IOP Conf. Series: Earth and Environmental Science **186** (2018) 012022 doi:10.1088/1755-1315/186/6/012022

Nocturnal sap flow of *Hedysarum scoparium* and its response to meteorological factors in semiarid Northwest China

Jifeng Deng[1,2], Hangyong Zhu[3]

[1]College of Forestry, Shenyang Agricultural University, Shenyang, 110866 Liaoning, P.R. China

[2]Research Station of Liaohe-River Plain Forest Ecosystem CFERN, Shenyang Agricultural University, Shenyang, 110866 Liaoning, P.R. China

[3]Harbin City Forestry Academy, Harbin, 150028 Heilongjiang, P.R. China

Corresponding author: jifeng-deng@syau.edu.cn, zhhy504@hotmail.com

Abstract: Nocturnal sap flow of shrub may indicate transpiration and water recharge storage at night. *Hedysarum scoparium* is an important sand fixation shrub in semiarid regions. This paper deals with the water use of *Hedysarum scoparium* at night in the semiarid Northwest China. Our primary goal was to reveal and understand the nature of nocturnal sap flow and its functional significance. Granier's stem heat balance method was used to determine the nocturnal sap flow of *Hedysarum scoparium* (stem of 25, 16, 13 and 9mm). Nocturnal sap flow was substantial and showed seasonal variation similar to the patterns of daytime sap flow. Mean nocturnal sap flow was higher in more precipitation months of year 2011 for more daytime transpiration and high soil water availability which can be the cause of more nocturnal sap flow. And vapour deficit pressure, mean air temperature and wind velocity were significantly correlated with nocturnal sap flow, they could explain a small fraction of the variance in nocturnal sap flow of studied trees. And the meteorological factors have greater impact on nocturnal sap flow rate of *Hedysarum scoparium* with smaller stem diameter than other diameter classes of *Hedysarum scoparium*.

1. Introduction

Due to intensively growing human activities, the earth's surface has warmed up by larger than 0.8°C in the 20th century and by approximately 0.6°C in the past 30 years. Especially in northern latitudes, night temperatures increased more than day temperatures in the past century. Such consequences may lead to an elevated evaporative demand on some tree and shrub species at night, which can alter the diurnal balance of forest water use in turn [1]. In order to predict a long term ecosystem water and energy fluxes to accurately make clear of physiological responses of semi-arid vegetation to soil and atmospheric drought, underlying mechanisms is critical and will provide a more mechanistic picture of plant response to drought [2]. Therefore, it is essential to update our knowledge concerning the nocturnal water use of forest trees. With the help of the sap flow measurement, a growing number of studies have recently revealed previously unknown information on nocturnal water use in *Sequoia sempervirens*, *Pseudotsuga menziesii*, *Lithocarpus densiflora* and *Acer rubrum* [3-6].

Based on the optimization theory, stomatal aperture varies over time to minimize water loss for a required amount of carbon gain [5]. It is generally accepted that for C_3 and C_4 plants stomatal closure minimizes transpiration water loss at night because no opportunity for carbon gain. However, there are many evidence that some species maintain substantial stomatal conductance and transpiration at night like *Arabidopsis, Betula*, *Brassica*, *Chrysothamnus*, *Fraxinus*, *Picea*, *Rosa*, *Sarcobatus* and *Tilia* [7, 8]. Nocturnal sap flow is defined as the stem sap flow when solar radiation was less than 5.0W.m^{-2}. It could either be explained as a result of both actual nocturnal transpiration of the canopy [9] and recharging the depleted internal water storage of trees [1, 10] or separately. One reasoning is daytime canopy transpiration causes a deficit in the internal water storage of trees that can be recharged by nocturnal sap flow [11]. As a commonly happening physiological activity, for plants nocturnal sap flow has the following benefits: (1) nocturnal sap flow could partially compensating for declines in plant Nitrogen content under CO_2 enrichment [12] (2) nocturnal sap flow helps to recover hydraulic conductance from partial xylem cavitation that might occur during stressful daytime conditions [13] and (3) nocturnal sap flow assures an earlier resumption of higher transpiration and photosynthetic rates in the following morning [1] and avoiding lags between assimilation and increased stomatal conductance simultaneously [14, 15]. To verify these thoughts above, some studies on promoting nutrient supply [15] and carbohydrate export [5] and so forth. However there is a robust physiological basis and understanding of its significance remain to be elucidated.

Hedysarum scoparium (Fabaceae) (*H.scoparium*) is an important xerophyte in the arid and semi-arid regions of Northwest China and can grow well as a pioneer plant in shifting sand dunes. With its traits of strongly light-tolerant and drought resistant it can be used for soil and water conservation, sheltering from wind and sand fixation [15]. With frequency small rainfall events occur and abundant sunshine, sap flow in Yanchi county of Ningxia autonomous province is more dynamic than in other arid regions.

There are many ways to measure plant transpiration and Granier's stem heat balance method is widely used with its advantages of simplicity, easy to use, high degree of accuracy, reliability and relatively low cost. The merit of this technique can not cause certain damage to the sample wood, do not affected by its installation position, minimizing the error of unit area fluid flow to the whole trees fluid flow conversion [14, 15]. Therefore, we investigated sap flow of four *H.scoparium* in the stems (stem of 25, 16, 13 and 9mm) by using stem heat balance method. Our primary goals of this study were (1) to reveal and understand the nature of nocturnal sap flow and its implications and (2) to analyze the characteristics of nocturnal sap flow and its environmental dependence.

2. Matherials and Methods

2.1. Site description and plant material

The experiment was conducted during the period from 11th May to 19th October in 2011. Experimental site is located in Yanchi County where lies in the eastern part of the Ningxia Hui autonomous region the middle north of China covers an estimated area of 6,743km^2 (ranging from 106°300´to 107°410´ and from 37°04´ to 38°10´ altitude 1354m). Soil types are primarily dark loessial soil in the south, in the north, soil changes to eolian sandy soil and sierozem, saline soil, planosol and other soil types. The area is dominated by a semiarid continental monsoonal climate with long winters, short summers, a late spring and an early autumn. There is an annual average sunshine of 3124h, with a mean annual temperature of 8.1°C, ranging from -24.2°C to 34.9°C in the whole year, frost-free days for 128 days. The relatively well-grown *H.scoparium* (17a) was selected as the experimental tree in this study. Four shrubs (25mm, 16mm, 13mm and 9mm in the stem diameter) were chosen in the plot.

2.2. Sap flow and meteorological measurements

Using Stem-flow gauges (Flow32 meters, Dynamax Inc., Houston, TX, USA) to measure sap flow rate of the stem. SGB9, SGB13, SGB16 and SGB25 gauges attached to the stems of *H.scoparium* (stem of 25, 16, 13 and 9mm). The data were recorded at 10s intervals and stored as 15min averages using a CR1000 datalogger. The theory of using sap-flow gauges have been described previously in detail [13-15]. Leaves were scanned with a portable scanner (University of ZheJiang Inc., HangZhou, ZheJiang, China) in 3 times in every month of the growing season. The meteorological data were measured using

Flux tower (Meteorological Tower) which can measured wind speed, solar radiation, active radiation net radiation, air temperature and relatively humidity.

2.3. Statistical analysis

Software Canoco for Windows 4.5 was used by redundancy analysis (RDA) to explore the sap flow responses to environmental factors and Figures were drew by CanoDraw (Canoco 4.5; University of South Bohemia, Ceske Budejovice, Czech Republic). Graphs were drew by software OriginPro 9.0 (OriginLab Inc., Northampton, MA, USA).

3. Results and discussion

3.1. The diurnal and seasonal variation of daytime and nocturnal sap flow

There were many peculiarities in the shrub sap flow data in daytime, for the sap flow values were very sporadic, jumpy and inconsistent, due to a sunlight or sunfleck and diffuse light exposure by the adjacent trees. During the night, however, the sap flow measurements were very stable, comparing to the daytime sap flow. Although there was minor turbulence in response to redistribution of water and nutrients, refilling or leaky stomata coupled with an atmospheric driver [13]. Both daytime and nocturnal mean sap flow of *H.scoparium* (25mm in the stem diameter) increased from May to August and went down in the September and October (Figure 1). The nocturnal mean sap flow had peak values in June and daytime mean sap flow had peak values in August, daytime sap flow was later than nocturnal sap flow (Figure 1). Furthermore, four shrubs were significantly correlated with each other both in day and nocturnal (data not shown). This is consistent with the results of Snyder's study, which revealed that higher nocturnal transpiration associated with higher daytime values across species and habitats, implying that quite an amount of nocturnal sap flow was used to refill the stem water deficit as a result of high water loss during previous daytime [13].

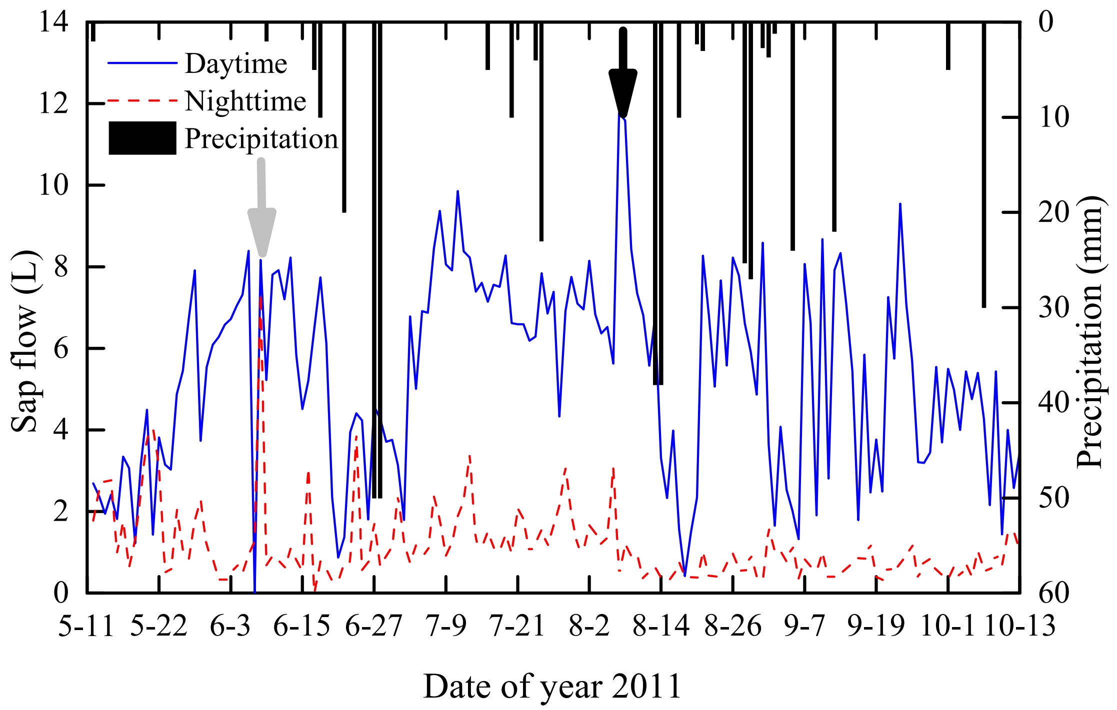

Figure 1. Daytime and nocturnal sap flow of *H.scoparium* (25mm in the stem diameter), as well as the rainfall in 2011. The black arrows pointed to peak values of daytime sap flow, while the grey arrows pointed to peak values of nocturnal sap flow.

Taking *H.scoparium* (25mm in the stem diameter) for example. Figure 2 illustrates the nocturnal sap flow activities in the whole growing season (May to October). Observations indicated that diurnal sap flow rate began before dawn and increased rapidly during the first several hours of light. Then presented a sustained rise along midday and reached a peak before nightfall. Sap flow rate was fluctuated more significantly and relatively higher before midnight while after then it was approaching a steady state. However, some month presented high fluctuations among days. The maximum daily sap flow rates were found in early August and mean of daily sap flow was higher in July, August and September, matching up with the rainy days with practically no flow due to a low vapour pressure deficit, the driving force of sap flow. Late summer was the least active period and also the maximum daily values were lower than in the other month. Sap flow series described different patterns depending on the month. The curve of sap flow was wider in early summer than in autumn in response to the longer photoperiod. It is likely that the shrubs are very well-adapted to drought conditions and will not lose any water at night unless moisture conditions are high. The contribution of internal water storage to total daily water consumption varies widely, from 9% to 48% [1, 15] .The amount of nocturnal sap flow was considerable since some days it represented up to 19.586% (*H. scoparium* (25mm)), 28.254% (*H. scoparium* (16mm)), 21.761% (*H. scoparium* (13mm)) and 48.471% (*H. scoparium* (9mm)) of whole-day flow, which is comparable with values published for other species. Nocturnal water use was 5% of total daily water use in *Eucalyptus grandis* [9]. On nights with extremely high wind speeds or vapour, or both, the percent of daily water use occurring at night was 53% in *Populus* and 15% in *Malus*. It revealed that nocturnal sap flow of *H. scoparium* was substantial and varied according to seasons and different times of the night depending on different diameter classes in *H. scoparium* (Figures 2).

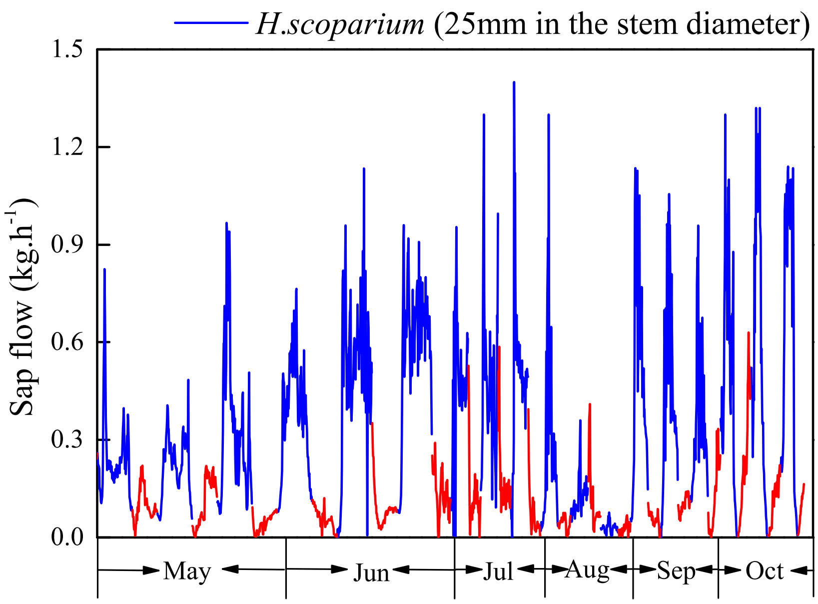

Figure 2. Daily cycles of sap flow of *H. scoparium* (25mm in the stem diameter). Three representative days per season are shown. Blue and red lines correspond to daytime and nocturnal sap flow.

3.2. Meteorological characteristics of the study period

Since radiation is absent (assume solar radiation less than 5W.m^{-2} and sap flow reaches 0kg.h^{-1}) during the nocturnal, the interaction of environmental driving factors is different from that during the daytime. The stand grows on a level slope at an elevation of 1300m above sea level. Annual mean temperature was 16.079°C with the monthly minimum in May (14.563°C) and the monthly maximum in August (20.809°C). Precipitation was 414mm in the area is unevenly distributed throughout the year of 2011 with approximately 33.0% of the total occurring in the August. The water storage was consisted of rainfall and soil moisture content (measured from surface to 1.0m deep) which was 227.585mm totally. And annual mean monthly vapour pressure deficit and relative humidity was 0.875kPa and 60.928% respectively (Figure. 3) and average wind speed was 2.601m.s^{-1} and range of the wind was southwest to the north.

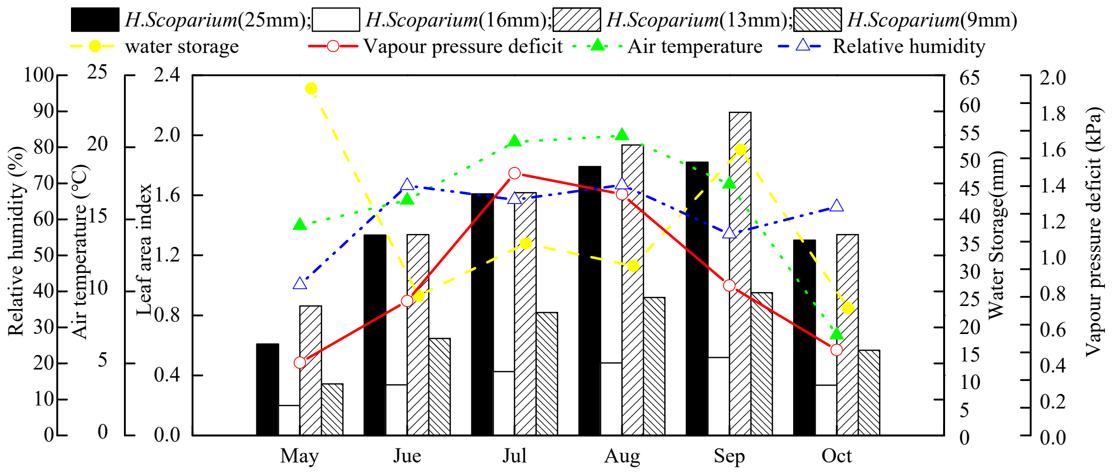

Figure 3. Monthly average leaf area index of the *H. scoparium* stand, water storage, the mean monthly vapour pressure deficit, relative humidity and air temperature for the study period.

3.3. Correlation between nocturnal sap flow rate and the meteorological factors

It has previously been suggested that environmental factors, such as air temperature and vapour pressure deficit significantly affect nocturnal sap flow [1, 4, 9]. The significant correlation between some environmental factors and the nocturnal sap flow of *H.scoparium* observed in this study supports these findings. The daily nocturnal sap flow in *H.scoparium* (especially in 9mm in the stem diameter) was in response to climate conditions, wind speed, vapour pressure deficit, air temperature and relative humidity, (Figure. 4). While limited information is available on how soil water content influence nocturnal sap flow seasonally. The nocturnal sap flow was higher in the more precipitation year 2011, which indicates that the nocturnal water recharge increased with annual rainfall occurred.

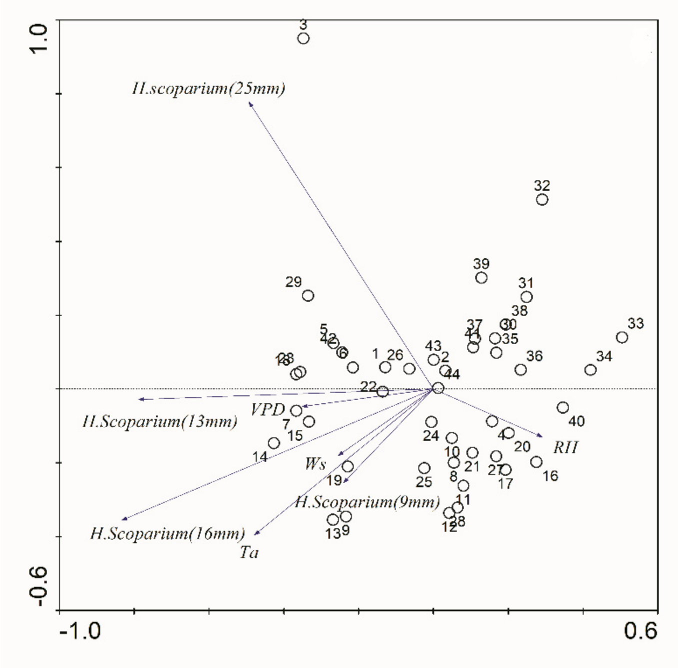

Figure 4. RDA for the relationship between nocturnal sap flow (kg.d^{-1}) and meteorological variables (*VPD* represents vapour pressure deficit, *Ws* represents wind speed, *Ta* represents air temperature, *RH* represents relative humidity).

Mean daily sap flow rate corresponded closely to mean air temperature and vapour pressure deficit at the study site. The regressions describing the relationship of the two variables (air temperature and vapour pressure deficit) were relevantly close to *H.scoparium* (9mm). While, the sensitivity of nocturnal sap flow of *H.scoparium* (25, 16,13mm) to air temperature and vapour pressure deficit was much lower than that of sap flow of *H.scoparium* (9mm) (data not shown). The results presented above are consistent with the assumption that nocturnal sap flow is principally allocated to the refilling of depleted water storages [1].

4. Conclusions

Transpiration is generally assumed to be insignificant at night when stomata close in response to the lack of photo synthetically active radiation. However, there is increasing evidence that the stomata of some species remain open at night, which would allow for nocturnal transpiration if there were a sufficient environmental driving force. Nocturnal sap flow was significantly correlated with daytime sap flow in *H.scoparium*. The influence of environmental factors also varied with seasonal, daytime and nocturnal dynamics. Nocturnal water recharge was more strongly affected by tree features and environmental factors at the daily scale. Its contribution to total transpiration loss changed with the seasons. Additional research is necessary to fully understand whether soil water content can affect sap flow rate. Furthermore, the nocturnal water recharge on whole stand transpiration deserves further investigation.

Acknowledgments

This paper was kindly supported by the Doctoral Scientific Research Foundation of Liaoning Province (20170520247); Shenyang Agricultural University Startup Foundation for Introduced Talents (8804016067); The Shenyang Agriculture University Training Programs of Innovation and Entrepreneurship for Undergraduate (the year of 2017)

References

[1]Daley M J and Phillips N G 2006 Interspecific variation in nighttime transpiration and stomatal conductance in a mixed New England deciduous forest. *Tree Physiology*, 26(4): 411-419.

[2]Naithani K J, Ewers B E and Pendall E 2012 Sap flux-scaled transpiration and stomatal conductance response to soil and atmospheric drought in a semi-arid sagebrush ecosystem. *Journal of Hydrology*, 461-465(25): 176-185.

[3]Dawson T E, Burgess S S, Tu K P, Oliveira R S, Santiago L S, Fisher J B, Simonin K A and Ambrose A R. 2007 Nighttime transpiration in woody plants from contrasting ecosystems. *Tree Physiology*, 27(4): 561-575.

[4]Fisher J B, Baldocchi D D, Misson L, Dawson T E and Goldstein A H 2006 What the towers don't see at night: nocturnal sap flow in trees and shrubs at two AmeriFlux sites in California. *Tree Physiology*, 27(4): 597-610.

[5]Marks C O and Lechowicz M J 2007 The ecological and functional correlates of nocturnal transpiration. *Tree Physiology*, 27(4): 577-584.

[6]Zeppel M, Tissue D, Taylor D, Macinnis-Ng C and Eamus D 2010 Rates of nocturnal transpiration in two evergreen temperate woodland species with differing water-use strategies. *Tree Physiology*, 30(8): 988-1000.

[7]Assaf G and Zieslin N 1996 Night water consumption by rose plants. *Journal of Horticultural Science*, 71(5): 673-678.

[8]Donovan L A, Linton M J and Richards J H 2001 Predawn plant water potential does not necessarily equilibrate with soil water potential under well-watered conditions. *Oecologia*, 129(3): 328-335.

[9]Benyon R G 1999 Nighttime water use in an irrigated *Eucalyptus grandis* plantation. *Tree Physiology*, 19(13): 853-859.

[10] Lu P, Biron P, Breda N and Granier A 1995 Water relations of adult Norway spruce (*Picea abie*s (L) Karst) under soil drought in the Vosges mountains: water potential, stomatal conductance and transpiration. *Annals of Forest Science,* 1995. 52(2): 117-129

[11] Wang H, Zhao P, Hoelscher D and Zeng X P 2012 Nighttime sap flow of *Acacia mangium* and its implications for nighttime transpiration and stem water storage. *Journal of Plant Ecology*, 5(3): 294-304.

[12] McDonald E P, Erickson J E and Kruger E L 2002 Research note: Can decreased transpiration limit plant nitrogen acquisition in elevated CO_2? *Plant Function and Evolutionary Biology*, 29(9): 1115-1120.

[13]Snyder K A, Richards J H and Donovan L A 2003 Night-time conductance in C_3 and C_4 species: do plants lose water at night? *Journal of Experimental Botany*, 54(383): 861-865.

[14] Oren R, Sperry J S, Ewers B E, Pataki D E, Phillips N and Megonigal J P 2001 Sensitivity of mean canopy stomatal conductance to vapor pressure deficit in a flooded *Taxodium distichum* L. forest: hydraulic and non-hydraulic effects. *Oecologia*, 126(1): 21-29.

[15]Christman M A, Donovan L A and Richards J H 2009 Magnitude of nighttime transpiration does not affect plant growth or nutrition in well-watered Arabidopsis. *Physiologia Plantarum*, 136(3): 264-273.