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Physiological response of natural *C.taklimakanensis* B.R.Pan et G.M.Shen to unconfined groundwater in the hinterland of the Taklimakan Desert

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Calligonum. taklimakanensis **B.R.Pan et G.M.Shen is an indigenous species that grows in the Taklimakan Desert. This study shows the relationship between** ***C.taklimakanensis*** **B.R.Pan et G.M.Shen and water conditions in the hinterland of the desert. The results show that: (1) Depth of water table is an important factor that affects water potential (ψ_p, ψ_A), osmotic potential (ψ_{sat}, ψ_{tlp}), relative water content (RWC_{tlp}, $ROWC_{tlp}$), and transpiration rate. (2) The degree of mineralization has a significant impact on the water potential of plants. A high degree of mineralization can strongly reduce plant productivity. (3)** ***C. taklimakanensis*** **B.R.Pan et G.M.Shen reduces the temperature of assimilation sticks through a high transpiration rate and maintains relatively high water content to adapt to drought and hot weather conditions in the hinterland of the desert. In addition,** ***C. taklimakanensis*** **B.R.Pan et G.M.Shen adapts to the water status in the desert through self-regulation or even sacrificing productivity.**

C.taklimakanensis B.R.Pan et G.M.Shen, water potential, transpiration rate, osmotic potential, relatively water content, depth of water table, degree of mineralization

As the rainfall is scarce in arid areas, the natural vegetation strongly depends on the groundwater[1]. Moreover, the depth of water table and the quality of the groundwater are the dominant factors that determine vegetation distribution, growth, population succession as well as the survival of wilderness oasis in arid areas[2,3]. Therefore, studying the response of arid area vegetation to groundwater conditions is important to understand plant community characteristics, water-control mechanism, and conditions that maintain the stability of desert ecosystems. Present research on the physiology of plants concentrates on the relationship between the depth of water table and physiological responses[4,5], the relationship between mineralization and plant growth[6−8], plant adaptation tactics and limit to salt stress, and so on[9,10]. Furthermore, most researches is simulated in the laboratory or limited to the study of cultivated plants in the field, while little research has been done on natural plants.

The climate of the Taklimakan Desert is extreme dry, which is greatly disadvantageous to the growth of natural vegetation, and water conditions are the most important and water conditions are the most important restric-

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tive factors that influence the growth and distribution of vegetation[11]. The study of the relationship between plants and water in this region can help understanding the viability and adaptive mechanisms of plants to extreme drought environments. At present, studies in the Taklimakan Desert are mostly conducted in the southern margin transition zone between the oasis and it is the open desert[11−15]. The study in the hinterland of this desert has not been reported. *Calligonum. taklimakanensis* B.R.Pan et G.M.Shen is an indigenous species, that grows mainly in the lowlands among the sand dunes of the Taklimakan Desert[16]. Now it is an extremely rare plant resource. Studying the physiological adaptation of *Calligonum.taklimakanensis* B.R.Pan et G.M.Shen has great theoretical significance and the value in practical of application.

The purpose of this study is to: (1) Grasp the characteristics of water status and its changes of *C. taklimakanensis* B.R.Pan et G.M.Shen in natural conditions in the hinterland of the Taklimakan Desert. (2) Discuss the physiological responses of *C. taklimakanensis* B.R.Pan et G.M. Shen to variations of the depth of water table and the degree of mineralization of unconfined groundwater under natural conditions, clarify the adaptive characteristics to environments. (3) Provide reference for the management of the shelterbelt that was irrigated with water of high salinity in desert highway.

1 Materials and methods

1.1 Experimental sites

Experimental plots are located in the hinterland of the Taklimakan Desert along the desert highway. We selected three experimental samples and marked them as A(84°18′E, 40°02′N), B(83°17′E, 38°34′N) and C (84°19′E, 40°17′N) according to the degree of mineralization from low to high, respectively. Samples A and C located on the early alluvial plain of the Tarim River, where many crescent sand dunes and wind erosion ditches are distributed. Sample B lies in the lowland and among the sand dunes, where natural vegetation and the simple structure of plant community are lacking. According to the data from Tazhong (83°40′E, 39°06′N) Meteorological Station and the Auto-Meteorological Station of the Botanical Garden, the annual average temperature is 12.4℃. It is hottest in July, with a monthly average temperature of 28.2℃ and coldest in December, with a monthly average temperature of −8.1℃. The highest recorded temperature is 45.6℃ and the lowest temperature is −20.2℃. The relative humidity is 29.4% on average. The mean annual precipitation is 36.6 mm. The potential evapo-transpiration is 3638.6 mm. The windy period is from April to August. Wind-heat occurs at the same period with much sandy weather.

The groundwater of the Taklimakan Desert comes mainly from snow in the surrounding mountains by infiltration. Rich surface water infiltrates the ground, which gathers together in the desert. Evaporation and strong consumption of water lead to high degree mineralization and high content halide in shallow groundwater[17].

1.2 Experimental designs

In October 2005, we selected the experiment samples along the desert highway. The sample plots are far away from the highway and similar in quality of soil, while the depth and salinity of the water are different (Tables 1 and 2). There is a well in every sample plot. Each sample plot is a circle with a well as the center with a 30-m radius. We measured the physiological parameters and the depth and the salinity of groundwater in May, July and September, 2006 to analyze the physiological response of *C. taklimakanensis* to the seasonal changes of groundwater conditions.

1.3 Experimental methods

(i) Water potential. The predawn water potential (ψ_P) was measured with a pressure chamber (P.M.S. Instruments, Co. Model 1000USA) between 05:00 and 06:00 and afternoon water potential (ψ_A) was measured between 13:00 and 14:00 in fine weather. In each case, leafy shoots were collected from five normal plants with six replicates per plant.

(ii) Transpiration and stomatal conductance rate. Leaf transpiration rate and stomatal conductance rate were measured for five plants every 2 hours from 08:00 to 20:00 using Portable Photosynthesis System LI-6400 (Li-cor, USA). This process was measured on the same day with water potential.

(iii) Pressure-volume procedures. Pressure-volume (P-V) curves represent the inverse water potential ($1/\psi$) versus relative water content (RWC) or volume of water expressed from the symplasm (Hammel), P-V curve is routinely used for estimating various tissue water relations arameters, such as osmotic potential at full turgor (ψ_{sat}), osmotic potential at zero turgor (ψ_{tlp}), relative water content (RWC) and relative osmotic water content ($\mathrm{ROWC}_{\mathrm{tlp}}$) at zero turgor. The procedure of P-V curve acts as reference methods[18].

The following procedure was used to construct P-V curves. Leaf tissue was weighed at full turgor, sealed in the sample chambers, and water potential was measured after an appropriate equilibration period. The sample holder was then removed from the chamber and the tissue was allowed to dry slightly, before being resealed in the chamber; the water potential was remeasured after equilibration. Tissue was weighed immediately after measuring water potential. This process was repeated until the tissue lost no more weight. Leaf explants were dried for 48 h at 85℃ to determine dry weight. All data were combined to draw a single P-V curve.

(iv) Buried depth and water quality. The depth and mineralization of groundwater through the well were measured in the samples every time.

(v) Data analysis. The analysis of data was carried out using EXCELL and SPSS; means were compared using least significant differences (LSD) test at 5% probability level.

2 Results

2.1 Conditions of growth and seasonal variations of water quality in all samples

Little rainfall and high evaporation in the hinterland of the Taklimakan Desert make the natural plants rely only on groundwater. Table 1, Table 2 and Figure 1 show the conditions of three samples.

2.2 Seasonal changes of plant water potential

Predawn water potential (ψ_{P}) reflects the recovery of plant water status. Afternoon water potential (ψ_{A}) shows the degree of drought stress[19]. Figure 2 shows that ψ_{P} and ψ_{A} are reduced with increasing salinity of water. ψ_{P} and ψ_{A} in sample A are the lowest in July, However ψ_{P} and ψ_{A} in sample A and B are decreasing gradually from May to September.

2.3 Daily change of plant transpiration and stomata conductance rate

From Figure 3, it can be seen that both daily changes of plant transpiration and stomata conductance rate are single-peak curves. Plant transpiration in July is higher than in September in all samples, and the transpiration is

Table 1 Ion content of unconfined groundwater in three samples (g/L)

Sample	pH	Degree of mineralization	HCO_3^-	Cl^-	SO_4^{2+}	Ca^{2+}	Mg^{2+}	K^++Na^+
A	7.89	4.96	0.201	1.843	0.983	0.151	0.18	1.228
B	7.76	7.92	0.1375	2.645	2.130	0.375	0.283	1.822
C	7.34	15.63	0.1825	5.475	3.98	0.722	0.512	3.728

Table 2 Growth conditions of *Calligonum.taklimakanensis* B.R.Pan et G.M.Shen in three samples

Sample	Degree of mineralization (g/L)	Depth of water table (m)	Average height (m)	Crown width (m^2)	Growth condition
A	4.96±0.0983	1.09－1.31 (0.22)	1.472±0.0985	0.430±0.1250	The plants are tall, assimilation branches lush and colors fresh, growth vigorous.
B	7.92±0.2567	2.02－2.25 (0.23)	1.273±0.1211	0.275±0.065	The plants are medial, assimilation branches less and peak green, growth commonly.
C	15.63±0.2214	1.16－1.56 (0.40)	1.276±0.148	0.156±0.057	The plants are big difference, assimilation branches less and short, color gloomy, growth poor and some dead branches.

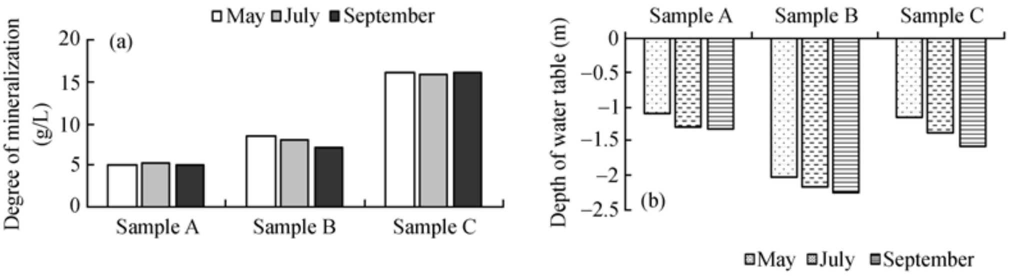

Figure 1 Seasonal variation of depth of water table and degree of mineralization of unconfined groundwater in three samples.

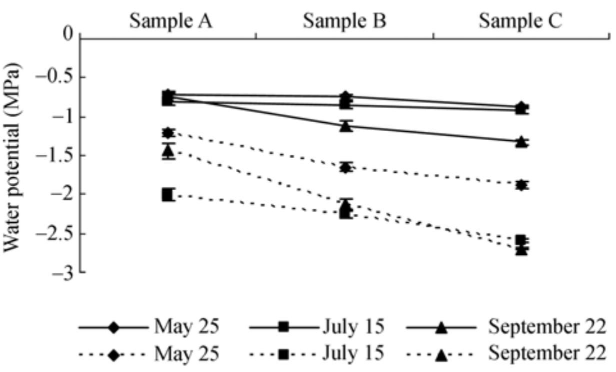

Figure 2 The seasonal changes of predawn water potential (ψ_p) and afternoon water potential (ψ_A) in three samples.

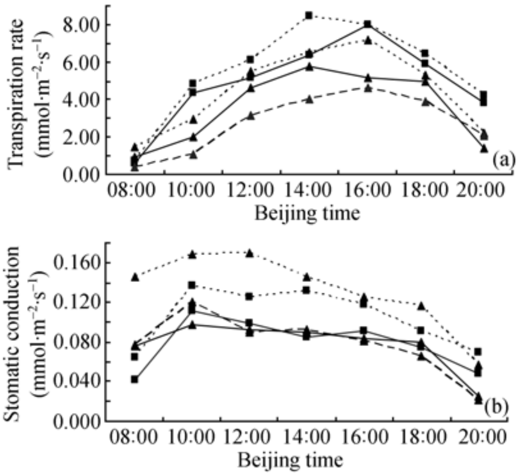

Figure 3 Daily change of plant transpiration and stomata conductance (no data in May). —, Sample A; ---, sample B; …, sample C; ■, July 15; ▲, September 22.

sample C > sample A > sample B in July and September. Stomata conductance in September is higher than in July in the sample C, while there has no regulation in sample A. Stomata conductance in sample C is highest in September, while it is very close in sample A and sample B.

2.4 Seasonal changes of P-V parameters

(i) The osmotic potential at full turgor osmotic potential at zero turgor and $|\psi_{sat}-\psi_{tlp}|$. Osmotic potential of plants have a close relation to the water status and the properties resistance drought[20]. The plants with lower osmotic potential have stronger tolerance to drought and higher capacity absorption[21]. Figure 4 shows that changes of osmotic potential (ψ_{sat} and ψ_{tlp}) are similar and have the same changes with the water potential in the same sample. There are no significant differences among the three samples in osmotic potential in May and September ($P < 0.05$). However, since sample B has the lowest water level, the values of osmotic potential (ψ_{sat} and ψ_{tlp}) in sample B is minimum. There are significant differences between sample A and samples B and C in ψ_{sat} in September ($P < 0.05$). But there is significant difference between sample A and sample C in ψ_{tlp} in September ($P < 0.05$), Osmotic potentials (ψ_{sat} and ψ_{tlp}) are lowest in sample C. The lower air temperature in September weakens the transpiration of plants, and salinity of groundwater is the main factor that determines osmotic potential.

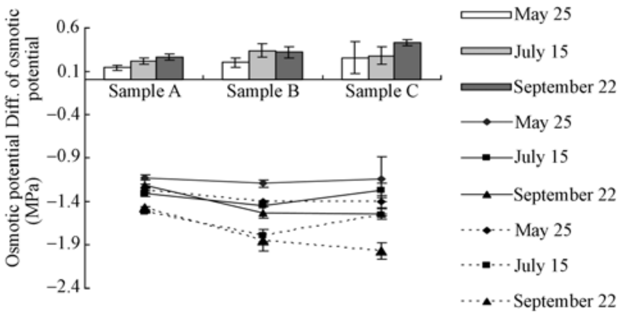

Figure 4 The changes of the osmotic potential at full turgor (ψ_{sat}), osmotic potential at zero turgor (ψ_{tlp}) and $|\psi_{sat}-\psi_{tlp}|$. —, Osmotic potential at full turgor (ψ_{sat}); ⋯, osmotic potential at zero turgor (ψ_{tlp}).

$|\psi_{sat}-\psi_{tlp}|$ is the range of osmotic potential decrease from water-saturated to water-deficient. It is related to the ability that plants regulate threshold value of stomata in station lack water closely[22]. Values of $|\psi_{sat}-\psi_{tlp}|$ in all samples were smaller in May, only between 0.1 and 0.2, they increased in September, but lower than 0.5. The lower $|\psi_{sat}-\psi_{tlp}|$ values show that plant turgor will be lost under the conditions of water loss, and stomata cannot open normally. However, it can stop or reduce plant transpiration to keep the water in the body of a plant. From the changes of plant stomata conductance and transpiration rate (Figure 3) it can be seen that plants showed no significant water deficit.

(ii) Relative osmotic water content ($ROWC_{tlp}$) and relative water content (RWC_{tlp}) at zero turgor. Relative osmotic water content ($ROWC_{tlp}$) is an important indicator of plant water stress[23], which will fall in conditions of serious water deficit[24,25]. Relative water content (RWC_{tlp}) shows the situation of water deficit at zero turgor[14]. $ROWC_{tlp}$ and RWC_{tlp} decrease gradually during the growing season, but there are no significant differences between May and September in each sample ($P < 0.05$)

and there are no significant differences between two samples in every month ($P < 0.05$). In addition to the ROWC$_{tlp}$ of sample C in September is 78.18%, the others are higher than 81% (Figure 5). This shows that plants keep a high water content. It is the way that *C.taklimakanensis* adapted to the conditions of water and climate in the desert. This is consistent with Li's conclusion[12].

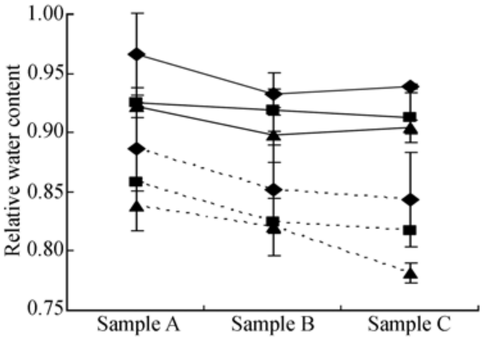

Figure 5 Changes of relative osmotic water content (ROWC$_{tlp}$) and relative water content (RWC$_{tlp}$) at zero turgor. —, RWC$_{tlp}$; ···, ROWC$_{tlp}$; ◆, May; ■, July; ▲, September.

3 Discussions

3.1 Physiological response of *C.taklimakanensis* B. R. Pan et G.M.Shen to depth of water table of unconfined groundwater

Water potential is an important indicator of the water status in plant physiology. It will decrease under the conditions of water deficit[26]. Water potential of plant reduces with the increase of the depth groundwater witch increases continuously from spring to autumn (Figure 1), because *C. taklimakanensis* is shallow-rooted shrubs. There is no significant difference between May and September in water potential in sample A($P < 0.05$), because its depth of water table is only 1.31 m. However, there are significant difference between May and September in water potential in sample B and sample C, because the depth of water table sample B is 2.25 m and the depth of water table in sample C changes 0.4 m during this time period. This shows that the increase in depth of water table will affect water potential. It is same to the results of Horton's study[27,28].

Changes of osmotic potential has the close relation with water deficit level and the ability of endure stress[29]. A study shows that osmotic potential of plant will reduce under drought condition[11]. Reduction of osmotic potential is helpful in maintaining turgor and plant absorb moisture from the soil. ψ_{sat} and ψ_{tlp} are decrease gradually in sample B and C from May to September, however, ψ_{sat} and ψ_{tlp} are higher in September than May in sample A. This is similar to the changes of water potential.

Relative osmotic water content (ROWC$_{tlp}$) and relative water content (RWC$_{tlp}$) indicate the plant water status[18]. Li[24] found that RWC$_{tlp}$ will decrease in the high-temperature drought or the soil freezing winter period. ROWC$_{tlp}$ and RWC$_{tlp}$ reduce with the depth of the water table of unconfined groundwater increases in different degrees, but there is no significant difference ($P < 0.05$).

Characteristics of stomata conductance and transpiration rate indicate the water situation in the environment and the body of plants to some degree[30]. Zhao[31] considers that plant transpiration is obviously a "single peak" under the conditions of normal moisture, and it is "double peak" in drought stress. Our study also shows that the variation of transpiration rate is a single peak (Figure 3), this is true for Deng[13] and Gong[32]. Plant transpiration rate in July is higher than in September. It is the response of plants to high temperature of the environment. High transpiration rate is the protection and adaptation mechanism of *Caliginous caputmedusae* to avoid injury of high temperatures[32]. Transpiration rate of plants in sample B is lowest in September, mainly due to the deepest water table in sample B. So, the depth of water table is an important factor that influences transpiration rate.

This study shows that *C. taklimakanensis* deals with the increase in the depth of water table through the decrease of water potential, osmotic potential, and relative water content. It reduces heat stress by its higher transpiration. Maintaining the relative high moisture content is the method of adaptation for *C. taklimakanensis* to the water and climate conditions in desert. The result is that *C. taklimakanensis* evolves and adapts to conditions of unconfined groundwater in the hinterland of the desert.

3.2 Physiological response of *C. taklimakanensis* B. R. Pan et G.M.Shen to degree of mineralization of unconfined groundwater

There is a scope for plants in degree of mineralization. If the degree of mineralization is beyond the scope, plants will decline[8,33]. In the mainstream area of Tarim River, the best degree of mineralization for plants is 3—5 g/L, while better degree of mineralization for plants is 5—8 g/L. If the degree of mineralization is more than 10 g/L, plants will wilt even die[33].

Water potential has a negative correlation with the degree of mineralization. When comparing the water potential of two sample plots (A and B) with the similar depth of water table and differences degree of mineralization, there is a significant difference between sample A and sample C in water potential in May and September ($P < 0.05$), and sample C has the lowest water potential. This shows that the high degree of mineralization has a significant impact on water potential of the plants. Although the depth of water table in sample B is lower than in sample C, water potential of the plants in sample B is higher than in sample C because the degree of mineralization in sample B is 7.71 g/L smaller than in sample C.

Salinity alters the relationship between plant and water mainly by osmoregulation[34]. Osmotic potential of plants will be reduced under the salt stress[35]. Depth of the water table is the main factor that influences osmotic potential. When the depth of water table is close, degree of mineralization will be the main factor for osmotic potential (Figure 4). Relative water content also decreases as the degree of mineralization increases, but there is no significant difference ($P < 0.05$). There is relatively high water content in all samples; this is the result of long-term adaptation of plants to their habitat.

There is no regularity between the degree of mineralization and transpiration rate as well as stomata conductance (Figure 4). This is different from other research results that state that high salinity can reduce transpiration rate and stomata conductance of plants[35,36]. Obviously, some studies have shown that salinity has no significant effect on the transpiration rate of plants[37]. So, the effect that salinity has on plant transpiration, stomata conductance is controversial.

In general, salinity will lead to slow plant growth[38]. This is the result of physiological changes, such as the dynamic balance of ions, water potential, transpiration and stomata movement[39]. Although plants can delay or reduce the negative impact through these physiological regulations, this regulation cannot promote plant growth or increase productivity[40]. Plants survive only by sacrificing some productivity. Conditions of plant growth (Table 2) in sample A and C show that the degree of mineralization has a significant impact on the growth of plants. This is the physiologic accommodation role of plants to the water condition of the hinterland of the desert.

To sum up, physiological changes and growth situations of plants is the integrated response to the degree of mineralization and the depth of the water table of unconfined groundwater. *C. taklimakanensis* attains its self-balance through the interactions between water potential, transpiration, osmotic potential and stomata change. This is also the result of its long-term adaptation to the environment and evolution.

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