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The vertical distribution of the root system of the desert highway shelterbelt in the hinterland of the Taklimakan Desert

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In this work, the vertical distribution of the root system in the Tarim Desert Highway shelterbelt under high salinity water drip irrigation was investigated. The effect of site condition and shelterbelt age was studied. The root sample was collected by plant side soil column excavation. The root distribution was found to be dependent on soil texture, aspect, and plant age. In harden sand, the roots were mostly in the 0–40 cm soil. The root distribution is deep in flat sandy ground and ridge sand. In unit soil volume, the root weight of flat sandy ground was the highest. Compared with the shady slope, the sunny slope had much high total root weight, deeper root distribution, but less hair root. The root weight increased rapidly with the increase of the shelterbelt ages, and the most substantial increase was observed in the early years after forest implantation.

Tarim Desert Highway, artificial shelterbelt, root

The distribution, morphology, growth, development, absorption and excrement of root system are dependent on plant species[1,2]. Root is very sensitive to environmental conditions such as soil, climate, etc. Root is also particularly important to the plant life activities, and has profound impact on the plant's environmental adaptability, competition with other species, and ecological strategy[1–5]. The root may change in shape, density and spatial distribution in order to absorb moisture and nutrients[6–13]. An accurate description of the root distribution is critical to the construction and sustainable management of the desert highway shelterbelt.

The 436 km Tarim Desert Highway shelterbelt resides in numerous environmental extremes such as high salinity (4—28 $g\cdot L^{-1}$) water drip irrigation. This work investigated the root distribution of plants of the shelterbelt at Tazhong, in order to provide a scientific basis for the construction and sustainable management of the desert highway shelterbelt.

1 Site profile

The experimental area is located in the continental temperate and arid desert climate zone. The average annual temperature is 12.4℃. The annual precipitation is 11.05 mm, whereas the annual evaporation potential is 3638.6 mm, 329.1 times of the precipitation. The precipitation is unevenly distributed throughout the year and occurs mainly from May to August. Only nine kinds of natural vegetations are present at Tazhong, and the community structure is simple. Most areas are not covered by vegetation. The experimental area has strong sand dune movement. The soil at Tazhong consists mostly of ae-

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olian sandy soil, and is characterized by the coarse soil texture, loose structure, and low organic matter content. The soil formation at Tazhong is extremely weak.

2 Materials and methods

2.1 Materials

The shelterbelt at Tazhong was selected because it contained a full collection of plants of different ages under various site conditions and soil types (Table 1).

2.2 Test methods

The fresh root weight is easily affected by plant ecological conditions, soil moisture content and post-sampling processing[1]. Therefore, in this work the root distribution was analyzed by the dry root weight.

2.2.1 Root sample collection. The plant of average growth in the shelterbelt was selected, and a soil column was excavated in a 1 m×1 m quadrat at the side of the plant until no apparent root was observed. The roots exposed were collected at regular vertical sampling intervals during the excavation[1]. The quadrat was located in the plant's sunny slope and was established by the criteria (1) one side of the quadrat superimposed with the row that the plant resided in, and (2) the plant was at the mid-point of that side. The collected roots were contributed by all neighboring plants of the quadrat, and thus represented the shelterbelt rather than individual plant. The shelterbelt root content at each depth was averaged from the dry root weight of three plants.

From September to October, 2004, one *Holocylon persicum*, one *Tamarix ramosissima*, and one *Calligonum leucocladum*, each of different ages in different soil conditions, were selected and the root samples were collected at vertical sampling intervals of 20 cm.

From August to October, 2005, the roots at both the sunny slope and the shady slope were collected on three *Calligonum leucocladum* plants at vertical sampling intervals of 10 cm. The roots were collected on a sieve (aperture 2 mm × 2 mm). The hair roots of each layer were collected on a sieve (aperture 1mm × 1 mm) after samples from six 10 cm × 10 cm quadrats of each layer were passed through, and the hair root level was calculated.

Root samples were washed (water), wiped, and grouped according to the root diameter (>1 mm and <1 mm). After the fresh root weights were measured, the roots were dried (105℃, 10－12 h) and the dry root weights were recorded.

2.2.2 EC determination. The soil sample was collected from six points during root collection and immediately sealed in a bag. The soil was air-dried, and the EC of the aqueous soil extract (soil/water 1/5 w/w) was measured.

3 Results and analysis

3.1 Root distribution in different site conditions

The root distribution is dependent on the environmental conditions[14–18]. In this section, the effects of soil texture and aspect on plant root distribution are discussed.

3.1.1 Root distribution in different soil textures. The roots of the seven-year-old shelterbelt in different soil textures were analyzed. The roots reached 180 cm in

Table 1 The Tarim highway shelterbelt at Tazhong area

Field planting time	Location	Landform	Soil	Plant
1995	the forest at Zhong san point	intredune flat land	sandy soil	*Holocylon persicum, Tamarix ramosissima, Calligonum leucocladum*
1997	1.2 km greening	intredune flat land	sandy soil, clay, hardening sand	
1998	forest land built by Lanzhou Institute of Deserts	rare dune in intredune	sandy soil	
1999	2 km greening on T-shaped Road Junctions	intredune flat land	sandy soil	
2001	31.8 km greening local at south of forest land on T-shaped Road Junctions	intredune flat land, rare dune in intredune, high complex portrait dune, longitudinal dune and transition region in intredune	sandy soil	
2003	greening longitudinal dune around the base of TaZhong oil field	high complex portrait dune, longitudinal dune and transition region in intredune	sandy soil	
2004	one-stage base Herba Cistanche	intredune flat land	sandy soil	

The plant spacing and row spacing were all 1.0 m in shelterbelts built in 1995 and 1998. In 2001 and 2004 the shelterbelts were built with mixed row spacing. The wide-row spacing was 2.0 m and the narrow-row spacing was 1.0 m. The plant spacing was still 1.0 m.

sand ridge land, 160 cm in flat sandy ground, 120 cm in clay, and only 60 cm in harden sand. In the harden sand, the soil bulk density was 1.5 g/cm^3 at 0—40 cm and 1.73 g/m^3 at deeper layers. The downward root development was hindered, and the roots were mainly in the 0—40 cm soil layers. In all layers the roots were flat, and the root hairs were flaky. In flat sandy ground, sand ridge and clay, the soil bulk density was 1.4—1.5 g/cm^3 at 0—100 cm soil, and the roots stretched normally. The root distribution in clay is shallower than sand ridge and flat sandy ground, because the flat sandy ground and sand ridge are favorably porous for the root to grow deep. In contrast, the clay has strong water retention and poor permeability. The water infiltration rate is small, and the moisture is mainly in the shallow soil. The plant roots grow towards water and fertilizer, and consequently end up mainly in the shallow layer of the clay.

In the soil column of the same volume, the root weight was 1660.97 g in flat sandy ground, 1376.32 g in sand ridge, 1075.55 g in clay, and 436.62 g in harden sand. The hair root (diameter <1 mm) weight was to 276.26 g in clay, 238.31 g in flat sandy ground, 195.4 g in sand ridge, and 136.47 g in harden sand.

The root distribution curve of flat sandy ground, sand ridge and clay exhibited a bell shape, and the root distribution curve of harden sand exhibited a sharp decline (Figure 1). The hair root distribution curve of flat sandy ground, clay and harden sand all exhibited a decline, and the hair root distribution curve of sand ridge exhibited a bell shape (Figure 2).

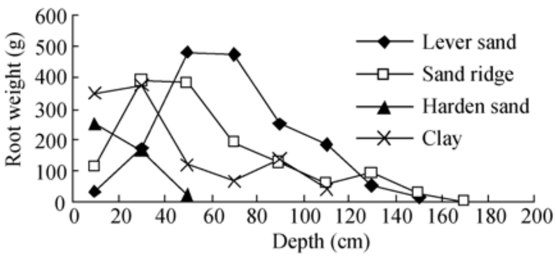

Figure 1 Root distribution in different soil textures.

The soil texture affects the root distribution. In sand ridge and flat sandy ground, the soil texture is loose and

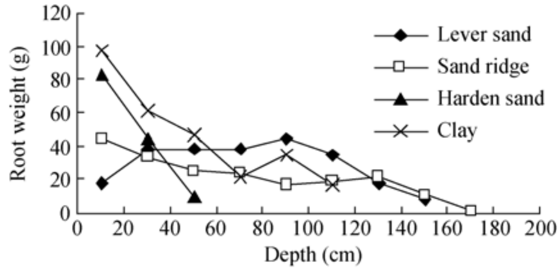

Figure 2 Hair root distribution in different soil textures.

uniform, and the dust sand content is small, therefore the root distribution is deep and wide. In harden sand, the dust sand content is 13.51%, and the soil texture is compact (soil bulk density 1.73 g/cm^3). The root extension is restricted, and the root distribution becomes shallow and narrow.

3.1.2 Root distribution in different aspects. The roots of the two-year-old shelterbelt in different aspects were analyzed. Compared with the shady slope, the sunny slope had much high total root weight, deeper root distribution, but less hair root. The total root weight of the sunny slope was 401.38 g, 1.21 times the total root weight of the shady slope (330.8 g). However, the hair root weight of the shady slope was 53.8 g, 1.44 times the hair root weight of the sunny slope (37.28 g). At the 0–50 cm soil layer, the root weight of the sunny slope (273.22 g) was much higher than that of the shady slope (161.69 g). At >50 cm soil layer, the root weight of the sunny slope and the shady slope were largely the same. The root depth of the sunny slope was 130 cm, deeper than the shady slope (120 cm).

The root distribution curve and the hair root distribution curve of both slopes exhibited a bell shape (Figures 3 and 4), and the roots were mainly in the 30—40 cm soil layer. In the shady slope, the hair roots were mainly in the 20—90 cm soil layer, and the hair root weight of the 30–40 cm soil layer was the highest. In the sunny slope, the hair root distribution was basically even, and the hair root weight in <20 cm soil was 2—4 g. The shady slope had more hair root than the sunny slope in every layer of the 0—100 cm soil.

The soil water content and the EC are dependent on

Table 2 Soil size (%)

Soil texture	Median *d* (0.5)	Clay < 5 μm	Silt 5—63 μm	Very fine sand 63—125 μm	Fine sand 125—250 μm	Middle sand 250—500 μm	Coarse sand >500 μm
Flat sandy ground	109.5027	0	7.94	54.44	32.25	0.99	4.38
Sand ridge	127.4946	0	5.13	42.93	46.62	5.28	0.04
Harden sand	105.29	0	13.51	49.08	23.97	5.47	7.97

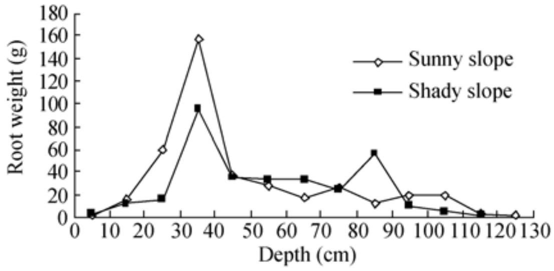

Figure 3 Root weight in different aspects.

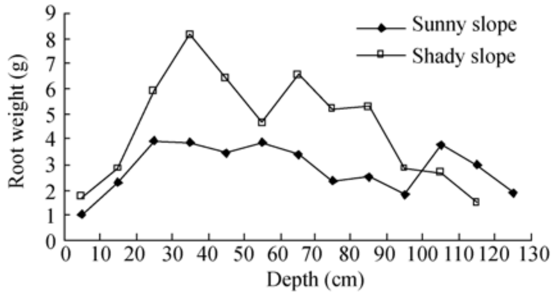

Figure 4 Hair root weight in different aspects.

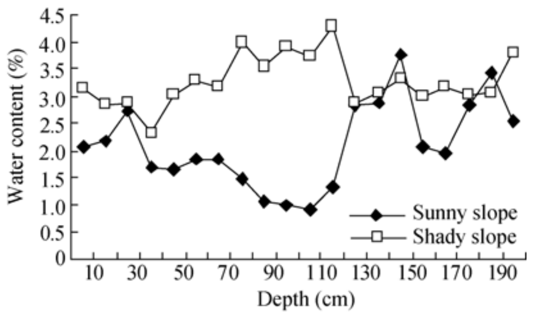

Figure 5 Soil moisture in different aspects.

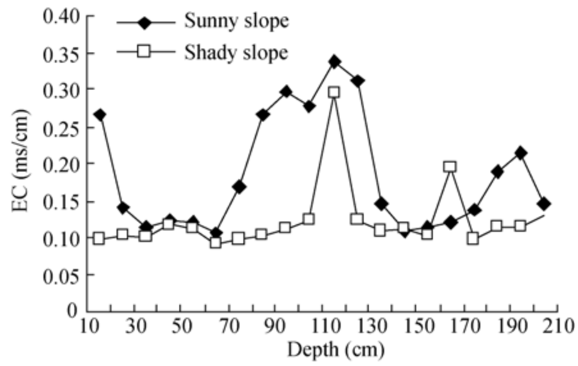

Figure 6 EC in different aspects.

the aspect. The average soil moisture content of the shady slope was 3.27%, higher than the sunny slope (2.10%) (Figure 5). The EC of the sunny slope was 0.18 ms/cm, higher than the shady slope (0.12 ms/cm) (Figure 6). The soil water content and the EC are affected by the sunshine and the wind. The sunny slope is a windward slope, thus having more active soil moisture evaporation and higher EC.

Compared with the shady slope, the sunny slope had deeper root distribution but less hair root. The sunny slope receives stronger solar radiation and has more soil moisture evaporation, therefore the soil water content is lower and the salinity leaching is weak. The salt accumulates in the soil and the EC becomes high. The low soil water content drives the root to grow downward for space, water and nutrient. But the growth of hair roots is inhibited by low moisture content and high EC.

3.2 Root distribution in different forest ages

The root biomass increases remarkably with the plant ages. The root biomass increases rapidly in the early stage of forest implantation, and the rate of increase gradually drops with the forest ages. The most substantial increase in root biomass was observed during the first three years after forest implantation. The root biomass of the four-year-old shelterbelt is 18.35 times that of the one-year-old shelterbelt; the root biomass of the seven-year-old shelterbelt is 1.89 times that of the four-year-old shelterbelt; and the root biomass of the ten-year-old shelterbelt is 1.22 times that of the seven-year-old shelterbelt.

The root distribution curve of forests at 1, 4 and 7 years old exhibited a bell shape, and the root distribution curve of ten-year-old forest showed two peaks (Figure 7). The hair root biomass increased remarkably in the 10—20 cm soil layer, but decreased in >20 cm soil layers (Figure 8).

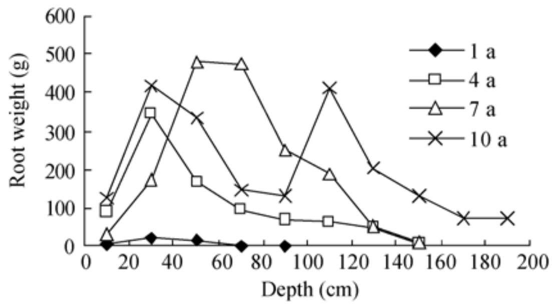

Figure 7 Root weight and forest age.

The core layer of the root distribution gradually deepened as the forest aged. Two core root layers were present in the ten-year-old shelterbelt: 36% of the root was in the 20—60 cm soil, and about 30% of the root was in the 100—140 cm soil. The 0—60 cm soil had 35% of the hair roots, and the rest of the hair root distributed evenly in the 60—140 cm soil (Figure 8). The root of *Calligonum leucocladum* is horizontal and has shal-

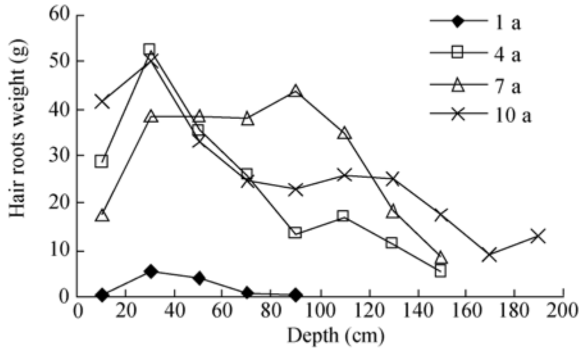

Figure 8 Hair root weight and forest age.

low distribution, whereas the root of *Tamarix ramosissima* is vertical and has deep distribution. In the ten-year-old shelterbelt, the roots in the 20—60 cm soil are mainly from Calligonum leucocladum, and the roots in the 100—140 cm soil are mainly from Tamarix ramosissima.

4 Conclusions

(1) The plant root distribution is dependent on soil type, soil texture, moisture permeability and soil bulk density. The root distribution is the deepest in sand ridge and shallowest in hardening sand. In unit soil volume, the root weight of the flat sandy ground is the highest, and the root weight of the harden sand is the lowest.

(2) The root distribution is dependent on the aspect. The sunny slope has higher root weight, deeper root distribution, but less hair root content than the shady slope.

(3) The root biomass increases rapidly as the forest ages, and the most substantial increase was observed in the early years after forest implantation.

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