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Effect of different water supply on morphology, growth and physiological characteristics of *Salix psammophila* seedlings in Maowusu sandland, China

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Abstract: Response pattern was investigated for seedlings of *Salix psammophila*, a dominant shrub in Maowusu sandland, to the simulated precipitation change by artificially controlling water supply at four levels. The growth characters, in terms of plant height, stem diameter, total branch number, total leaf number and area, total bifurcation ratio, total branch length and branch number, branch length, leaf number and leaf area of each branch order, and leaf, branch and root biomass significantly increased when water supply increased. That water supply had significant effect on biomass allocation showed different investment pattern of biomass resource of the seedlings grown under different water supply treatments. Stomatal density of abaxial leaf surface decreased, and stomatal apparatus length and width of adaxial and abaxial leaf surface increased with the increase of water supply, while Stomatal density of adaxial leaf surface was not affected by water supply. Water supply obviously affected the diurnal changes of photosynthetic rate, and the photosynthetic rate of the seedlings showed strongly midday depression grown under the 157.5 mm water supply, but not grown under higher water supply. Additionally the assimilation-light response curves and fluorescence efficiency more showed that water supply improve photosynthesis capacity. Finally, *S. psammophila* seedlings stood out by their slow growth and relatively high investments in root growth in order to reduce tissue losing rate and consumption of water resource for keeping water balance under water stress. The seedlings that grown under rich water supply did by their fast growth and relatively high investments in branch and leaf growth in order to improve the power of capturing light energy for higher photosynthesis.

Keywords: simulated precipitation; Maowusu sandland; semi-arid area; *Salix psammophila*

Introduction

IPCC (Intergovernmental Panel on Climate Change, 1990; 1992; 1995) has noted that human activities are substantially increasing the emissions of "greenhouse gases" such as carbon dioxide (CO_2), methane, chlorofluorocarbons and nitreous oxide into the atmosphere. These increases will enhance the natural greenhouse effect and the atmosphere will be global warmer. The atmosphere CO_2 concentration and temperature enhancement will greatly affect distribution pattern of the global precipitation. And the global precipitation change will greatly affect terrestrial ecosystem, especially arid and semi-arid one. There have been a lot of work in the response of global change to terrestrial ecosystem in the past (Lemon, 1983; Dahlman, 1985; Bazzaz, 1990; Arp, 1991; Bunce, 1992; Rogers, 1993; Wurr, 1998; Sarah, 1998). The work has been almost studied on CO_2 concentration double and temperature effect, and rarely on precipitation change effect on natural plant individual assimilation process of the terrestrial ecosystem (Dahlman, 1985; 1993; Malanson, 1993). So it is very necessary to investigate the effect of precipitation change on plant individuals of terrestrial ecosystem.

The Maowusu sandland of Inner Mongolia, a semi-arid area of China, lies on middle part of Chinese north desert (Yao, 1992). At present, desertification is becoming more serious and the landscape comprises large areas of sand-covered land there (Zhan, 1994; Chi, 1994). The environment is characterized by water shortage, strong evaporation, nutrient-poor soil and frequent disturbance (Zhu, 1993; Zhang, 1994; Danin, 1996). So the semi-arid ecosystem there possesses the most sensitive response to global change of water-heat pattern (Zhang, 1994). The ecosystems are mainly composed of shrubs (Dong, 1997), where *Salix psammophila*, a dominant shrub, plays an important role in the ecosystem. Its growth change will cause change of ecosystem structure and function here. There was little study on this kind of shrub species, but some physiological process being investigated in the field by Dong(Dong, 1997). And it was never studied on effect of water factor, a important ecological factor, on the seedling growth. Therefore, we study the responses of *S. psammophila* seedlings, in terms of canopy morphology, stomatal apparatus, biomass, photosynthesis, and fluorescence efficiency, to the global precipitation change by artificially controlling four water supply levels of 157.5 mm, 315 mm, 472.5 mm and 630 mm during the experiment. The purpose of this study is to discover different ecological adaptation strategies of the shrub in different water supply treatments from those responses, and offer parameters for modeling productivity of the shrub seedlings and studying water balance among sandland-plant-atmosphere system. Finally, this study is very important for us scientifically predicting in the change of semi-arid ecosystem and effectively preventing from desertification in Maowusu sandland. In addition, this work can offer theoretic suggestion for cultivating the shrub seedlings.

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1 Materials and methods

1.1 Study area and species

The experiment was performed at Ordos Sandland Ecological Station(OSES)(39°29.66'N, 110°11.47'E, 1295m a.s.l.), Institute of Botany, the Chinese Academy of Sciences. Annual average temperature is 6.0 – 8.5℃. Temperature of the most cold month (January) is – 10℃, and the most hot month (July) is 22℃. Annual average precipitation is 358.3 mm, 300 mm of which concentrates within June to September. The area there locates in the ecotone between desert-steppe and steppe-forest. The soil types mainly are light chestnut earth and sandified light chestnut earth. Detailed introductions of the study area are available in Zhang (Zhang, 1994) and Chi(Chi, 1994).

Salix psammophila is a sub-shrub that occurs in the Inner Mongolia Autonomous Region, Xinjiang Uygur Autonomous Region, Xizang Autonomous Region (Tibet), Shanxi Province of China. Usually its height is about 2 – 4m, and its leaf is odd and strip in shape. It is one of dominant shrub species which has the capacity of forbidding wind and fixing sand and can act as natural defence forest in Maowusu sandland.

1.2 Experiment material and design

The experiment was carried out on one-year *Salix psammophila* seedlings that were from the same population in near dune of OSES. Eighty individual seedlings of uniform appearance were randomly divided into four groups with uniform individuals, and then they were respectively planted in four sand pools($0.67 \times 1.5 \times 2$ m^3) on May 3, 1999. There was a pipe in each pool bottom just for draining enough water from the pools. All pools were constructed below great greenhouse. The top of the greenhouse is covered with repellent when it rains (of course, every sides of the greenhouse leaks out), and was exposed in sunshine. The sand matrix of each pool was from near dune of OSES, and the sand matrix depth was 60cm.

Based on the condition of natural precipitation there, and consideration of future global precipitation change, we designed four water supply levels. i.e. 157.5 mm, 315 mm, 472.5 mm and 630 mm during all experiment. The four water supply levels simulated respectively corresponded to less, equal, more and much more present mean precipitation of the growing season of this species in Maowusu sandland. The seedlings were cultivated from May 24 to September 5, 1999. To decrease artificial effect on water supply, water was supplied at afternoon of the same day for all treatments, and the seedlings was supplied water once every two days from the beginning of 24 May. So total numbers of supply water were 35, and water supply respectively was 4.5 mm, 9 mm, 13.5 mm and 18 mm once for each water supply treatment. At the same time, all sand pools of the experiment were managed well, and often weeded and splashed with insecticide.

1.3 Sand matrix moisture of the pools

Sand matrix moisture was measured by oven drying method. Seven sand matrix column along S in shape in each pool were sampled from surface to bottom every fifteen days during experiment. Each sand matrix column was sampled every 15 cm from surface to bottom. So twenty-eight sand matrix samples were sampled each pool once for sand matrix moisture. The sand matrix moisture percentage is shown in Fig.1. There was a significant difference among four water supply treatments in terms of sand matrix moisture percentage after beginning of the experiment, and water supply had significantly increased the sand matrix moisture percentage.

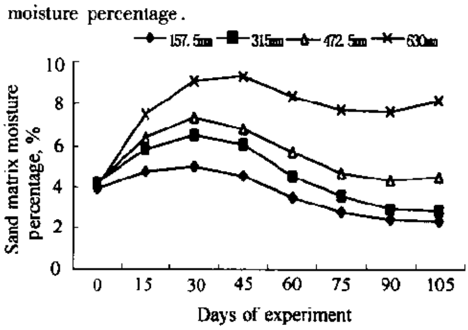

Fig. 1 Seasonal changes of sand matrix moisture percentage in sand pools of *S. psammophila* seedlings grown under four water supply treatments from May 24 to Sept. 5, 1999

1.4 Measurement

1.4.1 Canopy morphology

Ten seedlings with each water supply treatment were perpetually measured every fifteen days during the experiment in order to determine tree height, leaf number, leaf length, branch number and branch length of every branch order. Only leaf ≥ 5 mm long were counted and measured. Branch orders were measured by Strahler method (McMahon, 1976). Total bifurcation ratios were measured by formula $R_b = (N_T - N_S)/(N_T - N_1)$ (Whithe, 1976; Steigraeber, 1986), where R_b is the total bifurcation ratio; N_T is the total branch number; N_S is the branch number of the most order; N_1 is the branch number of the first order. As leaf was regularly stripe in shape, leaf areas were calculated using linear regression formula of leaf area (Y) on the product length (X). For this purpose, the circumferences of sets of leaf, with even representation of water supply treatments and leaf size classes, were drawn on paper and cut out. Length and area were measured with CI-203 area meter (USA). The following formula was found: $Y = 0.4686X - 0.3181$ ($R = 0.912$, $N = 70$).

1.4.2 Physiological character

On July 31, 1999, five seedlings of each water supply treatment were measured every one hour from six to nineteen o'clock in order to determine photosynthetic rate (Pn, $\mu mol.m^{-2}.s^{-1}$) using LCA-4 portable photosynthesis system (ADC, UK). Fluorescence efficiency was measured using fluorescence analyzer (PEA.UK) at midday on July 21, 1999.

1.4.3 Assimilation-light response curve

A series of light intensities from high to low till 0 $\mu mol \cdot m^{-2} \cdot s^{-1}$ were controlled by shading method (Guo, 1999). The detail method was that the standard leaves of *S. psammophila* seedlings grown under four water supply treatments were uniformly shaded with gauze on midday of August 6, 1999 (The light intensities were more than 2000 $\mu mol.\ m^{-2}.s^{-1}$ from ten o'clock to fifteen o'clock this day). The time for yielding a stable photosynthetic rate was set at 40 seconds for each light intensity. And the stable photosynthetic rate was measured with LCA – 4. Assimilation-light response curves were drawn by formula $P = P_{max}(1 - e^{-\alpha I/P_{max}})$ (Thornley, 1976) based on the series of light intensities and photosynthetic rates. Where P and I are the actural photosynthesis ($P = Pn + R$) and light intensity, respectively; R is the dark respiration; P_{max} is maximum photosynthesis; α is the initial slope of the curve.

1.4.4 Stomatal apparatus character

Density, length and width of Stomatal apparatus of abaxial and adaxial leaf surfaces were measured by epidermal imprint (Charles, 1981) placed under optical microscope. The detail method to make the epidermal imprint was as follows: five health leaves of each water supply treatment respectively were randomly selected on August 26, 1999, and every leaf of abaxial and adaxial surface was cleaned with absorbent cotton and gently smeared a light film of transparent nail varnish along two sides of leaf costa, and then the nail varnish film was gently denuded with nipper when it became dry.

1.4.5 Biomass determination

Ten seedlings of each water supply treatment were harvested on September 7, 1999. Roots were carefully washed free from sand using a spray gun, and the sand was recollected and checked thoroughly for living roots that had broken off. Root, shoot and leaf dry weights were determined after 48 hours in an oven at 85℃, and root systems were divided coarse root (root diameter < 1mm) and fine root (root diameter < 1 mm).

1.4.6 Data analysis

The following characters were tested with analysis of variance and Duncan multiple range test(Lu, 1997): (1) canopy morphology characters such as tree height, stem diameter, total branch number, total leaf number and leaf area, total bifurcation ratio, total branch length, and branch number, length and leaf area of each branch order; (2) biomass such as leaf, branch and root biomass; (3) stomatal apparatus characters such as its density, length and width; (4) physiological characters such as photosynthetic rate and fluorescence efficiency. In addition, between the data of light intensities and photosynthetic rates, and between water supply and fluorescence were analyzed by non-linear regression analysis(Lu, 1997).

2 Results

2.1 Canopy morphology

The plant height, stem diameter, total branch number, total leaf number and area of the seedlings had clear difference compared with the four water supply treatments on Sept. 5, 1999 ($P < 0.01$; Table 1). Those characters of the seedlings increased with the increase of water supply. However, there were not significant difference in those characters between the 630 mm and 472.5 mm water supply treatment (Table 1). There were a significant difference compared with four water supply in terms of architectural characters such as total bifurcation rate, total branch length, and branch number, length, leaf number and leaf area of each branch order on Sept. 5, 1999, except branch number of order 2 ($P < 0.05$; Table 1). Water supply increased the architectural characters of the seedlings. However, there were not significant difference in those characters

Table 1 The morphological characters of *S. psammophila* seedlings under different water supply treatments on Sept. 5, 1999

Architectual character	Water supply				
	157.5mm	315mm	472.5mm	630mm	ANOVA
Tree height, cm	76.9 ± 6.1^{c}	113.0 ± 5.1^{b}	143.4 ± 4.1^{a}	151.2 ± 5.6^{a}	* *
Stem diameter, mm	4.1 ± 0.3^{c}	6.8 ± 0.4^{b}	7.5 ± 0.3^{ab}	8.2 ± 0.5^{a}	* *
Total branch number	7.4 ± 3.7^{c}	16.6 ± 9.2^{b}	23.0 ± 4.6^{a}	24.8 ± 3.5^{a}	* *
Total leaf number	175.3 ± 20.2^{c}	390.2 ± 41.3^{b}	488.4 ± 35.7^{ab}	534.2 ± 46.5^{a}	* *
Total leaf area, cm^2	397.2 ± 54.6^{c}	895.9 ± 90.7^{b}	1179.5 ± 98.2^{ab}	1398.3 ± 159.6^{a}	* *
Total bifurcation ratio	0.44 ± 0.30^{b}	1.61 ± 0.46^{a}	1.84 ± 0.22^{a}	1.96 ± 0.24^{a}	* *
Total branch length, cm	239.6 ± 31.9^{b}	581.7 ± 72.6^{a}	635.2 ± 30.7^{a}	732.6 ± 67.3^{a}	* *
Branch number of order 1	1.5 ± 0.69^{c}	9.8 ± 2.79^{b}	14.7 ± 1.28^{ab}	16.0 ± 1.49^{a}	* *
Branch length of order 1, cm	17.2 ± 7.2^{b}	171.9 ± 57.5^{a}	207.0 ± 16.8^{a}	222.8 ± 35.2^{a}	* *
Leaf number of order 1	15.2 ± 7.4^{b}	160.4 ± 43.9^{a}	218.2 ± 24.0^{a}	226.9 ± 29.4^{a}	* *
Leaf area of order 1, cm^2	22.6 ± 12.1^{b}	279.3 ± 86.2^{a}	352.6 ± 42.6^{a}	390.9 ± 35.3^{a}	* *
Branch number of order 2	5.9 ± 1.1^{b}	6.8 ± 0.9^{ab}	8.3 ± 0.6^{ab}	8.8 ± 0.7^{a}	NS
Branch length of order 2, cm	222.4 ± 28.3^{b}	409.7 ± 46.4^{a}	428.2 ± 37.6^{a}	509.8 ± 81.5^{a}	* *
Leaf number of order 2	160.1 ± 19.4^{b}	229.8 ± 9.9^{ab}	270.2 ± 38.5^{a}	307.3 ± 49.9^{a}	*
Leaf area of order 2, cm^2	374.6 ± 54.7^{c}	616.7 ± 32.9^{bc}	826.8 ± 117.8^{ab}	1007.3 ± 169.4^{a}	* *

Notes: Data of the table represent average value ± standard error. Treatments with the same letters are not significantly different ($P < 0.05$) according to Duncan multiple range tests. NS, * and * * symbols represent significant level $P > 0.05$, $P < 0.05$, $P < 0.01$, respectively among the 630, 472.5 and 315 mm water supply treatments, and they were obviously higher than those of the seedlings grown under the 157.5 mm water supply.

2.2 Biomass allocation

The biomass of leaf, branch, coarse and fine root of the seedlings had obvious difference compared with four water supply treatments($P < 0.01$; Table 2). Like the morphological characters, water supply had clearly increased the biomass of the seedlings. However, there was not significant difference in biomass of the seedlings grown under the 630 mm and 472.5 mm water supply (Table 2). Root/shoot biomass also had a clear difference compared with the four water supply treatments ($P < 0.01$), and the ratio decreased with the increase of water supply (Table 2).

Table 2 The day biomass of *S. psammophila* seedlings under different water supply treatments(g)

Water supply	Leaf	Branch	Coarse root	Fine root	Total biomass	Root/shoot
157.5mm	3.11 ± 0.42^c	3.28 ± 0.42^c	2.28 ± 0.91^b	1.25 ± 0.45^b	9.91 ± 11.14^c	0.58 ± 0.05^a
315mm	6.26 ± 0.54^b	10.81 ± 1.41^b	6.06 ± 2.92^a	2.06 ± 1.15^{ab}	25.19 ± 2.91^b	0.47 ± 0.03^{ab}
472.5mm	8.34 ± 0.67^a	14.03 ± 1.86^a	6.38 ± 2.88^a	2.43 ± 11.23^a	31.17 ± 2.26^a	0.42 ± 10.06^b
630mm	9.77 ± 1.07^a	16.44 ± 1.97^a	7.11 ± 3.34^a	2.58 ± 10.72^a	35.90 ± 3.97^a	0.37 ± 10.01^b
ANOVA	* *	* *	* *	*	* *	* *

Notes: Data of the table represent average value ± standard error. Treatments with the same letters are not significantly different ($P < 0.05$) according to Duncan multiple range tests. * and * * symbols represent significant level $P < 0.05$, $P < 0.01$, respectively

2.3 Stomatal apparatus

There were significant difference between adaxial and abaxial leaf surface in terms of the densities of stomatal apparatus (Table 3), and the densities of adaxial leaf surface were about 141 – 150/mm², much less than those of abaxial leaf surface, 280 – 480/ mm²; The densities of stomatal apparatus of adaxial leaf surface had not significantly difference compared with four water treatments, but water supply obviously decreased the densities of stomatal apparatus of adaxial leaf surface ($P < 0.05$; Table 3). In addition, water supply had obviously affected the length and width of stomatal apparatus of the adaxial and abaxial leaf surface ($P < 0.01$; Table 3), and they increased with the increase of water supply.

Table 3 The characters of stoma apparatus on adaxial and abaxial leaf surface of *S. psammophila* seedlings under different water supply treatments

	Adaxial			Adaxial		
Water supply	Stomatal density, mm²	Stomatal apparatus length, μm	Stomatal apparatus width, μm	Stomatal density, mm²	Stomatal apparatus length, μm	Stomatal apparatus width, μm
157.5mm	147.5 ± 4.13	20.21 ± 10.37^c	17.06 ± 0.28^d	475.0 ± 7.72^a	13.11 ± 0.14^d	9.09 ± 0.11^c
315mm	146.2 ± 4.13	25.89 ± 0.28^b	19.11 ± 0.19^c	416.7 ± 5.81^b	15.90 ± 0.16^c	10.09 ± 0.15^b
472.5mm	141.7 ± 5.81	26.21 ± 0.23^b	20.99 ± 0.20^b	350.0 ± 5.98^c	19.65 ± 0.21^b	12.95 ± 0.20^a
630mm	150.0 ± 4.23	28.78 ± 0.25^a	22.40 ± 0.15^a	285.0 ± 4.76^d	23.98 ± 0.60^a	12.99 ± 0.22^a
ANOVA	NS	* *	* *	* *	* *	* *

Notes: Data of the table represent average value ± standard error. Treatments with the same letters are not significantly different ($P < 0.05$) according to Duncan multiple range tests. NS, * and * * symbols represent significant level $P > 0.05$, $P < 0.05$, $P < 0.01$, respectively

2.4 Photosynthetic rate

An example of the typical diurnal pattern of photosynthetic rate is shown in Fig. 2. There was a significant effect of water supply on the diurnal changes of photosynthetic rate. Water supply increased photosynthetic rate, and its curve of 157.5 mm water supply treatment had two obvious peak values at both ten and fifteen o'clock, and the former peak value was higher than that of the latter peak, and a obviously low value between two peaks at twelve o'clock. The diurnal changes of the 630 and 472.5 mm water supply treatments almost were similar, and they quickly rose from six to ten o'clock, and then dropped slowly, and dropped quickly from eighteen o'clock.

2.5 A-light response curves

The A-light response curves under four water supply treatments are shown in Fig. 3. The curves simulated had very significantly showed the observed values ($P < 0.01$), and there was a obviously difference compared with four water supply treatments in terms of the shape of those curves (Fig. 3, Table 4). Water supply had increased the maximum photosynthesis and initial slope of the curves, and they were higher at ten o'clock than fifteen o'clock under the same water supply treatment seen from the regression formula (Table 4).

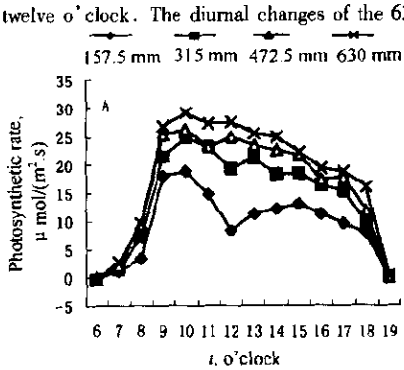

Fig.2 Diurnal changes physiological characters of *S. psammophila* seedlings under different water supply treatments on 31 July, 1999

Table 4 Regression formulas of light response of photosynthesis of *S. Psammophila* seedlings under different water supply treatments between 10:00 and 15:00 on August 6, 1999

Water supply	Regression formula 10:00	Regression formula 15:00
157.5mm	$P = 10.222[1 - e^{-0.0298I/10.222}]$, $R = 0.987^{**}$	$P = 10.179[1 - e^{-0.0214I/10.179}]$, $R = 0.993^{**}$
315mm	$P = 21.314[1 - e^{-0.0404I/21.314}]$, $R = 0.998^{**}$	$P = 19.673[1 - e^{-0.0378I/19.673}]$, $R = 0.0996^{**}$
472.5*mm*	$P = 24.299[1 - e^{-0.0425I/24.299}]$, $R = 0.998^{**}$	$P = 23.629[1 - e^{-0.0402I/23.629}]$, $R = 0.999^{**}$
630*mm*	$P = 26.791[1 - e^{-0.0470I/26.791}]$, $R = 0.997^{**}$	$P = 25.514[1 - e^{-0.0467I/25.514}]$, $R = 0.994^{**}$

Notes: significant level: ** $P < 0.01$

2.6 Fluorescence efficiency

There was a significant difference in fluorescence efficiency compared with the four water supply treatments ($F = 58.35 > F_{0.01(3,16)} = 5.29$, $P < 0.01$), and fluorescence efficiency increased with the increase of water supply. In addition, there was a significant relationship of rectangular hyperbola between fluorescence efficiency (Y) and water supply (X) ($P < 0.01$) (Fig. 4), as follows: $Y = 0.9131X/(57.2256 + X)$, $R = 0.9632$, where there was an asymptote, as follows: $Y = 0.9131$. Fluorescence efficiency increased, and its ascent slope ratio decreased with the increase of water supply clearly seen from the curve.

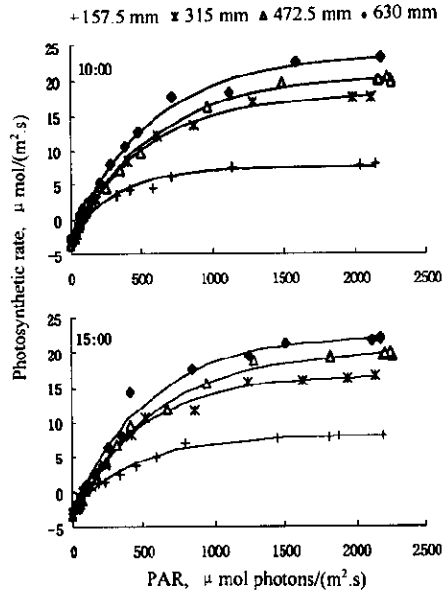

Fig.3 A-light response curves of *S. psammophila* seedlings under four water supply treatments between 10:00 and 15:00 on 6 August, 1999. The points are observed values, and the lines are simulated curves

3 Discussion and conclusions

The canopy development of *S. psammophila* seedlings was very sensitive to sand moisture. The growth of shrub height, stem diameter, branch number, leaf number and area of the seedling grown under 157.5 mm water supply treatment was inhibited, largely due to water stress to the seedling growth, and those characters increased with increase of water supply. The similar result was found by Collinson *et al*. (Collinson, 1999) and Hsiao (Hsiao, 1993). In addition, the 472.5 mm water supply had reached enough perfect effect on the seedlings growth seen from not significantly different in many growth characters of the seedling grown under the 630 and 472.5 mm water supply.

As the same morphology of the seedling, water supply significantly increased biomass production. In addition, what root /shoot biomass decreased with the increase of water supply fully discovered the different adaptation strategies in biomass distribution pattern under different water supply treatments. The seedlings stood out by their relatively high investments in root growth in order to absorb more water and nutriment in sand for higher survival competitive capacity under water stress environment. But seedlings that grown under high water supply were distinguished by relatively high investments in branch and leaf in order to get more growth spatial and capture more light energy for higher photosynthesis. There was the similar result of the other species found by Pearson (Pearson, 1966), EL Nadi (EL Dadi, 1969), Hoffman *et al*. (Hoffman, 1971) and Hsiao (Hsiao, 1993).

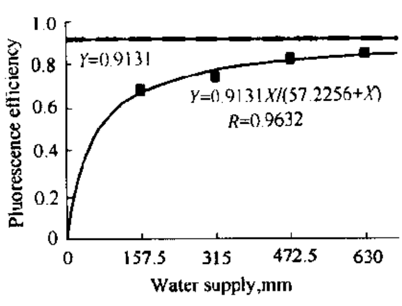

Fig.4 Correlation between water supply and fluorescence efficiency of *S. psammophila* seedlings

Stomatal apparatus of many plant species was easily affected by environment change (Madsen, 1973; Woodward, 1988; Penuelas, 1990; Yang, 1997). Like the species reported, the stomatal apparatus of the seedlings was also very sensitive to sand moisture. The density of stomatal apparatus of adaxial leaf surface was much lower than that of abaxial leaf surface of the seedlings. This reason was that light directly radiated the adaxial leaf surface. Water supply clearly increased the density of stomatal apparatus of abaxial leaf surface, but did not obviously improve the density of stomatal apparatus of adaxial leaf surface. However, the length and width of stomatal apparatus of adaxial and abaxial leaf surface significantly increased with the increase of water supply. It was obvious that water supply increased the open degree of stomatal apparatus for more CO_2 exchange. The stomatal conductance of the seedlings that increased with the increase of water supply was similar to the open degree of stomatal apparatus.

Water supply significantly affected the diurnal change of photosynthetic rate of the seedlings. Photosynthetic rate clearly increased while water supply increased, and they had obvious midday depression under 157.5 mm water supply treatment, which obviously showed there was strongly water stress to the seedlings grown under the water supply level. But the midday depression was banish under higher water supply from 1575 mm to 630 mm. Additionally A-light response curves, which had showed water supply increased the maximum photosynthesis and initial slope of the curves, more offered testimony of the fact that water supply improved the photosynthesis capacity of the seedlings.

Water supply significantly increased fluorescence efficiency, and there was a much significant relationship of rectangular hyperbola between water supply and fluorescence efficiency. The behavior of fluorescence efficiency mechanically explained why photosynthetic rate increased with the increase in water supply. The reason could be that fluorescence efficiency represents the capacity of light energy transmission and transformation to biological energy in reaction center light system Ⅱ (Hao 1990), and such a mechanism was previously considered to occur in bean (Hao, 1990).

Based on those results, we clearly find water supply has a positive effect on morphology, growth and photosynthesis of *S. psammophila* seedling in the range of water supply from 1575 mm to 630 mm. In addition, the seedlings adapt different water resource environment by the strategy of whole synergistic effect. The seedlings grown under 157.5 mm water supply decrease stomatal opening and photosynthesis, and then depress their growth degree and have relatively high investments in root growth in order to reduce tissue losing ratio and consumption of water resource and improve water use efficiency. However the seedlings grown under high water supply increase their stomatal opening and photosynthesis and have relatively high investments in branch and leaf growth in order to improve the capacity of capturing light energy for higher photosynthesis, and increase seedling growth finally. The similar response of the other plant species to water supply are found by Lauenroth *et al*. (Lauenroth, 1978), Chapin and Shaver (Chapin, 1985), and Bloom *et al*. (Bloom, 1985). In short, water supply significantly increases the sand matrix moisture percentage and improves water resource utilization availability, and causes the different ecological adaptation strategies of *S. psammophila* seedlings growing under different water resource environments in Maowusu sandland. Finally, this work helps to predict the ecological adaptation of *S. psammophila* seedlings to the future changes in precipitation, However, any practical adaptation strategy will also be determined by the temperature enhancement (Department of the Environment, 1996). So the future work on climate change should also include studies on the interaction between temperature and water supply.

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References:

Arp W J, Drake B G, 1991. Increased photosynthetic capacity of *Scirps olneyi* after 4 years of exposure to elevated CO_2 [J]. Plant Cell and Environment, 4:1004—1008.

Bazzaz F A, 1990. The response of natural ecosystems to the rising global CO_2 levels[J]. Ann Env Ecol System, 21:167—196.

Bloom A J, Chapin III F S, Mooney H, 1985. Resource limitation in plants and economic analogy[J]. Annual Review of Ecology and Systematics, 16:363—392.

Bunce J A, 1992. Stomatal conductance, photosynthesis and respiration of temperate deciduous tree seedlings growth outdoors at an elevated concentration of carbon dioxide[J]. Plant Cell and Environment, 15:541—549.

Chapin F S, Shaver G R, 1985. Individualistic growth response of tundra plant species to environmental manipulations in the field[J]. Ecol, 66:564—576.

Charles L, Wilson C L, Lawrence Pusey *et al*., 1981. Plant epidermal sections and imprints using cyanoacrylate adhesives[J]. Can J Plant Sci, 61:781—783.

Chi L J, 1994. The impact of global change on the desertification in China[J]. J Nat Res, 9:289—303.

Collinson S T, Berchie J, Azam-ali S N, 1999. Effect of soil moisture on light interception and the conversion coefficient for three landraces of bambara groundnut(*Vigna subterranea*)[J]. J Agri Science, 133:151—157.

Dahlman R C, 1985. Modelling needs for prediction responses to CO_2 enrichment: plants, communities and ecosystems[J]. Ecol Modell, 29: 77—106.

Dahlman R C, 1993. CO_2 and plants: revisited[J]. Vegetation, 104(415): 339—355.

Danin A, 1996. Plants of desert dune[M]. Berlin: Springer-Verlag.

Department of the Environment, 1996. Review of the potential effects of climate change in the United Kingdom[M]. London: HMSO.

Dong X J, Zhang X S, Yang B Z, 1997. A preliminary study on the water balance for some sandland shrubs based on transpiration measurements in field conditions[J]. Acta Phytoecologica Sinica, 21: 208—225.

El Nadi A H, Brouwer R, Locker J, 1969. Some responses of the root and the shoot of *Vicia faba* plants to water stress Neth[J]. J Agr Sci, 17: 133—142.

Hao N B, 1990. The study progress of applied base and technology in cultivating bean [M]. Nanjing: Jiangsu Science and Technology Press. 28—35.

Hoffman G J, Rawlins S L, Garber M J *et al*., 1971. Water relations and growth of cotton as influenced by salinity and relative humidity[J].

Agron J, 63: 822—826.

Hsiao T C, 1993. Effect of drought and elevated CO_2 on plant water use efficiency and productivity[M]. In: Interaction stresses on plants in a changing climate. NATO ASI Series 1: Global environmental change. Volume 16(M. B. Jackson & C. R. Black ed.). Berlin: Springer-Verlag. 435—465.

Intergovernmental Panel on Climate Change, 1990. Climate Change : The IPCC Scientific Assessment(J.T. Houghton, G.J. Jenkins and J. T. Ephraums ed.)[M]. Cambridge: Cambridge University Press.

Intergovernmental Panel on Climate Change, 1992. Climate Change 1992: The supplementary report to the IPCC scientific assessment(J. T. Houghton, B. A. Callender and S. S.K. Varney ed.)[M]. Cambridge: Cambridge University Press.

Intergovernmental Panel on Climate Change, 1995. Climate Change 1994: Radiative forcing of climate change and an evaluation of the IPCC IS92 emission scenarios(J.T Houghton, L.G. Meira Filho, J. Bruce *et al*. ed.)[M]. Cambridge: Cambridge University Press.

Lauenroth W K Dodd, J L & Sims P L, 1978. The effects of water and nitrogen induced stresses on plant community structure in a semi-arid grassland[J]. Oecologia, 36: 211—222.

Lemon E R, 1983. CO_2 and plants: The response of plants to rising levels of atmosphere dioxide[M]. Colorado: Westview Press.

Lu W D, Chu Y L, Sha J, Chu H B, 1997. SPSS for windows from rudiment to mastery [M]. Beijing: Publishing House of Electronics Industry.

Madsen E. 1973. Effect of CO_2 concentration on the morphological, histological and cytological changes in tomato plants[J]. Acta Agri Scand, 23: 241—246.

Malanson G P, 1993. Comment on modelling ecological response to climatic change[J]. Climatic Change, 23: 95—109.

McMahon T A, Kronauer R E, 1976. Tree structures: deducing the principle of mechanical design[J]. J Theor Biol, 59: 443—466.

Pearson R W, 1966. Soil environment and root development. In: Plant environment and efficient water use(W.H. Peirre, D. Kirkham, J. Pesek *et al*. ed.)[M]. Madison: Am Soc Agron and Soil Sci Am. 95—126.

Peauelas J, Matamala R, 1990. Changes in N and S leaf content, stomatal density and specific leaf area of 14 plant species during the last three centuriess of CO_2 increase[J]. J Exper Bot, 41: 1119—1124.

Rogers H H, Dahlman R C, 1993. Crop responses to CO_2 enrichment[J]. Vegetatio: 104/105: 117—131.

Sarah E Hobbie, E Stuart Chapin III, 1998. The response of tundra plant biomass, aboveground production, nitrogen, and CO_2 flux to experimental warming[J]. Ecology, 79: 1526—1544.

Steigraeber D A, Waller D M, 1986. Non-stationary of tree branching pattern and bifurcation ratios[J]. Proc R Soc Lond B,228: 187 194.

Stocker O, 1974. Der Wasser-und Photosynthesehaushalt[Z].

Thornley J H M, 1976. Mathematical models in plant physiology: A quantitative approach to problems in plant and crop physiology[M]. London: Academic Press.

Whithe G G, 1976. The bifurcation ratio as an indicator of adaptive strategy in woody plant species[J]. Bull Torrey Bot Club, 103: 67—72.

Woodward F I, Bazzaz F A, 1988. The response of stomatal density to CO_2 partial pressure[J]. J Exper Bot, 39: 1771—1781.

Wurr D C E, Hand D W, Edmondson R N *et al*., 1998. Climate change: a response surface study of the effects of CO_2 and temperature on the growth of beetroot, carrots and onions[J]. J Agri Science, 131: 125—133.

Yang S T, Li Y F, Hu Y X *et al*., 1997. Effect of CO_2 concentration doubling on the leaf morphology and structure of 10 species in *Gramineae* [J]. Acta Bot Sicica, 39: 859—866.

Yao H L, Wei C T, Miao M C, 1992. An introduction on the Maowusu sandland sands exploitation and control research center. In: Collected papers of the Maowusu Sandland Sands Exploitation and Control Research Center(First Vol.; Wang J Q ed.)[M]. Huhhut: Inner Mongolia University Press. 1—7.

Zhang X S, 1994. The ecological background of the MuUs sandland the principles and optimal models for grass land management[J]. Acta Photoecol Sinica, 18: 1—6.

Zhu L Y, Bao Y, 1993. Evaluation of habitat conditions for trees and shrubs at MuUs sandlands[M]. Beijing: Chinese Forestry Press.

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