Research paper

Responses of Photosynthetic Physiology and Biomass Accumulation of Sweet Kernel Apricot (*Prunus armeniaca*×*sibirica*) Seedling to Soil Drought Stress in the Ancient Course of the Middle Yellow River

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【Summary】

Sweet kernel apricot (*Prunus armeniaca*×*sibirica*) is a Chinese characteristic species and an important ecological, woody grain and oil tree in the "Sanbei" area, but the biomass accumulation and photosynthetic responses of sweet kernel apricot seedlings to soil drought stress are unclear. Samples of the *P. armeniaca*×*sibirica cultivar*, Zhongren No. 1 were collected, and 6 water content gradients were arranged in the ancient course of the middle Yellow River: 14.0 (±0.5%), 12.0 (±0.5%), 10.0 (±0.5%), 8.0 (±0.5%), 6.0 (±0.5%) and 4.0% (±0.5%). Results showed that (1) the leaf's net photosynthetic rate (P_n), transpiration rate (T_r) and stomatal conductance (G_s) initially increased and then gradually decreased as the water content decreased, while there was an increasing then declining tendency in water use efficiency (WUE). (2) The diurnal variation curve was a unimodal type for Zhongren No. 1 which had no midday depression of photosynthesis. When the soil water decreased, the light saturation point (LSP) gradually declined and the light compensation point (LCP) increased. (3) When the soil water content declined, the photosynthsis system PS II original light energy conversion efficiency (F_v/F_m), the maximum fluorescence (F_m), apparent photosynthetic electron transport rate (ETR) and coefficient of photochemical quenching (qP) all decreased while there was a little increment of 12.0% in the F_0, and the coefficient of photochemical quenching (qN) initially increased and then declined. (4) As the soil water decreased, the biomass accumulation gradually dropped while the root-shoot ratio increased. The damage from water deficits was regulated through an increment in the root-shoot ratio. Our results suggested that on 8.0~14.0% soil water content would be suitable, and on optimum moisture content was 12.0%. Meanwhile, the minimum moisture content in the soil to keep *P. armeniaca*×*sibirica* cultivar Zhongren No. 1 seedlings alive would be no less than 4.0%.

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研究報告

黃河古道中游乾旱逆境對甜仁杏(*Prunus armeniaca*×*sibirica*)光合生理及生物量積累影響

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摘 要

甜仁杏是中國特色的、“三北”地區適生的生態和木本油料樹種，對確保林業生態工程建設和國家糧油安全具有重要意義。但是，關於黃河古道中游土壤乾旱對苗期甜仁杏的適應性及光合生理、生物量積累的影響研究未見報道。以甜仁杏新品種“中仁1號”為研究物件，基於人工控水的方法，設置土壤品質含水量在14.0±0.5、12.0±0.5、10.0±0.5、8.0±0.5、6.0±0.5、4.0±0.5%共6個水準展開研究。研究結果表明：(1)隨著土壤水分含量的降低，“中仁1號”幼苗葉片淨光合速率(P_n)、蒸騰速率(T_r)和氣孔導度(G_s)先上升後下降，但水分利用效率(WUE)先降低後升高再降低。(2)“中仁1號”的日變化曲線為單峰型，無光合“午休”現象；在乾旱脅迫的條件下，“中仁1號”幼苗的光飽和點(LSP)逐漸減小，光補償點(LCP)逐漸增加；(3)葉綠素螢光PS II原初光能轉換效率(F_v/F_m)、最大螢光(F_m)、表觀光合電子傳遞速率(ETR)和光化學猝滅係數(qP)隨著乾旱脅迫的加劇而降低，在12.0%處理時有小幅度的上升，但最小螢光(F_0)、非光化學猝滅係數(qN)先上升後逐漸下降，但均比14.0%處理要高。(4)“中仁1號”苗期生物量積累隨乾旱脅迫加劇而受制約，而根冠比卻相反，說明自體可通過提高根冠比減緩水分缺失帶來的傷害。黃河古道中游“中仁1號號”苗期生長的土壤水分適應範圍為8.0~14.0%，最適含水量為12.0%，下限為4.0%左右。

關鍵詞：沙地、土壤含水量、光合作用、葉綠素螢光、幹物質積累。

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INTRODUCTION

Water deficit is one of the premier limitations to plant survival and growth in drought areas due to the complexity of water-limiting conditions and a changing climate (Hsiao 1973, Fang and Xiong 2015). According to statistics, 1/3 of the earth's land area belongs to arid and semi-arid areas (Fang and Xiong 2015); in China, the arid area reaches 2.8×10^6

km^2, and the sandy area of the ancient course of the Yellow River reaches to 1.3×10^4 km^2 and is important reserved soil that is undeveloped (Fang et al. 2004, Chen et al. 2015). It is estimated that by 2030, the amount of water shortage in West China will be up to 20×10^9 m^3, and North China will face even-more-severe drought situations with increasing times, intensity, and range of extreme drought in the next 40 yr (Zhou 2015). Li et al. (2004) investigated how plants produce organic matter by photosynthesis, with photosynthesis being the key factor of plant productivity, and the water regime being one of the most important factors that influence photosynthesis. Zhu et al. (2004) and Pei et al. (2013) showed that drought stress can cause the leaf stomatal to shut down and the transpiration rate to decrease, which causes a decrement in the net leaf photosynthetic rate and gradually lowers leaf fluorescence parameters such as F_0 (minimum fluorescence), the orginal light energy conversion efficiency F_v/F_m (Photosynthesis system II maximum quantum yield), and qP (coefficient of photochemical quenching), reduces rubisco activity, and partially inactivates photosynthesis system II (PS II) (Liao and Wang 2014, Fang and Xiong 2015). Moreover, the aboveground and underground biomass accumulation of plants changes (Yan et al. 2011). Therefore, by investigating photosynthetic physiological variations and biomass accumulation of plants in environment drought conditions, insights into the responses of plants to drought stress can be gained, and a theoretical basis of photosynthetic physioecology and biomass for promotion high-yield cultivation of economic trees in drought areas can be achieved.

The sweet kernel apricot (*Prunus armeniaca* ×*sibirica*) has often been considered a mutant of an interspecific natural crossing between the apricot and Siberian apricot (*P. sibirica*) that resulted in unique characteristics such as a sweet kernel, less pulp, a thin pericarp, and kernels as the production aim (Zhang et al. 2015). It has strong resistance to cold and drought, and is tolerant to saline conditions which makes it suitable for growing in drought areas (Hou et al. 2008). Together with the advantages of simple management, high economic value, and good ecological effects, it is one of the few ecologic and economic trees which are suitable for planting in drought areas. In recent years, researchers have focused on genetic diversity (Ai et al. 2011, Zhang et al. 2013), flowering and fruit setting (Jing and Zhai 2008), and low-temperature stress (Zheng et al. 2008, Wang et al. 2013). Research on the drought-resisting properties of apricot plants has shown that drought greatly influences their stomatal activity, transpiration rate, and net photosynthetic rate (Ruiz-Sánchez et al. 2000, Barradas et al. 2005, Wei and Cui 2008). Meanwhile, as drought stress intensifies, the ground diameter, plant height, above-ground biomass, and root dry weight decrease (Jing et al. 2005). On the other hand, drought stress promotes water use efficiency (Li et al. 2003), and the application of brassin promotes its photosynthesis and drought-resisting properties (Wang et al. 2000). However, 3 questions remain unconfirmed about sweet kernel apricot: (1) What is its ability to adapt to drought growth in the ancient course of the Yellow River? (2) What is the impact of drought on PS II of sweet kernel apricot? and (3) What are the degree of drought resistance, the duration time, and suitable soil water content, of the sweet kernel apricot?

In this paper, we used 2-yr-old seedlings of new sweet kernel apricot *P. armeniaca*×*sibirica* cultivar Zhongren No. 1 as a sample to study the influence of different water conditions on the photosynthetic physiology, chlorophyll fluorescence characteristics, and biomass accumulation by controlling water using quartz sand potted planting in the ancient course of the middle Yellow River. The study preliminarily discusses the influentid characteristics of drought stress on the growth and development of sweet kernel apricot in the seedling stage in the ancient course of the middle Yellow River.

MATERIALS AND METHODS

Study site

The study site was located at the Non-timber Forestry Research and Development Center, Chinese Academy of Forestry, Jinwu Village, Yuanyang County, Henan Province (113°36′~114°15′E, 34°55′~35°11′N). It belongs to the northern Henan plain, and overlooks the Yellow River to the south and Yu River channels to the north. The soil type is sand. The main climate type in the region is a continental monsoon climate, which means it has 4 distinct seasons and a large temperature difference. The average annual rainfall is 571.7 mm and is extremely uneven. About 70% of the total rainfall is concentrated in July, August, and September and the non-flood season witnesses much less rainfall. The multi-year average evaporation capacity is 1599.0 mm.

Experiment design

Samples

Zhongren No. 1 was selected and bred from offspring of the nationally cultivated sweet kernel apricot You Yi which has the largest cultivation area. It features a high yield, cold resistance and drought resistance. In late November, 2013, 2-yr-old sweet kernel apricot Zhongren No. 1 was planted in pottery flower pots with a depth of 0.5 m and a diameter of 0.6 m. The base fertilizer applied was 1.0 kg of organic fertilizer and 20.0 g of N, P, K fertilizer (N : P : K = 20 : 10 : 10) in November 2013 and a topdressing of 20.0 g of N, P, K fertilizer (N : P : K = 20 : 10 : 10) was added in March 2014. The bottom of the pot was covered with tiles to prevent roots from entering the soil. Sandy soil of the research station was selected, which had the following properties: 0.1~0.5 mm in diameter, 1.4 $g\cdot cm^{-3}$ of soil bulk density, organic matter content of 0.3 $mg\cdot kg^{-1}$, available P of 10.9 $mg\cdot kg^{-1}$, available K of 106 $mg\cdot kg^{-1}$, hydrolyzable nitrogen of 56.12 $mg\cdot kg^{-1}$, pH 8.52, and a maximum field capacity (volumetric water content) of 18~20%. Stem height was 0.6 m, and 4 lateral branches respectively located in 4 directions were preserved after trimming, from a uniform natural open-central training. In order to reduce the impact of rainfall and facilitate the measurement of photosynthetic indexes, the entire flower pot was covered with a polyproplene plastic membrane at 30 cm above the ground. For the lower part, adequate ventilation was required to prevent high temperatures. Trenches for isolation and drainage were dug between each treatment.

Soil water content gradient setting

After planting, watering was carried out until the water content reached the maximum field capacity, and was then stopped. The soil water content remained constant for 7 successive d, and a 3% water content of the soil was selected as the control value of the lower gradient limit in this research. Early preliminary experiments showed that when a 3% mass water content of the soil lasted for more than 5 d, the plant underwent irreversible damage, and if it lasted for more than 1 wk, the plant died. Therefore, in order to guarantee normal work, the lower limit of the water content gradient was set to 4.0±0.5%, and the water content gradient was set at an equidistant 2%. The experiment of the moisture gradient design was begun on 15 April 2014. Six treatments of soil water contents of 14.0±0.5, 12.0±0.5, 10.0±0.5, 8.0±0.5, 6.0±0.5, and 4.0±0.5 were separately established. Each water content was applied to 5 plants, and each treatment was repeated 3 times. A rapid soil moisture analyzer (TZS-3X Soil Detector, Zhejiang Topy Instrument, Hangzhou, China) was used to monitor the volumetric water content of the soil 25 cm above the substrate at 18:00. When the water content was below the required treatment, the plants were watered until the corresponding moisture gradient was achieved. Then, the corresponding indicators were determined when the soil water was maintained at the corresponding moisture gradient.

Measurement methods

Measurement of the photosynthetic index

On 25 June to 25 July 2014, one piece of mature leaf was picked from the middle-upper part of a branch in each pot and from each direction (south, north, east and west) at 09:00~11:30 on a sunny day. Photosynthetic indexes were measured with a Li-6400 portable photosynthesis system (LI-COR, Nebraska, 4647 Superior Street Lincoln, USA). The leaf temperature was set to 25℃ and the relative humidity to 50~65%. The CO_2 content of the control was consistent with the samples. Under photosynthetic active radiation (PAR) of 1500 $\mu mol \cdot m^{-2} \cdot s^{-1}$, the net photosynthetic rate (P_n), stomatal conductance (G_s), transpiration rate (T_r), and intercellular CO_2 concentration (C_i) were measured. Then, the instantaneous water use efficiency (WUE) was calculated from P_n and T_r according to WUE = P_n/T_r. The diurnal variation was measured every 2 h from 6:00 to 18:00. Meanwhile, the PAR was consistent between the inside and outside of the leaf chamber. The change in the P_n with PAR was measured under values of 0, 20, 50, 100, 200, 400, 600, 800, 1000, 1500, 2000, and 2500 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

Measurement of chlorophyll fluorescence parameters

Chlorophyll fluorescence parameters were measured with a PAM-2500 portable chlorophyll fluoroanalyzer (Walz, Effeltrich, Germany), including the F_0, maximum fluorescence (F_m), F_v/F_m, apparent photosynthetic electron transport rate (ETR), qP and coefficient of non-photochemical quenching (qN). The illumination intensity was fixed at 663.0 $\mu mol \cdot m^{-2} \cdot s^{-1}$ based on a previous experiment. Before measurement, the leaf was treated with dark adaption for 30 min.

Measurement of the biomass index

After measuring the photosynthesis physiological indexes, seedlings were carefully dug out, and the roots and stems were stored separately. Root were put on a 0.5-mm sieve and rinsed with water, and broken root pieces were collected and the moisture was absorbed on the surface. First, the root system was categorized according to the diameter grade, and for each grade, the length and weight of the small portion of the root system were measured. The overall length of the root system was obtained by estimating the mass-length ratio (Liu 1995). The fresh trunk, leaves, roots and twigs were put into a kraft bag, de-enzymed for 8 min at 105℃, and dried to a constant weight at 75℃. Finally, dry weights of the trunk, leaves, twigs, and roots were measured, and the root-shoot ratio was calculated.

Data processing

Experimental data were processed using

PASW Statistics version 18.0 (IBM, Armonk, New Orchard Road, USA) for one-way of analysis variance (ANOVA). Variation analysis between mean values was achieved using Duncan□s new multiple range method to compare differences among different data. The significance level was set to 0.05, and data were ploted with Excel 2007.

RESULT

The photosynthetic physiological response of Zhongren No. 1 at the seedling stage to different soil water contents

Influence of different soil water contents on P_n, T_r, G_s, C_i, and WUE

During the seedling stage, changes in P_n, T_r, G_s, C_i, and WUE showed the same tendency of an initial increase and a later decrease. Treatment of 12.0% yielded the highest P_n, T_r, G_s, and C_i, with the values of 13.00 $\mu mol \cdot m^{-2} \cdot s^{-1}$, 6.51 $\mu mol \cdot m^{-2} \cdot s^{-1}$, 0.28 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and 329.0 $\mu mol \cdot mmol^{-1}$, respectively. However, 4% treatment yielded the lowest values of 4.87 $\mu mol \cdot m^{-2} \cdot s^{-1}$, 1.72 $\mu mol \cdot m^{-2} \cdot s^{-1}$, 0.07 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and 237.3 $\mu mol \cdot mmol^{-1}$, respectively. The peak was different for the WUE, with the highest with the 8% treatment (3.48 $\mu mol \cdot mmol^{-1}$) and the lowest with the 14% threatment (2.00 $\mu mol \cdot mmol^{-1}$).

Influence of different soil water contents on diurnal variations in the net photosynthetic rate (P_n)

Diurnal variations in the P_n under water stress belonged to a single-peak type and showed no midday depression of photosynthesis (Fig. 1, P_n). The peak of 12.0% appeared at 12:00 with a value of 10.82 $\mu mol \cdot m^{-2} \cdot s^{-1}$, which was 20.06% higher than that of 14.0%. The P_n value of 12.0% before 10:00 and after 14:00 was smaller than that of 14.0%. The peaks with 10.0, 8.0 and 6.0% appeared at 10:00 with peak values of 10.82 $\mu mol \cdot m^{-2} \cdot s^{-1}$, 9.56 $\mu mol \cdot m^{-2} \cdot s^{-1}$, and 7.22 $\mu mol \cdot m^{-2} \cdot s^{-1}$, respectively. Peak values of 10.0 and 8.0% increased by 22.09 and 11.24%, respectively, compared to 14.0%. The peak of 4.0% appeared at 08:00, and its value was lowest among treatments.

Influence of different soil water contents on diurnal variations of the transpiration rate (T_r)

Diurnal variation trend of T_r belonged to a single-peak type (Fig. 1, T_r). T_r values of 14.0, 12.0, 10.0, 8.0, and 6.0% rapidly increased from 08:00 to 12:00, and reached

Table 1. Variations of P_n, T_r, G_s, C_i, and WUE of Zhongren No. 1 under different soil water contents

Treatment \ Index	P_n ($\mu mol \cdot m^{-2} \cdot s^{-1}$)	T_r ($mmol \cdot m^{-2} \cdot s^{-1}$)	G_s ($mmol \cdot m^{-2} \cdot s^{-1}$)	C_i ($\mu mol \cdot mmol^{-1}$)	WUE ($\mu mol \cdot mmol^{-1}$)
14%	11.76±0.19b	5.43±0.79b	0.26±0.008b	286.1±11.8c	***2.00±0.10c***
12%	***13.00±0.38a***	***6.51±0.36a***	***0.28±0.008a***	***329.0±4.5a***	2.23±0.08c
10%	9.97±0.25cd	3.94±0.10c	0.19±0.006c	307.9±6.4b	2.55±0.11bc
8%	9.37±0.38d	2.78±0.14d	0.21±0.009c	290.7±6.7c	***3.48±0.29a***
6%	8.76±0.29de	2.72±0.19d	0.14±0.005d	269.4±8.3d	3.30±0.16a
4%	***4.87±0.23e***	***1.72±0.12e***	***0.07±0.003e***	***237.3±6.2e***	3.03±0.38ab

Note: Different letters indicate a significant difference (p < 0.05). Data in the table are the mean±standard error.

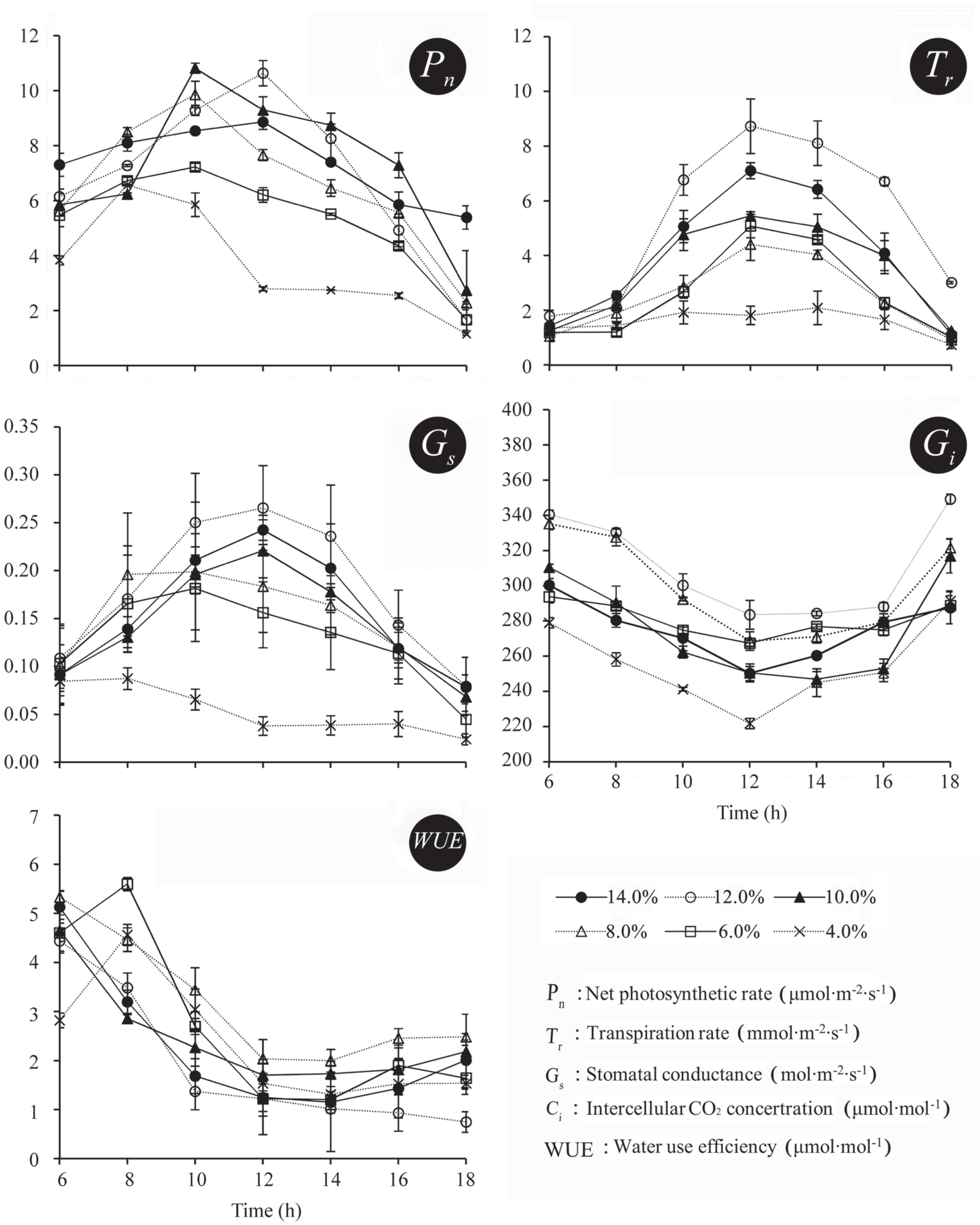

Fig. 1. Diurnal variation of P_n, T_r, G_s, C_i, and WUE of Zhongren No. 1 seedlings.

peak values at 12:00 of 7.10 $mmol \cdot m^{-2} \cdot s^{-1}$, 5.45 $mmol \cdot m^{-2} \cdot s^{-1}$, 4.42 $mmol \cdot m^{-2} \cdot s^{-1}$, and 5.08 $mmol \cdot m^{-2} \cdot s^{-1}$, respectively. The peak for 4.0% appeared at 10:00 with a peak value of 1.92 $mmol \cdot m^{-2} \cdot s^{-1}$. After 12:00, T_r values of different treatments slowly decreased. T_r value of 12.0% was higher than that of 14.0% on all days, contrary to the other 4 treatments.

Influence of different soil water contents on diural variations of stomatal conductance (G_s)

Diurnal variation in G_s belonged to a single-peak type (Fig. 1, G_s). Peaks of 14.0, 12.0, and 10.0% appeared at 12:00 with peak values of 0.1837 $mmol \cdot m^{-2} \cdot s^{-1}$, 0.2426 $mmol \cdot m^{-2} \cdot s^{-1}$, and 0.1808 $mmol \cdot m^{-2} \cdot s^{-1}$, respectively. Peaks of 8.0, 6.0, and 4.0% appeared at 08:00 with peak values of 0.2088 $mmol \cdot m^{-2} \cdot s^{-1}$, 0.1815 $mmol \cdot m^{-2} \cdot s^{-1}$, and 0.0875 $mmol \cdot m^{-2} \cdot s^{-1}$, respectively.

Influence of different soil water contents on diurnal variations of the intercellular CO_2 concentration (C_i)

Diurnal variation in C_i showed a single concave curve (Fig. 1, C_i), which was basically opposite to the diurnal variation trend of P_n. C_i values at 06:00 and 18:00 were relatively higher than that at 12:00, which was the lowest value all day. In general, the diurnal variation in C_i followed the order of 12.0 > 8.0 > 6.0 > 14.0 > 10.0 > 4.0%, which was basically in line with the variation in G_s.

Influence of different soil water contents on diurnal variations of the water use efficiency (WUE)

Diurnal variation in WUE obviously differed from the changing patterns of P_n and T_r (Fig. 1, WUE). WUE values of 6.0 and 4.0% were higher all day and reached a peak at 08:00. For the other 4 treatments, WUE values gradually decreased from 06:00 to 18:00.

Response of the net photosynthetic rate (P_n) to photosynthesis active radiation (P_n-PAR) of Zhongren No. 1 under different soil water contents

Variation trends of P_n-PAR photoresponse curves under different water treatments were basically the same. They had an apparent LSP, which means that as the light intensity increased, the P_n initially rase and later became steady (Fig. 2). When the soil water decline intensified, the LSP of Zhongren No. 1 gradually decreased, the

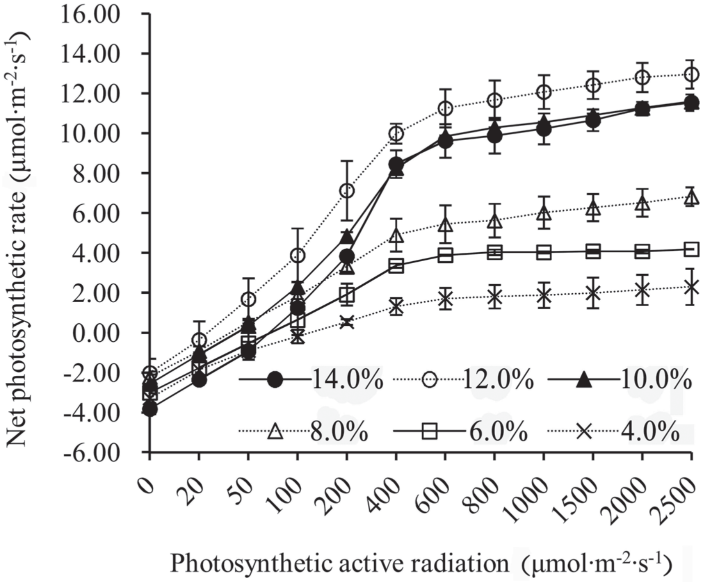

Fig. 2. Response of the net photosynthetic rate of Zhongren No. 1 to photosynthetically active radiation under different soil water contents.

LCP gradually increased, and the maximum photosynthesis rate also decreased in turn. When soil water contents were 14.0, 12.0 and 10.0%, Zhongren No. 1 showed relatively higher LSP values and maximum photosynthesis rates compared to 8.0, 6.0 and 4.0%.

Influence of different soil water contents on the chlorophyll fluorescence of Zhongren No. 1

The value of F_v/F_m changes very little under non-stress conditions, while it dramatically declines under stress conditions (Zhang 1999). There was no significant difference among 14.0, 12.0, 10.0, and 8.0%, and their F_v/F_m values were all around 0.80. However, the difference between 6.0 and 4.0% was significant, and the value of 4% was significantly lower than 6.0% (Table 2).

The value of qP represents the openness level of the PS II reaction center (Zhang 1999). Differences among various treatments were very significant. When the soil water decline intensified, the value of qP gradually declined (Table 2). The qP value of 12.0% was significantly higher than those of other treatments, while no significant difference was seen between 14.0 and 10.0%, and differences among 8.0, 6.0 and 4.0% were significant.

The value of qN reflects the light energy wasted as heat (Maxwell et al. 2000). Differences in qN values among treatments were significant. When the soil water decline intensified, the value of qN gradually increased (Fig. 4A). The 4.0% treatment had the highest qN value, which significantly differed from that of 14.0%. No significant difference was found between 14.0 and 12.0%. Differences among 10.0, 8.0, and 6.0% were significant, and no significant difference existed between 6.0 and 4.0%.

The value of F_0 represents the fluorescence yield when the PS II reaction center is fully open (Zhang 1999). When the soil water decline intensified, the F_0 value initially increased and then decreased, and differences in F_0 values among various treatments were significant (Table 2). Multiple comparisons with the new multiple range method showed that no significant differences existed among 14.0, 12.0 and 10.0%; 12.0, 10.0 and 8.0%; or 10.0, 8.0, and 4.0%, respectively. The difference between 6.0 and 12.0% was significant.

The value of F_m represents the fluorescence yield when the PS II reaction center is fully closed (Guo et al. 2007). When the soil water decline intensified, the F_m value initially increased and later decreased (Table 2), and differences in F_m values among various treatments were very significant. No significant difference in F_m values was found among 14.0 and 10.0%, or 8.0 and 6.0%. The 12.0% treat-

Table 2. Variations in F_v/F_m, F_0, qP, qN, F_m, and ETR of Zhongren No. 1 under different water treatments

Treatment \ Index	F_v/F_m	F_0	qP	qN	F_m	ETR ($\mu mol \cdot m^{-2} \cdot s^{-1}$)
14%	0.82±0.003a	***<u>0.29±0.021d</u>***	0.20±0.002b	0.61±0.011d	1.61±0.092bc	120.6±1.50a
12%	***<u>0.83±0.004a</u>***	0.34±0.009cd	0.21±00.006b	***<u>0.59±0.007d</u>***	***<u>2.14±0.049a</u>***	***<u>122.5±3.26a</u>***
10%	0.81±0.002a	0.37±0.021bc	***<u>0.26±0.007a</u>***	0.68±0.004c	2.02±0.013ab	113.0±2.42b
8%	0.79±0.001a	0.35±0.054bc	0.17±0.013c	0.76±0.038b	1.81±0.045c	103.8±0.83c
6%	0.72±0.011b	***<u>0.49±0.049a</u>***	0.12±0.001d	0.83±0.001a	1.83±0.079c	86.9±1.19d
4%	***<u>0.65±0.037c</u>***	0.39±0.023b	***<u>0.09±0.002e</u>***	***<u>0.85±0.008a</u>***	***<u>1.13±0.043d</u>***	***<u>76.2±0.66e</u>***

Note: Different letters in a column indicate a significant difference ($p < 0.05$). Data in the table are the mean±standard error.

ment had the highest F_m value, but it did not significantly differ from that of 10.0%. The 4.0% treatment had the lowest F_m value, and it was significantly lower than those of other treatments.

Differences in ETR values among various treatments were significant; as the water gradient declined, the ETR value sequentially decreased (Table 2). The difference in ETR values between 14.0 and 12.0% was not significant, but difference in ETR values among 10.0, 8.0, 6.0, and 4.0% were significant.

Responses of the growth and biomass distribution of Zhongren No. 1 at the seedling stage to different soil water contents

With respect to the biomass distribution, the underground dry weight and aboveground dry weight significantly differed from each other (Table 3). When the soil water content decreased, the aboveground and underground dry weight, initially increased and later declined. The aboveground and underground dry weights reached peak values under the 12.0% treatment and were significantly greater than those of other treatments. Differences among treatments were significant for the aboveground dry weight. There was no significant difference in the underground dry weights between 14.0 and 8.0%, and values of other groups significantly differed. In addition, root-shoot ratios under various treatments extremely significantly differed from each other. When the soil water content decreased, the ratio initially decreased and later increased. The 12.0% treatment was significantly lower than other treatments. Differences between 6.0 and 4.0%, and between 8.0 and 6% did not significantly differ ($p > 0.05$).

DISCUSSION

Responses of photosynthesis of the sweet kernel apricot at the seedling stage to different soil water contents

Farquhar et al. (1982) indicated that if a decline in the P_n was accompanied by declines in G_s and C_i, then stomatal factors were the main reason for the decrease in the P_n. Our results showed that as the soil water content decreased, the P_n value of Zhongren No. 1 significantly declined, and values of G_s and C_i also showed significant decreasing trends. This demonstrated that stomatal factors were one of the main reasons for the decline in the net photosynthetic rate of Zhongren No. 1, and this phenomenon was also found in other plants such as *Morus alba* (Huang et al. 2012) and *Eragrostis curvula* (Colom and Vazzana 2001). Various photosynthetic indexes under a 12.0% water content were higher than those under 14.0%, which demonstrated that a certain degree of soil water stimulated

Table 3. Variations in biomass accumulation of Zhongren No. 1 with different soil water contents

Index \ Treatment	14%	12%	10%	8%	6%	4%
Aboveground dry weight (g)	391.6±15.00b	***479.8±20.00a***	355.9±25.00c	228.3±21.02d	204.9±13.97e	***184.6±25.09f***
Underground dry weight (g)	155.0±17.56c	***170.0±32.92a***	165.0±27.27b	151.0±8.27c	145.0±25.96d	***135.0±12.71e***
Root-shoot ratio	0.28±0.06d	***0.26±0.08e***	0.32±0.04c	0.41±0.06b	0.41±0.04ab	***0.42±0.06a***

Note: Different letters in a column indicate a significant difference ($p < 0.05$). Data in the table are the mean±standard error.

photosynthesis of Zhongren No. 1 seedlings. Meanwhile, the P_n value declined when Zhongren No. 1 seedlings were subjected to some levels of soil water. However, the WUE was enhanced by a decrease in the T_r which could relieve the degree of water dissipation, similar to *Acanthopanxsen cosus* seedlings (Song et al. 2007), *Eleutherococcus senticosu* (Liao and Wang. 2014) and sweet sorghum (Karimi et al. 2015). The diurnal variation curve of the P_n was a typical single-peak curve, and showed that Zhongren No. 1 experienced no midday depression of photosynthesis during the growing season. This demonstrates that it is to a full-speed-growth plant (Shen and Zhai, 2011), which differs from other trees such as the Jinguang apricot-plum (Liu et al. 2007) and *Cerasus humilis* (Chu et al. 2008). When the soil water content decrease intensified, the LSP gradually decreased. The LCP gradually increasing for various treatments showed that the light adaptation range of Zhongren No. 1 seedlings was becoming smaller at the moment, which was one of main reasons for the decline in the P_n.

The fluorescence emission correspondingly changes with changes in photosynthesis; therefore, variations in fluorescence have been applied to reflect photosynthesis and thermal dissipation conditions (Peterson et al. 1988). In the case of chlorophyll fluorescence, the F_v/F_m reflects the efficiency of excitation energy captured by opening the PS II reaction center. It is an important parameter in plant stress research. Environmental stress has an effect on the PS II efficiency (Li et al. 2000). In this research, the F_v/F_m value with a 12.0% soil water content was slightly higher than that at 14.0%. When the soil water content decreased, the F_v/F_m value gradually declined, which demonstrated that an intensified water stress can damage PS II. Under conditions of water stress, the F_m value gradually declined, while the F_0 value gradually increased, which showed that the part of energy was dissipated as heat and the fluorescence increased, and the part of energy used for photosynthesis apparently declined as energy was absorbed by pigments (Shi et al. 2004). This was in accordance with the decline in the P_n. Meanwhile, serious water stress caused an increase in the qP and decreases in the qN and ETR, which showed that the drought blocked the transport of photosynthetic electrons absorbed by PS II antenna pigments, and caused an increase in light energy that was dissipated as heat.

Responses of seedling biomass accumulation to different soil water contents

An appropriate soil water content promotes plant growth (Jing et al. 2005), while soil drought causes difficulty for root water absorption and water shortages in plant cells, which restrain their division and growth. This research found that when the soil water content decreased, each growth index and biomass index of Zhongren No. 1 seedlings gradually declined, which demonstrated that water stress caused some inhibitory effects on seedling growth, particularly under heavy water stress (4.0%). However, the value of each index under a soil water content of 12.0% was higher than that of 14.0%, which showed that a suitable soil water content had positive effects on the growth of Zhongren No. 1 seedlings, in accordance with the performance of photosynthesis and fluorescence. Similar to cluster mulberry (Yan et al. 2011), this was probably an adaptation reaction of plants when the soil water content was lower. However, each index of cluster mulberry was apparently higher than the control group when faced with mild water stress. A drought condition forced the plants to adapt to environmental change, such as an increment in the root-shoot ratio, and transfer of photosynthetic products to underground storage (Fulda et al. 2011; Fang and Xiong, 2015). However, there are large differences among various plants, as the root shoot ratio difference of sweet kernel apricot was 1.5-fold among treatments, which demonstrated that Zhongren No. 1 is apparently equipped with a self-adjustment mechanism against lower soil water contents.

CONCLUSIONS

With a decline in the soil water content, the sweet kernel apricot Zhongren No. 1 could conduct self-adjustment reactions, such as enhancing WUE, and improving the LCP. Meanwhile, it experienced no midday depression of photosynthetic during the growing season and maintained a relatively high photosynthesis efficiency and biomass accumulation ability, which strengthened its drought resistance ability. Therefore, it belongs to xerophyte types, the same as one of its parents, *P. sibirica*. The optimal volumetric soil water content for its growth was 12.0%, and soil water contents of 8.0~14.0% had no significant impact on photosynthesis or growth. The minimum soil water content for Zhongren No. 1 seedlings to maintain growth should not drop below 4.0%.

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APPENDIX

P_n	Net photosynthetic rate
T_r	Transpiration rate
G_s	Stomatal conductance
C_i	Intercellular CO_2 concentration
WUE	Water use efficiency
LCP	Light compensation point
LSP	Light saturation point
PAR	Photosynthetic active radiation
PS Ⅱ	Photosystem Ⅱ
F_0	Minimal fluorescence
F_m	Maximum fluorescence
F_v/F_m	PSII maximum quantum yield
ETR	Apparent photosynthetic electron transport rate
qP	photochemical quenching
qN	non-photochemical quenching