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Correlations between Roots of *Caragana Korshinskii* and Soil Moisture after Stumping

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Abstract

Targeting at the artificial forests of *Caragana korshinskii* Kom. at the agro-pasture zigzag zone of Inner Mongolia, China, we applied four stump treatments before thawing in the spring of early March, 2016, including stumping at 0, 10 or 20 cm, and no stumping. In August the same year, the roots and soil moistures were hierarchically sampled using a quarter circle method. Then the spatial distributions of root morphology indices and soil water content at different root diameter levels of *C. korshinskii* were studied. It was found (1) the roots at three diameter levels after different treatments tended to be distributed at shallow layers, and mainly at the 0-40 cm layer, but rarely at the 180-200 cm layer. The root morphological indices shared basically consistent space distributive laws as the soil water contents, as both decreased with the increase of soil depth or horizontal distance from the trunk. (2) After different stumping treatments, the root distributions were positively correlated with the soil water contents, and the correlation coefficients of total root length, root volume, and specific root length with soil water contents were 0.725, 0.740 and 0.570, respectively. This study may theoretically underlie the planting management and vegetation recovery of artificial *C. korshinskii* forests in arid areas.

Keywords: Agro-pasture zigzag zone, *Caragana korshinskii,* total root length, root volume, specific root length, soil water content

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INTRODUCTION

Stumping is an important technical measure in forest fostering and management. During the growing period, trees gradually enlarge the nutritive areas and thereby intensify the competition for soil moisture, leading to deteriorations such as slowed growth, deadwood, or even death in some of the plants (Jiang et al. 2014). Soil moisture is the key influence factor on and major water source for plant survival, growth and development (Li and Guo 2011). However, the woodland and grasslands after certain period of growth are prone to soil drought (Yang 1996) and formation of dried soil layers (Qiu et al. 2001), which may further lead to soil and vegetation deterioration and finally to plant community decline and ecosystem degradation (Gao et al. 2017). Roots are the major organ of moisture absorption, the only organ under direct contact with soils, and the major channel of water transportation for plants. The morphologic and distributive characteristics of roots directly affect the supply of soil moisture to plants, and directly reflect the land use by vegetation, and the possibility and productivity of using material energy from soils, and thus have decisive effects on vegetation growth (Li et al. 2009, Niu et al. 2008, Tiarts et al. 2008). In this study, to prevent the formation of dried soil layers in artificial *Caragana korshinskii* forests, stimulate the growth of initiation branches, accelerate the growth and development of trunks, and alleviate the competition for soil moisture, we stumped *C. korshinskii* forests and regulated the plant-water relationship.

Caragana korshinskii Kom, belonging to Caragana Fabr, is a strong xerophytic shrub and mostly distributed in the desert areas of Northwest, North and west Northeast China. This shrub grows vigorously with well-developed roots and is outstanding with wide adaptability due to the resistance against drought, heat, cold, leanness, salt, wind and sand. Years of practice of forestation prove that *C. korshinskii* is one of the excellent tree species for soil & water conservation, wind prevention and sand fixation, and plays key roles in vegetation construction and ecosystem restoration in deserts (Zhou 2008). Recently, many researchers have

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Table 1. Growing conditions of *C. korshinskii* forests in the study area

Stumping	Growing conditions before stumping			Growing conditions after stumping		
	Average tree height (m)	Average tree height (m)		Average tree height (m)	Average tree height (m)	
		East-West	North-South		East-West	North-South
CK	2.35±0.117	2.83±0.216	2.06±0.152	2.47±0.219	2.87±0.238	2.23±0.187
0cm	2.31±0.174	2.79±0.239	2.13±0.165	2.73±0.187	3.18±0.252	2.59±0.132
10cm	2.37±0.187	2.81±0.197	2.24±0.178	2.84±0.216	3.32±0.254	2.71±0.162
20cm	2.29±0.169	2.87±0.219	2.26±0.218	2.64±0.217	2.97±0.179	2.54±0.225

studied the effects of stumping on *C. korshinskii* from different perspectives. Zheng et al. studied the effects of stumping treatments on the roots of *C. korshinskii* and thought stumping could largely facilitate the root growth and development (2010). Zhang et al. found stumping effectively addressed the decline and ageing of *C. korshinskii* and accelerated the renewal and rejuvenation of forests (2010). Chen et al. found stumping significantly restored the soil moistures of *Hippophae rhamnoides* forests (2000). Zhang et al. studied the *Calligonum mongolicum* protection forests in Tarim desert roads and found repeatedly stumping the aged and deteriorated forests could enhance soil moistures, reduce soil salts in root layers and effectively accelerate root rejuvenation and regeneration (2012). However, the existing research about stumping treatment on *C. korshinskii* is focused on the effects of stumping machine, stumping rejuvenation technology, and stumping measures on environmental and ecological benefits of *C. korshinskii* forests, which are all macroscopic aspects (Fang et al. 2006, Li et al. 2008). There are few studies about the effects or mechanism of different stumping treatments on soil moistures and the underground part, especially the root distributions at deep layers below 2 m.

In this study, we investigated how different stumping treatments would affect the root distributive characteristics and soil moistures of *C. korshinskii* forests, aiming to explore the ecological mechanism of rapid regeneration after stumping. This study will scientifically underlie the management of artificial *C. korshinskii* shrubs and provides theoretical guidance for vegetation recovery, soil moisture use improvement, and prevention & control of soil-water loss in arid areas. The findings are of significance for efficient prevention & control of soil desertification and drying.

STUDY AREA AND METHODS

Study Area

Huanghuadianzi catchment (N 42°17’ - 42°33’, E 119°36’ - 119°53’, ~ 30 km^2), the study area, is located at the west of Aohan Banner, Chifeng City, Inner Mongolia Autonomous Region and possesses the largest plantation of man-made forests in China. The terrains there are generally low hills and have gentle fluctuation with elevations of 400- 806 m. The catchment belongs to the medium-temperature semiarid continental monsoon climate with four distinctive seasons, strong solar radiation and sufficient sunlight. It has an annual precipitation of 400-470 mm and an annual evaporation of 2290-2400 mm. The annual sunshine duration is 2940-3060 h and the accumulated temperature >10 ºC is 3189 ºC. Wind is strong and persistent in spring and the annual wind speed is 4-6 m/s. The majority of soils are chestnut soils accompanied with minor sand soils. This catchment is dominated by artificial vegetation for water-soil conservation, wind prevention and sand fixation. The main afforestation species include *C. korshinskii*, *Pinus Tableulaeformis*, *Prunus sibirica*, and *Populus simonii*.

Methods

Investigation and sampling

From the study area, we selected 10-year-old *C. korshinskii* artificial forests under basically consistent site conditions and protection measures and at between-trunk distance of 2m×5m. The test sites were set at northwest slopes with slopes of ~ 4°. In March 2016 before the spring thawing, we stumped the *C. korshinskii* artificial forests at distance of 0 cm (cutting along ground surface), 10 or 20 cm from the ground, with the forest lands without stumping as a control. The sampling sites were all 150 m×50m in sizes and each treatment was conducted in triplicate. In August the same year, the trees in each sampling site were tallied, and 3 standard clusters were randomly selected from each sampling site for collection and measurement of root and soils. Totally, 36 clusters were collected. The growing conditions of the test woodlands were summarized in **Table 1**.

Investigations showed the majority (above 97% of total root weight) of roots of *C. korshinskii* were mainly distributed at 0-200 cm deep (Cao and Zhu 2007, Zhu et al. 2011). Thus, we set the root collection area as a circle 200 cm away from the trunk and at vertical depth of 0-200 cm. The roots were collected with a quarter circle method with the basal part of each standard cluster as the center. Specifically, any sector area with a central angle of 90° was selected as a representative of a whole root collection area. By considering the environment of a plot, the growth conditions of clusters, the accuracy and integrity of data, we selected the side of the sector area perpendicular to the strike of the forest. During investigations and sampling, the soil sections were divided by every 20 cm into 10 layers at both vertical and horizontal directions: 0-20, 20-40, 40-60, 60-80, 80-100, 100-120, 120-140, 140-160, 160-180, 180-200 cm. Then roots from each layer were all collected, weighed, recorded, numbered, and packed in kraft bags before being taken to the laboratory. The roots from each layer passed a 0.1 mm screen under washing until the soils on the roots were cleaned. The roots at each diameter level were measured with a vernier caliper. The roots were classified into three levels: diameter < 2 mm (fine roots), 2-10 mm (thick roots), and > 10-15 mm (bone roots) (Zhang et al. 2000). The root volume at each layer was measured by a dewatering method. Then the roots at each diameter level were scanned by an EPSON10000XL root scanner, and the root volumes, and total root lengths were analyzed on a WinRHIZO root analysis system. For measurement of specific root length, the roots at each level were oven-dried at 85 ºC until reaching constant weight, then weighed on an electronic balance, and calculated as the ratio of root length to dried weight. The morphological indices of roots (e.g. total length, volume and specific length) were all analyzed by using data in the unit volume of 1 m^3.

Measurement of soil water content (SWC)

SWC measurement and root sampling were conducted the same time. The measuring depth was also 200 cm, and soil layers were separated at every 20 cm, with a total of 10 layers. SWCs were measured by a QS-SFY soil moisture tachymeter, and each layer was measured 3 times. To validate the accuracy of this instrument, we also used the conventional drying method as a comparison. SWC based on the drying method was computed as follows:

$$SWC = \frac{(original\ soil\ weight - dried\ soil\ weight)}{dried\ soil\ weight} \times 100\%$$

Data Analysis

Data analyses were conducted on Microsoft Excel 2007 and SPSS.

RESULTS AND ANALYSIS

Effects of Stumping Treatments on Spatial Distributions of Root Morphological Indices of *C. Korshinskii*

The effects of stumping treatments on vertical spatial distributions of total root length of *C. korshinskii* are illustrated in **Fig. 1**. With the deepening of soil layers, the total root lengths at different diameter levels were generally shortened. Specifically, at the 0-60cm layer, the total root lengths were reduced with the soil deepening, and decreased at faster rate in the 40-60cm layer, gradually rose in the 60-80cm layer, and then gradually decreased again. Compared with the 0-20cm layer, the total lengths of fine roots, thick roots and bone roots declined by 15.70%, 22.65%, 9.85% (20-40 cm layer), 37.75%, 53.85%, 23.57% (40-60 cm layer), 23.43%, 43.73%, 11.41% (60-80 cm layer), and 39.97%, 70.61%, 49.76% (80-100 cm layer) (**Fig. 1c**).

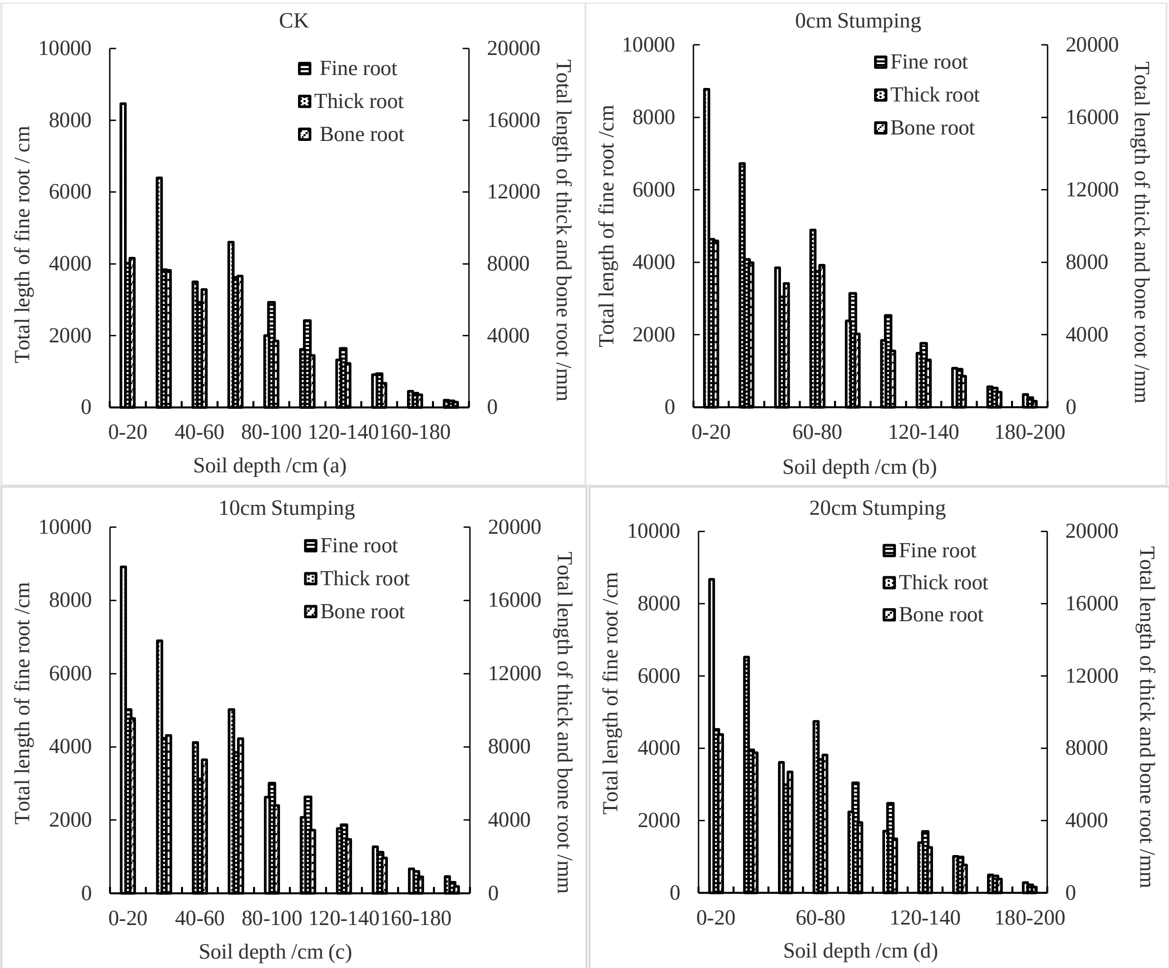

Fig. 1. Effects of stumping treatments on vertical spatial distributions of total root length of *C. korshinskii*

The three stumping treatments versus the control all well contributed to root growth from the perspective of total root lengths. In the control group, the total lengths of fine roots, thick roots and bone roots at the 0-40cm layer accounted for 23.83%, 9.02% and 4.84% of total root lengths at the corresponding diameter level in the whole layers, respectively (e.g.: total length of fine roots at the 0-40cm layer accounted for 23.83% of total length of fine roots at all layers). At the 180-200cm layer, the three proportions minimized to 0.57% (fine roots), 0.12% (thick roots) and 0.081% (bone roots). After the 0 cm stumping, at the 0-40cm layer, the total lengths of fine roots, thick roots and bone roots accounted for 24.47%, 8.70% and 4.82% of total root lengths of the corresponding diameter level in the whole layers, respectively. At the 180- 200cm layer, the three proportions were 0.74%, 0.20% and 0.093%, respectively. After the 10cm at the 0-40cm layer, the total lengths of fine roots, thick roots and bone roots accounted for 24.76%, 8.47% and 4.86% of total root lengths of the corresponding diameter level in the whole layers, respectively. At the 180- 200cm layer, the three proportions were 0.80%, 0.25% and 0.10%, respectively. After the 20 cm stumping, at the 0-40cm layer, the total lengths of fine roots, thick roots and bone roots accounted for 24.59%, 8.82% and 4.80% of total root lengths of the corresponding diameter level in the whole layers, respectively. At the 180- 200cm layer, the three proportions were 0.64%, 0.16% and 0.089%, respectively.

At the 0-40cm layer, the 10 cm stumping group showed larger total lengths at all diameter levels than other three groups. Specifically, the total lengths of fine roots, thick roots and bone roots after the 10 cm stumping were 1.18, 1.06 and 1.14 times larger than the control, respectively, 1.06, 1.02, 1.06 times larger the 0 cm stumping group, respectively; 1.09, 1.04, 1.10 times larger the 20 cm stumping group, respectively. Similar rules were found at the 180-200cm layer. Specifically, the total lengths at different diameter levels in the 10 cm stumping group were 1.61, 1.13 and 1.36 times larger than the control, respectively, 2.29, 1.31, 1.62 times larger than the 0 cm stumping group, respectively, and

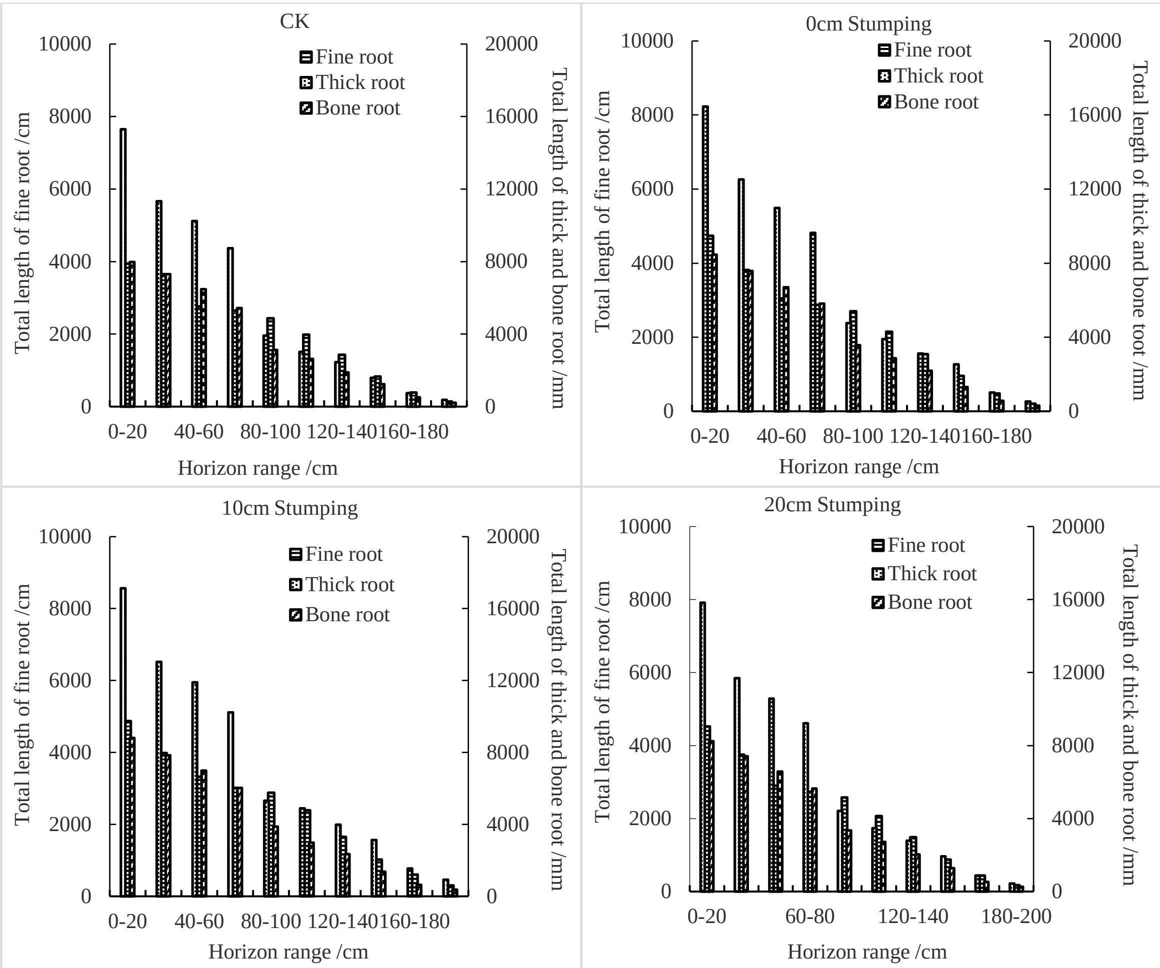

Fig. 2. Effects of stumping treatments on spatial distributions of total root length of *C. korshinskii*

1.27, 1.12, 1.21 times larger than the 20 cm stumping group, respectively. Comparative analysis showed the total root lengths at the vertical direction ranked among different treatments as follows: 10cm stumping >0cm stumping >20cm stumping > control.

The total root lengths at different diameter levels after different treatments all gradually decreased with the increase of horizontal distance (**Fig. 2**). In the control group, at the distance of 0-40cm from the base plants, the total lengths of fine roots, thick roots, and bone roots accounted for 25.59%, 8.97% and 5.15% of total root lengths of the corresponding diameter level in the whole layers, respectively. At the 180-200cm layer, the three proportions minimized to 0.48% (fine roots), 0.13% (thick roots) and 0.071% (bone roots). After the 0 cm stumping, at the 0-40cm layer, the total lengths of fine roots, thick roots and bone roots accounted for 25.93%, 8.78% and 4.86% of total root lengths at the corresponding diameter level in the whole layers, respectively. At the 180-200cm, the proportions were 0.62%, 0.16% and 0.092%, respectively. After the 10cm stumping, the three proportions were 25.04%, 8.52%, 4.70%, respectively, at the 0-40cm layer, and 0.84%, 0.26% and 0.10%, respectively, at the 180-200cm layer. Analyses showed after the 20 cm stumping, the proportions of fine roots, thick roots and bone roots accounting for total root lengths of the corresponding diameter level among the whole layers were 26.29%, 8.75% and 4.97% at the 0-40cm layer, and 0.56%, 0.14% and 0.083% at the 180-200cm layer.

At the 0-40cm layer, the 10 cm stumping group showed larger total lengths at all diameter levels than other three groups. Specifically, the total lengths of fine roots, thick roots and bone roots in the 10 cm stumping group were 1.17, 1.13 and 1.09 times larger the control, respectively, 1.04, 1.03, 1.05 times larger than the 0 cm stumping group, respectively, and 1.07, 1.10, 1.06 times larger the 20 cm stumping group, respectively. Similar rules were found at the 180-200cm layer. Specifically, the total lengths at different diameter levels in the 10 cm stumping group versus the control, 0 cm stumping group, and 20 cm stumping group, were 2.09, 1.47 and

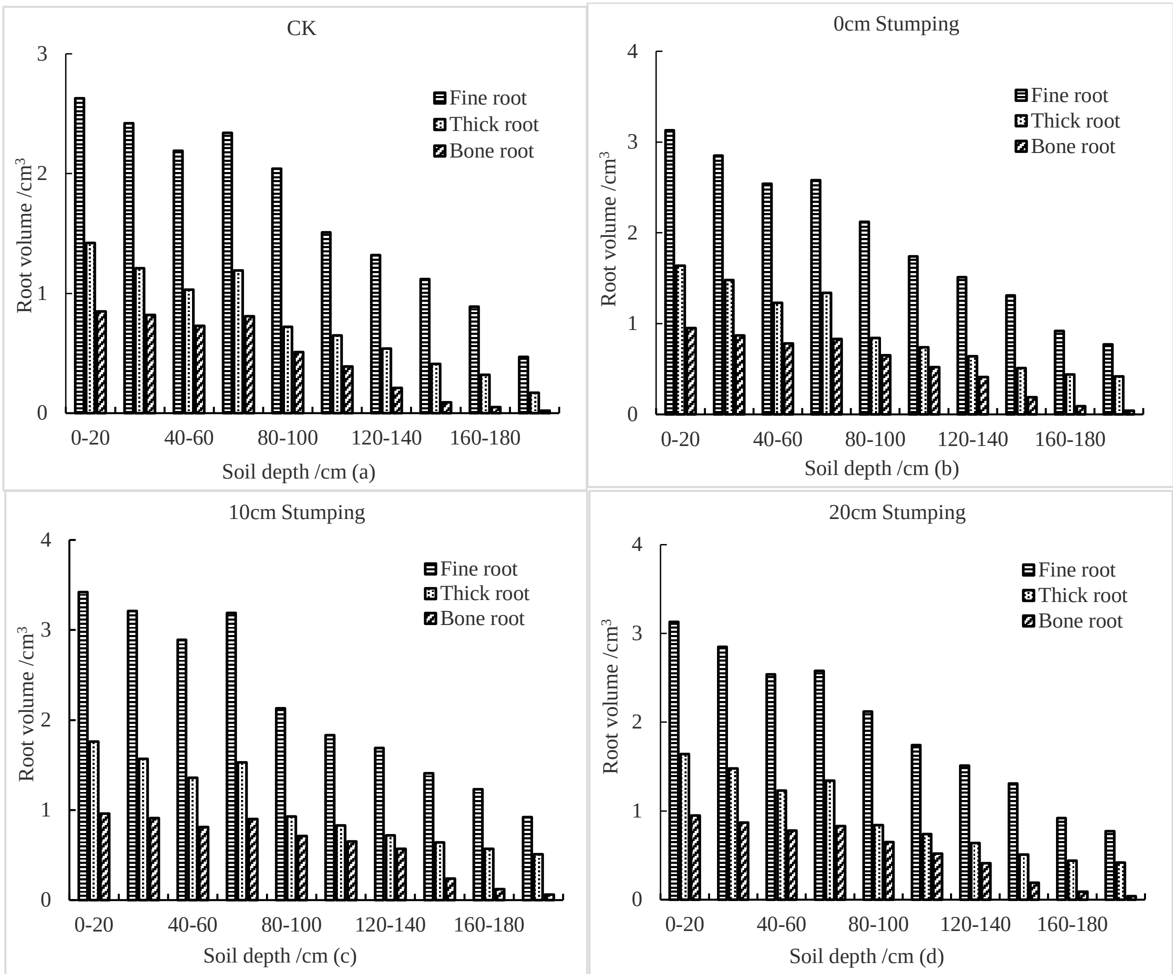

Fig. 3. Effects of stumping treatments on vertical spatial distributions of total root volumes of *C. korshinskii*

1.70 times larger (fine roots), 2.48, 1.76, 2.13 times larger (thick roots) and 1.71, 1.20, 1.39 times larger (bone roots). Comparative analysis showed the total root lengths at the horizontal direction ranked among different treatments as follows: 10cm stumping >0cm stumping >20cm stumping > control.

With the deepening of soil layers at the vertical direction, the total root lengths at different diameter levels were generally shortened (**Fig. 3**). Specifically, at the 0-60cm layer, the total root lengths were reduced with the soil deepening, and decreased at faster rate in the 40-60cm layer, rose in the 60-80cm layer, and then gradually decreased again. Compared with the 0-20cm layer, the volumes of fine roots, thick roots and bone roots declined by 6.14%, 10.80%, 5.21% (20-40 cm layer), 15.50%, 22.73%, 15.63% (40-60 cm layer), 6.73%, 13.07%, 6.25% (60-80 cm layer), and 37.72%, 47.16%, 26.04% (80-100 cm layer) (**Fig. 3c**).

The root volumes of different diameter levels were distributed differently in the control group. The volumes of fine roots, thick roots and bone roots were distributed among different layers following similar rules and focused in the 0-40cm layer, accounting for 17.37%, 9.05% and 5.74%, respectively of all layers at the corresponding diameter level. In the 180-200cm layer, the proportions decreased to 1.62%, 0.58% and 0.069%, respectively. After the 0 cm stumping treatment, the total root volume was 34.08 cm^3, which was occupied by fine roots (57.13%), thick roots (27.23%) and bone roots (15.64%). After the 10 cm stumping, the total root volume was 38.27 cm3, which was occupied by fine roots (57.28%), thick roots (27.23%) and bone roots (15.49%), which were significantly different. After the 20 cm stumping, the total volumes of fine roots, thick roots, and bone roots accounted for 57.39%, 27.17% and 15.44% of the total volume (31.61 cm^3), respectively.

At the 0-40cm layer, the 10 cm stumping group showed larger total volumes than other three groups at all diameter levels. Specifically, the total volumes of fine roots, thick roots and bone roots were 1.31, 1.27 and 1.12 times larger (control), 1.11, 1.07, 1.03 times larger

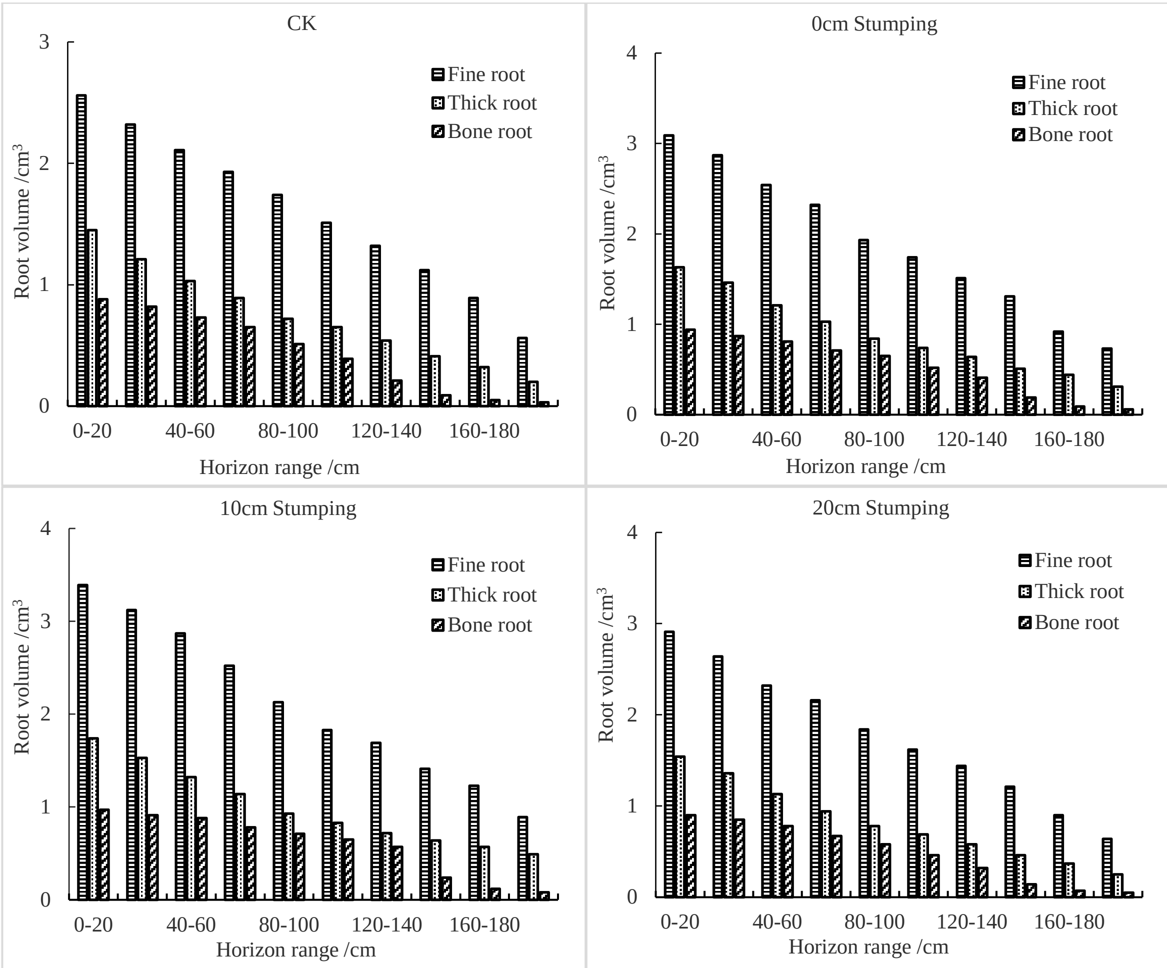

Fig. 4. Effects of stumping treatments on spatial distributions of root volumes of *C. korshinskii*

(0 cm stumping) and 1.17, 1.13, 1.07 times larger (20 cm stumping). Similar rules were found at the 180-200cm layer. Specifically, the total volumes at different diameter levels in the 10 cm stumping group were 1.96, 1.19 and 1.33 times larger (control), 3.00, 1.21, 1.59 times larger (0 cm stumping) and 3.01, 1.50, 2.00 times larger (20 cm stumping). Comparative analysis showed the total root volumes at the vertical direction ranked among different treatments as follows: 10cm stumping >0cm stumping >20cm stumping > control.

The effects of stumping treatments on spatial distributions of total root volumes of *C. korshinskii* are illustrated in **Fig. 4**. The total root volumes at different diameter levels after different treatments all gradually decreased with the increase of horizontal distance. The root volumes at different diameter levels were distributed differently in the control group. The volumes of fine roots, thick roots and bone roots were distributed among different layers following similar rules and focused in the 0-40cm layer, accounting for 17.53%, 9.55% and 6.11%, respectively, of total root volumes; at the 180-200cm layer, the proportions decreased to 2.01%, 0.72% and 0.11%, respectively. After the 0 cm stumping treatment, the total root volume was 33.02 cm^3, which was occupied by fine roots (57.42%), thick roots (26.68%) and bone roots (15.89%). After the 10 cm stumping treatment, the total root volume was 36.91 cm3, which was occupied by fine roots (57.13%), thick roots (26.86%) and bone roots (16.02%). After the 20 cm stumping treatment, the total root volume was 30.60 cm^3, which was occupied by fine roots (57.77%), thick roots (26.47%) and bone roots (15.75%).

At the 0-40cm layer, the 10 cm stumping group showed larger root volumes at all diameter levels than other three groups. Specifically, the volumes of fine roots, thick roots and bone roots in the 10 cm stumping group were 1.13, 1.18 and 1.13 times larger than the control, 1.04, 1.06, 1.07 times larger the 0 cm stumping group and 1.10, 1.12, 1.11 times larger the 20 cm stumping group. Similar rules were found at the 180-200cm layer. Specifically, the total volumes at different diameter levels in the 10 cm stumping group were 1.59, 1.31 and 1.51 times larger than the control, 1.70, 1.21,

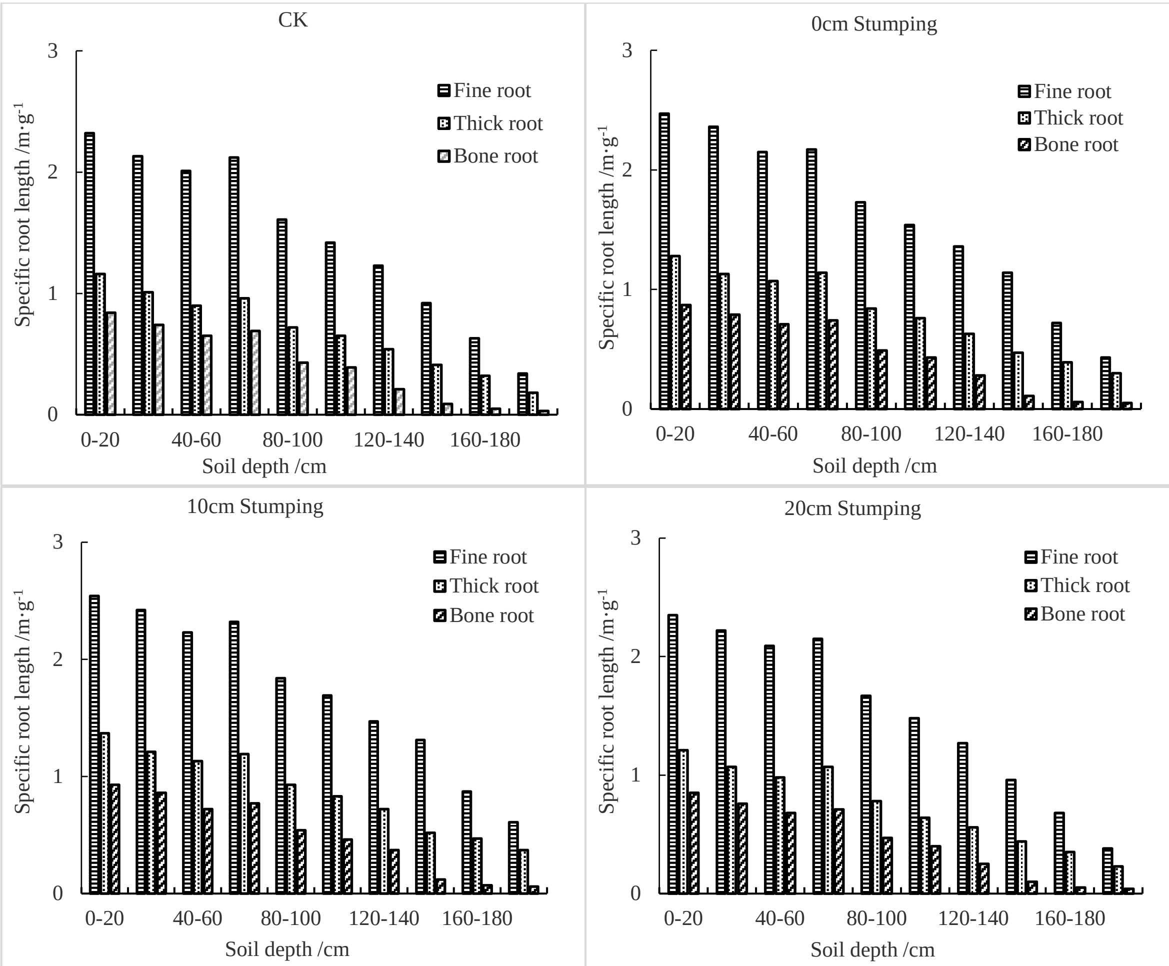

Fig. 5. Effects of stumping treatments on vertical distributions of specific root lengths of *C. korshinskii*

1.31 times larger the 0 cm stumping treatment and 1.67, 1.25, 1.65 times larger than the 20 cm stumping treatment. Comparative analysis showed the total root volumes at the horizontal direction ranked among different treatments as follows: 10cm stumping >0cm stumping >20cm stumping > control.

The spatial distributions of specific root lengths at different diameter levels were similar as total root length and root volume. With the deepening at the vertical direction, the specific root lengths at different diameter levels were generally shortened (**Fig. 5**). Specifically, at the 0-60cm layer, the specific root lengths were reduced with the soil deepening, and decreased faster in the 40-60cm layer, gradually rose in the 60-80cm layer, and then gradually decreased again. The specific root lengths at different diameter levels after different treatments all gradually decreased with the increase of horizontal distance (**Fig. 6**). Comprehensive analysis showed the specific root lengths at the vertical and horizontal directions ranked among different treatments as follows: 10cm stumping >0cm stumping >20cm stumping > control.

Effects of Stumping Treatments on Spatial Distributions of Soil Water Contents of *C. Korshinskii*

The effects of stumping treatments on vertical and horizontal spatial distributions of total SWCs of *C. korshinskii* are illustrated in **Fig. 7**. The total SWCs at different soil levels after different treatments all gradually decreased with the increase of horizontal or vertical distance. Specifically, at the vertical direction, the average SWCs changed by 2.56%-4.99% (control), 2.62%-5.32% (0 cm stumping), 2.71%-5.65% (10 cm stumping) and 2.58%-5.21% (20 cm stumping). Analyses showed at the same layer, the SWCs after 10 cm stumping were higher than other treatments, but were very low in the control; the maximum SWC was 2.43%, 2.7%, 2.94% and 2.63% larger than the minimum SWC in the control, 0 cm stumping, 10 cm stumping and 20 cm stumping, respectively. The SWC maximized in the 0-40cm layer, followed by the 60-

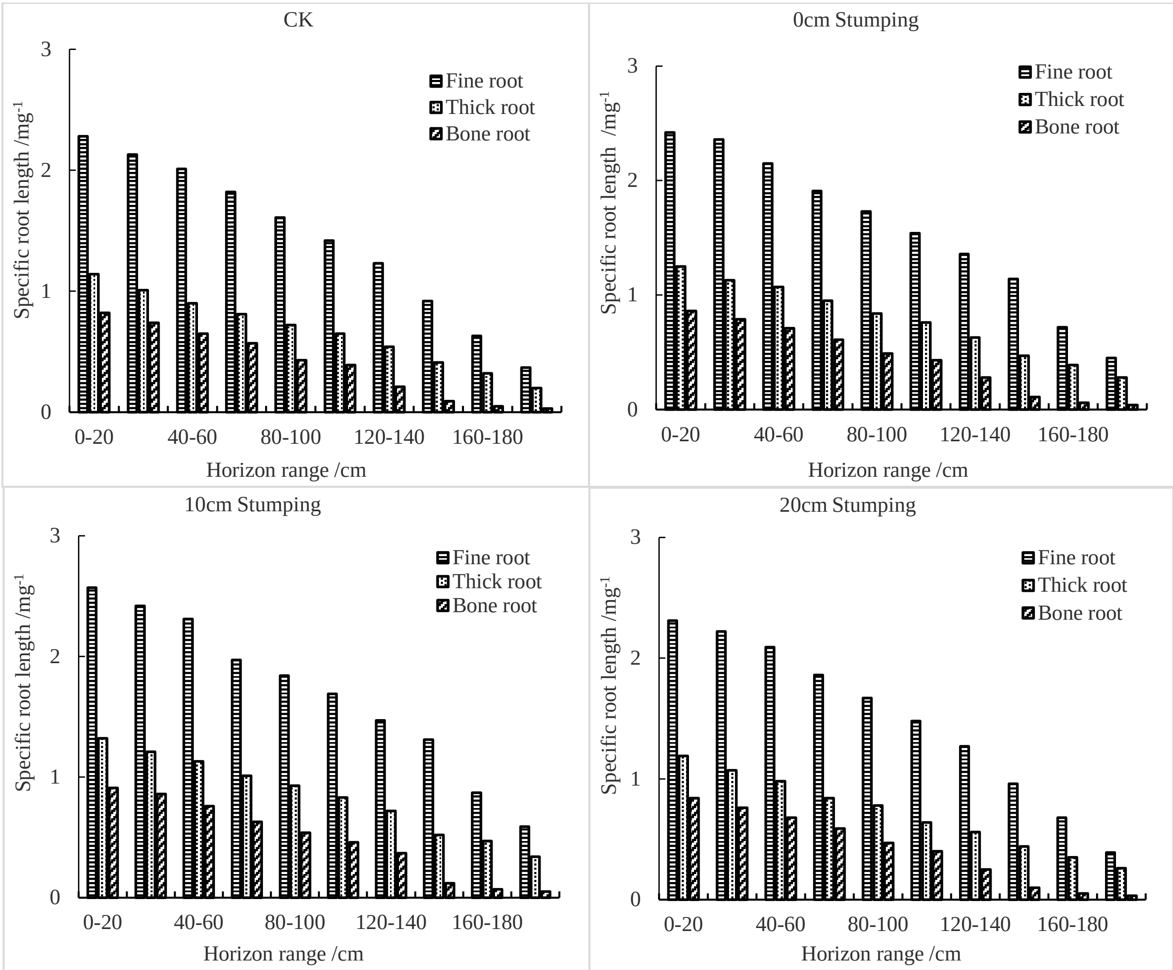

Fig. 6. Effects of stumping treatments on spatial distributions of specific root lengths of *C. korshinskii*

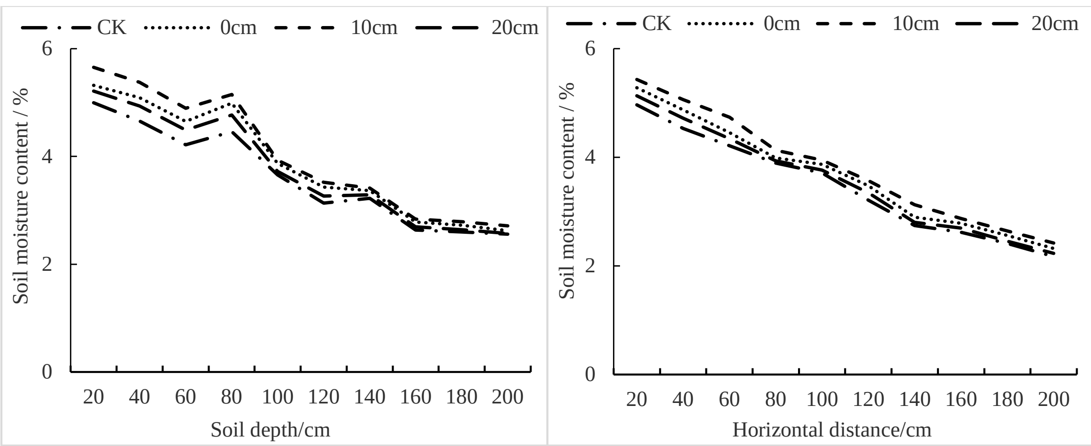

Fig. 7. Effects of stumping treatments on spatial distributions of SWCs of *C. korshinskii* at the vertical and horizontal directions

80cm layer, but was significantly lower in the 40-60cm layer compared with adjacent layers, which was due to the slight calcic horizon in the 40-60cm layer.

At the horizontal direction, the average SWCs at different layers changed within 2.17%-4.96% (control), 2.32%-5.28% (0 cm stumping), 2.43%-5.44% (10 cm stumping), and 2.23%-5.13% (20 cm stumping). At the 0-40cm layer, the average SWCs after different stumping treatments were 4.75% (control), 5.08% (0 cm stumping), 5.25% (10 cm stumping), and 4.93% (20 cm stumping). At the 160- 200cm layer, the average SWCs

Table 2. Correlation analysis between SWC and root morphology indices

	SWC	Total root length	Root volume	Specific root length
SWC	1	0.725**	0.740**	0.570**
Total root length	0.725**	1	0.842**	0.798**
Root volume	0.740**	0.842**	1	0.827**
Specific root length	0.570**	0.798**	0.827**	1

Note: all at P<0.01

after different stumping treatments were 2.29% (control), 2.44% (0 cm stumping), 2.53% (10 cm stumping), and 2.37% (20 cm stumping).

The SWCs at different layers were the largest after the 10cm stumping and the smallest in the control.

Correlation Analysis between SWC and Root Morphology Indices

The correlation analysis between average SWC and root morphological indices after different stumping treatments are showed in **Table 2**. The SWCs are significantly and positively correlated with root growth, as the correlation coefficients r of SWC with total root length, root volume and specific root length are 0.725, 0.740 and 0.570, respectively.

DISCUSSION

Stumping is an effective measure for shrub renewal and rejuvenation (Yan et al. 2006). The growing conditions of *C. korshinskii* shrubs are weakened with ageing. When no stumping was adopted, old shrubs grew slowly or even halted growth (Guo 2016). Stumping could adjust the structural characteristics of *C. korshinskii* forests and improve biomass. In this study, four stumping treatments were used. It was found stumping treatments promoted growing renewal and regeneration compared with the control. The spatial distributions of plant roots are regulated by multiple factors, such as characteristics of plants, planting density, years of planting, site conditions, precipitation, and soil properties (Liu et al. 2017). The root distribution is mainly embodied as differences in vertical distribution, or namely the non-uniformity of spatial distribution (Yu and Yu 2001). The root growth & development dynamics and morphological characteristics of plants result from the joint effects of biological characteristics and environmental factors. Moisture variation usually leads to differences in root growth and distribution, which would be accordingly changed dependent on the supply of soil moisture (Zhang and Liang 2002). The depth of roots decides the supply status of water and nutrients to vegetation (Cheng 2005).

In this study, *C. korshinskii* within the space range of 200 ×200 cm^2 was stumped by different methods, and then the root morphological indices at different diameter levels and the vertical and horizontal distributions of soil moisture were characterized. It was found at the vertical direction, the morphological indices and SWCs at different diameter levels all increased with the soil deepening after different treatments, and all maximized at the vertical distance of 0-40cm, followed by the 60-80cm layer, but all minimized at the 40-60cm layer. The reason was due to the slight calcic horizon in the 40-60cm layer, where the calcic horizon soils were structurally tight and less permeable, which complicated the downward water flow and downward root growth. Thus, the SWC and root morphological indices at the 40-60cm layer were significantly smaller than at the adjacent layers. This rule is consistent with the study on the root and soil moisture distributions of *Salix cheilophila* in Mu Us Sandland (Yang et al. 2011). Niu Cunyang et al. found the roots of some sand-fixing plants (e.g. *Salix gordejevii* Chang et Skv., *Dendrocalamus membranaceus*, *Caragana microphylla*) in Horqin tended to distribute in shallow layers and the SWCs decreased (Niu et al. 2015), which are consistent with our findings. In this study area, soil moisture is mainly supplemented by precipitation. Though roots of *C. korshinskii* are largely distributed at shallow layers, the soil moisture is still maintained at high levels. This phenomenon suggests when the precipitation supplements soil moisture during the growing season, the soil moistures still can maintain the normal growth of vegetation. Since the deep soil moisture decreased suddenly, the supplemented moisture was basically reserved in shallow soils and could hardly supplement the deep soils. Thus, the majority of precipitation in shallow soils is utilized by plants or evaporates at ground surfaces, which is also an effective cause for the distributive characteristics of shallow roots.

At the horizontal direction, with the increment of horizontal distance, the soil moisture and root morphological indices of *C. korshinskii* decreased. As reported, the root length, root volume and soil moisture of *Nitraria tangutorum* Bor. in loess hills of China gradually decreased with the increment of horizontal distance (Wang et al. 2013), which is consistent with our findings. Yang Shengli et al. studied the horizontal root distribution of cherries and found with the enlarging distance from the trunks, the root dried weight, volume, surface area and root length all gradually decreased (Yang et al. 2009). The reasons were that since the roots could absorbed and rejected water, the water contents decreased with the increment of horizontal distance.

CONCLUSIONS

The roots at different diameter levels after different stumping treatments tended to be distributed at shallow layers, and mainly at the 0-40cm layer, but rarely at the 180-200cm layer. The root morphological indices share basically consistent with space distributive laws as the root morphological indices decreased with the increase of soil depth and horizontal distance. The root morphological indices of *C. korshinskii* at different diameter levels at the vertical and horizontal directions ranked among different treatments as follows: 10cm stumping > 0cm stumping > 20cm stumping > control.

The spatial distributions of soil moisture were similar to those of root morphological indices after different stumping treatments. The root distributions were positively correlated with the soil moisture distribution at the same space. The correlation coefficients of soil moisture contents with total root length, root volume, and specific root length were 0.725, 0.740 and 0.570, respectively.

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