View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Institutional Repository of Xinjiang Institute of Ecology and Geography, CAS

Articles Chinese Science Bulletin
Geography
April 2010 Vol.55 No.10: 965–972
doi: 10.1007/s11434-009-0459-x

Analysis on the change of water potential of *Populus euphratica* Oliv. and *P. Russkii Jabl* under different irrigation volumes in temperate desert zone

FU AiHong, CHEN YaNing* & LI WeiHong

Key Laboratory of Oasis Ecology and Desert Environment, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China

Received March 10, 2009; accepted June 8, 2009; published online September 12, 2009

The measurement of plant water potential is considered to be a direct approach to confirming the irrigation time in present irrigation systems. In this current study, two shelter forests species in the Junggar Basin (Central Asia), *Populus euphratica* and *P. Russkii Jabl*, were studied. We monitored leaf water potential (ψ_l), stem water potential (ψ_s) and soil water potential (ψ_{soil}) under different irrigation conditions. The characteristics of the variation in leaf and stem water potential (ψ_l and ψ_s) of *P. euphratica* and *P. Russkii Jabl*, as well as the impact of soil water potential (ψ_{soil}) on the leaf and stem water potential (ψ_l and ψ_s) under different irrigation conditions were discussed. Our results showed the following. (1) With increased irrigation, the intensity of drought stress on *P. euphratica* and *P. Russkii Jabl* decreased. (2) The intensity of drought stress experienced was less for *P. Russkii Jabl* than for *P. euphratica* under the same irrigation conditions. (3) The more intense the drought, the less sensitive was *P. Russkii Jabl*, but the more sensitive was *P. euphratica*, and *vice versa*. (4) For the *P. euphratica* community the soil water potential (Ψ_{soil}) at 60 cm depth responded to variation in irrigation more strongly than at 30 and 90 cm depths. For the *P. Russkii Jabl* community the soil water potential (ψ_{soil}) in the shallow surface layer responded to irrigation variation more strongly than that in deep layers. (5) In the event of relatively sufficient soil water, predawn stem water potential (ψ_{pds}) of plant was a reasonable indicator reflecting soil water potential (ψ_{soil}). (6) The water demand of *P. euphratica* and *P. Russkii Jabl* shelter forests can be met with different irrigation policies: large volume and less frequency for *P. euphratica* but small volume and more frequency for *P. Russkii Jabl.*

water potential (ψ), *Populus euphratica*, *P. Russkii Jabl*, irrigation volume, temperate desert zone

Citation: Fu A H, Chen Y N, Li W H. Analysis on the change of water potential of *Populus euphratica* Oliv. and *P. Russkii Jabl* under different irrigation volumes in temperate desert zone. Chinese Sci Bull, 2010, 55: 965–972, doi: 10.1007/s11434-009-0459-x

There are two approaches to confirming the irrigation time in present irrigation systems [1]. One is to directly measure the soil water content or indirectly calculate the soil water balance from climatic data to evaluate the degree of available soil moisture and to confirm when irrigation is required. However, a scarcity of soil moisture does not adequately reflect a scarcity of plant moisture, which is also related to air evaporation, distribution of plant roots, plant growth characteristics, soil capacity to transport water, and air dry-humidity or saturation water vapour pressure. Due to the uneven distribution of soil moisture, it is very difficult to determine irrigation time by measuring soil moisture. The second way is to measure plant water potential (ψ), which reflects the integrated influence of soil, plant and atmosphere on plant water use. Measuring of ψ is a direct method to determine plant moisture status and confirm irrigation timing.

The plant water potential represents the energy level of plant water movement [2]. In arid zones, water is an important factor influencing the survival, growth and distribution of plants. After irrigation, the degree of drought stress lessens and ψ increases, reflecting the effect of irrigation. It has

---

*Corresponding author (email: chenyn@ms.xjb.ac.cn)

© Science China Press and Springer-Verlag Berlin Heidelberg 2009

been indicated that for the study of ψ under drought stress, fastened on the variation of ψ after different treatments (such as the use of growth depressor, desert bacterium and fertilization) under adequate irrigation and drought stress [3–5], the response of stem and leaf water potential (ψ_s and ψ_l) of plant in different periods of time to soil water potential (ψ_{soil}). For ψ reflecting the soil moisture, it has been shown that predawn leaf and stem water potential (ψ_{pdl} and ψ_{pds}) did not effectively reflect the soil moisture [6]. Midday leaf water potential (ψ_{ml}) better reflected the soil moisture than midday stem water potential (ψ_{ms}) [7]; however, there was a tight correlation between ψ_l and soil moisture [8]. Diurnal variation in ψ_l and ψ_s has shown a distinct V-curve by daylight in the case of relatively sufficient soil water [9]; however, in the case of insufficient soil water there can be no V-curve by daylight, and ψ in some species even has a gradual downward trend [10]. Therefore, the occurrence of a V-curve for diurnal variation of ψ is related to the scarcity of soil water or the extent of water stress to which plants are exposed. The more soil water, the less water stress plants are subjected to, and the more obvious a V-trend in diurnal variation of ψ; otherwise the diurnal variation in ψ shows no obvious V-trend. The moment of peak value of ψ reflects the time that ψ reaches a plant-soil balance, and the moment of minimum value of ψ reflects the sensitivity of plants to water stress. The earlier the minimum, the more sensitive the plant is to water stress under the same water stress conditions, and *vice versa*. The diurnal variation in ψ can reflect the drought sensitivity or resistant characteristics of plants. Studying the response of ψ to irrigation has important practical benefits in reducing irrigation amounts and improving its efficiency.

Populus euphratica has characteristics of tolerance to drought, cold, sand-coverage and alkali salts. It has a long life, low levels of disease and insect pests and high adaptability and is the only tree species and pioneer tree species in desert and salt-alkali areas in China [11]. *P. Russkii Jabl* has characteristics of high survival rate, rapid growth, and tolerance to drought and cold; it is a forestation tree species or green tree species in farmland shelter forest [12]. Until now, the study of *P. euphratica* has been on its ecophysiological response to water release of the lower reaches of the Tarim River, China [13]; genetic diversity of populations in northwestern China using RAPD DNA analysis [14]; effects of saline and osmotic stresses on proline and sugar accumulation *in vitro* [15]; and understanding saline and osmotic tolerance of suspended cells [16]. The study of ψ of *P. euphratica* has been on daily and monthly changes in ψ and their relationship with environmental factors [1,17,18], and there are few studies of ψ of *P. euphratica* at different levels of irrigation. For *P. Russkii Jabl*, most attention has been paid to the planting pattern and forestation technique [19], and responses of ψ to irrigation have not been studied. Analysis of the response of ψ of *P. euphratica* and *P. Russkii Jabl* to the different levels of irrigation will provide information for improving irrigation efficiency and for an effective water-saving forestation strategy.

In this study, we investigated the changes in ψ_s and ψ_l of *P. euphratica* and *P. Russkii Jab*l, and ψ_{soil}, after different levels of irrigation in the Junggar Basin in Xinjiang, and analyzed the response of the diurnal variations in ψ_s, ψ_l and ψ_{soil} to the different irrigation levels. We discussed the effect of ψ_{soil} on ψ of *P. euphratica* and *P. Russkii Jabl*, and proposed an effective water-saving irrigated forestation strategy.

1 Materials and methods

1.1 Study area

The study area is a new agricultural development zone of Karamay in the Junggar Basin in Xinjiang, which is located in the ancient Manas Lake basin in lake sediments. The soil is a heavy clay, compacted, and with salinity problems. This region has a continental arid temperate climate, with a dry hot summer and cold winter; annual mean temperature is 8°C, annual mean precipitation is 105.3 mm and corresponding pan-evaporation is 3545 mm. The wind is strong in spring. There are 119.7 d of wind of > 5 level and 45.6 d of wind of ⩾ 8 level in a year. The most wind speed is 25.1 m/s. The main wind direction is northwest [15].

1.2 Experiment design

The experimental area was the skeleton shelter forest belt of Xinjiang Karamay Agricultural Development Zone (Figure 1). *P. euphratica* and *P. Russkii Jabl* were the species studied. The area was divided into three areas, A, B and C, each with size of about 0.33 ha.

Every field had 20 rows of *P. euphratica* and 20 of *P. Russkii Jabl*. In May and June 2008, the 0, 80 and 200 m^3 irrigation treatments were performed for areas A, B and C, respectively. The irrigation ration was 60 and 150 m^3 per ha at one time in areas B and C, respectively. After the 1st irrigation, the 20 and 50 m^3 irrigation were performed for areas B and C, respectively. The total volume of four irrigations reached the 80 and 200 m^3. The frequency of irrigation was consistent. In the experimental field, one small sample with 25 m × 25 m and three plants of approximately average height, average age and canopy size were randomly selected for the study. The average age of *P. euphratica* is 10 years, height 8–10 m, diameter 25–30 cm; the average age of *P. Russkii Jabl* for 10 years, height 25–30 m, diameter 15–20 cm.

1.3 Measurement of plant water potential

A HR-33T Dew Point Microvoltmeter (WESCOR, USA)

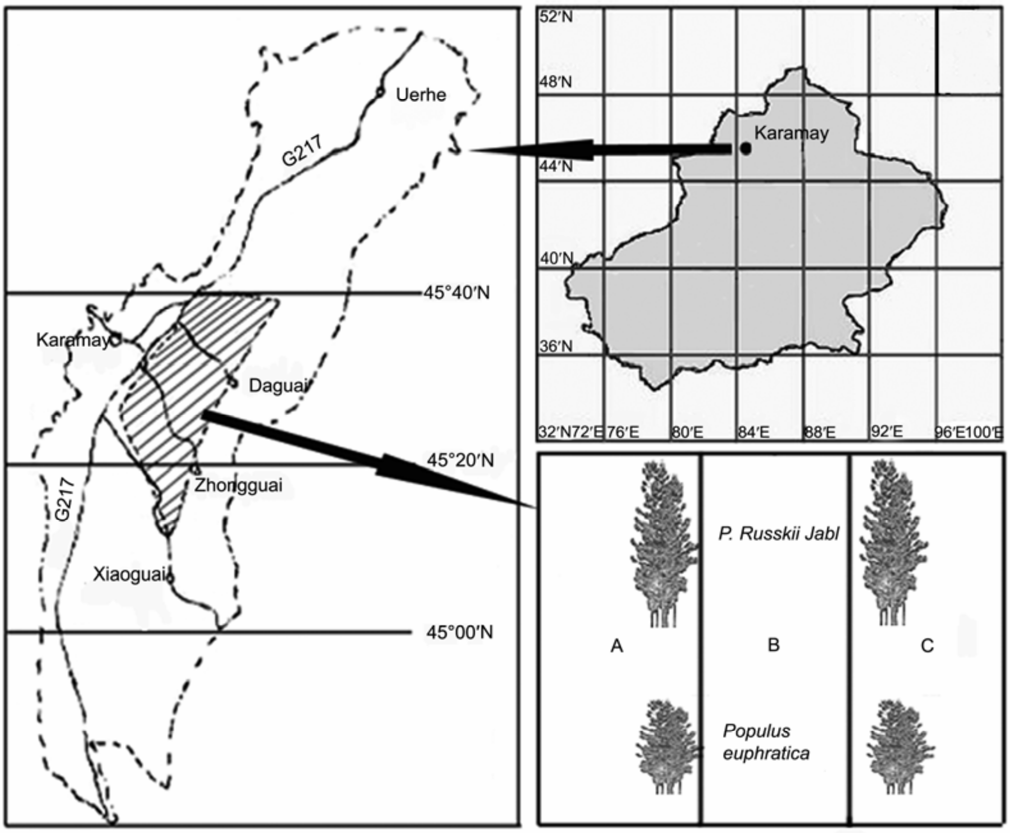

Figure 1 The map of study area in China's Xinjiang Karamay Agricultural Development Zone. ▨ is Xinjiang Karamay Agricultural Development Zone. A, B and C are the samples in the study area.

was used to measure ψ_s and ψ_l of *P. euphratica* and *P. Russkii Jabl*. On the sunward side of the selected trees, three normal leaves and sprigs in the upper part of tree crown were immediately sealed in polyethylene bags. The vein of the leaves was avoided, and three small discs with diameter of 5 mm were cut from the leaves and placed in three C-52 sample chambers connected to the Dew Point Microvoltmeter, respectively. Plant samples with epidermis and cuticle were allowed to equilibrate with chamber air in the C-52 sample chamber for 4 h. After achieving equilibration, according to the temperature of the sample chamber and the sensor model, an appropriate coefficient of refrigeration (Πv) value was chosen and dew-point value (in μV) was measured. ψ_l (in MPa) was calculated from (dew-point value)/7.5. The process of measuring ψ_s was as for ψ_l, except selected sprigs with length of 3 mm and diameter of 1.5–2.0 mm at the stem at the bottom of the petiole of the selected leaf. There were six C-52 sample chambers. Diurnal patterns of ψ_l or ψ_s of each species was measured from sunrise to sunset in one day. Three of the six C-52 sample chambers were used every 4 h in turn. Measurements were taken 30 d after the fourth irrigation. Except for ψ_{pd}, the measuring interval during the middle of the day was 2 h. In area A, B or C, nine replicate measurements of each species were taken on small leaves and branches, and the average value was calculated. ψ_{pd} were measured 20 min before sunrise. Measurements were taken on sunny days only.

1.4 Measurement of soil water potential

A HR-33T Dew Point Microvolt-meter (WESCOR, USA) was used to measure ψ_{soil}. The soil probes used for ψ_{soil} measurement were PSF-55-15-SF and PSF-55-30-SF. There were 18 soil probes. In areas A, B and C of the study area, for *P. euphratica* and *P. Russkii Jabl*, 18 pits in total were arbitrarily dug to a depth of about 1 m. There were three pits in every sample. In the pits at depths of 30, 60 and 90 cm were inserted soil probes, and then the pits were refilled with soil and the measuring sockets of probes were exposed at the surface and with the corresponding depth clearly marked. After allowing 24 h for equilibration of the buried probes, ψ_{soil} at the different depths were measured using the Dew Point Microvoltmeter over predawn–20:00, measured every 2 h. Each measurement was repeated three times, and the average value was calculated.

1.5 Data analysis

Data analysis and charting used the software Excel. Descriptive statistics were used to calculate averages and standard errors of the data from each set of replicates. Standard errors of the mean are shown by error lines. The differences between nine diurnal variations of ψ_s or ψ_l under each irrigation were analyzed by analysis of variance.

2 Results

2.1 The effect of different irrigation amounts on plant water potential

The diurnal variations of ψ_s and ψ_l with the different amounts of irrigation are shown in Figure 2. For the 0 m^3 irrigation, the diurnal variation in ψ_l of *P. euphratica* and *P. Russkii Jabl* showed an indistinct V-curve single peak trend; ψ_{pdl} of both species were at maxima of –2.65 and –3.00 MPa, respectively. The respective minima ψ of both species were 5.08 and 6.80 MPa at 18:00. After 20:00, ψ began to rise a little, showing the serious drought-stress both species suffered. For the irrigation of 80 m^3, the diurnal variation in ψ_l of *P. euphratica* and *P. Russkii Jabl* showed a V-curve single peak trend. ψ_{pdl} of both species were at their maximum of –2.30 and –2.00 MPa. After that, ψ decreased gradually with the rising of the temperature. The lowest ψ_l for *P. euphratica* was –4.60 MPa at 14:00, and for *P. Russkii Jabl* –6.24 MPa at 16:00. After that, ψ began to rise. ψ_{pdl} of both species were at their maximum, which showed that equilibrium was achieved between ψ and ψ_{soil}. The time of the lowest value of ψ_l for *P. euphratica* was earlier than *P. Russkii Jabl*, which showed that after irrigation of 80 m^3, the sensitivity of *P. euphratica* to water stress was greater than that of *P. Russkii Jabl*. For the 200 m^3 irrigation, the diurnal variation in ψ_l of *P. euphratica* was an 'initial rise-decrease-increase' trend, the difference of 9 measurement values of ψ_l of *P. euphratica* was not significant (Sig.=0.326); the diurnal variation in ψ_l of *P. Russkii Jabl* was an 'initial rise-decrease-increase-decrease' trend, the difference of 9 measurement values of ψ_l of *P. Russkii Jabl* was not significant (Sig.=0.455). The maximum value of ψ_l of both species was –1.89 and –2.69 MPa at 10:00, which was later than for the 80 m^3 irrigation, mainly because for the 200 m^3 irrigation ψ_{soil} was higher than for the 80 m^3. Achieving equilibrium between ψ and ψ_{soil} required a longer time; the minimum ψ_l of *P. euphratica* was –3.44 MPa at 16:00, and for *P. Russkii Jabl* –5.93 MPa at 14:00, with the reverse of the times of the minimum values for the 80 m^3 irrigation. After the 200 m^3 irrigation the sensitivity of *P. Russkii Jabl* to water stress was greater than that of *P. euphratica*.

In the 0 m^3 irrigation, the highest values of ψ_s of both *P. euphratica* and *P. Russkii Jabl* were –4.20 and –3.20 MPa at predawn, respectively, followed by a gradual descending trend. The lowest value was 8.20 and 6.20 MPa at 20:00, showing the serious drought-stress both species suffered. In the 80 m^3 irrigation, the highest value of ψ_s of both *P. euphratica* and *P. Russkii Jabl* was –2.91 and –2.64 MPa at predawn, respectively, followed by a gradual descending trend. ψ_s of *P. Russkii Jabl* appeared to be a little higher after 20:00 (Sig.=0.287), when for *P. euphratica* there was no obvious recovery. This indicated that for 80 m^3 irrigation, although both species were subjected to drought stress, that water loss of *P. euphratica* was greater than of *P. Russkii Jabl*. For the 200 m^3 irrigation, the diurnal variation in ψ_s of *P. euphratica* showed an inapparent V-curve single peak trend, with the highest value (–2.25 MPa) at predawn and the lowest (–4.10 MPa) at 18:00; the diurnal variation in ψ_s of *P. Russkii Jabl* showed a distinct V-curve single peak trend, with the highest value (–2.07 MPa) at 10:00 and the lowest (–4.91 MPa) at 14:00.

Regardless of the irrigation level, ψ_l of *P. euphratica* in the afternoon rose before ψ_s. Specifically, after the 0 m^3 irrigation, ψ_l rose after 20:00, but ψ_s did not rise. After the 80 m^3 irrigation, ψ_l rose after 14:00 and ψ_s did not clearly show recovery until 20:00. After the 200 m^3 irrigation, ψ_l of *P. euphratica* began to rise at 16:00, and ψ_s began to rise at 18:00; which may reflect the closure of leaf stomata lowering the transpiration under conditions of serious water deficit, and thus preventing further reduction in ψ_l. With decreasing of transpiration, soil moisture could not be transferred to the stem, so ψ_s would not have been able to recover. With decreasing of temperature, the opening of leaf stomata increased the transpiration, ψ_s began to rise. For the 0 m^3 irrigation, ψ_l of *P. Russkii Jabl* began to recover at 20:00, but ψ_s did not rise. For the 80 m^3 irrigation, ψ_l of *P. Russkii Jabl* in the afternoon recovered before ψ_s; however, for the 200 m^3 irrigation, ψ_s and ψ_l of both species began to rise after 14:00. After the 200 m^3 irrigation, the water status of *P. Russkii Jabl* improved, indicating that this irrigation volume helped its normal growth and development.

The difference between ψ_s and ψ_l can reflect the changes in plant water status [20] (Figure 3). When the difference between ψ_s and ψ_l was greater, this indicated ample soil moisture and better plant water status [20]. However, a smaller difference indicated a shortage of soil moisture and a worse plant water status [20]. Compared to 200 m^3, the 0 m^3 and 80 m^3 irrigation gave a smaller (and negative) difference between ψ_s and ψ_l in *P. euphratica*, which showed that little water was contained in *P. euphratica*, and that the plant suffered from a strong degree of drought stress. In comparison, for *P. Russkii Jabl*, the 0 m^3 and 80 m^3 irrigation gave a small difference between ψ_s and ψ_l and so the degree of drought stress suffered was weaker. For the 200 m^3 irrigation, the difference between ψ_s and ψ_l was less for *P. euphratica*, and larger and positive for *P. Russkii Jabl* (Figure 3). This indicated that for the 200 m^3 irrigation, *P. Russkii Jabl* had good water status and *P. euphratica* had poor. The 200 m^3 irrigation met the water requirements for normal growth of *P. Russkii Jabl*, but not of *P. euphratica*. Thus for the same

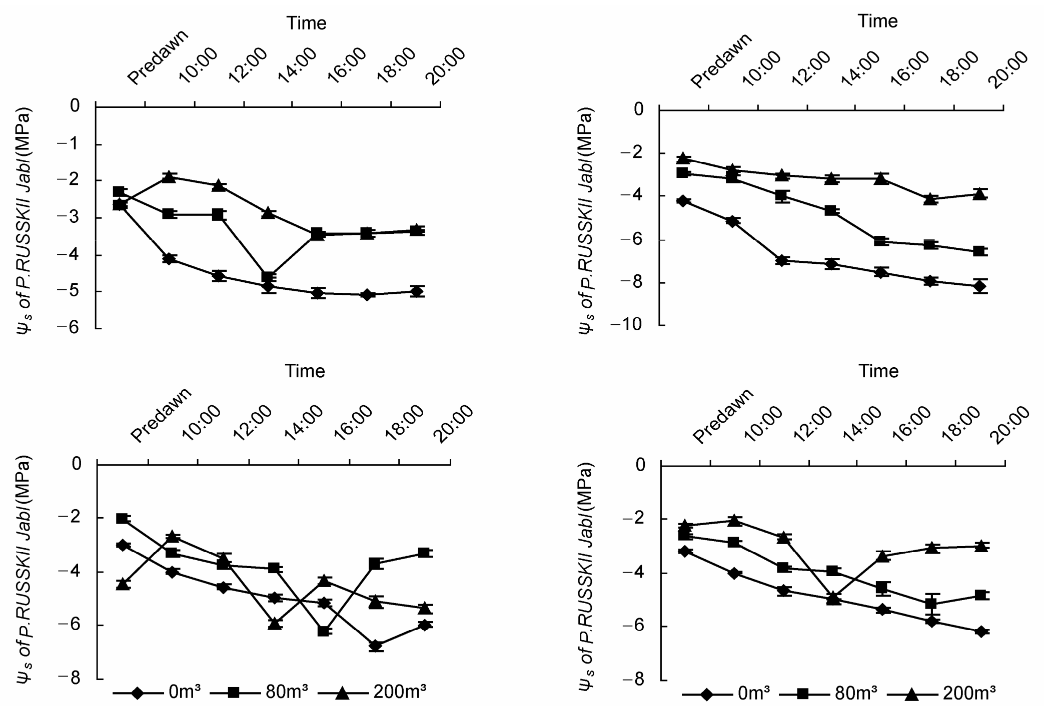

Figure 2 Diurnal variation of leaf and stem water potential of *P. euphratica* and *P. Russkii Jabl* under the different irrigation.

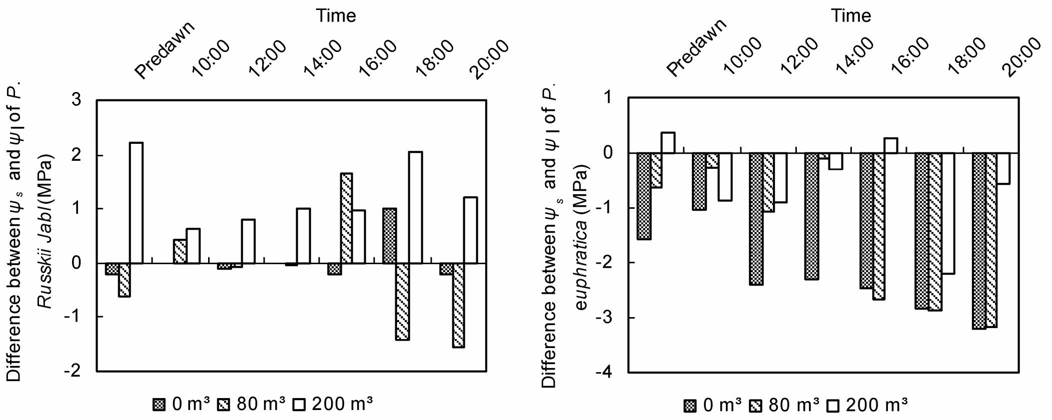

Figure 3 Diurnal variation of differences between stem and leaf water potential of *P. euphratica* and *P. Russkii Jabl.*

amount of irrigation, *P. Russkii Jabl* suffered less from drought stress than *P. euphratica*, which may be mainly related to the shallow root system of *P. Russkii Jabl* and the deeper root system of *P. euphratica*.

2.2 The effect of different irrigation levels on the diurnal variation in soil water potential

After the 0 m^3, 80 m^3 and 200 m^3 irrigations, the diurnal variation in ψ_{soil} in the pits at depths of 30, 60 and 90 cm was analyzed (Figure 4). Regardless of depth, ψ_{soil} after the 80 m^3 irrigation was higher than after 0 m^3, ψ_{soil} after the 200 m^3 irrigation was higher than after 80 m^3, which showed the impact of irrigation on ψ_{soil} at depths $\leqslant$90 cm was strong. For the *P. euphratica* community, when the amount of irrigation increased from 0 to 200 m^3, the increased ψ_{soil} at 60 cm depth was greater than at 30 and 90 cm. For the *P. Russkii Jabl* community, when the irrigation increased from 0 to 200 m^3, the increased ψ_{soil} were successively less with depth, indicating that the response of ψ_{soil} in the shallow layer to irrigation was stronger than in the deep layer.

2.3 The change in plant water potential with different soil water potential

ψ_{pd} and ψ_{m} of *P. euphratica* and *P. Russkii Jabl* at different ψ_{soil} are shown in Figure 5. With increased ψ_{soil}, ψ_{pds} and ψ_{m}

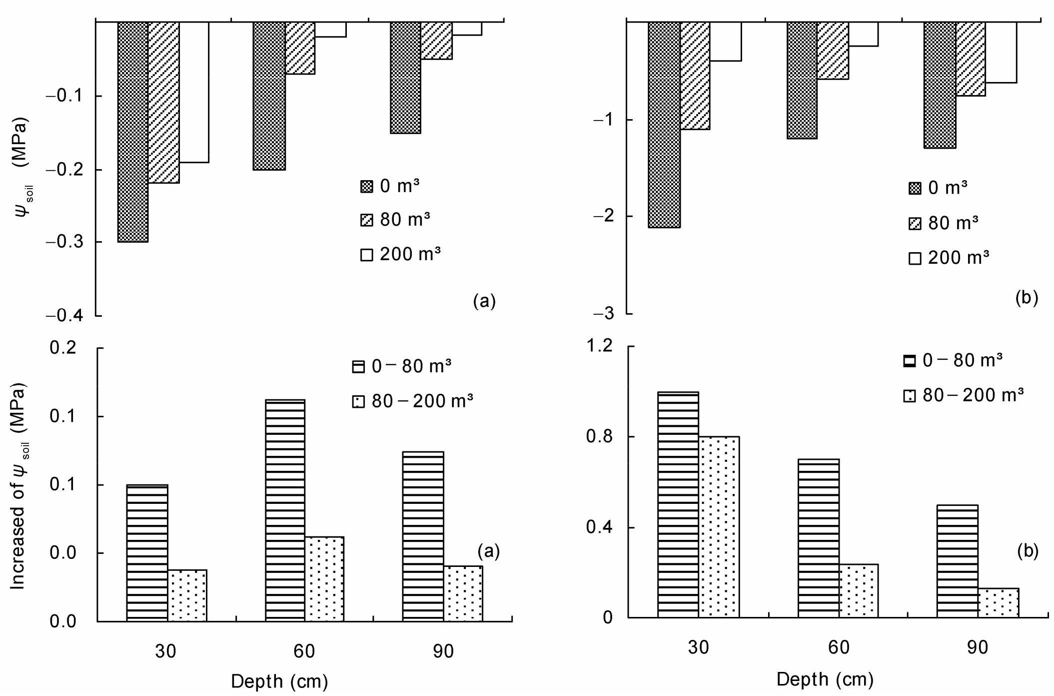

Figure 4 Diurnal average and increased of soil water potential at the depths of 30 cm,60 cm and 90 cm under the 0 m^3, 80 m^3 and 200 m^3 irrigation. (a) *P. euphratica* community; (b) *P. Russkii Jabl* community.

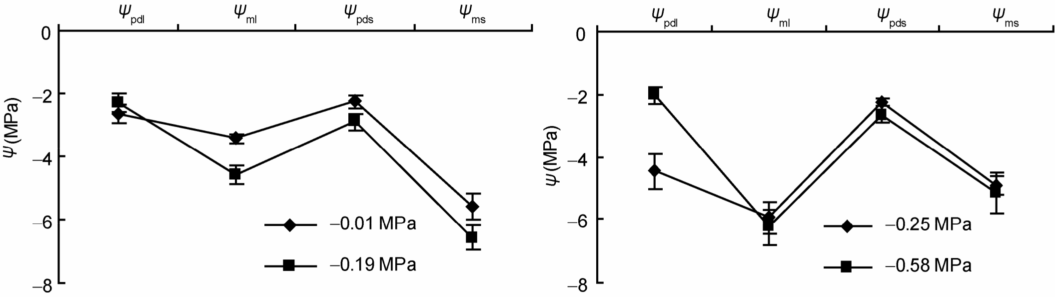

Figure 5 Leaf and stem water potential of *P. euphratica* and *P. Russkii Jabl* under the different soil water potential.

were higher; however, in contrast, $\psi_{\rm pdl}$ was lower when $\psi_{\rm soil}$ was higher. Specifically, when $\psi_{\rm soil}$ was reduced from –0.25 to –0.58 MPa, $\psi_{\rm pdl}$ of *P. Russkii Jabl* increased from –4.50 to –2.00 MPa, increased by –2.50 MPa. When $\psi_{\rm soil}$ was reduced from –0.01 to –0.19 MPa, $\psi_{\rm pdl}$ of *P. euphratica* increased from –2.50 to –2.20 MPa, increased by –0.30 MPa. Thus, for *P. euphratica* and *P. Russkii Jabl* neither suffering from water stress nor suffering from minor water stress, $\psi_{\rm pds}$ and $\psi_{\rm m}$ can be used to reflect the state of $\psi_{\rm soil}$; however, $\psi_{\rm pdl}$ could not.

3 Discussion

3.1 Contrast of drought stress experienced by *P. euphratica* and *P. Russkii Jabl*

With increased irrigation, there was increased $\psi_{\rm s}$ of *P. euphratica* in the afternoon, which showed a lower degree of water stress in *P. euphratica.* There was increased $\psi_{\rm s}$ of *P. Russkii Jabl* in the afternoon, which rose with $\psi_{\rm l}$ after 14:00, ahead of $\psi_{\rm s}$ of *P. euphratica*, showing that the degree of water stress of *P. Russkii Jabl* was weak gradually, and weaker than that of *P. euphratica* after 200 m^3 irrigation.

For three irrigation levels, $\psi_{\rm l}$ of *P. euphratica* rose before $\psi_{\rm s}$, which may reflect the conditions of water deficit, the stomatal closure lowering the leaf transpiration, and thus preventing further reduction in $\psi_{\rm l}$. For the 200 m^3 irrigation, there was insufficient water for normal growth of *P. euphratica*. For *P. Russkii Jabl*, in the 0 and 80 m^3 irrigations, $\psi_{\rm l}$ recovered before $\psi_{\rm s}$; in the 200 m^3 irrigation, $\psi_{\rm l}$ and $\psi_{\rm s}$ started to recover at 14:00, indicating that *P. Russkii Jabl* had not suffered from water stress and could grow normally.

3.2 Contrast of drought tolerance characteristics of *P. euphratica* and *P. Russkii Jabl*

In the 80 m^3 irrigation, the time of the minimum $\psi_{\rm l}$ and $\psi_{\rm s}$ of *P. euphratica* was before *P. Russkii Jabl*, except in the 200 m^3 irrigation, which was after *P. Russkii Jabl*. Analysis of the diurnal variation of ψ showed that the stronger the drought stress, the weaker was the sensitivity of *P. Russkii Jabl* reflecting the drought, possibly because it could not take timely measures to resist drought. The more humid the environment was, the stronger was the sensitivity of *P. Russkii Jabl* to indicating the drought. Greater drought stress of the environment increased the sensitivity of *P. euphratica* reflecting the drought, and *vice versa*. *P. euphratica* is considered very resistant to drought stress.

The time of the maximum ψ_l in the 200 m^3 irrigation was later than that of 80 m^3, which showed that ψ_{soil} in the 200 m^3 irrigation was higher than that of 80 m^3. Achieving equilibrium between ψ and ψ_{soil} required a longer time. In the 200 m^3 irrigation, the maximum ψ_s of *P. euphratica* appeared to be at predawn, and for *P. Russkii Jabl* at 10:00, which showed that the capacity of restoring the original state after suffering from water stress was less for *P. Russkii Jabl*.

3.3 The contrast in soil water potential characteristics of *P. euphratica* and *P. Russkii Jabl*

The responses of ψ_{soil} for *P. euphratica* and *P. Russkii Jabl* communities to the different amounts of irrigation differed, possibly due to the different distribution of roots of the species. *Populus euphratica* are the only natural forest trees in these desert areas, and have adapted to chronic drought stress. Roots of *P. euphratica* show hydrotropic growth (i.e. when soil moisture penetrates down, the roots also grow down)(http://yz.ag365.com/yangzhi/kejiyuan/2008/2008102246874.html).

The capacity to absorb deep soil moisture increased with increased irrigation; deep root systems absorb larger amounts of water. Soil moisture around shallow roots continued to infiltrate down to deeper roots, indicated by the higher ψ_{soil} in the deep than the shallow layer and a stronger impact of irrigation on ψ_{soil} at 60 cm depth than at 30 and 90 cm. *P. Russkii Jabl* are the main green trees in oasis, and so are usually grown in areas of abundant soil moisture, so possibly the ability to absorb moisture in the shallow soil layer was strong. Therefore, with increased irrigation, the shallow root system absorbed more water and tended to pull deeper soil moisture into shallower layers, indicating that ψ_{soil} in the shallow layer increased with increased irrigation.

3.4 The contrast in characteristics of absorbing water of roots of *P. euphratica* and *P. Russkii Jabl*

The present study showed that for the *P. euphratica* community, with the increased irrigation, the increase in ψ_{soil} at 60 cm depth was greater than at 30 and 90 cm. As the roots of *P. euphratica* in the area are mainly distributed in the layer 50–80 cm deep, so the increased amount of irrigation contributed to the plants' growth and development. The roots of *P. Russkii Jabl* are mainly distributed in the layer 20–50 cm deep, and have the ability to strongly absorb shallow soil moisture. That the increased amount of irrigation increased ψ in shallow rather than deeper soil is conducive to the growth and development of *P. Russkii Jabl*.

3.5 Determining a reasonable index reflecting soil water potential

After analyzing the characteristics of changes in ψ at different ψ_{soil}, we found that when soil moisture was adequate, ψ_{pdl} of plant did not reflect the status of ψ_{soil}. ψ_{pds} and ψ_m did reflect the status of ψ_{soil}. Donovan et al. [6] have shown that, when plants suffer severe drought stress, ψ_{pdl} can reveal the current soil moisture; they also found when soil moisture was adequate, ψ_{pdl} was not in balance with ψ_{soil} near plant roots, and could not be used to reveal soil moisture at that time. ψ_s was the most discriminating indicator for both moderate and severe water deficits [20]. ψ_m suffers from external environmental conditions, particularly the strong influence of climatic factors, and so cannot serve as a reasonable index of ψ_{soil}, only ψ_{pds} seemed useful.

4 Conclusions

The distribution of roots and the characteristics of water absorption of *P. euphratica* and *P. Russkii Jabl* differed. When soil moisture was adequate, the roots of *P. euphratica* were mainly distributed in the layer 50–80 cm deep, and could strongly absorb deep soil moisture. The roots of *P. Russkii Jabl* were mainly distributed in the layer 25–50 cm deep, and could strongly absorb shallow soil moisture. To exert the particular characteristics of root systems to the greatest degree, and absorb the maximum amount of water, requires different irrigation measures. We advise adopting an irrigation policy of large volume and less frequency to *P. euphratica* shelter forest, as the *P. euphratica* root system can be effectively induced to extend deeper during the infiltration of irrigation water. Thus the moisture self-maintenance capacity of *P. euphratica* could be improved, favoring its survival under drought stress since the roots can absorb soil water below the cultivated horizon. For the *P. Russkii Jabl* shelter forest, however, irrigation of small volumes and greater frequency should be implemented to meet the water demand of *P. Russkii Jabl* by accumulating water in the shallow surface layer.

The present study showed that the 200 m^3 irrigation met the water required for normal *P. Russkii Jabl* growth, the irrigation policy of small volumes and greater frequency could improve water use efficiency of *P. Russkii Jabl,* but not *P. euphratica*. To avoid water stress of *P. euphratica* requires an irrigation volume > 200 m^3; the increased amount could improve its water use efficiency.

When soil moisture was adequate, ψ_{pds} could effectively reflect ψ_{soil} and the intensity of drought stress suffered by plants in an arid zone.

This work was supported by the National Natural Science Foundation of China (Grant No. 40701052), National Key Technology R & D Program (Grant Nos. 2006BAD26B0901 and 2006BAC01A03) and Major Programs of Xinjiang (Grant No. 200733144-4).

1 Si J H, Feng Q, Zhang X Y. Leaf water potential of *Populus euphratica* and influencing factors in extreme arid region (in Chinese). J Des Res, 2005, 25: 505–510

2 Vogt U K, LÖsch R. Stem water potential and leaf conductance: A comparison of *Sorbus aucuparia* and *Sambucus nigra*. Phys Chem Earth (B), 1999, 24: 121–123

3 Morte A, Lovisolo C, Schubert A. Effect of drought stress on growth and water relations of the mycorrhizal association *Helianthemum almeriense-Terfezia claveryi*. Mycorrhiza, 2000, 10: 115–119

4 Zhu L H, Peppel A V D, Li X Y, et al. Changes of leaf water potential and endogenous cytokinins in young apple trees treated with or without paclobutrazol under drought conditions. Sci Horticulturae, 2004, 99: 133–141

5 Mrema A F, Granhall U. Sennerby-Forsse plant growth, leaf water potential, nitrogenase activity and nodule anatomy in *Leucaena leucocephala* as affected by water stress and nitrogen availability. Trees-struc Funct, 1997, 12: 42–48

6 Donovan L A, GriseÂ D J, West J B, et al. Predawn disequilibrium between plant and soil water potentials in two cold-desert Shrubs. Oecologia, 1999, 120: 209–217

7 Cutchan M, Sehackel H K A. Stem-water potential as a sensitive indicator of water stress in prune trees (*Prunus domestica* L.). J Am Soc Hort Sci, 1992, 117: 607–611

8 Atklnson C J, Policarpo M, Webster A D, et al. Drought tolerance of clonal Malus determined from measurements of stomatal conductance and leaf water potential. Tree Physiol, 2000, 20: 557–563

9 Bai R Q, Sun L H, Lv Z J, et al. Stubp on daily variation of water potential of apple trees of different stocks (in Chinese). J Inner Mongol Agr Univ (Nat Sci Edit), 2000, 21: 63–68

10 Zeng F J, Zhang X M, Li X Y. Seasonal variation of *Tamarix ramosissima* and *Populus euphratica* water potentials in southern fringe of Taklamakan desert, China (in Chinese). J Appl Ecol, 2005, 30: 108–114

11 SÍlvia F, Dora B, Susana S, et al. Morphogenesis induction and organosenic nodule differentiation in *Populus euphratica* Oliv leaf explants. Plant Cell Tiss Org, 2009, 96: 35–43

12 Meng M, Jiang H, He J C. Analysis on technique of group-foster and rapid-propagation in *P. Russkii Jabl* (in Chinese). Xinjiang Agr Sci, 2003, 40: 101–102

13 Wang Q, Ruan X, Chen Y N, et al. Eco-physiological response of *Populus euphratica* Oliv to water release of the lower reaches of Tarim River, China. Environ Geol, 2007, 53: 349–357

14 Saito Y, Shiraishi S, Tanimoto F, et al. Genetic diversity of *Populus euphratica* populations in northwestern China determined by RAPD DNA analysis. New For, 2002, 23: 97–103

15 Watanabe S, Kojima K, Ide Y, et al. Effects of saline and osmotic stress on proline and sugar accumulation in *Populus euphratica in vitro*. Plant Cell Tiss Org, 2000, 63: 199–206

16 Gu R S, Liu Q L, Pei D, et al. Understanding saline and osmotic tolerance of *Populus euphratica* suspended cells. Plant Cell Tiss Org, 2004, 78: 261–265

17 Song Y X, Zhou M X, Zhang X Y, et al. Relationship of water potential for some dominant plant species in Ejin Oasis to environmental factors(in Chinese). J Des Res, 2005, 25: 496–499

18 Gries D, Zeng F J, Foetzki A, et al. Growth and water relations of *Tamarix ramosissima* and *Populus euphratica* on Taklamakan desert dunes in relation to depth to a permanent water table. Plant Cell Environ, 2003, 26: 725–736

19 Li P J, Li H, Yaheti G L. Primary report on summer cottage forestation technique of *P. Russkii Jabl* (in Chinese). Xinjiang Agr Sci, 2005, 42: 32–34

20 Xavier C, Cornelis L, Denis D, et al. Stem water potential is a sensitive indicator of grapevine water status. Ann Bot, 2001, 87: 477–483