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Water relation characteristics of *Alhagi sparsifolia* and consequences for a sustainable management

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Abstract Water relation characteristics of the desert legume *Alhagi sparsifolia* were investigated during the vegetation period from April to September 1999 in the foreland of Qira oasis at the southern fringe of the Taklamakan Desert, Xinjiang Uygur Autonomous Region of China. The seasonal variation of predawn water potentials and of diurnal water potential indicated that *Alhagi* plants were well water supplied over the entire vegetation period. Decreasing values in the summer months were probably attributed to increasing temperatures and irradiation and therefore a higher evapotranspirative demand. Data from pressure-volume analysis confirmed that *Alhagi* plants were not drought stressed and xylem sap flow measurements indicated that *Alhagi* plants used large amounts of water during the summer months. Flood irrigation had no influence on water relations in *Alhagi* probably because *Alhagi* plants produced only few fine roots in the upper soil layers. The data indicate that *Alhagi sparsifolia* is a drought-avoiding species that utilizes ground water by a deep roots system, which is the key characteristic to adjust the hyper-arid environment. Because growth and survival of *Alhagi* depends on ground water supply, it is important that variations of ground water depth are kept to a minimum. The study will provide a theoretical basis for the restoration and management of natural vegetation around oasis in arid regions.

Keywords: Taklamakan Desert, *Alhagi sparsifolia*, water relation, sustainable management.

A large natural distribution of the desert legume *Alhagi sparsifolia* can be observed in the area between oasis and desert in the southern fringe of Taklamakan Desert. Because of its perennial nature and its wide distribution, it stabilizes sand dunes and prevents land erosion. As a legume *Alhagi sparsifolia* is the only plant species in the natural vegetation that can utilize atmospheric nitrogen. *Alhagi sparsifolia* has a high protein content and is the main source of fodder for livestock in the oasis foreland and is therefore of great social-economical significance. Consequently, it is very important to protect and manage existing *Alhagi* stands and to aid the restoration and re-establishment of *Alhagi* vegetation in the oasis foreland. Water is a key factor that limits the oasis enlargement and vegetation growth in this region. Hence, it is necessary to study the water relation characteristics of desert plants.

Because of its special characteristics, many researchers in China and abroad have studied *Alhagi* for a long time. The early studies concentrated on the morphological structure of thorns and leaves of *Alhagi* species[1—3], and Graham[4] noted that *Alhagi* should be protected. In China, Yang et al.[5] studied the ecological characteristics of *Alhagi* in anatomy. Li[6] investigated re-growth of *Alhagi* and its shelter effectiveness, while Zhang et al.[7,8] studied community character and ecological structure of *Alhagi*. Furthermore, Jin[9,10] analyzed the absorption and distribution of elements in *Alhagi*. However, there are very few studies on water relation characteristics of *Alhagi*. In order to provide a scientific basis for the protection, restoration and reestablishment of *Alhagi*, it is very important to understand the ecophysiological adaptations of *Alhagi* to its environment.

The aims of this study were to investigate different water relation parameters of *Alhagi sparsifolia* growing in the natural vegetation near Qira oasis. In particular, we first investigated the seasonal variation of predawn water potential and of diurnal water potential in *Alhagi*, and then the seasonal variation of sap flow and water relation parameters from *P-V* curves, at last we investigated the influence of flood irrigation on water relation parameters of *Alhagi*. The study will supply a significant theoretical basis for the sustainable management of natural vegetation in arid and semi-arid region.

1 Materials and methods

1.1 General conditions in experimental region

The experimental region was located at the northern edge of Kunlun Mountain and the southern fringe of Taklamakan Desert (E80°03′24″—E82°10′34″, N35°17′55″—N39°30′00″) and the study sites were located near the Research Station in Qira oasis of the Chinese Academy of Sciences. The climate in the area is extremely arid due to its continental location. The annual average temperature is 11.9℃; the average is –11.7℃ in January and 25.2℃ in July. The extreme maximum and minimum temperature is 41.9℃ and –23.9℃. Rainfall is highly erratic and mainly occurs between May and July, the annual average precipitation is 35.1 mm, and the evaporation is over 2595.3 mm. Sand drift and sand storm are the main ecological disasters here. There are nine seasonal rivers in Qira oasis, the snow and glacier melt water is the source of these rivers. A belt of natural vegetation in the foreland of Qira oasis sustained by surplus water from the rivers serves as a shelter against sand drift and as a source of livestock feed as well as of fuel. Therefore, it is thought that the irrigation derived from the mountains water determines the establishment and development of natural vegetation in the foreland of Qira oasis.

1.2 Materials and treatments

A permanent experimental site of *Alhagi* (50 m×45 m) was set in the foreland of Qira oasis in April 1999 (The heights of *Alhagi* is 1.5 m or so). For the experimental irrigation, water from the oasis irrigation system was conducted to the plot by a channel that was dug by local workers in the usual manner at the end of June 1999 (because of the distance between the *Alhagi* plot and water source, the irrigation amount is not calculated precisely). All measurements in the field were made on clear and sunny days.

1.3 Measurement methods

(1) Xylem sap flow. Xylem sap flow was measured with the sap flow meter T693.2 (J. Kucera, EMS, Brno, Czech Republic) on shoots with a diameter of 12 to 18 mm of six healthy plants at the *Alhagi* field site. Data were collected every week and the sap flow sum was calculated based on these data. The measurement of sap flow began on April 15, 1999 (based on the Julain Day), so the “0” means 105th day, “50” means the 155th day, and “100” the 205th day and so on.

(2) Predawn water potential and diurnal water potential. Monthly changes in predawn water potential and diurnal changes in water potential (700 to 2000 h) were measured in six *Alhagi* plants, three replicates per plant, with a pressure chamber (Plant Moisture Stress, Instrument Company, Corvallis, Oregon, USA).

(3) *P*-*V* curves. Monthly changes in *P*-*V* curves of *Alhagi*, three replicates every time, were measured with a pressure chamber (Plant Moisture Stress, Instrument Company, Corvallis, Oregon, USA). Water relation parameters were calculated from *P*-*V* curves, such as $\Psi_{\pi_{100}}$, the osmotic potential at full turgor; Ψ_{π_0}, the osmotic potential at the turgor loss point and $\varepsilon_{\max}$, the maximum bulk modulus of tissue elasticity.

$$\varepsilon_{\max} = \mathrm{d}P/\mathrm{dRWC} \times (\mathrm{RWC}_{\mathrm{mean}} - \mathrm{RWC}_{\mathrm{a}}),$$

where RWC means the relative water content of cell, $\mathrm{RWC}_{\mathrm{mean}}$ is the average relative water content of cell, and $\mathrm{RWC}_{\mathrm{a}}$ the relative water content in the point of incipence.

(4) Soil water content. The soil water content is measured weekly with TDR (time domain reflectometry) gauges (TRIME-FM2/P2 and TRIME-IT, IMKO, Ettlingen, Germany) at the depths of 20—30, 90—100, 190—200, 340—350 and 750—760 cm. The average is calculated based on these data in different depths.

2 Results

2.1 Predawn water potential (PWP)

Fig. 1 shows the changes of PWP over the whole growing season. PWP decreases slowly during the growing season except in August. PWP is the highest in May (–0.24 MPa) and lowest in September (–0.67 MPa). Compared to other desert species in the oasis foreland like *Populus euphratica*, *Calligonum caput-medusae* and *Tamarix ramosissma*, the average PWP of *Alhagi sparsifolia* is the highest.

2.2 Diurnal changes in water potential (WP)

Fig. 2 shows diurnal changes of water potential during the whole growing season. The water potential during the day follows the characteristic pattern with the highest water potential values before dawn and the lowest values around midday. The difference between PWP and the midday water potential (MWP) was lowest in May, where the MWP dropped only to –0.80 MPa. In the other months of the vegetation period the MWP was much lower (–1.50 to –2.00 MPa) and reached their minimum in September.

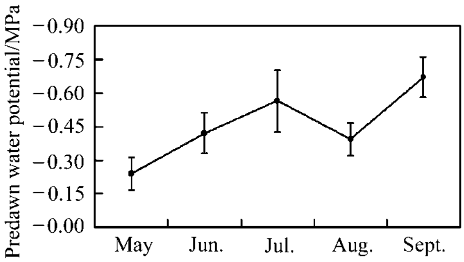

Fig. 1. Seasonal change of predawn water potential of *Alhagi sparsifolia* in 1999 (n = 18).

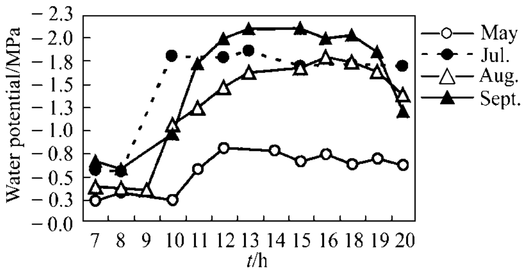

Fig. 2. Seasonal change of water potential daily course of *Alhagi sparsifolia* in 1999 (n = 18).

2.3 Water relation parameters in *P*-*V* curves

The monthly changes of water potential parameters obtained from *P*-*V* curves are shown in Fig. 3. Osmotic potential at full turgor ($\Psi_{\pi_{100}}$) and osmotic potential at turgor loss point (Ψ_{π_0}) are decreasing during the whole growing season except in August with $\Psi_{\pi_{100}}$ being higher than Ψ_{π_0} all times. Bulk elastic modulus ($\varepsilon_{\max}$) decreases constantly from May to September.

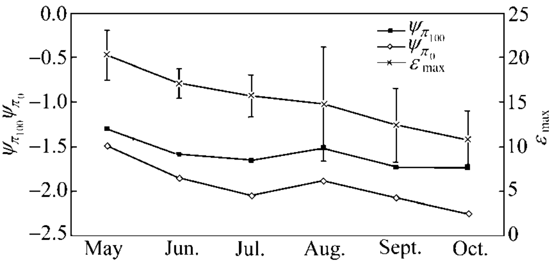

Fig. 3. Comparison of part water relation parameters in 1999.

2.4 Daily sap flow sum

Fig. 4 shows the seasonal fluctuation of daily sap flow sum. Sap flow is increasing from April to June, and the highest sap flow rates were observed in July. From June to August sap flow rates were constant between 1.5 and 2.0 kg/day and decreased in September.

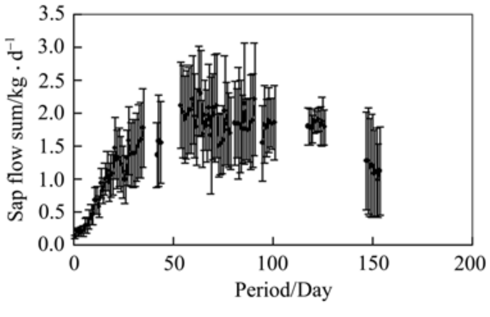

Fig. 4. Comparison of sap flow sum everyday in *Alhagi sparsifolia* site in 1999 (n = 6).

2.5 Soil water content

The seasonal change of soil water content in *Alhagi* site is shown in Fig. 5. Soil water content in all depths is below 4% before irrigation. The soil water content in 20—30 cm is increasing rapidly after irrigation, but it begins to drop few days later. The soil water content in 90—100 and 190—200 cm is increasing a little bit from several days to several weeks after irrigation. The soil water content in 340—350 cm is increasing very slowly, and keeps zero all the time in 750—760 cm.

3 Discussion

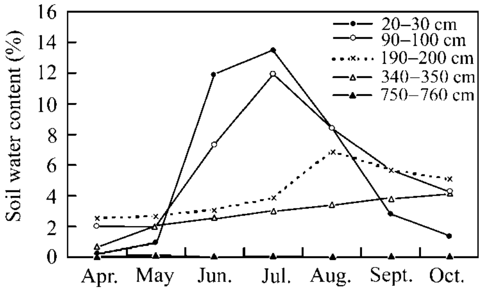

Fig. 5. Seasonal change of soil water content in *Alhagi sparsifolia* site in 1999.

Water potential is one of the most important parameters in the evaluation of plant water relations. The recovery from the daily water deficit can be assessed by the PWP and the MWP is an estimate of the maximum daily water deficit. A high PWP is indicative of a plant species that is well water supplied and PWP will decrease rapidly if a plant is drought stressed[11]. Although PWP decreased during the vegetation period in *Alhagi* (Fig. 1), the PWP values were high in comparison with other species measured in the oasis foreland. The trend to more negative PWP later in the growing season was accompanied with more negative MWP (Fig. 2). This trend was probably caused by changes in the climatic conditions during the growing season. Temperature and irradiance are usually low in the early months of the vegetation period. With temperatures and irradiance increasing in the summer months the evapotranspirative demand also increases and causes a greater daily water deficit. A similar decrease in the water potential was observed in other Chinese desert species and was also attributed to climatic changes and declines of plant growth[12]. Therefore, the water potential data are not indicative for drought stress in *Alhagi* during the vegetation period.

This was also confirmed by the *P-V* (pressure-volume) data. *P-V* curves mean the water content in volume of cell in somewhat pressure. Preparation of *P-V* curves enables identification of a number of key water relation properties of plants. They show how different species and ecotypes respond to the same growing conditions, and how the same species can change its water relation properties if water availability changes. The osmotic potential at full turgor ($\Psi_{\pi_{100}}$) and the osmotic potential at turgor loss point (Ψ_{π_0}) in *Alhagi* decrease during the growing season but the overall changes were small. A decrease of osmotic potential of the vacuolar sap is indicative that more solutes have been secreted into the vacuole. Therefore, the amount of solutes in *Alhagi* was the lowest in May and increased slowly with the season. The bulk elastic modulus ($\varepsilon_{\max}$) decreased constantly in *Alhagi* during the vegetation period. A high $\varepsilon_{\max}$ is an indication for a low elasticity and more rigid cell walls whereas low $\varepsilon_{\max}$ points to more elastic cell walls. The decreasing $\varepsilon_{\max}$ in *Alhagi* thus indicates that the elasticity of cell walls increases during the vegetation period. Weatherley[13] pointed out that the tissues with high elasticity had a stronger ability to keep turgor pressure than tissues with lower elasticity when the water content decreases in tissues and water potential. However, drought-tolerant plants tend to have higher $\varepsilon_{\max}$. This is because their cells are smaller and have thicker, denser walls and smaller vacuoles, so that more water is apoplasmic and the cell walls are less elastic. Compared to other species in arid lands $\Psi_{\pi_{100}}$ and Ψ_{π_0} values in *Alhagi* were very high and the seasonal changes of both parameters were small. For example, drought tolerant *Hakea polyanthema* seedlings had −1.75 MPa in winter and −2.57 MPa in the dry summer[14], which indicated osmotic adjustment. Drought tolerant plants usually have a more negative $\Psi_{\pi_{100}}$ and Ψ_{π_0} than drought-sensitive or drought-avoiding plants.

The sap flow data also indicate that the water was not limited during the entire vegetation period. The daily sap flow sum increased early in the season, was high during the summer months and decreased only at the end of the season in September. The high amount of water flux, as was indicated by the sap flow values, the low PWP and MWP values, confirms that *Alhagi* plants were not water limited and therefore had constant contact to groundwater sources. The soil water content in the Taklamakan is generally very low and precipitation is scarce. Consequently, the only constant water source for perennial plants is groundwater and *Alhagi* tapped ground water sources by its deep root system. It is well known that *Alhagi* plants can establish a deep root system. Shmueli[15] found that the root length of *Alhagi* was beyond 15 m. Vander[16] reported that *Alhagi* had a deep roots system to absorb water and grew in the area where the underground water was shallow. The same was observed for *Alhagi* species growing in Australia[17].

There was no evidence that the water status of *Alhagi* was improved after the flood irrigation in June 1999. In contrast, PWP values were more negative in July than those before the irrigation. However, the irrigation water penetrated the soil only in the first three meters of the soil profile[18]. From Fig. 5, the soil water content in 340—350 cm increases very slowly after the irrigation, it is impossible to take effect on water condition of *Alhagi*. Previous investigations of *Alhagi* root systems showed that there are very few fine lateral roots occurring in the first three meters of the soil profile. Therefore, *Alhagi* cannot use water effectively in this range. *Alhagi* connect the underground water with its deep roots system, it is the fluctuation of the underground water that influences the water condition of *Alhagi*.

Our experimental results show that *Alhagi* survives and grows in the arid conditions of the Taklamakan mainly by utilizing ground water sources which guarantee an unrestricted water supply over the entire vegetation period.

4 Conclusions

The seasonal variation of PWP and of diurnal water potential are indicative that *Alhagi* plants are well water supplied over the entire vegetation period. Decreasing values can be attributed to the changes of climatic variables.

The constantly high $\Psi_{\pi_{100}}$ and Ψ_{π_0} values confirm little osmotic adjustment in *Alhagi* and the decrease in $\varepsilon_{\max}$ indicates that the cell wall elasticity increases during the season. The values are typical for drought-avoiding species.

Flood irrigation had no influence on water relations in *Alhagi* because *Alhagi* plants produce only few fine roots in the upper soil layers. Therefore, *Alhagi* survives and grows not by using surface water but by utilizing ground water that was absorbed by its deep roots system.

It is therefore important for a sustainable management of *Alhagi* to keep the groundwater level stable, and to maintain a proper oasis scale. Furthermore, the water resources and the land need to be utilized properly, and the increase speed of population needs to be properly controlled as well.

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References

1. Robbins, W. W., Ball, W. S., Camelthorn, *Alhagi camelorum* Fish, Monthly Bull., California State Dept., 1933, 22: 258—260.
2. Kearney, T. A., Peebles, R. H., Arizone Flora, Berkeley: Univ. California Press, 1951, 1031.
3. Munz, P. A., Keck, D. D., A California Flora, Berkeley: Univ. California Press, 1959, 1681.
4. Graham, E. H., Legumes for Erosion Control and Widelife, Washington: U.S. Govt. Printing Office, 1941, 153.
5. Yang, G., Li, Y. F., The relationship between afforestation and water balance in arid region (in Chinese), Urumqi: Xingjiang Peoples Press, 1992, 12—23.
6. Li, R. N., An experimental study on the re-growth of *Alhagi* and its shelter effectiveness, Grass-Eating Animals (in Chinese), 1994, 2: 3—9.
7. Zhang, L. Y., MaiMai-ti, The influence of summer irrigation on the morphological characteristics and ecological structure of community of *Alhagi sparsifolai*, Journal of Arid Zone Research (in Chinese), 1995, 12(4): 34~40.
8. Xia, Y., Zhang, L. Y., Some ecological and biological characteristics of *Alhagi sparsifolia*, Journal of Arid Zone Research (in Chinese), 1995, 12(4): 53—60.
9. Jin, Q. H., Population character of *Alhagi sparsifolia* and plant community succession, Acta Phytoecologica Sinica (in Chinese), 1995, 19(3): 255—260.
10. Jin, Q. H., A study on the characters of content and distribution of K, Na, Ca, Mg elememts in *Alhagi sparsifolia*, Acta Phytoecologica Sinica (in Chinese), 1996, 20(1): 80—84
11. Sobrado, M. A., Turner, N. C., Comparison of the water relations characteristics of *Heilianthus annuus* and *Helianthus petiolaris* when subjected to water deficits, Oecologia, 1983, 58: 309.
12. Han, D. R., Yang, W. B., Yang, M. R., Water Dynamics and Its Application of Shrubs in Arid and Semi-arid (in Chinese), Beijing: Chinese Science and Technology Press, 1996, 29—35.
13. Weatherley, P. E., Some aspects of water relations, Adv. Bot. Res., 1970, 3: 31—110.
14. Witkowski, E., Lamont, B., Walton, C. et al., Leaf demography, sclerophylly and ecophysiology of two banksias with contrasting leaf life spans, Australian Journal of Botany, 1992, 40, 849—862.
15. Shmueli, E., The water balance of some plants of the Dead Sea Salines, Palestine J. Bot., Jerusalem Series, 1948, 4: 117—135.
16. Vander E. T., Walt, J. L., The camelthorn bush, Farming in South Africa, 1955, 30: 401—403.
17. Kassas, M., On the reproductive capacity and life cycle of *Alhagi* maurorum, Proc. of Egyptian Acad. Sciences, 1952a, 8: 114—122.
18. Thomas, F. M., Arndt, S. K., Bruelheide, H. et al., Ecological basis for a sustainable management of the indigenous vegetation in a central-Asian desert: presentation and first results, Journal of Applied Botany, 2000, 74: 212—219.