Front. For. China 2007, 2(4): 410–416
DOI 10.1007/s11461-007-0065-5

RESEARCH ARTICLE

AN Yuyan, LIANG Zongsuo, HAN Ruilian, LIU Guobin

Effects of soil drought on seedling growth and water metabolism of three common shrubs in Loess Plateau, Northwest China

Abstract The growth and water metabolism of three common shrubs on the Loess Plateau were studied under soil with different water contents. Results showed that water consumption of those species decreased with the increase in drought stress, and water consumptions of these shrubs were different: *Forsythia suspensa* was the greatest, and *Syringa oblata* was the lowest. The growth rate of new branches and leaf area of three species were the fastest under adequate soil water conditions, and were the lowest under severe drought. Under the same water conditions, the growth of *F. suspensa* was the fastest while that of *S. oblata* was the slowest. The water content, proline and chlorophyll content of different species changed with the increase in soil water stress. The leaf water content of *Periploca sepium* and *F. suspensa* was obviously higher than that of *S. oblata*, while the leaf proline content of *F. suspensa* and *S. oblata* was lower than that of *P. sepium*. The ratio leaf chlorophyll $a:b$ of *F. suspensa* and *S. oblata* decreased with the decrease in soil water content. Although these three shrubs had different mechanisms in response to drought stress, they all had higher drought resistance and could adapt to the drought condition on the Loess Plateau. This paper provided some bases for choosing tree species on the Loess Plateau.

Keywords Loess Plateau, water metabolism, growth, water consumption characteristics, drought stress

Translated from *Acta Botanica Boreali-Occidentalia Sinica*, 2007, 27(1): 91–97 [译自: 西北植物学报]

AN Yuyan, LIANG Zongsuo (✉)
College of Life Science, Northwest A&F University, Yangling 712100, China
E-mail: liangzs@ms.iswc.ac.cn

LIANG Zongsuo, HAN Ruilian, LIU Guobin
Institute of Soil and Water Conservation, Northwest A&F University, Yangling 712100, China

1 Introduction

Drought is an important factor of environment that limited the growth and development of the plants. The Loess Plateau belongs to typical drought and semi-drought area. Water deficit is due to climate and special geographical features on the Loess Plateau (Hou et al., 2000; Han et al., 2003). There has been an urgent problem that how to use limited water source to finish forest vegetation restoration, broaden forest source and improve ecological environment. The choice of drought-resistance plants is a basis and prerequisite of vegetation restoration and ecosystem benigh cycle. There are more than 790 species (including trees, shrubs, liana) on the Loess Plateau (Fu, 2000). *Syringa oblata* Lindl is a deciduous shrub or dwarf of family Oleaceae. *Periploca sepium* Bunge is a straggling shrub of Apocynaceae. *Forsythia suspensa* (Thunb.) Vahl is deciduous shrub of Oleaceae (Ren, 1997). Three shrubs are distributed on hills of the Loess Plateau. Many previous studies reported on photosynthetic and ecological characteistics of three shurbs (Li and Shao, 2004; Ru et al., 2004; Yang et al., 2006). However, it is scarce of studies on the water consumption characteristics, water metabolism and growth of the three shurbs under the maximum temperature in summer. Three native shurbs, *S. oblata*, *P. sepium*, *F. suspensa*, were selected as experimental materials on the Loess Plateau (Fu, 2000), and the water consumption characteristics and leaves physiological change were systemically studied under different soil water conditions by controlling artificially soil water conditions and stimulating natural soil water conditions. This study aimed at providing the scientifically theoretical bases for selecting tree species for vegetation restoration on the Loess Plateau, and also providing valuable bases for the global eco-environmental improvement of water saving agriculture and the raise of planting seedling survival rate.

2 Materials and methods

2.1 Materials and water treatments

Native wild seedlings from close hillsides, *S. oblata*, *P. sepium* and *F. suspensa*, were used as experimental materials provided by Ansai Ecological Position Station of the Chinese Academy of Sciences. The mean height and diameter of these seedlings were 26.30 and 0.85 cm, 59.20 and 0.85 cm, 30.10 and 0.20 cm, respectively.

The maximum soil water content (FC) was 21.5%. Three soil water levels were set as appropriate soil water, medium-stressed soil water and severe-stressed soil water, which were corresponding to 70%–75%, 50%–55% and 35%–40% FC, respectively. Six replicates were made for each treatment and there were three to four plants in each treatment. When the plants were alive, two plants uniformly growing were selected and maintained. On March 8, 2006, the plants were planted in each growing oven made of black plastics (27 cm × 30 cm), which was placed in the mobile-stimulation-drought waterproof room affiliated to Centre of Soil and Water Conservation and Eco-environmental Research, the Chinese Academy of Sciences. From the second day of transplanting, soil water content was controlled with the weighting method every day and supplemented with some water to make up the water loss from evapotranspiration by covering the naked land of ovens with thin plastic films. Water amount for adding to each treatment was recorded by flasks. The whole experiment was carried out until half of October, 2006 (210 days).

2.2 Methods

2.2.1 Water status and water use efficiency (WUE)

Leaf relative water content (RWC) was measured by selecting functional leaves, drying and weighting the total biomass (Gao, 1999). Total WUE equaled to total biomass: total water consumption during each growing season (Yang et al., 2004).

2.2.2 Growth rate of new branches and increase rate of new leaf area

For every seven days, the length change of new branches was recorded. Net increase in dry matter for each month was measured by drying. Total biomass was equal to total dry weight of the seedlings at the end of the experiment before transplanting, which came from the mean of ten seedlings. CI-202 portable scanning apparatus was used to test the increase rate of individual leaf area, through which five to six new growing leaves were chosen for each treatment and measured once every two days during 14 days and the mean was used for discussion.

2.2.3 Physiological indices

The detection of proline content and chlorophyll content was done according to Gao (1999). All data were measured three times at the same time and the mean used for results analysis and discussion.

2.2.4 Water consumption

Every day, the weight of pots at regular time was recorded and the diurnal water consumption was calculated except the soil evapotranspiration. The ten-day water consumption is equal to the sum of water consumption per ten days. The monthly water consumption is equal to the sum of water consumption per day in one month. Total water consumption is equal to the sum of water consumption through the whole growth period and the soil water change between pre-transplanting and after the harvesting of *S. oblata*, *P. sepium* and *F. suspensa* seedlings. The progression of diurnal water consumption was measured by weighing method from 7:00 to 19:00 with an interval of 2 h and the reduced weight of pots was used as the water supplement to maintain the corresponding soil water treatments.

2.2.5 Data analysis

All data were analyzed by SPSS 12.0 statistics software and Microsoft Excel.

3 Results and analysis

3.1 Effects of soil water content on water consumption

3.1.1 Effects of soil water content on water consumption amount

It was observed from Figs. 1–3 that the diurnal water consumption change over the whole growing period showed a multi-peak curve. The peak and cave represented the water consumption on sunny and cloudy days, respectively. The changes of diurnal water consumption curve were similar in soil moisture regimes of three species seedlings. However, the diurnal water consumption amounts were obvious different, the order was given as follows: *S. oblata* > *P. sepium* > *F. suspensa*. Water consumption under three soil water conditions, the order was given as follows: adequate water content > medium-drought water stress > severe-drought water stress condition.

Han et al. (1994) reported that water consumption of different tree species was obviously different in diurnal water consumption, ten-day water consumption and monthly water consumption. In this experiment, under the condition of adequate soil water content, the mean diurnal water consumption of *S. oblata*, *P. sepium* and *F. suspensa* was 0.22, 0.31 and 0.49 kg, respectively. The diurnal water consumption of

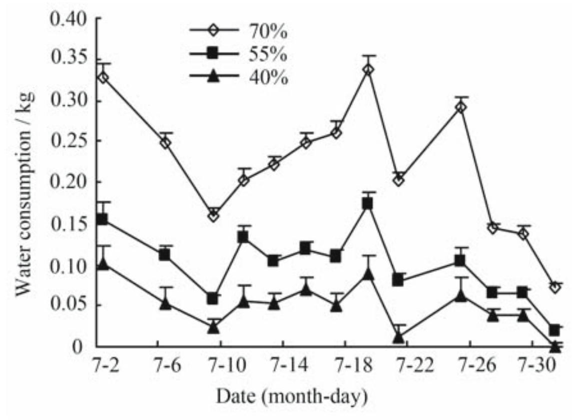

Fig. 1 Changes of diurnal water consumption of *Syringa oblata* seedlings under different soil water stresses

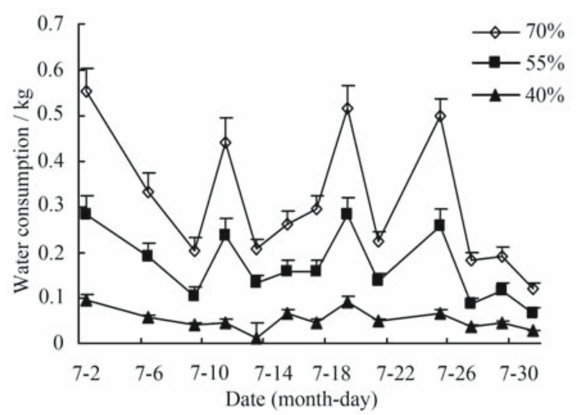

Fig. 2 Changes of diurnal water consumption of *Periploca sepium* seedlings under different soil water stresses

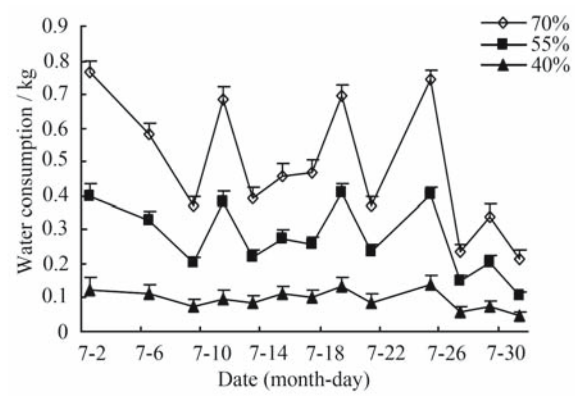

Fig. 3 Changes of diurnal water consumption of *Forsythia suspensa* seedlings under different soil water stresses

F. suspensa was 1.57 times and 2.2 times as great as that of *P. sepium* and *S. oblata*, respectively. Under the condition of medium-drought water stress, the diurnal water consumption of *F. suspensa* was 1.62 times and 2.77 times as great as that of *S. oblata* and *P. sepium*, respectively. Under the condition of severe-drought water stress, the diurnal water consumption of *F. suspensa* was 1.84 times and 1.94 times as great as that of *S. oblata* and *P. sepium*, respectively. Under different soil moisture regimes, the diurnal water consumption of the same tree species was obviously different. In this experiment, under the condition of adequate soil water content, the mean diurnal water consumption of *S. oblata*, *P. sepium* and *F. suspensa* was 2.2 times, 1.8 times and 1.8 times as large as that of *P. sepium* and *F. suspensa* under medium-drought water stress, 4.4 times, 5.9 times and 5.0 times as large as that of *P. sepium* and *F. suspensa* under severe-drought water stress, respectively.

3.1.2 Effects of soil water content on the diurnal process of water consumption

It was found from Fig. 4 that the diurnal processes of water consumption of *S. oblata*, *P. sepium* and *F. suspensa* was significantly different. On July 17, the changes of diurnal water consumption of *S. oblata* and *P. sepium* were a double-peak curve under three soil moisture regimes, and the peak at adequate water content was during about 11:00 to 17:00, respectively. The change of diurnal water consumption of *F. suspensa* was double-peak-shape curve under adequate water content and medium-drought water stress, and it was a single peak curve under severe-drought water stress condition, the peak at adequate water content was during about 13:00 to 17:00 p.m., respectively. The diurnal water consumption of *S. oblata, P. sepium* and *F. suspensa* for three soil water conditions was higher on day than that in night. The diurnal water consumption of *S. oblata*, *P. sepium* and *F. suspensa* for three soil moisture regimes in night was 8.5%, 11.3% and 9.0% of that on day under adequate soil water content, 5.6%, 16% and 11.8% under medium-drought water stress, as well as 3.8%, 34% and 9.3% under severe-drought water stress. The diurnal water consumption of *S. oblata, P. sepium* and *F. suspensa* on day was higher than that in night under three soil moisture regimes.

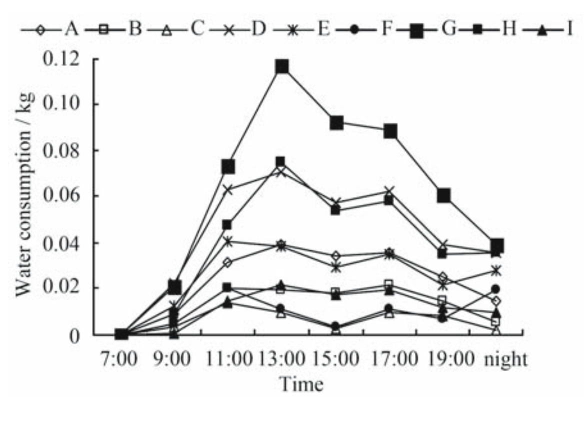

Fig. 4 Changes of water consumption of three shrubs on July 17
Note: A), B), C) the seedlings of *S. oblata* under water content of 70%, 55% and 40% respectively; D), E), F) the seedlings of *P. sepium* under water content of 70%, 55% and 40% respectively; G), H), I) the seedlings of *F. suspensa* under water content of 70%, 55% amd 40% respectively; they are the same as below.

3.2 Effects of soil drying on shoot growth rate and increase rate of new leaves area

3.2.1 Effects of soil drying on shoot growth rate

It was found from Figs. 5–8 that for *S. oblata*, *P. sepium* and *F. suspensa*, the growth rate of seedlings and increase rate in individual new leaf area were significantly different in three soil moisture regimes, and the order was given as follows: appropriate water level > medium-drought level > severe-drought level. The shoot growth rate of *P. sepium* and *F. suspensa* demonstrated an "S-shape" curve. *P. sepium* and *F. suspensa* grew fast from the first ten-day period to the second ten-day period then slowly after last ten-day period of July. The growth rate of *S. oblata* almost took on a linear increase. Under the condition of medium-drought water stress, the main growth of *P. sepium* was in the last ten-day period of July, and it was delayed compared with that under the condition of adequate soil water content. The growth rates of *S. oblata* and *F. suspensa* were slow. Under the condition of severe-drought water stress, the growth rate of *S. oblata*, *P. sepium* and *F. suspensa* were very slow without peak, which showed that the growth of three shrubs was affected by severe-drought water stress. In this experiment, the shoot growth rates of these three shrubs were different under same soil water content, the order was *F. suspensa* > *P. sepium* > *S. oblata.*

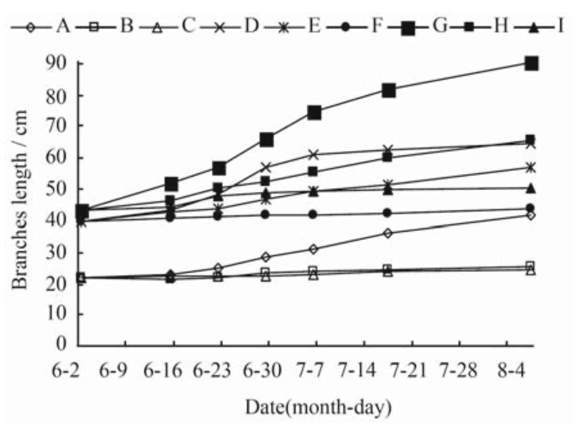

Fig. 5 Growth rate of three shrubs seedlings branches under different soil water stresses

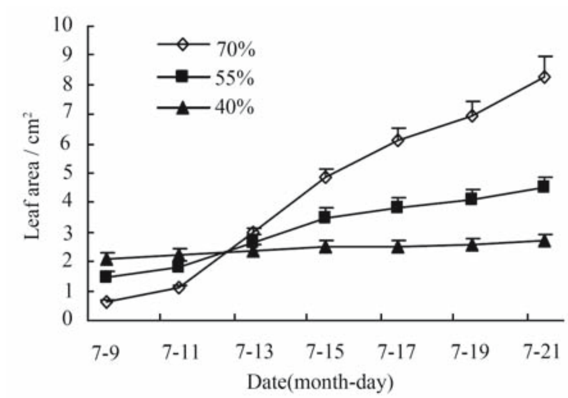

Fig. 6 Changes of new single leaf area in *Syringa oblata* seedlings under different soil water stresses

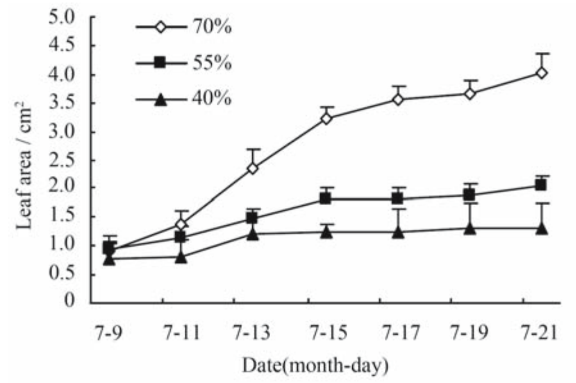

Fig. 7 Changes of new single leaf area in *Periploca sepium* seedlings under different soil water stresses

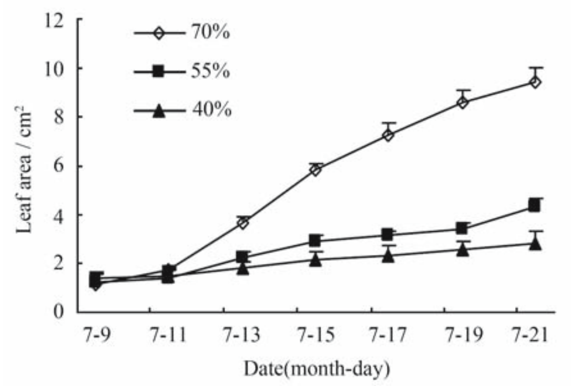

Fig. 8 Changes of new single leaf area in *Forsythia suspensa* seedlings under different soil water stresses

3.2.2 Effects of soil drying on the increase rate of new leaf area

The increase rate of individual new leaf area of *S. oblata*, *P. sepium* and *F. suspensa* under suitable soil water condition demonstrated an "S-shape" curve. Individual new leaf area increased rapidly after new leaves grew on the second day. The increase in individual new leaves of *S. oblata* and *F. suspensa* was higher than that of *P. sepium*. The increase in new leaves of *P. sepium* was rapid during the second day to the sixth day since leaves grew, but after the eighth day, new leaves grew slowly. The rapid increasing period of individual new leaf area of three shrubs was after new leaves grew during the second to the sixth and the second to the fourth day under medium-drought water stress and severe-drought water stress condition, respectively. Comparing with that of suitable soil water condition, the increase tendency of individual new leaf area was resemble, but the increase rate of individual new leaf area was lower and the rapid increasing period of new leaf was shorter under medium-water stress treatment and severe water stress treatment.

3.3 Effects of soil drying on water content and relative water content of leaves

Water content and relative water content of leaves directly reflect the water status, water retaining capacity and against dehydration of plants. It was observed from Fig. 9 that leaf water content of three shrubs under three soil moisture regimes occurred regular change with water stress time prolonging. The order of leaf water content of *P. sepium* was: appropriate water level > medium-drought level > severe-drought level, and in three water contents, the leaf water content all ascended at begin then decreased. However, leaf water content of *P. sepium* under appropriate water level was suddenly drop and was lower than that in medium-drought water condition at the latter period of water stress. Leaf water content of *F. suspensa* rose at the beginning, then decreased under suitable soil water content and medium soil water stress. Leaf water content of *F. suspensa* under severe drought stress was the lowest than that under suitable soil water content and medium soil water stress, and the order was given as follows: appropriate water content > medium-drought content > severe-drought soil water content. Leaf water content of *S. oblata* had greater differences than that of *P. sepium* and *F. suspensa*. At the beginning period of water stress, leaf water content of *S. oblata* was: severe-drought level > medium-drought level > appropriate water level. With water stress time prolonging, leaf water content began increasing then decreased under suitable soil water content, and leaf water content under medium-drought level and severe-drought level was always lower than that under suitable soil water content. The order of leaf water content at the latter period of water stress was: appropriate water level > medium-drought level > severe-drought level.

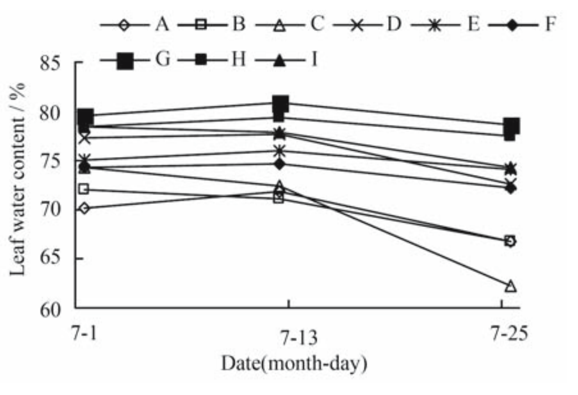

Fig. 9 Changes of water content of three species under different soil water stresses

It can be found from Fig. 10 that the relative water content of leaf of three shrubs under three soil moisture regimes went through different change tendencies with soil water content

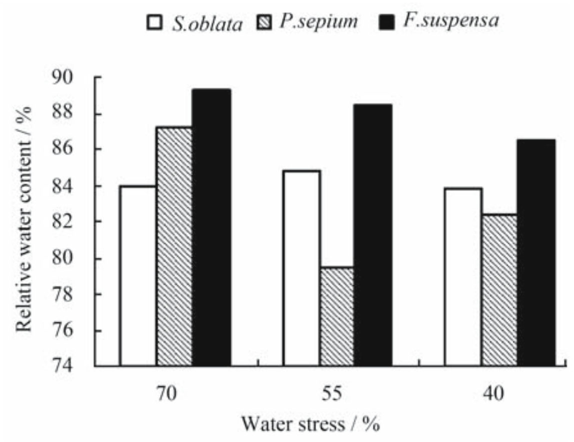

Fig. 10 Relative water content of three species under different soil water stresses

reduction. Relative water content of leaf of *S. oblata* rose at the beginning stage of soil water stress and then reduced with soil water stress time prolonging. Relative water content of leaf of *P. sepium* reduced at the beginning stage of soil water stress and then rose with soil water stress time prolonging. Relative water content of leaf of *F. suspensa* kept decreasing. It was expressed that *S. oblata* and *P. sepium* have certain adaptability and adjust capacity on drought stress.

3.4 Effects of soil water content on proline content of leaves

Proline content change was regarded that it was a sensitive material under adverse circumstances. It was the biggest amino acid of water soluble amino acid (162.3 g/100 g, 25°C). It has a stronger capacity of hydration. Proline content increased under adverse circumstances, which was important for maintaining cell moisture and steady organism marcro-molecule structure (Ding et al., 2006). It was found from Fig. 11 that proline content of *P. sepium* was not obviously different under appropriate water level and medium-drought

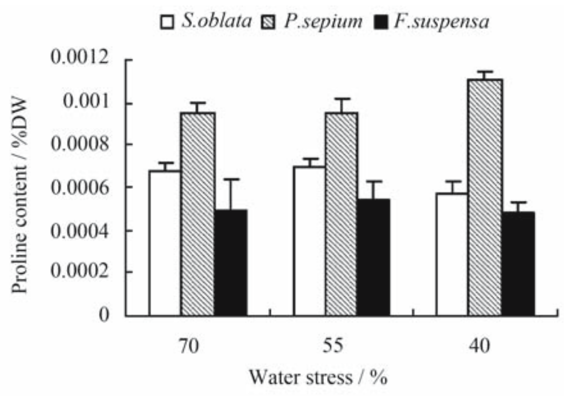

Fig. 11 Proline content of three species under different soil water stresses

level, but it increased obviously under severe drought water stress. *P. sepium* improved drought resistance through increasing osmotic material under drought stress condition. Proline contents of *S. oblata* and *F. suspensa* rose at the beginning stage of soil water stress and then decreased with soil water content reducing and drought stress time prolonging. Proline content of *S. oblata* and *F. suspensa* under medium soil water content increased and improved stress resistance and adaptability. However, under severe drought stress, proline contents of *S. oblata* and *F. suspensa* were decreased at different degrees.

3.5 Effects of soil water content on chlorophyll content

It was observed from Fig. 12 that chlorophyll contents of *S. oblata* and *F. suspensa* obviously increased with soil water content reducing, but chlorophyll content of *P. sepium* decreased. Chlorophyll *a*/*b* change was different for different shrubs. Chlorophyll *a*/*b* of *S. oblata* and *F. suspensa* was always dropped with soil water content reducing (Fig. 13). Chlorophyll *a*/*b* change of *P. sepium* was not obvious under medium soil water content, but obvious under severe drought stress.

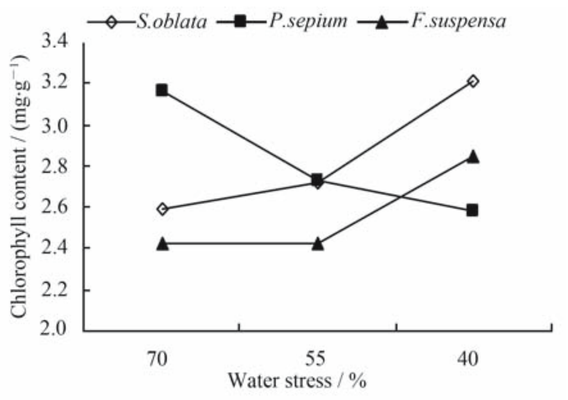

Fig. 12 Chlorophyll content of three species under different soil water stresses

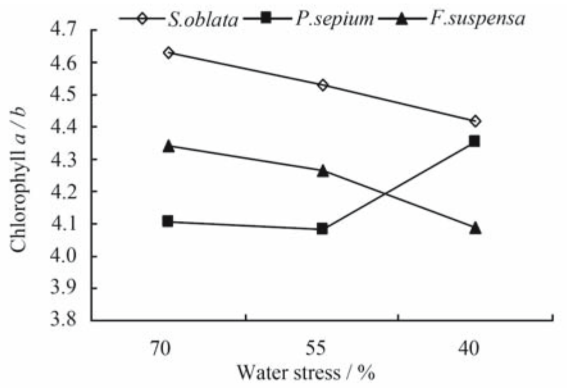

Fig. 13 Changes of chlorophyll *a*/*b* of three species under different soil water stresses

3.6 Effects of soil water content on WUE

Total WUE equaled to the ratio of total biomass to total water consumption during each growing season. It reflected energy transformation rate in plant production process, and it was an index of evaluating plant growth under water stress (Huang and Shan, 1998). Table 1 showed that the WUE of *S. oblata* and *F. suspensa* obviously dropped with soil water content reducing. The WUE of *P. sepium* under medium soil water level rose, and it had not significant difference from suitable soil water content. Under appropriate soil water condition, the WUE of *S. oblata* was greatly higher than that of *P. sepium*. The difference of WUE of *P. sepium* and *P. sepium* was not obvious. However, under medium-drought soil water content and severe-drought soil water content, WUE of *P. sepium* was the highest, and WUE of *F. suspense* was the lowest. It showed that *P. sepium* can more efficiently use limited water source under drought condition.

Table 1 WUE of three shrub species under three soil moisture regimes (unit: $g \cdot kg^{-1}$)

Water treatment	*Syringa oblata*	*Periploca sepium*	*Forsythia suspensa*
70%	0.76 a	0.47 a	0.44 a
55%	0.46 b	0.50 a	0.33 b
40%	0.15 c	0.18 b	0.12 c

Note: the same letters indicate no difference at $\alpha = 0.05$ level (*SSR* test).

4 Discussion

The soil water content is a main factor affecting plant transpiration. Many researches showed that water consumption was higher under suitable soil water content, and water consumption was lower under drought stress condition (Xu, 1993). In this experiment, soil water content had a significant influence on diurnal, ten-day and monthly water consumption of three shrubs, and the order was given as follows: appropriate water level > medium-drought level > severe-drought level. In this experiment, the water consumption was different with different shrubs, the order was given as: *F. suspensa* > *P. sepium* > *S. oblata*. There was relativity between soil water content and water consumption of trees (Wang et al., 1996). This study showed that leaf relative water content of three shrubs at drought stress last certain time was as follows: appropriate water regime > medium-drought regime > severe-drought regime. Leaf water content of *F. suspensa* and *P. sepium* was obvious higher than that of *S. oblata*. It was explained that leaf water content of *S. oblata* was maintained higher level than that of *F. suspensa* and *P. sepium*, and lasted longer time than that of *F. suspensa* and *P. sepium* under drought stress condition. New branches growth and increase rate of individual new leaf area of three shrubs was significantly decreased with soil water content reducing. The growth rate of *F. suspensa* under three soil moisture regimes was higher than that of *S. oblata* and *P. sepium*. The growth rate of *S. oblata* was obviously affected by medium soil water level. It showed that *S. oblata* adapted suitable soil water content. This study showed that the leaf proline content was not largely affected under three soil moisture regimes conditions. Comparing the three shrub species, proline content of *P. sepium* was greatly higher than that of *S. oblata* and *F. suspense*. Proline content of *F. suspense* was the lowest. It showed that *P. sepium* had the greater ability of quickly increasing proline content to adapt drought stress than that of *S. oblata* and *F. suspense*. The decrease in chlorophyll a/b was an important physiological index of leaf senescence (Ren et al., 2000). Chlorophyll *a*/*b* of *S. oblata* and *F. suspensa* gradually dropped with soil water content reducing. However, chlorophyll *a*/*b* of *P. sepium* increased. Compared with *P. sepium*, chlorophyll *a*/*b* of *S. oblata* and *F. suspensa* always maintained higher level. It showed that three shrubs all had stronger drought resistance but mechanisms adapting water stress were different.

This study showed that the soil water content affected water consumption of trees and growth rate, the order was given as follows: appropriate water regime > medium-drought regime > severe-drought regime. However, the growth of *S. oblata* was slow under medium soil water level. It showed that *S. oblata* only adapted suitable soil water content. Under appropriate water regime, WUE of *S. oblata* was higher than that of *P. sepium*. The WUE of *P. sepium* was not greatly different from that of *P. sepium*. However, under medium-drought soil water regime and severe-drought soil water regime, WUE of *P. sepium* was the highest and showed that *P. sepium* had stronger drought resistance. Under drought stress, the change of proline content and chlorophyll content of three shrubs was different. The three shrubs had different drought resistance mechanism, but they all had stronger drought resistance and great adaptability under summer drought condition on the Loess Plateau. Water consumption and drought resistance of three shrubs at total growing stage will be further studied.

Acknowledgements The work in this paper was supported by the National Natural Science Foundation of China (Grant No. 90302005), Knowledge Innovation Engineering of the Chinese Academy of Sciences (KZCX01-6), and the Application and Dissemination Program of Forestry Office (2005).

References

Ding C, Yang Q H, Li F S (2006). Effect of cold stress on the content of free-proline in leaf of *Snccharum spontaneum* L. and *Sderostachya*. J Anhui Agric Sci, 34(5): 846–849 (in Chinese)

Fu K J (2000). Flora Loess Plateaus Sinicae. Science Press (in Chinese)

Gao J F (1999). Experimental Technology of Plant Physiology. Xi'an: World Publishing Corporation (in Chinese)

Han R L, Jing W J, Hou Q C (2003). Research advance of artificial preparation and drought-resistant afforestation on Loess Plateau. Acta Bot Boreal-Occident Sin, 23(8): 1,331–1,335 (in Chinese)

Han R L, Liang Z S, Hou Q C (1994). Water consumption properties of adaptable nursery stocks on Loess Plateau. Chin J Appl Ecol, 5(2): 210–213 (in Chinese)

Hou Q C, Han R L, Li H P (2000). On problems of vegetation reconstruction in Yan'an experimental area. Res Soil Water Conserv, 7(2): 119–123 (in Chinese)

Huang Z B, Shan L (1998). Research progression on water use efficiency and its physio-ecological mechanism. Eco-agricult Agric Res, 6(4): 19–23 (in Chinese)

Li Y Y, Shao M A (2004). The change of plant diversity during natural recovery process of vegetation in Ziwuling area. Acta Ecol Sin, 24(2): 252–260 (in Chinese)

Ren A Z, Gao Y B, Liu S (2000). Effects of Cr, Cd and Pb on free proline content etc in leaves of *Brassica chinensis* L. Chin J Appl Environ Biol, 6(4): 112–116 (in Chinese)

Ren X W (1997). Trees. Beijing: China Forestry Publishing House (in Chinese)

Ru W M, Qu X X, Hou J Q (2004). Study on the characteristics of *Forsythia suspense* community in Taiyue wood district. Acta Bot Boreal-Occident Sin, 24(8): 1,462–1,467 (in Chinese)

Wang M B, Li H J, Chai B F (1996). Water ecophysiological characteristics of *Caragana korshinskii*. Acta Phytoecol Sin, 20(6): 494–501 (in Chinese)

Xu D Y (1993). Tree Hydrology. Beijing: China Forestry Publishing House (in Chinese)

Yang C H, Wang Y Y, Zhou Z F, Zhang G C (2006). Response of gas exchange parameters of *Periploca sepium* Bunge to soil water content in Loess Plateau. For Res, 19(2): 231–234 (in Chinese)

Yang J W, Liang Z S, Han R L (2004). Water use efficiency and water consumption characteristics of poplar under soil drought conditions. Acta Phytoecol Sin, 28(5): 630–636 (in Chinese)