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Spatiotemporal heterogeneity of soil water and salinity after establishment of dense-foliage *Tamarix chinensis* on coastal saline land

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ABSTRACT

Dense-foliage tamarisk (*Tamarix chinensis*) varieties are widely planted for landscape construction projects in the highly saline coastal soil of northern China. Because these plants are salt-secreting halophytes, their growth in arid land usually leads to soil salinization and water loss. In this work, a tamarisk plantation was established in a coastal area within a semi-arid region of China, and the water content, salinity levels and spatial distribution patterns in the soil were analysed in 1×1 m grids of a 10×10 m sample plot in July 2014 and July 2016. Four layers of soil within the 0–80 cm profile were sampled, and the soil water, salt, Na^+ and Cl^- contents and pH were determined. In 2016, the soil water content had decreased slightly, and the soil salt content had increased by 0.49 g kg^{-1}, representing a 7.0% increase compared with the value in 2014. Both the soil Cl^- and Na^+ content increased from 2014 to 2016, accounting for a greater fraction of the total salt, and the mean soil pH also increased by approximately 0.4. The spatial variation was weaker in the deeper layers but moderate in the surface layer. After tamarisk establishment, the spatial variation in soil salinity declined and showed a trend toward homogeneity. The secreted salt and litterfall from the tamarisk might explain the higher soil salinity and increased homogeneity, which suggests that tamarisk growth will lead to increased soil salinity and a more homogeneous salt distribution throughout the soil.

1. Introduction

A large area with saline soil is located surrounding the Bohai Sea in the semi-arid region of northern China. Because of the shallow saline groundwater table and high evaporation during the drought season, the soil salinity in these coastal lowlands is usually beyond the survival threshold of plants except for a few halophytes (Guo and Liu, 2015; Li et al., 2015a). Therefore, these highly saline areas are covered by bare land or sparse vegetation. However, the rapid economic development of these coastal regions has increased the demand for vegetation establishment on these bare saline soils (Li et al., 2015b).

Tamarisk (*Tamarix chinensis*) is one of the few native shrub species that is widely distributed in coastal regions, and it is usually used for vegetation restoration in highly saline soil because of its high tolerance to salt, drought and flooding (Cui et al., 2010; Cao et al., 2011). In recent years, several new landscape-use tamarisk varieties have been bred from superior local wild individuals (Liu et al., 2014; Zhang et al., 2016). These new varieties have inherited a high tolerance to saline environments and are characterized by dense foliage and rapid growth (Liu et al., 2014; Zhang et al., 2016). Therefore, these dense-foliage tamarisk varieties have been planted en masse in coastal regions because of their lower costs and excellent landscape effects. In addition, local governments have launched costal ecological restoration projects to plant large amounts of dense-foliage tamarisk on highly saline coastal land for vegetation restoration over the next few years.

Reports have indicated that the establishment of plant communities on saline soil can alter the soil properties because of the biochemical and physical interactions between plants and soil (Ravindran et al., 2007); studies have also shown that the establishment of halophytes in saline soil promotes soil desalinization (Ghaly, 2002; Ravindran et al., 2007; Wu et al., 2009). Tamarisk is a salt-excreting species that excretes salt from glands in its leaves (Sookbirsingh et al., 2010). Many studies have indicated that the establishment of tamarisk in arid regions leads to salt enrichment of the surface soil and water loss (Lesica and DeLuca, 2004), whereas the establishment of these plants in semi-arid regions leads to

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the leaching of soil salt into deeper soil via precipitation during the rainy season (Liu et al., 2010). However, whether soil salt will increase because of the accumulation of excreted salt after the planting of dense-foliage tamarisk in semi-arid regions remains unknown.

Soil heterogeneity is a basic element in competitive or facilitative interactions between plants in stressed environments (Bazihizina et al., 2012). Individual plants and the community composition also affect the distribution of soil salinity and are important factors in the regulation of soil salinity and distribution because plants alter the physical, chemical, and biological properties of the soil beneath plant roots and concentrate biomass and organic matter (He et al., 2015). Thus, soil salinity spatial patterns and variability change under different plant community compositions (He et al., 2014). In addition, the scale and degree of the spatial variability of soil properties can have important influences on both a plant community's structure and patterns (Xie et al., 2015). Therefore, analysing and quantifying the temporal and spatial heterogeneity of soil salinity variability with the growth of dense-foliage tamarisk can lead to a deeper understanding of the ecological relationship between halophytes and saline soil and provide new insights into the construction and management of plant communities following the restoration of coastal saline fields.

Although many studies have focused on the spatial variation of salinity in coastal saline soil, almost all of these studies were conducted at landscape, regional or larger scales (Yao and Yang, 2010; Liu et al., 2016; She et al., 2016), and few studies have been conducted at the field scale. In addition, most of these studies were based on measurements of soil electrical conductivity (EC) using electronic sensors (Shi et al., 2005; Yao and Yang, 2010; Guo et al., 2015), and the spatial variation of Na^+ and Cl^-, which are the primary ions that affect plant growth, have not been assessed. Thus, limited knowledge of the spatial and temporal variability of soil salinity in highly saline areas planted with dense-foliage tamarisk is available.

Tamarix chinensis 'Haicheng 1', which was bred from wild tamarisk, is a new landscape-use, dense-foliage variety characterized by fast growth and heavy leaves (Liu et al., 2014). In this paper, we aimed to detect the relationships between the planting of the dense-foliage variety *Tamarix chinensis* 'Haicheng 1′ and the spatial and temporal variation of soil salinity in highly saline soil. We hypothesized that after the establishment of the dense-foliage tamarisk, (1) the soil salinity would increase and (2) the spatial heterogeneity of the soil salinity would decline with continued tamarisk growth.

2. Methods

2.1. Study site

This study was conducted in the highly saline costal land around the Bohai Sea in Haixing County (117°33′5″ E, N38°09′59″N), Hebei Province, northern China. This area has a typical semi-humid continental monsoon climate characterized by short rainy summers and long dry springs, autumns and winters. The annual mean precipitation is 582 mm, with more than 75% occurring in the rainy season from July to September (Guo and Liu, 2015). The daily temperature and precipitation from 2014 to 2016 are shown in Fig. 1. In 2014, the total precipitation was 385 mm and the mean temperature was 14.5 °C; in 2016, the total precipitation was 685 mm and the mean temperature was 14.0 °C. A comparison of 2014 and 2016 showed that the climatic conditions before the soil sample collection in these years were similar, with the total precipitation before July 10th at 139 mm in 2014 and 131 mm in 2016. The similar precipitation levels in the drought season allowed us to compare the soil salt content between two years under similar water and salt dynamic processes. The soil in this area has a silty clay loam texture and suffers from strong salinization, with soil salinities ranging from 4 to 30 $g\,kg^{-1}$. The soil bulk density was 1.35–1.51 $g\,cm^{-3}$, and the saturated water content was 29.5–32.3%. The field sits atop a shallow groundwater table (0.8–1.5 m layer) that maintains a high salinity range (25–35 $g\,L^{-1}$). The main ions are Na^+ and Cl^-, which account for more than 75% of the total ions. The soil salt in the root zone leaches in summer and accumulates during spring, autumn and winter (Guo and Liu, 2015). The soil salt content and water content change in the dry and rainy seasons. The salinity peak occurs in July of each year, and this month presents the lowest soil moisture. However, after the heavy rains in August, the soil salinity is lowest and the soil moisture is the highest.

2.2. Sample set and soil collection

In this study, 'Haicheng 1' cuttings were planted at a density of 0.5 × 1 m on April 15, 2014. A 10 × 10 m quadrate sample plot was selected before the rainy season in the first year after tamarisk establishment on July 10, 2014. One hundred sampling points were selected in a 1 × 1 m grid between two tamarisk rows. At each point, soil samples were collected at depths of 0–20, 20–40, 40–60 and 60–80 cm using a soil auger. The tamarisk shoot height and stem diameter at the soil surface were measured. Tamarisk biomass was determined by cutting down 4 individuals located in the same field, but not in the study plot, in October 2014 and 2016. The leaves were separated from the plant, and the dry weight of the leaves and the entire plant were measured. The same investigation was conducted in the same plot on July 12, 2016, using soil samples collected at the same points and the shoot height and stem diameter measured at the soil surface. During the monthly collection of the three soil samples in the plantation and bare land sites, the soil water and salt content were determined. In the plantation, the surface (0–20 cm) soil water and salt content were also monitored by sampling soil collections near the 10th of each month from March 2014 to September 2016.

2.3. Determination of soil properties

Each soil sample was divided into two parts: one part was oven dried at 105 °C and weighed to determine the gravimetric soil water content, and the other part was air dried, ground and passed through a 1 mm sieve. The EC, pH, soluble cations and anions in the soil were analysed in 1:5 soil water extracts. The Cl^- content was determined by titration with $AgNO_3$, the $SO_4{}^{2-}$ content determined by EDTA indirect complexometric titration, the $HCO_3{}^-$ content was determined by the double-indicator neutral method (Bao, 1999); and the Na^+, K^+, Ca^{2+} and Mg^{2+} contents were measured using an atomic absorption spectrophotometer (wyx-402c, Shenyang, China) (Bao, 1999). The soil total salt content was calculated as the sum of the ions (Cl^-, $SO_4{}^{2-}$, $HCO_3{}^-$, Na^+, K^+, Ca^{2+}, and Mg^{2+}).

2.4. Spatial variation analysis

The water and salt content of each layer were tested using the Kolmogorov-Smirnov test; the data did not fit a normal distribution when the values were log transformed. A semivariogram model was used to calculate the spatial variability (Isaaks, 1989). The variograms of the soil proprieties were calculated using the following function:

$$\gamma(h) = 1/2N(h)\sum_{i=1}^{n}[Z(Xi) - Z(Xi + h)]^{2}$$