Stem Sap Flow Characteristics of Haloxylon ammodendron(C.A.Mey)Bunge in the Minqin Oasis-Desert Ecotone and Its Response to Environmental Factors: Postprint

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Abstract

Continuous measurements of sap flow in Haloxylon ammodendron stems were conducted using the Grainer thermal diffusion probe (TDP) method in the Minqin oasis-desert ecotone during the growing season, with simultaneous monitoring of external environmental factors. The diurnal and seasonal variations of sap flow in H. ammodendron stems of different diameters and their correlations with external environmental factors were investigated from June to November. The results showed that: (1) With the progression of months, the peak region of diurnal variation in sap flow velocity (SV) of H. ammodendron stems of different diameters under sunny conditions gradually decreased. Furthermore, during June-August, SV for all diameter classes exhibited a distinct "broad-peak" pattern, with SV under sunny conditions being significantly higher than that under cloudy and rainy conditions; (2) With seasonal changes, SV of H. ammodendron of different diameters showed considerable fluctuation, with larger diameters exhibiting higher variability; however, SV did not demonstrate a pattern of increasing sap flow velocity with increasing stem diameter; (3) From June to November, water consumption of H. ammodendron stems first increased and then decreased, reaching its peak in July, with larger diameter trees showing greater total water consumption; (4) The correlation between H. ammodendron sap flow and environmental factors was substantially influenced by different weather conditions and temporal scales, with correlations under sunny conditions being slightly higher than those under cloudy and rainy conditions. Air temperature, net radiation, and vapor pressure deficit were the primary meteorological factors affecting H. ammodendron sap flow. Soil moisture in the 0-250 cm root zone above the 0-100 cm soil layer had the most significant influence on stem sap flow. (5) Compared with the total water consumption of

458-1044 kg and daily average water consumption of 1.8-6.4 kg/d for H. ammodendron during the growing season (May-October) in the Gurbantünggüt Desert, H. ammodendron in the Minqin oasis-desert ecotone exhibited total water consumption of 495-1232 kg and daily average water consumption of 2.0-8.3 kg/d during the entire growing season (June-November), indicating similar water consumption between the two regions. The use of TDP technology for measuring water consumption in H. ammodendron demonstrates certain reliability.

Full Text

Preamble

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Title: Stem Sap Flow Characteristics of *Haloxylon ammodendron* (C.A. Mey.) Bunge and Their Response to Environmental Factors in the Minqin Oasis-Desert Ecotone

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Abstract

In arid and semi-arid ecosystems, water resources are the key ecological factor restricting the structure and function of oasis-desert ecotones. This study aimed to determine the effects of environmental factors on stem sap flow characteristics and water consumption of *Haloxylon ammodendron* throughout the entire growing season. Thermal dissipation sap flow velocity probes (TDPs) and an automatic weather station were used to measure sap flow velocity in trunks of different diameters and environmental factors including air temperature (T), relative humidity (RH), solar net radiation (Rn), vapor pressure deficit (VPD), and precipitation (Rain) in the Minqin oasis-desert ecotone, Gansu Province, China, from June to November 2014.

On clear days, the peak wave area of daily sap flow velocity in *H. ammodendron* trunks of different diameters gradually reduced with changing seasons, whereas the phenomenon showed excessive growth from June to August. The sap flow velocity of *H. ammodendron* on cloudy or rainy days was lower than that on sunny days. The sap flow velocity of different trunk diameters often fluctuated, with larger diameters showing higher fluctuation during the growing season. However, there was no obvious consistency or relationship between sap flow velocity and stem diameter. From June to November, the water consumption of *H. ammodendron* initially increased then decreased, with the highest peak in July. Larger stem diameter resulted in higher water consumption. Environmental factors correlated positively with *H. ammodendron* sap flow velocity, but the correlation was affected by different weather conditions and time scales. The correlation was slightly higher on sunny days than on cloudy days. Vapor pressure deficit was the main meteorological factor affecting sap flow velocity, while soil moisture in the root area was the most significant factor. Compared with *H. ammodendron* in the Gurbantunggut Desert, the total water consumption (458–1044 kg) and daily water consumption (1.8–6.4 kg/d) during the growing season (May–October) were similar to those in Minqin oasis-desert ecotone (495–1232 kg and 2.0–8.3 kg/d for June–November). The TDP technique demonstrated reliability for measuring water consumption in *H. ammodendron*.

Keywords: *Haloxylon ammodendron*; thermal diffusion technique; meteorological factors; soil moisture; sap flow; TDP

Introduction

Water scarcity is a severe global challenge, particularly pronounced in arid and semi-arid regions. In these areas, most herbaceous and shrub vegetation depends primarily on precipitation to maintain life activities, with over 90% of precipitation lost to the atmosphere through evapotranspiration. Vegetation transpiration is an important component of evapotranspiration and a major factor influencing ecological water demand. With increasingly severe global warming, water resources in arid and semi-arid regions are becoming increasingly scarce, inevitably disrupting vegetation water consumption and causing ecosystem structure and function disorders.

Haloxylon ammodendron (Chenopodiaceae), a deciduous shrub or small tree, is a cold- and drought-resistant plant in Central Asian desert habitats. It plays an important role in maintaining soil-plant-atmosphere continuum (SPAC) water cycling and has become an excellent sand-fixing tree species in the Minqin oasis-desert region of Gansu Province, serving functions in windbreak, sand fixation, and ecosystem structure maintenance. However, due to human factors (groundwater over-extraction) and natural disasters, *H. ammodendron* forests in Minqin are experiencing large-scale degradation, causing fixed dunes to become activated and quicksand to spread rapidly toward the oasis.

Numerous studies have investigated water consumption of drought-resistant vegetation in arid regions using various methods including wind tunnels, steady-state porometers, photosynthesis measurement, whole-plant chambers, potted weighing, stable isotopes, and sap flow measurement. Among these, sap flow measurement offers advantages of simple installation, high data reliability, zero pollution, and continuous observation, and has been widely applied internationally. While many studies have analyzed *H. ammodendron* water consumption characteristics using heat pulse methods, few have reported using the thermal diffusion method.

This study focused on *H. ammodendron* as a typical sand-fixing plant in the Minqin oasis-desert transition zone. Using the Granier thermal diffusion probe method (TDP), we continuously measured stem sap flow throughout the growing season while synchronously measuring environmental factors. We analyzed seasonal dynamics of sap flow in different diameter trees and correlations with environmental factors to provide a scientific basis for vegetation ecological water demand research and rational water management of *H. ammodendron* forests.

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1. Study Area

The experimental site was located at the Minqin Desert Research Station (38°36 N, 102°56 E, 1365 m) in the Minqin oasis-desert ecotone on the southeastern edge of the Badain Jaran Desert. The region has a typical temperate continental climate with mean annual precipitation of 115.90 mm, annual potential evaporation of 2452.70 mm, mean annual temperature of 7.76°C, maximum temperature of 41.00°C, and minimum temperature of -30.80°C. Precipitation is concentrated in July–September. The soil type is typical desert soil, susceptible to strong wind erosion forming coarse structures. Northwest winds prevail year-round at 2.40 m/s, with maximum wind speed of 5.30 m/s.

Vegetation mainly grows on fixed and semi-fixed dunes, including *Haloxylon ammodendron*, *Calligonum arborescens*, *Nitraria tangutorum*, and *Agriophyllum squarrosum*.

The experimental plot was a semi-fixed dune *H. ammodendron* plantation in the desert oasis area (38°36 38.5 N, 102°56 55.5 E). Soil type was wind-deposited sandy soil with capillary porosity of 30.11–35.31%, non-capillary porosity of 20.06–24.41%, and maximum water holding capacity of 1.50–1.66 g/cm³. The plantation area was 300 m × 300 m. Basic characteristics of sample trees are shown in .

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2. Methods

2.1 Plant Stem Sap Flow and Water Consumption Measurement

Thermal dissipation sap flow sensors (TDP-10, Dynamax Inc., USA) were installed on three representative sample trees with base diameters of 9.90, 10.95, and 13.06 cm. Probes were installed on east and west sides of each trunk at 50 cm height, wrapped with radiation-shielding aluminum foil, and fixed with special foam. A CR1000 data logger (Campbell Scientific Inc., USA) recorded temperature differences every 10 minutes. The average of east and west measurements represented each tree' s sap flow value.

The Granier empirical formula was used to calculate sap flow flux density (Fd):

$$K = \frac{\Delta T_{max} - \Delta T}{\Delta T}$$

$$Fd = 119.99 \times 10^{-6} \times K^{1.231}$$

where ΔT_{max} is the maximum temperature difference between probes at zero flow (°C), ΔT is the temperature difference at specific flow (°C), and K is a dimensionless unit.

Daily transpiration (Q) was calculated from sap flow flux density:

$$Q = \int_{86400} Fd \times As \, dt$$

where As is sapwood area and Fd is sap flow flux density.

The relationship between sapwood area and diameter was determined using dye extraction, showing a significant exponential function:

$$y = 0.699e^{0.349x} \quad (R^2 = 0.996)$$

where x is diameter (cm) and y is sapwood area.

2.2 Meteorological Factors

Photosynthetically active radiation (PAR), air temperature and humidity, relative humidity (RH), vapor pressure deficit (VPD), precipitation (Rain), and reference crop evapotranspiration (ET) were measured using a CR1000 data logger at 10-minute intervals. Calculation methods followed references [31-32].

2.3 Soil Moisture

Soil volumetric water content was measured using time-domain reflectometry (TDR) (SEC002-minitrace, Soilmoisture Equipment Corp., USA) at horizontal distances of 20, 150, 250, and 400 cm from sample trees, and vertical depths of 20, 150, 250, and 400 cm. Horizontal points at 20, 150, and 250 cm were designated as root zones, while 400 cm was non-root zone. Data were recorded every 30 minutes and validated using oven-drying methods.

2.4 Data Analysis

Sap flow measurements and meteorological data from June–November were analyzed using Excel for correlation analysis and regression fitting. Origin software was used for graphical presentation of sap flow flux and water consumption.

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3. Results

3.1 Dynamics of Meteorological Factors

During the observation period (2014), meteorological factors showed distinct seasonal patterns. Precipitation (Rain) totaled 93.1 mm, with the highest monthly precipitation of 34.8 mm in July, making it the most concentrated rainfall month. Air temperature (T) and PAR showed initial increase then decrease, with maximum temperature of 30.3°C and maximum PAR of 180.9 W/m². RH fluctuated between 18.1-91.4%. VPD showed high overall volatility with maximum of 3.4 kPa. Wind speed averaged 4.6 m/s at 4 m height and 0.4 m/s at 2 m height. Reference evapotranspiration (ET) averaged 6.4 mm/d, with total of 337.5 mm during the observation period [Figure 1: see original paper].

3.2 Diurnal Variation of Stem Sap Flow Flux

3.2.1 Clear Days On typical clear days, sap flow velocity (SV) showed distinct patterns across months. From June to August, SV 启动时间 (start time) was 7:00–8:00, peaking at 12:00–13:50 with maximum values of 21.19–24.04 cm/h. The peak area gradually decreased with advancing season. From September to November, SV 启动时间 delayed to 9:00–11:00, showing narrow peak patterns or no obvious peaks, with maximum values of 9.21–9.90 cm/h. Sample tree No. 3 (largest diameter) consistently showed higher SV values than trees No. 1 and 2 [Figure 2: see original paper].

3.2.2 Rainy Days On rainy days, diurnal SV patterns were irregular, showing double or multiple peaks. During June–August with higher rainfall, SV showed smaller diurnal variation. In months with less rainfall, day-night SV differences were more pronounced. Nighttime sap flow was evident, particularly in sample tree No. 3, likely due to water balance recovery [Figure 3: see original paper].

3.2.3 Cloudy Days On cloudy days, SV diurnal patterns were more consistent with net radiation variation, showing double or single peaks. Peak SV values were significantly lower than on clear days, with maximum values of 12.00–14.41 cm/h in June and August, and 9.21–9.90 cm/h in October–November [Figure 4: see original paper].

3.3 Seasonal Variation of Sap Flow Flux (SV)

All sample trees showed similar seasonal trends but with large daily fluctuations. Trees No. 1 and 2 showed initial increase then decrease, with maximum SV in July (325.70 and 283.89 cm/h respectively). Tree No. 3 showed a continuous decreasing trend. Daily average SV values were 146.79, 119.89, and 120.62 cm/h for trees No. 1, 2, and 3 respectively. Larger diameter trees showed higher SV values but also greater seasonal fluctuations [Figure 5: see original paper].

3.4 Water Consumption Dynamics During Growing Season

Total water consumption varied significantly among trees: 495.80, 583.02, and 1232.73 kg for trees No. 1, 2, and 3 respectively. Daily water consumption increased with diameter: 2.7, 3.2, and 6.8 kg/d. The average daily consumption across all trees was 5.1 kg/d. When converted per unit canopy area, this represented 0.8 mm. Water consumption accounted for only 35.6% of reference ET, indicating high water use efficiency. Monthly consumption peaked in July then declined [Figure 6: see original paper].

3.5 Correlation Between Sap Flow and Meteorological Factors

3.5.1 Daily Scale Correlations between SV and meteorological factors varied by month. In June, SV correlated most strongly with net radiation (Rn). In July, relative humidity (RH) showed the highest correlation. In August, air temperature (T) and VPD were dominant. Overall, VPD was the most influential factor across the season, with correlation coefficients exceeding 0.842 ($P < 0.01$), followed by Rn ($r = 0.811$) and T ($r = 0.769$). Correlations were stronger on sunny days than cloudy/rainy days .

3.5.2 Hourly Scale At hourly scale, SV showed stronger correlations with meteorological factors than at daily scale. Under sunny conditions, the correlation order was: VPD > Rn > T > RH. Under cloudy/rainy conditions, the dominant factors varied by tree diameter .

3.6 Correlation Between Sap Flow and Soil Moisture

On sunny days, SV showed extremely significant positive correlations with soil moisture at 0-250 cm depth within the root zone (20-250 cm from stem), particularly at 0-100 cm depth ($r > 0.57$, $P < 0.01$). Negative correlations were found at the stem base. On cloudy/rainy days, correlations were weaker but still significant at certain depths .

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4. Discussion

4.1 Dynamics of Sap Flow Flux (SV) The delayed SV 启动时间 from June to November was likely due to progressively later sunrise times. The narrow peak patterns in autumn resulted from reduced plant metabolism, lower temperatures, and decreased VPD. Nighttime sap flow on rainy days helped replenish water balance. Seasonal SV fluctuations were mainly caused by soil water stress, dry air, and high radiation intensity, creating time lags between root water uptake and canopy transpiration.

4.2 Water Consumption Characteristics The exponential relationship between sapwood area and diameter explained why larger trees had higher water consumption. However, sap flow flux density did not consistently increase with diameter, indicating that under small diameter differences, no positive correlation exists. The peak consumption in July corresponded with maximum precipitation and vigorous growth. Compared with *H. ammodendron* in other deserts, Minqin trees showed similar daily consumption (1.8-6.4 kg/d vs. 2.0-8.3 kg/d), demonstrating strong adaptability and water-saving characteristics.

4.3 Environmental Factor Effects Correlations between SV and meteorological factors varied by timescale and weather. At daily scale, Rn dominated in June (high radiation), while RH became limiting in July (high precipitation). At hourly scale, VPD was consistently the most important factor. Soil moisture significantly modulated these relationships, with root zone moisture (0-250 cm) being most influential, particularly at 0-100 cm depth where absorptive roots concentrated.

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5. Conclusion

1. Sap flow velocity 启动时间 and peak area decreased progressively with advancing months. Rainy days showed double/multiple peaks with significantly lower flow than clear days.
2. Seasonal SV fluctuation was greater in larger diameter trees, with daily average flow of 119.89-146.79 cm/h across trees.
3. Water consumption peaked in July, with total seasonal consumption of 495-1232 kg and daily consumption of 2.0-8.3 kg/d, similar to Gurbantunggut Desert populations.
4. VPD was the dominant meteorological factor, while root zone soil moisture (0-250 cm, especially 0-100 cm) most significantly influenced sap flow.
5. The TDP technique proved reliable for measuring water consumption in *H. ammodendron*, confirming its status as an efficient, drought-resistant species.

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