

Hydraulic resistance partitioning between shoot and root system and plant water status of *Haloxylon ammodendron* growing at sites of contrasting soil texture

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Abstract: Hydraulic resistance components and water relations were studied on *Haloxylon ammodendron*, a small xeric tree, growing at sites significantly differed in soil texture. Soil water content, leaf water potential (ψ_l), xylem water potential (ψ_x), root water potential (ψ_{root}), leaf transpiration rate (TR) and stomatal conductance (g_s) were measured at the two sites during the growing season of 2005 and 2006. Leaf specific hydraulic resistance (R_{plant}) during the whole growing season, hydraulic resistance of plants (R_p), shoots (R_{shoot}) and roots (R_{root}) in the August of both years were calculated and expressed on leaf area basis. The results showed the proportion of the hydraulic resistance of the aerial part (R_{shoot}) to the R_p was the same to the proportion of the hydraulic resistance of the soil part (R_{root}) to the R_p , indicating that both parts were equivalent important to plant water hydraulic system from soil to leaf. Positive significant correlations were found between R_p and R_{root} , suggesting that root hydraulics resistance was a major determinant of plant hydraulic resistance (R_p) and transpiration rate. The integrated effect of stomatal control, hydraulic regulation and morphology adjustment enabled plants at heavy soil site surviving the extreme water deficit period.

Keywords: hydraulic architecture; leaf water potential; transpiration; hydraulic resistance; stomatal conductance; hydraulic limitation

1 Introduction

The hydraulic architecture of a plant first coined by Zimmermann (1978), which refers to the partitioning of hydraulic conductance in a plant and includes changes in xylem efficiency and vulnerability to cavitations (Zimmermann 1978; Zimmermann and Sperry, 1983; Tyree and Ewers, 1991a). Tyree (2007) defined the terminology as a quantitative description of the plant in terms of the Ohm's law analog using a simple linear model of conductance elements or a complex branched catena of a few or even thousands of conductance elements. Hydraulic architecture is an important determinant of the plant water balance, and influences plant water relations and growth potential (Sperry, 2000; Meinzer, 2002). Environmental variables have shown to influence hydraulic archi-

ture extensively. Soil water limiting, for example, promotes plants investing more biomass to below ground and thus alters the corresponding absorption-transport-transpiration cross-sectional area ration, which in sequence change the organs and individual specific hydraulic conductance (Ewers *et al.*, 2000; Hacke *et al.*, 2000; Li *et al.*, 2005; Addington *et al.*, 2006). Furthermore, nutrient and water deficiency lead to plant morpho-functional adjustment and alter hydraulics conductance to facilitate nutrient and water capture (Ewers *et al.*, 2000; Trubat *et al.*, 2006). Nitrogen fertilization has shown to increase leaf area production (Albaugh *et al.*, 1998), thereby decreasing both root-leaf surface area ratio and sapwood-

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leaf area ratio. Additionally, the reduction of irradiance and light regimes also influence hydraulic architecture and water relations (Tyree *et al.*, 1998; Hernández *et al.*, 2009; Raimondo *et al.*, 2009).

The partitioning of hydraulic resistance or its reciprocal, conductance, along the water transport path was one of the important factors of hydraulic architecture (Zimmermann, 1978; Zimmermann and Sperry, 1983; Tyree *et al.*, 1991b; Cruziat *et al.*, 2002). The evolutionary, adaptive and responsive significance of hydraulic separations prevailing environmental factors had been given extensively attention since the hydraulic architecture concept introduced by Zimmermann (1978), especially on hydraulic resistance coordination among organs changes (Nardini *et al.*, 1998, 1999b, 2003; Tyree *et al.*, 1999; Aranda *et al.*, 2005). Hydraulic resistance was an important factor in predicting plant water status (Iro *et al.*, 1995), characterizing the drought resistance ability of plants (Nardini, 1998, 1999a; Trifilò *et al.*, 2004), and explaining competitive advantage among plant species (Nardini, 1998; Trifilò, 2004). Plant growth rate and biomass production were also closely related to plant hydraulic conductance (Nardini, 1999b; Solari, 2006). Newly advance of resistances partition had been carried out at finely organs to tissues levels, such as changes in the conductance to water of the vascular and non-vascular compartment of roots and leaves (Amodeo, 1999; Salleo *et al.*, 2003) and on micro-time scales, such as circadian regulation of leaf and root hydraulic conductance (Henzler 1999; Nardini, 2005).

Soil texture is particularly important to plant and soil water relations in arid systems (Alizai and Hubert, 1970; Noy-Meir, 1973). Due to higher saturated conductivity (Jury *et al.*, 1991), smaller capillary water in topsoil and less tightly bound to particles, sandy soil have a greater soil water potential than a clay soil in the period of relative higher soil water content following rain pulse in desert ecosystem (Nilsen and Orcutt, 1996). However, it declines quickly with prolonged drought. Plants may overcome the effects of steeply declining soil hydraulic conductivity at high soil water potential by developing higher root to leaf area ratios, or by lowering the transpiration rate (Hacke *et al.*, 2000; Xu and Li, 2008). Both features will alter the plants hydraulic traits above and below ground thus preventing the loss of hydraulic contact

between the root system and the soil (Sperry *et al.*, 1998, Hacke *et al.*, 2000). Furthermore, higher porosity in coarse textured soil than in fine textured soil facilitated root-soil air gaps formation at drying period which could benefit desert plant by maintaining a higher root water potential in the early stages of drought, and later by limiting root water loss at the root-soil interface when the water potential exceeds that of soil (North and Nobel, 1997). Despite the influence of soil texture on hydraulic traits and plant water relations has been extensively studied, scarce research pay attention to the hydraulic resistance distribution and adjustment in relation to soil texture change and corresponding variation of soil water availability. Hydraulic separations and changes between organs would allow plants to favor certain parts at the expense of others especially for plants undergoing prolonged drought, which may mirror the plant water use strategy.

Haloxylon ammodendron (C.A.Mey.) Bunge is a sub-tree xerophilous plant that is native to a variety of Central Asian and African desert habitats, including gravel desert, heavy-textured desert soil, and sandy desert. The leaves of *H. ammodendron* have retrogressed as succulent branches and showed a C₄ type of photosynthesis (Pyankov *et al.*, 1999). Previous research on *H. ammodendron* in different soil texture have integrated morphology and physiology traits, and investigated the traits performance under nature and artificial water conditions with the aim to better understanding their response to drought at different scales (Xu and Li, 2008; Zou *et al.*, 2009). In this paper we aimed to clarify the difference and consistency of plant water status and hydraulic resistance partitioning of aerial part versus underground part in *H. ammodendron* growing at different soil habitats and quantify the contribution of resistance in root and shoot to the whole plant resistance.

2 Materials and methods

2.1 Plant materials and growing conditions

Field experiments were carried out during the growing season of 2005 and 2006 at Fukang Station of Desert Ecology, Chinese Academy of Sciences, which is in the hinterland of Eurasia (44°17'N, 87°56'E, 475 m above sea level). The plain area of this region has a

continental arid temperate climate, with a hot dry summer and cold winter. Annual mean precipitation is about 160 mm. Annual pan evaporation is about 1,000 mm. *H. ammodendron* is a major dominant species of the region and is highly drought and salt-tolerant. Studies were conducted at two *H. ammodendron* habitats of contrasting soil textures with similar climatic conditions (less than 8 km apart). One site was at the edge of a sandy desert with a sandy soil (referred to as sandy hereafter, 44°22'N, 87°55'E, 448 m above sea level); the other site was at the fringe of an alluvial plain with a heavy textured soil (referred to as heavy hereafter, 44°14'N, 87°51'E, 454.5 m above sea level). The sites were far from direct human influence. Average height and canopy radius was 1.77±0.10 m and 1.41±0.14 m for sandy soil site; and 1.70±0.10 m and 1.05±0.11 m for heavy textured soil site.

2.2 Measurement of soil water moisture and rainfall

Soil particle sizes were measured with a laser diffraction system in the laboratory on soil samples taken from experiment sites (Sympatec GmbH, System-Partikel-Technik, Clausthal-Zellerfeld, Germany). The sampling depth was from soil surface to 400 cm with interval of 20 cm. The soil water content was measured during growing season at two sites every five days at depths of 0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm, 80–100 cm, 100–120 cm, 120–140 cm and 140–160 cm with five replicates, by oven-drying and weighing. A portable meteorological station (Campbell Scientific, Logan, Utah, US) installed between the two sites, and meteorological data was collected.

2.3 Gas exchange and plant water status

The leaf transpiration rate (TR) was measured by the compensated heat-pulse system of Cohen *et al.* (1983). Ten heat-pulse probes were installed for each site on branches of diameter of 8–15 mm, and the sap flow rate for each branch (TR of the branches) recorded every 30 min. To overcome the effect of variation in branch size, the TR value was normalized on a leaf-area basis. To quantify leaf area of each branch, all foliage on each selected branch was photographed every two weeks with a 6×10^8 pixel digital camera (Canon 300D, Canon Inc, Tokyo, Japan). The leaf surface area of each branch was calculated from the photographs using CI-400 CIAS software (ComCID

Co, Logan, UT, US). The TR value was then converted to a leaf-specific value according to the leaf surface area of each branch. A steady-state porometer (Model LI-1600; LI-COR, Lincoln, NE, US) was used to determine stomatal conductance (g_s). Ten replicates were measured every hour on ten fixed, labeled leaves at each site. Leaf water potential (ψ_l) was measured with Model 1000 pressure chamber (PMS Instrument Co., Albany, US). For each measurement 10 replicates were taken on 10 individual plants. For tracing diurnal ψ_l , measurements were done every 30 min at early and late afternoon, and every hour around noon. Predawn leaf water potential (ψ_{pd}) was measured 30 min before sunrise and midday leaf water potential (ψ_m) was measured at solar noon. The xylem water potential at trunk base (ψ_x) from predawn to sunset was estimated by covering four to five leaves growing near the base of plants with aluminum foil on the evening before the trial day. Under this condition, leaf water potential is generally equilibrium to the adjacent xylem (Nardini *et al.*, 2003; Raimondo *et al.*, 2009). Because of the limiting amount of sucker leaves, the measurement was performed only in August in both years.

The shallow layers soil (0–1 m) was removed and the roots were carefully exposed without damage. Target roots (2–3 mm in diameter) were cut into segments with length of 4–6 cm, sealed with cyanoacrylate adhesive at one cut end and wrapped quickly with insulating tape. Measurement was completed within 3 min of excision. Due to the limitation of instrument and manpower, all the leaf and root water potential and stomata were measured alternatively: e.g. one day at sandy soil site, the next day at heavy textured soil site.

The impact of water stress on plants (WSIS) was expressed in the integrated form (Mishio and Yokoi, 1991; Vertovec *et al.*, 2001):

$$WSIS = \int_{t_0}^{t_x} \psi_L \cdot dt, \quad (1)$$

where WSIS is the impact of water stress on individuals of a given species and dt is the time interval when ψ_L (shoot water potential) measurements are performed. t_0 and t_x are pre-dawn, and sunset times, respectively. Because the diurnal course of shoot water potential and transpiration rate showed that after 12:00 the both values were unstable, which inferred that there must exist other means of regulation, such as

stomata adjustment or osmotic adjustment. Therefore t_x was taken as 12:00 in the current study.

2.4 Hydraulics measurement

To estimate seasonal change in the hydraulic resistance of whole plant (leaf specific hydraulic resistance, R_p), diurnal ψ_l was plotted against diurnal transpiration flux density (Cohen *et al.*, 1983). The slope of the linear relationship is taken as the hydraulic resistance of the plant. The hydraulic resistance of aerial part and root system were calculated using the evaporative flux method (Nardini *et al.*, 2003; Raimondo *et al.*, 2009). Hydraulic resistance of whole plant (R_{plant}), shoots (R_{shoot}) and roots (R_{root}) was calculated as:

$$R_{plant} = (\psi_{pd} - \psi_m) / E_L, \quad (2)$$

$$R_{root} = (\psi_{pd} - \psi_x) / E_L, \quad (3)$$

$$R_{shoot} = (\psi_x - \psi_m) / E_L. \quad (4)$$

Where ψ_{pd} is assumed to equilibrate to soil water potential; E_L is maximum transpiration rate at noon; ψ_x is the xylem water potential at trunk base. All of the hydraulic resistances were expressed on leaf area basis.

2.5 Data analysis

Descriptive statistics were used to calculate mean and standard errors of the mean. Mean value of hydraulic parameters (ψ_{pd} , ψ_m , ψ_{root} , g_s and TR_{max}) were compared with student's *t*-tests at two sites. The Pearson product moment correlation was used for correlation analysis. All statistical analyses were performed using Minitab 15. Charting used the mapping software origin 8.0 (Origin Lab. Corp., Northampton, MA, USA.).

3 Results

3.1 Soil particle composition and soil water moisture

The particle size was 0–500 μ m for the sandy soil and 0–50 μ m for the heavy textured soil. The data of soil particle composition indicating no significance difference by *t*-tests at variation soil depth intervals were pooled together. Therefore only the soil compositions of particle sizes at depth of 0–20 cm, 20–150 cm and 150–400 cm were given in Fig. 1.

The seasonal pattern of soil moisture changes in the profiles can be seen in Fig. 2. Influenced by precipitation, the surface layer (0–20 cm) soil water content fluctuated at the range of 1% to 7% in sandy soil and 4% to 16% in heavy textured soil. Except the surface

layer, the soil water content showed little variation with the depth in sandy soil. However, there existed a high soil water moisture zone at 40–80 cm in heavy textured soil.

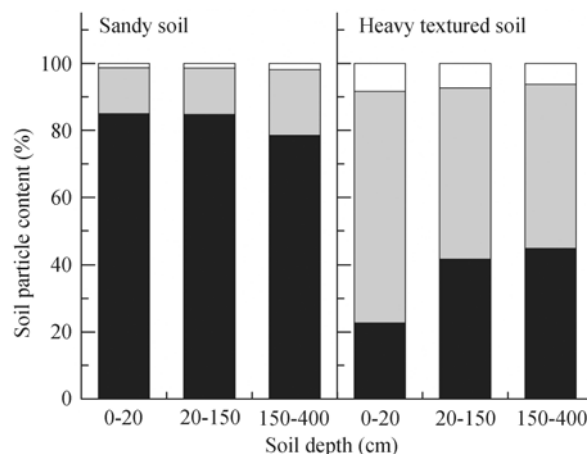


Fig. 1 Sand, silt, and clay fractions for sandy soil and heavy textured soil at 0–20 cm, 20–150 cm and 150–400 cm depth

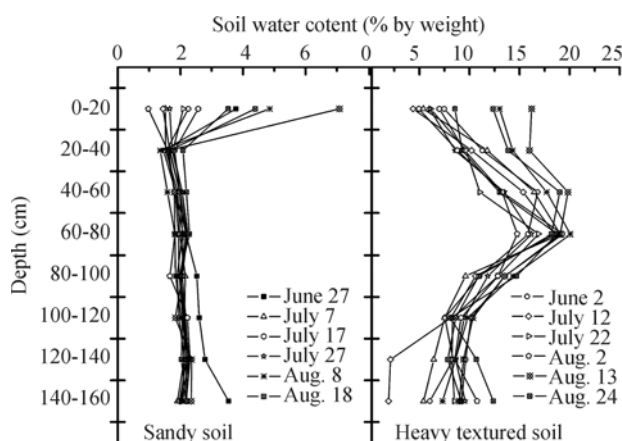


Fig. 2 Seasonal variation in soil water content along the soil profiles from 0 to 160 cm at interval of 20 cm in the growing season of 2005. Legend indicated the date of the year.

3.2 Seasonal and diurnal changes in plant water status

The seasonal variation of predawn (ψ_{pd}) and midday (ψ_m) leaf water potential and the occurring of precipitation were reported in Fig. 3. In both soil types, ψ_{pd} and ψ_m were affected by rain events, which were higher after rain and declined with prolonged drought. Mean midday-predawn water potential gradient in two growing season was 1.70 ± 0.27 MPa and 1.19 ± 0.18 MPa for sandy and heavy textured soils, respectively ($P < 0.001$). In heavy textured soil, the lowest water potential gradient appeared on 4 July 2005 and on 5

August 2006, which were close to zero. The total rainfall in 2005 was 133.8 mm and 102.7 mm in 2006. In August when the covered leaves (xylem water potential) measurements were done, the total rainfall was 35.7 mm in 2005 and 6.1 mm in 2006.

The mean ψ_{pd} and ψ_m value of sandy soil in 2005 vs. 2006 was -2.31 ± 0.09 MPa against -2.52 ± 0.08 MPa ($P=0.124$) and -4.09 ± 0.12 MPa against -4.19 ± 0.06 MPa ($P=0.498$). The mean ψ_{pd} and ψ_m of heavy textured soil in 2005 vs. 2006 was -3.14 ± 0.18 MPa against -3.42 ± 0.06 MPa ($P=0.171$) and -4.42 ± 0.10 MPa against -4.56 ± 0.06 MPa ($P=0.251$). The averaged values of Ψ_{root} , Ψ_{pd} , Ψ_m , g_{noon} , TR_{max} , and R_p in two years were shown in Table 1. There were significant differences among ψ_{pd} and ψ_m in the two sites.

However, the Ψ_{root} , g_{noon} , TR_{max} and R_p showed no difference.

The calculated $WSIS$ of each trial day were averaged for months (Fig. 4). The result showed $WSIS$ increased from May to July and decreased in August in 2005. In 2006, the $WSIS$ increased from June to September continuously. The $WSIS$ was significantly different on different soil textures for the same month, except for August 2005.

The maximum transpiration (TR_{max}) was plotted against the whole plant hydraulic conductance (R_p) in the two sites (Fig. 5). There were good relationship between the TR_{max} and R_p . TR_{max} , which declined with the increase of R_{plant} indicating that the TR_{max} , which partially controlled by the R_p .

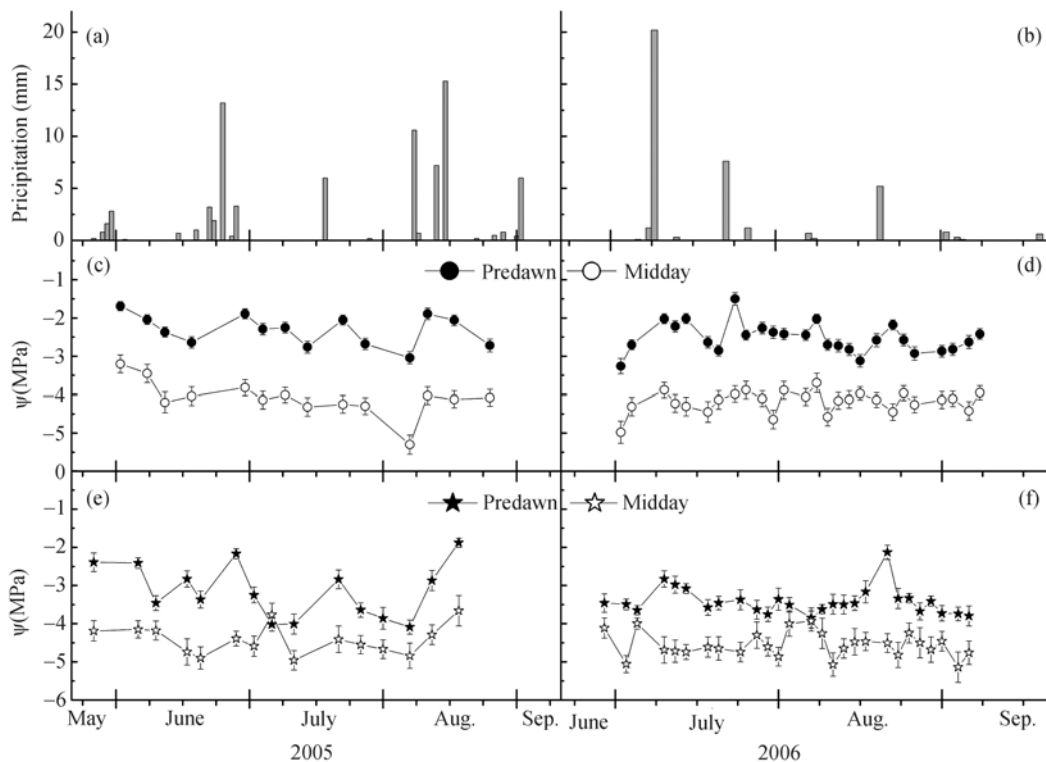


Fig. 3 Seasonal pattern of predawn and midday leaf water potential measured at sandy soil from 2005 (c) to 2006 (d) and at heavy soil from 2005 (e) to 2006 (f) with average value \pm S.E. Rainfall at the two experimental sites in 2005 (a) and 2006 (b) were also given.

Table 1 Comparison of the mean physiological parameters of *H. ammodendron* through the two growing season at two contrasting textured soils

Sites	Ψ_{root} (MPa)	Ψ_{pd} (MPa)	Ψ_m (MPa)	g_{noon} (mmol/(m ² ·s))	TR_{max} (mmol/(m ² ·s))	R_p (MPa·m ² ·s/mmol)
Sandy soil	$-1.2 \pm 0.02a$	$-2.5 \pm 0.1a$	$-4.0 \pm 0.2a$	$40.1 \pm 2.6a$	$3.9 \pm 0.2a$	$0.56 \pm 0.03a$
Heavy soil	$-0.96 \pm 0.03a$	$-3.3 \pm 0.1b$	$-4.5 \pm 0.1b$	$46.5 \pm 3.2a$	$3.7 \pm 0.2a$	$0.47 \pm 0.03a$

Values are means \pm S.E. within columns with different letters are significantly different at $P=0.05$

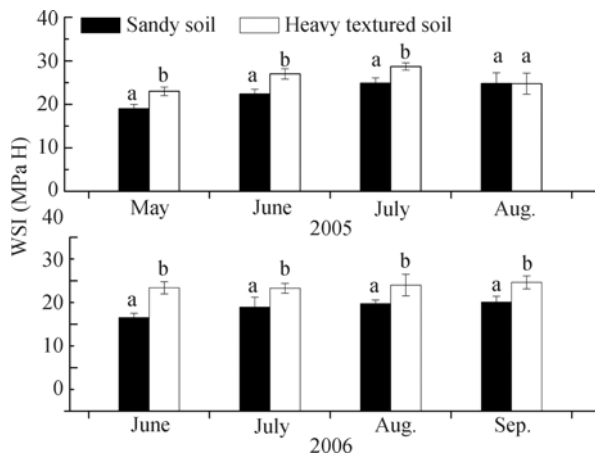


Fig. 4 Integration of the half-diurnal course of leaf water potential measured between predawn and midday was named as water stress index (WSI). The WSI of each trial day were averaged for months in 2005 to 2006. The different letters mean significant differences at $P=0.05$. Vertical bars are S. E. of the mean.

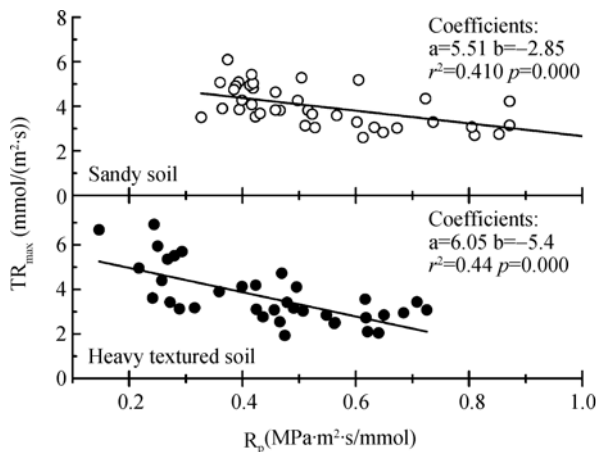


Fig. 5 The relationship between daily maximum transpiration rate (TR_{max}) and whole plant hydraulic resistance (R_p) for sandy and heavy textured soils

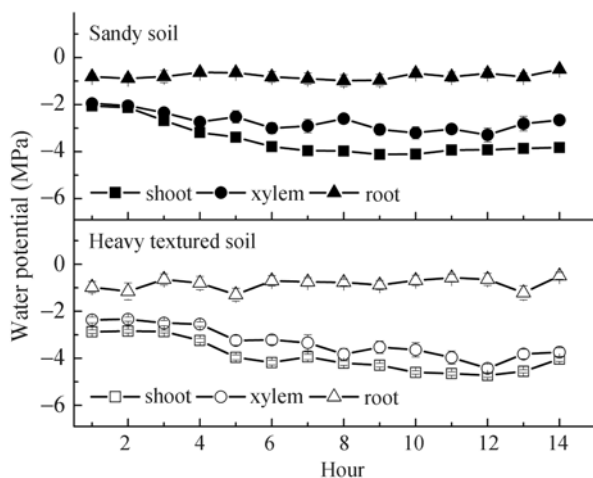


Fig. 6 The diurnal courses of water potential of shoot, xylem and root at sandy soil and heavy textured soil from dawn to sunset

Diurnal course of plant water potential from root to leaf was described in Fig. 6. Root water potential kept relative constant from predawn to sunset. The leaf and xylem water potential decreased from dawn to midday and increased at later afternoon. Water potential sequential descended from root to leaf in accordance with the water movement direction. The water potential gradient from root to xylem was narrower than that of xylem to leaf.

3.3 Partitioning of hydraulic resistances

The average plant hydraulic resistance (R_{plant}) and its components (R_{root} and R_{shoot}) in August of the two years were given in Fig. 7. There were no significant differences between R_{root} and R_{shoot} in the dry and wet August of the two years.

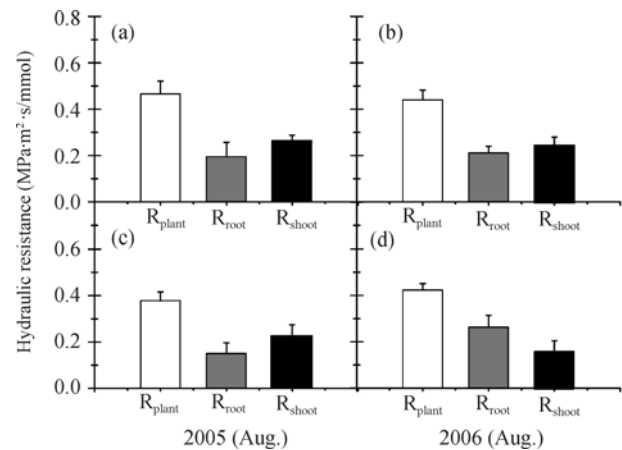


Fig. 7 Hydraulic resistance (R) of the whole plant (R_{plant} , open column), roots (R_{root} , gray column) and shoots (R_{shoot} , closed column) measured at the two sites in August of 2005 and 2006: (a) and (b) were in sandy soil, (c) and (d) were in heavy textured soil. The R values were average \pm S.E. of the August with $n=4$ to 7 days average for each year.

However, comparing with the wet August, the R_{root} increased and R_{shoot} declined in heavy textured soil in the dry August. The relationship between R_{root} , R_{shoot} and R_{plant} was described in Fig. 8, where all R_{root} and R_{shoot} values were plotted against corresponding R_{plant} values. The results showed that there was good relationship between R_{plant} and R_{root} . Comparison of average hydraulic parameters at two sites in August 2005 and 2006 were shown in Table 2. The predawn leaf water potential (Ψ_{pd}) and noon stomatal conductance (g_{noon}) at 12:00 to 14:00 were lower in 2006 vs. 2005 at each site. The midday leaf water potential (Ψ_m) and maximum transpiration rate (TR_{max}) kept same.

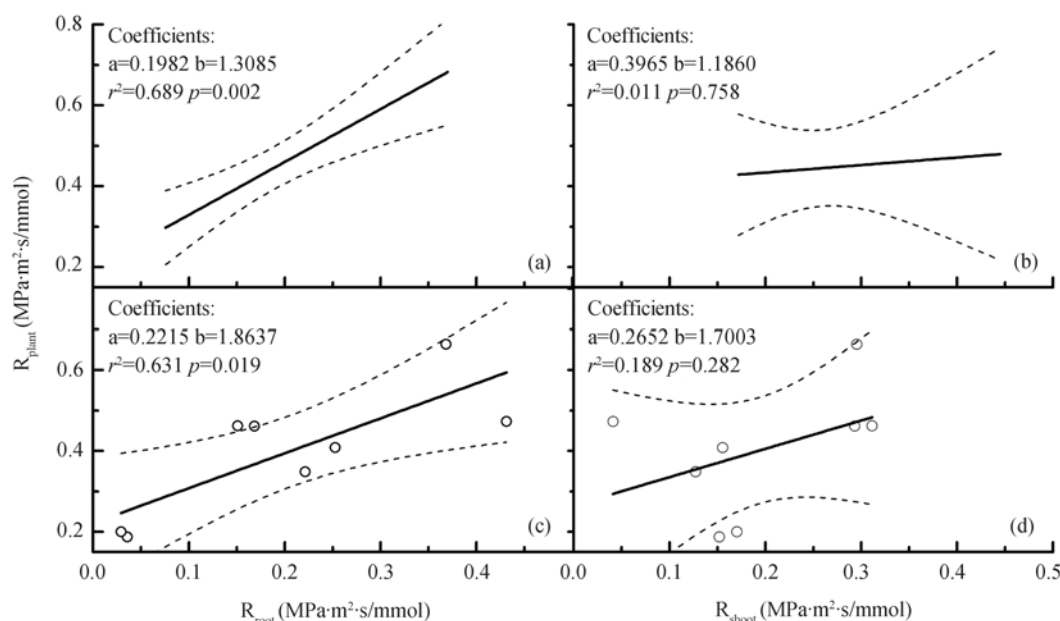


Fig. 8 Relationship between the hydraulic resistances of whole plant (R_{plant}), roots (R_{roots}) and shoots (R_{shoots}): (a) and (b) were in sandy soil, (c) and (d) were in heavy textured soil. The centre solid line is the linear regression and the dashed lines are 95% confidence intervals. The coefficients of the straight line are reported together with the coefficient of determination (r^2) and the P value (Pearson Product Moment Correlation).

Table 2 Comparison of the mean physiological parameters of *H. ammodendron* at two contrasting textured soils in August of the two growing seasons

Sites	August in 2005				August in 2006			
	Ψ_{pd} (MPa)	Ψ_{m} (MPa)	g_{noon} (mmol/(m ² ·s))	TR_{max} (mmol/(m ² ·s))	Ψ_{pd} (MPa)	Ψ_{m} (MPa)	g_{noon} (mmol/(m ² ·s))	TR_{max} (mmol/(m ² ·s))
Sandy soil	$-2.2 \pm 0.2\text{a}$	$-4.0 \pm 0.02\text{a}$	$55.69 \pm 3.0\text{a}$	$3.25 \pm 0.2\text{a}$	$-2.7 \pm 0.1\text{a}$	$-4.2 \pm 0.1\text{a}$	$41.02 \pm 2.6\text{a}$	$3.41 \pm 0.15\text{a}$
Heavy soil	$-2.9 \pm 0.4\text{b}$	$-4.0 \pm 0.3\text{a}$	$47.15 \pm 6.6\text{a}$	$2.95 \pm 0.3\text{a}$	$-3.4 \pm 0.1\text{b}$	$-4.6 \pm 0.1\text{b}$	$34.29 \pm 1.5\text{b}$	$3.01 \pm 0.16\text{a}$

Values are means \pm S.E. within columns with different letters are significantly different at $P=0.05$

4 Discussion and conclusion

For the plants experience similar weather condition, the differences in soil properties (Fig. 1) appeared to have significantly affected on the water status of *H. ammodendron*. The target plants at sandy soil site had better water conditions than that of heavy soil site (Figs. 3, 4 and Table 1), which consistence with parallel studies on *Larrea tridentate*, *Pinus raeda* and eight desert plant species (Hacke *et al.*, 2000; Hamerlynck *et al.*, 2000; Sperry and Hacke, 2002). The driving force for liquid water from soil to and through roots, plant vascular, and eventually evaporates in the sub-stomata cavities of leaves is water potential gradient (Campbell and Norman, 1998). The water potential gradient from soil (represented by predawn water potential) to leaf (symbolized by midday leaf water

potential) was relative stability and high in sandy soil in our trial days. However, in heavy textured soil the water potential gradient was low and lost during the extremely drought period (Fig. 3). As a result, population in heavy soil suffered severer water stress than that of sandy soil when significant water deficits occurred on 4 July 2005 and 5 August 2006 due to prolonged drought without rainfall. The WSIS was impressively higher at heavy site than at sandy site in the most of months in the two growing seasons, which further verification the better water condition in the sandy site. The exception of the same value of WSIS at the both sites in August 2005 was attributed to the relative rich rainfall which shielded the influence of soil texture on soil water availability (Fig. 4). Plants in sandy soil experiencing better water status than that in heavy textured soil were not only the results of low

soil evaporation but also mainly the deeper root systems, larger root surface areas and higher root:leaf surface area ratio than in heavy textured soil (Xu and Li, 2008).

The overall plant hydraulic resistance (R_{plant}) and leaf specific hydraulic resistance (R_p) were the same at the both sites (Table 1 and Fig. 7). The proportion of the hydraulic resistances of each plant part was also the same between sites during the Augusts of the two years (Fig. 7). Namely, the hydraulic resistances above and below ground were equally important to plant water transport system at the both sites. The significant correlation between the overall plant hydraulic resistance and root hydraulic resistance (Fig. 8), confirmed the root as an organ highly sensitive to the changes in environmental factors like water availability and plant growth rhythm. This is in accordance with recent study result which confirmed roots play an important role in determining the whole plant water balance (Nardini *et al.*, 2003). Based on above discussion and the close correlation between maximum transpiration and leaf specific hydraulic resistance (Fig. 5), we proposed that root hydraulic resistance was a major factor in control plant transpiration rate. Although, there were no significant variation of hydraulic resistance components between dry and wet August at the both sites, R_{root} increased and R_{shoot} decreased in dry August, 2006. Because R_{root} derived from equation 3 included the resistance of the soil-to-root pathway, it was possible that the measured R_{root} was due to the increase of R_{soil} . Decrease in leaf area per branch and branch growth rate in August 2006 (Zou *et al.*, 2009) were responsible for the descent of R_{shoot} . Apparently, the leaf shedding led to the decrease of hydraulic resistors, and thus shoots hydraulic resistance declined. Comparing with the wet August 2005, the stomata

conductance at noon showed downward adjustment to limited maximum transpiration at the both sites in the dry August, 2006 (Table 2). Namely, the decreased root hydraulic resistance, especially in the root-soil interface preventing the water outflow from root to soil (North and Nobel, 1997), combined with the stomata limitation may have facilitated the plant at heavy site to survive under extreme water deficit. Such hydraulic coordination may also function together with morphology adjustment, namely the suspending leaf growth and even shedding of leaves (Zou *et al.*, 2009), to facilitating the survival of plants under extreme drought.

To extract and use water successfully, plants that exist across a range of habitats must make adjustment in hydraulic architecture to maintain hydraulic compatibility between plants and environments (Addington *et al.*, 2006). Understanding hydraulic architecture of the plant can not only deepen our study in classic plant water relations but also provide new insight in plant adaptation to limiting environmental factors. More detailed research should carry out on plant water resistance components of *H. ammodendron* at both vascular and non-vascular system and from tissues to organs levels, and at different time scales, which will finally facilitate better interpreting and predicting the future of *H. ammodendron* under the background of climate changes.

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