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Fine Root Distribution Characteristics of *Populus cathayana* Plantations at Different Ages in Alpine Sandy Land

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Abstract [**Objectives**] The paper was to study the fine root distribution characteristics of *Populus cathayana* plantations at different ages in alpine sandy land. [**Methods**] With 5, 10, 15, 20, and 25 years old *P. cathayana* plantation in the eastern margin of Gonghe Basin, Qinghai Province as the research objects, fine roots were collected by root core drilling method, and the differences of fine root biomass, root length density, average diameter and root tip number at the soil depths of 0 - 20, 20 - 40, 40 - 60, 60 - 80 and 80 - 100 cm were analyzed. [**Results**] The total biomass density of *P. cathayana* plantation was mainly distributed in the soil layer of 0 -60 cm, accounting for 76% of the entire soil layer, and its value increased with the increase in forest age. With the increase in different forest ages, the root length density, average diameter and root tip number of living fine roots in the soil layer of 0 -60 cm accounted for 74% -81% of the entire soil layer, and the proportions in the soil layers of 60 -80 and 80 -100 cm were 9% -11%. The biomass density, root length density, average diameter and root tip number of living and dead fine roots of *P. cathayana* plantation increased with the increase of forest age. The root length density, average diameter and root tip number of *P. cathayana* fine roots showed a linear function change trend with the growth of forest age, which could be described by the linear function equation $y = ax + b(a > 0)$. The analysis results showed that the root length density, average diameter and root tip number of *P. cathayana* were significantly correlated with the total biomass density of fine roots, and the root length density and average diameter had an extremely positive correlation with the total biomass density. [**Conclusions**] In the future, *P. cathayana* plantation should be properly tended to promote the development of fine roots and maximize its ecological benefits.

Key words *Populus cathayana* plantation; Biomass; Fine root distribution; Morphological characteristics

1 Introduction

As the most active functional organ of forest trees, fine root (diameter ≤ 2.0 mm) is the main source of water and nutrient absorption of forest trees. Due to large surface area for water and nutrient absorption and strong physiological activity, fine root plays an important role in maintaining soil and water conservation, improving soil structure and promoting nutrient cycling[1-3]. The study of fine root biomass and morphological characteristics, one of the parameters of vegetation underground ecosystem, is the basis of the structure and function of the entire underground ecosystem, and also an important index to measure the ability of artificial vegetation community to obtain corresponding resources[4]. Forest trees can adapt to interspecific competition by adjusting the biomass and morphological indexes of fine roots, thus influencing the growth and development of forest trees and the composition of community dynamic structure[5]. Therefore, it is of great significance to understand forest growth and underground ecological process by studying the distribution characteristics of fine root biomass.

Populus cathayana is a constructive species of vegetations in Gonghe Basin in the northeast of the Qinghai - Tibet Plateau, and it is the preferred primary native tree for water conservation and sand-fixation vegetation in the region[6-9]. The distribution characteristics of its fine roots can reflect the adaptability to the surrounding environment and the acquisition of resources. At present, most studies on fine root biomass and morphological characteristics of artificial vegetation communities focus on soil characteristics and environmental factors[10], while less efforts have been dedicated to fine root biomass and morphological characteristics of plantations at different ages. In recent years, there have been more and more researches on fine root biomass in different regions. For example, Li Hao *et al.*[11] studied the distribution characteristics of fine roots in plantations in hilly areas; Zhang Mi *et al.*[12] searched the fine root biomass of plantations in the Loess Plateau; Wang Kai *et al.*[13] figured out the distribution characteristics of fine roots of *P. sylvestris* plantation in the southeastern part of Horqin sandy land. However, the fine roots biomass and morphological characteristics of plantations at different ages in alpine sandy land have not been studied thoroughly and need further study.

The eastern margin of Gonghe Basin is one of the typical areas of alpine sandy land, dominated by moving dunes. Special environmental conditions and excessive grazing have led to severe soil desertification. However, with the increase in vegetation restoration years, the local microclimate has been improved[14-15]. Therefore, the biomass and morphological characteristics of living and dead fine roots of *P. cathayana* plantations at 5 different ages in the eastern margin of Gonghe Basin were studied, in order to provide a theoretical basis for studying fine root biomass and morphological characteristics of alpine desert ecosystems.

2 Materials and methods

2.1 Overview of survey site The research was conducted in the Qinghai Guinan Desert Ecosystem Positioning Observation and Research Station of the National Forestry and Grassland Administration Land Ecological Observation System. The site is located in

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Huangshatou comprehensive desertification control pilot area of Guinan County, Qinghai Province in Gonghe Basin in the northeastern part of the Qinghai – Tibet Plateau, and it is the most active part of southeastward sand movement on the eastern edge of Gonghe Basin, 35°30′ – 35°59′ N, 101°03′ – 101°06′ E, with an altitude of about 3 200 – 3 400 m. The region belongs to the alpine and semi-arid grassland climate zone, with an average annual temperature of 2.3 ℃, an average annual rainfall of 380 mm, and an average annual evaporation of 1 400 mm, as well as long sunshine hours, strong radiation and large evaporation, but insufficient rainfall. Aeolian sandy soil is the dominated soil in the region, and *P. cathayana* is the major local plantation tree.

2.2 Plot setting and sample collection This study was conducted in August 2022, and representative *P. cathayana* plantations of 5, 10, 15, 20 and 25 years old were selected in Gonghe Basin sand control experimental station. Three quadrats of 20 m × 20 m were set in each plantation at different ages, with a total of 15 quadrats, and the quadrats were spaced by more than 300 m. According to the overall average growth level, 5 plants with similar growth were selected as replicates in each plot. Five representative *P. cathayana* plants with good and similar growth were selected from each plot, and fine roots were collected at the lower edge of their crown width about half of the standard plant. Soil cores of 0 – 20, 20 – 40, 40 – 60, 60 – 80, and 80 – 100 cm were collected by using a soil drill with an inner diameter of 9 cm. The basic information of survey site is shown in Table 1.

Table 1 Basic information of survey site

Forest age//years old	Average DBH//cm	Average crown width//m^2	Canopy density	Stand density//hm^2	Altitude//m	Latitude and longitude
5	(2.03 ±0.13) c	(0.64 ×0.68) c	0.10 ±0.03	(805 ±36) e	3 360	35°33′20″ N, 101°3′20″ E
10	(3.33 ±0.19) c	(0.95 ×0.93) c	0.14 ±0.06	(775 ±52) d	3 347	35°35′45″ N, 101°4′13″ E
15	(4.94 ±0.08) c	(1.64 ×1.68) b	0.24 ±0.04	(750 ±63) c	3 342	35°30′25″ N, 101°5′50″ E
20	(7.79 ±0.09) b	(2.18 ×2.06) a	0.44 ±0.05	(717 ±46) b	3 336	35°31′30″ N, 101°3′35″ E
25	(8.26 ±0.47) a	(2.94 ×2.69) a	0.43 ±0.03	(625 ±25) a	3 334	35°30′14″ N, 101°5′15″ E

Note: Different lowercase letters in the same column represent significant differences among forest ages ($P < 0.05$).

2.3 Sample processing The collected soil core samples were initially sieved (sieve diameter 0.45 cm) to eliminate sandy soil, and rinsed with running water for 3 times to remove plant residues and grass roots. The fine roots with the diameter ≤ 2 mm were picked out with a vernier caliper. *P. cathayana* fine roots were picked out according to the appearance of fine roots and the color characteristics of root bark. Epson v850 root scanner was used to scan and store fine root images, and WinRHIZO Pro2019 plant root image analysis system was used for corresponding analysis. The root length (m), average diameter (mm) and root tip number (individual) of fine roots were obtained successively. Then, the fine roots obtained from each forest age were put into an envelope and baked in an oven at 85 ℃ to a constant weight (g). Based on the soil sampling volume (m^3), the root length density and fine root biomass density were calculated by an algorithm. The algorithm formula is as follows:

Fine root biomass density (g/m^3) = Fine root biomass (g)/Volume (m^3);

Root length density (m/m^3) = Root length (m)/Volume (m^3)[16 – 17].

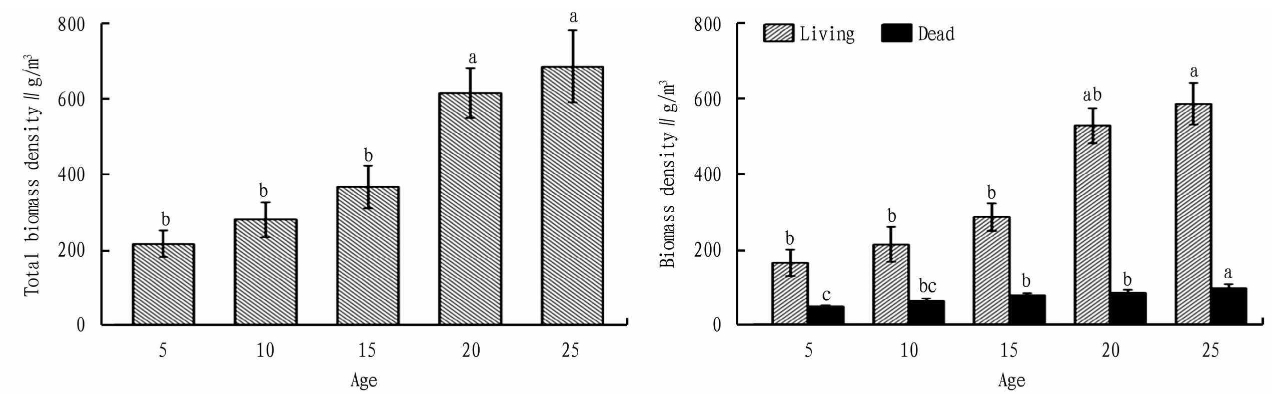
2.4 Data analysis Excel 2018 was used to conduct preliminary statistics and calculation of data. SPSS 26 (Chinese version) was selected to conduct one-way ANOVA analysis of fine roots biomass density at different ages and various morphological parameters, and correlation analysis between morphological parameters and biomass density. Duncan's multiple range test was applied to conduct multiple comparisons of the data. The charts were plotted using Origin 2019.

3 Results and analysis

3.1 Fine roots biomass density of *P. cathayana* As shown in Fig. 1, the total biomass density of fine roots, the biomass density of living fine roots and dead fine roots in *P. cathayana* plantations of 5 different ages in the soil layers of 0 – 100 cm all increased with the increase of forest age, and the specific performance was 5 years old < 10 years old < 15 years old < 20 years old < 25 years old. The total biomass density of fine roots ranged from 216.40 to 687.00 g/m^3; the biomass density of living fine roots ranged from 166.00 to 588.33 g/m^3, and that of dead fine roots ranged from 50.40 to 98.60 g/m^3. The biomass densities of living and dead fine roots accounted for 76.71% – 85.96% and 14.04% – 23.31% of the total biomass density of fine roots, respectively. Variance analysis showed that the total biomass density of fine roots, total biomass density of living fine roots and dead fine roots differed significantly among different forest ages ($P < 0.05$). The biomass densities of fine roots, living fine roots and dead fine roots of 25 years old *P. cathayana* were significantly higher than those at other forest ages. There was a significant difference in total biomass density of fine roots and biomass density of living fine roots between 15 and 20 years old *P. cathayana* ($P < 0.05$), and a significant difference in biomass density of dead fine roots between 20 and 25 years old *P. cathayana* ($P < 0.05$), but no significant difference in biomass density of dead fine roots between 15 and 20 years old *P. cathayana*.

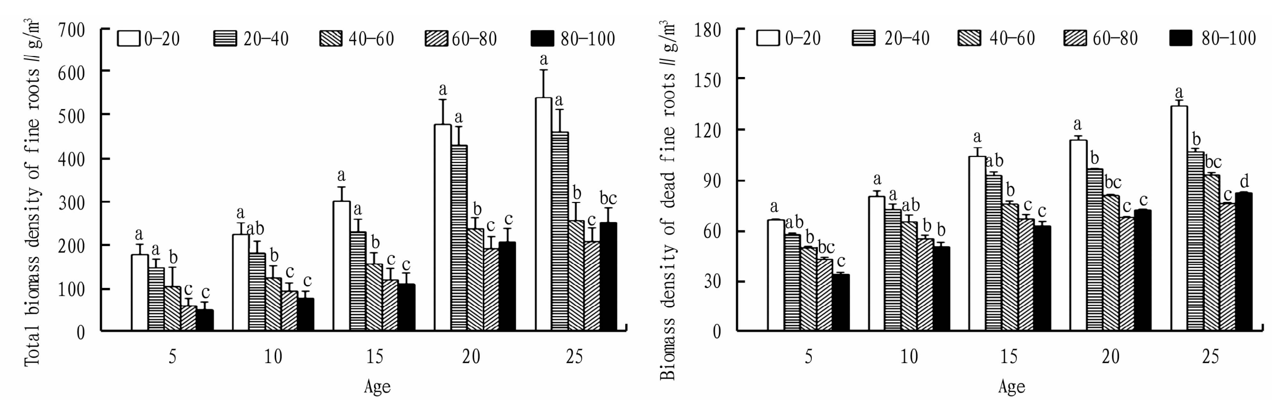
The vertical distribution of fine roots is influenced by multiple factors, such as environment and tree species. As shown in Fig. 2, with the increase in soil depth in vertical structure, the total biomass density of fine roots and the biomass density of dead fine roots at different forest ages showed a decreasing trend in the soil layers of 0 – 60 and 60 – 80 cm, and the biomass density of fine roots in 20 and 25 years old *P. cathayana* showed an increasing trend in the soil layers of 80 – 100 cm, with significant differences among soil layers ($P < 0.05$). The analysis results showed that the biomass density of fine roots at different forest ages in the soil layer of

0 – 40 cm was significantly higher than that in the soil layer of 60 – 100 cm, and the total biomass density of *P. cathayana* fine roots mainly concentrated in the soil layer of 0 – 60 cm, accounting for 76.92% – 73.20% of the total biomass density in the soil layer of 0 – 100 cm. The fine root biomass density of *P. cathayana* plantation in each soil layer and the proportions in total fine root biomass density varied among different ages. The total biomass densities of fine roots in the soil layer of 0 – 20 cm were 25 years old > 20 years old > 15 years old > 10 years old > 5 years old, accounting for 32.90% – 30.92% of the total biomass density of fine roots in the soil layer of 0 – 100 cm; the total biomass densities of fine roots in the soil layer of 20 – 40 cm were 25 years old > 20 years old > 15 years old > 10 years old > 5 years old, accounting for 25.04% – 28.81% of the total biomass density of fine roots in the soil layer of 0 – 100 cm. The total biomass densities of fine roots in the soil layers of 0 – 20 and 20 – 40 cm accounted for 33.0% and 27.8% of the total biomass density in the soil layer of 0 – 100 cm, which were significantly higher than that in other soil layers, indicating that the fine root biomass of *P. cathayana* plantation is mainly distributed in the surface soil, and with the increase in forest age, the root system of *P. cathayana* plantation has the tendency of developing to the deep soil.



Note: Different lowercase letters indicate significant differences among different forest ages ($P < 0.05$).

Fig. 1 Fine root biomass density of *Populus cathayana* plantations at different forest ages



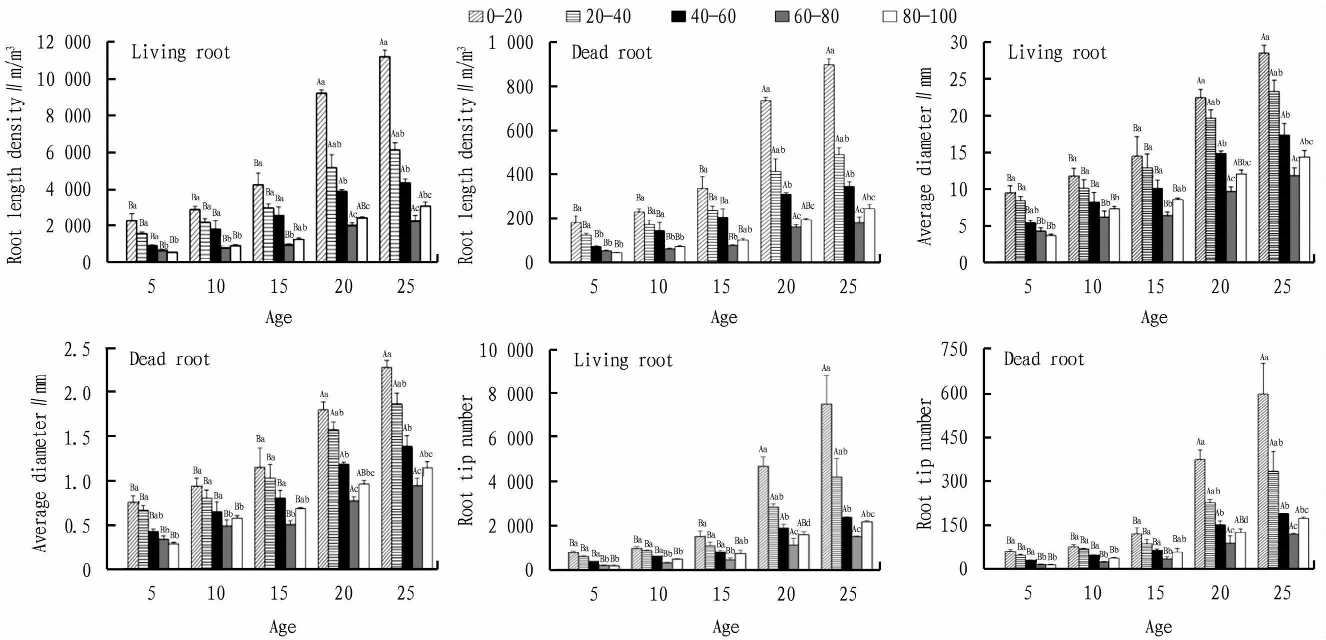
Note: Different lowercase letters indicate significant differences among different soil layers ($P < 0.05$).

Fig. 2 Fine root biomass density of *Populus cathayana* plantations at different forest ages in different soil layers

3.2 Morphological characteristics of fine roots of *P. cathayana* As shown in Fig. 3, the root length density, average diameter and root tip number of living and dead fine roots of *P. cathayana* plantations at different ages increased with the increase in age, and there were no significant differences among other forest ages except for the significant difference between 15 and 20 years old ($P < 0.05$), generally 5 years old < 10 years old < 15 years old < 20 years old < 25 years old; the root length densities of living fine roots were 1 197, 1 711, 2 396, 4 552 and 5 400 m/m^3; the average diameter and root tip number were 6.26 – 19.1 mm and 417 – 3 533, respectively. The growth rate of living fine root length density of 15 and 20 years old plantations was the largest of 22%, which had a significant difference with those of other forest ages ($P < 0.05$), indicating that 15 – 20 years old was a rapid growth period for *P. cathayana* plantations, and there was no significant difference among other different forest ages. And the growth rates were 5% (5 – 10 years old), 7% (10 – 15 years old), and 8% (20 – 25 years old).

The root length density, average diameter and root tip number of living and dead fine roots of *P. cathayana* plantations at different ages decreased with the deepening of soil depth, and gradually developed to the deep layer with the increase in growth years, and there were significant differences among soil layers ($P < 0.05$). Comprehensive analysis demonstrated that the root length density, average diameter and root tip number of living fine roots were mainly distributed in the soil layer of 0 – 60 cm, and others were successively distributed in the soil layers of 60 – 80 and 80 – 100 cm. The root length density of living fine roots in the soil layer of

0 – 60 cm accounted for 79% – 81% of the total depth of soil layer. The average diameter and root tip number of living fine roots accounted for about 74% – 81%, and the proportion in the soil layers of 60 – 80 and 80 – 100 cm were 9% – 11%, indicating that the roots of *P. cathayana* plantation are distributed in the middle and upper soil, and gradually develop to the deep layer with the increase in forest age, showing a vertical distribution law. The above results showed that the root length density, average diameter and root tip number of living fine roots decreased with the deepening of soil layer, and the root length density, average diameter and root tip number of living fine roots in deep soil plantation gradually increased with the increase in growing years, and there were significant differences among soil layers ($P<0.05$). With the increase in forest age, the root length density, average diameter and root tip number of dead fine roots gradually increased in the deep soil. In general, the deepening of soil layer of *P. cathayana* plantation can significantly increase the root length density, average diameter and root tip number of fine roots of *P. cathayana* plantation.



Note: Different capital letters indicate significant differences among different forest ages in the same soil layer ($P<0.05$); different lowercase letters indicate significant differences among different soil layers at the same forest age ($P<0.05$).

Fig. 3 Morphological characteristics of fine roots of *Populus cathayana* at different ages

3.3 Relationship between morphological characteristics and biomass of fine roots As shown in Fig. 4, correlation analysis between total biomass density and total fine root length density, average diameter and root tip number of *P. cathayana* plantations at different ages showed that the total fine root length density, average diameter and root tip number had linear function change trend with the total biomass density ($y=ax+b$, $a>0$). The total fine root length density, average diameter and root tip number increased with the increase in total biomass density. The analysis results showed that the pairwise correlation of total fine root biomass density, total fine root length density and average diameter reached an extremely significant level, and the correlation coefficients were 0.90 and 0.96. There was no extremely significant correlation between root tip number and total biomass density of fine roots, and the correlation coefficient was 0.86. Due to the complex relationship between total fine root morphology and total biomass density, it is necessary to further study this relationship, because fine root function is not only affected by root length density, average diameter and root tip number, but also related to fine root morphology in the whole root network structure.

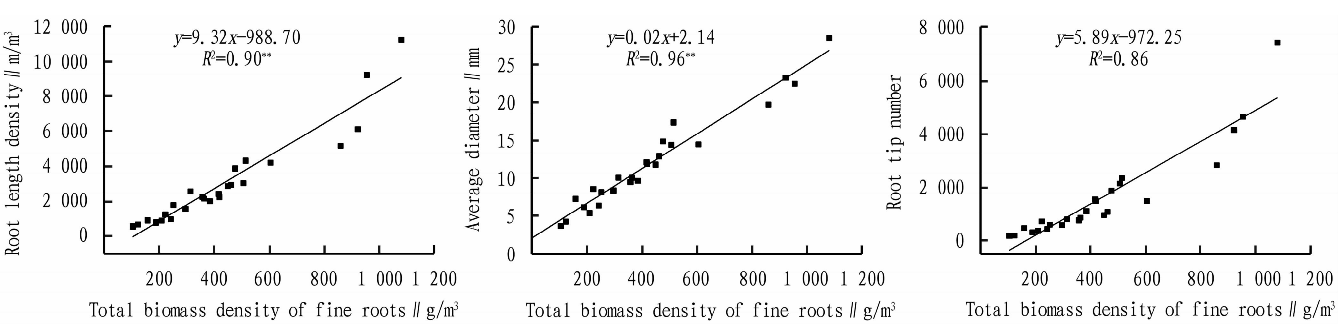


Fig. 4 Correlation analysis between fine root index and biomass density of *Populus cathayana* at different ages

4 Conclusions and discussion

The biomass density of fine roots is influenced by both habitat and forest age[18-19]. The biomass density of fine roots in *P. cathayana* plantations at different ages increased with the increase of forest age and decreased with the deepening of soil layer, which was similar to the characteristics of fine roots in *Salix cheilophila* plantations at different ages reported by Yu Yang *et al.*[20]. Generally speaking, with the deepening of soil layer, soil nutrients gradually decrease, while spatial differences in soil stability, *etc.* will affect fine roots, and the biomass density of fine roots will decrease correspondingly[21]. At the same time, relevant studies have shown that in arid areas, water is the main limiting factor for plant growth. In sandy land with bad habitats, high evaporation and low rainfall all year long result in great soil water shortage during vegetation recovery period, and water determines the distribution characteristics of plant roots[22]. A large number of fine roots are distributed in shallow middle-layer soil, which is conducive to full absorption and utilization of quantitative rainfall by plants in arid areas[23-26]. The biomass density of fine roots varies significantly in vertical space. The fine root biomass density of *P. cathayana* plantation is mainly distributed in the shallow middle-layer soil of 0-60 cm, accounting for 73.20%-76.92% of the total biomass density, which may be due to the fact that the carbohydrates obtained by vegetation during plant photosynthesis are distributed to the shallow middle-layer soil according to the principle of proximity. Particularly under the adverse effect of local environment, the transport cost of organic matter by vegetation is reduced, which is also helpful to improving the fast absorption of nutrients that penetrate into shallow middle-layer soil by sand-fixing vegetation[27-28]. The biomass density of living and dead fine roots decreased with the deepening of soil layer, but the biomass density of living fine roots at the age of 20-25 years old gradually increased in the soil layer of 80-100 cm. This is similar to the research results of Zhang Liheng *et al.*[29] on fine root characteristics of *Caragana sinica* plantations at different ages in alpine sandy land. The reason may be that this region belongs to alpine region, with perennial drought climate, high evaporation and high radiation, and water and nutrient resources are extremely scarce. The scarce seasonal rainfall is easily absorbed by shallow fine roots in the first time, and the infiltration water of soil decreases accordingly, resulting in relatively high soil water content at the soil layer of 0-60 cm. In conclusion, factors affecting the fine root biomass density and vertical characteristic distribution are not only related to their own heritability, but also closely related to site factors[30].

The morphology of fine roots is an important index of the functional shape of fine roots and the absorption of nutrients and water by plants, reflecting the adaptability of fine roots to the underground environment[31]. The results showed that the root length density, average diameter and root tip number of *P. cathayana* plantations at different ages increased with the increase in forest age, and the fine root indexes changed greatly in the recovery rapid growth stage of vegetation; and the root length density, average diameter and root tip number were mainly distributed in the soil layer of 0-60 cm. This is in agreement with the conclusion of Hu Hui *et al.*[32] and Zhang Liheng *et al.*[33] on the characteristics of fine roots of cultivated tree species and *C. sinica* plantation in Minjiang River. With the increase in recovery years, the average diameter and root tip number increased successively, which promoted the absorption of nutrients by fine roots and increased the absorption efficiency. In order to obtain sufficient nutrients, the fine roots of *P. cathayana* increased the absorption rate by changing the unit root length density and average diameter through morphological plasticity, so as to better adapt to the local harsh environment. 15 and 20 years old *P. cathayana* plantations are middle-age and mature forests. At this rapid growth stage, the canopy density of vegetation increases, and more photosynthetic products and nutrients are distributed by plant photosynthesis to the underground part, which promotes the absorption, utilization and turnover of fine root nutrients, resulting in greater energy flow between the ground and underground of *P. cathayana*, and the maximum of fine root indexes in the recovery rapid growth stage of vegetation. Through the plasticity of fine root morphology, plants can enhance the adaptability of roots to habitat changes, and still meet the nutrient supply required for plant growth in the case of large differences in site factors such as stand density, canopy density of forest and altitude. This is a high-efficiency nutrient acquisition strategy used by plants in alpine regions to adapt to harsh habitats.

In general, the fine root biomass density of forest trees gradually decreases with the deepening of soil layer[34-36], which is mainly attributed to the availability of soil resources and the role of trees[37-38]. In this study, the total biomass density of fine roots decreased with the deepening of soil layer, and the root length density, average diameter and root tip number of living and dead fine roots decreased with the deepening of soil layer. The fine root parameters concentrated in the soil layer of 0-60 cm, which may be because the middle and upper layers of the soil had better growth conditions for fine roots. Further analysis showed that the morphological parameters and biomass density of *P. cathayana* plantations varied with different ages, and the biomass density had an extremely significant correlation with root length density and average diameter. Therefore, the study on the morphological characteristics of fine roots is not always related to the distribution law, but also closely related to the biomass density, which needs to be studied in detail.

The results showed that the total fine root biomass density, root length density, average diameter and root tip number of *P. cathayana* plantation increased with the increase in forest age, mainly distributed in the soil layer of 0-60 cm, accounting for about 76% of the whole soil layer; the indexes in the soil layer of 60-100 cm accounted for about 24%, and that at the soil layer of 80-100 cm accounted for about 14%, indicating that fine roots gradually develop into deeper layers. After 20 years of development, *P. cathayana* plantation grows slowly, so it is necessary to carry out reasonable tending and management to promote the development of fine roots and maximize the ecological benefits, so as to achieve the purpose of ecological restoration.

References

[1] HE YL, LI GD, XI BY, *et al.* Coupling effects of drip irrigation and nitrogen fertigation on fine root growth, distribution and morphological characters of 2-year-old *Populus tomentosa* plantations[J]. Journal of Beijing Forestry University, 2022, 44(4): 1 – 11. (in Chinese).

[2] WANG WQ, WANG SJ, LIU YR, *et al.* Distribution and growth characteristics of the root systems of poplar, willow, elm and locust on site of renewed land by fine ash of coal[J]. Scientia Silvae Sinicae, 1994(1): 25 – 33. (in Chinese).

[3] LEPPÄLAMMI-KUJANSUU J, ARO L, SALEMAA M, *et al.* Fine root longevity and carbon input into soil from below-and aboveground litter in climatically contrasting forests[J]. Forest Ecology and Management, 2014 (326): 79 – 90.

[4] YU WT, YU YQ. Advances in the research of underground biomass[J]. Chinese Journal of Applied Ecology, 2001(6): 927 – 932. (in Chinese).

[5] XI BY. Morphology, distribution, dynamic characteristics of poplar roots and its water uptake habits[J]. Journal of Beijing Forestry University, 2019, 41(12): 37 – 49. (in Chinese).

[6] IFO SA, KOUBOUANA F, NGANGA D, *et al.* Fine roots dynamics in a tropical moist forest: Case of two forest groves in the Congo Basin[J]. Baltic Forestry, 2015(21): 204 – 211.

[7] YAN H, LIU GQ, LI HS. Changes of root biomass, root surface area, and root length density in a *Populus cathayana* plantation[J]. Chinese Journal of Applied Ecology, 2010, 21(11): 2763 – 2768. (in Chinese).

[8] HE HY, XY GF, MA GQ, *et al.* Studies on water physiology of main affore station tree in east Qinghai[J]. Journal of Northwest Forestry College, 2003(2): 9 – 12. (in Chinese).

[9] CAO DM, ZHANG YH, CHENG XQ, *et al.* Genetic variation of leaf phenotypic traits in different populations of *Populus cathayana*[J]. Scientia Silvae Sinicae, 2021, 57(8): 56 – 67. (in Chinese).

[10] LIAOY, MCCORMACK ML, FAN H. Elation of fine rootdistribution to soil C in a *Cunninghamia lantation* in subtropical China[J]. Plant and Soil, 2014, 381(1/2): 225 – 234.

[11] LI H, HU CJ, ZHAO RQ, *et al.* Root distribution characteristics of three typical plantations in a Loess Hills region[J]. Arid Zone Research, 2021, 38(5): 1420 – 1428. (in Chinese).

[12] ZHANG M, LIU YF, JIA YM, *et al.* Fine root morphology and biomass of *Robinia pseudoacacia* in the loess plateau[J]. Journal of Northwest Forestry University, 2019, 34(2): 22 – 27. (in Chinese).

[13] WANG K, SONG LN, LU LY, *et al.* Fine root vertical distribution characters of different aged *Pinus sylvestris* var. *mongolica* plantations on sandy land[J]. Journal of Northeast Forestry University, 2014, 42(3): 1 – 4. (in Chinese).

[14] ZHU YJ, XUE HX. Root distribution difference of two *Salix* shrubs in Gonghe Basin[J]. Journal of Arid Land Resources and Environment, 2016, 30(8): 172 – 176. (in Chinese).

[15] YU Y, JIA Z, ZHU YJ, *et al.* Effects of *Salix cheilophila* plantation on the improving of soil properties in vegetation restoration area of high-cold sandy land[J]. Scientia Silvae Sinicae, 2013, 49(11): 9 – 15. (in Chinese).

[16] SU Y, WU SL, HE W, *et al.* Fine root biomass and its morphological characteristics of *Picea asperata* along an elevation gradient of gonggang mountains[J]. Acta Botanica Boreali-Occidentalia Sinica, 2022, 42 (1): 138 – 144. (in Chinese).

[17] DENG L, ZHU CY, YU SC, *et al.* Effects of mingling intensity on morphological characteristics of fine roots of a middle-aged *Picea crassifolia* natural forests in Qilian Mountains[J]. Scientia Silvae Sinicae, 2020, 56(1): 191 – 200. (in Chinese).

[18] YOU JJ, ZHANG WH, DENG L, *et al.* Effects of thinning intensity on fine root biomass and morphological characteristics of middle-aged *Pinus tabulaeformis* plantations in the Huanglong Mountains[J]. Acta Ecologica Sinica, 2017, 37(9): 3065 – 3073. (in Chinese).

[19] FENG LL, JIA ZQ, LIU T, *et al.* Comparative study on fine roots productivity and turnover rates of several typical sand-fixation plants in alpine sandy land[J]. Research of Soil and Water Conservation, 2018, 25 (2): 120 – 125, 130. (in Chinese).

[20] YU Y, JIA ZQ, ZHU YJ, *et al.* Root distribution of *Salix cheilophila* along a chronosequence in high-cold sandland[J]. Journal of Desert Research, 2014, 34(1): 67 – 74. (in Chinese).

[21] ZHANG LH, LI QX, WANG XQ, *et al.* Biomass dynamics and turnover of fine roots of *Caragana intermedia* plantations in alpine sandy land[J]. Arid Zone Research, 2020, 37(1): 212 – 219. (in Chinese).

[22] GUO JH, LI CJ, ZENG FJ, *et al.* Relationship between root biomass distribution and soil moisture, nutrient for two desert plant species[J]. Arid Zone Research, 2016, 33(1): 166 – 171. (in Chinese).

[23] HE YT, SHI PL, ZHANG XZ, *et al.* Fine root production and turnover of poplar plantation in the Lhasa river valley, Tibet Autonomous Region [J]. Acta Ecologica Sinica, 2009, 29(6): 2877 – 2883. (in Chinese).

[24] ZHAO P, XU XY, JIANG SX, *et al.* Water utilization pattern of *Tamarix ramosissima* Ledeb. Nebkhas with different decline degrees in the lower reaches of Shiyang River[J]. Acta Ecologica Sinica, 2022, 42(17): 7187 – 7197. (in Chinese).

[25] WEI LD, ZHU JY, LI XR, *et al.* Interspecific trait variation in the adaptation of root functional traits to dry barren sites: A case study of the main ornamental tree species in stony mountainous region of Beijing[J]. Acta Ecologica Sinica, 2021, 41(23): 9492 – 9501. (in Chinese).

[26] HUANG G, ZHAO X, SU Y, *et al.* Vertical distribution, biomass, production and turnover of fine roots along a topographical gradient in a sandy shrubland[J]. Plant and Soil, 2008, 308(1/2): 201 – 212.

[27] CHANG R, FU B, LIU G, *et al.* Effects of soil physicochemical properties and stand age on fine root biomass and vertical distribution of plantation forests in the Loess Plateau of China[J]. Ecological Research, 2012, 27(4): 827 – 836.

[28] OPPELT L A, KURTH W, JENTSCHKE G, *et al.* Contrasting rooting patterns of some arid-zone fruit tree species from Botswana-I. Fine root distribution[J]. Agroforestry Systems, 2005, 64(1): 1 – 11.

[29] ZHANG LH, WANG XQ, JIA ZQ, *et al.* Root distribution characteristics of *Caragana intermedia* plantations at different ages in alpine sandy land[J]. Journal of Arid Land Resources and Environment, 2018, 32 (11): 163 – 168. (in Chinese).

[30] WAN HX, CAI JJ, GUO YZ, *et al.* Characteristics of root distributions of typical herbs in loess hilly region of southern Ningxia[J]. Research of Soil and Water Conservation, 2020, 27(4): 149 – 156, 163. (in Chinese).

[31] SCHIPPERS P, OIFF H. Biomass partitioning, architecture and turnover of six herbaceous species from habitats with different nutrient supply[J]. Plant Ecology, 2000(149): 219 – 231.

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Province and applied in large areas are mainly selected as parents. For example, the two wheat varieties, Yumai 54 and Zhoumai 16, have been approved and applied in large areas, with good performance. Yumai 54 is a medium early maturity variety, with lodging resistance, more ears per unit area, but slightly less grains. Zhoumai 16 is a medium and late mature variety with large grains and general lodging resistance. With the hybridization of these two varieties, the large spike of Zhoumai 16 can supplement the small spike characteristics of Yumai 54. The trait of good inverted resistance of Yumai 54 can supplement the disadvantage of weak inverted resistance of Zhoumai 16, and simultaneously ensure high number of ears per unit area, laying a foundation for high yield, stable yield and fast breeding.

6.2 Adhering to the principle of early generation testing and production selection At present, most breeders will conduct yield testing in the high generation, and in the early single plant selection period, there are not many practices for yield screening for the early generation. According to the determined breeding objectives, we determined to adopt the mixed pedigree method. The main point was that high yield was the main goal from beginning to end in the early generation (F_2-F_3). F_1 generation was used for single plant harvest, threshing, planting, while F_2 generation conducted on-demand selection and strip broadcast measurement simultaneously. The single plants with good comprehensive performance in the field were harvested and measured, and high-yield lines were screened out, to determine the key combination quickly and accurately. The excellent single plant system was selected in advance, and the organic combination of homozygosity optimization, artificial selection and directional cultivation was realized through strain selection and production measurement. By the F_3 generation, the excellent sister line group can be obtained, and the excellent single strain can be selected in the selected lines. After the F_5-F_6 generation, the stable strain with good performance can be harvested, and then the strain yield and comprehensive character identification test can be carried out.

References

[1] CHENG X, QIN HY. Technical regulations for drought-resistant, water-saving and efficient cultivation of winter wheat in Puyang City[J]. Bulletin of Agricultural Science and Technology, 2020(11): 229 – 232. (in Chinese).

[2] XU FC, LI MF, DONG J, *et al.* Breeding and cultivation techniques of high yield and multiple disease-resistance wheat cultivar E′mai 398 [J]. Hubei Agricultural Sciences, 2018, 57(23): 32 – 34. (in Chinese).

[3] CHEN QS, ZHANG XB, ZHANG DR, *et al.* Breeding and application of a new wheat variety Xiangmai 55 with high yield and high quality [J]. China Seed Industry, 2010(6): 58 – 59. (in Chinese).

[4] LIU YK, TONG HW, ZHU ZW, *et al.* Breeding and cultivation techniques of a new wheat variety E-mai 580 with weak gluten [J]. Crops, 2013(4): 158 – 159. (in Chinese).

[5] ZHAO GC, CHANG XH, WANG DM, *et al.* One spray three control technology of wheat [J]. Crops, 2013(2): 120 – 121. (in Chinese).

[6] LIU YK, FA J, ZHANG Y, *et al.* Breeding and cultivation techniques of the new wheat variety E-mai 170 [J]. Hubei Agricultural Sciences, 2015, 54(24): 6191 – 6192. (in Chinese).

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[32] HU H, BAO WK, LI FL. Differential vertical distribution of functional traits of fine roots of four cultivated tree species in the upper reaches of Minjiang River[J]. Chinese Journal of Ecology, 2020, 39(1): 46 – 56. (in Chinese).

[33] ZHANG LH, LI QX, WANG XQ, *et al.* Root distribution and soil properties under *Caragana intermedia* plantations in alpine sandy land [J]. Chinese Journal of Soil Science, 2019, 50(4): 840 – 846. (in Chinese).

[34] DAVIS JP, HAINES B, COLEMAN D, *et al.* Fine root dynamics along an elevational gradient in the southern Appalachian mountains[J]. USA For Ecol Manage, 2004(187):19 – 34.

[35] CAIN ML, SUBLER S, EVANS JP, *et al.* 1999. Sampling spatial & temporal variation in soil nitrogen availability[J]. Oecologia (118): 397 – 404.

[36] YANG XD, DENG L. Fine root biomass and morphological characteristics in *Populus cathayana* plantations at different ages along the eastern margin of the gonghe basin[J]. Journal of Northwest Forestry University, Journal of Northwest Forestry University, 2023, 38(2): 8 – 16, 131. (in Chinese).

[37] GALE RM, GRIGAL FD. Vertical root distributions of northern tree species in relation to successional status[J]. Canadian Journal of Forest Research, 1987, 17(8): 829 – 834.

[38] YAN XL, DAI TF, JIA LM, *et al.* Responses of the fine root morphology and vertical distribution of *Populus × euramericana* ‘Guariento’ to the coupled effect of water and nitrogen[J]. Chinese Journal of Plant Ecology, 2015, 39(8): 825 – 837. (in Chinese).