatiotemporal kriging and Bayesian maximum entropy with interval soft data. *Geoderma*, 128(3):(2005), 234-248.

2 Whitney, K., Scudiero, E., El-Askary, H. M., Skaggs, T. H., Allali, M. &Corwin, D. L.,Validating the use of MODIS time series for salinity assessment over agricultural soils in California, USA. *Ecol. Indic.*, 93(2018), 889-898.

3 Corwin, D. L., Kaffka, S. R., Hopmans, J. W., Mori, Y., Groenigen, J. W. V.& Kessel, C. V., Assessment and field-scale mapping of soil quality properties of a saline-sodic soil. *Geoderma*, 114(3)(2003), 231-259.

4 Amezketa, E., An integrated methodology for assessing soil salinization, a pro-condition for land desertification. *J. Arid. Environ*, 67(2006), 594-606.

5 Gorji, T., Tanik, A.& Sertel, E., Soil salinity prediction, monitoring and mapping using modern technologies. *Proc. Earth Planetary Sci.*, 15(2015), 507-512.

6 Sereshti, H., Poursorkh, Z., Aliakbarzadeh, G., Zarre, S.&Ataolahi, S., An image analysis of TLC patterns for quality control of saffron based on soil salinity effect: A strategy for data (pre)-processing. *Food. Chem.*,239(2017), 831-839.

7 Liu, Q. S., Analysis on characteristics of soil salinization in Liaohe river delta. *Acta Pedologica Sinica*, 41(2) (2004), 190-196.

8 Wang, W. P., Li, G. K., Hou, J. Y.&Liu, Y. T., Salinization characteristics of soil profile in coastal area of Tianjin and its affecting factors. *Geophy. Geochem. Explor.*, 39 (1): (2015), 172-179.

9 Li, K. L., Chen, J.& Tan M. Z., Spatio-temporal variability of soil salinity in alluvial plain of the lower reaches of the yellow river-a case study. *Pedosphere*, 21(6): (2011), 793-801.

10 Liu, W. Q., Yu, H. J.& Xu, X. Y., Rules of variation of salt ions in soil profiles in the south coastal area of Laizhou Bay. *Acta Pedol. Sin.*, 51(6) (2014), 1213-1222.

11 He, B., Cai, Y., Ran, W.& Jiang, H., Spatial and seasonal variations of soil salinity following vegetation restoration in coastal saline land in eastern China. *Catena*, 118(2014), 147-153.

12 Campbell, J. B., Spatial variation of sand content and pH within single contiguous delineations of two soil mapping units. *Soil. Sci. Soc. Am. J.*, 42(3) (1978), 460-464.

13 Zhu, Q.&Lin, H. S., Comparing ordinary kriging and regression kriging for soil properties in contrasting landscapes. *Pedosphere*, 20(5): (2010), 594-606.

14 Martín, J. A. R., Ramos-Miras, J. J., Boluda, R.& Gil, C., Spatial relations of heavy metals in arable and greenhouse soils of a mediterranean environment region (spain). *Geoderma*, 200-201(6): (2013), 180-188.

15 Batlle-Sales, J., Peris, J. B.& Ferrandis, M., 2–multi-temporal soil salinity assessment at a detailed scale for discriminating halophytes distribution. *Halophytes for Food Security in Dry Lands*, (2016),17-35.

16 Milillo, T. M. Applying Geostatistical interpolation methods to studies of environmental contamination of urban soils and image analysis of time-of-flight secondary ion mass spectrometry, *State University of New York. Ph.D. Thesis*, 2009, pp. 2.

17 Shi, Z.& Li, Y., Utilization of Geostatistics in soil sciences. *Beijing:China Agriculture Press.*,2006, pp. 70.

18 Sylla, M., Stein, A., Nvan, B.& Fresco, L. O., Spatial variability of soil salinity at different scales in the mangrove rice agro-ecosystem in west africa. *Agr. Ecosyst. Environ.*, 54(1-2): (1995), 1-15.

19 Zheng, Z., Zhang, F.R., Ma, F. Y., Chai, X. R., Zhu, Z. Q., Shi, J. L.& Zhang, S. X., Spatio-temporal changes in soil salinity in a drip-irrigated field. *Geoderma*, 149(2009), 243-248.

20 He, B., Cai, Y., Ran, W., Zhao, X.& Jiang, H., Spatio-temporal heterogeneity of soil salinity after the establishment of vegetation on a coastal saline field. *Catena*, 127(4): (2015), 129-134.

21 Yao, R. J., Yang, J. S., Zhan, T. J., Gao P., Wang, X. P., Hong, L. Z.&Wang, M. W., Determination of site-specific management zones using soil physicochemical properties and crop yields in coastal reclaimed farmland. *Geoderma*, 232-234(2014), 381-393.

22 Metternicht, G.& Zinck, J. A., Spatial discrimination of salt and sodiumaffected soil surfaces. *Int. J. Remote. Sens.*, 18(12) (1997), 2571-2586.

23 Gutierrez, M.& Johnson, E., Temporal variations of natural soil salinity in an arid environment using satellite Images. *J. S. Am. Earth. Sci.*, 30(2010), 46-57.

24 Scudiero, E., Skaggs, T. H.& Corwin, D. L., Regional scale soil salinity evaluation using landsat 7, western san joaquin valley, california, usa. *Geoderma. Reg.*, 2-3(2014), 82-90.

25 Scudiero, E., Skaggs, T. H.& Corwin, D. L., Regional-scale soil salinity assessment using Landsat ETM+ canopy reflectance. *Remote. Sens. Environ.*, 169(2015), 335-343.

26 Eldeiry, A.& Garcia, L. A., Detecting soil salinity in alfalfa fields using spatial modeling and remote sensing. *Soil. Sci. Soc. Am. J.*, 72(2008), 201-211.

27 Furby, S., Caccetta, P., Wallace, J.& Lobell, D. B., Salinity monitoring in western australia using remotely sensed and other spatial data. *J. Environ. Qual.*, 39(1) (2010), 16-25.

28 Ding, J. L.&Yu, D., Monitoring and evaluating spatial variability of soil salinity in dry and wet seasons in the Werigan–Kuqa Oasis, China, using remote sensing and electromagnetic induction instruments. *Geoderma*, 235(2014), 316-322.

29 Li, H. Y.& Shi, Z., Research on three-dimension spatial variability of soil electrical conductivity of coastal saline land using 3D ordinary kriging method. *Acta Pedol. Sin.*, 47(2) (2010), 359-363.

30 Wang, S. H., A preliminary study of marine bed and its depositional conditions in late quaternary off the west coast of Laizhou Bay. *Oceanol. Limnol. Sin.*, 1(10) (1979), 9-23.

31 Gao, M., Zheng, Y., Liu, S., Wang, S., Kong, X.& Zhao, J., Palaeogeographic condition for origin of underground brine in southern coast of laizhou bay, Bohai sea. *Geol. Rev.*, 2(61): (2015), 393-400.

32 Chen, G. Q., Liu, W. Q., Hong-Jun, Y. U., Chen, S. L., Xing-Yong, X. U.& Zhao, N., Analysis of soil salinization in the southern Laizhou bay based on GIS. *Advan. Mar. Sci.*, 30(4) (2012), 501-507.

33 Salinity Laboratory Staff, Diagnosis and Improvement of Saline and Alkali Soils, *USDA Handbook No. 60, Washington, DC, USA*, 1954.

34 Davatgar, N., Neishabouri, M. R.&Sepaskhah, A. R., Delineation of site specific nutrient management zones for a paddy cultivated area based on soil fertility using fuzzy clustering. *Geoderma*, 173-174(2012), 111-118.

35 Van Meirvenne, M., Maes, K.&Hofman, G., Three-dimensional variability of soil nitrate-nitrogen in an agricultural field. *Biol. Fert. Soils.*, 37(3) (2003), 147-153.

36 Li, H., Wang, Z.& Wang, Q., Theory and methodology of spatial heterogeneity quantification. *Chinese J. Appl. Ecol.*, 9(1998), 651-657.

37 Güler, M., Arslan, H., Cemek, B.& Erşahin, S., Long-term changes in spatial variation of soil electrical conductivity and exchangeable sodium percentage in irrigated mesic ustifluvents. *Agr. Water. Manage.*, 135(4) (2014), 1-8.

38 Liu, G., Li, J., Zhang, X., Wang, X., Lv, Z.& Yang, J., Gis-mapping spatial distribution of soil salinity for eco-restoring the yellow river delta in combination with electromagnetic induction. *Ecol. Eng.*, 94(2016), 306-314..

39 Yao, R. J., Yang, J. S.& Liu, G. M., Spatial variability of soil salinity in characteristic field of the Yellow River Delta. *Transactions of the CSAE*, 22(6) (2006), 61-66.

40 Kravchenko, A. N. Influence of spatial structure on accuracy of interpolation methods. *Soil. Sci. Soc. Am. J.,* 267(5): (2003), 1564-1571.

41 Chien, Y. J., Lee, D. Y.&Guo, H. Y., Geostatistical, analysis of soil properties of mid-west taiwan soils. *Soil Sci.*, 162(4): (1997), 291-298.

42 Zhang, J., Cui, S. Y., Feng, Z. X., Wang. K. S. & Zhai, C. J., Climate factors and mulching affect soil salinity dynamics in coastal areas. *Chinese J. Eco-Agricul.*, 26(2) (2018), 294-302.

43 Ivushkin, K., Bartholomeus, H., Bregt, A. K., Pulatov, A., Bui, E. N.&Wilford, J., Soil salinity assessment through satellite thermography for different irrigated and rainfed crops. *Int. J. Appl. Earth Obs Geoinform.*, 68(2018), 230-237.

44 Najib, S., Fadili, A., Mehdi, K., Riss, J., Makan, A. & Guessir, H. Salinization process and coastal groundwater quality in Chaouia, Morocco. *J. Afr. Earth. Sci.*, 115(2016), 17-31.

45 Su, Y. Z., Zhao, H. L.&Zhang, T. H., Soil properties following cultivation and non-grazing of a semiarid sandy grassland northern China. *Soil. Till. Res.*, 75(1) (2003), 27-36.

46 Yu, P. J., Liu, S. W., Yang, H. T., Fan, G. H. & Zhou, D. W., Short-term land use conversions influence the profile distribution of soil salinity and sodicity in northeastern China. *Ecol. Indic.*, 88(2018), 79-87.

47 Heenan, D. P., Chan, K. Y.& Knight, P. G., Long-term impact of rotation, tillage and stubble management on the loss of soil organic carbon and nitrogen from a chromic luvisol. *Soil. Till. Res.*, 76(1) (2004), 59-68.

48 Katerji, N., Hoorn, J. W. V., Hamdy, A. & Mastrorilli, M., Salt tolerance classification of crops according to soil salinity and to water stress day index. *Agr. Water. Manage.*, 43(1) (2000), 99-109.

49 Chen, Z., Cai, S. B., Yang, J. S., Zhang, Q. F., Wu, J. Z., Jiang, Y. J., Yan, W.& Wu, X. Y.,Comparison of Salinity Tolerence among Main Crops at Germination Stage. *Hans J. Agricul. Sci.*, 2(4): (2012), 59-65.