Agricultural Journal 2 (5): 564-569, 2007
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Spatial Variability of Soil Properties Related to Salinity and Alkalinity in Meliorated Grasslands of Horqin Sand Land, Northeast China

[1]Xiumei Liu, [1]Chunjian Shi, [1]Wenju Liang, [1]Yong Jiang,
[1]Deming Jiang and [1,2]Yosef Steinberger
[1]Institute of Applied Ecology, Chinese Academy of Sciences,
Shenyang 110016, China
[2]The Mina and Everard Goodman Faculty of Life Science,
Bar-Ilan University, Ramat Gan 52900, Israel

Abstract: The objective of this study was to assess the spatial distribution patterns of soil properties related to salinity and alkalinity including soil Electrical Conductivity (EC), exchangeable Na^+, Exchangeable Sodium Percentage (ESP) and soil pH in the grassland meliorated in 2005 (G1ym) and meliorated in 2001 (G5ym), respectively, in Horqin Sand Land, Northeast China. The results showed that EC, exchangeable Na^+, ESP and soil pH decreased by 3.92-41.96% under G5ym compared with G1ym. Significant differences were observed on EC, exchangeable Na^+, ESP and soil pH between G5ym and G1ym ($p<0.05$). Positively correlations were found between soil pH and EC, ESP and exchangeable Na^+ and between EC and ESP ($p<0.05$). Semivariogram models and parameters showed that the sill value and spatial dependence of EC, exchangeable Na^+, ESP and soil pH were lower and their ranges and fractal dimension were higher under G1ym than under G5ym, indicating that the spatial variability was lower under G1ym than under G5ym. Kriging-interpolated maps also reflect the different spatial distribution patterns of soil properties tested between G5ym and G1ym. The obtained data in the present study suggest that the level of soil salinity and alkalinity has been alleviated with the period of melioration. It was inferred that the increase of vegetation coverage after melioration may contribute to the decrease of soil salinity and alkalinity and improve the spatial variability of soil properties at the same time.

Key words: Spatial heterogeneity, geostatistics, soil salinity, alkalinity, meliorated grassland, Horqin Sand Land

INTRODUCTION

Soil degradation is a severe problem by a combination of human abuses of land and adverse climate variations under arid and semi-arid lands worldwide (Herrmann and Hutchinson, 2005). Soil degradation causes not only soil nutrients deficiency and soil organism diversity decrease and also soil salinity and alkalinity (Jiang *et al*., 2003). The level of soil salinity in the soil solution and the exchange phase of cations can affect the soil physical properties, including structural stability, hydraulic conductivity, infiltration rate and soil erosion (Jordan *et al*., 2004). Subsequently, the growth of plants and soil biota activity will be affected because of their close relationships with soil structure, texture and soil solution concentration (Ardahanlioglu *et al*., 2003). Therefore, much attention needs to be paid to the level of saline-alkali in soil which plays an important role in soil environment in arid and semi-arid regions (Jiang *et al*., 2003; Jordan *et al*., 2004).

The Horqin Sand Land, located in the northern areas of China, is one of the regions suffered gravely from degradation over the past 30 years, in which 45.9% of grassland (4 703 500 ha) was degraded (Jiang *et al*., 2003). Soil salinity and alkalinity has reduced pasturage productivity and limited the regional economic development. In order to improve soil properties, management practices have been carried out on the degraded grassland, including grassland enclosures, sowing leguminous grass and fertilization (Jiang *et al*., 2003). Jiang *et al*. (2003), Liu *et al*. (2005) and Chu *et al*. (2006) have showed in their study that soil physicochemical properties and biodiversity have been improved after melioration of the degraded grassland. However, study on soil properties related to salinity and alkalinity is fairly limited in these regions, especially after melioration.

Soil Electrical Conductivity (EC) and Exchangeable Sodium Percent (ESP) were regarded as good indicators to reflect the level of soil salinity and alkalinity by many

Corresponding Author: Wenju Liang, Institute of Applied Ecology, Chinese Academy of Sciences, P.O.Box 417, Shenyang 110016, China

researchers (Boivin *et al.*, 2002; Kilic and Kilic, 2007). Kiliç and Kiliç (2007) showed in their study that the spatial variability in salinity (EC) and alkalinity (ESP) depend on ground water level, quality of irrigation water and textural differences.

Spatial heterogeneity of soil properties is a general characteristic in arid and semi-arid grassland ecosystems (Schlesinger *et al.*, 1996). Assessment of the spatial variability in salinity and alkalinity by geostatistics can greatly contribute to the understanding of randomness and quantify the scale and intensity of the spatial variation. Goovaerts (1998), Jiang (2002) and Liang *et al.* (2005) had successfully applied the methods in their study of the spatial distribution of soil physical, chemical and biological properties, showing that geostatistics method is a powerful tool for the description and modeling the spatial variability of soil abiotic and biotic properties.

The aim of our study, was to assess the spatial variability in soil EC, exchangeable Na^+, soil pH and ESP in the meliorated grasslands in Horqin Sand Land. Based on the above, we hypothesized that: The spatial variation in soil EC, exchangeable Na^+, soil pH and ESP will be increased with the process of plant restoration and the problem of soil salinity and alkalinity will be alleviated at the same period. In order to test this, these soil properties during the vegetation restoration after melioration processes were examined.

MATERIALS AND METHODS

Study site: This study was conducted at the Wulanaodu Experimental Station of Desertification (43°02'N, 119°39'E, 479 m elevation), Chinese Academy of Sciences, western Horqin Sandy Land, Northeast China. The station is located in a continental temperate semi-arid zone with an average multiannual temperature of 6.2°C. The average multiannual precipitation rate is 340.5 mm, of which 70% occurs from June to August. The mean annual evaporation rate is 2500 mm and the non-frost period is 130 days (Jiang *et al.*, 2007). The soil at our experimental sites is a Usti-Sandic Primosols (Chinese Soil Taxonomy), with 72% sand, 15% silt and 13% clay.

In order to undertake the study in an enclosure located in a degraded grassland two plots were selected: One was meliorated in April 2001 and the other was meliorated in April 2005. The melioration practice integrated, soil plowing (to a depth of 20 cm) and sowing leguminous grass (*Astragalus adsurgens*), etc. Both plots received no fertilization and were harvested every autumn for animal consumption. The meliorated plot in 2001 (G5ym) was dominated by grasses including *Hemarthia japonica*, *Phragmites communis*, *Aneurolepidium Chinese* and *Calamagrostis epigeios*, etc and the second plot meliorated in 2005 (G1ym) was found to be dominated by grasses including *Astragalus adsurgens*, *Phragmites communis* and *Aneurolepidium chinese*, etc.

Soil sampling and analyses: In each plot an area of 160× 160 m was selected which was divided into 20× 20 m grid a total of 64 square units. Soil samples from each one of the units were collected using a corer (5 cm diameter) to a depth of 20 cm in April, 2006. The soil samples-a composed sample of 5 cores-were randomly collected from each unit and each one of the sampling location was mapped by using Global Positioning System (GPS) (Liang *et al.*, 2003). The soil samples were placed in individual plastic bags and transported in an insulated container to the laboratory, where they were stored at 4°C.

Each sample was air-dried and passed through a 2-mm screen to remove roots and other debris for chemical analysis. The following analyses were conducted on each one of the sample: Electrical Conductivity (EC) was determined with Thermo Orion 150 A+ in a 1:5 soil to water suspension (Liu *et al.*, 2006); the amounts of Na^+ in the leachate were recorded on the flame emission photometer (Saikh *et al.*, 1998) Cation Exchange Capacity (CEC) was determined with ammonium acetate at pH 7 (Jiang *et al.*, 2003) Exchangeable Sodium Percent (ESP) was calculated by the exchangeable Na^+ content percentage of CEC (Kilic and Kilic, 2007) soil pH was measured with a potentiometric glass electrodes in a 1:2.5 soil to water suspension (Shukurov *et al.*, 2005).

Statistical analyses: Geostatistical analysis-classical statistical parameters, i.e., mean, median, Standard Deviation (SD), minimum, maximum and Coefficient of Variation (CV) were calculated using Statistics Package for Social Science (SPSS) 10.0 software. Semivariances of data were calculated using GS+ geostatistical software (Gamma Design Software). Semivariance γ(h) is defined in the following equation:

$$r(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2$$

Where N(h) is the number of sample pairs with distance h as an interval and $z(x_i)$ and $z(x_i + h)$ are the values of variable at any two places separated by distance h. The semivariogram is the plots of the semivariances against the distance. Its shape indicates whether the variables are spatially dependent. Experimental semivariograms were fitted by theoretical models that are defined with well-known parameters nugget C_0, sill C_0+C and range of spatial dependence A_0 (Jiang, 2002; Liang *et al*., 2003). Kriging maps of soil EC, exchangeable Na^+, ESP and soil pH were constructed by GS+ software (Version 5.1 b, Gamma Design software)(Liang *et al*., 2005).

RESULTS

Summary statistics: The main statistical moments for soil EC, exchangeable Na^+, ESP and soil pH are presented in Table 1. Compared with G1ym, the mean values of soil EC, exchangeable Na^+, ESP and pH under G5ym were found decreased by 41.44, 41.96, 37.65 and 3.92%, respectively. Significant differences ($p<0.05$) were observed on soil EC, exchangeable Na^+, ESP and soil pH between treatments. The Coefficients of Variation (CV) of all variables tested were lower under G1ym than under G5ym, indicating the lower spatial variability under G1ym than under G5ym. Soil pH was significantly ($p<0.05$) correlated with EC, ESP and Na^+, with the r^2 of 0.732, 0.888 and 0.875, respectively. Significant correlation ($p<0.05$) was also observed between EC and ESP ($r^2 = 0.841$).

Semivariogram analysis: Sample semivariogram models and best-fitted model parameters based on the smallest Residual Sum of Square (RSS) are given in Fig. 1. Semivariagrams models of all variables tested under G1ym were fitted to an exponential model and those under G5ym fitted to an exponential model except EC fitted to a Gaussian model. The nugget values of soil EC, exchangeable Na^+, ESP and pH were generally smaller under G1ym as compared to G5ym, indicating that soil properties had spatial variability at large distances (Table 2). The still values of soil EC, exchangeable Na^+, ESP and pH were smaller under G1ym than under G5ym, indicating that these variables had greater magnitude of spatial variability under G1ym compared to G5ym. All variables studied showed a moderate or strong spatial dependence under both G1ym and G5ym plots with the proportions of spatial structure $[C/(C_0+C)]$ ranging from 50-83.7%. In particular, the proportions of sample variance explained by small-scale patchiness $[C/(C_0+C)]$ showed a very high value for almost all the variables under G5ym, suggesting that the G5ym had higher degree of fine-grained variability compared to G1ym within the sampling scale (Su *et al*., 2006). The magnitude of spatial dependence for all the variables tested was lower under G1ym than under G5ym. And the range of autocorrelation (A_0) and fractal dimension for all variables studied was higher under G1ym compared to G5ym. All the results indicated that the spatial variability in soil properties examined were greater under G5ym than under G1ym (Table 2).

Distribution maps constructed by kriging: The maps obtained by block kriging for soil properties tested were shown in Fig. 2. It was obvious that the values of soil EC, exchangeable Na^+, ESP and soil pH were generally higher under G1ym as compared to G5ym, which were consistent with the results by the classical statistics methods (Table 1). The spatial distribution patterns of soil properties examined were similar to some degree in the same study plot, but different between treatments. The degree of patch fragment was higher under G5ym than under G1ym, indicating the higher spatial variability under G5ym than under G1ym.

Table 1: Statistical characters of soil EC, exchangeable Na^+, ESP and soil pH under G1ym and G5ym

Treatments	Variables	Mean	SD	CV (%)	Minimum	Maximum
G1ym	EC(ms cm^{-1})	354.70	75.94	21.41	191.01	582.02
	Exchangeable Na^+ (cmol kg^{-1})	3.67	0.74	20.21	1.39	5.15
	ESP (%)	31.87	5.01	15.72	19.76	40.01
	pH	9.70	0.28	2.85	9.04	10.19
G5ym	EC(ms cm^{-1})	207.72	73.54	35.40	95.80	432.01
	Exchangeable Na^+ (cmol kg^{-1})	2.13	1.44	67.44	0.32	5.11
	ESP (%)	19.87	11.12	56.00	4.22	42.19
	pH	9.32	0.50	5.33	8.32	10.28

Table 2: Semivariogram models and parameters of soil EC, exchangeable Na^+, ESP and soil pH under G1ym and G5ym in Horqin

Variables	Modle	Nugget (C_o)	Still (C_o + C)	C / (C_o + C)	A_O (m)	R^2	RSS	Fractal dimension
G1ym								
EC	Exponential	4750.01	9501.00	0.500	410.90	0.416	644371.02	1.957
Exchangeable Na^+	Exponential	0.45	0.89	0.501	335.10	0.712	0.71	1.943
ESP	Exponential	20.26	40.53	0.500	410.90	0.594	4.96	1.960
pH	Exponential	0.05	0.13	0.500	410.90	0.324	0.32	1.969
G5ym								
EC	Gaussian	5030.01	10061.01	0.500	410.90	0.549	3.610E+06	1.946
Exchangeable Na^+	Exponential	1.24	2.96	0.580	120.90	0.831	0.83	1.876
ESP	Exponential	68.50	144.50	0.526	53.40	0.818	269.01	1.893
pH	Exponential	0.07	0.28	0.837	27.70	0.856	0.86	1.874

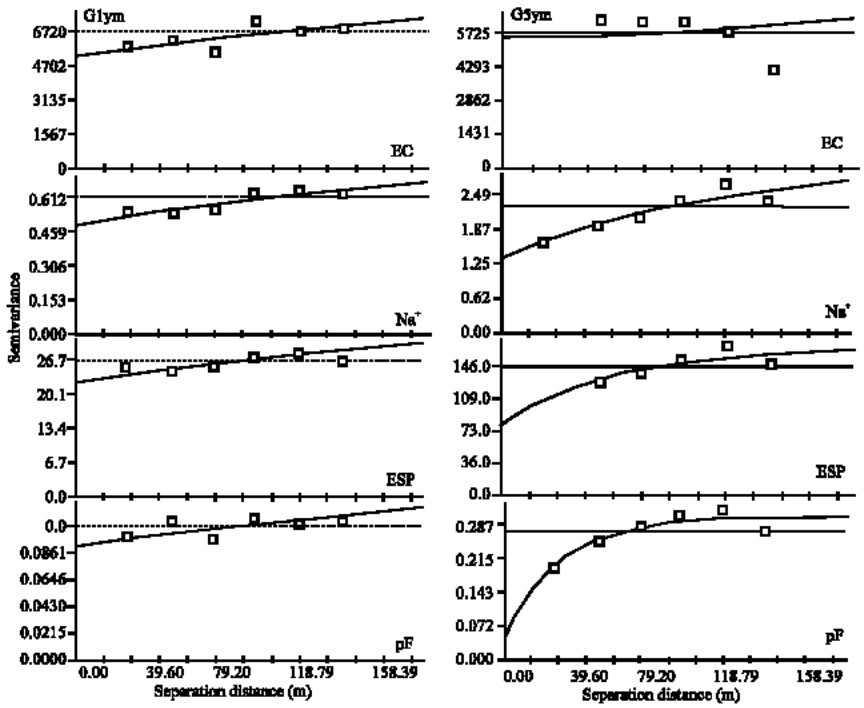

Fig. 1: Experimental semivariograms for soil EC, exchangeable Na^+, ESP and pH under G1ym and G5ym

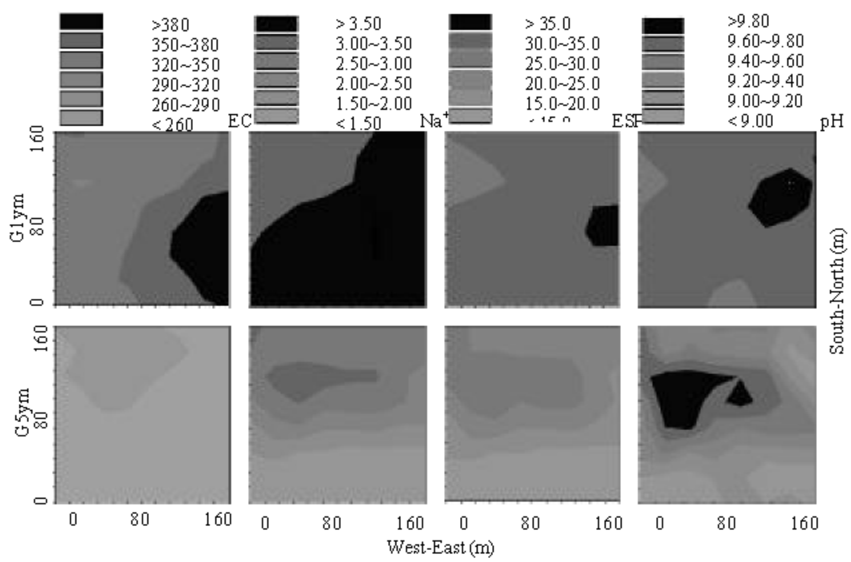

Fig. 2: Spatial distribution maps of soil EC, exchangeable Na^+, ESP and soil pH under G1ym and G5ym

DISCUSSION

Soil salinity and alkalinity is a highly important problem in arid and semi-arid regions. The assessment of spatial variability in salinity and alkalinity plays an important role in site-specific management (Kilic and Kilic, 2007). Compared to G1ym, soil properties of EC, exchangeable Na^+, ESP and soil pH under G5ym decreased by 3.57-41.6%. Significant differences ($p<0.05$) were observed on these soil properties between treatments. The results illustrated that the level of soil salinity and alkalinity has been alleviated with the period of vegetation restoration. The reason may be due to the melioration practice of sowing leguminous grass in the rainy season (from June to August) in Horqin steppe. With the growth of grasses, the coverage of vegetation can alleviate the water evaporation and prevent salts from aggregating on the ground. The decrease of soil pH under G5ym compared to G1ym may be attributed to the influence of perennial grass roots secretion and respiration (Zhang *et al*., 2004). Significant correlations were found between soil pH and EC, ESP and exchangeable Na^+ ($p<0.05$). The result indicated that high soil pH was associated with sodium (Ardahanlioglu *et al*., 2003).

In our study, semivariogram models and kriging-interpolated maps showed that the spatial variability of soil EC, ESP, exchangeable Na^+ and pH was higher under G5ym than under G1ym. The results can be attributed to the different period of melioration. The practice of plowing is benefit to disrupt the hard crust and increase soil homogeneity in short time. With the formation of shrubs, the influence of plant coverage will be obvious. The plant vegetation can increase the spatial variability of soil physicochemical properties by absorbing and metabolizing soil nutrients, which might contribute to the higher heterogeneity under G5ym than under G1ym. Our results were consistent with the reports from Su *et al.* (2006) and Cheng *et al.* (2007) who found that increase in shrub dominance in a community is responsible for elevating the spatial variability of both above- and belowground properties.

The analysis of spatial distribution patterns of soil properties related to salinity and alkalinity can enable us to have a deep understanding of the ecological relationships between soils and the environment (Rossi *et al*., 1992). In our study, the spatial variation of soil EC, exchangeable Na^+, ESP and pH were higher under G5ym than under G1ym, which may be influenced by the growth of plants during vegetation restoration. The analysis of spatial variability of soil EC, exchangeable Na^+, ESP and pH is helpful to predict the restoration process of degraded grassland ecosystem. More studies might be required to fully understand the ecological process during the vegetation restoration.

ACKNOWLEDGEMENT

This research was supported by the National Key Technologies R and D Program of China (No. 2005BA517A-8).

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