Postprint: Relationship Between Sea Buckthorn Sap Flow Characteristics and Environmental Factors Under Different Irrigation Gradients

Authors: Wang Zhuo, Guo Yuefeng, Qi Wei, Yao Yunfeng, Zhongchen, Liu Lu, Wang Jiakun

Date: 2020-06-27T00:00:00+00:00

Abstract

Using chestnut soil developed from arsenic sandstone parent material as the test soil and sea buckthorn as the test tree species, this study investigated the variation characteristics of sea buckthorn sap flow rate under different irrigation gradients—T1 (field capacity FC25%), T2 (FC40%), and T3 (FC55%)—in a greenhouse using the stem heat balance (SHB) method. A HOBO micro weather station was employed to monitor environmental factors and examine the response relationship of sea buckthorn sap flow rate to these factors. The results indicated: Sea buckthorn sap flow rate exhibited not only pronounced diurnal variation but also a "photosynthetic midday depression" phenomenon, with the sap flow variation curve displaying a bimodal pattern; Sap flow rate was positively correlated with soil moisture content, with both sap flow rate and daily cumulative amount following the order T1 < T2 < T3, though the difference between T2 and T3 was relatively small; Sap flow rate showed positive correlations with photosynthetically active radiation and air temperature, and a negative correlation with air humidity; the absolute values of correlation coefficients between sap flow rate and environmental factors under different irrigation gradients followed the pattern T1 < T3 < T2. The R^2 values of regression equations also followed T1 < T3 < T2. Under the T2 gradient, sea buckthorn sap flow rate maintained relatively high levels and exhibited the highest responsiveness to environmental factors, with temperature identified as the dominant factor influencing sap flow rate variation.

Full Text

Relationship Between Sap Flow Characteristics of *Hippophae rhamnoides* and Environmental Factors Under Different Irrigation Gradients

WANG Zhuo[1], GUO Yuefeng[1]*, QI Wei[1],[2], YAO Yunfeng[1], ZHONG Cheng[1], LIU Lu[1], WANG Jiakun[1]

[1]Institute of Desert Governance, Inner Mongolia Agricultural University, Hohhot 010011, Inner Mongolia, China
[2]Inner Mongolia Water Resources and Hydropower Exploration and Design Institute, Hohhot 010020, Inner Mongolia, China

Abstract

This study investigated the sap flow rate characteristics of *Hippophae rhamnoides* (sea buckthorn) under different irrigation gradients using the stem heat balance (SHB) method in a greenhouse setting. Chestnut soil derived from arsenic sandstone served as the test substrate, with three irrigation treatments established: T1 (25% of field capacity, FC25%), T2 (FC40%), and T3 (FC55%). Environmental factors were monitored using a HOBO micro weather station to examine the response relationships between sap flow rate and environmental conditions. The results revealed: (1) In addition to pronounced diurnal variation, sap flow rates exhibited a "photosynthetic midday depression" phenomenon, producing a bimodal daily curve; (2) Sap flow rate was positively correlated with soil moisture content, with both flow rates and daily cumulative amounts following the pattern T1 < T2 < T3, though the difference between T2 and T3 was relatively small; (3) Sap flow rate showed positive correlations with photosynthetically active radiation and air temperature, and a negative correlation with air humidity. The absolute values of correlation coefficients between sap flow rate and environmental factors across different irrigation gradients followed the order T1 < T3 < T2, while the coefficients of determination (R^2) from regression equations showed the same pattern. Under the T2 gradient, *Hippophae rhamnoides* maintained relatively high sap flow rates with the strongest response to environmental factors, and temperature emerged as the dominant factor influencing sap flow rate variation.

Keywords: arsenic sandstone; *Hippophae rhamnoides*; sap flow rate; irrigation gradient; environmental factors; Inner Mongolia

Introduction

The Loess Plateau region contains extensive areas of loose rock strata known as "arsenic sandstone," a layered rock formation composed of thick sandstone, sandy shale, and argillaceous sandstone. This material is characterized by extreme hardness when dry but rapid disintegration when wet, coupled with severe wind erosion, which results in fragmented terrain and exceptionally serious soil and water loss. Water resources constitute a critical factor affecting plant growth in the Loess Plateau, with plant water utilization primarily manifested through transpiration—more than 99.8% of absorbed water is lost to the atmosphere via this process. Stem sap flow largely reflects a plant' s transpirational water consumption capacity. Consequently, investigating the transpiration characteristics and water use patterns of well-adapted vegetation, and clarifying the water supply-demand relationship for plant growth, represent urgent issues for ecological vegetation construction in the Loess Plateau region.

The arsenic sandstone area features thin soil layers and insufficient precipitation, causing difficulties for root establishment and resulting in large-scale plant mortality, as well as ecological degradation phenomena such as "stunted old trees." These conditions negatively impact ecological restoration and optimal water resource utilization. Under limited water resource conditions, large-area planting for ecological restoration is no longer feasible. Therefore, determining the water use status and water dissipation characteristics of existing well-adapted tree species holds significant importance for the sustainable development of ecological construction in arsenic sandstone regions.

Hippophae rhamnoides, a deciduous shrub in the Elaeagnaceae family, exhibits drought tolerance, wind resistance, and survival capability in saline-alkali soils. The actinomycetes in sea buckthorn root nodules can fix atmospheric nitrogen, promoting growth and enhancing soil fertility, with particularly notable increases in soil available nitrogen. Research by Hu Jianzhong et al. demonstrates that sea buckthorn roots exhibit progressive branching and 迂回 growth patterns, primarily distributed within the 35 cm soil layer. The strong penetrating ability of sea buckthorn roots enables them to penetrate hard arsenic sandstone layers to reach water-bearing strata, facilitating water acquisition more easily than other plants.

In recent years, numerous studies have employed thermal diffusion methods to determine sap flow rates for assessing vegetation water status and its relationship with environmental factors. However, few reports have investigated vegetation water dissipation characteristics using chestnut soil derived from arsenic sandstone as the growth medium. Addressing water scarcity issues in arsenic sandstone regions and focusing on selecting low water-consumption plants to enhance ecological management, this study monitored sap flow characteristics of suitable species under greenhouse conditions. By analyzing water dissipation characteristics and environmental responses of sea buckthorn under different water stress conditions, we aim to reveal the operational patterns of water management in sea buckthorn in arsenic sandstone areas and determine water consumption requirements for maintaining normal growth, thereby providing scientific guidance for local forest management and effective water resource utilization.

Materials and Methods

1.1 Experimental Materials

The experiment was conducted from June to August 2018 in a solar greenhouse at the Key Laboratory of Inner Mongolia Agricultural University, located at 40°41 30 N, 111°22 30 E, at an elevation of 1040 m. The site experiences a continental Mongolian plateau climate with an average annual temperature of 6.7 °C and mean annual precipitation of 335–535 mm, concentrated primarily in July and August. In early April 2017, undisturbed soil (chestnut soil derived from arsenic sandstone) was collected from the Arsenic Sandstone Soil and Water Conservation Demonstration Area in Ordos City, Inner Mongolia. Based on literature reports and field investigations showing that 3–5-year-old sea buckthorn roots concentrate in the 0–50 cm soil layer, typical sites were selected to extract 50 cm × 50 cm × 50 cm soil monoliths. These were placed in 50 cm × 50 cm nursery bags and transported to the experimental greenhouse, where 3–5-year-old sea buckthorn from the demonstration area were transplanted for measurement preparation.

Nine healthy sea buckthorn plants with similar growth status were selected and subjected to three irrigation gradient treatments with three replicates each. Greenhouse conditions maintained air temperatures of 20–34 °C and relative humidity of 34%–89%. Soil sampling occurred in April 2017. To ensure long-term observation viability and prevent plant mortality, the experiment included a preparation period from April to October 2017 to guarantee plant survival. Basic properties and physical parameters of the test soil, along with basic parameters of the test species, are presented in Table 1 through Table 3 .

1.2 Experimental Design

Field capacity measured by the ring knife method was 2.5 L. Three water treatments were established: T1: FC25% (irrigation amount 0.63 L); T2: FC40% (irrigation amount 1 L); T3: FC55% (irrigation amount 1.38 L). The wilting moisture content of chestnut soil in arsenic sandstone areas is approximately 5.5%. Orgaz et al. reported that potential evapotranspiration in greenhouses is 60%–80% of outdoor values. Based on experimental constraints and regional differences, a severe stress irrigation level (FC25%) was established within the wilting moisture and growth-inhibiting moisture range. Literature on soil moisture in the Loess Plateau indicates that stable deep soil moisture corresponds to approximately 49%–54% of field capacity (9%–11% soil moisture content), representing a difficult-to-utilize water range. To simulate this deep stable moisture condition, a moderate stress irrigation level (FC40%) was established. Given the harsh natural conditions and soil moisture content below the moderately effective water range in arsenic sandstone areas, a light stress irrigation level (FC55%) was established to explore differences in sap flow rates between adequate irrigation and drought stress, thereby providing practical guidance for field conditions.

Soil water suction serves as an intensity indicator of soil water potential; higher suction corresponds to lower soil moisture content, while lower suction indicates greater moisture content, making soil tension an effective metric for soil moisture status. An irrigation threshold of 0.03 MPa was established, with twice-daily observations. When tensiometer readings reached or exceeded 0.03 MPa, indicating soil moisture at wilting point (approximately 4.56%), irrigation was applied after 18:00 to avoid excessive water loss.

1.3 Measurement Methods

1.3.1 Stem Sap Flow Measurement Sap flow was measured using an EMS62 portable dual-channel plant sap flow monitor, comprising a dual-channel data logger and EMS62 plant sap flow measurement modules to form a complete wrapped-type measurement system based on the stem heat balance (SHB) principle. This method involves wrapping a heating collar around stems or branches to continuously heat the bark, wood, and sap. Temperature sensors installed around the stem surface monitor temperature changes. EMS62 sensors are available in two sizes: small (8-12 mm) and large (12-16 mm); appropriate sensors were selected based on stem diameter to minimize experimental error. Prior to sensor installation, suitable stems were selected and rough bark was removed to expose the inner bark. Two 20 mm deep holes were drilled using a 2 mm diameter drill bit, positioned as parallel as possible. Probes were inserted into the holes while avoiding internal damage, then wrapped with aluminum foil and sealed with black tape. The instrument collected data every 30 minutes with continuous 24-hour monitoring, using hourly averages for analysis.

Based on heat balance principles, the heat carried away by sap flow was calculated to determine flow rates within the stem. Compared with heat pulse velocity methods, this approach offers two major advantages: it requires no calibration and eliminates the need to insert temperature probes directly into stems, enabling direct measurement results and long-term, fixed-point measurements with minimal plant damage.

The calculation formula is as follows:

$$P = Q \times dT \times C_w + dT \times z \quad (1)$$

where P is heat input power (W), Q is sap flow rate ($\mathrm{kg \cdot s^{-1}}$), dT is temperature difference at measurement points, C_w is water specific heat capacity ($\mathrm{J \cdot kg^{-1} \cdot K^{-1}}$), and z is heat loss coefficient at measurement points. When water flows through the heated stem section, temperature increases, and sap flow rate can be calculated from actual power input and temperature rise.

1.3.2 Meteorological Observations A HOBO micro weather station was installed in the greenhouse open space to monitor environmental factors including photosynthetically active radiation (PAR, $\mathrm{W \cdot m^{-2}}$), air temperature (Ta,

°C), and air relative humidity (RH, %). Wind speed and ground temperature were not considered due to minimal greenhouse ventilation and container planting. Environmental factor monitoring synchronized with sap flow measurement, with automatic data collection every 30 minutes and hourly averages used for analysis.

1.4 Data Analysis

Data analysis was performed using Excel 2016 and SPSS 22.0 for correlation analysis and stepwise regression analysis.

Results

2.1 Sap Flow Rate Variation Patterns Under Different Irrigation Gradients

Over seven consecutive days (August 8–14), sea buckthorn sap flow rates exhibited clear diurnal variation with bimodal daily curves [Figure 1: see original paper]. As solar radiation intensified and temperature increased, sap flow rates rose continuously. Increasing atmospheric water vapor pressure deficit caused stomatal conductance to decline, producing a "photosynthetic midday depression" phenomenon that slowed sap flow rates around noon, creating the characteristic bimodal pattern. As solar radiation subsequently decreased, sap flow rates declined, though nighttime flow rates remained stable at non-zero values.

Significant differences in sap flow rates were observed among irrigation gradients, following the overall pattern T1 < T2 < T3. Within individual gradients, sap flow rates gradually decreased as soil moisture was consumed. Following irrigation on August 11, flow rates in all gradients showed an upward trend, demonstrating positive correlation between sap flow rate and soil moisture content. As soil water depletion continued, sea buckthorn could not absorb sufficient water, causing flow rates to decrease and peak shapes to diminish. Post-irrigation, increased soil moisture corresponded with elevated sap flow rates. Differences in daily sap flow rates among gradients became more pronounced, with T3 and T2 showing marked peak variations, while T1 remained at low levels even after irrigation due to severe drought stress. This occurs because when soil moisture content falls within the wilting coefficient range, low soil matrix potential and high soil suction hinder root water absorption, restricting sap flow and reducing physiological activity.

2.2 Typical Daily Sap Flow Patterns Under Different Irrigation Gradients

As illustrated in Figures 2 [Figure 2: see original paper] through 4 [Figure 4: see original paper], typical daily sap flow patterns across different months showed pronounced diurnal variation with significant bimodal shapes under all irrigation gradients. Sap flow initiation remained stable around 07:00, while peak arrival times showed distinct differences, occurring on either side of the temperature peak period between 10:00–14:00. Nighttime flow rates were relatively similar across treatments. The T3 gradient, with the highest irrigation level, maintained consistently high sap flow rates. The T2 gradient showed clear variation, with June flow peaks of 36.41 $g \cdot h^{-1}$ increasing to 45.37 $g \cdot h^{-1}$ in August —a 20% enhancement. The T1 gradient, with irrigation slightly above wilting moisture, maintained low flow rates. In June, lower solar radiation and air temperature created more pronounced differences among gradients, while July and August increases in radiation and temperature reduced these differences, with T2 patterns approaching those of T3. Across all gradients, sap flow rates followed T1 $<$ T2 $<$ T3, with significant monthly variation during the growing season.

Sap flow initiation in the T3 gradient lagged behind T1 and T2 by approximately 30 minutes, and peak arrival was similarly delayed. Except in July and August, the T1 gradient showed no significant "photosynthetic midday depression,"resulting in less pronounced bimodal curves and lower peaks—September and October peaks were less than half those of other gradients. Nighttime flow rates in T3 significantly exceeded other gradients, indicating that higher soil moisture content increases daytime transpiration water consumption, while root pressure-driven nighttime water uptake becomes more prominent to compensate for daytime water loss. The T2 gradient showed similar flow patterns to T3 across months in terms of initiation time and peak values, demonstrating strong drought adaptability. However, during the high-temperature month of August, T2 peak flow rates were slightly lower than T3, confirming the positive relationship between sap flow rate and soil moisture content. While sea buckthorn possesses considerable drought adaptability through physiological regulation, prolonged severe water stress (T1) causes significant damage to physiological mechanisms, substantially reducing sap flow rates and indicating limited drought tolerance.

Analysis of August 14 as a typical day revealed that daily sap flow accumulation followed T1 $<$ T2 $<$ T3 [Figure 5: see original paper]. Cumulative sap flow curves under all gradients exhibited an "S" shape, with daily accumulation positively correlated with irrigation amount. Before 07:00, curve slopes remained constant; from 08:00–11:00, slopes began increasing; between 13:30–14:30, slopes reached maximum values before declining; and by 20:00–21:00, slopes showed minimal change. This pattern aligns with the diurnal variation analysis. The T2 and T3 curves were relatively similar, with daily cumulative sap flow amounts of 441 g, 556 g, and 641 g for T1, T2, and T3, respectively.

Seven-day periods in June (June 12–18) and July (July 18–24) showed consistent overall trends with the August pattern. Sap flow rates under different irrigation gradients from June to August are compared in Table 4 , with measured values showing small variation ranges around mean values, confirming data reliability.

2.3 Relationships Between Sap Flow and Environmental Factors

2.3.1 Correlation Analysis Analysis of consecutive daily data (August 8-14) revealed significant correlations between sap flow rates and environmental factors across irrigation gradients (Table 5). Sap flow rate showed positive correlations with photosynthetically active radiation and air temperature, and negative correlation with air relative humidity. Based on absolute correlation values, environmental factors influenced sap flow rate in the order: photosynthetically active radiation < air humidity < air temperature. Temperature emerged as the dominant factor affecting sap flow rate, with correlations between sap flow and environmental factors across gradients following T1 < T3 < T2.

2.3.2 Regression Analysis Stepwise deletion multiple regression analysis was performed to clarify the comprehensive effects of environmental factors on sap flow rates under different irrigation gradients, using sap flow rate as the dependent variable and solar radiation, air humidity, and air temperature as independent variables. The resulting regression equations were:

$$V_{T1} = -2.35 + 0.005X_{PAR} + 0.706X_{Ta}, \quad R^2 = 0.721$$

$$V_{T2} = -2.259 + 0.01X_{PAR} + 1.118X_{Ta} - 0.135X_{RH}, \quad R^2 = 0.841$$

$$V_{T3} = 20.92 + 0.012X_{PAR} + 0.868X_{Ta} - 0.298X_{RH}, \quad R^2 = 0.832$$

All variable coefficients showed significance probabilities of 0.00. In these equations, V represents sap flow rate ($\mathrm{g \cdot h^{-1}}$), Ta is air temperature (°C), PAR is photosynthetically active radiation ($\mathrm{W \cdot m^{-2}}$), and RH is air humidity (%). Coefficients of determination followed the pattern T1 < T3 < T2 across gradients.

Discussion

Sea buckthorn sap flow exhibited clear diurnal variation with distinct bimodal patterns. Morning flow rates increased with rising air temperature and solar radiation, lagging solar radiation by approximately 30 minutes and showing overall positive correlation—consistent with Liu et al.' s research on sea buckthorn transpiration in the Zhungeer soft sandstone area. At noon, peak solar radiation caused transpiration to reach threshold levels, prompting stomatal closure to reduce water loss and resulting in the "photosynthetic midday depression" phenomenon. Although photosynthesis and transpiration ceased at night, root pressure-driven active water uptake continued to replenish daytime water deficits and restore plant water balance, maintaining stable non-zero nighttime flow rates.

Both temporal analysis within individual gradients and comparative analysis across gradients demonstrated positive correlation between soil moisture content and sap flow rate, following T3 > T2 > T1. However, water stress did not alter sea buckthorn' s growth rhythm, and the relatively high sap flow rates under moderate stress (T2) indicated enhanced drought tolerance under appropriate water deficit conditions.

Sap flow is influenced by three main factors: tree biological characteristics, soil water supply, and meteorological factors. Biological traits determine potential sap flow capacity, soil moisture determines overall flow levels, and meteorological factors control instantaneous flow variations. The complex and relative nature of tree transpiration regulation mechanisms involves close relationships with environmental factors beyond intrinsic characteristics. Previous research indicates that due to variations in geography, environmental factors, temporal scales, and seasons, even the same species in identical habitats shows differential environmental factor effects on sap flow.

Wang et al. reported that for *Larix gmelinii*, light and air humidity were primary influencing factors at hourly scales, soil temperature, light, and air temperature at daily scales, and soil temperature and moisture at monthly scales. Our study demonstrated that at both daily and monthly scales, sea buckthorn sap flow rate was positively correlated with photosynthetically active radiation and air temperature, and negatively correlated with air humidity. Air temperature showed the highest correlation across all gradients, consistent with Li et al.' s findings on young jujube trees under different irrigation levels. At daily scales, sap flow also showed positive correlation with soil moisture content. At monthly scales, correlation coefficients between sap flow and environmental factors increased from June to August then decreased, indicating that sea buckthorn water consumption during the growing season depends on both environmental factors and phenological characteristics. In summary, sea buckthorn transpiration response mechanisms involve comprehensive interactions among multiple factors dominated by specific characteristics, with environmental factor influences following T2 > T3 > T1 across irrigation gradients.

Conclusion

Sea buckthorn sap flow rate displayed distinct diurnal variation accompanied by "photosynthetic midday depression," producing a bimodal curve pattern. Sap flow rate was positively proportional to soil moisture content, following the pattern T1 < T2 < T3. Across different irrigation gradients, sap flow rate showed positive correlations with photosynthetically active radiation and air temperature, and negative correlation with air humidity. The correlation strength between sap flow rate and environmental factors followed T1 < T3 < T2, with regression equation coefficients of determination (R^2) showing the same pattern.

Given that irrigation conditions cannot be met in arsenic sandstone areas with insufficient precipitation and no groundwater supplementation, the T2 gradient maintained relatively high sap flow rates with the strongest environmental response. Temperature represents the dominant factor controlling sea buckthorn sap flow rate variation, making moderate water stress conditions optimal for balancing growth and water conservation in this species.

References

[1] Wang Yuanchang, Wu Yonghong, Kou Quan, et al. Definition of arsenic sandstone distribution range and classification[J]. Science of Soil and Water Conservation, 2007, 5(1): 14-18.

[2] Bi Cifen, Tai Yuanlin, Wang Fugui, et al. Probe to integrated soil conservation techniques for soil erosion prevention in soft rock areas[J]. Journal of Sediment Research, 2003, 3(14): 63-65.

[3] Tian Jinghui. Studies on water consumption characteristics of main tree species of soil and water conservation forest in semi-arid region on loess plateau[D]. Beijing: Beijing Forestry University, 2005.

[4] Zhang Yongliang. Study on biomechanical characteristics of *Hippophae rhamnoides* Linn. roots[D]. Hohhot: Inner Mongolia Agricultural University, 2011.

[5] Wu Jianfeng, Lin Xiangui. Effects of soil microbes on plant growth[J]. Soils, 2003, 35(1): 18-21.

[6] Hu Jianzhong. Landscape heterogeneity in soft sandstone area in different periods after seabuckthorn planting[J]. International Hippophae rhamnoides Research and Development, 2012, 10(1): 12-18.

[7] Wu Yonghong, Hu Jianzhong, Yan Xiaoling, et al. Reduction effects of flood and sediment yield of *Hippophae rhamnoides* Linn forest in soft sandstone area[J]. Science of Soil and Water Conservation, 2011, 9(1): 68-73.

[8] Hu Jianzhong, Liu Liyin, Yin Liqiang, et al. Vertical distribution law of roots for *Hippophae rhamnoides* community in soft sandstone area[J]. Protection Forest Science and Technology, 2011, (1): 15-19.

[9] Hu Mengjun. Study on water balance and soil moisture ecological characteristic of *Hippophae rhamnoides* and *Caragana microphylla* in loess hilly region[D]. Yangling: Northwest A&F University, 2003.

[10] Orgaz F, Fernandez M D, Bonachela S, et al. Evapotranspiration of horticultural crops in an unheated plastic greenhouse[J]. Agricultural Water Management, 2005, 72: 81-96.

[11] Yang Wenzhi, Han Shifeng. Soil water ecological environment on the manmade woodland and grassland in loess hilly region[J]. Collected Papers of Northwest Institute of Water and Soil Conservation, Chinese Academy of Sciences (Symposium on Soil Water and Soil Fertility), 1985, (2): 18-28.

[12] Liu Zengwen, Wang Youming. Study on transpiration water consumption of artificial *Pinus tabulaeformis* and water dynamic characteristics of forest land[J]. Bulletin of Soil and Water Conservation, 1990, 10(6): 78-84.

[13] Li Yushan. The properties of water cycle in soil and their effect on water cycle for land in the loess region[J]. Acta Ecologica Sinica, 1983, 3(2): 91-101.

[14] Liu Sichun, Wang Guodong, Zhu Jianchu, et al. Improvement and application on soil tension meter with negative-pressure mercury[J]. Acta Agriculturae Boreali-occidentalis Sinica, 2002, 11(2): 29-33.

[15] Han Zhaoming, Yao Yunfeng, Guo Yuefeng, et al. Sap flow characteristics of *Pinus tabulaeformis* in soft rock area and its relationship with environmental factors[J]. Ecology and Environmental Sciences, 2017, 26(7): 1145-1151.

[16] Luo Zhongling. The development and application of thermal methods for measuring sap flow[J]. Chinese Journal of Agrometeorology, 1997, 18(3): 52-56.

[17] Weibel P F, Boersma K. An improved stem heat balance method using analog heat control[J]. Agricultural and Forest Meteorology, 1995, 75(1): 191-208.

[18] Allen S J, Grime V L. Measurements of transpiration from savannah shrubs using sap flow gauges[J]. Agricultural and Forest Meteorology, 1995, 75(1): 23-41.

[19] Sun Pengfei. Research on the water consumption rule and water requirement of main desert shrub in southern margin of Junggar basin[D]. Shihezi: Shihezi University, 2010.

[20] Liu Long, Yao Yunfeng, Guo Yuefeng, et al. Correlations between the transpiration water consumption of *Hippophae rhamnoides* Linn. and environmental factors in soft sandstone area of Zhungeer[J]. Journal of China Agricultural University, 2018, 23(6): 108-120.

[21] Sun Pengsen, Ma Lyuyi, Wang Xiaoping, et al. Temporal and spatial variation of sap flow of Chinese pine (*Pinus tabulaeformis*)[J]. Journal of Beijing Forestry University, 2000, 22(5): 1-6.

[22] Umethan Kakem, Halil Kurban, Chen Qijun, et al. Study on daily change and midday depression of photosynthesis of *Alhagi pseudoalhagi* and *Vigna radiata* under salt stress[J]. Arid Zone Research, 2012, 29(6): 1039-1045.

[23] Zhang Jinchi, Huang Xiayin, Lu Xiaozhen. Stem sap flow of poplar of shelter-belt in Xu-Huai farmland plain[J]. Science of Soil and Water Conservation, 2004, 2(4): 21-25, 36.

[24] Liu Xin. Research on transpiration of typical tree species in the Yangtze river delta region[D]. Nanjing: Nanjing Forestry University, 2014.

[25] Wu Peng, Yang Wenbin, Cui Yingchun, et al. Characteristics of sap flow and correlation analysis with environmental factors of *Acer wangchii* in the karst

area[J]. Acta Ecologica Sinica, 2017, 37(22): 7552-7567.

[26] Wang Wenjie, Zhang Zhe, Wang Wei, et al. Framework and method system of watershed ecosystem health assessment ( ): framework and indicator system[J]. Journal of Environmental Engineering Technology, 2012, 2(4): 271-277.

[27] Li Hong, Liu Bang, Cheng Ping, et al. Variability of young jujube tree sap flow under different irrigation amount[J]. Agricultural Research in the Arid Areas, 2016, 34(1): 23-30.

Note: Figure translations are in progress. See original paper for figures.