Chapter

Water Source of Six Woody Plants in Different Habitats on Desertified Land of Ordos Plateau, Semi-Arid China

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Abstract

Water and soil erosion and sandy desertification are two mainly land desertification types on eastern and southern Ordos Plateau, north China. *Hippophae rhamnoides*, *Armeniaca sibirica* and *Pinus tabuliformis* are three woody plants for soil and water conservation on loess slope. *Sabina vulgaris*, *Artemisia ordosica* and *Salix psammophila* are three shrubs for sand control on sand dune. Water source of six woody plants were investigated by stable isotope technology. The results showed that the $\delta^{18}O$ of shallow soil water was similar to that of rainwater in July and September in two habitats. Both of six woody plants in two habitats mainly used shallow soil water in May. However, three shrubs on sand dune mainly used both of shallow and deep soil water in July and September. Three woody plants on loess slope mainly used rainwater or deep soil water in July and September. Therefore, six woody plants utilized different depths of soil water or rain water based on their availability in different seasons, which is an adaptive strategy to the semiarid climate on Ordos Plateau.

Keywords: land desertification control, rain water, soil water, stable oxygen isotope, water source

1. Introduction

In semi-arid region, water is the key factor for the survival and succession of plant community [1]. The use of limited water resource concerns not only plant survival, but also interspecific interaction and community dynamics. Since there is generally no stable isotope fractionation during water uptake by root system and water transportation before arriving leaf, water source of a plant could be identified by comparing stable isotope of xylem water and potential water sources [2]. The potential water sources for plant species are shallow soil water recharged by rainwater, deep soil water recharged by rainwater, snow water or groundwater in semi-arid region [3–10]. Different life form plants usually used different water source, which related to their root types. Generally, tree and shrub with deep root system could use deep soil water or groundwater [6]. Woody species with dimorphic root system may use different depths of soil water or groundwater simultaneously [9]. And shallow rooted shrub and perennial grass only used shallow or middle soil water [11]. Water source of plant species in semi-arid region was affected by many environmental factors, like season [6, 7], annual variance of climate [8] and habitat heterogeneity [12].

Ordos Plateau is located in the middle reaches of Yellow River, which is the ecotone between Loess Plateau and Mongolian Plateau, with the total area of 1.30×10^5 km^2. The eastern part is hilly gully area with loess hill and valley, the southern part is Mu Us Sandy Land with fixed and semi-fixed sand dune, and the northern part is Hobq Desert with moving sand dune [13]. The elevation increases from 774 m in southeast to 2148 m in northwest [14]. From southeast to northwest, the annual precipitation decreased from 400 mm to 200 mm; meanwhile, the natural vegetation varies from forest grassland, grassland, and sandy land to desert [13]. In the last decades, land desertification was severely on Ordos Plateau. From 1994 to 2000, land desertification area increased for 1.90×10^4 km^2, focused on west Hobq Desert and south Mu Us Sandy Land [15]. In these years, many measures was taken to increase vegetation coverage, decrease sand storm hazard and improve ecological environment, such as air seeding, fence and afforestation.

In eastern Ordos Plateau, the hilly gully area is one of the most severely soil and water erosion region in the middle reaches of Yellow River, which is sand stone covered by loess and contributed up to 25% of the total course sediment for the lower reaches [16]. Both of engineering measure and vegetation restoration was carried out to control soil and water erosion, such as plant trees and shrubs, including *Hippophae rhamnoides*, *Pinus tabuliformis* and *Armeniaca sibirica*.

Mu Us Sandy Land is one of the four sandy land in China, which located in central Inner Mongolia, Northern Shaanxi and Northeast Ningxia. The total area is 4.22×10^4 km^2, with the elevation varies from 1000 to 1600 m [17]. The main natural vegetation are forest steppe, steppe, and shrub sandy land and desert steppe. Vegetation growth was improved in Mu Us Sandy Land, which were resulted by climate change and human activity [18]. The dominant species of sand control are *Sabina vulgaris*, *Artemisia ordosica*, *Salix psammophila* and *Caragana intermedia* in shrub sandy land [19].

Previous studies in Mu Us Sandy Land showed that *S. vulgaris* mainly used soil water within 1.5 m and groundwater, whereas *A. ordosica* mainly used shallow soil water within 50 cm [5]. Moreover, *A. ordosica* mainly used deep soil water recharged by 65 mm rainstorm in summer, *Cynanchum komarovii* mainly used middle rain of 10–20 mm, whereas *Stipa bungeana* mainly used shallow soil water recharged by small rain [3]. However, we still do not know the seasonal dynamic of water source for these dominant shrubs in Mu Us Sandy Land. Moreover, there is few report about water source of woody species in hilly gully area of Ordos Plateau. Therefore, seasonal dynamic of water source of six woody plants was explored by stable isotope technology in two different habitats of Ordos Plateau. The purpose of this study was to understand how these trees and shrubs adapt to the semi-arid climate by adjusting water source in the growing season. The results would give theoretical supports for ecological forestry engineering, including Natural Forest Protection, Grain for Green and Three Norths Shelterbelt Program.

2. Water source of three woody species on loess slope

2.1 Three soil and water conservation woody species on loess slope

This study was conducted in Soil and Water Conservation Park of Jungar Banner, Ordos City, Inner Mongolia. The banner has a temperate continental climate, which mean air temperature varies from 6.2°C to 8.7°C, mean annual precipitation is 400 mm, potential evapotranspiration is 2093 mm and forest free days are 145 d [20]. The natural vegetation is steppe dominated by *Stipa bungeana*, whereas few *P. tabuliformis*, *Juniperus rigida* and *Platycladus orientalis* are distributed on hill slope.

Hippophae rhamnoides (sea buckthorn) is a small tree or shrub with the height of 1–5 m. It often inhabits in hill ridge, valley, dry river bed or slope with rock, sandy loam or loam, which distributes in Hebei, Inner Mongolia, Shanxi, Shaanxi, Gansu, Qinghai and West Sichuan. This shrub was widely used on Loess Plateau as a soil and water conservation species [21]. It grows fast, resistant to drought and could fix nitrogen.

Pinus tabuliformis (Chinese pine) is an evergreen tree with the height of 25 m and the diameter at breast height of 1 m. It is the dominant species in coniferous forest with elevation varies from 100 to 2600 m, which distributes in south Jilin, Liaoning, Hebei, Henan, Shandong, Shanxi, Inner Mongolia, Shaanxi, Ningxia, Qinghai and Sichuan. It is used as a sand binding and soil and water conservation trees in north China [22].

Armeniaca sibirica (wild apricot) is a small tree or shrub with the height of 2–5 m. It mainly inhabits on dry slope, hill steppe or mixed with deciduous forest, which distributes in Heilongjiang, Jilin, Liaoning, Inner Mongolia, Gansu, Hebei and Shanxi, and also in East and Southeast Mongolia, Far East and Siberia of Russia [23]. It is cold-resistant and was used as a soil and water conservation species in Northeast and North China.

In the study site, three woody species was planted in 2013 with density of 1000 plants per hectare. The mean height of *H. rhamnoides*, *P. tabuliformis* and *A. sibirica* were 2.10, 2.14 and 2.71 m, respectively. The main water source of three woody species was measured by comparing their xylem water with different water sources, e.g. rainwater and soil water in 10, 25, 50, 75 and 100 cm. Lignified, two years old twigs of shrubs were collected and the bark was removed with scissor, then the xylem was sampled. Soil and xylem were placed in 8 mL glass vial, sealed with Parafilm, and stored in a medical cool box. Water in soil and xylem was vacuum-extracted and their $\delta^{18}O$ value was measured with a Flash 2000HT elemental analyzer and a Finnigan MAT 253 mass spectrometer. Meteorological data was obtained from Meteorology Bureau of Dongsheng District, Ordos City, which is 50 km west to the study site. The contribution of different water sources to their total water use was analyzed by Iso-source 1.3.1 software [24]. The input data of the model were $\delta^{18}O$ value of xylem water and potential water source, e.g. soil water in different depths or rain water. The results of water use ratio to different sources were expressed as mean ± SD.

2.2 Precipitation of study site in the growing season of 2018

The total precipitation of Dongsheng District was 385.00 mm in the growing season of 2018 (**Figure 1**), which was slightly lower than annual mean precipitation of 400 mm. The maximal daily precipitation was 52.0 mm and occurred on May 19, the next value was 48.8 mm on July 19. The monthly precipitation were 32.0, 77.9, 15.5, 118.3, 85.0 and 54.3 mm from April to September.

2.3 Stable oxygen isotope of xylem water of three woody species, soil water and rainwater on loess slope

On May 12, stable oxygen isotope ratio of *H. rhamnoides* and *P. tabuliformis* xylem water were closer to soil water in 10 cm, whereas stable oxygen isotope ratio of *A. sibirica* xylem water was closer to soil water in 10–25 cm. On July 15, stable oxygen isotope ratio of 10–25 cm soil water was closer to rainwater. Stable oxygen isotope

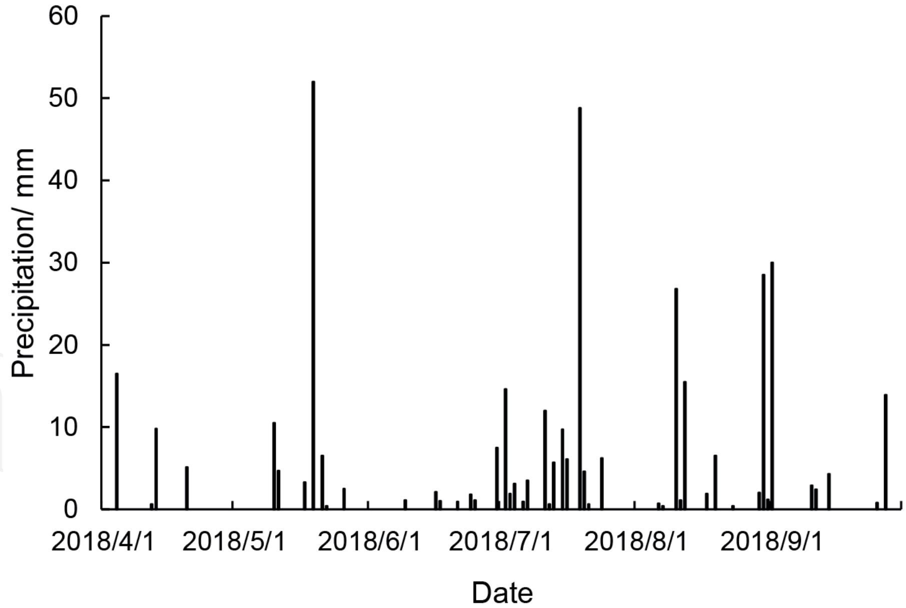

Figure 1.
Daily precipitation of study site from April to September of 2018.

ratio of *H. rhamnoides*, *P. tabuliformis* and *A. sibirica* xylem water were closer to soil water in 10–100 cm, 25–50 cm and 25–100 cm, respectively; moreover, stable oxygen isotope ratio of *P. tabuliformis* and *A. sibirica* xylem water were also closer to rainwater. On September 23, stable oxygen isotope ratio of *H. rhamnoides* xylem water was closer to soil water in 25–100 cm, whereas stable oxygen isotope ratio of xylem water of other two woody species were closer to soil water in 10–100 cm (**Figure 2**).

2.4 Contribution of different depth of soil water and rainwater to the water source of three woody species on loess slope

Iso-source analysis showed that *H. rhmnoides* mainly used 10 cm soil water on May 12, which accounted for 88.5% of its total water source. On July 15, it mainly used 10–25 cm soil water and rainwater, which accounted for 44.6% and 35.4% of its total water source. On September 23, it mainly used 25 cm and 75–100 cm soil water, which accounted for 88.9% of its total water source (**Table 1**).

Iso-source analysis showed that *P. tabuliformis* mainly used 10 cm soil water on May 12, which accounted for 94.0% of its total water source. On July 15, it mainly used rainwater, which accounted for 93.7% of its total water source. On September 23, it mainly used 10 cm and 50–75 cm soil water, which accounted for 84.5% of its total water source (**Table 2**).

Iso-source analysis showed that *A. sibirica* mainly used 10 cm soil water on May 12, which accounted for 91.6% of its total water source. On July 15, it mainly used 25–100 cm soil water and rainwater, which accounted for 55.9% and 36.8% of its total water source. On September 23, it evenly used 10–100 cm soil water (**Table 3**).

Three woody species on loess slope selected different water source in the growing season, which is an adaptive strategy to semi-arid environment. They mainly used shallow soil water recharged by spring rain. However, there are interspecific difference of water source in summer. For *H. rhmnoides*, it mainly used shallow soil water and rainwater. For *P. tabuliformis*, it mainly used rainwater. However, for *A. sibirica*, it mainly used middle and deep soil water and rainwater. In autumn, *H. rhmnoides* mainly used shallow and deep soil water, *P. tabuliformis* mainly used shallow and middle soil water. However, *A. sibirica* evenly used different depths soil water. The interspecific difference in water source of three woody species is related

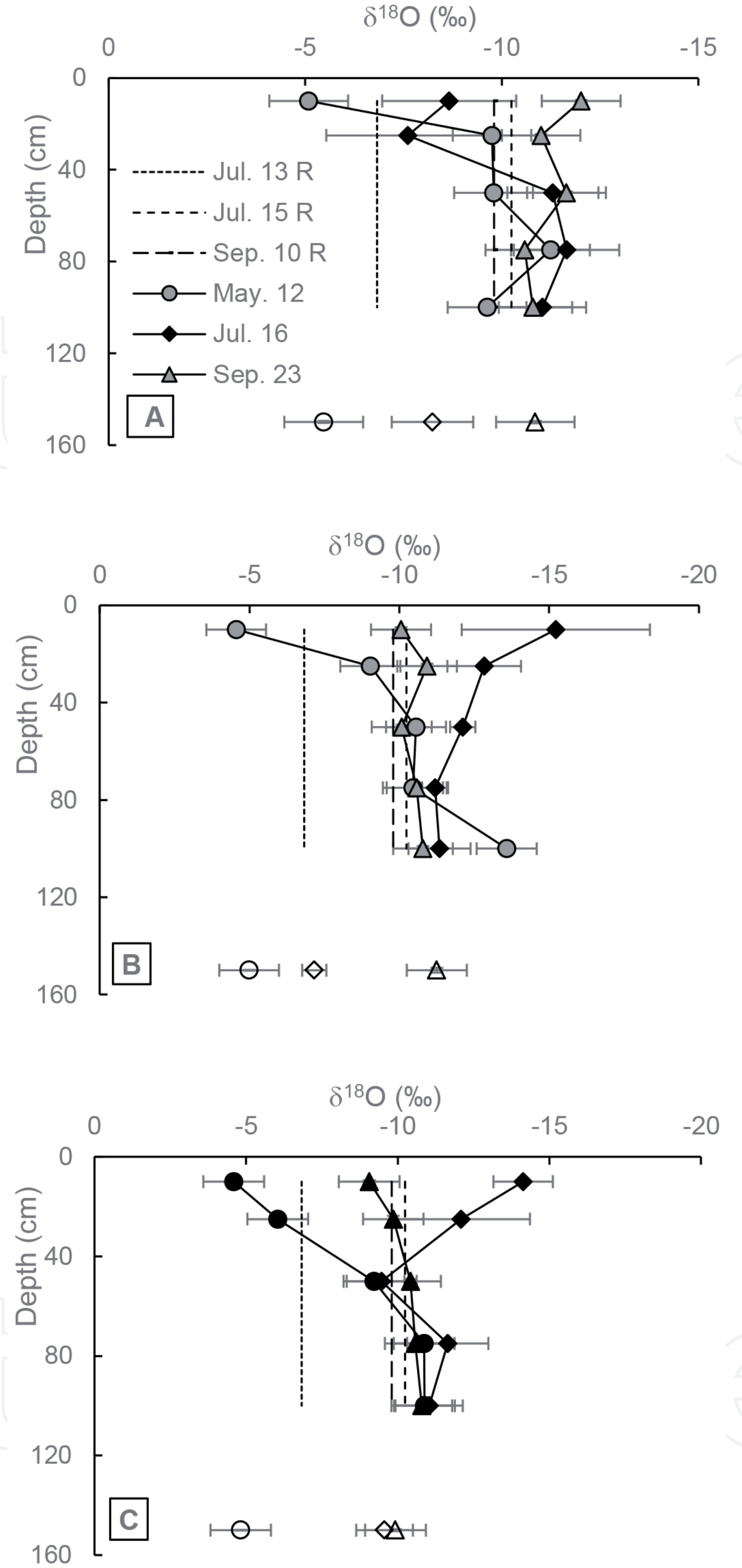

Figure 2.
Stable oxygen isotope ratio of xylem water, soil water and rainwater of Hippophae rhamnoides (A), Pinus tabuliformis (B) and Armeniaca sibirica (C) in hilly gully area. Dark symbol is soil water, white symbol is xylem water of three woody species.

to their life form and root distribution. Other shrubs on Loess Plateau also changed their water source. For example, *Caragana korshinskii* and *Salix psammophila* used 40–80 cm soil water in the drought season. However, they mainly used 0–40 cm soil water in the rain season [25]. *Armeniaca sibirica* in the mixed plantation used more shallow soil water than that in the pure plantation. However, *Robinia pseudo-acacia* always used shallow and middle soil water in different plantation types [26].

Water source	May 12	Jul. 15	Sep. 23
10 cm soil water	88.5 ± 0.7	16.4 ± 13.7	4.6 ± 3.8
25 cm soil water	3.1 ± 2.8	28.2 ± 20.5	17.0 ± 13.3
50 cm soil water	3.0 ± 2.8	6.7 ± 5.6	6.4 ± 5.2
75 cm soil water	1.9 ± 2.2	6.2 ± 5.2	41.4 ± 18.3
100 cm soil water	3.4 ± 2.6	7.1 ± 0.6	30.5 ± 22.8
Rainwater	—	35.4 ± 17.1	—

Table 1.
Contribution of different depths of soil water and rainwater to the water source of Hippophae rhamnoides in hilly gully area (%, mean ± SD).

Water source	May 12	Jul. 15	Sep. 23
10 cm soil water	94.0 ± 0.9	0.6 ± 0.8	36.8 ± 21.0
25 cm soil water	1.8 ± 2.3	1.2 ± 1.2	7.1 ± 5.3
50 cm soil water	1.6 ± 1.7	1.3 ± 1.2	36.1 ± 21.7
75 cm soil water	1.6 ± 1.7	1.5 ± 1.6	11.6 ± 8.7
100 cm soil water	0.9 ± 1.1	1.6 ± 1.7	8.4 ± 6.3
Rainwater	—	93.7 ± 0.7	—

Table 2.
Contribution of different depths of soil water and rainwater to the water source of Pinus tabuliformis in hilly gully area (%, mean ± SD).

Water source	May 12	Jul. 15	Sep. 23
10 cm soil water	91.6 ± 3.3	7.4 ± 6.4	30.4 ± 10.4
25 cm soil water	5.7 ± 4.4	10.3 ± 8.8	27.1 ± 21.1
50 cm soil water	1.2 ± 1.2	21.1 ± 17.6	15.9 ± 12.6
75 cm soil water	0.7 ± 0.9	11.4 ± 9.7	14.2 ± 11.3
100 cm soil water	0.7 ± 0.9	13.1 ± 11.1	12.4 ± 9.9
Rainwater	—	36.8 ± 9.5	—

Table 3.
Contribution of different depths of soil water and rainwater to the water source of Armeniaca sibirica in hilly gully area (%, mean ± SD).

Moreover, the 18-yr *Robinia pseudoacacia* were sensitive to precipitation variation and used more deep soil water in a drier year, whereas the 30-yr *R. pseudoacacia* always used middle and deep soil water in wetter or drier year in the central region of Loess Plateau [27]. Therefore, woody species which could use deep soil water as a reliable water source during drought will have advantage in semi-arid region.

3. Water source of three shrubs in sandy land

3.1 Three sand binding shrubs in Mu Us Sandy Land

This study was conducted in Ordos Sandy Land Ecological Station, Institute of Botany, Chinese Academy of Forestry, which located in Ejin Holo Banner, Ordos

City, Inner Mongolia. The banner has a temperate continental climate, which mean air temperature varies from 5.0°C to 8.5°C, mean annual precipitation is 350 mm, potential evapotranspiration is 2300 mm and forest free days are 136 d [28]. The natural vegetation is sandy land dominated by *Sabina vulgaris*, *Artemisia ordosica*, *Salix psammophila* and *Caragana intermedia*, and steppe dominated by *Stipa bungeana* and *Iris lactea* var. *chinensis*.

Sabina vulgaris is an evergreen shrub with height of 0.3–1.0 m. It is a drought resistant species and widely used as sand binding and soil and water conservation shrub. It mainly inhabits on rocky slope, mixed coniferous and broad-leaf forest or sand dune, which distributes in Tianshan Mountain, Altai Mountain, Helanshan Mountain, Inner Mongolia, Northeast Qinghai, Gansu and North Shaanxi [22].

Artemisia ordosica is a small shrub with mean height of 0.5–1.0 m. It is resistant to sand burial and was widely used as a good sand-binding plant with air seeding. It mainly inhabits in moving, semi-fixed and fixed sand dunes in desert and slope in steppe, which distributes in Inner Mongolia, North Hebei and North Shanxi [29].

Salix psammophila (sand willow) is a shrub with mean height of 3–4 m. It is resistant to wind and sand burial, which was widely used as a sand-binding and afforestation species. It mainly distributes in Shaanxi, Inner Mongolia, Ningxia and Shanxi [30].

In the study site, the mean height of *S. vulgaris*, *A. ordosica* and *S. psammophila* were 0.78, 0.92 and 3.33 m, respectively. The semi-shrub *Hedysarum fruticosum* var. *laeve* was the associated species in *A. ordosica* and *S. psammophila* community. The main water source of four shrubs was measured by comparing their xylem water with different water sources, e.g. soil water in 10, 25, 50, 75, 100 and 150 cm for *A. ordosica*, whereas soil water in 10, 25, 50, 100, 150 and 200 cm for other two shrubs. The sample and extraction of soil water and xylem water was shown in 2.1. Groundwater was not sampled because shallow groundwater was depleted after coal mining in 2012. Deep groundwater table was 70 m at the study site, which is unavailable for vegetation. Meteorological data was obtained from Ordos Ecological Station. The contribution of different water sources to their total water use was analyzed by Iso-source 1.3.1 software [24].

3.2 Precipitation in Ordos Ecological Station in the growing season of 2018

The total precipitation of Ordos Ecological Station was 367.00 mm in the growing season of 2018 (**Figure 3**), which was slightly higher than the annual mean precipitation of 350 mm. The maximal daily precipitation was 34.4 mm and occurred on August 30, the next value was 32.2 mm on July 19, and 31.8 mm on July 16. The monthly precipitation were 25.6, 47.6, 11.4, 144.2, 92.2 and 46.0 mm from April to September.

3.3 Stable oxygen isotope of xylem water of four shrubs, soil water and rainwater in sandy land

On May 13, stable oxygen isotope ratio of *S. vulgaris* xylem water were closer to soil water in 10–25 cm, stable oxygen isotope ratio of *A. ordosica* and *H. fruticosum* var. *laeve* xylem water were closer to soil water in 10–150 cm, whereas stable oxygen isotope ratio of *S. psammophila* and *H. fruticosum* var. *laeve* xylem water was closer to soil water in 10 cm and 50–200 cm. On July 13, stable oxygen isotope ratio of 10 cm soil water was closer to rainwater on July 11. Stable oxygen isotope ratio of *S. vulgaris* was closer to soil water in 25 cm and 100–200 cm, stable oxygen isotope ratio of *A. ordosica* and *H. fruticosum* var. *laeve* xylem water were closer to soil water in 10 cm and 150 cm, whereas stable oxygen isotope ratio of *S. psammophila*

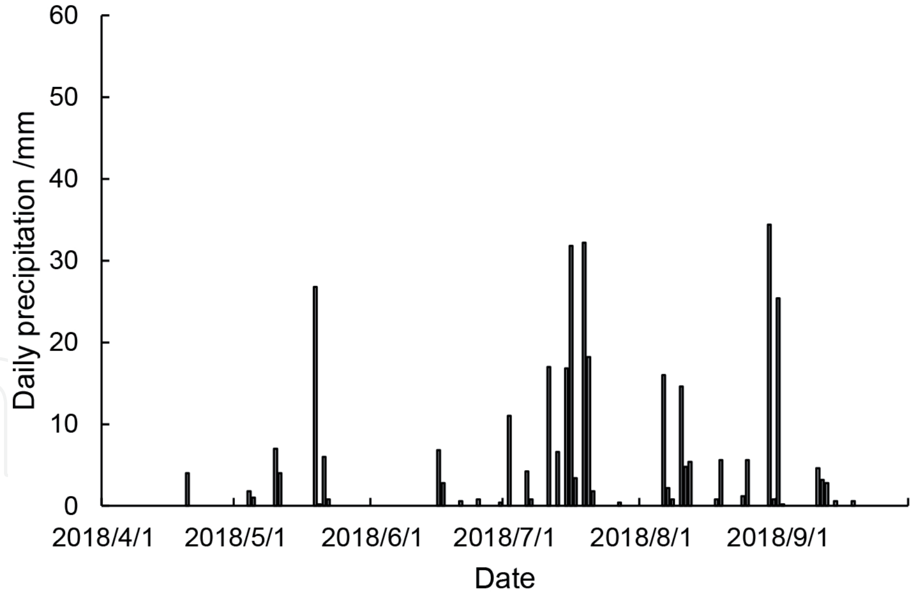

Figure 3.
Daily precipitation at Ordos Ecological Station from April to September of 2018.

and *H. fruticosum* var. *laeve* xylem water was closer to soil water in 10–25 cm and 100–200 cm. On September 22, stable oxygen isotope ratio of 10 cm soil water was closer to rainwater on September 11. Stable oxygen isotope ratio of *S. vulgaris* xylem water was closer to soil water in 25–200 cm, stable oxygen isotope ratio of *A. ordosica* and *H. fruticosum* var. *laeve* xylem water were closer to soil water in 10–150 cm, whereas stable oxygen isotope ratio of *S. psammophila* and *H. fruticosum* var. *laeve* xylem water were closer to soil water in 25–200 cm (**Figure 4**).

3.4 Contribution of different depth of soil water to the water source of four shrubs in sandy land

Iso-source analysis showed that *S. vulgaris* mainly used 25 cm soil water on May 13, which accounted for 78.5% of its total water source. On July 17, it mainly used 10–25 cm and 100–200 cm soil water and rainwater, which accounted for 50.8% and 40.7% of its total water source. On September 22, it mainly used 10–25 cm and 100–200 cm soil water, which accounted for 51.2% and 39.8% of its total water source (**Table 4**).

Iso-source analysis showed that *A. ordosica* and *H. fruticosum* var. *laeve* mainly used 10 cm soil water on May 13, which accounted for 72.9% and 66.5% of their total water source, respectively. On July 17, they mainly used 10 cm and 150 cm soil water, which accounted for 65.8% and 54.9% of their total water source, respectively. On September 22, they mainly used 10–25 cm soil water, which accounted for 46.1% and 49.0% of their total water source, respectively (**Table 5**).

Iso-source analysis showed that *S. psammophila* and *H. fruticosum* var. *laeve* mainly used 10–25 cm soil water on May 13, which accounted for 59.0% and 37.9% of their total water source. On July 17, they mainly used 50–200 cm soil water and 10–25 cm and 100–200 cm soil water, which accounted for 71.0% and 91.8% of their total water source, respectively. On September 22, they mainly used 10–100 cm soil water, which accounted for 73.8% and 72.5% of their total water source, respectively (**Table 6**).

Four shrubs in sandy land have a resource-dependent water use strategy, e.g. used different depths of soil water based on their availability in the growing season. *Sabina vulgaris* mainly used 25 cm shallow soil water in spring; however, it mainly

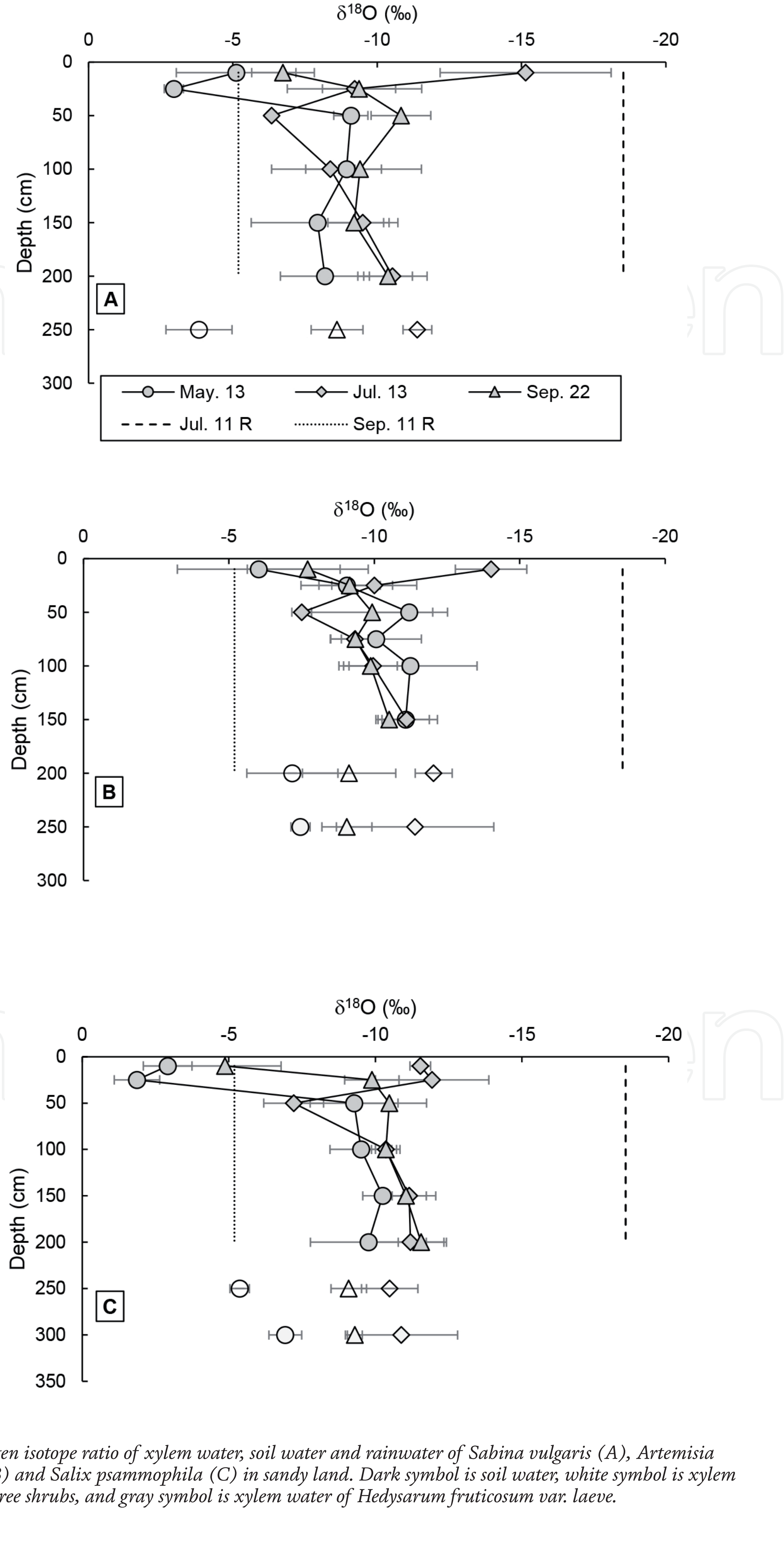

Figure 4.
Stable oxygen isotope ratio of xylem water, soil water and rainwater of Sabina vulgaris (A), Artemisia ordosica (B) and Salix psammophila (C) in sandy land. Dark symbol is soil water, white symbol is xylem water of three shrubs, and gray symbol is xylem water of Hedysarum fruticosum var. laeve.

Water source	May 13	Jul. 17	Sep. 22
10 cm soil water	8.9 ± 7.7	38.1 ± 5.5	36.8 ± 5.5
25 cm soil water	78.5 ± 4.9	12.7 ± 10.7	14.4 ± 12.1
50 cm soil water	2.8 ± 2.7	8.4 ± 7.2	9.1 ± 7.8
100 cm soil water	2.9 ± 2.8	11.0 ± 9.4	14.2 ± 12.0
150 cm soil water	3.6 ± 3.3	13.3 ± 11.3	15.4 ± 13.0
200 cm soil water	3.4 ± 3.2	16.4 ± 13.8	10.2 ± 8.8

Table 4.
Contribution of different depths of soil water and rainwater to the water source of Sabina vulgaris in sandy land (%, mean ± SD).

Water source	May 13		Jul. 17		Sep. 22	
	Ao	Hf	Ao	Hf	Ao	Hf
10 cm soil water	72.9 ± 3.1	66.5 ± 3.6	51.9 ± 5.5	36.6 ± 7.0	26.0 ± 7.9	30.0 ± 7.5
25 cm soil water	7.9 ± 6.9	9.7 ± 8.4	9.9 ± 8.5	13.1 ± 11.1	20.1 ± 16.8	19.0 ± 16.0
50 cm soil water	4.4 ± 4.0	5.5 ± 4.9	5.9 ± 5.3	7.9 ± 6.8	12.9 ± 11.0	12.2 ± 10.4
75 cm soil water	5.8 ± 5.1	7.2 ± 6.3	8.4 ± 7.3	11.2 ± 9.5	17.6 ± 14.8	16.7 ± 14.0
100 cm soil water	4.4 ± 4.0	5.5 ± 4.9	9.8 ± 8.4	13.0 ± 11.0	13.3 ± 11.2	12.5 ± 10.7
150 cm soil water	4.5 ± 4.1	5.7 ± 5.0	13.9 ± 11.8	18.3 ± 15.4	10.1 ± 8.7	9.6 ± 8.2

Table 5.
Contribution of different depths of soil water and rainwater to the water source of Artemisia ordosica (Ao) and Hedysarum fruticosum var. laeve (Hf) in sandy land (%, mean ± SD).

Water source	May 13		Jul. 17		Sep. 22	
	Sp	Hf	Sp	Hf	Sp	Hf
10 cm soil water	28.6 ± 18.5	19.5 ± 12.1	15.2 ± 12.8	18.0 ± 14.6	26.4 ± 3.2	22.7 ± 3.4
25 cm soil water	30.4 ± 16.0	18.4 ± 10.5	13.8 ± 11.7	16.6 ± 13.3	16.9 ± 14.2	17.8 ± 14.9
50 cm soil water	10.8 ± 8.8	16.2 ± 13.0	16.9 ± 5.1	8.2 ± 4.3	15.1 ± 12.7	15.8 ± 13.3
100 cm soil water	10.5 ± 8.5	15.8 ± 12.7	20.9 ± 17.4	18.6 ± 14.1	15.4 ± 13.0	16.2 ± 13.6
150 cm soil water	9.6 ± 7.8	14.7 ± 11.7	16.7 ± 14.0	19.4 ± 16.0	13.7 ± 11.6	14.3 ± 12.1
200 cm soil water	10.1 ± 8.3	15.4 ± 12.3	16.5 ± 13.8	19.2 ± 15.8	12.6 ± 10.7	13.2 ± 11.2

Table 6.
Contribution of different depths of soil water and rainwater to the water source of and Salix psammophila (Sp) and Hedysarum fruticosum var. laeve (Hf) in sandy land (%, mean ± SD).

used both of 10–25 cm shallow and 100–200 cm deep soil water in summer and autumn. *Artemisia ordosica* and the accompany plant *H. fruticosum* var. *laeve* always used the same water source, e.g. 10 cm surface soil water in spring, 10 cm surface soil water and 150 cm deep soil water in summer, and 10–150 cm soil water in autumn. *Salix psammophila* mainly used 10–25 cm shallow soil water whereas *H. fruticosum* var. *leave* mainly used 50–200 cm soil water in spring. However, they both mainly used 10–25 cm shallow soil water and 100–200 cm deep soil water in summer, and 25–200 cm soil water in autumn. Soil water recharged by rainwater is the main water source for vegetation in sandy land since shallow groundwater was depleted by coal mining. However, in the habitat with shallow groundwater in the sandy land, woody species still could use groundwater. For example, *Salix matsudana* and *S. vulgaris* mainly used deep soil water and groundwater, whereas *A. ordosica* mainly used groundwater in Mu Us Sandy Land. The groundwater table were 1.0 m for *S. matsudana* in interdune, 1.5 m and 1.3 m for *S. vulgaris* and *A. ordosica* on sand dune, respectively [5].

The water source of the company shrub *H. fruticosum* var. *leave* were similar to the dominant shrub *A. ordosica* or *S. psammophila*, which indicated water competition between them. Water source of shrubs was closely related to their root type in sandy land, especially fine root. The root length of *H. fruticosum* var. *laeve* was 80 cm, with the biomass concentrated within 40 cm [31]. The distribution of its root system is partly overlap with two dominant shrubs. The root depth of *A. ordosica* was 200 cm, with the fine root concentrated within 40 cm [32]. The root system of *S. psammophila* was as deep as 150 cm, with fine root concentrated within 50 cm [33]. Similar phenomenon occurred in other sandy land vegetation. For example, *Salix gordejevii* mainly used soil water, whereas *Artemisia halodendron* mainly used 10–150 cm soil water in Horqin Sandy Land [11]. Their root biomass concentrated within 40 cm in the mixed community [34]. Therefore, the distribution of deep-rooted species should be arranged appropriately to avoid excessive water competition in the restoration of degraded vegetation in sandy land. It was suggested to keep reasonable afforestation density in the ecological engineering in Mu Us Sandy Land and other area of semi-arid region.

4. Conclusion

Soil water recharged by rainwater is the main water source for dominant species on Ordos Plateau. Six woody species have resource-dependent water use strategy, which is an adaptive advantage to the semi-arid climate. On loess slope of eastern Ordos Plateau, *H. rhmnoides, P. tabuliformis* and *A. sibirica* selected different water source based on their availability in the growing season, including shallow soil water, deep soil water and rainwater. In Sandy Land of southern Ordos Plateau, *S. vulgaris*, *A. ordosica*, *S. psammophila* and the company semi-shrub *H. fruticosum* var. laeve used different depths of soil water based on their availability in the growing season. However, there were water competition between the company semi-shrub and two dominant shrubs. Therefore, it was suggested to avoid vegetation degradation resulted from excessive water competition by appropriate distribution and afforestation density in semi-arid region.

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Conflict of interest

The author declares no conflict of interest.

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