

1-1-2015

## Effects of gradual soil drought stress on the growth, biomass partitioning, and chlorophyll fluorescence of *Prunus mongolica* seedlings

YOUYAN GUO

HONGYUAN YU

DONGSHENG KONG

FANG YAN

DONGHUA LIU

*See next page for additional authors*

Follow this and additional works at: <https://journals.tubitak.gov.tr/biology>



Part of the [Biology Commons](#)

---

### Recommended Citation

GUO, YOUYAN; YU, HONGYUAN; KONG, DONGSHENG; YAN, FANG; LIU, DONGHUA; and ZHANG, YAJUAN (2015) "Effects of gradual soil drought stress on the growth, biomass partitioning, and chlorophyll fluorescence of *Prunus mongolica* seedlings," *Turkish Journal of Biology*. Vol. 39: No. 4, Article 2.

<https://doi.org/10.3906/biy-1412-20>

Available at: <https://journals.tubitak.gov.tr/biology/vol39/iss4/2>

This Article is brought to you for free and open access by TÜBİTAK Academic Journals. It has been accepted for inclusion in Turkish Journal of Biology by an authorized editor of TÜBİTAK Academic Journals. For more information, please contact [academic.publications@tubitak.gov.tr](mailto:academic.publications@tubitak.gov.tr).

---

# Effects of gradual soil drought stress on the growth, biomass partitioning, and chlorophyll fluorescence of *Prunus mongolica* seedlings

## Authors

YOUYAN GUO, HONGYUAN YU, DONGSHENG KONG, FANG YAN, DONGHUA LIU, and YAJUAN ZHANG

## Effects of gradual soil drought stress on the growth, biomass partitioning, and chlorophyll fluorescence of *Prunus mongolica* seedlings

Youyan GUO, Hongyuan YU\*, Dongsheng KONG, Fang YAN, Donghua LIU, Yajuan ZHANG  
Hexi University, Zhangye, P.R. China

Received: 05.12.2014 • Accepted/Published Online: 06.03.2015 • Printed: 30.07.2015

**Abstract:** The present study aimed to determine the effects of gradual drought stress on *Prunus mongolica* seedlings. The growth and chlorophyll fluorescence of the seedlings were investigated under drought and control conditions. The short-term (21 day) decline in soil water content from 30.46% to 15.55% did not significantly influence the growth of *P. mongolica* seedlings but increased the height, basal diameter, crown, leaf number, stem mass, leaf mass, and root mass of the seedlings. The growth of the drought group reached the maximum, but remained lower than that of the control group, within 21 days. Compared with the control group, the drought group showed 1.46%, 9.65%, 9.44%, 5.19%, 29.09%, 19.20%, and 0.03% lower height, basal diameter, crown, leaf number, stem mass, leaf mass, and root mass, respectively. With the gradual manifestation of soil drought through the decline in soil water content from 15.55% to 11.38% from 21 days to 42 days, growth of the drought group became significantly lower than that of the control group ( $P < 0.05$ ). The minimal fluorescence decreased and then increased, whereas the nonphotochemical quenching initially increased and then decreased. Thus, *P. mongolica* can protect the PSII reaction center from damage at the early stage of drought stress. The maximal fluorescence, the maximum quantum yield of PSII, and the photochemical quenching slightly decreased during the initial period of drought stress. These results suggest that drought can slightly influence the openness of PSII reaction centers. This influence was further proven by the decreased quantum yield of PSII. This study provided insights into the adaptive mechanism of *P. mongolica* seedlings under drought and may serve as a theoretical basis to protect the *P. mongolica* population. Comparing these responses is crucial for elucidating the drought-tolerance mechanisms in *P. mongolica* cultivars.

**Key words:** *Prunus mongolica*, seedling, growth, biomass, chlorophyll fluorescence

### 1. Introduction

The growth of plants is controlled by their genetic constitution and by several environmental factors, such as water stress (Arora et al., 2002; Saruhan Guler et al., 2012). Water stress in plants is characterized by continuous water loss through transpiration into the atmosphere and by decreased water uptake resulting from reduced soil moisture (Barbara et al., 2014). Soil water depletion inhibits numerous important processes (Yin et al., 2005). Most plants initially respond to water stress through stomatal closure and a decreased CO<sub>2</sub>-to-O<sub>2</sub> ratio. Prolonged drought limits photosynthesis, plant growth, and productivity (Franca et al., 2000; Royo et al., 2001; Anyia and Herzog, 2004; Dias et al., 2007; Zhang et al., 2011) and alters biomass allocation patterns (Li et al., 2009). Water stress suppresses the accumulation of oilseed rape biomass and decreases chlorophyll content and leaf water status (Liu et al., 2013). Yin et al. (2005) reported that shoot height, dry mass accumulation, leaf number, total leaf

area, and fine root mass significantly decrease under water stress. Biomass is a key parameter that influences plant growth; therefore, the accumulation and distribution of dry mass are major considerations when investigating the effect of water stress on plant growth. Plant photosynthesis is closely affected by environmental factors, such as water stress (Wu et al., 2010). Therefore, research on plant photosynthesis and biomass allocation under water stress is important for revealing the mechanism by which plants adapt to drought.

The perennial deciduous shrub *Prunus mongolica* is an endemic, endangered, and third-class nationally protected species in China. This species is a suitable ecological and landscape plant and an important resource plant in China because its seeds can be used as food, medicine, and fuel. It is mainly distributed in Neimenggu, Ningxia, and Gansu in northwestern China (Siqinbatee and Xiu, 2007). However, natural forests dominated by *P. mongolica* can only be found in the desert regions and arid slopes

\* Correspondence: yhy\_2000\_113@163.com

of desert grassland. The distribution areas of this species and its communities have progressively diminished, and protection of this endangered species has become an urgent concern (Zhang et al., 2012).

The conservation situation of *P. mongolica* and its forest is becoming worse because of the destruction of natural vegetation and extreme drought. Some studies investigated the biological characteristics (Ma et al., 2010), spatial patterns (Ma et al., 2014), and community structure characteristics (Hong et al., 2010) of this endangered species. However, the effects of drought on the growth and chlorophyll fluorescence of *P. mongolica* seedlings remain unclear. Water is the primary ecological element that threatens the survival and reproduction of desert plants. Therefore, exploring the effect of water stress on *P. mongolica* seedlings is important. Chlorophyll fluorescence analysis has been extensively used to detect photosynthetic physiological conditions and investigate photosynthetic mechanisms (Li et al., 2013). This technique can be applied to rapidly detect changes in photosynthesis; thus, it may be used to evaluate the relationship between photosynthetic physiology and drought stress (Li et al., 2013). The present study aimed to determine the effects of gradual drought stress on the seedling growth, biomass accumulation and allocation, and chlorophyll fluorescence of *P. mongolica* seedlings.

## 2. Materials and methods

### 2.1. Plant materials, growth conditions, and stress treatments

The experiment was conducted at the Hexi University Agronomy Practice Base in Zhangye City (37°28'N, 97°20'E), Gansu Province, China. The area has a continental climate with a mean annual temperature of 6 °C, rainfall of 113 mm–120 mm, and evaporation of 2291 mm. *P. mongolica* seeds were harvested in October 2013 from Sunan County (39°04'N, 97°20'E), Gansu Province, China. After drying for 1 week in open sunlight, deformed and damaged seeds were discarded, and apparently healthy seeds were air-dried and then stored at 4 °C until the start of the experiment.

Before sowing, seeds stored at low temperature were surface sterilized with a 2% potassium permanganate solution. Seeds of similar size were sown in 40 pots (23 cm in diameter and 20 cm in height) with five seeds per pot on 10 March 2014. Each pot contained similar volumes of soil, sandy soil, and humus in a ratio of 1:2:1. The pots were initially watered thoroughly, with soil moisture maintained at approximately 80% field capacity, to ensure seed germination. Upon development of two to three true leaves, the seedlings were thinned to two plants per pot, and stress treatment was initiated on 27 June 2014. The experiment layout consisted of the control group and

the drought group with 20 pots each. The plants in the control group were grown under normal water conditions. Meanwhile, all pots in the drought group were watered only until the soil reached its maximum water-holding capacity, and the soil moisture was based on the natural consumption of the seedlings. After 0, 7, 14, 21, 28, 35, and 42 days, the growth, biomass, and fluorescence parameters were measured in both groups. Soil moisture was measured by using a TDR soil moisture meter (TRIME-PICO, Germany).

### 2.2. Growth parameters

Plant height was measured from the base of the stem at the soil level to the terminal bud of the main stem; the basal diameter was measured from the base of the stem; the crown was measured from east and west to south and north; and the number of leaves was recorded after 0, 7, 14, 21, 28, 35, and 42 days in both groups.

### 2.3. Water status of leaves

The relative water content (RWC) of leaves was determined in accordance with the method described by Kavas et al. (2013). Five fully expanded leaves at the mid-canopy position were collected per seedling after 0, 7, 14, 21, 28, 35, and 42 days. The fresh weight (FW) of the leaves was determined and recorded. Each leaf was placed in a petri dish filled with distilled water for 24 h at 4 °C and then weighed to determine the turgid weight (TW). The dry weight (DW) of the leaves was determined after oven-drying for 48 h at 70 °C. The RWC was calculated as  $RWC (\%) = (FW - DW) / (TW - DW) \times 100$ .

### 2.4. Biomass

Three same-sized seedlings were harvested after 0, 7, 14, 21, 28, 35, and 42 days from the control and drought groups. The seedlings were washed to remove any debris; separated into roots, stems, and leaves; and dried to constant weight at 60 °C for at least 48 h. Then the roots mass, stems mass, and leaves mass were determined for each plant. The total plant biomass was the sum of the root, stem, and leaf masses. The root:shoot (R:S) ratio was calculated from the aboveground and belowground masses. The leaf mass ratio (LMR) was calculated from the leaf mass and the total biomass. The stem mass ratio (SMR) was calculated from the stem mass and the total biomass. The root mass ratio (RMR) was calculated from the root mass and the total biomass.

### 2.5. Chlorophyll fluorescence

Chlorophyll fluorescence was measured with a FMS-2 pulse modulation fluorometer (Hansatech, United Kingdom) following the procedure described by van Kooten and Snel (1990). Selected leaves were dark adapted for 20 min before measuring the chlorophyll fluorescence after 0, 7, 14, 21, 28, 35, and 42 days. The minimal fluorescence ( $F_0$ ) was measured by applying a low-

intensity red light source. The maximal fluorescence ( $F_m$ ) was measured by a saturating light pulse (0.8 s) of 6000  $\mu\text{mol photon}/(\text{m}^2 \text{ s})$ . After dark measurement, the leaf was continuously illuminated with actinic light to obtain steady-state Chl fluorescence ( $F_s$ ). Saturating pulses (0.8 s) of white light at 6000  $\mu\text{mol photon}/(\text{m}^2 \text{ s})$  were applied to determine the maximum fluorescence in the light-adapted state ( $F'_m$ ). The maximum quantum yield of PSII ( $F_v/F_m$ ) and the quantum yield of PSII ( $\Phi\text{PSII}$ ) were read with the FMS-2 instrument. The photochemical quenching (qP) was calculated as  $qP = (F'_m - F_s)/(F'_m - F_0)$ , and the nonphotochemical quenching (qN) was calculated as  $qN = (F_m - F'_m)/F'_m$ .

**2.6. Statistical analysis**

All data were subjected to one-way ANOVA. Data analysis was conducted with SPSS 18.0 for Windows. LSD multiple comparison tests were used to separate significant differences among all treatments at the 0.05 level. SE was calculated and is shown in the figures and Table.

**3. Results**

**3.1. Effect of drought stress on soil water content**

The soil water content of the drought group significantly decreased ( $P < 0.05$ ) from 30.46% to 15.55% within 21 days (Table). However, the soil water content of the control group was maintained at 27% to 30%, and the change was not significant throughout the experiment ( $P > 0.05$ ). The soil water content of the control group was significantly higher than that of the drought group from 7 days to 42 days ( $P < 0.05$ ). In particular, the control group showed 15.24%, 36.42%, 50.62%, 52.54%, 55.23%, and 61.86% higher soil water content than the drought group after 7, 14, 21, 28, 35, and 42 days, respectively.

**3.2. Effect of drought stress on *P. mongolica* growth**

The leaf RWC of the control group did not significantly change and was retained at 69% to 75% throughout the experiment ( $P > 0.05$ ). By contrast, the leaf RWC of the drought group gradually decreased with increasing stress levels (Table). From 0 days to 21 days, the RWC of the drought group was unchanged. However, the RWC significantly decreased after 28 days, with a total reduction of 43.35% after 42 days compared with the RCW after 0 days. The RWC of the control group was greater than that of the drought group from 21 days to 42 days, with a significant difference after 35 days and 42 days ( $P < 0.05$ ).

Changes in the height, basal diameter, crown, and leaf number are shown in Figures 1a–1d. These parameters in the control group increased with experimental time, whereas those in the drought group initially increased and then decreased with increasing stress levels. The height, basal diameter, crown, and leaf number of the drought group reached their maximum after 21 days; these parameters increased by 17.91%, 13.40%, 9.34%, and 32.69% from 0 days to 21 days, respectively. After 42 days, the leaves in the drought group curled and shed, and some of the plants died. At this period, the height, basal diameter, crown, and leaf number in the drought group were lower by 26.77%, 34.60%, 48.84%, and 52.58% compared to those in the control group ( $P < 0.05$ ).

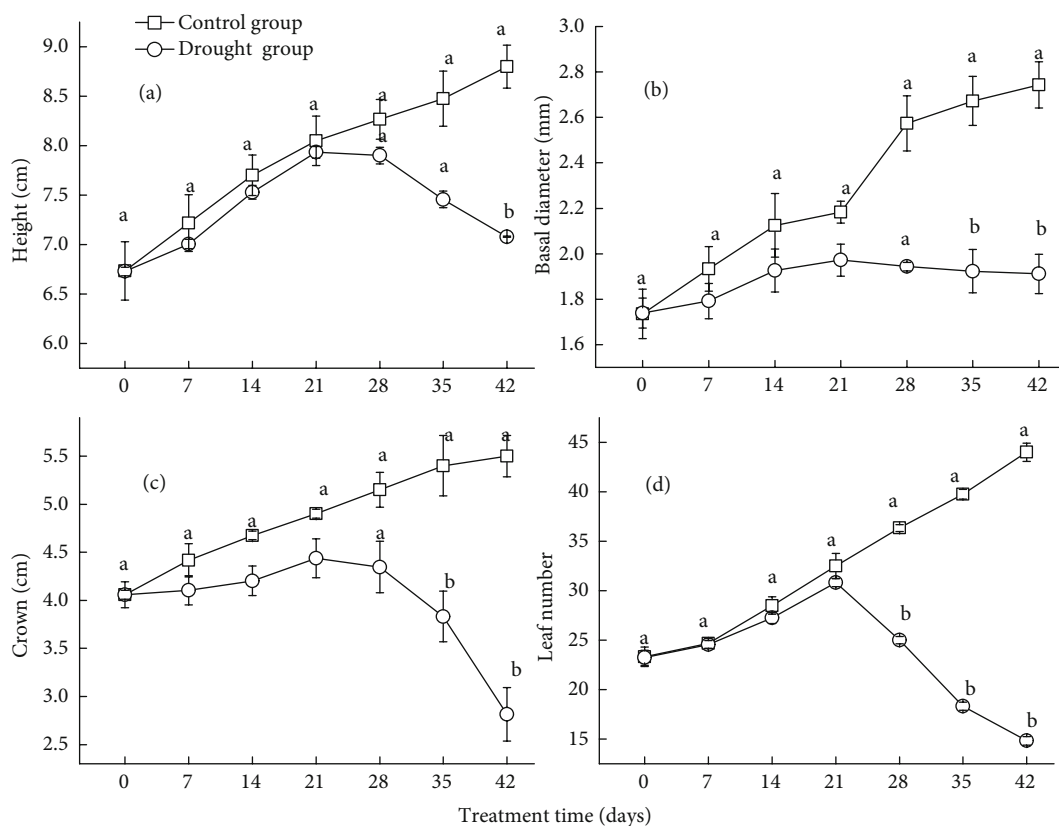
**3.3. Effect of drought stress on biomass**

The effects of drought stress on biomass are summarized in Figures 2a–2c. The stem, leaf, and root masses in the control group increased with experimental time. In the drought group, the stem and leaf masses initially increased and then decreased, whereas the root mass increased with increasing stress levels. The stem and leaf masses in the drought group reached their maximum after 21 days. The

**Table.** Changes in soil water content and leaf water content during the experimental period.

Treatment time (days)	Soil water content (%)		Relative water content (%)	
	Control group	Drought group	Control group	Drought group
0	30.12 ± 1.13a	30.46 ± 2.67a	75.69 ± 2.90a	75.84 ± 2.45a
7	28.02 ± 1.39a	23.75 ± 0.62b	73.49 ± 1.62a	71.66 ± 4.08ab
14	28.80 ± 0.40a	18.31 ± 0.52c	74.45 ± 1.41a	70.65 ± 2.41ab
21	27.39 ± 3.48a	15.55 ± 0.51cd	71.42 ± 2.49a	68.42 ± 4.75ab
28	30.13 ± 0.98a	14.30 ± 0.71de	69.97 ± 0.94a	64.69 ± 3.37b
35	30.22 ± 1.60a	13.53 ± 0.62de	70.73 ± 1.43a	58.19 ± 4.32c
42	29.84 ± 0.29a	11.38 ± 1.31e	70.80 ± 4.40a	42.96 ± 4.77d

Data were shown as means ± SE. Different letters in the table indicate significant differences between treatments ( $P < 0.05$ ).



**Figure 1.** Effect of drought stress on the seedling growth of *Prunus mongolica*. Data are shown as means  $\pm$  SE. Different letters in the table indicate significant differences between treatments ( $P < 0.05$ ).

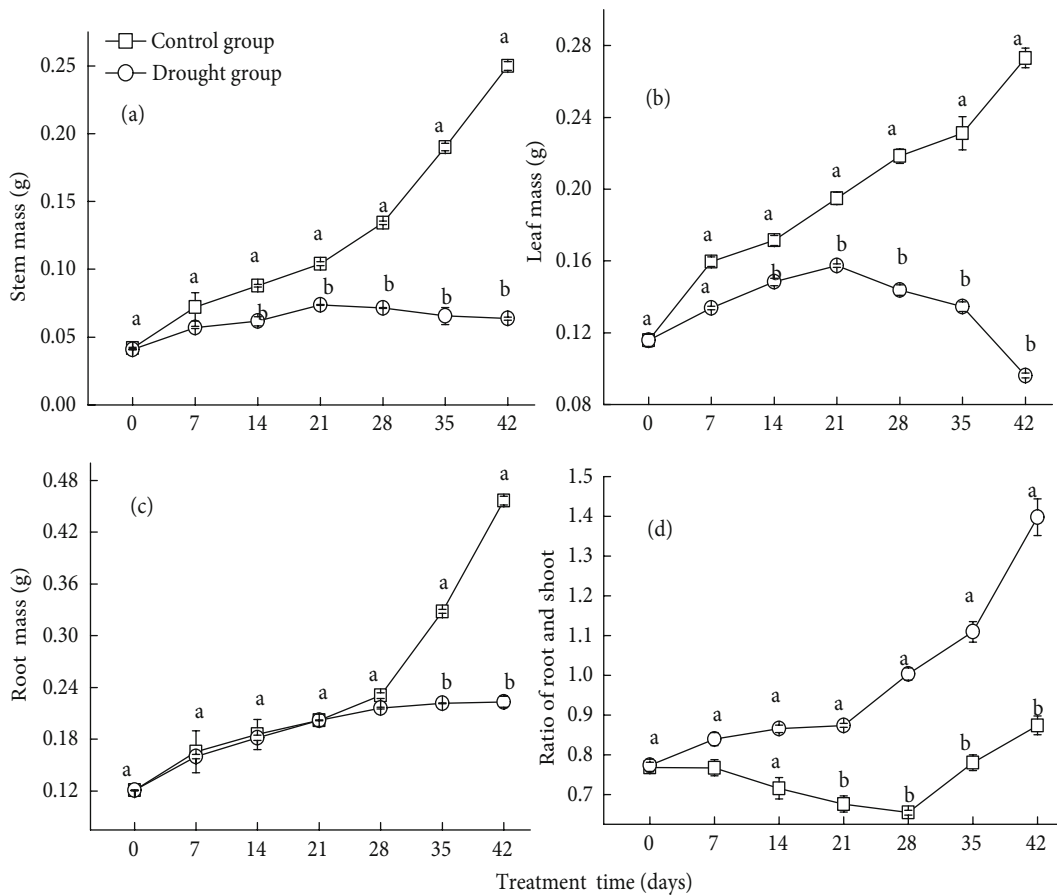
stem and leaf mass in the control group were higher than those in the drought group throughout the experiment, and the difference became prominent with experimental time. After 42 days, the stem, leaf, and root masses in the drought group were lower by 74.51%, 64.78%, and 51.04% than those in the control group, respectively ( $P < 0.05$ ). The R:S ratio in the control group initially decreased and then increased with experimental time. However, the R:S ratio in the drought group steadily increased (Figure 2d). After 21 days, the R:S ratio in the drought group was significantly higher than that in the control group ( $P < 0.05$ ) (Figure 2d).

The total biomass in the control group increased with experiment time, whereas in the drought group, it increased initially and then decreased (Figure 3a; Figures 2a–2c). The total biomass in the drought group reached its maximum after 21 days (Figure 3a). The total biomass in the control group was higher than that of the drought group throughout the experiment (Figure 3a). The SMR in the control group increased with experimental time (Figure 3b), the LMR decreased with experimental time (Figure 3c), and the RMR initially decreased and then increased with experimental time (Figure 3d). However, the SMR in the drought group did not change throughout

the experiment; it was consistently 14% to 17% lower in the control group than in the drought group (Figure 3b). The variation in LMR was similar in the control and drought groups, and this parameter decreased with increasing stress levels (Figure 3c). The RMR in the drought group steadily increased with increasing stress levels, and it was higher than that in the control group throughout the experiment (Figure 3d).

### 3.4. Effect of drought stress on chlorophyll fluorescence

The  $F_0$  in the control group remained within 58–63 throughout the experiment, whereas in the drought group it initially decreased and then increased with increasing stress levels (Figure 4a). After 21 days, the  $F_0$  in the drought group was higher than that in the control group, and the difference became significant with increasing stress levels ( $P < 0.05$ ) (Figure 4a). After 42 days, the  $F_0$  in the drought group was 23.19% higher than control (Figure 4a). The  $F_m$  in the control group remained constant, whereas  $F_m$  in the drought group gradually decreased with increasing stress levels (Figure 4b). After 21 days, the  $F_m$  in the control group was higher than that in the drought group; the  $F_m$  values were 15.77%, 39.14%, 44.79%, and 52.69% lower in the drought group than in the control group after 21, 28, 35, and 42 days, respectively (Figure 4b).  $F_v/F_m$  is a



**Figure 2.** Effect of drought stress on the biomass allocation of *Prunus mongolica*. Data are shown as means  $\pm$  SE. Different letters in the table indicate significant differences between treatments ( $P < 0.05$ ).

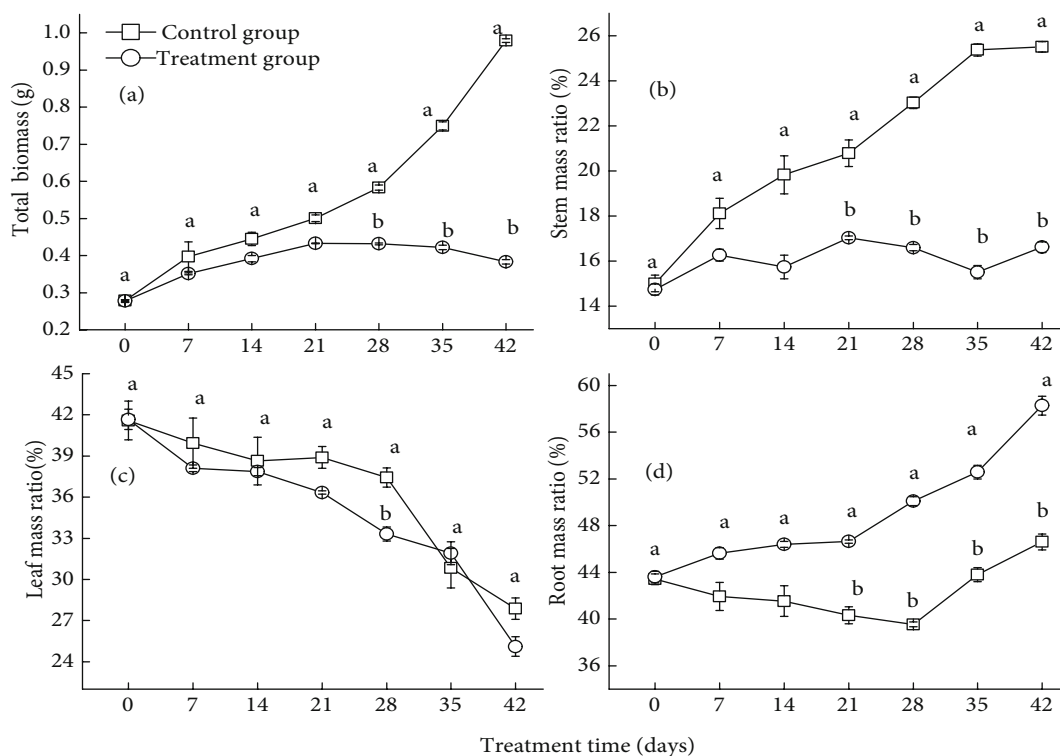
measure of the maximum photochemical efficiency of PSII when all the reaction centers are open. The  $F_v/F_m$  values in the control group remained constant, and were stabilized at 0.82–0.85 throughout the experiment, whereas those in the drought group decreased with increasing stress levels (Figure 4c). The  $\Phi$ PSII and qP in the drought group decreased with increasing stress levels, whereas those in the control group remained constant (Figures 4d and 4e). The qN in the control group remained constant, whereas in the drought group, it increased initially and then decreased with increasing stress levels (Figure 4f). The  $\Phi$ PSII and qP in the control group were higher than those in the drought group throughout the experiment (Figures 4d and 4e). After 42 days, the  $\Phi$ PSII, qP, and qN in the control group were 29.98%, 22.54%, and 60.91% higher than those in the drought group, respectively ( $P < 0.05$ ) (Figures 4d–4f).

#### 4. Discussion

Gradual drought stress can impose severe levels of soil water deficit. In particular, the soil water content decreased from 30.46% to 11.38% from 0 days to 42 days (Table), and soil water content greater than or equal to 15.55% will

be beneficial to the growth and survival of *P. mongolica*. However, soil water content less than or equal to 11.38% adversely affected the growth and survival of *P. mongolica* (Figures 1a–1d).

Leaf RWC is a reliable and common indicator for defining the sensitivity of plants to dehydration (Rampino et al., 2006; Sanchez-Rodriguez et al., 2010; Kavas et al., 2013). In the present study, the leaf RWC in *P. mongolica* was influenced by the intensity of the stress imposed. After 28 days, the RWC in the drought group significantly declined, reaching less than 50% after 42 days. Previous studies observed similar results in crops (Ogbonnaya et al., 1998; Gindaba et al., 2004) and woody plants (Gratani and Varone, 2004; Masinde et al., 2006; Li et al., 2008), and indicated that RWC rarely falls below 50% in well-watered conditions but commonly reaches 50%–40%, and occasionally 30%–20%, during severe drought. The growth of *P. mongolica* seedlings was significantly influenced by the soil water content. The seedling height, basal diameter, crown, and leaf number of *P. mongolica* were initially insensitive to the decline in soil water content (soil water content  $\geq 15.55\%$ ), which benefitted the growth of *P.*



**Figure 3.** Effect of biomass production and its allocation on *Prunus mongolica* seedlings at different drought stress levels. Data are shown as means  $\pm$  SE. Different letters in the table indicate significant differences between treatments ( $P < 0.05$ ).

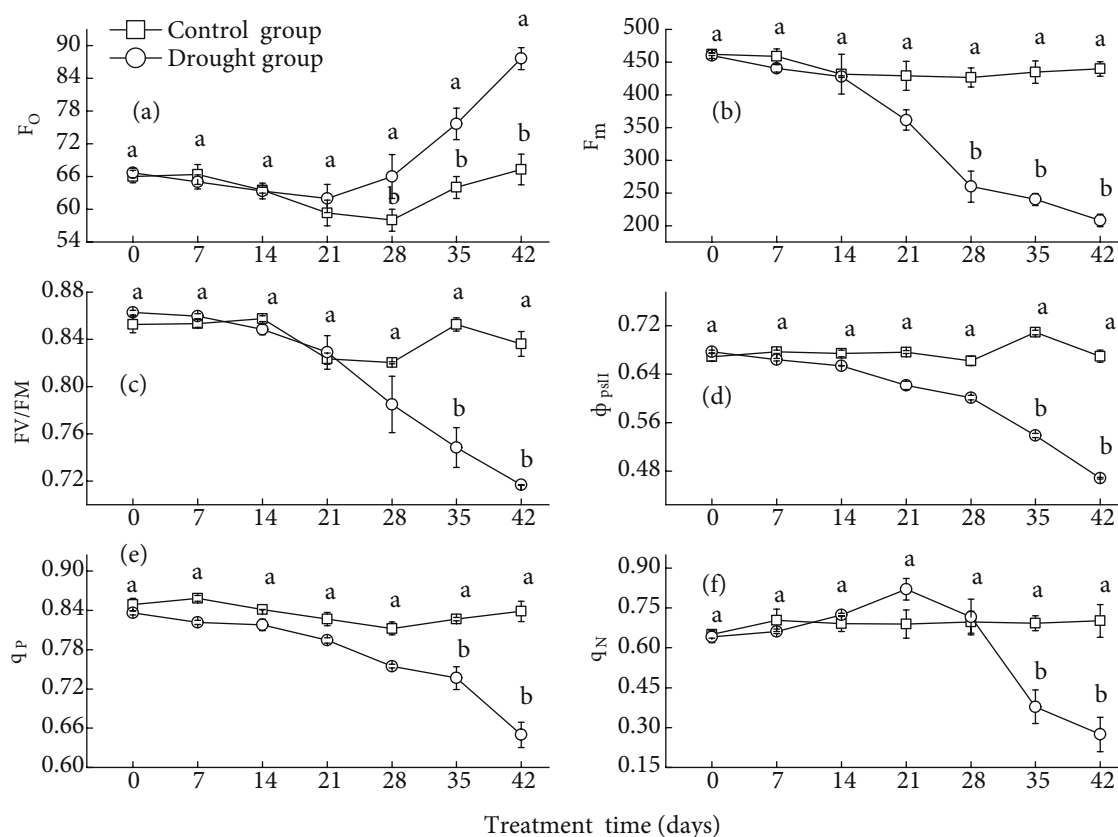
*mongolica* seedlings (Figures 1a–1d). The growth of *P. mongolica* seedlings was inhibited under severe drought. This mechanism might be a strategy developed to prolong the existence and growth of a desert plant. Our study was consistent with previous research on other species (Rodiyati et al., 2005; Li et al., 2008; Wang et al., 2013).

Plant productivity is strongly related to biomass partitioning under water stress (Kage et al., 2004; Li et al., 2008). Most species deal with heterogeneous water supply by changing biomass allocation patterns (Padilla et al., 2009). Short-term water stress increased the total dry mass and the components of *P. mongolica* seedlings, whereas prolonged drought decreased the total dry mass and their components, altered the biomass allocation from the shoot to the root system, and, thus, increased the R:S ratio (Figures 2 and 3). The large R:S ratio obtained under severe water stress could be interpreted as a strategy to maximize absorptive root surfaces and increase the water and nutrient uptake rate (Fernández and Reynolds, 2000; Cornelissen et al., 2003).

This study showed that drought stress significantly affected the PSII photochemical activity in *P. mongolica* seedling leaves. In the present study, the  $F_0$  of *P. mongolica* seedling leaves initially decreased and then increased, whereas the  $F_m$  decreased under drought stress. This

result indicated that the transport of energy absorbed by the PSII antenna pigments to the photochemical reactions was partially suppressed. The energy increased by fluorescence and dissipation heat loss, and the energy for photosynthesis obviously decreased. With prolonged drought stress (starting at 28 days), the photosynthetic apparatus of *P. mongolica* seedlings was damaged. From 0 days to 21 days, the  $F_v/F_m$  of *P. mongolica* seedling leaves gently decreased, indicating that the growth of *P. mongolica* seedlings was not restricted by environmental conditions. However, the  $F_v/F_m$  value significantly decreased after 21 days, indicating that the original light energy conversion efficiency was reduced, and the potential active center was inhibited, which suppressed the primary reaction of *P. mongolica* seedling leaves to photosynthesize. qP indicates the openness of the PSII reaction center (Li et al., 2013), and qN is the protection mechanism of the photosynthetic apparatus (Maxwell and Johnson, 2000). In the present study the qP of *P. mongolica* seedling leaves decreased under drought stress, and the decrease was significant from 28 days onward. The heat dissipation of the PSII reactions can be evaluated by monitoring the changes in qN. The excess energy was dissipated effectively by an increase in qN to avoid damage to PSII reaction centers (Li et al., 2013). Our study showed that the qN initially increased





**Figure 4.** Effect of chlorophyll fluorescence parameters on the leaves of *Prunus mongolica* under drought stress. Data are shown as means ± SE. Different letters in the table indicate significant differences between treatments ( $P < 0.05$ ).

and then decreased from 28 days. The results suggest that the degree of openness decreased in the reaction centers, the photosynthetic electron transport rate declined, and the photochemical activity weakened. Moreover, the excess energy was effectively dissipated by increasing the qN to avoid damage to the PSII reaction centers at the early stage of drought stress. After 28 days the qN started to decrease, suggesting damage to the photosynthetic apparatus (PSII) of *P. mongolica* seedling leaves and loss of heat dissipation capability. This phenomenon was evident from the increase in  $F_0$  and decrease in both  $F_v/F_m$  and  $q_p$  during the later stages of drought stress.  $\Phi_{PSII}$  reflects the efficiency of light energy transformation in PSII; in particular, it indicates the efficiency of primary light capture when the PSII reaction center is partially shut down (Li et al., 2013). In the present study,  $\Phi_{PSII}$  decreased with increasing drought stress levels, and the decrease was prominent from 28 days onward. This result suggests that the photosynthetic apparatus PSII of *P. mongolica* seedling leaves was damaged and lost its heat dissipation capability.

In conclusion, the growth, biomass partitioning, and chlorophyll fluorescence of *P. mongolica* have been

observed under gradual soil drought stress. The short-term (0–21 days) decline in soil water content will be beneficial to the growth and survival of *P. mongolica*. However, the long-term (21–42 days) decline in soil water content adversely affected the growth and survival of *P. mongolica*. *P. mongolica* can protect the PSII reaction center from damage at the early stages of drought stress. Drought can slightly influence the openness of the PSII reaction centers of *P. mongolica*. This study provided insights into the adaptive mechanism of *P. mongolica* seedlings under drought and may serve as a theoretical basis to protect *P. mongolica* populations.

#### Acknowledgments

This work was supported by the Programs for the Young Fund of Hexi College (QN-2013-03), the National Natural Science Foundation (31460189), and the Scientific Research Project of the Higher Education Institutions of Gansu Province (2014A-111). We wish to thank Jiande Chang, Zhengnan Wang, and Changqing Deng for providing suggestions and assistance during the experiment and EnPapers for English language editing.

## References

- Anyia AO, Herzog H (2004). Water-use efficiency, leaf area and leaf gas exchange of cowpeas under midseason drought. *Eur J Agron* 20: 327–339.
- Arora A, Sairam RK, Srivastava GC (2002). Oxidative stress and antioxidative systems in plants. *Current Sci* 82: 1227–1238.
- Barbara EK, Nora LE, Edith S (2014). Compartment specific response of antioxidants to drought stress in *Arabidopsis*. *Plant Sci* 227: 133–144.
- Cornelissen JHC, Lavorel S, Garnier E (2003). A handbook of protocols for standardised and easy measurements of plant functional traits worldwide. *Aust J Bot* 51: 335–380.
- Dias PC, Araujo WL, Moraes GA, Barros RS, DaMatta FM (2007). Morphological and physiological responses of two coffee progenies to soil water availability. *J Plant Physiol* 164: 1639–164.
- Franca MG, Pham TT, Pimentel C, Rossiello ROP, Fodil YZ, Laffray D (2000). Differences in growth and water relation among *Phaseolus vulgaris* cultivars in response to induces water stress. *Environ Experi Bot* 43: 227–337.
- Gindaba J, Rozanov A, Negash L (2004). Response of seedlings of two *Eucalyptus* and three deciduous tree species from Ethiopia to severe water stress. *Forest Eco Manag* 201: 119–129.
- Gratani L, Varone L (2004). Leaf key traits of *Erica arborea* L., *Erica multiflora* L. and *Rosmarinus officinalis* L. co-occurring in the Mediterranean maquis. *Flora* 199: 58–69.
- Hong Yu, Zou LL, Zhu QF (2010). Community structure characteristics of endangered plant *Prunus mongolica*. *Chinese J Eco* 29: 1907–1911.
- Kage H, Kochler M, Stützel H (2004). Root growth and dry matter partitioning of cauliflower under drought stress conditions: measurement and simulation. *Eur J Agron* 20: 379–394.
- Kavas M, Baloğlu MC, Akça O, Köse FS, Gökçay D (2013). Effect of drought stress on oxidative damage and antioxidant enzyme activity in melon seedlings. *Turk J Biol* 37: 491–498.
- Li FL, Bao WK, Wu N, You C (2008). Growth, biomass partitioning, and water-use efficiency of a leguminous shrub (*Bauhinia faberi* var. *microphylla*) in response to various water availabilities. *New Forest* 36: 53–65.
- Li FL, Bao WK, Wu N (2009). Effects of water stress on growth, dry matter allocation and water-use efficiency of a leguminous species, *Sophora davidii*. *Agroforest Syst* 77: 193–201.
- Li GL, Wu HX, Sun YQ, Zhang XY (2013). Response of chlorophyll fluorescence parameters to drought stress in sugar beet seedlings. *Russ J Plant Physiol* 60: 337–342.
- Liu D, Wu LT, Muhammad NS, Liu HB, Deng XQ, Xu L, Zhang F, Zhou WJ (2013). 5-Aminolevulinic acid enhances photosynthetic gas exchange, chlorophyll fluorescence and antioxidant system in oilseed rape under drought stress. *Acta Physiol Plant* 35: 2747–2759.
- Ma J, Ni X, Shi HY, Liu WZ (2010). Flowering biology of *Amygdalus mongolica*. *Acta Botanica Boreali-Occidentalia Sinica* 30: 1134–1141.
- Ma SM, Nie YB, Geng QL, Wang RX (2014). Impact of climate change on suitable distribution range and spatial pattern in *Amygdalus mongolica*. *Chinese J Plant Eco* 38: 262–269.
- Masinde PW, Stützel H, Agong SG, Fricke A (2006). Plant growth, water relations and transpiration of two species of African nightshade (*Solanum villosum* Mill. ssp. *miniatum* (Bernh. ex Willd.) Edmonds and *S. sarrachoides* Sendtn.) under water-limited conditions. *Sci Hortic-Amsterdam* 110: 7–15.
- Maxwell K, Johnson GN (2000). Chlorophyll fluorescence: a practical guide. *J Exp Bot* 51: 659–668.
- Ogbonnaya CI, Nwalozie MC, Roy-Macauley H, Annerose DJM (1998). Growth and water relations of Kenaf (*Hibiscus cannabinus* L.) under water deficit on a sandy soil. *Ind Crop Prod* 8: 65–76.
- Padilla FM, Miranda JD, Jorquera MJ (2009). Variability in amount and frequency of water supply affects roots but not growth of arid shrubs. *Plant Eco* 204: 261–270.
- Rampino P, Pataleo S, Gerardi C, Mita G, Perrotta C (2006). Drought stress response in wheat: physiological and molecular analysis of resistant and sensitive genotypes. *Plant Cell Environ* 29: 2143–2152.
- Royo A, Gil L, Pardos JA (2001). Effect of water stress conditioning on morphology, physiology and field performance of *Pinus halepensis* Mill seedlings. *New Forest* 21: 127–140.
- Sanchez-Rodriguez E, Rubio-Wilhelmi M, Cervilla LM, Blasco B, Rios JJ, Rosales MA, Romero L, Ruiz JM (2010). Genotypic differences in some physiological parameters symptomatic for oxidative stress under moderate drought in tomato plants. *Plant Sci* 178: 30–40.
- Saruhan GN, Sağlam A, Demiralay M, Kadioğlu A (2012). Apoplastic and symplastic solute concentrations contribute to osmotic adjustment in bean genotypes during drought stress. *Turk J Biol* 36: 151–160.
- Siqinbatee, Xiu M (2007). Hydrological characteristic of the desert plant *Prunus mongolica* on the Mongolian plateau of China. *J Plant Eco* 31: 484–489.
- Van Kooten O, Snel JFH (1990). The use of chlorophyll nomenclature in plant stress physiology. *Photosynth Res* 25: 147–150.
- Wang WL, Wan YJ, Liu B, Wang GX, Tang XY, Chen X, Liang B, Zhuang W (2013). Influence of soil gradual drought stress on *Acorus calamus* growth and photosynthetic fluorescence characteristics. *Acta Ecologica Sinica* 33: 3933–3940.
- Wu GL, Duan RY, Wang ZG, Zhang ZX, Wu LF (2010). Effects of drought stress and rehydration on chlorophyll fluorescence characteristics in *Fragaria* × *ananassa* Duch. *Acta Ecologica Sinica* 30: 3941–3946.
- Yin CY, Wang X, Duan BL, Luo J, Li C (2005). Early growth, dry matter allocation and water use efficiency of two sympatric *Populus* species as affected by water stress. *Environ Exp Bot* 53: 315–322.
- Zhang J, Wang J, Li HY, Zhang HR, Wang YC (2012). Genetic diversity of different eco-geographical populations in endangered plant *Prunus mongolica* by ISSR Markers. *Acta Ecologica Sinica* 32: 4443–4452.
- Zhang YJ, Xie ZK, Wang YJ, Su PX, An LP, Gao H (2011). Effect of water stress on leaf photosynthesis, chlorophyll content, and growth of Oriental lily. *Russ J Plant Physiol* 58: 844–850.