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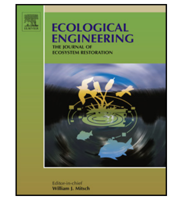

The spatial and seasonal variation characteristics of fine roots in different plant configuration modes in new reclamation saline soil of humid climate in China

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ABSTRACT

In order to study the spatial and seasonal variation characteristics of fine roots in a salinization area, we examined three configuration modes through soil samples collected via soil drilling. Fine roots biomass (FRB) showed significant differences among the different modes. Significant differences of FRB were observed at a soil depth of 0–60 cm in the three modes ($p < 0.05$). More than 60% of FRB were concentrated in the soil depth range between 0 and 20 cm, and decreased exponentially as soil depth increased. Specific root length (SRL) and fine root length density (FRLD) showed a similar vertical distribution pattern to the FRB. In all three modes, FRB showed significant seasonal differences ($p < 0.05$). FRB was highest in July, and showed the bimodal variation, while monthly variation of FRB in the root diameter range of $\Phi \leq 2$ mm and 2 mm $< \Phi \leq 5$ mm showed significant positive correlations ($p < 0.05$). Total FRB was highest in the tree-shrub stand model (TSSM). Due to the effect of salinity, FRB showed significant differences in different soil depths and resulted in FRB spatial niche separation. We found that high salt content salt had an obvious inhibitory effect on the distribution of FRB. Therefore, salinity should be below 1.5 mS/cm, which was conducive the growth of plant roots. The results indicated that TSSM had the highest FRB, SRL, and FRLD, and may have the strongest effect on salt suppression and salt control in saline-alkali land.
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1. Introduction

The root system of a plant absorbs water and nutrients from the environment to support plant growth and development. Fine roots play a very important role in plant growth and in ecological restoration because they respond directly to changes in the environment. Therefore, the number of fine roots and fine root biomass (FRB) directly affect plant growth.

FRB is influenced by many factors, such as climate change, soil moisture, nutrient availability, vegetation type, and soil salinity (Meinen et al., 2009; Finér et al., 2011; Plante et al., 2014; Hulugalle et al., 2015). FRB directly reflects the quantity of nutrition adsorbed from soil, and it varies with climate type, vegetation type, and plant community diversity (Schmid and Kazda, 2002).

FRB typically shows a regular vertical distribution, with most of the fine roots distributed above a soil layer depth of 30 cm, and especially in the mineral soil layer at a depth of about 10 cm (Finér et al., 2011). However, FRB is affected by plant configuration, planting density, and soil characteristics, so the vertical distribution of FRB shows significant differences based on these factors. For example, FRB decreases exponentially as the soil depth increases, and FRB in mixed forests is higher than that in pure forests (Schenk and Jackson, 2002). FRB also shows obvious seasonal dynamics, such as unimodal and bimodal seasonal variations (Zhou and Shangguan, 2007; Liu et al., 2014).

Due to special geographical and environmental circumstances, FRB in arid areas is significantly different from that in non-arid areas. Soil moisture affects the vertical distribution of fine root distribution in the growing season. Drought stress is one condition where fine root distribution shows this effect. In order to absorb

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water in deeper soil, fine roots display niche separation in their vertical distribution (February and Higgins, 2010; Gwenzi et al., 2011; Imada et al., 2013). Because fine roots adapt to the environment via “hydraulic lift” and physiological and metabolic changes, they can thus enhance the plant’s drought resistance (Caldwell and Richards, 1989). At the same time, the distribution pattern of fine roots in the soil reflects the plant’s ecological adaptation countermeasures (Hartle et al., 2006).

Fine roots are directly damaged by salt and alkali, and the plant damage caused by the stress of salt and alkali was similar to that caused by drought stress and a high-temperature environment (Schubert et al., 2009). In some habitats, the soil salt content is generally above 8–16 mS/cm (Zhu, 2001). Fine root distribution, root length and other morphological indicators were affected by salt stress under these conditions (Ashraf and Harris, 2004). Some scholars have found that changes in soil salinity in the root cap zone in halophytes are related to plant configuration, stand structure and plant growth condition. In the root cap zone of plants with vigorous growth, salt has an obvious desalination effect on topsoil (Yu et al., 2014). With a decrease in growth potential, salt accumulation occurs in the marginal soil of the root cap (Nichols et al., 2009), especially at the crown edge; thus, the formation of “salt islands” can be observed at root cap edge (Chen et al., 2004). The impact of salt stress on plant growth and development can be summarized in two effects. First, higher salinity reduces soil water potential and inhibits the water absorption by fine roots, thus causing an osmotic stress effect. Second, the accumulation high amounts of salt destroy the balance of ions in the cytoplasm, resulting in an ion stress effect (Zhu, 2001). Therefore, high salinity possibly limits plant growth and production. In order to enhance plants’ ability to use water and their environmental tolerance, it is necessary to understand the vertical distribution variations and seasonal dynamics of fine roots in different soil environments.

Fine roots are more sensitive to salt stress than the plant part above the ground, so under conditions of high salt stress, the nutrient absorption capability of fine roots significantly declines (Galvan-Ampudia and Testerink, 2011), making it difficult to establish vegetation. Therefore, in areas with high soil salinity, the quality and quantity of afforestation are restricted (Zhu, 2001), thus affecting ecological restoration and forestry development.

Unfortunately, fine roots under salt stress, especially in coastal saline habitats under humid climate conditions, have seldom been studied. Soil salinity above 2 mS/cm is adverse to plant growth (Nichols et al., 2009); in the Shanghai Lingang New Reclamation Area, soil salinity averages about 2–6 mS/cm (Nichols et al., 2009). Therefore, studying FRB in different plant configuration modes in the Shanghai Lingang New Reclamation Area will help us understand the correlation between plant configuration mode and fine root growth in coastal saline soil. The study is of great significance because it can identify how plants adapt to environmental stress and ecological restoration.

This research examines fine roots under three different plant configuration modes in saline soil in the Shanghai Lingang New Reclamation Area. We studied the relationship between fine root indicators (the vertical distribution and seasonal changes of fine roots) and environmental factors (the spatial gradients of soil water and salt) in order to explore the adaptation mechanisms of plant roots under different configuration modes in coastal saline soil. We began with the following three assumptions. Firstly, FRB of tree-shrub mixed forest is higher than that of forest trees or shrubbery alone in saline soil. Secondly, influenced by salinity, underground niche separation of fine roots occurs, which increases both underground soil utilization and FRB. Thirdly, salinity may adversely affect fine root distribution in different seasons.

2. Materials and methods

2.1. Study area

The field site (N30°52′54″, E121°54′24″) was located in the Lingang New Urban Area in Shanghai. It is a coastal monsoon climate with warm and rainy springs, hot and humid summers, wet early autumns and dry later autumns, and cold and dry winter. Annual total solar duration is 2000–2200 h. Monthly average evaporation is 91.9 mm. Annual average temperature is 15.7 °C. The lowest monthly average temperature (3.3 °C) occurs in January, and the highest temperature (38 °C) occurs in August, with an average annual temperature of 28.8 °C. The annual average rainfall is 1061.9 mm. The soil is saline sandy soil with a pH value of about 7.8. The underground water level is between 0.5 m and 2.5 m. Ecological restoration forestry started in February 2011 and was completed in April 2011. The restoration field is about 800 m long and 12 m wide. All the plants are native tree species. Beginning March 2014, we selected three representative plant configuration modes for the study of FRB: tree stand model (TSM), shrub stand model (SSM) and tree-shrub stand model (TSSM), as shown in Table 1.

2.2. Plot design

The deciduous trees examined in this paper generally entered the leaf expansion period in the middle of April and the abscission period in late September. The abscission period was completed in November. From March to November in 2014, fine roots were sampled with a steel bucket-type soil auger (bucket auger with the diameter of 50 mm and the height of 20 cm) with a T-handle. We selected 3 plots for each mode. The size of each plot was 10 m × 20 m, and the plots for each mode are 100 m away from the plots of other modes. Each plot was divided into 8 subplots of 5 m × 5 m. Fine root samples were collected in depth intervals of 0–10, 10–20, 20–30, 30–40, and 40–60 cm. We collected soil core samples in the 8 subplots in 3 random samplings of the 3 plots in each model and at each soil layer for a total of 72 randomly selected soil core samples. Each sample was placed in a self-sealing plastic bag and the samples were then used to determine the FRB for every month and every soil layer in each model.

2.3. Fine root measurements

Fine root samples were soaked in tap water in the laboratory and then washed with a metal-sieve stack (pore size of 0.40 mm), and all roots and root nodules were manually collected. Clean fine roots were immediately put into a plastic bag and stored at low temperature (−4 °C). We separated the living roots from the dying roots and, using clips and magnifiers on evaporation pans, removed the grassroots according to the shape, color, smell, elasticity, and other features (Liao et al., 2014). We put samples on the glass with grid paper and separated living roots into two tiers according to the root diameter: $\Phi \leq 2$ mm and 2 mm < $\Phi \leq 5$ mm by using a vernier caliper (Finér et al., 2011; Zhang et al., 2012). We extended the roots with clips on both ends, numbered, bagged, and baked them at 80 °C for 24 h and weighed the dry roots with electronic scales (accuracy: 0.001 g). We calculated specific root length (SRL) according to root length and FRB of each layer, and then we calculated fine root length density (FRLD) according to root length and the volume of the core soil. Finally, we calculated the averages of the 72 soil core samples in each soil layer and converted the averages into FRB, SRL, and FRLD per unit area. Then we calculated the monthly averages of SRL and FRLD in the five soil layers. SRL and FRLD were calculated as follows: SRL = m/g (m/g) and FRLD = L/V (m/m^3) (g = fine root dry

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