Pak. J. Bot., 40(3): 1081-1090, 2008.

RELATIONSHIP BETWEEN SOIL CHARACTERISTICS AND HALOPHYTIC VEGETATION IN COASTAL REGION OF NORTH CHINA

WEI-QIANG LI[1], LIU XIAO-JING[1*], M. AJMAL KHAN[2] AND BILQUEES GUL[3]

[1]*Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Science, Shijiazhuang, Hebei, 050021. P.R. China,*
Email: wqli@ms.sjziam.ac.cn
[2]*Institute of Sustainable Halophyte Utilization, University of Karachi, Karachi-75270, Pakistan*
E-mail: majmalk@uok.edu.pk
[3]*Department of Botany, University of Karachi, Karachi-75270, Pakistan*
E-mail: ishu_gul@yahoo.com

Abstract

Plant-soil relationship of saline coastal plain of north China was studied. Principle component analysis (PCA) and cluster analysis were used to generate a hypothesis that the distribution pattern of halophytic vegetation was influenced by the variation in soil properties. The hypothesis was tested by canonical correlation analysis (CCA). PCA results showed that salinity, pH, moisture and available nitrogen were the major soil factors responsible for variations in the pattern of vegetation. For vegetation, primarily richness, cover, plant height, and biomass, were the main factors. The results of cluster analysis were consistent with field investigation, and CCA showed results similar to PCA. Canonical correlation coefficient between soil parameters and vegetation factors was 0.731. The relationship of soil salinity with vegetation biomass, and that of soil salinity with available nitrogen were both negative. Biomass was the main vegetation factor in indicating soil salinity.

Introduction

About 950 million hectares of land in the world are saline (Wang, 1993) and not suitable for growing conventional crops. However, these degraded areas have a huge potential to serve as crop and pasture resources. Chemical methods to reduce soil and water salinity are both expensive and time intensive (Bui & Henderson, 2003). Hence other methods have to be devised to use the lands economically, and halophytes might permit such utilization, if the areas are properly characterized. The use of halophytes as indicators of soil physical and chemical properties could be an effective and useful method to facilitate the transfer of information about these lands from laboratories to extension agents, and ultimately to end users (Bui & Henderson, 2003; Piernik, 2003). Soil-vegetation relationship of saline localities have been documented in Australia (Bui & Henderson, 2003; Crowley, 1994), China (Li, 1993; Toth *et al*., 1995), Egypt (Serag & Khedr, 2001; Abd El-Ghani & Amer, 2003; Abd El-Ghani & El-Sawaf, 2005), USA (Ungar, 1976; Skougard & Brotherson, 1979; Gul *et al*., 2001; Omer, 2004), Iran (Jafari *et al*., 2003; 2004), Italy (Silvestri *et al*., 2005) and Spain (Rogel *et al*., 2001). Results generally indicated that the salinity gradient, moisture and available nutrient in soil are the important factors in controlling the distribution of vegetation (Rogel *et al*., 2001).

The distribution of halophytic vegetation is related to inter-specific and intra-specific competition, grazing and management (Lenssen *et al*., 2004; Marc *et al*., 2003). Land and water management is critical in order to reclaim saline-sodic soils (Qadir & Oster, 2004), and vegetative bioremediation or restoration of saline land through re-vegetation is a new strategy for the management of saline-sodic soils (Barrett-Lennard, 2002; Qadir & Oster, 2004). This management could be even more useful because a number of halophytes

*Corresponding author E-mail: xjliu@ms.sjziam.ac.cn

could be utilized as crops for food, fiber, pot herb, edible oil, fiber materials, traditional medicines etc., (Glenn *et al*., 1999; Zhao *et al*., 2002). Therefore, it is necessary to investigate the plant-soil relationship using the cultivation of halophytic crops.

Considerable research has been done on soil-vegetation relationship in saline soils of China but the work has been mainly confined to inland areas like Songnen plain and Xinjiang (Pan *et al.*, 1998; Yan *et al.*, 2001; Li & Yang, 2004; Xin *et al.*, 1999; Qu & Guo, 2003). Studies identifying the major environmental factors associated with vegetation patterns in coastal salt marshes are scarce (Li, 1993; Wu *et al.*, 1994; Wang *et al*., 1994; Hu & Wang, 1997; Toth *et al.*, 1995; Liu *et al.*, 2003). Many of the studies on coastal salt marshes are just descriptive documentation of species and their classification. Recently, multivariate analyses including PCA (principle component analysis), CCA (canonical correlation analysis) and cluster analysis, have been used for analyzing soil-vegetation relationship (Ukpong, 1994; Feoli *et al.*, 2002.). Therefore, it was considered worthwhile to study the relationship between soil characteristics and halophytic vegetation in coastal saline soil of north China using multivariate analyses.

The present study aims to describe the composition and distribution of plant species in a coastal salt marsh in north China and explores the relationship between halophytic vegetation and soil factors.

Materials and Methods

Study area: The salt marshes studied are located in Haixing County of the west coastal Plain of Bohai Gulf of China, East Plain of north China (Fig. 1), which occupies an area of 8 577 Km^2. The site studied is a 1 Km^2 natural saline soil area (38°11’30’’ N; 117°39’34’’ E) on the supra tidal coastal plain. Freshwater shortage is a serious problem in the area. The only fresh water resource is rainfall or deep ground water at 400 *m* depth, which is un-rechargeable and was formed 20 000 years ago. More than 90% of shallow ground water is saline. Being characterized by monsoon-type climate, the rainfall in the area is highly variable. The mean annual precipitation is 500-600 mm. Of this 80% is received between June and September. The mean annual temperature is 12.1^{o}C. Salt content of the surface soil is 0.3-1.2%. The depth to groundwater is 0.5-1.5 *m*, and salty water that is not suitable for irrigation is extensively distributed in the area (Hu & Wang, 1997).

The diversity of halophytic species in these marshes is low, and includes *Suaeda salsa*, *Nitraria sibirica*, *Aeluropus littoralis*, *Phragmites australis*, *Limonium bicolor*, *Imperata cylindrica* etc. (Zhao *et al.*, 2002).

Sampling methods and chemical analysis: The 1 Km transverse transect of halophyte community was marked basing on the typical characters of the halophytic vegetation in the area with little change in micro-topography. As the vegetation type changed in transect, one quadrant was marked for each type of vegetation. A total of 33 quadrants were investigated, in the autumn of 2004. Each quadrant was 5*m* x 5*m* in size and divided into three homogeneous sub-quadrats (one *m* x one *m* for each) along the diagonal line of each quadrat for vegetation survey and sampling. The species were identified and relative frequency, plant height and canopy cover of each species were determined. Plant samples were collected from an area of one m x one m for biomass measurement. All plant samples were oven dried at 70^{o}C for 48 hours for dry mass determination. The samples were wet-ashed and analyzed for Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} using a HITACHI-170-10 atomic absorption spectrometer (Yu & Wang, 1988).

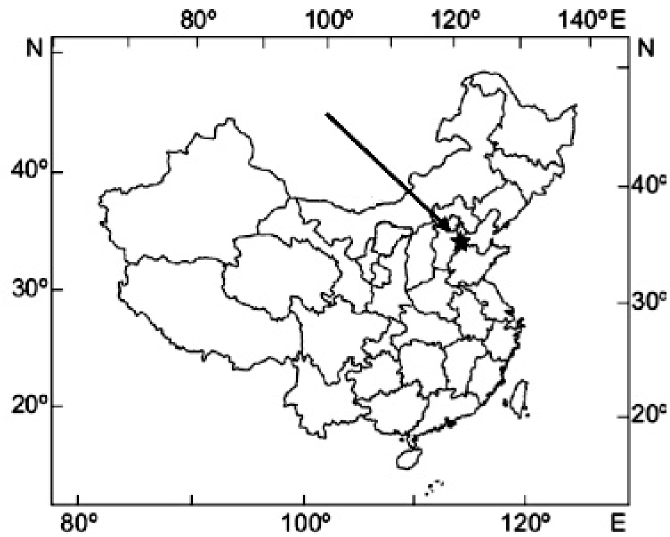

Fig. 1. Location of the study area in north China.

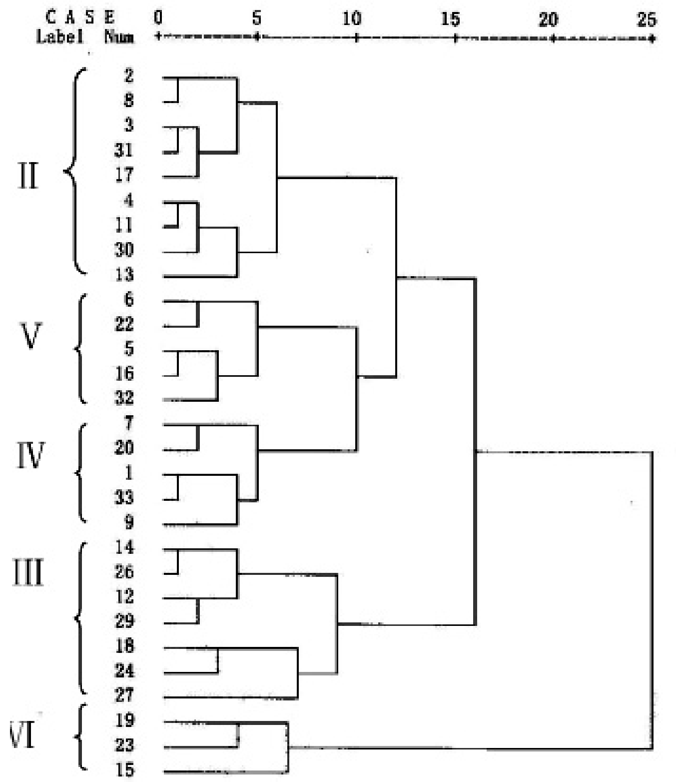

Fig. 2. The dendrogram result of cluster analysis of 33 plots using squared Euclidean Distance.

Five soil cores (3.6 cm in diameter and 30 cm in depth) were taken from the root zone of each plot (sub-quadrat, hereafter called plot), and the soil separated from each soil core was prepared for analysis including soil moisture, salt content, pH value and available nitrogen content. Each soil sample was divided into two parts, one part was used for determining soil water content by weight loss after oven-drying at 105^{o}C to constant weight, and the other part was air-dried, thoroughly mixed, and passed through a two mm sieve to remove gravel and boulder. The weight of gravel in each soil sample was determined and expressed as a percentage of the total weight of the sampled soil. The soil portion less than two mm in size was kept for chemical analysis. Electrical conductivity (EC) and soil reaction (pH) were evaluated in 1:5 (by weight) soil-water extract using conductivity meter and a glass electrode pH-meter, respectively. Soluble calcium and magnesium were determined by titration with EDTA, soluble chlorine by titration with $AgNO_3$, and soluble carbonate and bicarbonate by titration with H_2SO_4 using methylorange and phenolphthalein, respectively. Soil salt content was determined by adding all the ions together. Available nitrogen content was determined by NaOH extraction method (Yu & Wang, 1988).

Data analysis: Two data matrices representing soil and vegetation characteristics were constructed and the SAS system for windows (Ver. 6.0) and SPSS for windows (Ver. 11.5) software package were used for multivariate statistical analysis (PCA, cluster analysis and CCA) (Hong & Hou, 2001; Lu, 2002).

In order to find the main factors affecting the classification of soil and vegetation, PCA and cluster analysis (*Q* type) were used. Principal components were considered useful if their cumulative percentage of variance approached 80%. Cluster analysis was attempted to identify relatively homogeneous groups of cases based on selected characteristics (principal components), using an algorithm that starts with each case in a separate cluster and combines clusters until only one is left. Based on the component capacity coefficient values of PCA, representative factors of different groups were selected for cluster analysis using Ward's cluster method (Hong & Hou, 2001). Squared Euclidean Distance was used in the proximities procedure. Main soil characters and plant characters were used for cluster analysis with SPSS software package.

CCA was used to analyse the relationship between the soil and vegetation variables. It provides a simple picture of complex relationship between soil and vegetation variables

Results

Principal component analysis: PCA was performed for soil and vegetation analysis in 33 plots in order to determine soil parameters controlling the distribution of vegetation. Nine plant species and 10 soil factors were used in the analysis. The first four principal components (***PC1***, ***PC2***, ***PC3*** and ***PC4***) of soil factors together accounted for 85% of the total variance in data set (Table 1) with their individual contribution being 51%, 15%, 10%, 9%, respectively. PCA screened out four components for vegetation factors and their percentage variance values were 34%, 20%, 16%, 11%. The components cumulative percentage reached 80% (Table 1).

The first principal component for soil was total salt content, followed by pH value, soil moisture and available soil nitrogen. For vegetation, the first principal component was richness followed by coverage, plant height and biomass.

Table 1. Factor loading, eigenvalue and cumulative percentage of principal component analysis.

Plant factors	Components of plant				Soil factors	Components of soil			
	PC1	PC2	PC3	PC4		PC1	PC2	PC3	PC4
Na^- (%)	0.86	-- 0.01	--0.09	--0.03	Na^- (%)	0.96	0.16	--0.04	0.11
K^- (%)	0.08	0.62	0.53	0.08	Cl^- (%)	0.95	0.10	--0.05	0.12
Ca^{2-} (%)	0.60	--0.51	0.39	0.11	Ca^{2-} (%)	0.62	--0.46	--0.18	--0.05
Mg^{2-} (%)	0.86	0.09	--0.25	0.03	Mg^{2-} (%)	0.95	0.14	0.07	0.13
Total cations (%)	0.88	--0.02	0.07	0.02	SO_4^{2-} (%)	0.88	0.07	0.04	0.01
Biomass (g)	0.01	0.22	--0.52	0.79	HCO_3^{--} (%)	- -0.57	0.65	0.04	--0.09
Height (cm)	--0.03	0.03	0.78	0.37	Total salt content (%)	0.98	0.11	--0.03	0.10
Coverage (%)	0.02	0.79	0.05	0.10	PH	- -0.13	0.86	0.31	0.16
Richness (No. m^{-2})	0.93	0.69	--0.07	--0.38	Moisture (%)	0.53	--0.27	0.64	--0.46
					Available nitrogen (%)	- -0.44	--0.52	0.41	0.57
Eigenvalues	3.02	1.80	1.42	0.95	Eigenvalues	5.64	1.65	1.10	1.02
% of variance	33.53	20.02	15.74	10.60	% of variance	51.30	15.03	9.82	9.24
Cumulative %	33.53	53.55	69.29	79.89	Cumulative %	51.30	66.33	76.15	85.39

Cluster analysis: Based on the results of PCA, soil salt content, pH, soil moisture and available nitrogen were used to represent soil characters, while richness, cover, height and biomass were used to represent vegetation characters for cluster analysis (Fig. 2). Plots 10, 21, 25 and 28 were bare, and they were first classified out in the process of cluster analysis and were not shown in Fig. 2. The remaining 29 plots were classified into five groups according to Squared Euclidean Distance (=ten). The theoretical classification corroborated the results of vegetation investigation. Each group differed from the other in terms of vegetation and environment characters (Table 2). Names of communities were taken from the name of one or two species that dominated in the patches or occurred in typical combination. The vegetation types were categorized as follows: (1) bare soil with extremely high salt content and low available nitrogen; (2) *A. littoralis* and *S. salsa* community with high salt content and low water content and moderate available nitrogen; (3) *S. salsa* and *A. littoralis* community with moderate soil salt content and rich vegetation and moderate available nitrogen; (4) *P. australis* and *A. littoralis* community located in lower positions with low salt content and high water content and high available nitrogen; (5) *I. cylindrica* and *S. viridis* community with low soil salt content and low water content and high available nitrogen; (6) and farmland with low soil salt content and low water content and low available nitrogen. One-way ANOVA analysis showed that the cluster results were significantly ($p<0.05$) different.

Moreover, micro-topography affected soil water and salt movement, which in turn affected vegetation types and soil nutrient condition. For example, vegetation type II was mainly located in higher position, while type IV (*Phragmites australis*) mainly occurred in lower position.

Canonical correlation analysis: The results showed that salt content (X_1), soil water content (X_2), available nitrogen (X_3) and pH (X_4) were selected as soil factors, when soil matrix was formed; while cover (Y_1), biomass (Y_2), height (Y_3), richness (Y_4) were selected as vegetation factors, when vegetation matrix was formed (Table 1). The results of CCA ordination (Table 3) showed that the first axis (eigenvalue = 1.148) accounted for 71.0% of variation in soil factors data. Canonical correlation coefficient between the first axis and vegetation-soil variables was 0.731 and significant at 5% level (P=0.045), while not significant (P=0.489) for the second axis. This indicated that the first principal component was by far the most important for representing the variation of the 6 site types. The linear relationship between vegetation and soil is shown in Eq.1 and Eq. 2,

$$SF= 0.670\, X_1 + 0.125\, X_2 - 0.4143\, X_3 + 0.545\, X_4 \qquad (1)$$

$$VF= -0.231\, Y_1 - 0.478\, Y_2 - 0.377\, Y_3 + 0.088\, Y_4 \qquad (2)$$

where SF represents soil factors and VF for vegetation factors. The Eq.1 and Eq.2 showed that soil salt content played the most important role among soil factors, followed by pH and available nitrogen, and biomass was the most important vegetation factor. The salt content of soil played the key role in the variation of vegetation particularly biomass, and the relationship between vegetation biomass (or height), and soil salinity was negative.

Table 2. Soil index and vegetation features of six soil types.

Type	Plot No.	Available nitrogen (g kg^{-1})	Soil pH (5:1)	Soil salinity (%)	Soil moisture (%)	Richness (No. m^{-2})	Biomass (g m^{-2})	Height (cm)	Cover (%)
	4	26.25 ± 5.81	7.83 ± 0.11	2.74 ± 0.61	19.21 ± 0.34	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	9	38.44 ± 2.70	7.50 ± 0.06	2.24 ± 0.35	20.67 ± 0.51	3.44 ± 0.41	14.16 ± 3.98	18.89 ± 3.41	53.89 ± 8.97
	7	33.71 ± 3.17	7.95 ± 0.11	1.48 ± 0.36	16.78 ± 2.61	2.29 ± 0.61	23.83 ± 3.19	31.43 ± 7.05	78.57 ± 7.05
	5	52.60 ± 6.45	7.83 ± 0.08	0.35 ± 0.10	19.41 ± 3.70	3.00 ± 0.55	10.53 ± 2.43	48.00 ± 2.00	64.00 ± 7.48
	5	59.80 ± 5.09	7.83 ± 0.08	0.51 ± 0.18	11.28 ± 2.96	2.60 ± 0.93	13.88 ± 2.05	32.00 ± 3.74	85.00 ± 9.49
	3	27.00 ± 6.43	7.87 ± 0.17	0.94 ± 0.83	11.73 ± 4.16	1.00 ± 0.00	5.37 ± 5.37	122.00 ± 15.28	1.67 ± 1.67
F-value		**7.89****	**3.83***	**5.29****	**2.61***	**4.33***	**4.77****	**34.45****	**14.69***

Table 3. Results of canonical correlation analysis.

	Axis	Eigenvalue	Proportion	Cumulative	Canonical correlation coefficient	*P>F*
Soil	First	1.148	0.710	0.710	0.731	0.045
Vegetation factors	Second	0.318	0.197	0.907	0.491	0.498

Discussion and Conclusions

Although low in plant diversity and poor in species, the vegetation of the coastal saline land in north China is a mosaic of six plant communities viz., *Suaeda salsa*, *Tamarix chinensis*, *Nitraria sibirica*, *Aeluropus littoralis*, *Phragmites australis* and *Limonium bicolor* are the ubiquitous species, indicating their wide range of ecological adaptation. *Imperata cylindrica* was recorded only in low saline area. Most of these communities have analogues in Yellow River Delta (Li, 1993) in north China. Some of the dominant plant species are known to be of economic importance for food, oil, vegetable, good quality fodder and as a tool for reclamation of saline soils (Zhao *et al*., 2002).

The results of PCA and cluster analysis showed that the distribution of vegetation types was most strongly correlated with soil salinity and moisture among different soil factors (Fig. 2). Results of CCA analysis showed that salinity was the most important factor in affecting the distribution of halophytic vegetation. These results were in conformity with the results reported by many workers in arid regions, such as Ungar (1976) in USA; Toth *et al*., (1995) and Pan *et al*., (1998) in China; Rogel *et al*., (2001) in Spain; Bui & Henderson (2003) in north Queensland and Abd El-Ghani & El-Sawaf (2005) in Egypt, although the investigations were in different area with different soil type and climatic condition.

Available soil nitrogen in the area was another important soil factor in the distribution of vegetation types. With a decrease in soil salinity, the available nitrogen increased significantly. For example, cluster *IV* (*P. australis* and *A. littoralis* community) and *V* (*I. cylindrica* and *S. viridis*) were different from other types in available nitrogen and soil salinity, and had higher vegetation cover than other types. Cluster *V* and *IV* were different in soil water content and micro-topography. Cluster *IV* always appeared in lower place, while cluster *V* always appeared in higher position.

In this study, micro-topography was an important environmental factor, which affected other soil characteristics and the halophytic vegetation distribution. For example, in Spring (April and May), soil evaporation was very strong with little rainfall. Salt might have accumulated in the high position because of water evaporation. High salt content in soil is known to inhibit halophyte seed germination and population establishment (Khan & Gul, 2002). When the rainy season came (July and August), rain water would have accumulated in depressions and remained there for longer time during which the salt would be dissolved and leached down into deep soil. The surface soil would thus be made free of salt. Some other soluble chemicals, including nutrients, might have also leached out in the process. The low position was very suitable for plant growth and always showed high biomass. Micro-topography has been reported to affect soil water and salt distribution, and, as a result halophyte seed germination, seedling growth and distribution (Li, 1993; Wu *et al.*, 1994). Thus soil micro-topography should also be considered in halophytic vegetation distribution.

Our cluster analysis results were similar to those reported previously (Li, 1993; Wu *et al.*, 1994) for Yellow River Delta area. The four soil factors and four vegetation factors were suitable to represent the soil and vegetation characters in the study area. In addition, the methods used in analysis have prevented inclusion of ineffective factors and reduced data complexity from affecting ecological models (Jafri *et al.*, 2004).

The CCA results showed a good relationship between soil characteristics and vegetation distribution. Biomass was the main vegetation factor reflecting the soil salinity status and this was followed by plant height and species richness. The results confirm that halophytic vegetation could be used as an indicator for soil salinity, water content and nutrient content in coastal areas of north China.

With an increase in population and economic growth in the studied area, there has been an expansion of alfalfa (*Medicago sativa* L.) cultivation as a cash crop in recent years. With the help of halophytic vegetation indicator, local farmers might be able to easily find the soil suitable for alfalfa planting.

Acknowledgements

The authors express their gratitude to Dr. Mohan Chandra Saxena for revision of the manuscript.

References

Abd El-Ghani, M.M. and W.M. Amer. 2003. Soil-vegetation relationships in a coastal desert plain of southern Sinai, Egypt. *J. Arid Environ*., 55: 607-628.

Abd El-Ghani, M.M. and N.A. El-Sawaf. 2005. The coastal roadside vegetation and environmental gradients in the arid lands of Egypt. *Community Ecol*., 6: 143-154.

Barrett-Lennard, E.G. 2002. Restoration of saline land through renegotiation. *Agric. Water Manage*., 53: 213-226.

Bui, E.N. and B.L. Henderson. 2003. Vegetation indicators of salinity in northern Queensland. *Austral Ecol*., 28: 539-552.

Crowley, G.M. 1994. Quaternary soil salinity events and Australian vegetation history. *Quat. Sci. Rev*., 13: 15-22.

Feoli, E., L.G. Zurich and W. Cerium. 2002. Evaluation of environmental degradation in northern Ethiopia using GIS to integrate vegetation, geomorphologic, erosion and socio-economic factors. *Agro. Ecosys. Environ*., 91: 313-325.

Glenn, E.P., J.J. Brown and E. Blueweed. 1999. Salt tolerance and crop potential of halophytes. *Crit. Rev. Plant Sci*., 18: 227-255.

Gul, B., D.J. Weber and M.A. Khan. 2001. Growth, ionic and osmotic relations of an *Allenrolfea occidentalis* population in an inland salt playa of the Great Basin Desert. *J. Arid Environ*., 48: 445-460.

Hong, N. and J. Hou. 2001. *Tutorial of SAS for Windows*. Publishing House of Electronics Industry, Beijing. [In Chinese].

Hu, C.S. and Z.P. Wang. 1997. A preliminary study on the differentiation mechanisms of soil salinity and plant community of micro-topography in muddy coastal zone. *Eco-agri. Res*., 5(4): 45-49. [In Chinese with English abstract].

Jafari, M., M.A.Z. Chahouki, A. Tavili and H. Azarnivand. 2003. Soil-vegetation in Hon-e-Soltan region of Qom Province, Iran. *Pak. J. Nut*., 2: 329-334.

Jafari, M., M.A.Z. Chahouki, A. Tavili and H. Azarnivand. 2004. Effective environmental factors in the distribution of vegetation types in Poshtkouh rangelands of Yazd Province (Iran). *J. Arid Environ*., 56: 627-641.

Khan, M.A. and B. Gul. 2002. Some ecophysiological aspects of seed germination in halophytes . In: *Halophytes utilization and regional sustainable development of agriculture*. (Eds.): X. Liu, M. Liu. Meteorological Press of China, Beijing. 56-68.

Lenssen, J.P.M., F.B.J. Menting and P.W.H. van der. 2004. Do competition and selective herbivory cause replacement of *Phragmites australis* by tall forbs. *Aquat. Bot*., 78: 217-232.

Li, J.D. and Y.F. Yang. 2004. Combinatorial structures of plant species in saline communities in the Songne Plains in China. *Acta Prataculturae Sin*., 13: 32-38. [In Chinese with English abstract].

Li, X.D. 1993. Canonical analysis and the principal components analysis of plant community with its environmental factors in the Yellow River Delta. *Acta Botanica Sin.*, 35(Supplement): 139-143. [In Chinese with English abstract].

Liu, X.J., W.Q. Li and Y.M. Yang. 2003. Studies on the nutrient characteristics of soil and halophyte in coastal saline soil of Hebei Province. *Eco-agr. Res*., 11(2): 76-77. [In Chinese with English abstract].

Lu, W. 2002. *SPSS for Windows statistical analysis*. Publishing House of Electronics Industry, Beijing. 311-334. [In Chinese].

Marc, T., V. Jean-Paul, O. Annie, G. Jean-Claude and L. Jean-Claude. 2003. Vegetation dynamics and plant species interactions under grazed and un-grazed conditions in a western European salt marsh. *Acta Oecol*., 24: 103-111.

Omer, L.S. 2004. Small-scale resource heterogeneity among halophytic plant species in an upper salt marsh community. *Aquat. Bot*., 78: 337-348.

Piernik, A. 2003. Inland halophilous vegetation as indicator of saline salinity. *Basic Appl. Ecology*, 4: 525-536.

Pan, D., A. Bouchard, P. Legendre and G. Domon. 1998. Influence of edaphic factors on the spatial structure of inland halophytic communities: A case study in Xingjiang, China. *J. Veg. Sci*., 9: 797-804.

Qadir, M. and J.D. Oster. 2004. Crop and irrigation management strategies for saline-sodic soils and waters aimed at environmentally sustainable agriculture. *Sci. Total Environ*., 323: 1-19.

Qu, G.H. and J.X. Guo. 2003. The relationship between different plant communities and soil characteristics in Songnen grassland. *Acta Prataculturae Sin*., 12(1): 18-22. [In Chinese with English abstract]

Rogel, J.Á., F.A. Ariza and R.O. Silla. 2000. Soil salinity and moisture gradients and plant zonation in Mediterranean salt marshes of southeast Spain. *Wetlands*, 20: 357-372.

Rogel, J.Á., R.O. Silla and F.A. Ariza. 2001. Edaphic characterization and soil ionic composition influencing plant zonation in a semiarid Mediterranean salt marsh. *Geoderma*, 99: 81-98.

Serag, M.S. and A.H.A. Khedr. 2001. Vegetation-environment relationships along El-Salam Canal, Egypt. *Environmetrics*, 12: 219-232.

Silvestri, S., A. Defina and M. Marani. 2005. Tidal regime, salinity and salt marsh plant zonation. *Estua. Coast Shelf Sci*., 62: 119-130.

Skougard, M.G.. and J.D. Brotherson. 1979. Vegetational response to three environmental gradients in the salt playa near Goshen, Utah county, Utah. *Great Basin Nat*., 39: 44-58.

Toth, T., S. Matsumoto, R. Mao and Y. Yin. 1995. Precision of predicting soil salinity based on vegetation categories of abandoned lands. *Soil Sci*., 160: 218-231.

Ukpong, I.E. 1994. Soil-vegetation interrelationships of mangrove swamps as revealed by multivariate analyses. *Geoderma*, 64: 167-181.

Ungar, I.A. 1976. Vegetation-soil relationships on saline soils in North Kansas. *Am. Mid. Nat*., 78: 98-120.

Wang, L.H., H.L. Sun and W. Li. 1994. Relationship between halophytic vegetation and soil salt content and its indicator effect to soil salinity. *Shanghai Environ. Sci*., 13(10): 33-36. [In Chinese with English abstract].

Wang, Z. 1993. *China Saline Soil*. Chinese Science press, Beijing 1-2. [In Chinese].

Wu, Z.F., S. Zhao and X. Zhang. 1994. Studies on interrelation between salt vegetation and soil salinity in the Yellow River delta. *Acta Phytoecologica Sin*., 18(2): 184-193. [In Chinese with English abstract].

Xin, X., Q. Gao, Z. Li and Z. Yang. 1999. Partitioning the spatial and environmental variations of plant community structure of alkaline grassland on Songnen Plain. *Acta Bot. Sin*., 41: 775-781. [In Chinese with English abstract].

Yan, X., G.R. Sun and J. Li. 2001. Soil nutrient field analysis for plant species in Songnen alkaline grassland. *Acta Ecol. Sin*., 21: 1973-1985 [In Chinese with English abstract].

Yu, T.R. and Z.Q. Wang. 1988. *Soil Chemical analysis*. Chinese Science Press, Beijing 224-301. [In Chinese].

Zhao, K., H. Fan and I.A. Ungar. 2002. Survey of halophyte species in China. *Plant Sci*., 163: 491-498.

(Received for publication 14 May 2007)