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Spatial distribution characteristics of fine roots of *Populus euphratica* in a desert riparian forest

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Abstract The soil-plant system is a very important subsystem of the soil-plant-atmosphere continuum (SPAC). The water uptake by plant roots is an important subject in the research on water transport in this SPAC and is also the most active study direction in the fields of ecology, hydrology and environment. The study of the spatial distribution pattern of fine roots of plants is the basis of constructing a water absorption model of plant roots. Our study on the spatial distribution pattern of fine roots of *Populus euphratica* in a desert riparian forest shows that the density distribution of its root lengths can be expressed horizontally as a parabola. The fine roots are concentrated within the range of 0–350 cm from the tree trunk and their amount accounts for 91.9% of the total root mass within the space of 0–500 cm. In the vertical direction, the density distribution of the fine root lengths shows a negative exponential relation with soil depth. The fine roots are concentrated in the 0–80 cm soil layer, accounting for 96.8% of the total root mass in the 0–140 cm soil layer.

Keywords *Populus euphratica*, fine roots, root length density, spatial distribution

1 Introduction

The root system is the main tissue for plants to absorb water from the soil and to take it up through root hairs to root vessels and then to leaves to evaporate into the air. These steps form the soil-plant-atmosphere continuum

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(SPAC) system. The soil-root system is an important SPAC subsystem, of which the study on the water absorption pattern of roots has received considerable interests in related research areas worldwide. Many international projects, as their major research area, study the role the root system playing in water absorption in material and energy transport. Their aims are to explore the biological and physical transformation procedures of the plants themselves, by means of experimental studies of the role of the root-soil system in ecological and hydrological interactions of a specific area, their carbon cycling, and environmental control procedures. These studies allow plants themselves to determine the interchange relationships among the atmosphere and soil. Research in these areas has gained great interest in the international circles of hydrologists, ecologists and botanists. The study of constructing fine root water absorption models has become the most active field in ecology-hydrology research and is expected to become an integral part of land interchange procedures (Ji et al., 2006). At present, most studies focus on agricultural crop root systems (Yao, 1989; Kang et al., 1992; Hudan, 1996; Shao and Li, 1997; Zuo et al., 1998; Bai et al., 2001; Chi et al., 2004) and less on tree and plant root systems (Hao et al., 1998; Zhang et al., 2002; Yao et al., 2004a, 2004b; Zhang and Meng, 2004) and even less on tree and plant systems in arid regions, except for some studies on root systems of shrubs (Zhu et al., 2001a, 2001b).

Populus euphratica Oliv. is a unique tree growing naturally in arid desert oases. It endures salt-alkali and damp environments and, moreover, is able to resist aridity and sandstorms. *P. euphratica* maintains the balance of the ecosystem, protects agricultural production, stockbreeding, and the livelihood of the inhabitants of arid desert oases. This tree has a huge root system and its extensive side root system spreads to 1 m below the surface. The interface between roots and soil plays a key role in its water transport system and acts as a “bottleneck”. Making actual measurements of the density of the root length of *P. euphratica* in the period from May to July in 2006, we analyzed the spatial distribution pattern of its

fine root system growing in an extreme, arid desert oasis and provide key references for the construction of the root water absorption model of this species and then demonstrate the water transport mechanism between root and soil. The outcome of the composite model indicating the amount of water transported by the SPAC system of this tree, can make a great contribution to the protection and development of *P. euphratica* and provides a theoretical basis for its future management and operation.

2 Experimental area and methods

2.1 Experimental site

The experiment was conducted in the Qidao Bridge Reserve Area of *P. euphratica* forests in Ejina Banner, Inner Mongolia Autonomous Region, China (42°21'N, 101°15'E), with an area of 1333 hm² at an elevation of 920 m. The site is one of the driest areas in China, with average annual precipitation of only 37.9 mm, while the average annual evaporation is 3700 mm and average annual temperature 8.2°C. The physical characteristics of the site are shown in Table 1. The organic content at a depth of 0–30 cm is 0.73% and 0.13% at 30–200 cm. The underground water levels range from 1.5 to 3.5 m.

2.2 Experimental material

First, we investigated the distribution of diameter at breast height (DBH) of the standing forest and chose one 20 m × 50 m area as our standard sample area. After that, we conducted our investigation on DBH, height, density and shade density of the sample trees, with the following results: average age 25 years, shade density 0.8, tree density 800 trees/hm², average tree height 10 m, average DBH 19 cm. We established 2 cm diameter classes. The diameter of the biggest trunk was 18–20 cm. The results are shown in Fig. 1.

Given the aim of our forest investigation and the results of our measurements, we chose our standard trees on the principle that the trunks of our trees were not shaded. We selected two well-developed straight and healthy trees as our experimental, standard trees (DBH 18 and 20 cm).

2.3 Experimental methods

The experiment was conducted during the period of May to July, 2006, when nearly every day the weather was

clear. Since the roots of *P. euphratica* are distributed unevenly both vertically and horizontally and its root system is large, normally samples were collected from the soil-root section. The roots of *P. euphratica* are oriented towards water sources and circle the trunk symmetrically. We conducted 3-dimensional stratified sampling. At first, we excavated a section in a prearranged direction around the trunk. At the horizontal level we collected soil samples every 20 cm continuously along a length, from 0–400 cm, of the section, with a sample space 20 cm long, 10 cm wide and 20 cm high. Vertically, we collected soil samples with the same dimensions every 20 cm continuously from 0–140 cm. At the laboratory, we separated the roots from the soil with a 2 mm sieve. The roots whose diameters were less than 2 mm were selected as our samples by using the 2 mm sieve. These were cleaned and dried in the sun for a day. We obtained the length of all samples by using equation (1) and the root length density of each soil cores was obtained from equation (2) (Ma et al., 1997; Zhang et al., 2002; Zhang and Meng, 2004).

$$L = 11/14 \times N \times \gamma \tag{1}$$

$$RD = L/V \tag{2}$$

where *L* is length of root (cm), *N* the number of roots that cross a point of intersection, γ a constant related to the form of the grid, *RD* density of root length (cm/cm³) and *V* is the volume of each soil core (cm³).

3 Results and analysis

3.1 Horizontal distribution characteristics of fine roots

Our calculations show that the average density of fine root lengths of *P. euphratica*, in a horizontal direction, is distributed parabolically as a function of the horizontal distance from the trunk. We carried out a regression analysis of the density of the root lengths and the horizontal distance to the trunk at a range of 0–500 cm. The equation is:

$$RD = -9 \times 10^{-7}d^2 + 0.0003d + 0.0534 (R^2 = 0.7997) \tag{3}$$

where *RD* is the density of root length (cm/cm³); *d* the horizontal distance to the trunk (cm).

Figure 2 shows that horizontally, the amount of fine roots is concentrated between 0–350 cm from the trunk

Table 1 Physical characteristics of soil profile at the experimental site

depth/cm	texture	bulk density/g·cm ⁻³	saturation moisture content/g·cm ⁻³	field capacity/g·cm ⁻³	wilting moisture/g·cm ⁻³
0–80	sand	1.402	21.70	3.55	2.28
80–100	clay	1.644	22.32	3.67	2.34
>100	sand	1.548	21.93	3.62	2.30

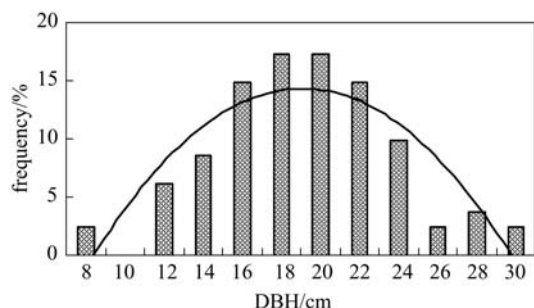


Fig. 1 Frequency by DBH classes

of the tree. Beyond this range, the amount of fine roots clearly decreases. Further calculation shows that the amount of fine roots in the 0–350 cm zone accounts for 91.9% of the total amount. The ranges from 0–100 cm, 100–250 cm and 250–350 cm account for 23.7%, 48.9% and 9.3% respectively. The density of fine roots lengths of *P. euphratica* is the highest in the area 140–220 cm from the tree trunk, i.e., 0.105 cm/cm³. The amount of the fine roots in the 350–500 cm zone only accounts for 8.1% of the total and that between 350–400 cm and 400 cm and beyond account for 6.1% and 2.0%, respectively.

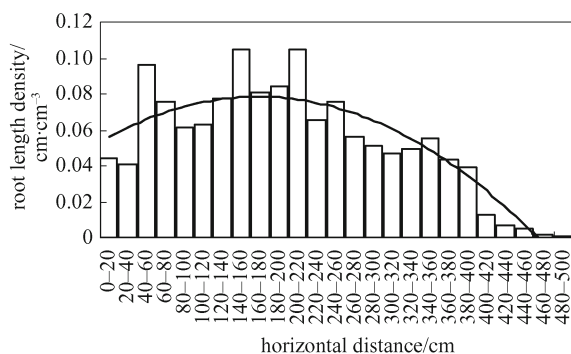


Fig. 2 Distribution of density of fine roots lengths of *Populus euphratica* in the horizontal direction

3.2 Vertical distribution characteristics of fine roots

The calculation of the mean density distribution of fine roots lengths of *P. euphratica*, conducted separately at each vertical level in a horizontal direction, shows that vertically, this distribution shows a negative exponential relation. We carried out a regression analysis on the density of the root lengths and depth of soil in the 0–500 cm vertical range. The equation is:

$$RD = 0.6049e^{-0.8871Z} \quad (R^2 = 0.9636) \quad (4)$$

where *RD* is the density of root length (cm/cm³) and *Z* is the soil depth.

Figure 3 shows that vertically, the amount of fine roots of *P. euphratica* is concentrated in the 0–80 cm, range, which accounts for 96.8% of the total amount of fine roots

at a depth of 0–140 cm. Within this depth, the amount of fine roots from 0–20, 20–40, 40–60 and 60–80 cm account for 51.9%, 20.1%, 18.0% and 6.7%, respectively. In the 80–140 cm range, the density clearly decreases. In the 120–140 cm range, there are hardly any fine roots at all.

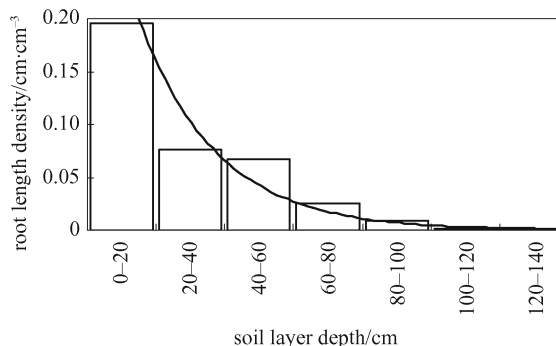


Fig. 3 Distribution of density of fine root lengths of *Populus euphratica* in the vertical direction

3.3 Two-dimensional distribution of density of fine root length

Figure 4 shows the two-dimensional distribution of the amount of fine roots of *P. euphratica* in a 500 cm horizontal direction and at 140 cm depth. In the 0–80 cm horizontal range, there are fine roots at every vertical soil level; beyond 80 cm, with an increased distance to the trunk, the soil depth where the fine roots system exists also increases. For example, if we take the density of the root lengths of 0.00625 cm/cm³ and the distance to the trunk as 80 cm, the root system appears at a depth of 120–140 cm. If we next take the distance as 200 cm, the root system appears at a depth of 100–120 cm; at a distance of 300–400 cm, the root system appears at a depth of 80–100 cm; at the 400–450 cm horizontal distance, the root system appears at a depth of 60–80 cm; at 450–500 cm, the depth ranges from 20–60 cm. The isogram shows that, when the distance to the trunk increases, the depth of the soil in which no root system exists also increases.

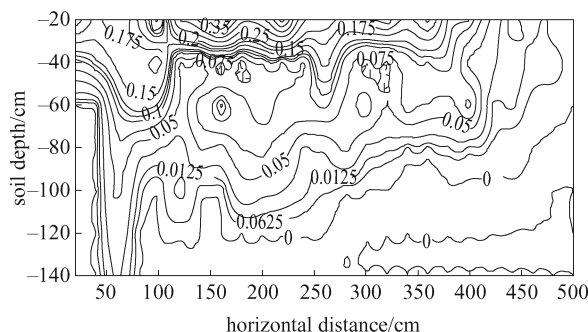


Fig. 4 Two-dimensional isogram of density of fine roots lengths of *Populus euphratica*

In the 0–500 cm horizontal range at soil depth of 0–140 cm, the total amount of fine root system is 48.5 kg. If we take the total amount of the fine root system at a section as 100%, the relative amounts of the fine root system at different distances and depths are presented in Fig. 5. This figure shows that the fine root system of *P. euphratica* is mainly distributed in the 0–350 cm horizontal range and at a depth of 0–80 cm, accounting for 96.8% of the total amount of the fine root system. In the horizontal range from 350–500 cm and at a depth of 80–140 cm, the relative amount of fine roots accounts for only 3.2% of the total. Beyond a horizontal distance of 350 cm from the trunk and at a depth of 80 cm there are hardly any fine roots.

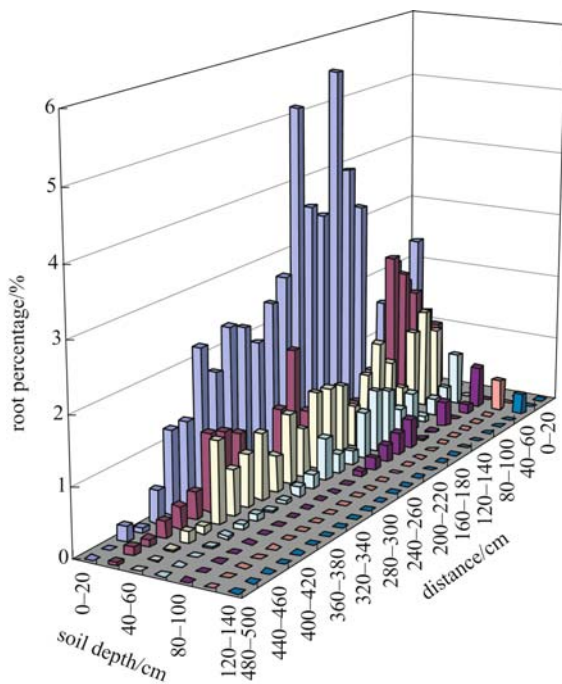


Fig. 5 Two-dimensional distribution of relative percentage of fine roots of *Populus euphratica*

4 Conclusions

Horizontally, the density distribution of fine root lengths shows a parabola, varying with the distance to the trunk. The amount of fine roots is concentrated in the 0–350 cm zone, which accounts for 91.9% of the total amount in the 0–500 cm range. Beyond a distance of 350 cm, the amount of fine roots of *P. euphratica* clearly decreases. The amount of the fine roots in the 350–500 cm zone only accounts for 8.1% of the total. Vertically, the density distribution of fine roots lengths shows a typical negative exponential curve. The amount of fine roots is concentrated in the 0–80 cm range, which accounts for 96.8% of the total amount of fine roots of

P. euphratica in the 0–140 cm range. At a depth of 80–140 cm, the amount of fine roots clearly decreases and only accounts for 3.2% of the total. In the horizontal direction, there are fine roots at different soil levels and beyond 80 cm, with an increased distance to the trunk, the soil depth, in which the fine root system exists, also increases. In the 0–500 cm horizontal distance and a soil depth ranging from 0–140 cm, the total amount of fine root system is 48.5 kg.

The aim of our study of the spatial distribution characteristics of fine roots of *P. euphratica* in a desert riparian forest was to construct a model of water absorption. Because *P. euphratica* is a large tree and distributed sparsely in this hostile region, the variation of roots at a horizontal level is relatively obvious, and because its roots are spread deeply in the soil, its vertical variation is also clear. Even more, although the growing conditions of *P. euphratica* at the selected site are relatively homogeneous, with the variation in natural conditions, differences between single *P. euphratica* trees are inevitable. In terms of a single *P. euphratica* tree, the construction of a three-dimensional water absorption model of roots can reflect the real condition of fine roots for comparative purposes. However, the natural site conditions within a standing forest vary greatly, which usually leads to the root system being distributed unevenly. Therefore, the model of the water absorption of the root system based on several trees inevitably has some inaccuracy. Therefore, how to reduce this inaccuracy caused by individual differences among trees should be the subject of an important future research project.

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