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Spatiotemporal heterogeneity of soil salinity after the establishment of vegetation on a coastal saline field

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ABSTRACT

Changes in plant community composition resulting from ecological restoration can affect the spatial pattern and variability of soil salinity. Understanding and quantifying the temporal and spatial heterogeneity of soil salinity is essential before decisions can be made about the cost-effective management measures for plant communities following restoration on coastal saline filed. In this study, we selected three types of vegetation and conducted soil bulk electrical conductivity (EC_b) by a hand held device in the topsoil (0–20 cm) at regular 1 m intervals across the field over a year period. Conventional statistics and geostatistics were used to analyze the data. The results showed significant differences and high coefficients of variation in top-soil salinity among different vegetation types. Simple mean EC_b comparison revealed that soil salinity varied from spring to winter and tended to be higher in autumn. The generalized semivariogram for soil salinity indicated that woodland possessed a much smaller effective range (1.9 m) and nugget/sill ratio (7.37%) than that for other plant communities. Krigged contour maps showed different spatial distribution patterns among three types of vegetation and the consistently high and low salinity areas of the field at different seasons for the same vegetation. These results suggest that plant communities have significant influences on the temporal and spatial variability of soil salinity when vegetation is established in coastal saline field. The selection of plant species and management measures to plant should be special attention in the reclamation of saline land.

1. Introduction

Coastal tideland is formed by the large number of sediment deposition and the buffer zone of connecting land and sea. In China, there are about 2270 km^2 coastal tidelands (Ma et al., 2008). With rapid development of economy and urbanization, these areas are not only important habitat and transition zones, but also gradually become the focus of regional development and construction. However, because of long-time tidal influence, excessive amounts of soil salt contents are key factor limiting the growth of individual plants. Urban landscaping in saline soil has become a major problem to be solved. Thus, in order to implement landscape greening construction on coastal tideland, it is meaningful to detect the relationship between vegetation and soil following vegetation restoration of saline soil.

In coastal tidelands, soil physical and chemical properties, especially soil salinity level presented considerably high temporal and spatial heterogeneity because of the differences in reclamation measures and farming practices. Many studies have shown that soil heterogeneity is a basic element for competitive or facilitative interactions between plants in stressed environments (Chapin et al., 1994), and the scale and degree of spatial variability in soil properties can have important influences on both plant community structure and patterns (Robertson et al., 1993). Meanwhile, individual plants and plant community composition also affect the distribution of soil nutrients at a variety of spatial scales (Hook et al., 1991; Jackson and Caldwell, 1993a), because plants are important in the regulation of soil nutrient availability and distribution by altering the physical, chemical, and biological properties of the soil beneath plant canopies and by concentrating biomass and organic matter (Gross et al., 1995; Augusto et al., 2002; Jackson and Caldwell, 1993a,b; Schlesinger et al., 1996; Zhang and Chen, 2007). Thus, analyzing and quantifying the temporal and spatial heterogeneity of soil-salinity variability in different plant community compositions can permit a deeper understanding of the ecological relationship between vegetation and soil and provide new insights on the decision of cost-effective constructing and managing measures for plant communities following restoration on coastal saline field.

In spite of many studies on spatial and temporal heterogeneity of soil properties have been carried out (Chevallier et al., 2000; Sun et al., 2003), we have very limited knowledge about soil-salinity variability in space and time in coastal saline soils that have been reclaimed for a few years. Chongming Island is located in the Yangtze River estuary,

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which is the third largest island in China and the world's largest river alluvial island. Due to the long-term influence of tidal, salt dust and fog, Chongming Island is one of the most serious soil salinization regions in southeast China. In recent years, the government increased the investment of saline soil restoration and landscaping construction, and achieved remarkable results. However, with regard to the landscape construction of coastal saline land, there still exist a series of common problems, such as serious secondary salinization of soil, low survival rate of plants, high cost of greening and maintenance, and weak sustainability of urban green-land system.

In this paper, we aim to detect the relationship between vegetation restoration and spatial and temporal heterogeneity variation of soil salinity in saline soil. We hypothesized that (1) spatial heterogeneity in soil salinity would change with different vegetation restoration of saline soil, and (2) arbor community have higher spatial heterogeneity than other plant communities.

2. Materials and methods

2.1. Study sites

The study was conducted at the Chongming Dongtan located in the eastern end of Chongming Island (31°27′00″–31°51′15″N, 121°09′30″–121°54′00″E), Shanghai Province, China. The climate of the region is classified as north subtropical marine monsoon according to Koeppen's classification. Its mean annual precipitation is about 1100 mm, which concentrates predominantly in April to September. The annual average relative humidity is about 77%. The mean annual temperature is 15.3 °C. The average temperature at local waved severely among seasons (the average temperature in July is 27.5 and in January is 2.8 °C). The mean annual evapotranspiration is about 1225 mm. The soils were formed by the modern marine and alluvial deposit matters. The soil is seashore solonchak, which average salinity is from 0.2% to 0.6%. Soil textures are light loam. Soil pH change greatly and are greater than 8.0, with an average of 8.4. Soil organic matter is relatively poor, with an average of 8.86 g/kg. Over the past 30 years, many coastal tideland areas have been successively reclaimed for agricultural uses. The study was conducted in a field of about 300 ha, which was reclaimed in the year 2000. After ten years of ecological restoration, it becomes the ecological demonstration area of wetland protection and rational utilization. And many plant species were introduced and planted for coastal salt flat restoration.

2.2. Soil sampling and analysis

In our experiment, the three sites, each about 1 ha in size, were selected within the three plant communities that had been establishment, respectively. Each site was located at the same micro-topographic situations, as confirmed by detailed topographic map and direct observations in the field. Near the center of each site, a 5 m × 20 m plot was chosen for sampling in March 2012, oriented east–west. In each quadrat, plant species, height, and cover were recorded. A summary of vegetation characteristics at each quadrat is given in Table 1.

A rectangular grid-sampling scheme (Fig. 1) was imposed on the field to select points of measurements. The samples were collected from 100 sample points in a regular grid with 1 m between adjacent points. Bulk electrical conductivity (EC_b) measurements for topsoil (0–20 cm) were performed on each grid point in situ using a portable and corrected sensor probe (Spectrum Technologies Inc., USA). The sensor probes were inserted into the soil to measure the electrical conductivity and temperature. Meanwhile, at each sampling point, after the removal of surface litter, soil samples were collected and loaded in aluminum boxes, and timely carried to the lab for the determination of moisture contents. And the soil electrical conductivity (EC) was measured in a 1:5 soil–water suspension and then compared with those from sensor. On each grid-cell, three samplings distributed triangularly within a 20-cm radius near the cell center were measured by inserting the sensor probes into the soil and then the average reading was computed as the EC_b value at that point. The four sampling dates were April 18, 2012, July 16, 2012, October 18, 2012 and January 20, 2013, respectively.

The EC1:5 readings were linearly well correlated with EC_b readings, and the general regression equation can be expressed by the following formula: $y = 3.312\,x + 0.5805$ ($r^2 = 0.9846$) (Fig. 2), where y indicates the EC1:5 readings and x indicates the EC_b readings. In other words, the EC_b readings can be used to replace EC1:5 readings to a great extent with an acceptable accuracy, especially in a large number of experimental data.

2.3. Statistical analysis

Differences in soil EC between the different plant communities and the different seasons in the same plant communities were compared using the multiple comparison and one-way analysis of variance (ANOVA) procedures. Results were checked by Tukey's test ($P < 0.05$). The descriptive statistical parameters and significance test were calculated by SAS Release 9 (SAS Institute, Cary, NC). Descriptive statistics including the mean, standard deviation (S.D.), coefficient of variation (CV), skewness and kurtosis, were determined for each sample plot. The general variation in soil EC was described by the mean EC and the CV.

The distribution of soil EC was tested for normality by the Kolmogorov–Smirnov test at the 0.05 significance level. For those soil EC not passing the normal distribution test, we used data log-transformation. The variability of soil EC in each plot was analyzed using geostatistical techniques. These techniques evaluate the autocorrelation commonly observed in spatial data, where data values from locations close to each other are more similar than data values from locations far apart (Wallace et al., 2000). The semivariance calculation and function model fitting were performed using geostatistical soft-ware, GS+ version 9.0 for Windows (Gamma Design Software, Plainwell, MI). Spherical, exponential, linear, and Gaussian formulas that best fitted the model are presented in the semivariogram. Based on the regression coefficient of determination (r^2), the model with the least sum of squares was chosen as the "best fit" (Robertson et al., 1993). When a model was fit well to the data, the following parameters were determined. The "range" was the maximum distance over which the measured soil properties exhibited significant spatial autocorrelation; the "sill" (C + Co) was the total sample variability at which the semivariogram levels for the patterned data; the "nugget" (Co) was the random variation that is usually resulted from the inaccuracy of measurements or variations of the properties that cannot be detected in the sample range (Trangmar et al., 1985); the structure variance (C) was the difference between the sill and nugget; the ratio of nugget to sill (Co/(Co + C)), an especially

Table 1
Summary of vegetation characteristics in three plots.

Vegetation type	Plant species	Height (cm)	Coverage (%)	Individual and row space (m)	Salt tolerance (%)
Grasses	*Taxodium distichum* Rich.	15	90	–	<0.3
Shrubs	*Nerium indicum* Mill.	200	45	2.5 × 2.5	0.3–0.6
Trees	*Cynodon dactylon* L. Pers.	1000	85	2 × 2	<0.3