Sap Flow Characteristics of Salix psammophila and Its Response to Environmental Factors in the Mu Us Sandy Land (Postprint)

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Date: 2021-06-13T00:00:00+00:00

Abstract

Using the Flow32-1K wrapped-type heat balance sap flow gauge, long-term monitoring of sap flow in Salix psammophila branches of different diameter classes was conducted in the Mu Us Sandy Land, with simultaneous observation of meteorological variations in the experimental plot, to analyze the variation patterns of sap flow in Salix psammophila branches and establish relationship models with environmental factors. The results showed that: (1) With increasing diameter class of Salix psammophila branches, the diurnal variation of sap flow transitioned from a broad-peak curve to a distinct single-peak curve, and the sap flow rate showed an increasing trend; weather conditions had a significant influence on sap flow, with sap flow rates fluctuating more dramatically on rainy days, showing a distinct multi-peak curve; on sunny days, sap flow rate variation exhibited a distinct double-peak curve, and both sap flow rates and daily sap flow volumes of Salix psammophila branches were lower on rainy days than on sunny days, with the difference in daily cumulative sap flow volume between sunny and rainy days gradually increasing as diameter class increased. (2) Sap flow rate showed extremely significant positive correlations with surface temperature, atmospheric temperature, vapor pressure deficit, solar radiation, and wind speed, and an extremely significant negative correlation with relative air humidity. (3) Among environmental factors on rainy days, vapor pressure deficit and relative air humidity had greater influence on sap flow rate, with average R^2 values of fitting results above 0.8; on sunny days, solar radiation intensity was the key factor controlling sap flow rate in Salix psammophila branches, with average R^2 values of fitting results above 0.85. Through monitoring sap flow rates in Salix psammophila branches and analyzing transpiration consumption characteristics of Salix psammophila communities, this study provides data support for rational water resource utilization and optimization and regulation of community structure in sandy lands.

Full Text

Characteristics of Salix psammophila Sap Flow and Its Response to Environmental Factors in the Mu Us Sandy Land

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Abstract

Using a Flow32-1K wrapped heat balance sap flow meter, we conducted long-term monitoring of sap flow in *Salix psammophila* branches of different diameter classes in the Mu Us Sandy Land, while simultaneously observing meteorological changes in the experimental plots. We analyzed the variation patterns of sap flow in *S. psammophila* branches and established relationship models with environmental factors. The results showed that: (1) With increasing branch diameter class, the daily variation of sap flow transitioned from a broad-peak curve to a distinct single-peak curve, and the sap flow rate showed an increasing trend. Weather conditions significantly influenced sap flow; on rainy days, sap flow rates fluctuated dramatically, exhibiting an obvious multi-peak curve, while on sunny days, the sap flow rate showed a distinct bimodal curve. The sap flow rate and daily sap flow volume of *S. psammophila* branches on rainy days were lower than those on sunny days, and the difference in cumulative daily sap flow between sunny and rainy days gradually increased with increasing diameter class. (2) Sap flow rate showed extremely significant positive correlations with surface temperature, atmospheric temperature, saturated water vapor pressure deficit, solar radiation, and wind speed, and an extremely significant negative correlation with relative air humidity. (3) On rainy days, saturated water vapor pressure deficit and relative air humidity had substantial effects on sap flow rate, with average R^2 values of fitted results above 0.85. On sunny days, solar radiation intensity was the key factor controlling sap flow rate in *S. psammophila* branches, with average R^2 values of fitted results above 0.90. Through monitoring sap flow rates in *S. psammophila* branches and analyzing the transpiration consumption characteristics of *S. psammophila* communities, this study provides data support for the rational utilization of water resources and optimal regulation of community structure in sandy lands.

Keywords: Flow32-1K wrapped heat balance sap flow meter; *Salix psammophila*; sap flow; meteorological factors; Mu Us Sandy Land

Introduction

In ecohydrology, plant transpiration water consumption constitutes an important component of the "soil-plant-atmosphere" continuum. Plant transpiration reflects water consumption status and environmental responses, with transpiration accounting for more than 99% of plant sap flow [1]. Scholars have investigated sap flow characteristics in different parts of trees at various times to estimate transpiration water consumption at individual and community scales [2-4]. Currently, global climate change has led to high-frequency fluctuations in rainfall patterns, increasing the vulnerability and sensitivity of arid and semi-arid ecosystems. Therefore, studying plant sap flow responses to meteorological factors can help elucidate plants' self-regulation capabilities regarding transpiration water consumption patterns under climate change.

Salix psammophila is a pioneer tree species in the Mu Us Sandy Land. Due to its strong sprouting ability, tolerance to sand burial, and well-developed root system, it has become the main afforestation species for artificial vegetation restoration in this region. The Mu Us Sandy Land has a temperate continental semi-arid climate with low annual rainfall, high evaporation, and limited available water resources. Studies have shown that existing *S. psammophila* plantations exhibit overall growth decline, increased mortality, and decreased productivity. According to ecological principles, this indicates that community water consumption has exceeded the threshold of soil water carrying capacity [5]. Consequently, questions have been raised about the sustainable development of *S. psammophila* plantations in the Mu Us Sandy Land, and there is an urgent need to find ways to restore ecological functions.

In recent years, with continuous improvements in heat balance technology, wrapped stem flow meters have become an effective method for estimating whole-tree transpiration in ecohydrological research. This method does not directly damage plants, provides accurate measurements, enables continuous fixed-point monitoring, and is suitable for monitoring herbs and trees with small diameters [6]. Scholars have used heat balance technology to study the transpiration water consumption characteristics of *Haloxylon ammodendron*, *Hippophae rhamnoides*, tomatoes, *Tamarix chinensis*, *Calligonum mongolicum*, and other plants in different regions [7-11]. The sap flow characteristics of plant stems are related to their biological structure, soil available water content, and meteorological factors [12]. Plants' physiological characteristics determine their potential transpiration capacity, but trees' physiological changes are also affected by the environment. Soil available moisture determines plant sap flow volume, while meteorological factors influence instantaneous sap flow changes. Among meteorological factors, atmospheric temperature, solar radiation intensity, and atmospheric relative humidity have substantial effects on plant transpiration [13-15].

1. Study Area Overview

The Mu Us Sandy Land is located at 37°27.5 -39°22.5 N, 107°20 -111°30 E, covering southern Ordos City in Inner Mongolia Autonomous Region, the northern sandy area of Yulin City in Shaanxi Province, and northeastern Yanchi County in Ningxia Hui Autonomous Region. This study established sample plots primarily at the Ulan Tolgoi Sand Control Station in Uxin Banner, Ordos City, in the hinterland of the Mu Us Sandy Land. The region has a temperate semi-arid continental monsoon climate, with an average annual temperature of 6.0–8.5 °C, average annual evaporation of 1800–2500 mm, and average annual precipitation of 250–440 mm. The soil type is typical aeolian sandy soil, which is susceptible to strong wind erosion, resulting in a coarse structure. Landform types include fixed, semi-fixed, semi-mobile, and mobile dunes, as well as inter-dune lowlands.

Vegetation cover is low and species are limited, mainly consisting of xerophytic and psammophytic plants such as *Salix matsudana*, *Sabina vulgaris*, *Salix psammophila*, *Hedysarum leave*, and *Hedysarum scoparium* [16].

2.1 Experimental Plot Selection

This study selected *S. psammophila* artificial shrubland in the Mu Us Sandy Land as the research object. The experimental area was coppiced in 2014, and according to existing research, *S. psammophila* shrubland enters a period of slow growth in the 5th year after coppicing [17]. A baseline survey of height growth, ground diameter, and crown width of *S. psammophila* in the experimental area was conducted. Based on the relationship between *S. psammophila* branches and stand age, different ground diameter classes were divided, primarily into 2–8 mm, 8–12 mm, 12–18 mm, and >18 mm. Representative branches were selected for continuous monitoring within each diameter class.

2.2 Instrument Installation and Settings

This study used the Flow32 wrapped heat balance sap flow meter (Dynamax, USA) to measure sap flow changes in selected *S. psammophila* branches of different diameter classes. The measurement system consisted of a CR1000 data collector, EXTP-50 heat dissipation sensors, solar panels, and other auxiliary equipment. Different sensor specifications were selected according to ground diameter. The measured branches and their corresponding sensor types are shown in . Through a computer, parameters such as stem type, cross-sectional area, probe voltage, start time, and data recording interval of the measured branches were input into the data collector, and the data collection time was set. The data collection interval in this study was 30 min. Sap flow monitoring of *S. psammophila* branches was conducted from May 1 to September 30, 2019.

2.3 Meteorological Factor Measurement and Analysis

A HOBO U30 mini weather station was installed at the experimental site. The weather station monitored and collected meteorological factors in the experimental area synchronously with sap flow, including atmospheric temperature (T), wind speed (V), wind direction (F), precipitation (P), solar radiation intensity (R), atmospheric relative humidity (RH), and surface temperature (Td). Data were recorded and stored every 30 min. Weather with continuous high temperature and strong radiation was defined as sunny days, while weather with rainfall events was defined as rainy days.

To accurately analyze the diurnal variation of sap flow rates in *S. psammophila* under different weather conditions, representative sunny and rainy days during the full leaf expansion period of *S. psammophila* were selected. Weather with no rainfall during the day and high effective solar radiation was selected as representative sunny days, while weather with continuous rainfall during the day and high vapor pressure deficit was selected as representative rainy days. Therefore, July 15, 2019 was selected as a representative sunny day, and August 6, 2019 was selected as a representative rainy day to analyze the dynamic changes of stem sap flow under different weather conditions.

2.4 Saturated Vapor Pressure Deficit (VPD)

Saturated vapor pressure deficit (VPD) refers to the difference between saturated vapor pressure and actual vapor pressure in the air at a given temperature. It represents the degree to which actual air deviates from water vapor saturation, i.e., the dryness of the air, which affects stomatal closure in plants, thereby controlling physiological processes such as transpiration and photosynthesis. This has important impacts on evapotranspiration processes and water use efficiency in forest ecosystems. The VPD calculation method is:

$$VPD = 0.61078 \times \exp\left(\frac{17.27 \times t}{237.3 + t}\right) \times (1 - RH)$$

where E is saturated air pressure, RH is relative humidity, and t is air temperature (°C).

2.5 Data Processing

Excel 2007 software was used to process branch sap flow data and meteorological factor data and to create graphs. SPSS 19.0 software was used for Pearson correlation analysis and regression analysis of the data.

3.1 Diurnal Variation Patterns of *Salix psammophila* Branch Sap Flow

Sap flow rates in *S. psammophila* branches were higher during the day than at night [Figure 1: see original paper]. For 2–8 mm diameter branches, sap flow initiated at 6:00, reached a relatively high value of approximately 5.3 $g \cdot h^{-1}$ at 10:00, peaked at 6.6 $g \cdot h^{-1}$ at 14:00, began to decline rapidly around 16:00, and dropped sharply at 18:00, remaining at low values. At 21:00, sap flow rate showed a transient fluctuation with a rate of 50.39 $g \cdot h^{-1}$, and at 24:00 it remained at a low level.

For 8-12 mm diameter branches, sap flow initiated at 6:00, increased sharply, reached a first peak of 92.5 $g \cdot h^{-1}$ at 12:00, declined slightly after the first peak, reached a second peak of 90.9 $g \cdot h^{-1}$ at 14:00, and gradually declined after the second peak. At 18:00, the sap flow rate dropped rapidly and remained at a low level. At 21:00, sap flow showed a transient increase with a rate of 109.6 $g \cdot h^{-1}$.

For 12-18 mm diameter branches, the sap flow rate curve was trapezoidal, with sap flow rates sustained at relatively high values for an extended period. Sap flow initiated at 6:00, reached a first peak of 689 $g \cdot h^{-1}$ at 12:00, declined slightly after the first peak, reached a second peak at 14:00, and gradually declined after the second peak. At 18:00, the sap flow rate dropped rapidly and remained at a low level. At 21:00, sap flow showed a transient increase with a rate of 19.9 $g \cdot h^{-1}$, and at 24:00 it remained at a low level.

For >18 mm diameter branches, sap flow initiated at 6:00, increased sharply, reached a first peak of 4.0 $g \cdot h^{-1}$ at 12:00, declined slightly after the first peak, reached a second peak at 14:00, and gradually declined after the second peak. At 18:00, the sap flow rate dropped rapidly and remained at a low level. At 21:00, sap flow showed a transient increase with a rate of 4.3 $g \cdot h^{-1}$, and at 24:00 it remained at a low level.

3.2 Sap Flow Variation in *Salix psammophila* Branches Under Different Weather Conditions

As shown in [Figure 2: see original paper], sap flow rates in *S. psammophila* branches increased with increasing diameter class, with obvious differences between sunny and rainy days. Under sunny conditions, daily sap flow variation gradually changed from a broad-peak curve to a distinct single-peak curve. Under rainy conditions, daily sap flow rates in *S. psammophila* branches fluctuated frequently due to weather influences, showing a multi-peak pattern. For 2-8 mm diameter branches, the maximum sap flow rate was higher on rainy days than on sunny days, while for 12-18 mm and >18 mm diameter branches, the maximum sap flow rate was higher on sunny days than on rainy days.

Daily cumulative sap flow in *S. psammophila* branches increased with increasing branch diameter class. Under both sunny and rainy conditions, daily sap flow volume increased with branch diameter class, and values were greater on sunny days than on rainy days. On sunny days, wind speed was the main factor controlling sap flow rates in 2-8 mm diameter branches, while solar radiation also controlled sap flow rates in 8-12 mm, 12-18 mm, and >18 mm diameter branches.

3.3 Relationship Between *Salix psammophila* Branch Sap Flow Rate and Major Environmental Factors

Analysis of the relationship between sap flow rate and meteorological factors in *S. psammophila* branches revealed that sap flow rate showed extremely significant positive correlations with surface temperature, atmospheric temperature, solar radiation, wind speed, and saturated vapor pressure deficit, and an extremely significant negative correlation with relative humidity. The correlation coefficients between sap flow rate and meteorological factors under different weather conditions are presented in .

3.4 Composite Analysis of *Salix psammophila* Branch Sap Flow Rate with Multiple Meteorological Factors

Multiple regression models effectively fitted the relationship between sap flow rate and meteorological factors in *S. psammophila* branches, with R^2 values all greater than 0.85. Under rainy conditions, saturated vapor pressure deficit was the main factor controlling sap flow rates in *S. psammophila* branches. On rainy days, atmospheric temperature was also a major factor affecting sap flow rates in >18 mm diameter branches. The relationship models between daily variation of sap flow rate and meteorological factors under different weather conditions are shown in , and the multiple regression models of sap flow rate and meteorological factors under different weather conditions are presented in .

4. Discussion

Sap flow rates in *S. psammophila* branches of different diameter classes showed significant differences under various weather conditions. On sunny days, as branch diameter class increased, the daily variation of sap flow exhibited a transition from broad-peak to single-peak curves, similar to the "几" -shaped curve reported by Pei et al. [18]. The brief sap flow reflux phenomenon occurring during 11:00–12:00 resulted from instantaneous changes in meteorological factors affecting plant sap flow. In arid regions, strong midday radiation and high temperatures cause plants to temporarily close stomata to protect against excessive water loss, leading to reduced sap flow and a "midday depression" phenomenon. The sharp increase in sap flow rate at 21:00 occurred because *S. psammophila* branches replenished water in stems through sap flow at that time, increasing stem and leaf water potential.

The larger the diameter class and leaf area of *S. psammophila* branches, the greater the transpiration water consumption, resulting in higher sap flow. On rainy days, the daily variation of sap flow in *S. psammophila* branches fluctuated strongly, with average sap flow rates lower than on sunny days. This is consistent with research on transpiration water consumption characteristics of shrublands [19], which found that different weather conditions affect stem sap flow rates differently. Due to higher relative humidity, lower solar radiation intensity, and reduced saturated vapor pressure deficit on rainy days, leaf surfaces remain wetter or stomata close more frequently, weakening the water vapor exchange process inside and outside leaves and thus limiting the transpiration rate of *S. psammophila* branches.

Different diameter classes of *S. psammophila* branches exhibited different sap flow rates. As diameter class increased, sap flow rate showed an increasing trend, and the difference in cumulative daily sap flow between sunny and rainy days also increased. This is because plant transpiration water consumption gradually increases with leaf area and stem size, and plant xylem vessels and leaf area are the main factors determining plant stem hydraulic transport efficiency [20]. Sap flow rates in 8-12 mm diameter branches showed lower correlation coefficients with meteorological factors than other diameter classes under sunny conditions. Under rainy conditions, correlation coefficients between sap flow rate and meteorological factors increased with branch diameter class.

Changes in sap flow rate of *S. psammophila* branches are closely related to external environmental factors. Under different weather conditions, sap flow rates in *S. psammophila* branches showed strong correlations with meteorological factors. Sap flow rate was extremely significantly positively correlated with surface temperature, atmospheric temperature, saturated vapor pressure deficit, solar radiation, and wind speed, and extremely significantly negatively correlated with relative humidity. Meteorological factors comprehensively affected the transpiration water consumption rate of *S. psammophila* branches. Overall, correlation coefficients between sap flow rate and individual meteorological factors were higher on rainy days than on sunny days, indicating that meteorological factors are the main factors affecting stem sap flow when water is not limiting [21].

Although the mechanisms affecting tree transpiration water consumption are complex, different environmental factors have different effects on stem transpiration water consumption [22]. The fitting between sap flow rate and relative humidity and saturated vapor pressure deficit was optimal on rainy days, while the fitting between sap flow rate and solar radiation and atmospheric temperature was highest on sunny days. The multiple regression models of sap flow rate and meteorological factors all achieved relatively high R^2 values, enabling good simulation of sap flow rates in *S. psammophila* branches through meteorological factors.

5. Conclusion

(1) Sap flow rates in *S. psammophila* branches showed obvious diurnal variation with a "midday depression" phenomenon. The daily dynamic variation of sap flow in *S. psammophila* branches differed significantly under different weather conditions. Under sunny conditions, as branch diameter class increased, the daily variation characteristics of sap flow transitioned from broad-peak curves to distinct single-peak curves, and sap flow rates showed an increasing trend. Under rainy conditions, sap flow rates in *S.*

psammophila branches exhibited a multi-peak pattern.

(2) Daily sap flow volume in *S. psammophila* branches increased with branch diameter class. For the same diameter class, daily sap flow volume was greater on sunny days than on rainy days, and the difference between sunny and rainy days gradually increased with diameter class.

(3) Sap flow rates in *S. psammophila* branches showed extremely significant positive correlations with atmospheric temperature, surface temperature, solar radiation, relative humidity, and saturated vapor pressure deficit, and extremely significant negative correlations with wind speed. Under sunny conditions, sensitivity to meteorological factors increased with branch diameter class.

References

[1] Swanson R H. Significant historical developments in thermal methods for measuring sap flow in trees[J]. Agricultural & Forest Meteorology, 1994, 72(1-2): doi: 10.1016/0168-1923(94)90094-9.

[2] Wullschleger S D, Meinzer F C, Vertessy R A. A review of whole plant water use studies in tree[J]. Tree Physiology, 1998, 18(8-9): doi: 10.1093/treephys/18.8-9.499.

[3] Yu Guirui, Wang Qiufeng. Ecophysiology of plant photosynthesis, transpiration, and water use[J]. Journal of Nuclear Agricultural Sciences, 2010, 24(3): 579.

[4] Jiang Gaoming. On the origin and development of ecological plant physiology[J]. Chinese Journal of Plant Ecology, 2004, 28(2): 278-284.

[5] Hong Guangyu, Wang Xiaojiang, Liu Guohou, et al. Research progress on stem sap flow[J]. Inner Mongolia Forestry Science and Technology, 2020, 46(3): 50-55.

[6] Xu Shiqin, Ji Xibin, Jin Bowen. Dynamics and responses of sap flow of typical sand binding plants *Haloxylon ammodendron* to environmental variables[J]. Chinese Journal of Plant Ecology, 2015, 39(9): 890-900.

[7] Wang Zhuo, Guo Yuefeng, Qi Wei, et al. Relationship between the characteristics of *Hippophae rhamnoides* fluid flow and environmental factors under different irrigation gradients[J]. Arid Zone Research, 2020, 37(4): 1018-1025.

[8] Xiao Huaijuan, Li Juanqi, Wang Jiqing, et al. Effects of sub low temperature and drought stress on water transport and morphological anatomy of tomato plant[J]. Chinese Journal of Applied Ecology, 2020, 31(8): 2630-2636.

[9] Liu Yi, Jin Qian, Gui Dongwei, et al. Characteristics of sap flow of dwarf red jujube trees and the response to environmental factors in South Xinjiang[J]. Arid Zone Research, 2019, 36(5): 1146-1152.

[10] Duan Guangdong, Suyalabayaer, Pei Zhiyong. Problems and scientific countermeasures of *Salix psammophila* plantation management in Mu Us Sandy Land[J]. Adviser of Peasant Families, 2019(7): 130-130.

[11] Zhao Ziguo, Zhao Fengjuan, Xia Jiangbao, et al. Effects of groundwater salinity on photosynthesis and water consumption of *Tamarix chinensis* in the Yellow River Delta[J]. Journal of Natural Resources, 2019, 34(12): 2588-2600.

[12] Nadezhdina N, Cermak J, Ceulemans R. Radial patterns of sap flow in woody stems of dominant and understory species: Scaling errors associated with positioning of sensors[J]. Tree Physiology, 2002, 22(13): doi: 10.1093/treephys/22.13.907.

[13] Chen Guopeng, Zhao Wenzhi. Age structure and dynamics of *Salix psammophila* branches in southern edge of the Mu Us Sandy Land[J]. Journal of Desert Research, 2015, 35(6): 1520-1526.

[14] Hong Guangyu, Wang Xiaojiang, Zhang Lei, et al. Dynamic study on stem sap flow rate of *Hedysarum fruticosum* var. *mongolicum* in Mu Us Sandy Land[J]. Inner Mongolia Forestry Science and Technology, 2018, 44(4): 37-40.

[15] Russell S C, Brett W, Justin D H, et al. The upscaling of transpiration from individual trees to areal transpiration in tree belts[J]. Plant and Soil, 2007, 297(1-2): doi: 10.1007/s11104-007-9420-4.

[16] Cao Quan, Wang Zikui, Shen Yuying. Seasonal variation of soil moisture content in apple orchard and grass intercropping system in Longdong[J]. Arid Zone Research, 2019, 36(1): 77-84.

[17] Xu Xianying, Sun Baoping, Ding Guodong, et al. Sap flow patterns of three main sand fixing shrubs and their responses to environmental factors in desert areas[J]. Acta Ecologica Sinica, 2008, 28(3): 895-905.

[18] Hai Long, Wang Xiaojiang, Zhang Wenjun, et al. Stumping rejuvenation technology of artificial shrubbery in the Mu Us Sandy Land[J]. Journal of Desert Research, 2016, 36(1): 131-136.

[19] Pei Zhiyong, Hao Shaorong, Qiao Jingwei, et al. Characteristics of stem flow of *Salix psammophila*'s branch in Mu Us Sand Land[J]. Ecology and Environment Sciences, 2019, 28(1): 48-56.

[20] Xia Guimin, Kang Shaozhong, Li Wangcheng, et al. Diurnal and seasonal variation of stem sap flow for *Caragana korshinskii* on the arid desert region in Shiyang river basin of Gansu[J]. Acta Ecologica Sinica, 2006, 26(4): 1186-1193.

[21] Yue Guangyang, Zhao Halin, Zhang Tonghui, et al. Evaluation of water use of *Caragana microphylla* with the stem heat balance method in Horqin Sandy Land, Inner Mongolia, China[J]. Agricultural & Forest Meteorology, 2008, 148(11): 1668-1678.

[22] Xu Xiaoyan, Tong Ling, Li Fusheng, et al. Sap flow of irrigated *Populus alba* pyramidalis and its relationship with environmental factors and leaf area

index in an arid region of Northwest China[J]. Journal of Forest Research, 2011, 16(2): doi: 10.1007/s10310-010-0220-y.

[23] Yu Hongbo, Yang Jie, Zang Chunxin, et al. Diurnal variation of *Hippophae rhamnoides* sinensis subsp. stem sap flow in Huangfuchuan Basin and related environmental factors[J]. Chinese Journal of Ecology, 2008, 27(7): 1071-1076.

[24] Wu Fang, Chen Yunming, Yu Zhanhui. Growing season sap flow dynamics of *Robinia pseudoacacia* plantation in the semi-arid region of Loess Plateau, China[J]. Chinese Journal of Plant Ecology, 2010, 34(4): 469-476.

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