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Full Length Research Paper

Root distributions and drought resistance of plantation tree species on the Weibei Loess Plateau in China

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In this study, soil drilling and pot-culture methods were applied to study vertical root distributions and root drought resistance of plantation tree species on the Weibei Loess Plateau. Results indicated that site conditions had clear effects on vertical root distribution characteristics of *Robinia pseudoacacia*. Differences existed in vertical root distributions among the four study species, and *R. pesudoacacia* had the deepest roots. Results from pot-culture experiments revealed that root vigor decreased gradually with a decrease in soil moisture, and soil moisture levels below a certain level resulted in the death of seedlings. Among the four tree species used in the study, *Prunus armeniaca* var. *ansu* Maxim showed the strongest drought resistance, followed by *Platycladus orientalis, R. pseudoacacia and Pinus tabulaeformis*. Root vigor was affected not only by the degree of soil drought, but also drought duration. When soil moisture was lower than 40% of field water capacity for more than 30 days, growth of *P. tabulaeformis* was limited, but little negative effect was observed for *P. armeniaca* var. *ansu* Maxim, *P. orientalis* and *R. pseudoacacia*. Based on the analysis of root distribution and root drought resistance, it can be concluded that *P. orientalis* and *P. armeniaca* var. *ansu Maxim* could be planted on most sites in Chunhua County. *R. pesudoacacia* could be used in more sites because of its larger root distribution space, while *P. tabulaeformis* is more suited for sites with better soil moisture conditions, such as northern slopes and valley plains.

Key words: Soil drilling, site types, vertical root distribution, soil drying gradient, root vigor, Weibei Loess Plateau.

INTRODUCTION

Research related to ecological and physiological characteristics of root systems has a long Coile, 1936; Böhm, 1979; Gale et al., 1987; Stone and Kalisz, 1991; Farrish, 1991; Sainju and Good, 1993; Jackson et al., 1996. The functions of the root system and its effect on vegetation growth and soil productivity have been a central topic in many of these studies Gale and Grigal, 1991; Kiniry et al., 1983; Peng li et al, 2002. Studies have verified that the characteristics of root distribution (especially of fine roots) and drought-resistance ability are the main factors affecting the growth and stability of forest stands, especially in arid and semi-arid areas (Bartsch, 1987; Leena et al., 1997; Hendrik and Pregitzer, 1993; Berrish and Ewel, 1988; Parker and Van, 1996; Stone and Kalisz, 1991, Jackson et al., 1996; Ronald and Kurt, 1993; Peng Li et al., 2002). Parker (1996) demonstrated that vertical and horizontal root distribution characteristics determine the underground nutrient and moisture space, which have great importance for upper plant growth. Although there are a smaller proportion of fine roots in deeper soil layers, the effect on the utilization of soil moisture and nutrients is crucial.

The Loess Plateau is the most seriously eroded area in China and possibly the world, and is almost entirely located in arid and semi-arid areas. Research in the region has confirmed that soil layers with low soil

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moisture content (desiccation layers) have typically existed at certain depths of the soil profile, where soil moisture content has decreased to a point that limits root system development in the deep layer, and subsequently the utilization of water and nutrients (Changzhong et al., 1998; Shao, 2000). Although great effort has been extended to rehabilitate and reconstruct local vegetation in this region, a lower survival ratio, lower conservatory ratio, and lower productivity were still the main limiting factors for local agriculture and forestry development, mainly because of a lack of understanding of the adaptability of tree species to arid conditions. Furthermore, research related to tree growth and resistance to drought conditions has mainly focused on the upper part of the tree, and little attention has focused on root systems of trees. Consequently, it is important to investigate root distribution characteristics and drought-resistance ability to benefit plantation forestry on the Loess Plateau.

The objective of this study was to study the root distribution characteristics and root drought-resistance features of the primary plantation tree species on the Weibei Loess Plateau, to reveal the differences of drought resistance among tree species, and consequently the reason for different productivity of different tree species, which may have profound effects on forestry management in the region.

MATERIALS AND METHODS

Site conditions

Two gullies were selected as sampling plots for root investigation. One is Nihe Gully, running from north to south; the other is Qinzhuang Gully, running from west to east. Both of the two gullies are located in Chunhua County on the Loess Plateau with an altitude ranging from 630 to 1809 m. Main soil types are calcic cinnamon soils and loess. Soil fertility is lower as the organic matter content is below 1%. Average annual temperature is 9.6℃, with an average in January of -4.3℃, and 23.1℃ in July. The average annual precipitation is 600.6 mm, mostly occurring during the period from July to September with a maximum of 822.6 mm and a minimum of 409.5 mm. The average rainfall in the growing season is 454 mm. Since the 1960s, an increasing number of trees have been planted for soil and water conservation. Initially, *Robinia pseudoacacia* was a popular species used in the area for its effect on soil and water conservation. Later, other species, such as *Pinus tabulaeformis*, *Platycladus orientalis* and *Prunus armeniacia*, were introduced for their ecological and economic benefits.

Characteristics of root distributions

Description of sampling plots

Vertical root distribution characteristics of *P. tabulaeformis, P. orientalis, R. pseudoacacia,* and *P. armeniacia* were investigated using the soil drilling method. Because of an insufficient number of stands, only *R. pseudoacacia* on different slope directions and *P. tabulaeformis* of different ages (Table 1) were investigated for comparison.

Root sampling method and measurement

In each sampling plot, average height and breast-height diameter of the stand were determined by randomly selecting 30 trees, among which, four trees with height and breast-height diameter closest to the average of the stand were selected as standard trees for root investigation. For each standard tree, a 1/4 circle around the tree was used as a sampling section according to the direction distribution (Figure 1). Thus, the root distribution characteristics of four trees in the same stand were calculated to represent the general root distribution information of one complete tree in the stand. Three points located evenly on the 0.5 and 1.5 m radii, respectively, were established as sampling points and the roots from every 10 cm layer were sampled by coring. On each point, a soil auger (φ=6.8 cm) was used to drill into each layer (10 cm increments) until there were no roots available in the soil. Roots collected from each soil layer were taken back to the laboratory in a plastic bag.

After washing with distilled water and drying to constant weight in an oven at 85℃, the weight of all roots of each size from each layer was measured. Roots from each tree (and from each of the different directions) were merged and calculated to determine the tree root distribution characteristics according to the following equation:

$$RD = \frac{\sum_{i=1}^{n}\sum_{j=1}^{k} m}{nk} \times \frac{1}{\pi R^2 h \times 1000} \tag{1}$$

where RD is the root density of a certain layer (kg/m^3), R is the radius of soil auger (0.034 m); h= thickness of soil layer (0.1 m); m = root weight; k and n are the number of sampling trees and sampling points, respectively.

Root drought-resistance of plantation species

Seedlings and potted soil: Seedlings of *P. tabulaeformis, P. orientalis, R. pesudoacacia* and *P. armeniaca var.ansu Maxim* were potted (Table 2). Potted soil was a 3:1 mixture of loess and river sand. Each pot (φ40 cm, H50 cm) was filled with 13.3 kg of potted soil. The soil water character curve of the potted soil was determined using the centrifugal method, as described in the equation:

$$Y=17.567X^{-0.1658} \ (R^2=0.9989) \tag{2}$$

where Y = soil water content (%), X = soil water potential (bar). Thus, the field moisture capacity (that is, the water content when soil water potential is 1/3 bar, Zhao et al., 2000) of the potted soil was determined as 21.08%.

Experimental layout: In this study, each tree species was planted in three water content gradients with five replicates. In the first gradient, potted soil water content was controlled at 70% field moisture capacity (that is the water content was 14.76%). In the second gradient, potted soil water content was controlled at 40% field moisture capacity (that is the water content was 8.43%). In the third gradient, no water (including rainfall) was added to the pot when the experiment started until the upper parts of the seedling died. A covering of plastic cloth was necessary to shelter the seedlings from natural rainfall. To maintain the potted soil at the designed soil moisture level, water was injected into the soil through a plastic tube (φ3 mm). Typically, the water gradient in the pot experiment was a reverse of that in the forest where soils are irrigated from the top. To avoid this problem, pinholes were put into

Table 1. A brief overview of sampling plots for root investigation of major tree species planted in Chunhua county.

Plot No.	Tree* species	Location**	Slope exposition	Grade	Position on slope	Soil types***	Stand age(y)	Average height (m)	Average BHD (cm)
1	R	NH	SW	23	Middle	YLS	15	8.31	8.8
2	R	NH	E	9	under	YLS	15	8.85	9.3
3	P.t	NH	SE	25	over	YLS	6	0.87	2.9
4	P.t	NH	E	5	over	YLS	8	2.36	3.2
5	P.t	NH	SE	15	middle	YLS	10	3.12	4.5
6	P.t	QZ	N	24	over	YLS	15	4.46	7.5
7	R	QZ	E	31	Middle	OL	24	12.25	15.2
8	R	QZ	EN	31	Middle	YLS	24	12.58	16.3
9	R	QZ	W	33	Middle	YLS	24	11.91	13.3
10	R	QZ	W	26	Middle	OL	24	12.38	13.2
11	P.o	NH	E	20	Over	YLS	12	2.75	3.8
12	P.o	NH	SE	18	Over	YLS	12	2.84	3.2
13	P.a	NH	SE	23	Middle	YLS	8	3.56	4.2***
14	P.a	NH	SE	16	Over	YLS	8	3.97	4.6****

*R = *R. pseudoacacia*, P.t = *P. tabulaeformis*, P.o= *P. orientalis*, P.a= *P. armeniacia,* **NH = Nihe gully, QZ = Qinzhunang gully, ***LS = yellow loessial soil, OL = old loess, *****As P. armeniacia* was pruned for higher fruit production, most branched under 1.5 m; thus, breast height diameter was measured at 1.2 m.

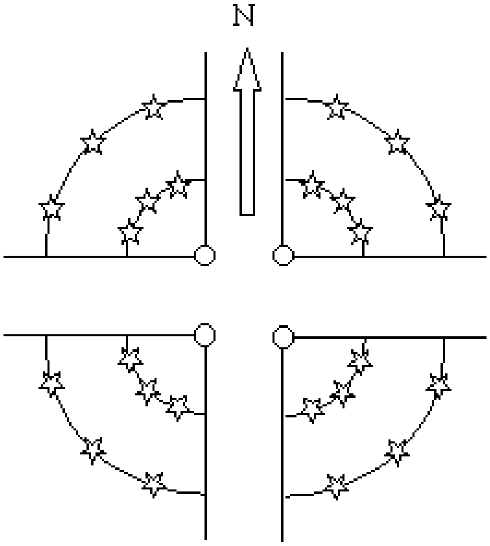

Figure 1. Sketch map of root investigation sampling. "☆" represents the sampling points 0.5 and 1.5 m from the trunk; "O" represents the sampling trees.

the plastic tube at a distance of 10 cm to the bottom; thus the potted soil water content distributed more evenly, and approximated actual water conditions in the forest.

During the experiment, soil and root samples were drilled periodically by soil auger to determine soil moisture content and root vigor level. Root vigor was measured by the TTC method. First, root samples were put into liquid mixed by TTC and buffering liquid, and warmed for 1 h at 37°C. Then, it was extracted by ethyl acetate after trituration, and the extract was transferred to a 10 ml container. The quantity of TTC deoxidized in 1 h/g root was measured at the wavelength of 485 nm. The root vigor was expressed by deoxidized density, and its unit was µg/g.h. Soil moisture content was measured by the oven-drying method.

RESULTS AND DISCUSSION

Root distribution characteristics of the primary tree species on the Loess Plateau

R. pseudoacacia is a popular species for soil and water conservation on the Loess Plateau. It is planted on different sites due to its large range of adaptability. *R. pseudoacacia* has a large root system without a notable taproot, and was once considered a shallow-root species (Liu et al., 1987). Recent studies have verified that *R. pseudoacacia* is a deep-rooted species on the Loess Plateau, with a significant number of roots in the deeper soil layers (Zhao et al., 2000). Slope direction was the main factor influencing water distribution by changing the timing and duration of sunshine on the different sites, and was the main factor in division of site types.

Effect of site conditions on root distribution characteristics of R. pesudoacacia

On the Loess slope, root distribution depth of *R. pesudoacacia* decreased with the increase of distance from the trunk, and slope exposure had a remarkable effect on root distribution characteristics. On northern slopes, the root distribution depth of *R. pesudoacacia*

Table 2. Pot experiment seedlings information.

No.	Tree species	Seedling age	Seedling type
1	*R. pesudoacacia*	1	Seedling
2	*P. orientalis*	2	Container seedling
3	*P. armeniaca var.ansu Maxim*	1	Seedling
4	*P. tabulaeformis*	2	Container seedling

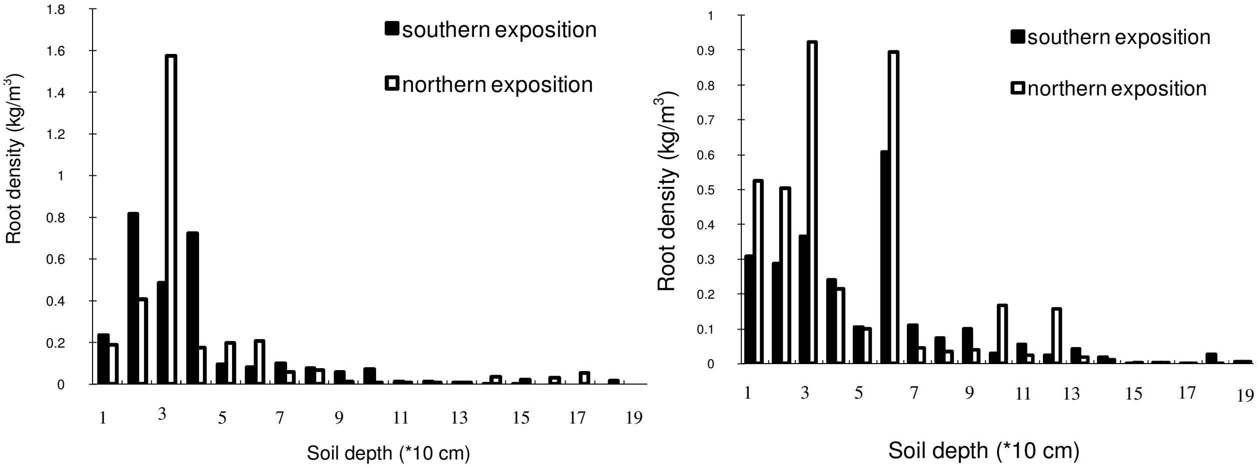

Figure 2. Vertical root distribution characteristics of *R. pseudoacacia* on different sites (Left graph is 0.5 m from the stem; right graph is 1.5 m from the stem).

was clearly deeper than that on the southern slopes, especially near the trunk (Figure 2). Studies related to soil moisture (Changzhong et al, 1998; Yu et al, 1996) on the Loess Plateau have verified that the excessive consumption of water in plantation forests resulted in gradual drying in the deeper soil layer, especially on southern slopes. Compared to the original slope of the same site, soil moisture content in the 1.0 to 1.5 m layer of *R. pesudoacacia* forestland on northern slopes decreased rapidly to 13.71%, and was comparatively stable under 1.5 m, which accounted for 59.2% of field moisture capacity.

On southern slopes, soil water content above 1.5 m of *R. pesudoacacia* forestland accounted for 58.1% of field moisture capacity, while below 1.5 m, it only accounted for 38.8% of field moisture capacity, meaning soil moisture was only 8.8%, which is near the wilting point. The negative effect of artificial forests on soil water in deeper layers caused the roots of *R. pesudoacacia* to remain centralized in the soil above 1.4 m. It also explained why the root distribution depth of *R. pesudoacacia* on northern slopes was deeper than that on southern slopes and why the forest productivity of *R. pesudoacacia* on northern slopes is higher than that on southern slopes. During the study, we also encountered old loess in some stands. Old loess is a kind of heavier textured soil, developed from old red soil. Compared to the *R. pesudoacacia* growing on the loess site, the root biomes of *R. pesudoacacia* on old loess were obviously decreased. Old loess is sticky, heavy, and easily agglomerated, which provides greater mechanical resistance to root growth than the yellow loess soil. The old loess was only present in soil above 1.4 m on southern slopes, and the root distribution depth on these sites surpassed that on northern slopes. These results indicated that soil type and structure also affected root distribution characteristics.

The effect of stand age on the root distribution characteristics of P. tabulaeformis

Investigations (Table 3) of root distribution characteristics of *P. tabulaeformis* indicated that the root system of 6-year-old *P. tabulaeformis* only distributed in the 0 to 90 cm layer. At 8 years, it could reach 120 cm, and it stabilized at this depth until 10 and 15 years, which meant both its root biomes and density increased as the stand aged. This indicated that the root system of *P tabulaeformis* could reach its maximum distribution depth at an early age, which is in agreement with other studies (Lyr and Hoffman, 1967). Further analysis also indicated that for the stands under 8 years of age, there were almost no root diameters larger than 3 mm, while for

Table 3. Effect of stand age on root biomes and density distribution characteristics of *P. tabulaeformis*.

Stand age	6 year		8 year		10 year		15 year	
Soil depth (cm)	**RB (g)**	**RD (kg/m^3)**	**RB (g)**	**RD (kg/m^3)**	**RB (g)**	**RD (kg/m^3)**	**RB (g)**	**RD (kg/m^3)**
10	0.06	0.15	0.06	0.15	0.29	0.79	0.27	0.74
20	0.12	0.34	0.12	0.34	0.18	0.48	0.25	0.69
30	0.24	0.66	0.32	0.87	0.17	0.47	0.31	0.86
40	0.12	0.33	0.17	0.47	0.68	1.88	0.17	0.48
50	0.09	0.25	0.11	0.30	0.24	0.66	0.36	0.99
60	0.03	0.07	0.03	0.07	0.15	0.40	0.16	0.45
70	0.01	0.02	0.01	0.02	0.10	0.28	0.28	0.77
80			0.00	0.00	0.03	0.08	0.68	1.86
90			0.02	0.06	0.03	0.09	0.07	0.20
100					0.00	0.00	0.17	0.48
110					0.14	0.38	0.07	0.20
120					0.02	0.05	0.01	0.04
Total	0.66	1.82	0.83	2.29	2.02	5.56	2.82	7.76

*RB is root biomass; **RD= root density (kg/m^3).

Table 4. Vertical root distribution of tree species planted on the same site of Nihegou gully at Chunhua County.

Hor. of soil (cm)	*P. tabulaeformis*		*P. orientalis*		*R. pseudoacacia*		*P. armeniaca* var. *Ansu*	
	RD*	**RI****	**RD**	**RI**	**RD**	**RI**	**RD**	**RI**
0-10	0.07	1.4	0.79	20.8	0.33	4.0	0	0
10-20	1.22	23.4	0.92	24.1	0.24	2.9	0.49	29.1
20-30	1.86	35.5	0.85	22.3	0.08	1.0	0.008	0.5
30-40	0.21	4.0	0.29	7.6	0.15	1.9	0.22	12.8
40-50	0.99	19.0	0.18	4.6	1.98	24.2	0.08	4.8
50-60	0.15	2.8	0.18	4.6	1.12	13.7	0.13	7.9
60-70	0.01	0.2	0.17	4.5	0.15	1.8	0.76	44.8
70-80	0.06	1.2	0.11	2.8	0.59	7.2	0.0004	0.02
80-90	0.02	0.4	0.33	8.6	0.08	1.0	0.0009	0.05
90-100	0.02	0.4	0	0	2.28	27.8	0.0009	0.05
100-110	0.61	11.7	0	0	1.19	14.5	0.002	0.1
110-120	0	0	0	0	0.003	0.03	0	0

*RD= Root density (kg/m^3), **RI= (RD/ΣRD)×100.

trees of 10 and 15 years of age, thicker roots were distributed in the soil. With the increase of stand age, root biomes and density tended to distribute evenly in the soil.

Vertical root distribution characteristics of different tree species

Investigations of the root distribution characteristics of four tree species on the same slope (plots 2, 4, 11, 12, 13, and 14) of the same site indicated that there were great differences among the four tree species. *P. tabulaeformis* distributed in the 0 to 110 cm layer, and was concentrated in the 0 to 60 cm soil layer (Table 4). *P. orientalis* was limited to the 0 to 90 cm soil layer, and was mainly concentrated in the 0 to 40 cm soil layer. *R. pesudoacacia* was the deepest of the four, its root was distributed relatively even in 0 to 120 cm soil layer. Although *P. armeniaca* var. *ansu Maxim* can reach 110 cm, it was mainly concentrated in the 10 to 70 cm soil layer.

Previous studies have verified that deep-rooted vegetation usually have higher productivity than shallow-rooted species (Gale and Grigal, 1987; Jackson et al., 1996). Based on the vertical root distribution investigation of every tree species, it can be inferred that the order of tree species productivity should be as follows: *R. pseudoacacia* > *P. armeniaca* var. *ansu Maxim* > *P.*

Table 5. The relationship between soil moisture and seedling root vigor of major tree species planted on the Weibei Loess Plateau.

Pinus tabulaeformis		***Platycladus orientalis***		***Robinia pesudoacacia***		***Prunus armeniaca* var. *ansu* Maxim**	
Water content (%)	**Root vigor**	**Water content (%)**	**Root vigor**	**Water content (%)**	**Root vigor**	**Water content (%)**	**Root vigor**
8.43	94.69	8.43	79.800	8.73	40.70	8.03	245.45
6.81*	176.34**	5.35	204.60	6.22	35.90	7.59	295.79
4.92	139.31	4.87	200.95	5.83	50.56	6.10	312.51
4.05	30.95	4.47	183.18	4.53*	191.79**	4.43	148.03
3.58	76.99	3.33*	402.08**	3.65	112.43	3.62*	469.40**
		2.96	315.08	3.31	125.36	3.4	277.83
				3.08	45.25		

* Critical soil moisture content for roots; ** root vigor level at critical soil moisture.

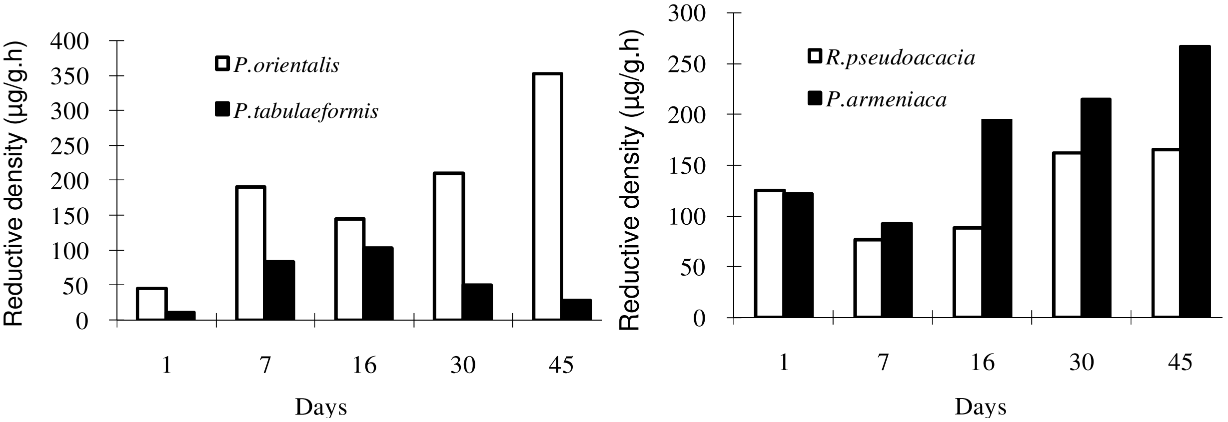

Figure 3. Changes of seedling root vigor of *P. tabulaeformis* and *P. orientalis* (left), *R. pseudoacacia* and *P. armeniaca* var. *ansu* (right) with 70% of field moisture capacity.

tabulaeformis> *P. orientalis*.

Seedling root drought-resistance of primary tree species

Relationship between root vigor and soil water content

Research has confirmed that root vigor generally refers to the absorbency and synthesis ability of the root, its value essentially reveals the relationships among seedling root absorption ability, soil water, and the environment. Root vigor results under drought conditions (Table 5) indicated there were both similarities and differences in root vigor changing. When the potted soil water content was under 40% of field moisture capacity, root vigor of *R. pesudoacacia*, *P. tabulaeformis*, *P. orientalis* increased rapidly with decreasing soil water content, and when soil water content dropped to a certain threshold value, root vigor decreased. This trend demonstrated that seedlings could maintain absorbency for water and other materials in adapting to the drought environment by improving root inspiration density to release more energy, which was essential to survival of the seedling under drought conditions.

The soil water content that could seriously detain the root growth of *R. pesudoacacia*, *P. tabulaeformis*, *and P. orientalis* was 4.53, 6.81 and 3.33%, respectively. The changing root vigor patterns of *P. armeniaca* var. *ansu Maxim* were different from the other three species. Root vigor increased after a sharp decrease, and when soil water content dropped to a certain threshold, root vigor decreased gradually again leading to the death of the upper parts of the plant. The soil water content that can seriously detain the root growth of *P. armeniaca* var. *ansu Maxim* was 3.62%.

Differences of root vigor of each tree species in light dry soil

Figure 3 described the root vigor changes of each tree

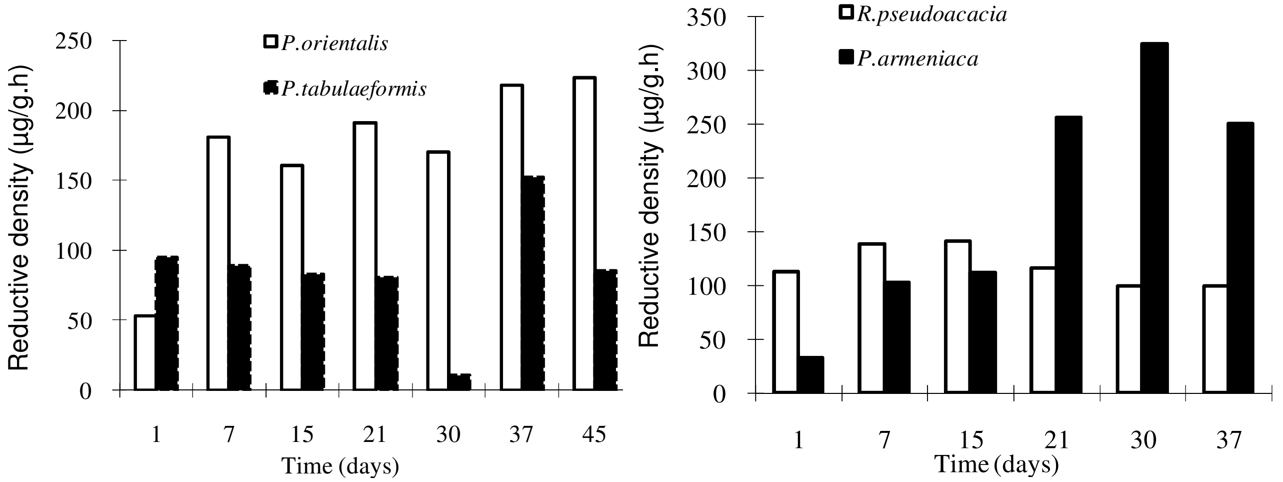

Figure 4. Changes of seedling root vigor of *P. tabulaeformis* and *P. orientalis* (left), *R. pseudoacacia* and *P. armeniaca* var. *ansu* (right) with 40% of field moisture capacity.

species over 45 days under light dry conditions (70% of field moisture capacity). It was clear that the root vigor of *P. orientalis, R. pseudoacacia* and *P. armeniaca* var. *ansu Maxim* increased with time during the 45 days of light drying, which indicated that these 3 species had greater drought resistance ability. As for *P. tabulaeformis*, its root vigor increased during the first phase (0 to 15 days), but declined after that period, which indicated that if the light drying conditions continued for 15 days, it would have a negative effect on the absorption of *P. tabulaeformis*. The order of root vigor changes under light dry conditions was: *P. orientalis* > *P. armeniaca* var. *ansu Maxim* > *R. pesudoacacia* > *P. tabulaeformis*, the same as that under drought conditions (Table 5). Also, the maximum root vigor value of every tree species was less than that under drought conditions (Table 5). Results also indicated that besides the effect of drying extent on root vigor, continuous drying time also had a great impact.

Root vigor changes in medium dry soil

Results clearly showed that different species had different reactions to the medium dry conditions (Figure 4). Although the root vigor of *P. tabulaeformis* fluctuated with time, it maintained at a higher level, which was close to the maximum value under drought conditions (Table 5). This indicated that when soil water content dropped to 40% of field moisture capacity, it had negative effect on the growth of *P. tabulaeformis*. Root vigor of *P. orientalis* under medium dry conditions was similar to that under light dry conditions, which was far from the peak value (Table 5). This result indicated that when soil water content dropped to 40% field moisture capacity, it had little negative effect on *P. orientalis*, and it could still maintain absorption ability.

Under medium dry conditions, root vigor of *P. armeniaca* var. *ansu Maxim* and *R. pseudoacacia* (Figure 4, right) showed different trends. Over 45 days of the medium dry experiment, there was little fluctuation in root vigor of *R. pseudoacacia*, and its value was near to that of 70% field moisture capacity. This showed that *R. pseudoacacia* can maintain normal growth when soil water content dropped to 8.432%. Under the same dry conditions, the root vigor of *P. armeniaca* var. *ansu Maxim* increased with time, and later surpassed *R. pseudoacacia*. Compared to the results under light dry conditions, there was little difference between them, which indicated that *P. armeniaca* var. *ansu Maxim* had stronger drought resistance ability.

Analysis of species drought adaptability

R. pesudoacacia has the deepest roots, and among the four tree species, the order of root distribution depth was as follows (Table 5): *R. pesudoacacia* > *P. armeniaca* var. *ansu Maxim* > *P. tabulaeformis* > *P. orientalis.* Results of root drought resistance indicated that the level of soil moisture content that could seriously impede the root growth of *R. pesudoacacia,* P*. tabulaeformis*, *P. orientalis* and *P. armeniaca* var. *ansu Maxim* was 4.53, 6.81, 3.33 and 3.62%, respectively, indicating that *P. orientalis* and *P. armeniaca* var. *ansu Maxim* had stronger drought resistance ability. Drought degree and time also affected species reaction. Under the light drought conditions (soil moisture content was 14.76%), the order of the drought resistance ability of the four trees was: *P. orientalis* > *P. armeniaca* var. *ansu Maxim* > *R. pesudoacacia* > *P. tabulaeformis*. Under the medium drought conditions (soil moisture content was 8.43%), *P. armeniaca* var. *ansu Maxim* and *P. orientalis* showed better drought resistance ability; *R. pesudoacacia* was affected somewhat under the medium drought conditions, and it can be concluded from the pot culture experiment that its absorption ability tended to be decreased as the drought period continued. The root vigor of *P. tabulaeformis* decreased, which indicated that it was more easily affected by drought. According to the results of soil moisture monitoring (Meng et al., 2008; He et al., 2003), vegetation species and its density, growing season and meteorological features also had effects on soil moisture. Around Chunhua County, soil moisture content between 4 m layers ranged from 7.5 and 15%; that is, in most cases, soil moisture corresponded to light and medium drought conditions. Thus, it can be concluded that *P. orientalis* and *P. armeniaca* var. *ansu Maxim* can be planted on most sites in Chunhua County. Although such conditions had some negative effect on *R. pesudoacacia,* it had a larger root distribution space and thus better adaptability and could be used on more different types of sites.While *P. tabulae formis* is more suited for sites with better soil moisture conditions, such as northern slopes and valley plains.

Conclusions

Based on the results of this study of root distribution characteristics and root drought-resistance ability, the following conclusions were reached:

1) Site conditions influenced the root distribution characteristics of *R. pesudoacacia*. Vertical root distribution depth of *R. pesudoacacia* on sites with northern exposure was deeper than that on southern exposed sites, especially for samples taken at 0.5 m distance from the trunk. Differences of soil moisture conditions on different sites were the cause of the differences in vertical root distribution characteristics, and also were the cause of higher forest productivity on northern exposed sites. In addition, soil type, structure, and composition also had important effects on root distribution characteristics.

2) There were great differences in vertical root distribution characteristics among the four tree species. Root distribution depth of *R. pesudoacacia* was the deepest of the four species, reaching over 120 cm, which made it possible to absorb soil moisture in deeper layers. These results also confirmed that on the Loess Plateau, *R. pseudoacacia* is a deep-rooted species. Based on the vertical root distribution characteristics, a ranking productivity of each tree species on southern exposed sites was as follows: *R. pesudoacacia* > *P. armeniaca* var. *ansu Maxim* > *P. tabulaeformis* > *P. orientalis*.

3) On the Loess Plateau, root drought resistance ability and utilization of soil moisture under arid conditions directly influenced the adaptability and productivity of the plantation trees. Also, root vigor is an important physiological index determining the drought resistance ability of tree species. In certain lower soil moisture ranges, seedlings could improve respiratory intensity to reveal more energy for absorption of soil moisture and nutrients. While soil moisture was under the critical value, root vigor decreased gradually, and led to the death of the upper parts of the plant. Results indicated that the drought resistance ability order of the four tree species was as follows: *P. armeniaca* var. *ansu Maxim* > *P. orientalis* > *R. pesudoacacia* > *P. Tabulaeformis.*

4) Root vigor was affected not only by the degree of soil dryness but also by the drying time. When soil moisture was lower than 40% of field water capacity for more than 30 days, growth of *P. tabulaeformis* was limited, but it did not have clear negative effects on *P. armeniaca* var. *ansu Maxim*, *P. orientalis* and *R. pseudoacacia*.

5) P. orientalis and *P. armeniaca* var. *ansu Maxim* can be planted on most sites in Chunhua County. *R. pseudoacacia* had a larger root distribution space, and can be used in more cases. While *P. tabulaeformis* is better suited for sites with better soil moisture conditions, such as northern slopes and valley plains.

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