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Contribution of root decay process on soil infiltration capacity and soil water replenishment of planted forestland in semi-arid regions

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ABSTRACT

Large-scale afforestation has seriously aggravated the consumption of soil water and caused soil desiccation and even the dry soil layers, which has been restricting the survival and sustainability of vegetation in semi-arid areas. How to solve soil water deficit reasonably is an important practical problem we are facing. Here, a field experiment of the decayed roots with different times on soil water infiltration processed was conducted in planted forestland by a double-ring infiltration instrument, to determine the contribution of decayed tree roots on soil water infiltration process and replenishment. Results showed that the decayed process of tree roots in forestland could significantly reduce root density (RD) and increase the relative porosity improved by the roots (RPIR) ($P < 0.05$). The macropore formed by root decay could not only significantly increase the infiltration rate at each stage ($P < 0.05$), but also reduce the decrease rate of infiltration rate. Compared with bare land, the decayed roots of the 1–4 yr, the 5–8 yr, and the 9–12 yr increased the amount of soil water replenishment by 37.12%, 217.52%, and 259.85%, respectively. Overall, the decayed tree roots could maintain a relatively high and stable infiltration rate by reduced root density, which increased the effective replenishment of soil water of dry soil layers in forestland. These findings have potential implications for understanding the effect of decay process of tree roots on soil water replenishment, and provide a theoretical basis for the solution to dry soil layers and sustainable management of forestland in semi-arid areas.

1. Introduction

Afforestation is one of the main measures for soil desertification control, water and soil conservation, and ecological environment restoration in semi-arid areas (Chirino et al., 2006; Wang et al., 2010; Fu et al., 2011; Elbakidze et al., 2011; Jia et al., 2018; Liu et al., 2018). However, large scale and long-term artificial afforestation can continuously aggravate soil water consumption, which will lead to soil desiccation and even the appearance of dry soil layers (Deng et al., 2016; Jia et al., b, 2017a; Liu et al., 2018). Soil water deficit even soil drying is one of the most important problem affecting the survival and sustainability of artificial afforestation. However, rainfall is the main source of soil water replenishment in semi-arid areas, which makes the transformation process of rainfall to soil water most crucial for sustainable vegetation (Wu et al., 2017). Therefore, research on the efficient replenishment of soil water is particularly important for vegetation maintainence and sustainable management in semi-arid areas. As the main component of the terrestrial water cycle, rainfall infiltration is the main source of soil water replenishment (Liu et al., 2019). The soil infiltration rate is an important index to evaluate the water replenishment capacity of the soil reservoir during the rainfall process (Ebel and Moody, 2013; Mao et al., 2016). The process of water infiltration into the soil mainly involves two forms, soil matrix infiltration and preferential flow (Stumpp and Maloszewski, 2010; Zhang et al., 2017a). Soil matrix infiltration was considered as the slow percolation of water and solutes through the soil body, which is only controlled by the capillary action of the soil matrix (Zhang et al., 2017a). However, preferential flow was the process of rapid infiltration of water and solutes into the soil through macropores

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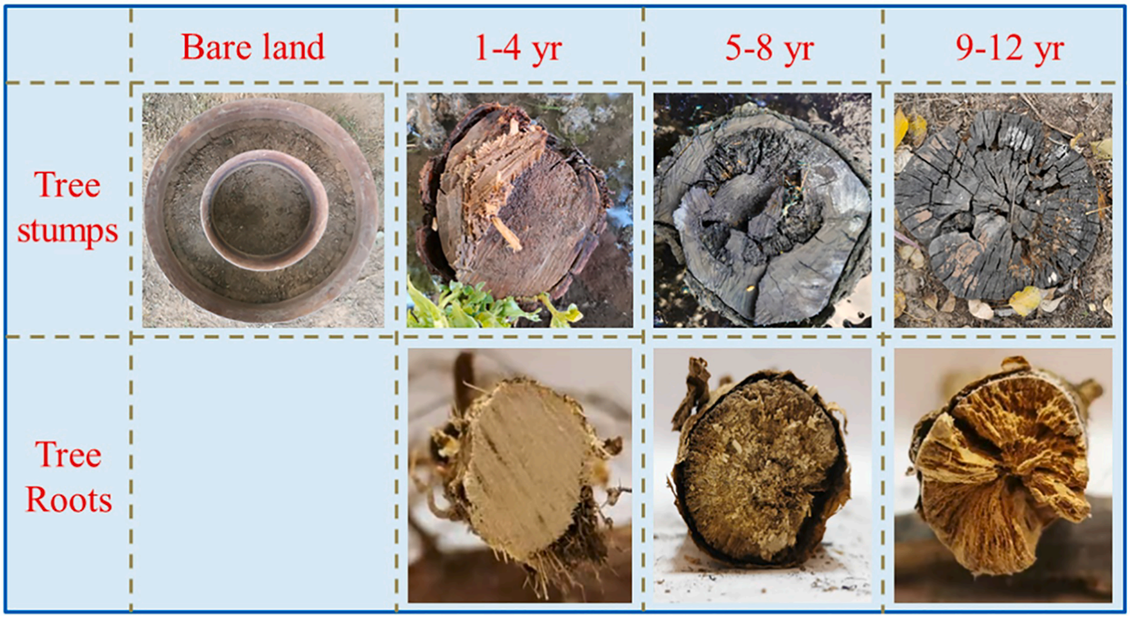

Fig. 1. Changes in tree stumps and roots after the death of Populus davidiana. Note: 1–4 yr, Populus davidiana with a decaying time of 1–4 years; 5–8 yr, Populus davidiana with a decaying time of 5–8 years; 9–12 yr, Populus davidiana with a decaying time of 9–12 years.

(Jarvis, 2007; Allaire et al., 2009; Zhang et al., 2015, 2017b; Guo et al., 2019).

It's well known that the hydrological process of the plant root-soil interface dominated by the vegetation root system plays a very critical role in the water cycle of the dryland ecosystem (Volpe et al., 2013). As the main source of soil carbon input, root residues can increase the content of soil organic matter and promote the formation of soil aggregates (Cui et al., 2019; Liu et al., 2020). And, the formation of soil aggregates makes the soil have higher soil porosity and better soil structure, thereby improving soil infiltration properties (Franzluebbers, 2002; Six et al., 2004; Zhao et al., 2013; Huang et al., 2017; Cui et al., 2019). Zhao et al. (2013) found that long-term grassland restoration could increase organic matter and improve soil pore structure, thereby significantly improving soil permeability. Alaoui (2015) also found that the interaction between macroporosity and bulk density increased the rate of water infiltration in four representative grassland soils. Liu et al. (2019) also reported that the root biomass was positively correlated with the soil infiltration rate in different grassland types. Because the higher root biomass could increase soil organic matter and total soil porosity, which improved soil infiltration properties (Wu et al., 2016; Huang et al., 2017).

The existence of plant roots, especially for dead roots can provide preferential flow channels for soil water infiltration (Cui et al., 2019; Guo et al., 2019). Benegas et al. (2014) found that both live roots and rotting roots can have a positive impact on soil permeability by increasing soil aggregates and porosity. Similarly, by comparing the difference in soil permeability between alfalfa grassland and bare land, Guo et al. (2019) found that the continuous macropores formed after roots decay could accelerate the rate of water movement in the soil and improve soil permeability. Therefore, plant root system can not only affect soil infiltration properties by changing soil properties (Wu et al., 2016), but also can improve soil infiltration properties by forming root channels through its own decay and decomposition (Tracy et al., 2011; Huang et al., 2017; Guo et al., 2019). The channel formed by the decay of plant roots is a common and important path for preferential flow of water and solutes in the soil (Bogner et al., 2010; Zhang et al., 2017b). The macropores established by the root channel may cause rapid horizontal and vertical flow of water, leading to rapid water infiltration after rainfall (van Schaik, 2009; Wu et al., 2017). Therefore, exploring the influence of preferential flow channels by plant root systems on soil infiltration processes is of vital importance to soil water replenishment in semi-arid areas. However, all the studies mentioned above do not consider the study on soil water replenishment of plant roots decayed processes. The knowledge about the influence of root decay time on the process of water infiltration is relatively lacking.

Populus davidiana forest is important part of artificial afforestation on the Loess Plateau due to its fast growth and strong adaptability. However, the long-term planting of Populus davidiana also aggravated soil water consumption, especially in the 100–150 cm soil layer (Liu et al., 2018). The dry soil layers in this depth is difficult for replenishing by penetrated water only through matrix flow from natural rainfall. Recently, thinning has become one of the main measures in forestry management (del Campo et al., 2019). Given a lots of tree stumps and rotting tree roots appeared after forestland thinning on the one hand and decayed plant roots maybe potentially contributed to soil water infiltration and replenishment as preferential flow channels on the other, we put forward the hypothesis that the decayed tree roots may significantly contribute to soil water infiltration process and replenishment well in semi-arid areas. In this vein, the current study therefore aimed to 1) examine the effects of root decayed time on the soil water infiltration process; and 2) determine the benefits of soil water replenishment at different root decayed times. This study has realistic implications for understanding the contribution of the preferential flow formed by the decay of tree roots to soil water replenishment into deeper soil layers, especially for soil desiccation areas.

2. Materials and methods

2.1. Study areas

The experiment site was conducted on Yongle village, Xiaqu township, Wenshui county, Lvliang city, in Shanxi Province (37°15″-37°35′9″N, 111°29′47″-112°19′15″E). The study area is located on the eastern part of the Loess Plateau, belonging to a semi-arid region and a temperate continental monsoon climate. The average altitude and annual average temperature of this area are 745 m and 10.1℃ respectively. The average annual rainfall is 457 mm, but most of the rainfall events in a year mainly occur in summer. The soil in the study area is classified as Calcaric Regosol by the soil classification (WRB, 2014). Since the 1980 s, artificially planted poplar trees have been planted in

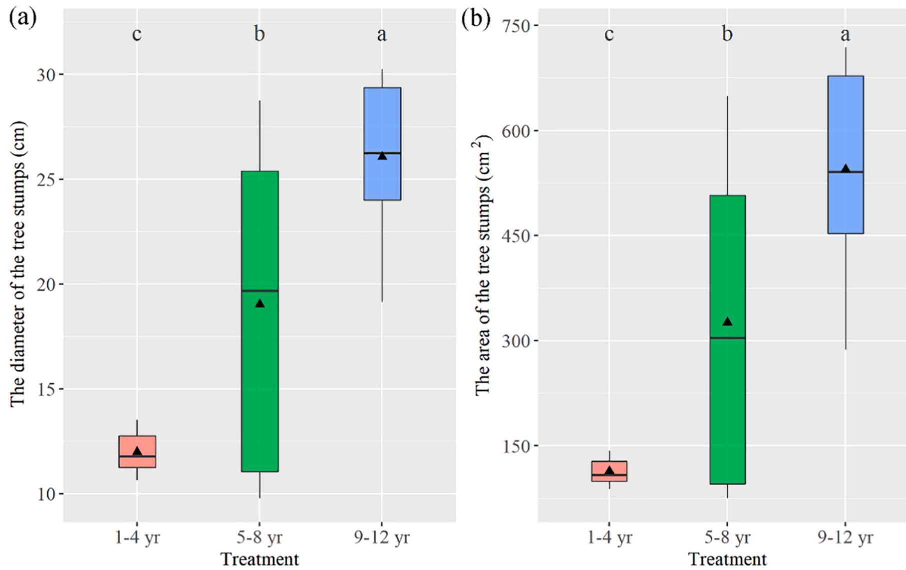

Fig. 2. The stump diameter and stump area of Populus davidiana. Note: 1–4 yr, Populus davidiana with a decaying time of 1–4 years; 5–8 yr, Populus davidiana with a decaying time of 5–8 years; 9–12 yr, Populus davidiana with a decaying time of 9–12 years; The black triangles represent the mean value of stump diameter and the mean value of stump area. Different lowercase letters indicate that there are significant differences between different experimental treatments at the 0.05 level.

most areas as the main protection forest.

2.2. Experimental design

Two *Populus davidiana* (*P. davidiana*) forests more than 10 km apart were selected as the sample plot for this experiment. Four different treatments were selected in each *P. davidiana* forest, namely: bare land as control, decayed *P. davidiana* (1–4 yr), decayed *P. davidiana* (5–8 yr) and decayed *P. davidiana* (9–12 yr) (Fig. 1). The planting time and death time of *P. davidiana* was determined by consulting data and consulting local residents. At the beginning, each treatment for two *P. davidiana* forest had 3 repetitions. The infiltration data were checked after infiltration experiments. If there was too much variation in the infiltration data of the same treatment, we would conduct a supplementary test for this treatment. Hence, there was an uneven number of repetitions of different treatments in this study. Finally, infiltration experiment was carried out: Bare land (7 repetitions), *P. davidiana* decayed for 1–4 year (7 repetitions), *P. davidiana* decayed for 5–8 year (8 repetitions), *P. davidiana* decayed for 9–12 year (7 repetitions).

2.3. Measurement of infiltration rates

The operation steps of the entire infiltration process of the study were based on Zhang et al. (2017a) and Guo et al. (2019). In brief, the infiltration rate of all treatments was evaluated using a double-ring infiltrometer. The device consists of an inner ring with a diameter of 32 cm and an outer ring with a diameter of 60 cm. The litter and herbaceous plants on the soil surface were removed before the infiltration experiment. The double-ring infiltrometer was gently and vertically inserted into the soil about 5 cm to minimize the impact of human disturbance on the soil structure. And, the location of the infiltrometer ensured that the tree stump was in the center of the inner ring. Then, the inner ring and outer ring were quickly filled with water to a height of 4 cm at the same time. The time for the water level of the inner ring to drop by 5 mm was recorded during the experiment. The inner and outer ring water would be refilled to a height of 4 cm when the water line dropped to 1 cm. The water level of the inner ring and outer ring remained the same throughout the infiltration process.

2.4. Measurement of root characteristics

The diameter of the tree stump (the remaining part of the tree on the ground after being felled) was measured by a 5-meter tape (accuracy 1 mm) (Guo et al., 2019). And, the diameter of each stump was measured four times repeatedly. The area of the tree stump was calculated as follows (Wu et al., 2017):

$$\overline{TSD} = \sum_{i=1}^{n} \frac{TSD_i}{n} \ (n = 4)$$

$$TSA = \pi \times \frac{\overline{TSD}^2}{4}$$

where TSD is the diameter of the tree stump (cm), $\overline{TSD}$ is the mean value of stump diameter (cm), n is the number of repeated measurements of the same stump, TSA is the area of the tree stump (cm^2).

In addition, root density (RD) was also measured after infiltration experiments. First, we whittled the root into a sample with a regular shape. There are at least 5 replicates of the root sample in each treatment. Then, the length of each side of the sample was measured with a vernier caliper to calculate its volume. Finally, the weight of each sample was obtained by the oven-drying method. RD was calculated as follows:

$$RD = \frac{RW}{RV}$$

where RW is the weight of the root (g), and RV is the volume of the root (cm^3).

The relative porosity improved by the roots (RPIR) was calculated as follows:

$$\overline{RD}_{max} = \sum_{i=1}^{n} \frac{RD_{maxi}}{n} \ (n = 9)$$

$$RPIR = \left(RD - \overline{RD}_{max}\right) \times \frac{TSA}{A} \times 100\%$$

where $\overline{RD}_{max}$ is the mean of the first nine larger root densities in all data ($g\ cm^{-3}$), A is the area of inner ring (cm^2).

2.5. Statistical analysis

Non-linear regression models were used to analyze the relationship between infiltration time and infiltration rates (Fig. 2). The rate of

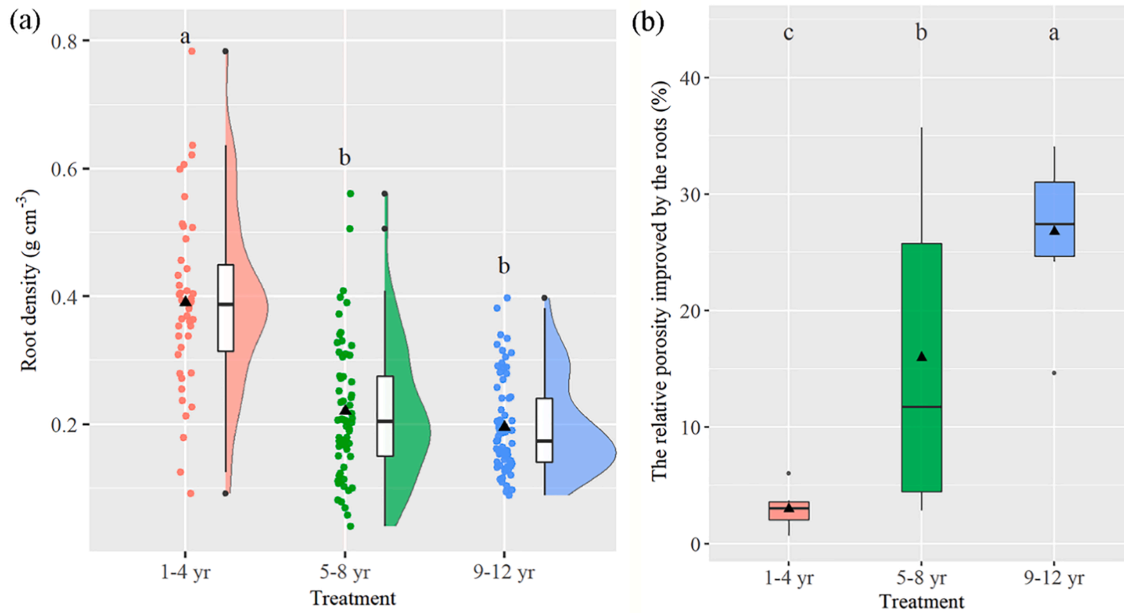

Fig. 3. The root density and relative porosity of Populus davidiana. Note: 1–4 yr, Populus davidiana with a decaying time of 1–4 years; 5–8 yr, Populus davidiana with a decaying time of 5–8 years; 9–12 yr, Populus davidiana with a decaying time of 9–12 years; The triangles represent the mean value of root density and the mean value of relative porosity improved by the roots. Different lowercase letters indicate that there are significant differences between different experimental treatments at the 0.05 level.

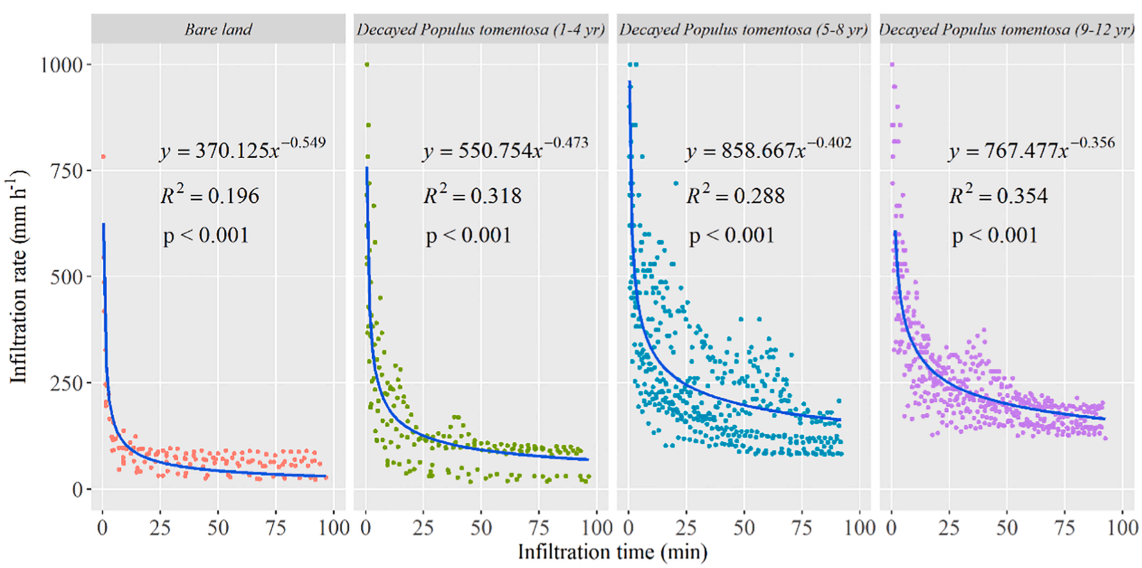

Fig. 4. Change of soil infiltration rate with infiltration time. The blue line represents the fitted relationship between infiltration rate and infiltration time. Bold numbers represent the relevant statistical indicators of regression analysis.

change of the infiltration rate was obtained by calculating the slope of the fitted equation. We divided the entire infiltration process into six parts according to the rate of change of the infiltration rate (Fig. 3). And, the infiltration rate of each part was defined as the initial infiltration rate (IIR), the infiltration rate of stage I (IR-I), the infiltration rate of stage II (IR-II), the infiltration rate of stage III (IR-III), the infiltration rate of stage IV (IR-IV) and the stable infiltration rate (SIR). The initial infiltration rate was calculated by the average value of the first minute of infiltration. And the stable infiltration rate was determined by the mean value of the last three values at the end of the infiltration. Then, we used one-way analysis of variance (ANOVA) to compare the difference in infiltration rates between different treatments (Fig. 4). Similarly, we also used one-way analysis of variance (ANOVA) to compare the differences in TSD, TSA, RD, RPIR and soil water replenishment between different treatments. Correlation analysis was used to analyze the relationship between infiltration rate (IIR, IR-I, IR-II, IR-III, IR-IV, SIR) and various root system characteristics (TSD, TSA, RD, RPIR). Then, stepwise regression analysis and partial correlation analysis are used to explore and test the main factors affecting the infiltration rate (IIR, IR-I, IR-II, IR-III, IR-IV, SIR).

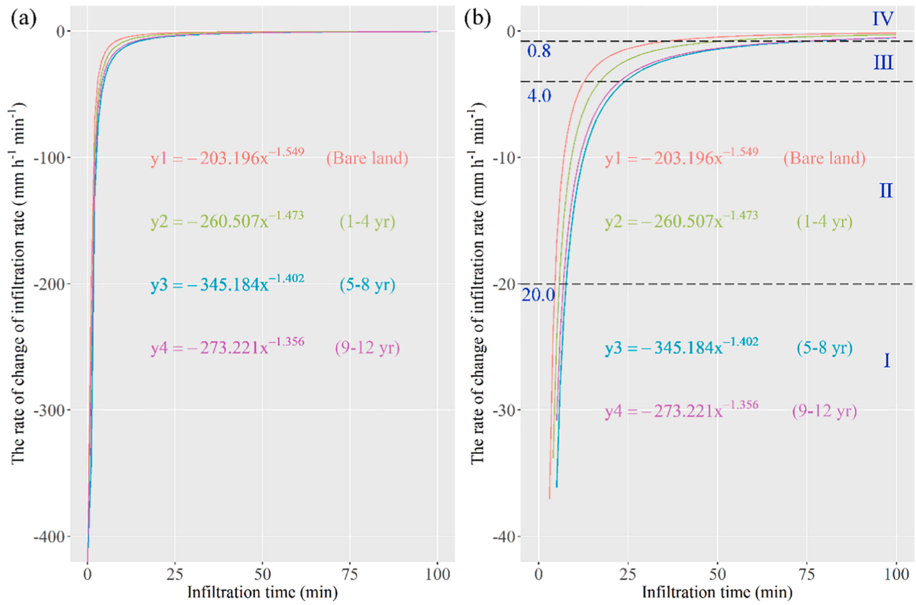

Fig. 5. Change rate of soil infiltration rate in different experimental treatments. Note: 1–4 yr, Populus davidiana with a decaying time of 1–4 years; 5–8 yr, Populus davidiana with a decaying time of 5–8 years; 9–12 yr, Populus davidiana with a decaying time of 9–12 years.

Fig. 6. Soil infiltration rate at each stage in different experimental treatments. Note: A, Bare land; B, Populus davidiana with a decaying time of 1–4 years; C, Populus davidiana with a decaying time of 5–8 years; D, Populus davidiana with a decaying time of 9–12 years. Different lowercase letters indicate that there are significant differences between different experimental treatments at the 0.05 level.

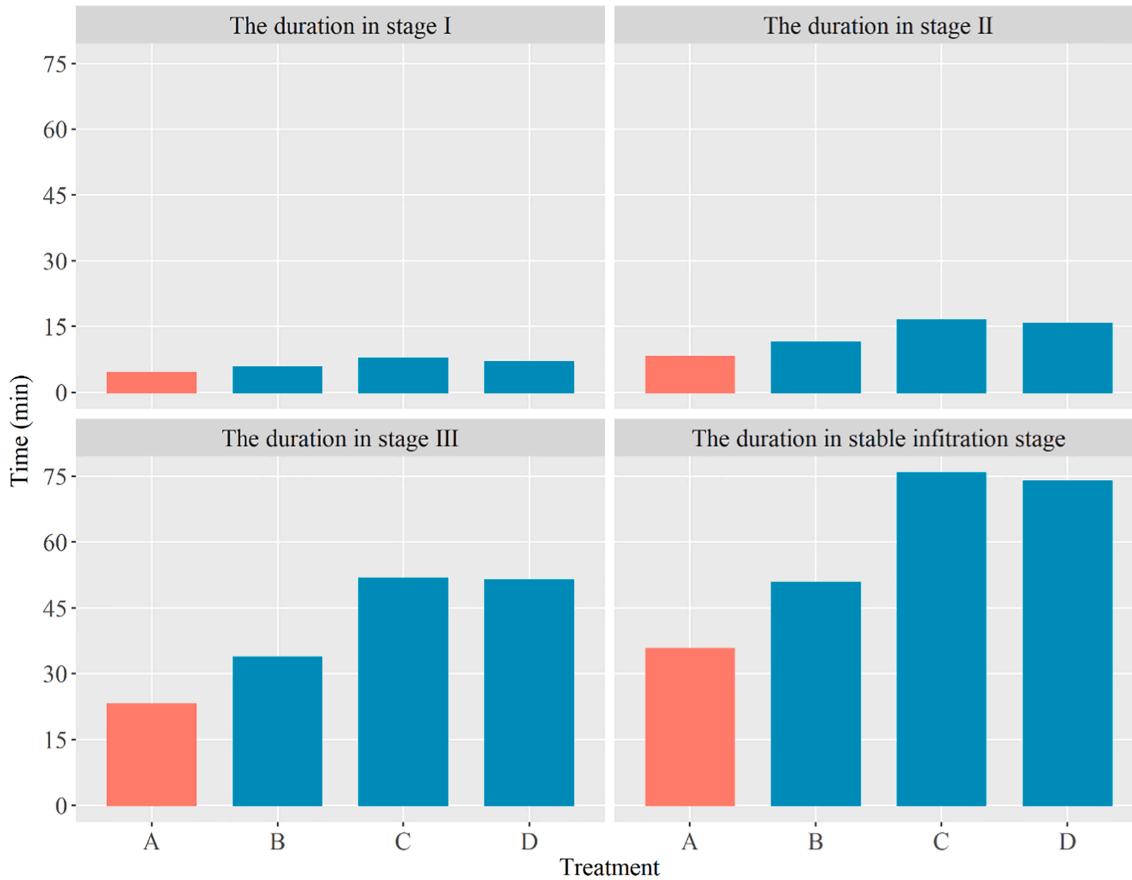

Fig. 7. The duration of each infiltration stage in different experimental treatments. Note: A, Bare land; B, Populus davidiana with a decaying time of 1–4 years; C, Populus davidiana with a decaying time of 5–8 years; D, Populus davidiana with a decaying time of 9–12 years.

3. Results

3.1. The decayed roots characteristics and its effects on relative soil porosity

There were significant differences in the diameter and area of the tree stump between different decay years (Fig. 2). The stump diameter and stump area of the decayed roots for the 9–12 yr was the highest, followed by the 5–8 yr, and the 1–4 yr was the smallest. And, the stump diameter and stump area of 5–8 yr and 9–12 yr were significantly higher than those of the 1–4 yr. However, the root density of the 5–8 yr and the 9–12 yr were significantly smaller than those of the 1–4 yr (Fig. 3a). The relative porosity improved by the decayed roots was significantly different between different decay years (Fig. 3b). The relative porosity improved by the decayed roots of the 9–12 yr was the highest, followed by the 5–8 yr, and the 1–4 yr. And, the relative porosity improved by the decayed roots of the 5–8 yr and the 9–12 yr were significantly higher than those of the 1–4 yr.

3.2. Soil infiltration rate in different treatment

In general, the soil infiltration rate of different treatments decreased with the increase of infiltration time (Fig. 4). And, the change rate of soil infiltration rate also decreased with the increase of infiltration time (Fig. 5). At the same time, the change rate of soil infiltration rate of the 5–8 yr and the 9–12 yr decayed roots was the smallest, followed by the 1–4 yr, and the highest was bare land. The soil infiltration rates (initial infiltration rate, infiltration rate of stage I, II, and III) of the 5–8 yr and the 9–12 yr were significantly higher than those of the 1–4 yr and bare land (Fig. 6). And, in the late stage of infiltration, the IR IV and SIR of the 9–12 yr were significantly higher than that of the 5–8 yr. The IT-I, IT-II, IT-III and T-SIR of the 5–8 yr (9–12 yr) of the decayed roots was the longest, followed by the 1–4 yr and the bare land (Fig. 7). Hence, soil water replenishment of the 5–8 yr and the 9–12 yr were significantly higher than those of the 1–4 yr and bare land (Fig. 9). Compared with bare land, the decayed roots of the 1–4 yr, the 5–8 yr, and the 9–12 yr increased the amount of soil water replenishment by 37.12%, 217.52%, and 259.85%, respectively.

3.3. The effect of decayed root system characteristics on soil infiltration rate

The IIR, SIR, IR-I and IR-IV have a significant positive correlation with decayed root system characteristics (stump diameter, stump area, the relative porosity improved by the roots), but a significant negative correlation with root density (Fig. 8). Through stepwise regression analysis, we found that the initial infiltration rate and the stable infiltration rate were mainly affected by the relative porosity improved by the roots (Table 1). And the infiltration rate of stage II, III, and IV were mainly affected by root density (Table 1; Fig. 8). After excluding the influence of root area, the influence of root density on soil infiltration rate was greater than that of the relative porosity improved by the roots, especially in the later stage of infiltration (Table 2).

4. Discussion

Our study provides compelling evidence of contribution of root decay process on soil infiltration capacity and soil water replenishment of planted forestland in semi-arid regions, and quantified the effective soil water replenishment for different decayed root ages. Our findings

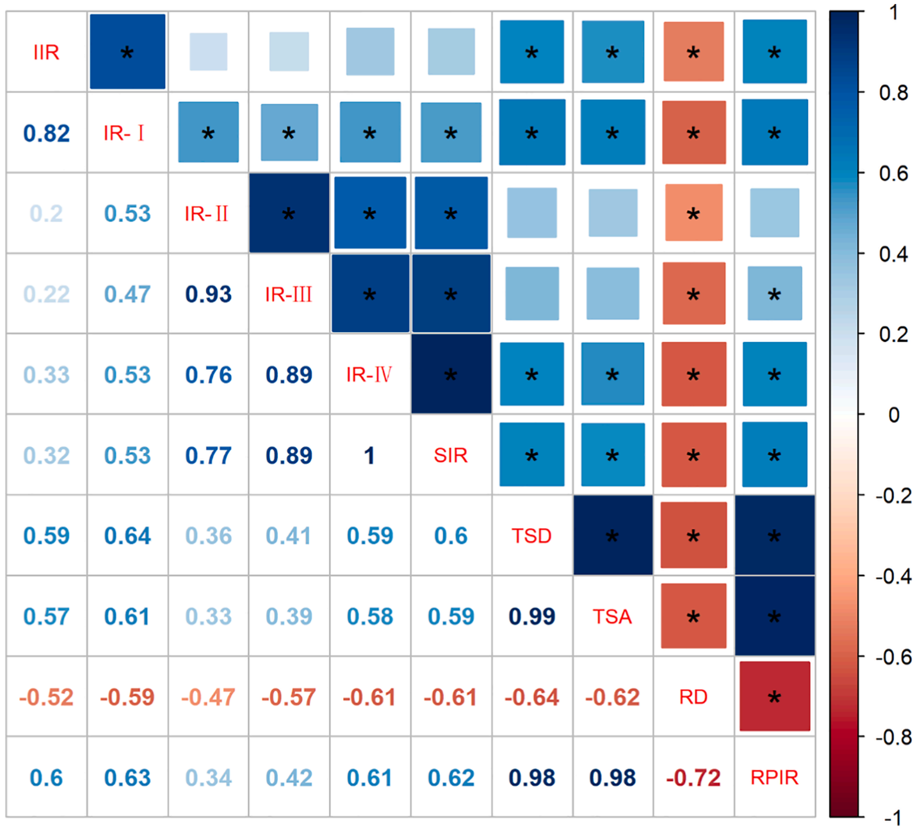

Fig. 8. Correlation analysis of soil infiltration property and root characteristics. Note: IIR, the initial infiltration rate; SIR, the steady infiltration rate. IR-I, IR-II, IR-III and IR-IV represent the average infiltration rate in stage I, II, III and IV, respectively. RDI, root diameter; RA, root area; RDE, root density; RPRS, the relative porosity improved by the roots. * Correlation is significant at the $p < 0.05$ probability level.

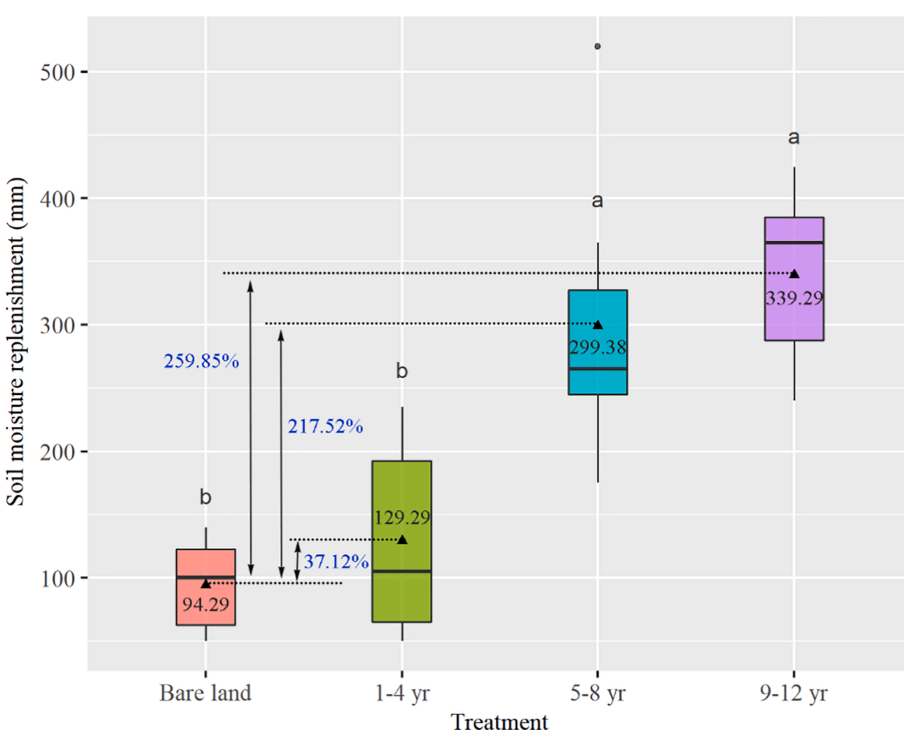

Fig. 9. Soil moisture replenishment of different experimental treatments. Note: 1–4 yr, Populus davidiana with a decaying time of 1–4 years; 5–8 yr, Populus davidiana with a decaying time of 5–8 years; 9–12 yr, Populus davidiana with a decaying time of 9–12 years. The black triangles and digits represent the mean value of soil moisture replenishment. The blue digits represent the percentage increase in soil moisture replenishment by decayed Populus davidiana relative to bare land. Different lowercase letters indicate that there are significant differences between different experimental treatments at the 0.05 level.

showed that the macropores formed by the decayed roots significantly increase the soil infiltration rate at each stage, thereby promoting soil-water replenishment. Further, soil infiltration rate increased with the root decayed ages. Soil infiltration rate affects surface runoff and soil water recharge efficiency during natural rainfall (Jiang et al., 2018; Guo et al., 2019). Understanding the influence of plant root characteristics on

Table 1
Results of the stepwise regression analysis. The root system characteristics were considered as independent variable in stepwise regression.

Dependent variables	Regression equation	F	P	R^2
The initial infiltration rate	Y = 18.04 RPIR + 620.79	11.38	< 0.01	0.36
The average infiltration rate in stage I	Y = 16.30 TSD + 217.36	14.06	< 0.01	0.41
The average infiltration rate in stage II	Y = -480.66 RD + 361.65	5.78	0.03	0.22
The average infiltration rate in stage III	Y = -399.80 RD + 258.64	9.68	0.01	0.33
The average infiltration rate in stage IV	Y = -298.53 RD + 191.03	11.88	< 0.01	0.37
The steady infiltration rate	Y = 2.56 RPIR + 70.40	12.21	< 0.01	0.38

Note: TSD, the diameter of the tree stump; TSA, the area of the tree stump; RD, root density; RPIR, the relative porosity improved by the roots.

water infiltration is essential for soil water replenishment and vegetation restoration in dryland ecosystems (Neris et al., 2012; Costantini et al., 2015; Guo et al., 2019). Plant roots not only have a physical entanglement effect, but also release large amounts of secretions to improve soil properties (Cui et al., 2019; Wu et al., 2019). Meanwhile, the decayed of roots of vegetation improved soil infiltration properties by promoting the formation of macropores as as preferential flow channels, e.g., the Medicago sativa grassland improved the soil infiltration rate by improving the macropores in the soil (Bronick and Lal, 2005; Zhang et al., 2017b; Cui et al., 2019; Guo et al., 2019). The preferential flow formed by plant roots affects the process of water infiltration, which will facilitate the replenishment of groundwater and the prediction of runoff generation (Weiler and Naef, 2003; Guo et al., 2019). Studies have shown that root channels formed by decay and decomposition of plant roots may cause natural rainfall to move to deeper layers of soil, especially in dryland ecosystems (Bogner et al., 2010; Cui et al., 2019; Guo et al., 2019).

Particularly significant were that our research provided a direct and favorable evidence that preferential flow formed by the decayed roots significantly increase the soil infiltration rate at each stage, thereby promoting soil water replenishment. By studying the Medicago sativa that has been dead for 3 to 5 years, Guo et al., (2019) found that the root channel formed by root decay affects the preferential flow, thus increasing soil infiltration rate and promoting soil water replenishment. It's well known that the preferential flow is a non-uniform flow, which is mainly affected by soil macropores (Weiler, 2005; Germann et al., 2007; Allaire et al., 2009). The complex root network system formed by the growth of trees promotes the formation of large pores, improves the soil structure, and forms a root channel for rapid water movement (Johnson and Lehmann, 2006). Root channels increase the density of macropores and improve the continuity of pores, which may be more conducive to the flow of water and material transport in the soil (Johnson and Lehmann, 2006; Bogner et al., 2010). Our findings suggest that the macropores formed by root decay and decomposition are the main factors affecting the formation of preferential flow and soil infiltration and recharge increased significantly with the root decayed ages. In general, the alive roots and rotten roots both could increased soil organic matter and porosity, and improve soil structure. (Wu et al., 2016, 2019; Guo et al., 2019). However, the decayed roots may be easier to form a large and continuous network of pores than alive roots (Mitchell et al., 1995).

Additionally, this study analyzed the influence of roots with different decay ages on the entire soil infiltration processes. Results show that the increase of root decay time can not only increase the infiltration rate of each stage (such as initial infiltration rate, stable infiltration rate, etc.), but also reduce the decreasing rate of soil infiltration rate. Meanwhile, we also found compared with bare land, the decayed roots of 1–4 yr, 5–8 yr, and 9–12 yr increased the amount of soil water replenishment by 37.12%, 217.52%, and 259.85%, respectively. This may be due to the significant positive correlation between soil infiltration rate and root diameter and area of decayed roots (Guo et al., 2019). Our results also show that the IIR, SIR, IR-I and IR-IV are significantly related to root system characteristics (the diameter of the tree stump, the area of the tree stump, root density, the relative porosity improved by the root). And, through stepwise regression and partial correlation analysis, we found that root density is the main factor affecting soil infiltration capacity. This method eliminates the difference in root area between different treatments caused by artificial selection of sample plots, which makes the research results more credible. Therefore, the root density decreases with the increase of the root decay time, which further improves the soil infiltration capacity and improves the efficiency of soil water replenishment. Given these findings of this study, tree stumps and rotting tree roots resulted from forestland thinning will present great potential contribution on soil water replenishment for soil desiccation area caused by artificial afforestation, which provide a theoretical basis for the solution to dry soil layers and sustainable management of forestland in semi-arid areas.

5. Conclusions

Our work provides novel evidence for contribution of root decay process on soil infiltration capacity and soil water replenishment of planted forestland in semi-arid regions. Our results showed that the infiltration rate at each stage presented significant positive correlations with root system characteristics (stump diameter, stump area, the relative porosity improved by the roots). We also found that decayed roots density of is the main factor affecting soil infiltration capacity by preferential flow. The decayed process of tree roots in forestland could significantly reduce root density and increased the relative porosity improved by the roots. Further, the roots channel formed by the decayed roots could significantly increase the infiltration rate at each stage and keep the higher infiltration rate. Compared with bare land, the decayed roots of 1–4 yr, 5–8 yr, and 9–12 yr increased the amount of soil water replenishment by 37.12%, 217.52%, and 259.85%, respectively. Overall, the decayed tree roots could maintain a relatively high and stable infiltration rate by reduced root density, which increased the effective replenishment of soil water of dry soil layers in forestland. These findings have potential implications for understanding the effect of decay process of tree roots on soil water replenishment, and provide a theoretical basis for the solution to dry soil layers and sustainable management of forestland in semi-arid areas.

Table 2
Results of the partial correlation analysis. The root area was considered as control variable in stepwise regression.

	Dependent variables	IIR	IR-I	IR-II	IR-III	IR-IV	SIR
Root density	Correlation coefficient	−0.27	−0.34	−0.36	−0.45	−0.39	−0.39
	P	0.25	0.13	0.11	**0.04**	0.08	0.08
The relative porosity improved by the roots	Correlation coefficient	0.28	0.21	0.07	0.21	0.25	0.24
	P	0.22	0.36	0.76	0.35	0.28	0.30

Note: IIR, the initial infiltration rate; SIR, the steady infiltration rate. IR-I, IR-II, IR-III and IR-IV represent the average infiltration rate in stage I, II, III and IV, respectively.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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