Response to the reviewers' comments

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Title: **Soil moisture control on sap-flow response to biophysical factors in a desert-shrub species, *Artemisia ordosica***
Authors: TianShan Zha, Duo Qian, Xin Jia, Yujie Bai, Yun Tian , Charles P.-A. Bourque, Jingyong Ma, Wei Feng, Bin Wu, Heli Peltola

Dear Editor,

Thank you very much for your helpful comments and suggestions in improving this manuscript. We have carefully looked at your comments and have substantially revised the manuscript accordingly. Please find below our responses to your comments and/or revisions to the manuscript.

We look forward to your comments and the possible publication of our manuscript in the special issue of BG, *Ecosystem processes and functioning across current and future dryness gradients in arid and semi-arid lands*.

Kind regards,
Tianshan Zha

Comments to the Author:
The revised manuscript by Zha et al. represents a modest improvement, but still requires substantial work. The methods and results sections are largely sound with some important avenues for further improvement noted below. I still struggle with the Introduction and Discussion (which is barely longer than three pages). Both require improvement for the manuscript to be publishable in Biogeosciences. Statements like "In general, VWC has an influence on physiological processes of plants in water-limited ecosystems (Lei et al., 2010; She et al., 2013)" do not lend confidence that this manuscript synthesizes existing knowledge effectively. The problem is that fundamental references regarding the response of leaf and canopy conductance to water availability and micrometeorological drivers is largely missing. As a consequence, the manuscript has a weak foundation and results are presented as surprising because existing knowledge has not been synthesized.
Re: We have read the relevant literature and have substantially revised the manuscript, especially the introduction and discussion. The literature information regarding the response of leaf and canopy stomatal conductance to water availability and micro-meteorological factors are added to the revised manuscript; for details see the introduction and discussion/conclusions of the revised manuscript.

At a minimum, please read (and cite if you choose):
Jarvis and McNaughton 1986:
(http://www.sciencedirect.com/science/article/pii/S0065250408601191)
Jarvis 1976: (http://rstb.royalsocietypublishing.org/content/roybtb/273/927/593.full.pdf)
Oren et al. 1999:

(http://onlinelibrary.wiley.com/store/10.1046/j.1365-3040.1999.00513.x/asset/j.1365-3040.1999.00513.x.pdf?v=1&t=j2glnk7z&s=3c262f2ce665cf0835b5c17c02962ae104087e06)
Koerner 1995: (https://link.springer.com/chapter/10.1007/978-3-642-79354-7_22#page-1)
Re: We have read these papers and revised the manuscript accordingly.

I note that Jarvis and McNaughton is cited with respect to the decoupling coefficient on page 8, but this information was never synthesized in a meaningful way the Discussion.
Re: The decoupling coefficient (Ω) is now discussed more fully in lines 93-95 and lines 361-363 of the manuscript.

A number of specific passages require rethinking. A selection:
"Changes in stomatal conductance and, thus, transpiration may equally affect plant water use efficiency (Pacala et al., 2001; Vilagrosa et al., 2003)" is an odd statement given that transpiration is part of the equation for water use efficiency. I recommend re-wording.
Re: We have revised those wordings throughout (e.g. see lines 95-100, or all introduction part, and discussion part).

On line 98 it need not be only mid-day.
Re: We changed this as well.

The sentence on line 105 should be cut. It seems like the authors are surprised that we know quite a bit about the controls over transpiration. The fundamental literature is largely not cited as noted. Including it seems in Artemisia species. One example: "Soil water content, in combination with other environmental factors, may have a significant influence on sap-flow rate" Of course it does when it is limiting! It's like the introduction was written with not cognizance of fundamental plant ecohydrology.
Re: We removed the sentence on line 105 and revised the introduction.

On line 187, these are the normal climatological season definitions.
Re: We removed the sentence.

"Our finding regarding lower sensitivity in Js to environmental factors (Rs, T and VPD) during dry periods was consistent with an earlier study of boreal grasslands (Zha et al., 2010)" has little meaning. How, and why was this paper written by the authors selected for a vague comparison?
Re: We have added the specific comparison to this revised version (lines 314-319), e.g. "and some other species in arid and semiarid region, e.g. sap flow in *Picea crassifolia* peaked at noon (12:00 and 14:00), and then decreased, it was heightened by increasing Rs, T, and VPD within limits (Rs < 800 W m-2, T < 18.0 ◦C and VPD < 1.4 kPa, Chang et al., 2014), and sap flow in *Caragana korshinskii* was significantly lower during the stress period, meanwhile, its conductance decreased linearly after the wilting point (She et al., 2013)."

The passage on line 247 could mean any number of things ("Soil water was shown to modify the response of Js to environmental factors (Fig. 4)." Given the specific subsequent sentences

I recommend removing it.
Re: We have revised the sentence.

On line 278, “The effect of…”
Re: We have revised the sentence.

“In general, VWC has an influence on physiological processes of plants in water-limited 302 ecosystems (Lei et al., 2010; She et al., 2013).” is not informative.
Re: We have removed the sentence.

On line 304, the literature is almost entirely cherry-picked to reflect papers of the authors rather than more relevant papers in the sapflux literature. Why are boreal grasslands and (on line 299) Scots pine chosen for comparison?
Re: We’ve added the relevant comparison in this revised version (see lines 314-319 in the revised manuscript).

Line 334 reiterates my point about foundational plant physiology, “According to O'Brien et al. (2004), diurnal variation in Rs could cause change in the diurnal variation in the consumption of water.” Yes, of course. Plants respond to photosynthetically active radiation, which comprises the major component of incident shortwave radiation.
Re: We have removed the sentence “According to O'Brien et al. (2004), diurnal variation in Rs could cause change in the diurnal variation in the consumption of water.”

The paragraph beginning on line 338 could still be written in a way that reflects that we know how stomata respond to environmental stimuli for decades or longer. Researchers have just discovered that stomatal responses to VPD are controlled by de novo synthesis of abscisic acid (McAdam et al., 2015, http://onlinelibrary.wiley.com/doi/10.1111/pce.12633/full).
Re: The paragraph was revised by focusing on acclimation to water shortage, rather than on mechanisms of hysteresis (see lines 349-363).

No meaningful discussion of the differences between 2013 and 2014 are presented in the Discussion.
Re: The results show the differences between 2013 and 2014 caused by drought, thus more drought in 2013 leading to lower gs and lower sensitivities of sap flow to micrometeorological variables (Rs, VPD, T) than in 2014. Also hysteresis between sap flow and environmental factors is larger in 2013 than those in 2014. The discussion focus on water use strategy in response to water limitation. We hope the key point of this paper in the revised manuscript could be clearer.

How certain are the values presented in Table 2 (i.e. what is the representative uncertainty)?
Re: The data are given as monthly mean (daytime) values; we discarded data on days affected by rainfall, including one day before and after rainfall and during rainfall, so that the real time lag could be determined between sap flow and the environmental variables.

Soil moisture control on sap-flow response to biophysical factors in a desert-shrub species, *Artemisia ordosica*

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Short title: **Sap flow in *Artemisia ordosica***

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Author Contribution Statement:

Dr.’s Duo Qian and Tianshan Zha contributed equally to the design and implementation of the field experiment, data collection and analysis, and writing the first draft of the manuscript.

Dr. Xin Jia gave helpful suggestions concerning the analysis of the field data and contributed to the scientific revision and editing of the manuscript.

Prof. Bin Wu contributed to the design of the experiment.

Dr.’s Charles P.-A. Bourque and Heli Peltola contributed to the scientific revision and editing of the manuscript.

Yujie Bai, Wei Feng, and Yun Tian were involved in the implementation of the experiment and in the revision of the manuscript.

Key Message: This study provides a significant contribution to the understanding of acclimation processes in desert-shrub species to drought-associated stress in dryland ecosystems

Conflict of Interest:

This research was financially supported by grants from the National Natural Science Foundation of China (NSFC No. 31670710，No. 31670708), the National Basic Research Program of China (Grant No. 2013CB429901), and by the Academy of Finland (Project No. 14921). The project is related to the Finnish-Chinese collaborative research project, EXTREME (2013-2016), between Beijing Forestry University and the University of Eastern Finland, and USCCC. We appreciate Dr. Ben Wang, Sijing Li, Qiang Yang, and others for their help with the fieldwork. **The authors declare that they have no conflict of interest.**

Abstract: Current understanding of acclimation processes in desert-shrub species to drought stress in dryland ecosystems is still incomplete. In this study, we measured sap flow in *Artemisia ordosica* and associated environmental variables throughout the growing seasons of 2013~~-~~ and 2014 (May-September period of each year) to better understand the environmental controls on the temporal dynamics of sap flow. We found that the occurrence of drought in the dry year of 2013 during the leaf-expansion and leaf-expanded periods caused ~~sap flow~~ sap flow per leaf area (J_s) to decline significantly, resulting in transpiration being 34% lower in 2013 than in 2014. ~~Sap flow~~ Sap flow per leaf area correlated positively with radiation (R_s), air temperature (T), and water vapor pressure deficit (VPD), when volumetric soil water content (VWC) was > 0.10 m^3 m^{-3}. Diurnal J_s was generally ahead of R_s by as much as ~~6~~ six hours. This ~~lag time~~time lag, however, decreased with increasing VWC. Relative response of J_s to the environmental variables (i.e., R_s, T, and VPD) varied with VWC, J_s being more strongly controlled by ~~biologically controlled~~plant-physiological processes during periods of dryness indicated by ~~with~~ a low decoupling coefficient and low sensitivity to the environmental variables~~ during periods of dryness~~. According to this study, soil moisture is shown to control sap-flow (and, therefore, plant-transpiration) response in *Artemisia ordosica* to diurnal variations in biophysical factors. This species escaped (acclimated to) ~~to and acclimated to~~ water limitations ~~with~~by invoking a water-conservati~~ve~~on strategy ~~through hysteresis effect with~~ with the ~~advancing J_s peaking time and stomatal~~ regulat~~ion with reducing~~ion of stomatal conductance and advancement of J_s peaking time, manifesting in a hysteresis effect. The findings of this study add to the knowledge of acclimation processes in desert-shrub species under drought-associated stress. This knowledge is essential ~~to~~ in modeling desert-shrub-ecosystem functioning under changing climatic conditions.

Keywords: sap flow; transpiration; cold-desert shrubs; environmental stress; volumetric soil water content

1. Introduction

Due to the low amount of precipitation and high potential evapotranspiration in desert ecosystems, low soil water availability limits both plant water- and gas-exchange and, as a consequence, limits vegetation productivity (Razzaghi et al., 2011). Shrub and semi-shrub species are replacing grass species in ~~desert land~~arid and semi-arid lands ~~to escape and resist~~ in response to ongoing aridification of the land surface ~~water shortage~~ (Huang et al., 2011a). This progression is predicted to continue under a changing climate (Houghton et al., 1999; Pacala et al., 2001; Asner et al., 2003). Studies have show~~ed~~n that desert shrubs are able to adapt to hot-dry environments ~~due to~~as a result of their small plant-surface area, thick epidermal hairs, and large root-to-shoot ratios~~, etc.~~ (Eberbach and Burrows, 2006; Forner et al., 2014). Plant~~s~~ traits related to water use are likely ~~expected~~ to ~~be~~ adapt~~ively~~ differ~~entiated~~entially ~~with~~with ~~habitats and~~ species and habitat type (Brouillette et al., ~~2013~~2014). Plants may select water-acquisiti~~ve~~on or water-conservati~~ve~~on strateg~~y~~ies in response to water limitations (Brouillette et al., 2014~~3~~). ~~The k~~Knowledge of physiological acclimation of changing species to water shortages in deserts~~this area~~, particularly ~~of~~with respect to transpiration, is ~~not~~ inadequate and, in the context of plant adaptation to changing climatic conditions, ~~has been~~is ~~a~~of immense ~~great concern~~interest ~~in the context of adaptation to changing climate~~ (Jacobsen et al., 2007; Huang et al., 2011a). Transpiration maintains ecosystem balance through the soil-plant-atmosphere continuum~~, but~~and ~~is~~its magnitude and timing is ~~often affected~~related to the prevailing ~~by biotic and abiotic factors~~biophysical factors (Jarvis 1976; Jarvis and McNaughton, 1986).

Sap flow ~~in shrub species~~ can ~~accurately~~ be used to reflect species-specific water consumption ~~during~~ by plants ~~transpiration~~ (Ewers et al., 2002; Baldocchi, 2005; Naithani et al., 2012)~~,~~. Sap flow can also be used ~~and~~ to continuously ~~estimate~~monitor canopy conductance (g_s) and its response to environmental variables (Ewers et al., 2007; Naithani et al., 2012). ~~. The controlling mechanisms of sap flow in desert shrubs act as a function of biotic and abiotic factors (Jarvis 1976; Jarvis and McNaughton, 1986). The b~~Biotic- and abiotic effects on sap flow ~~or~~and transpiration are often interactive and confounded. ~~D~~The decoupling coefficient (Ω) was used to examine the relative contribution~~s~~ of ~~biotic effect~~plant control through stomatal regulation ~~and environmental effect~~ o~~n~~f transpiration (Jarvis and McNaughton, 1986)~~,~~. S~~with more control by s~~tomatal regulation becomes stronger as Ω approach~~ing~~es ~~0~~zero. Stomatal conductance (g_s) at ~~a~~the plant scale ~~under dry condition can represent~~exerts a ~~by~~ large biotic ~~effect~~control on transpiration particularly during dry conditions (Jarvis 1976; Jarvis and McNaughton, 1986). Stomatal conductance ~~The g_s~~ couples photosynthesis and transpiration (Cowan and Farquhar, 1977), ~~which makes it~~making this parameter an important ~~key~~ ~~parameter~~component ~~in~~of climate models ~~for~~in quantifying ~~biosphere~~biospheric~~–~~-atmospheric~~ere~~ interactions (Baldocchi et al., 2002). ~~It~~

~~maintains ecosystem balance through the soil-plant-atmosphere continuum, but is often affected by environment factors (Huang *et al*., 2010; Zhao et al., 2016).~~

Studies have shown that xylem hydraulic conductivity was closely correlated with drought resistance (Cochard et al., 2008, 2010; Ennajeh et al., 2008). With increasing aridity, trees can ~~were expected to show~~ progressively lessen ~~lower~~ their stomatal conductance, resulting in lower transpiration (McAdam et al., 2016). Generally, desert shrubs can close their stomata, ~~and reduce~~reducing stomatal conductance, ~~to reduce~~and reduce their water consumption ~~by transpiration~~ when exposed to dehydration stresses ~~around mid-day.~~ ~~However,~~. However, ~~but~~ differences exist among shrub species in terms of ~~with respect to~~ their stomatal response to changes in ~~soil and~~ air and soil moisture deficits (Pacala et al., 2001).

In *Elaeagnus angustifolia*, transpiration is observed to peak at noon, i.e., just before stomatal closure ~~at mid-day~~ under water-deficit conditions (Liu et al., 2011), peaking earlier than radiation, temperature, and water vapor pressure deficit. This response lag or hysteresis effect have been widely noticed in dry-land species (Du et al., 2011; Naithani et al., 2012), but its function ~~needs to be further~~ is not completely understood. ~~In contrast, t~~Transpiration in *Hedysarum scoparium* peaks multiple times during the day ~~(Xia et al., 2007)~~. During dry periods of the year, sap flow in *Artemisia ordosica* has been observed to be controlled by VWC at about a 30-cm depth in the soil (Li et al., 2014). For ~~some~~ other shrubs, sap flow has been observed to decrease rapidly when the volumetric soil water content (VWC) is lower than the water loss through evapotranspiration (Buzkova et al., 2015). ~~On the contrary, Wwhen VWC rise after rainfall events, Ss~~Sap flow in *Caragana korshinskii* and *Hippophae rhamnoides* has been found to increase with increasing rainfall intensity (Jian et al., 2016)~~,~~ ~~andbut .sap flowthat in~~, whereas in *Haloxylon ammodendron*, it was found to ~~response to precipitation~~ var~~ied~~ys in response to rainfall, from an immediate decline after a heavy rainfall to no observable change after a small rainfall event (~~Asner et al., 2003;~~ Zheng and Wang, 2014). ~~Sap flow has been found to increase with increasing rainfall intensity (Jian et al., 2016).~~ Drought-insensitive shrubs have relatively strong stomatal regulation and, therefore, tend to be insensitive to soil water deficits and rainfall, unlike their drought-sensitive counterparts (Du et al., 2011). ~~Above all,~~ ~~In general, u~~Support~~nderstandings~~ ~~of~~for the relationship between sap flow ~~rates~~ in desert shrubs ~~plants~~ and prevailing environmental factors is decidedly variable ~~inconsistent~~(McDowell et al., 2013; Sus et al., 2014), potentially varying with plant habitat and species (Liu et al., 2011). ~~Knowledge gaps remain for desert shrubs in their responses to water shortage (McDowell et al., 2013; Sus et al., 2014).~~

Artemisia ordosica, a shallow-rooted desert shrub, is the dominant ~~plant~~ species in the Mu Us Desert of northwestern China. It plays an~~The shrubs~~ ~~have an~~ important role in combating desertification and in stabilizing sand dunes (Li et al., 2010). Increases in air temperature and precipitation variability and associated shorter wet ~~periods~~ and longer dry periods ~~intervals of periodic drought~~ are expected to ensue ~~with projected climate change~~under changing climate change (Lioubimtseva and Henebry, 2009). ~~During dry periods of the year, sap flow in *Artemisia ordosica* has been observed to be controlled by VWC at about a 30-cm depth in the soil (Li et al., 2014).~~However, our understanding of the mechanisms ~~regarding~~of desert-shrub acclimation during periods of ~~strategies for~~ water ~~limitation~~shortage ~~– under drought stresses~~ remains~~ inadequate~~ incomplete. Questions needing ~~to be further addressed on~~answering from our research include~~:~~ (1) ~~how~~how do changes in sap flow ~~in response to drought are regulated~~relate to changes in~~ by~~ biotic- –and abiotic factors~~?~~, ~~A~~and (2) whether~~ water limitation select~~*Artemisia ordosica* selects a strategy of ~~ for~~ water-conservati~~ve~~on or –water-acquisiti~~ve~~on ~~strategies~~under conditions of drought ~~in this species~~? ~~In this study~~To attend to these questions, we continuously measured stem sap flow in *Artemisia ordosica* and associated environmental variables *in situ* ~~in *Artemisia ordosica* and associated environmental variables~~ throughout the growing seasons of 2013~~-~~ and 2014 (May-September period of each year)~~ to better understand the environmental controls on the temporal dynamics of sap flow and to address the above-mentioned questions~~. ~~We believe that~~ ~~Oour~~Our findings will lead to insights~~ into the~~ concerning ~~optimal key~~the main environmental factors affecting transpiration in *Artemisia ordosica*, e.g., ~~the~~ optimal temperature, VPD, ~~or~~and VWC. ~~provide further understanding of acclimation processes in desert-shrub species under stress of dehydration.~~~~The u~~This understanding ~~will~~can ~~improve~~lead to improving phytoremediation practices in desert-shrub ecosystems~~in adapting to changing climate in the desert area~~.

2. Materials and Methods

2.1 Experimental site

Continuous sap-flow measurements were made at the Yanchi Research Station (37°42′ 31″ N, 107°13′ 47″ E, 1530 m above mean sea level), Ningxia, northwestern China. The research station is located between the arid and semi-arid climatic zones along the southern edge of the Mu Us Desert. The sandy soil in the upper 10 cm of the soil profile has a bulk density of 1.54±0.08 g cm^{-3} (mean ± standard deviation, n=16). Mean annual precipitation in the region is about 287 mm, of which 62% falls between July and September. Mean annual potential evapotranspiration and air temperature are about 2,024 mm and 8.1ºC ~~–~~based on meteorological data (1954-2004) from the Yanchi County weather station. Normally, shrub leaf-expansion, leaf-expanded, and leaf-coloration stages begin in April, June, and September~~ (Chen et al., 2015)~~, respectively (Chen et al., 2015).

2.2 Environmental measurements

Shortwave radiation (R_s in W m^{-2}; CMP3, Kipp & Zonen, Netherland), air temperature (T in ºC), wind speed (u in m s^{-1}, 034B, Met One Instruments Inc., USA), and relative humidity (RH in %; HMP155A, Väisälä, Finland) were measured simultaneously near the sap-flow measurement plot. Half-hourly data were recorded by data logger (CR3000 data logger, Campbell Scientific Inc., USA). Volumetric soil water content (VWC) at a 30-cm depth~~s~~ were measured using three ECH$_2$O-5TE soil moisture probes (Decagon Devices, USA). In the analysis, we used half-hourly averages of VWC from the ~~the~~ three soil moisture probes. ~~Vapor~~ Water vapor pressure deficit (VPD in kPa) was calculated from recorded RH and T.

2.3 Measurements of sap flow, leaf area and stomatal conductance

The experimental plot (10 m × 10 m) was located on the western side of Yanchi Research Station in an *Artemisia ordosica*-dominated area. Mean age of the *Artemisia ordosica* was 10-years old. Maximum monthly mean leaf area index (LAI) for plant specimens with full leaf expansion was about 0.1 m^2 m^{-2} (Table 1). Over 60% of their roots were distributed in the first 60 cm of the soil complex (Zhao et al., 2010; Jia et al., 2016). Five stems of *Artemisia ordosica* were randomly selected within the plot as replicates for sap-flow measurement. Mean height and sapwood area of sampled shrubs were 84 cm and 0.17 cm^2, respectively. Sampled stems represented the average size of stems in the plot. A ~~heat~~ heat-balance sensor (Flow32-1K, Dynamax Inc., Houston, USA) was installed at about 15 cm above the ground surface on each of the five stems (Dynamax, 2005). Sap-flow measurements from each stem were taken once per minute. Half-hourly data were recorded by a Campbell CR1000 data logger from May 1 to September 30, for both 2013~~-~~ and 2014 (Campbell Scientific, Logan, UT, USA).

Leaf area was estimated for each stem every 7-10 days by sampling about 50-70 leaves from five randomly sampled neighboring shrubs with similar characteristics to the shrubs being used for sap-flow measurements. Leaf area was measured immediately at the station laboratory with a portable leaf-area meter (LI-3000, Li-Cor, Lincoln, NE, USA). Leaf area index (LAI) was measured ~~at~~ on a ~~roughly~~ weekly ~~intervals~~ basis ~~on~~ from a 4 × 4 grid of 16 quadrats (10 m × 10 m each) within a 100 m × 100 m plot centered on ~~the~~ a flux tower using measurements of sampled leaves and allometric equations (Jia et al., 2014). Stomatal conductance (g_s) was measured *in situ* for three to four leaves on each of the sampled shrubs with a LI-6400 portable photosynthesis analyzer (Li-Cor Inc., Lincoln, USA). The g_s measurements were made every two hours from 7:00 to 19:00 h every ten days from May to September, 2013 and 2014.

The degree of coupling between the ecosystem surface and the atmospheric boundary layer was estimated with the decoupling coefficient (Ω). The decoupling coefficient varies from ~~0~~ zero (i.e., leaf transpiration is mostly controlled by g_s) to ~~1~~ one (i.e., leaf transpiration is mostly controlled by radiation). The Ω was calculated as described by Jarvis and McNaughton (1986~~):~~), i.e.,

$$\Omega = \frac{\Delta + \gamma}{\Delta + \gamma\left(1 + \frac{g_a}{g_s}\right)}, \tag{1}$$

where Δ is the rate of change of saturation vapor pressure *vs.* temperature (kPa K^{-1}), γ is the psychrometric constant (kPa K^{-1}), and g_a is the aerodynamic conductance (m s^{-1}; Monteith and Unsworth, 1990~~):~~),

$$g_a = \left(\frac{u}{u^{*2}} + 6.2u^{*-0.67}\right)^{-1}, \tag{2}$$

where u is the wind speed (m s^{-1}) at 6 m above the ground, and u^* is the friction velocity (m s^{-1}), ~~which was~~ measured ~~using~~ by a nearby eddy covariance system (Jia et al., 2014) ~~(Jia et al., 2014)~~.

2.4 Data analysis

In our analysis, ~~March-May represented spring, June-August summer, and September-November autumn (Chen et al., 2015).~~ d~~D~~rought days were defined as those days with daily mean VWC < 0.1 m^3 m^{-3}. This is based on a VWC threshold of 0.1 m^3 m^{-3} for J_s (Fig. 1), with J_s increasing as VWC increased, saturating at VWC of 0.1 m^3 m^{-3}, and decreasing as VWC continued to increase. The VWC threshold of 0.1 m^3 m^{-3} is equivalent to a relative extractable soil water (REW) of 0.4 for drought conditions (Granier et al., 1999 and 2007; Zeppel et al., 2004 and 2013~~08~~; Fig. 2d, e). Duration and severity of ‘drought’ were defined based on a VWC threshold and REW of 0.4. REW was calculated ~~as from equation (3):~~with

$$REW = \frac{VWC - VWC_{\min}}{VWC_{\max} - VWC_{\min}}, \tag{3}$$

where VWC is the specific daily soil water content (m^3 m^{-3}), VWC$_{\min}$ and VWC$_{\max}$ are the minimum and maximum VWC during the measurement period in each year, respectively.

Sap-flow analysis was conducted using mean data from five sensors. ~~Sap flow~~ Sap flow per leaf area (J_s) was ~~used in this study, i.e.,~~calculated according to

$$J_s = \left(\sum_{i=1}^{n} E_i / A_{li} \right) \Big/ n , \qquad (4)$$

where~~,~~ J_s is the ~~sap flow~~ sap flow per leaf area (kg m^{-2} h^{-1}~~)~~ or ~~(~~kg m^{-2} d^{-1}), E is the measured sap flow of a stem (g h^{-1}), A_l is the leaf area of the sap-flow stem, and “n” is the number of stems ~~used~~ sampled (n = 5).

Transpiration per ground area (T_r) was estimated in this study according to:

$$T_r = \left(\sum_{i=1}^{n} J_s \times LAI \right) \Big/ n ,$$

(5)

where~~,~~ T_r is transpiration per ground area (mm d^{-1})~~, and LAI is the leaf area index (m^2 m^{-2})~~.

Linear and non-linear regressions were used to analyze abiotic control on ~~sap flow rate~~sap flow. In order to minimize the effects of different phenophases and rainfall, we only used data ~~only~~ from the mid-growing season, non-rainy days, and daytime ~~measurements~~ hours ~~(~~from 8:00-20:00~~)~~, i.e., from June 1 to August 31, with hourly shortwave radiation > 10 W m^{-2}. Relations between mean ~~sap flow rates~~sap flow at specific times over a period of 8:00-20:00 and corresponding environmental factors from June 1 to August 31 were derived ~~with~~ from linear regression (p<0.05; Fig. 3). Regression slopes were used as indicators of sap-flow sensitivity (degree of response) to the various environmental variables (see e.g., Zha et al., ~~(~~2013). All statistical analyses were performed with SPSS v. 17.0 for Windows software (SPSS Inc., USA). Significance level was set at 0.05.

3. Results

3.1 Seasonal variations in environmental factors and sap flow

The range of daily means (24-hour mean) for R_s, T, VPD, and VWC during the 2013 growing season (May-September) were 31.1-364.9 W m^{-2}, 8.8-24.4^{o}C, 0.05-2.3 kPa, and 0.06-0.17 m^3 m^{-3} (Fig. 2a, b, c, d), respectively, annual means being 224.8 W m^{-2}, 17.7^{o}C, 1.03 kPa, and 0.08 m^3 m^{-3}. Corresponding range of daily means for 2014 were 31.0-369.9 W m^{-2}, 7.1-25.8^{o}C, 0.08-2.5 kPa, and 0.06-0.16 m^3 m^{-3} (Fig. 2a, b, c, d), respectively, annual means being 234.9 W m^{-2}, 17.2^{o}C, 1.05 kPa, and 0.09 m^3 m^{-3}.

Total precipitation and number of days with rainfall events during the 2013 measurement period (257.2 mm and 46 days) were about 5.6% and 9.8% lower than those during 2014 (272.4 mm and 51 days; Fig. 2d), respectively. ~~In 2013, more~~ More irregular rainfall events occurred in 2013 than in 2014, with 45.2% of rainfall falling in July and 8.8% in August.

Drought mainly occurred in May, June, and August of 2013 and in May and June of 2014 (shaded sections in Fig. 2d, e). Both years had dry springs. Over a one-month period of summer drought occurred in 2013.

The range of daily J_s during the growing season was 0.01-4.36 kg m^{-2} d^{-1} in 2013 and 0.01-2.91 kg m^{-2} d^{-1} in 2014 (Fig. 2f), with annual means of 0.89 kg m^{-2} d^{-1} in 2013 and 1.31 kg m^{-2} d^{-1} in 2014. Mean daily J_s over the growing season of 2013 was 32%~~,~~ lower than that of 2014. Mean daily T_r were 0.05 mm d^{-1} and 0.07 mm d^{-1} over the growing season of 2013 and 2014 (Fig. 2f), respectively, being 34% lower in 2013 than in 2014. The total T_r over the growing season (May 1-September 30) of 2013 and 2014 were 7.3 mm and 10.9 mm, respectively. Seasonal fluctuations in J_s and T_r corresponded with seasonal patterns in VWC (Fig. 2d, f). Daily mean J_s and T_r decreased or remained nearly constant during dry-soil periods (Fig. 2d, f), with the lowest J_s and T_r observed in spring and mid-summer (August) of 2013.

3.2 Sap flow response to environmental factors

In summer, J_s increased with increasing VWC, R_s, T, and VPD ~~–~~(Fig. 2d, f; Fig. 3~~d~~). ~~Soil water was shown to modify the response of J_s to environmental factors (Fig. 4).~~Besides, ~~Ss~~Sap flow increased more rapidly with increases in R_s, T, and VPD under high VWC (i.e., VWC > 0.1 m^3 m^{-3} in both 2013 and 2014; Fig. 4) compared with periods with lower VWC (i.e., VWC < 0.1 m^3 m^{-3} in both 2013 and 2014; Fig. 4). ~~Sap flow J_s~~Sap flow was more sensitive to R_s, T, and VPD under high VWC (Fig. 4), which coincided with a ~~larger~~ steeper regression slope under high VWC conditions.

Sensitivity of J_s to environmental variables (in particular, R_s, T, VPD, and VWC) varied depending on time of day (Fig. 5). Regression slopes for the relations of J_s-R_s, J_s-T, and J_s-VPD were greater in the morning before 11:00 h, and lower during mid-day and early afternoon (12:00-16:00 h). In contrast, regression slopes of the relation of J_s-VWC were lower in the morning (Fig. 5), increasing thereafter, peaking at ~13:00 h, and subsequently decreasing in late afternoon. Regression slopes of the response of J_s to R_s, T, and VPD in 2014 were ~~greater~~ steeper than those in 2013.

3.3 Diurnal changes and hysteresis between sap flow and environmental factors

Diurnal patterns of J_s were similar in both years (Fig. 6), initiating at 7:00 h and increasing thereafter, peaking before noon (12:00 h), and subsequently decreasing thereafter and remaining near zero from 20:00 to 6:00 h. Diurnal changes in g_s were similar to J_s, but peaking about 2 and 1 h earlier than J_s in July and August, respectively (Fig. 6).

There were pronounced time lags between J_s and R_s over the two years (Fig. 7), J_s ~~peaked~~ peaking earlier than R_s and, thus, earlier than either VPD or T. These time lags differed seasonally. For example, mean time lag between J_s and R_s was 2 h during July, 5 h during May, and 3 h during June, August, and September of 2013. However, the time lags in 2014 were generally shorter than those observed in 2013 (Table 2).

Clockwise hysteresis loops between J_s and R_s during the growing period were observed (Fig. 7). As R_s increased in the morning, J_s increased until it peaked at ~10:00 h. ~~Sap flow rate~~Sap flow declined with decreasing R_s during the afternoon. Sap flow (J_s~~)~~) was higher in the morning than in the afternoon~~, forming a clockwise hysteresis loop~~.

Diurnal time lag in the relation of J_s-R_s were influenced by VWC (Fig. 8, 9). For example, J_s peaked about 2 h earlier than R_s on days with low VWC (Fig. 8a), 1 h earlier than R_s on days with moderate VWC (Fig. 8b), and at the same time as R_s on days with high VWC (Fig. 8c). Lag hours between J_s and R_s over the growing season were negatively and linearly related to VWC (Fig. 9: Lag (h) =-133.5×VWC+12.24, R^2=0.41). The effect of VWC on time lags between J_s and R_s was smaller in 2014, with evenly distributed rainfall during the growing season, than in 2013, with a pronounced summer drought (Fig. 9). ~~State variables~~ Variables g_s and Ω showed a significantly increasing trend with increasing VWC in 2013 and 2014~~, respectively~~ (Fig. 10). This trend was more obvious in the dry year of 2013 than in 2014.

4. Discussion and conclusions

4.1 Sap flow response to environmental factors

Drought tolerance of some plants may be related to lower overall sensitivity of plant physiological attributes to environmental stress and/or stomatal regulation (Huang et al., 2011b; Naithani et al., 2012). In this study, ~~large~~ steep regression slopes between J_s and the environmental variables (R_s, VPD, and T) in the morning indicated that sap flow was ~~more~~ less sensitive to variations in R_s, VPD, and T during the drier and hotter ~~period~~ part of the day (Fig. 5). The lower sensitivity combin~~ing~~ed with lower s~~S~~tomatal conductances led to lower sap~~–~~ flow, ~~rates~~ and, thus, lower ~~water consumption by~~ transpiration (water consumption) during hot mid-day summer hours~~ in a summer day~~, ~~explaining~~pointing to a water~~—~~-conservati~~ve~~on strategy ~~to~~in plant acclimat~~e~~ion ~~to~~during dry and hot conditions.~~were the largest in the morning (Fig. 6), which led to increases in water fluxes to the atmosphere as a result of increased R_s, T, and VPD.~~ When R_s peaked during mid-day (13:00-14:00 h) in summer, there was often insufficient soil water to meet the atmospheric demand~~ for water~~, causing g_s to be limited by available soil moisture and making J_s more responsive to VWC at noon, but less responsive to R_s and T. Similarly, sap flow in *Hedysarum mongolicum* and some other shrubs in a nearby region was positively correlated with VWC at noon (Qian et al., 2015)~~, and some other species in arid and semiarid region~~area~~,~~. For instance, ~~e.g.~~ sap flow in *Picea crassifolia* peaked at noon (12:00 and 14:00)~~,~~ and then decreased, ~~it was~~ heighten~~ed~~ing by increasing R_s, T, and VPD, ~~within limits (~~when $R_s < 800$ W m^{-2}, $T < 18.0$-°C, and VPD < 1.4 kPa~~,~~ (~~-~~Chang et al., 2014); ~~the~~

~~evapotranspiration of a Scots pine stand showed higher sensitivity to surface conductance, temperature, vapor pressure deficit, and radiation in the morning than in the afternoon (Zha et al., 2013), and~~ sap flow in **Caragana korshinskii** was significantly lower during the stress period, ~~meanwhile,~~ its conductance decreas~~ed~~ing linearly after the wilting point (She et al., 2013). ~~Our finding that~~The fact that J_s was less sensitive to meteorological ~~factor~~variables when VWC ~~was limited being less than~~< 0.10 m^3 m^{-3}, highlights~~indicated a~~the water-conservati~~ve~~on strategy taken by~~for water use to~~ drought-afflicted ~~avoid drought stress~~*Artemisia ordosica*. ~~L~~The ~~inearly~~ positive linear relationship between g_s and VWC ~~for the species~~in this study further ~~indicated that plant reduced water consumption by transpiration through reducing stomatal conductance under lower VWC, further indicating the conservative~~supports this conclusion~~ strategy for water use~~.

Precipitation, being the ~~main~~ most important source of ~~VWC~~ soil moisture and, thus, VWC~~at our site~~, affected transpiration directly. ~~In this sense, f~~Frequent small rainfall events (< 5 mm) ~~were~~ are crucially important to the survival and growth of ~~the~~ desert plants (Zhao and Liu, 2010). Variations in J_s were clearly associated with the intermittent supply of water to the soil during rainfall events ~~, as revealed at our site~~ (see Fig. 2d, f). Reduced J_s during rainy days can be largely explained by a reduction in incident R_s and liquid water-induced saturation ~~on~~ of the leaf surface, which led to a decrease in leaf turgor and stomatal closure. After each rainfall event, J_s increased quickly when soil ~~water~~ moisture was replenished. Schwinning and Sala (2004) have previously shown ~~showed previously for similar research sites~~ that VWC contributed the most to the post-rainfall response in plant transpiration at similar sites~~ to post-rainfall events~~. The study ~~We showed in this study~~shows that *Artemisia ordosica* responded ~~in a different way~~differently to wet and dry conditions. In the mid-growing season, high J_s in July ~~were~~ was related to rainfall-fed ~~VWC~~soil moisture, which increased the rate of transpiration. However, dry soil conditions combined with high T and R_s~~,~~ led to a reduction in J_s in August of 2013 (Fig. 2). In some deep-rooting desert shrubs, groundwater may replenish water lost by transpiration~~ by having deep roots~~ (Yin et al., 2014). ~~In our site,~~ *Artemisia ordosica* roots are generally distributed in the upper 60 cm of the soil (Zhao et al., 2010), and as a result the plant usually depends on water ~~directly~~ directly supplied by precipitation because groundwater levels in drylands can ~~be well~~often be below the rooting zone of many shrub species, typically~~,~~ at depths ⩾ 10 m as witnessed at our site. Similar findings regarding the role of rainfall and VWC in desert vegetation ~~wa~~is reported by Wang et al. (2017).

4.2 Hysteresis between sap flow and environmental factors

Diurnal patterns in J_s corresponded with those of R_s from sunrise until diverging later in the day (Fig. 7), suggesting that R_s was a primary controlling factor of diurnal ~~variation in~~ J_s.

~~According to O'Brien et al. (2004), diurnal variation in R_s could cause change in the diurnal variation in the consumption of water.~~ As an initial energy source, R_s also can force T and VPD to increase, causing a phase difference ~~–~~in time lags among the relations of J_s-R_s, J_s-T, and J_s-VPD.

~~We found a consistent clockwise hysteresis loop between J_s and R_s over a diurnal cycle (Fig. 7). This~~ The hysteresis effect ~~reflected~~reflects ~~the~~ plant acclimation to water limitations, ~~may be~~ due to stomatal conductance being inherently dependent on plant hydrodynamics (Matheny et al. 2014). The large g_s in the morning promoted higher rates of transpiration (Fig. 6, 7), while lower g_s in the afternoon reduced transpiration. Therefore, diurnal curves (hysteresis) were mainly caused by ~~the~~ a g_s-induced hydraulic process (Fig. 7). The finding that hysteresis varied seasonally, decreasing with increasing VWC, further ~~supports the hydrodynamic explanation of hysteresis~~reflects the acclimation to water limitation ~~through advancing~~causing J_s to peak in advance of the environmental factors~~peaking time~~. At our site, dry soils accompanied with high VPD in summer, led to a decreased ~~in~~ g_s and ~~greater~~ a more significant control of the stomata on J_s relative to ~~other~~ the environmental factors. The result that g_s increased with increasing VWC (Fig. 10a), along with the synchronization of J_s and g_s, suggests that J_s is more sensitive to g_s in low VWC and less so to R_s. Due to the incidence of small rainfall events in ~~desert~~ drylands, soil water supplied by rainfall pulses was largely insufficient to meet the transpiration demand under high mid-day R_s, resulting in clockwise loops. Lower Ω values (< 0.4) at our site also support the idea that ~~VPD and~~ g_s have a greater control on transpiration than R_s under situations of water limitation (Fig. 10).

Altogether~~In all~~, ~~diurnally~~ stomatal control on the diurnal evolution of J_s by reducing g_s combin~~ing~~ed with lower sensitivity to meteorological variables during the mid-day dry hours ~~make~~help to reduce water consumption in *Artemisia ordosica*~~the plant to consume water less by transpiration~~. Seasonally, ~~the~~ plant~~–~~-~~reduced~~moderated reductions in g_s and increased hysteresis, ~~thus~~leads to reduced~~ing~~ J_s ~~or transpiration~~ and acclimat~~ing~~ion to ~~water limitation~~drought conditions. It ~~wa~~is suggested here that water limitation ~~selects for~~invokes a ~~–~~water~~–~~-conservati~~ve~~on~~–~~ strategy ~~strategies in~~in *Artemisia ordosica*. Contrary to our findings, counterclockwise hysteresis has been observed to occur between ~~transpiration (~~J_s~~)~~ and R_s in tropical and temperate forests (Meinzer et al., 1997; O'Brien et al., 2004; Zeppel et al., 2004), ~~,~~ which ~~was~~ is reported to be consistent with the capacitance ~~in~~ of the particular soil-plant-atmosphere system being considered~~s;~~. Unlike short-statured vegetation, i~~–i~~t usually takes more time for water to move up and expand vascular elements in tree stems during the transition from night to day.

4.3. Conclusions

~~Drought during the leaf-expansion and leaf-expanded periods led to a greater decline in J_s,~~

~~causing J_s to be lower in 2013 than in 2014.~~ The relative influence of R_s, T, and VPD on J_s in *Artemisia ordosica* was modified by ~~volumetric~~ soil water ~~content~~, indicating J_s's lessened sensitivity to the environmental variables ~~(R_s, T and VPD)~~ during dry periods. Sap flow ~~J_s~~ was constrained by soil water ~~deficiency~~deficits, causing J_s to peak several hours prior to the peaking of R_s. Diurnal hysteresis between J_s and R_s varied seasonally and was mainly controlled by ~~hydrodynamic~~ hydraulic stresses. ~~According to this study,~~ S~~s~~oil moisture controlled sap-flow response in *Artemisia ordosica* to meteorological factors. This species escaped and acclimated to ~~and acclimated to~~ water limitations ~~with~~by invoking a water-conservati~~ve~~on strategy through hysteresis effect and stomatal regulation. ~~is capable to tolerate and adapt to soil water deficits and drought conditions during the growing season. Altogether,~~ Our~~our~~ findings add to our understanding of acclimation in desert-shrub species under stress of dehydration. The ~~knowledge~~ information advanced here ~~gain~~ can assist in modeling desert-~~shreub~~shrub~~-~~ ecosystem functioning under changing climatic conditions.

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References

Asner, G. P., Archer, S., Hughes, R. F., Ansley, R. J., and Wessman, C. A.: Net changes in regional woody vegetation cover and carbon storage in Texas Drylands, 1937–1999, Global Change Biology, 9, 316-335, 2003.

Baldocchi, D. D., Wilson, K. B., Gu, L.:~~, 2002.~~ How the environment, canopy structure and canopy physiological functioning influence carbon, water and energy fluxes of a temperate broad-leaved deciduous forest – an assessment with the biophysical model CANOAK~~.~~, Tree Physiology~~.~~, 22, 1065–1077, 2002.

Baldocchi, D. D.:~~, 2005.~~ The role of biodiversity on the evaporation of forests. In: Scherer-Lorenzen, M., Körner, C., Schulze, E.-D. (Eds.), Forest d~~D~~iversity and f~~F~~unction ~~E~~ecological ~~S~~studies~~.~~, Springer, Berlin, Heidelberg, pp. 131–148, 2005.

Brouillette, L. C., Mason, C. M., Shirk, R. Y. and Donovan, L. A.: Adaptive differentiation of traits related to resource use in a desert annual along a resource gradient, New Phytologist, 201: 1316–1327, 2014.

Buzkova, R., Acosta, M., Darenova, E., Pokorny, R., and Pavelka, M.: Environmental factors influencing the relationship between stem CO2 efflux and sap flow, Trees-Struct Funct, 29, 333-343, 2015.

Chang, X., Zhao, W., He, Z.: Radial pattern of sap flow and response to microclimate and soil moisture in Qinghai spruce (*Picea crassifolia*) in the upper Heihe River Basin of arid northwestern China, Agricultural and Forest Meteorology, 187, 14-21, 2014.

Chen, Z. H., Zha, T., Jia, X., Wu, Y., Wu, B., Zhang, Y., Guo, J., Qin, S., Chen, S., and Peltola, H.: Leaf nitrogen is closely coupled to phenophases in a desert shrub ecosystem in China, Journal of Arid Environments, 122, 124-131, 2015

Cochard, H., Barigah, S., Kleinhentz, M.:~~ 2008.~~ Is xylem cavitation resistance a relevant criterion for screening drought resistance among Prunus species?~~.~~, Journal of Plant Physiology 165: 976–982, 2008.

Cochard, H., Herbette, S., Hernandez, E.:~~ 2010.~~ The effects of sap ionic composition on xylem vulnerability to cavitation,~~.~~ Journal of Experimental Botany, 61: 275–285, 2010.

Cowan, I.R., Farquhar, G.D.~~, 1977.~~ : Stomatal function in relation to leaf metabolism and environment,~~.~~ ~~Symp. Soc. Exp. Biol.~~Symposia of the Society for Experimental Biology, 31, 471–505, 1977.

Du, S., Wang, Y.-L., Kume, T., Zhang, J.-G., Otsuki, K., Yamanaka, N., and Liu, G.-B.: Sapflow characteristics and climatic responses in three forest species in the semiarid Loess Plateau region of China, Agricultural and Forest Meteorology, 151, 1-10, 2011.

Dynamax: Dynagage® Installation and Operation Manual, Dynamax, Houston, TX, 2005.

Eberbach, P. L. and Burrows, G. E.: The transpiration response by four topographically distributed Eucalyptus species, to rainfall occurring during drought in south eastern Australia, Physiologia~~.~~ Plantarum~~.~~, 127, 483-493, 2006.

Ennajeh, M., Tounekti, T., Vadel, AM.:~~ 2008.~~ Water relations and droughtinduced embolism in olive (Olea europaea) varieties ‘Meski’ and ‘Chemlali’ during severe drought,~~.~~ Tree Physiology, 28: 971–976, 2008..

Ewers, B.E., Mackay, D.S., Gower, S.T., Ahl, D.E., Samanta, S.N.B.:~~, 2002.~~ Tree species effects on stand transpiration in northern Wisconsin,~~.~~ ~~Water Resour. Res.~~Water Resources Research, 38, 1– 11, 2002.

Ewers, B.E., Mackay, D.S., Samanta, S.:~~, 2007.~~ Interannual consistency in canopy stomatal conductance control of leaf water potential across seven tree species,~~.~~ Tree Physiology,~~.~~ 27, 11–24, 2007.

Forner, A., Aranda, I., Granier, A., and Valladares, F.: Differential impact of the most extreme drought event over the last half century on growth and sap flow in two coexisting Mediterranean trees, Plant Ecol, 215, 703-719, 2014.

Granier, A., Bréda, N., Biron, P., and Villette, S.: A lumped water balance model to evaluate duration and intensity of drought constraints in forest stands, Ecological Modelling, 116(2), 269-283, 1999.

Granier, A., Reichstein, M., Bréda, N., Janssens, I. A., Falge, E., Ciais, P., and Buchmann, N.: Evidence for soil water control on carbon and water dynamics in European forests during the extremely dry year, Agricultural and forest meteorology, 143(1), 123-145, 2007.

~~Gao, Q., Yu, M., and Zhou, C.: Detecting the Differences in Responses of Stomatal Conductance to Moisture Stresses between Deciduous Shrubs and Artemisia Subshrubs, PLoS ONE, 8, e84200, 2013.~~

Houghton, R. A., Hackler, J. L., and Lawrence, K. T.: The U.S. c~~C~~arbon b~~B~~udget: c~~C~~ontributions from l~~L~~and-u~~U~~se c~~C~~hange, Science, 285, 574-578, 1999.

Huang, H., Gang, W., and NianLai, C.: Advanced studies on adaptation of desert shrubs to environmental stress, Sciences in Cold and Arid Regions, 3, 0455–0462, 2011a~~.~~

Huang, L., Zhang, Z.S., and Li, X.R.: Sap flow of Artemisia ordosica and the influence of environmental factors in a revegetated desert area: Tengger Desert, China, Hydrological Processes, 24, 1248-1253, 2010.

Huang, Y., Li, X., Zhang, Z., He, C., Zhao, P., You, Y., and Mo, L.: Seasonal changes in Cyclobalanopsis glauca transpiration and canopy stomatal conductance and their dependence on subterranean water and climatic factors in rocky karst terrain, Journal of Hydrology, 402, 135-143, 2011b.

~~Huang, Y., Zhao, P., Zhang, Z., Li, X., He, C., and Zhang, R.: Transpiration of Cyclobalanopsis glauca (syn. Quercus glauca) stand measured by sap-flow method in a karst rocky terrain during dry season, Ecological Research, 24, 791-801, 2009.~~

Jacobsen, A. L., Agenbag, L., Esler, K. J., Pratt, R. B., Ewers, F. W., and Davis, S. D.: Xylem density, biomechanics and anatomical traits correlate with water stress in 17 evergreen shrub species of the Mediterranean-type climate region of South Africa, Journal of Ecology, 95, 171-183, 2007.

Jarvis, P. G.:~~, 1976.~~ The interpretation of the variations in leaf water potential and stomatal conductance found in canopies in the field,~~.~~ Philosophical Transactions of the Royal Society of London B: Biological Sciences,~~Philos. Trans. Roy. Soc. Lond. Ser. B: Biol. Sci.~~ 273, 593–610, 1976.

Jarvis, P. G.,~~ JARVIS~~ and McNaughton, K. G.~~ MCNAUGHTON~~: Stornatal Control of Transpiration: Scaling Up from Leaf' to Region,~~. ADVANCES IN ECOLOGICAL RESEARCH~~Advances in ecological research, 15, 1-42, 1986.

Jia, X., Zha, T., Wu, B., Zhang, Y., Gong, J., Qin, S., Chen, G., Kellomäki, S., and Peltola, H.: Biophysical controls on net ecosystem CO^2 exchange over a semiarid shrubland in northwest China, Biogeosciences 11, 4679-4693, 2014.

Jia, X., Zha, T, Gong, J., Wang, B., Zhang, Y., Wu, B., Qin, S., and Peltola, H.: Carbon and water exchange over a temperate semi-arid shrubland during three years of contrasting precipitation and soil moisture patterns, Agricultural and Forest Meteorology, 228, 120-129, 2016.

Jian, S. Q., Wu, Z. N., Hu, C. H., and Zhang, X. L.: Sap flow in response to rainfall pulses for two shrub species in the semiarid Chinese Loess Plateau, J Hydrol Hydromech, 64, 121-132, 2016.

~~Larry C. Brouillette, Chase M. Mason, Rebecca Y. Shirk and Lisa A. Donovan. Adaptive differentiation of traits related to resource use in a desert annual along a resource gradient. New Phytologist (2014) 201: 1316–1327.~~

~~Lei, H., Zhi-Shan, Z., and Xin-Rong, L.: Sap flow of Artemisia ordosica and the influence of environmental factors in a revegetated desert area: Tengger Desert, China, Hydrological Processes, 24, 1248-1253, 2010.~~

Li, S. L., Werger, M. A., Zuidema, P., Yu, F., and Dong, M.: Seedlings of the semi-shrub Artemisia ordosica are resistant to moderate wind denudation and sand burial in Mu Us sandland, China, Trees, 24, 515-521, 2010.

Li, S. J., Zha, T. S., Qin, S. G., Qian, D., and Jia, X.: Temporal patterns and environmental controls of sap flow in Artemisia ordosica, Chinese Journal of Ecology, 33, 1-7, 2014.

Lioubimtseva, E. and Henebry, G. M.: Climate and environmental change in arid Central Asia: Impacts, vulnerability, and adaptations, Journal of Arid Environments, 73, 963-977, 2009.

Liu, B., Zhao, W., and Jin, B.: The response of sap flow in desert shrubs to environmental variables in an arid region of China, Ecohydrology, 4, 448-457, 2011.

Matheny, A. M., Bohrer, G., Vogel, C. S., Morin, T. H., He, L., Frasson, R. P. D. M., Mirfenderesgi, G., Schäfer, K. V, R., Gough, C. M., Ivanov, V. Y., and Curtis, P. S.: Species‐ specific transpiration responses to intermediate disturbance in a northern hardwood forest, Journal of Geophysical Research: Biogeosciences, 119(12), 2292-2311,2014.

McAdam, S. A., Sussmilch, F. C. and Brodribb, T. J.: Stomatal responses to vapour pressure deficit are regulated by high speed gene expression in angiosperms, Plant, Cell and Environment, 39, 485–491, 2016.

McDowell, N. G., ~~et al.~~Fisher, R. A., Xu, C.:~~, 2013.~~ Evaluating theories of drought-induced vegetationmortality using a multimodel-experiment framework~~.~~, New Phytologist,~~.~~ 200 (2),304–321, 2013.

~~Scott A. M. McAdam, Frances C. Sussmilch & Timothy J. Brodribb. Stomatal responses to vapour pressure deficit are regulated by high speed gene expression in angiosperms. Plant, Cell and Environment (2016) 39, 485–491~~

Meinzer, F. C., Andrade, J. L., Goldstein, G., Holbrook, N. M., Cavelier, J., and Jackson, P.: Control of transpiration from the upper canopy of a tropical forest: the role of stomatal, boundary layer and hydraulic architecture components, Plant, Cell and~~&~~ Environment, 20, 1242-1252, 1997.

Naithani, K. J., Ewers, B. E., and Pendall, E.: Sap flux-scaled transpiration and stomatal conductance response to soil and atmospheric drought in a semi-arid sagebrush ecosystem, Journal of Hydrology, 464, 176-185, 2012.

O'Brien, J. J., Oberbauer, S. F., and Clark, D. B.: Whole tree xylem sap flow responses to multiple environmental variables in a wet tropical forest, Plant, Cell & Environment, 27, 551-567, 2004.

Pacala, S. W., Hurtt, G. C., Baker, D., Peylin, P., Houghton, R. A., Birdsey, R. A., Heath, L., Sundquist, E. T., Stallard, R. F., Ciais, P., Moorcroft, P., Caspersen, J. P., Shevliakova, E., Moore, B., Kohlmaier, G., Holland, E., Gloor, M., Harmon, M. E., Fan, S.-M., Sarmiento, J. L., Goodale, C. L., Schimel, D., and Field, C. B.: Consistent l~~L~~and- and a~~A~~tmosphere-b~~B~~ased U.S. c~~C~~arbon s~~S~~ink e~~E~~stimates, Science, 292, 2316-2320, 2001.

Qian, D., Zha, T., Jia, X., Wu, B., Zhang, Y., Bourque, C. P., Qin, S., and Peltola, H.: Adaptive, water-conserving strategies in Hedysarum mongolicum endemic to a desert shrubland ecosystem, Environmental Earth Sciences, 74(7), 6039,2015.

~~Xin-ping Wang, Benjamin Eli Schaffer, Zhenlei Yang, and Ignacio Rodriguez-Iturbe. Probabilistic model predicts dynamics of vegetation biomass in a desert ecosystem in NW China. PNAS, www.pnas.org/cgi/doi/10.1073/pnas.1703684114, 2017.~~

Razzaghi, F., Ahmadi, S. H., Adolf, V. I., Jensen, C. R., Jacobsen, S. E., and Andersen, M. N.: Water r~~R~~elations and t~~T~~ranspiration of q~~Q~~uinoa (c~~C~~henopodium quinoa w~~W~~illd.) u~~U~~nder s~~S~~alinity and s~~S~~oil d~~D~~rying, Journal of Agronomy and Crop Science, 197, 348-360, 2011.

Schwinning, S. and Sala, O. E.: Hierarchy of responses to resource pulses in arid and semi-arid ecosystems, Oecologia, 141, 211-220, 2004.

She, D., Xia, Y., Shao, M., Peng, S., and Yu, S.: Transpiration and canopy conductance of Caragana korshinskii trees in response to soil moisture in sand land of China, Agroforestry systems, 87, 667-678, 2013.

~~Oliver~~ Sus,O., ~~Rafael~~ Poyatos, R., ~~Josep~~ Barba, j., ~~Nuno~~ Carvalhais, N., ~~Pilar~~ Llorens, P., ~~Mathew~~ Williams, M., and ~~Jordi Martínez~~ Vilalta, J. M.: Time variable hydraulic parameters improve the performance of amechanistic stand transpiration model. A case study of MediterraneanScots pine sap flow data assimilation,~~.~~ Agricultural and Forest Meteorology, 198–199,~~ (2014)~~ 168–180, 2014.

~~Vilagrosa, A., Bellot, J., Vallejo, V. R., and Gil - Pelegrosa, A., Bellot, J., Vallejo, V. R., and GilTranspiration and seedlings of two co - occurring Mediterranean shrubs during an intense drought, Journal of Experimental Botany, 54, 2015-2024, 2003.~~

Wang, X. P., Schaffer, B. E., Yang, Z. and Rodriguez-Iturbe, I.: Probabilistic model predicts dynamics of vegetation biomass in a desert ecosystem in NW China. Proceedings of the National Academy of Sciences, 201703684, 2017.

~~Xia, G., Kang, S., Du, T., Yang, X., and Zhang, J.: Transpiration of Hedysarum scoparium in arid desert region of Shiyang River basin, Gansu Province, Chinese Journal of Applied Ecolog, 18, 1194-1202, 2007.~~

~~Xia, G., Kang, S., Li, F., Zhang, J., and Zhou, Q.: Diurnal and seasonal variations of sap flow of Caragana korshinskii in the arid desert region of north - west China, Hydrological Processes, 22, 1197-1205, 2008.~~

~~Yang, Y. and Zhu, Y.: Plant Ecology (Second Edition), Higher Education Press, Beijing, 2011.~~

Yin, L., Zhou, Y., Huang, J., Wenninger, J., Hou, G., Zhang, E., Wang, X., Dong, J., Zhang, J., and Uhlenbrook, S.: Dynamics of willow tree (Salix matsudana) water use and its response to environmental factors in the semi-arid Hailiutu River catchment, Northwest China, Environmental earth sciences, 71, 4997-5006, 2014.

Zeppel, M. J. B., Murray, B. R., Barton, C., and Eamus, D.: Seasonal responses of xylem sap velocity to VPD and solar radiation during drought in a stand of native trees in temperate Australia, Functional Plant Biology, 31, 461-470, 2004.

Zeppel, M.: Convergence of tree water use and hydraulic architecture in water- limited regions: a review and synthesis, Ecohydrology, 6(5), 889-900, 2013.

Zha, T., Li, C., Kellomäki, S., Peltola, H., Wang, K.-Y., and Zhang, Y.: Controls of ~~E~~evapotranspiration and CO^2 f~~F~~luxes from s~~S~~cots p~~P~~ine by s~~S~~urface c~~C~~onductance and a~~A~~biotic f~~F~~actors, PloS one, 8, e69027, 2013.

~~Zhang, X., Gong, J., Zhou, M., and Si, J.: A study on the stem sap flow of Populus euphrtaicr and Tamaris spp. By heat pulse technique, J Glaciol Geocryol, 25, 584-590, 2003.~~

Zhao, W. and Liu, B.: The response of sap flow in shrubs to rainfall pulses in the desert region of China, Agricultural and Forest Meteorology, 150, 1297-1306, 2010.

Zhao, Y., Yuan, W., Sun, B., Yang, Y., Li, J., Li, J., Cao, B., and Zhong, H.: Root ~~D~~distribution of ~~T~~three ~~D~~desert ~~S~~shrubs and ~~S~~soil ~~M~~moisture in Mu Us ~~S~~sand ~~L~~land,– Research of Soil and Water Conservation, 17, 129-133, 2010.

Zheng, C. and Wang, Q.: Water-use response to climate factors at whole tree and branch scale for a dominant desert species in central Asia: Haloxylon ammodendron, Ecohydrology, 7, 56-63, 2014.

Table 1 Seasonal changes in monthly transpiration (T_r), leaf area index (LAI), and stomatal conductance (g_s) ~~of~~ in *Artemisia ordosica* ~~from~~ during the growing seasons (May-September period) of 2013 ~~to~~ and 2014.

	T_r (mm mon^{-1})		LAI (m^2 m^{-2})		g_s (mol m^{-2} s^{-1})	
	2013	2014	2013	2014	2013	2014
May	0.57	1.59	0.02	0.04	0.07	0.18
June	1.03	2.28	0.05	0.06	0.08	0.13
July	3.36	3.46	0.10	0.06	0.09	0.14
August	1.04	2.45	0.08	0.06	0.10	0.08
September	1.23	1.13	0.05	0.04	0.15	0.05

Table 2 Mean monthly diurnal cycles of ~~sap flow rate~~sap flow (J_s) response to shortwave radiation (R_s), air temperature (T), and water vapor pressure deficit (VPD), including ~~time~~ lag~~s~~ times (h) ~~in J_s~~ as a function of R_s, T, and VPD.

~~Pattern~~Relationship	May		June		July		August		September	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
J_s-R_s	5	2	3	0	2	1	3	1	3	2
J_s-T	8	6	7	4	4	4	6	5	6	6
J_s-VPD	8	5	7	4	6	4	6	5	6	5

Figure captions:

Fig. 1 ~~Sap flow rate~~Sap flow per leaf area (J_s) as a function of soil water content (VWC) at ~~30~~ 30-cm depth in non-rainy, daytime hours during the mid-growing period from June 1-August 31, ~~over~~ 2013~~-~~ and 2014. Data points are binned values from pooled data over two years at a VWC increment of 0.003 m^3 m^{-3}. Dotted line represents the VWC threshold for J_s.

Fig. 2 Seasonal changes in daily (24-hour) mean shortwave radiation (R_s; a), air temperature (T; b), water vapor pressure deficit (VPD; c), volumetric soil water content (VWC; d), relative extractable water (REW; e), daily total precipitation (PPT; d), and daily ~~sap flow~~ sap flow per leaf area (J_s; f), and daily transpiration (T_r, mm d^{-1}; f) from May to September for both 2013 and 2014. Horizontal dash lines (d, e) represent VWC and REW threshold of 0.1 m^3 m^{-3} and 0.4, respectively. Shaded bands indicate periods of drought.

Fig. 3 Relationships between ~~sap flow rate~~sap flow per leaf area (J_s) and environmental factors [shortwave radiation (R_s), air temperature (T), water vapor pressure deficit (VPD), and soil water content at 30-cm depth (VWC)] in non-rainy days between 8:00-20:00 h during the mid-growing season of June 1-August 31 for 2013 and 2014. Data points are binned values from pooled data over two years at increments of 40 W m^{-2}, 1.2~~-~~°C, 0.3 kPa, and 0.005 m^3 m^{-3} for R_s, T, VPD and VWC, respectively.

Fig. 4 ~~Sap flow rate~~Sap flow per leaf area (J_s) in non-rainy, daytime hours during the mid-growing season of June 1-August 31 for both 2013 and 2014 as a function of shortwave radiation (R_s), air temperature (T), vapor pressure deficit (VPD) under high volumetric soil water content (VWC > 0.10 m^3 m^{-3} both in 2013 and 2014) and low VWC (< 0.10 m^3 m^{-3}, 2013 and 2014). J_s is given as binned averages according to R_s, T, and VPD, based on increments of 100 W m^{-2}, 1°C, and 0.2 kPa, respectively. Bars indicate standard error.

Fig. 5 Regression slopes of linear fits between ~~sap flow rate~~sap flow per leaf area (J_s) in non-rainy days and shortwave radiation (R_s), vapor pressure deficit (VPD), air temperature (T), and volumetric soil water content (VWC) between 8:00-20:00 h during the mid-growing season of June 1-August 31 for 2013 and 2014.

Fig. 6 Mean monthly diurnal changes in ~~sap flow rate~~sap flow per leaf area (J_s) and stomatal conductance (g_s) in *Artemisia ordosica* during the growing season (May-September period) for both 2013 and 2014. Each point is given as the mean at specific times during each month.

Fig. 7 Seasonal variation in hysteresis loops between ~~sap flow rate~~sap flow per leaf area (J_s)

and shortwave radiation (R_s) using normalized plots for both 2013 and 2014. The y-axis represents the proportion of maximum J_s (dimensionless), and the x-axis represents the proportion of maximum R_s (dimensionless). The curved arrows indicate the clockwise direction of response during the day.

Fig. 8 ~~Sap flow rate~~Sap flow per leaf area (J_s) and shortwave radiation (R_s) over consecutive three days in 2013, i.e., (a) under low volumetric soil water content (VWC) and high vapor pressure deficit (VPD; DOY 153-155, VWC=0.064 m^3 m^{-3}, REW=0.025, VPD=2.11 kPa), (b) moderate VWC and VPD (DOY 212-214, VWC=0.092 m^3 m^{-3}, REW=0.292, VPD=1.72 kPa), and (c) high VWC and low VPD (DOY 192-194, VWC=0.152 m^3 m^{-3}, REW=0.865, VPD= 0.46 kPa~~).~~); REW is the relative extractable soil water. VWC, REW, and VPD are the 3-day mean value~~ of the three days~~.

Fig. 9 ~~Time lag~~Time lag between ~~sap flow rate~~sap flow per leaf area (J_s) and short wave radiation (R_s) in relation to volumetric soil water content (VWC). Hourly data in non-rainy days during the mid-growing season of June 1-August 31 for 2013 and 2014. The lag hours were calculated by a cross-correlation analysis using a three-day moving window with a one-day time step. Rainy days were excluded. The solid line is based on exponential regression ($p<0.05$).

Fig. 10 Relationship between volumetric soil water content (VWC) and (a) stomatal conductance (g_s) in *Artemisia ordosica*, and (b) decoupling coefficient (Ω) for 2013 and 2014. Hourly values are given as binned averages based on a VWC-increment of 0.005 m^3 m^{-3}. Bars indicate standard error. Only statistically significant regressions ~~with~~ (with p-values < 0.05) are shown.

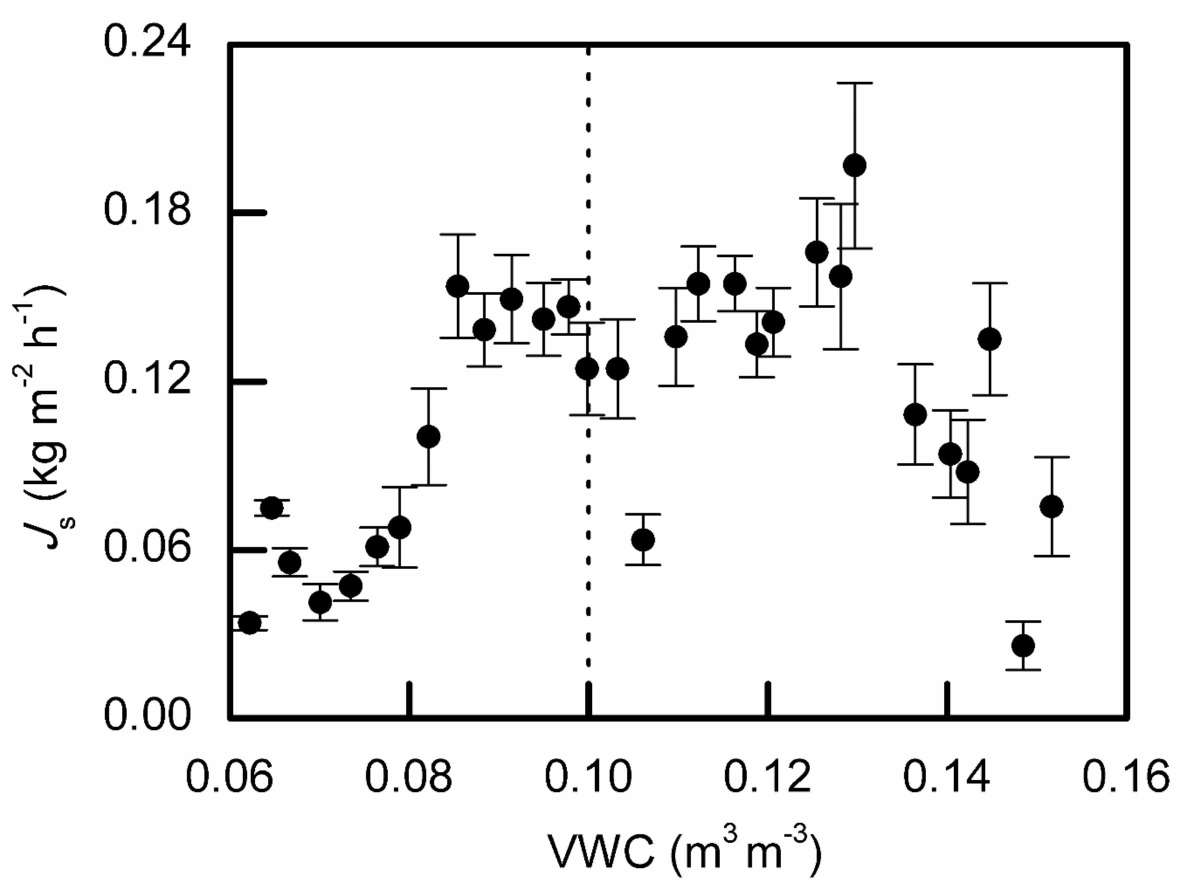
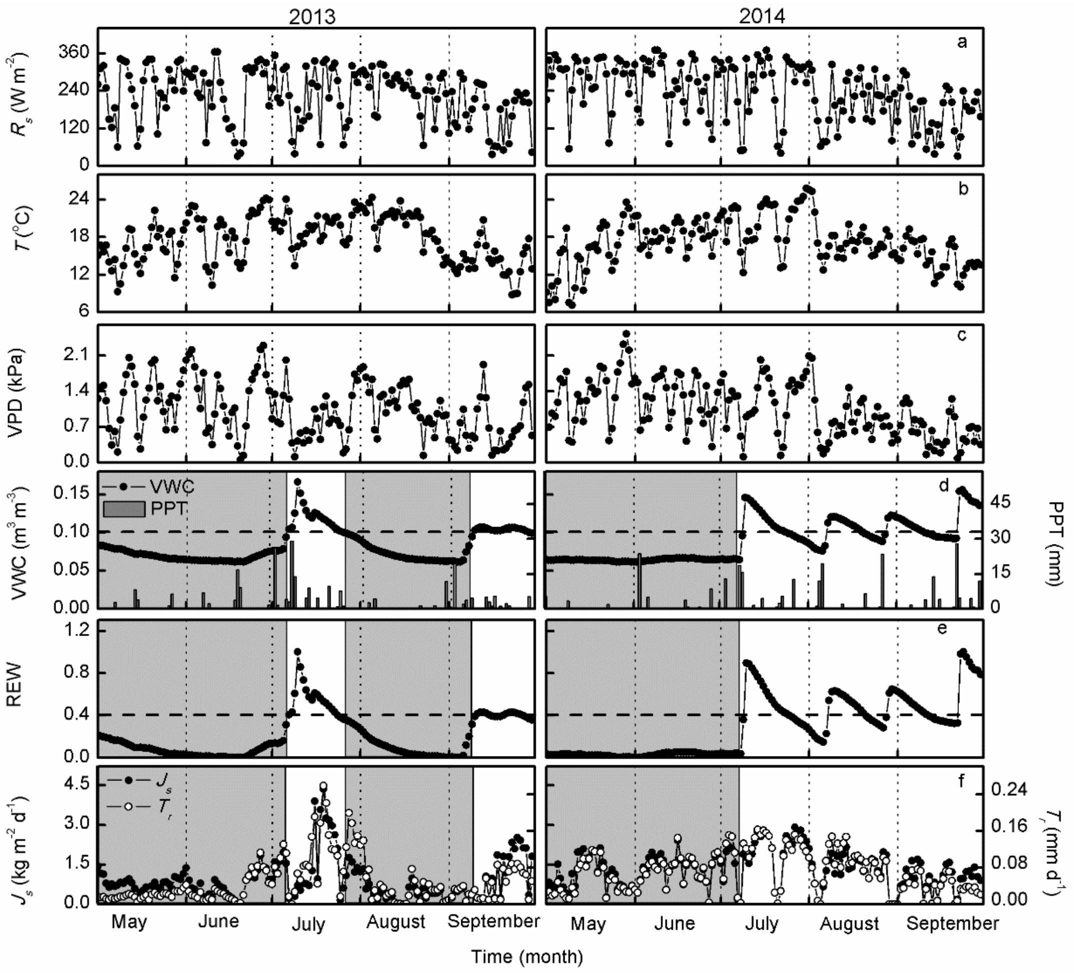


Fig. 1 Sap flow per leaf area (J_s) as a function of soil water content (VWC) at 30-cm depth in non-rainy, daytime hours during the mid-growing period from June 1-August 31, 2013 and 2014. Data points are binned values from pooled data over two years at a VWC increment of 0.003 m^3 m^{-3}. Dotted line represents the VWC threshold for J_s.

~~**Fig. 1** Sap flow rate per leaf area (J_s) as a function of soil water content (VWC) at 30 cm depth in non-rainy, daytime hours during the mid-growing period from June 1-August 31 over 2013-2014. Data points are binned values from pooled data over two years at a VWC increment of 0.003 m^3 m^{-3}. Dotted line represents the VWC threshold for J_s.~~



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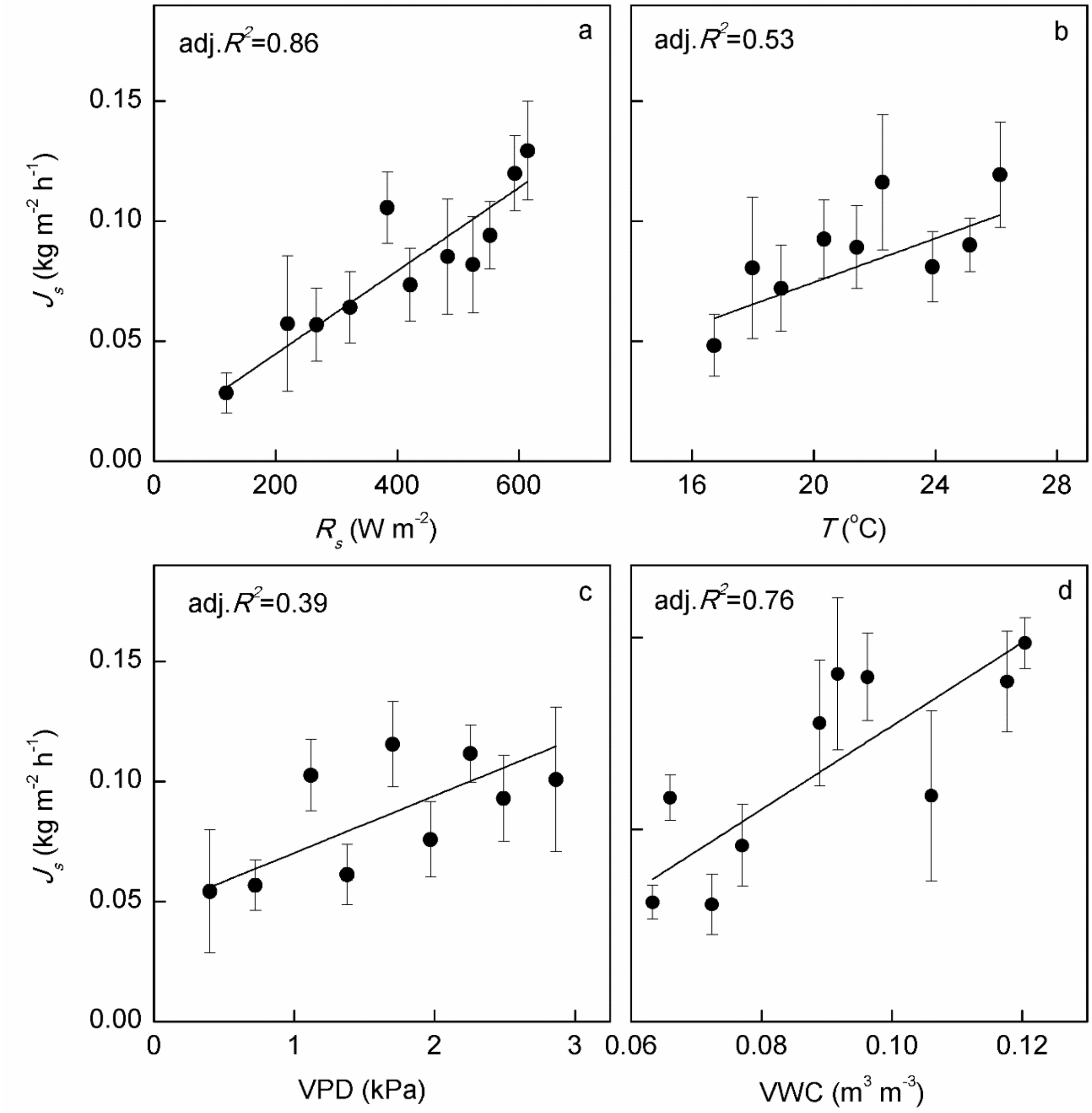

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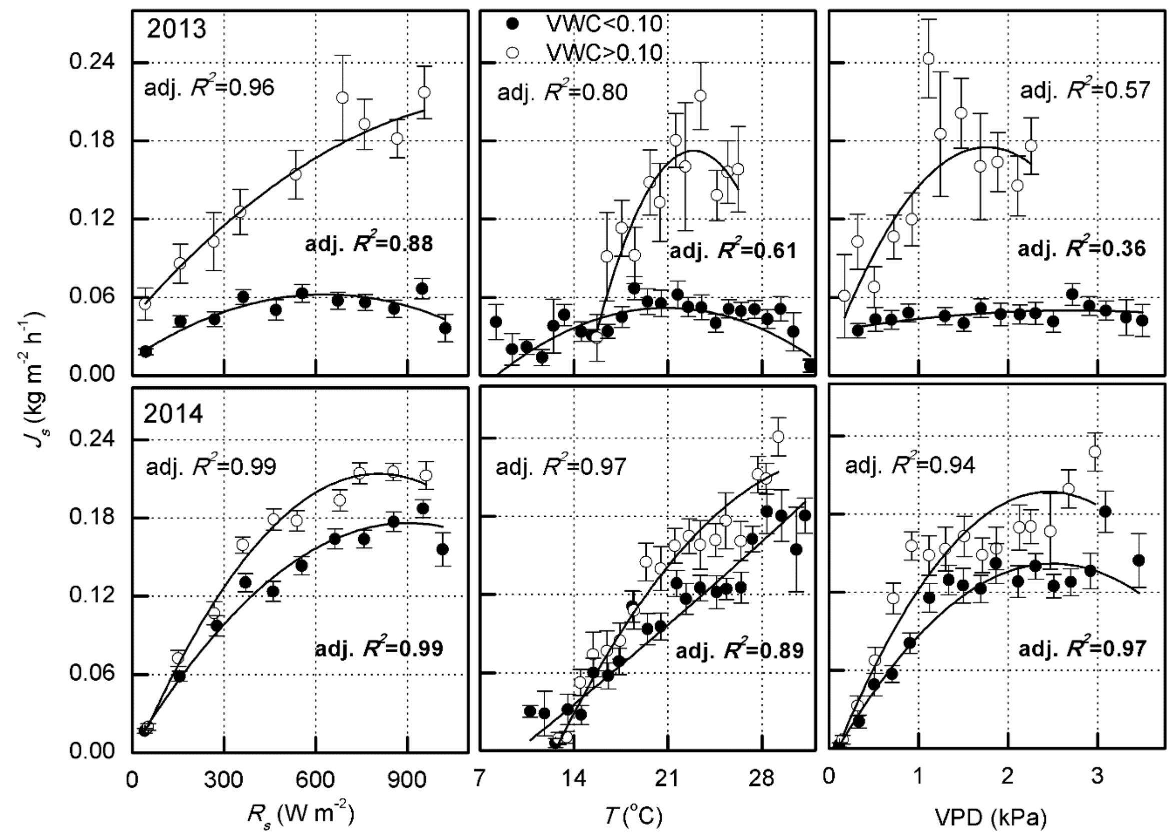

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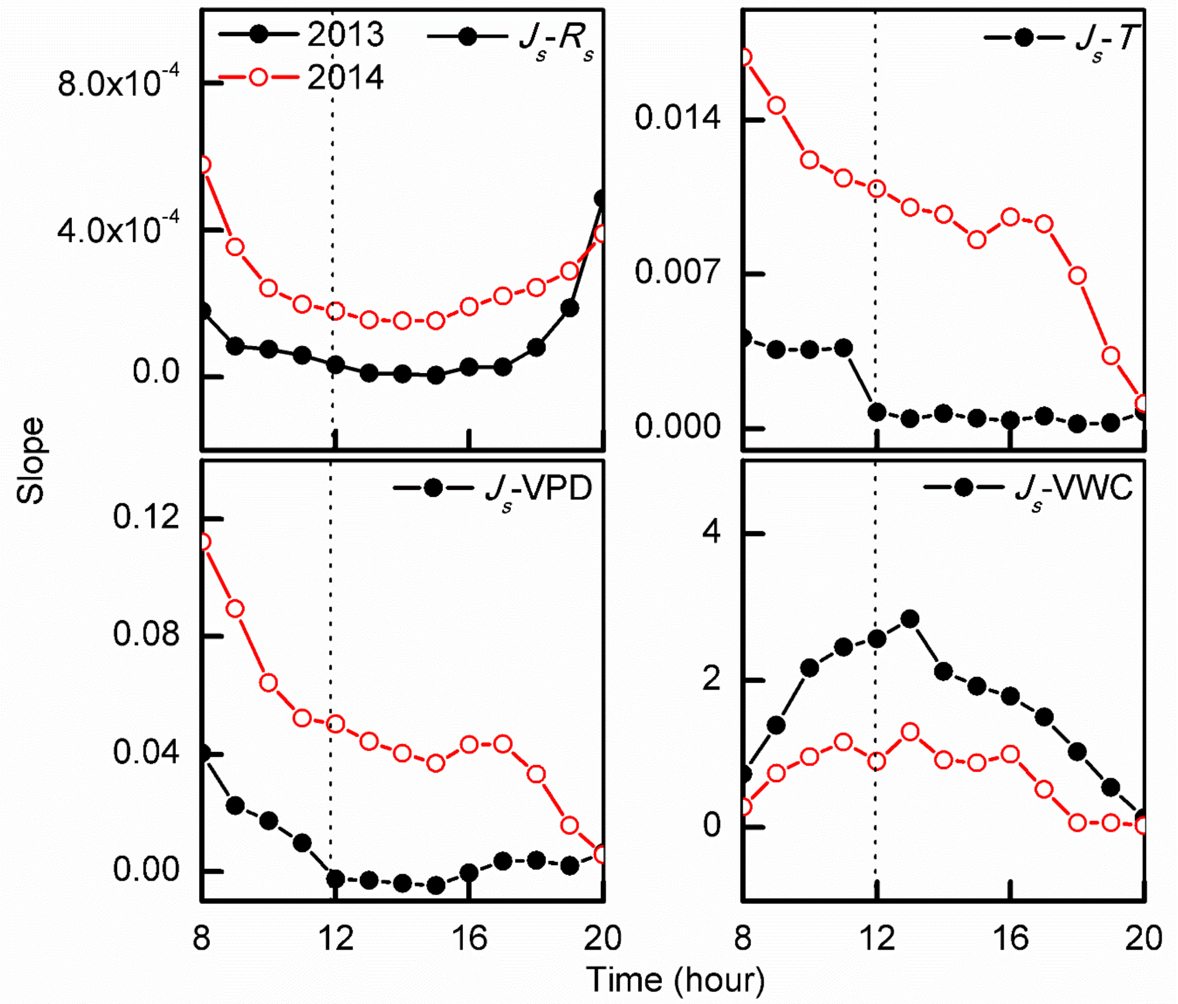

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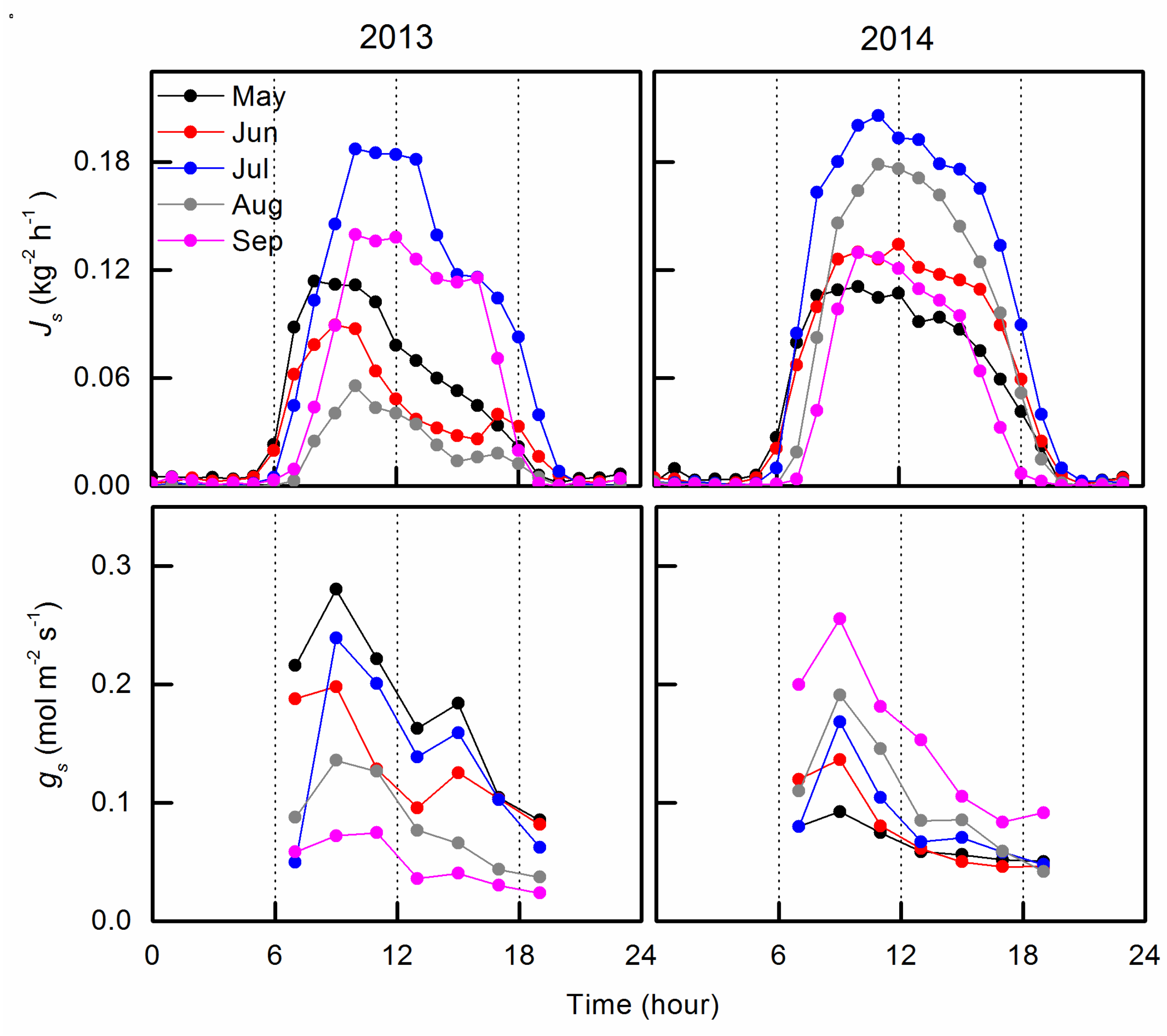

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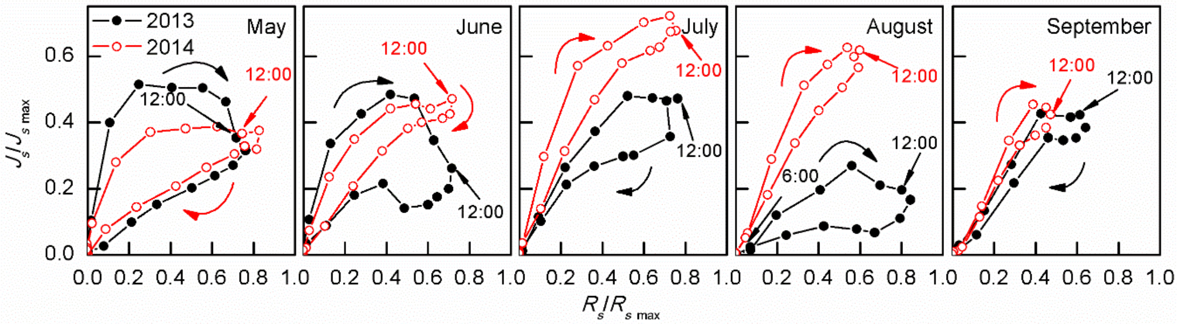

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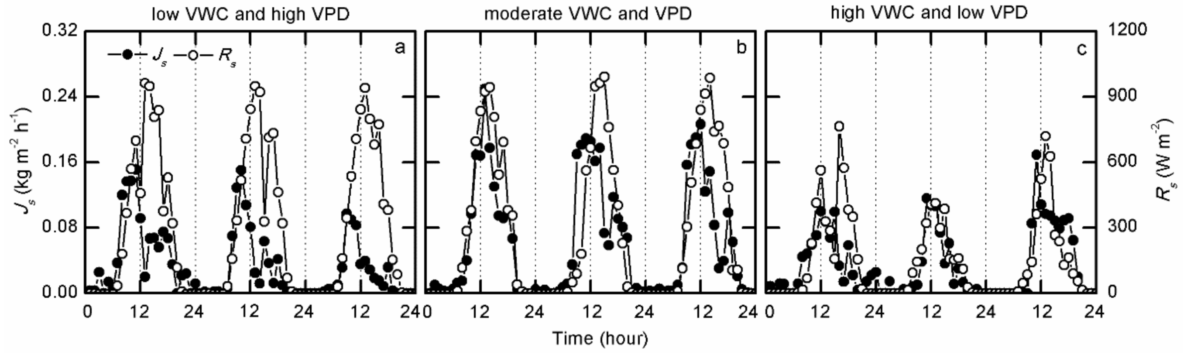

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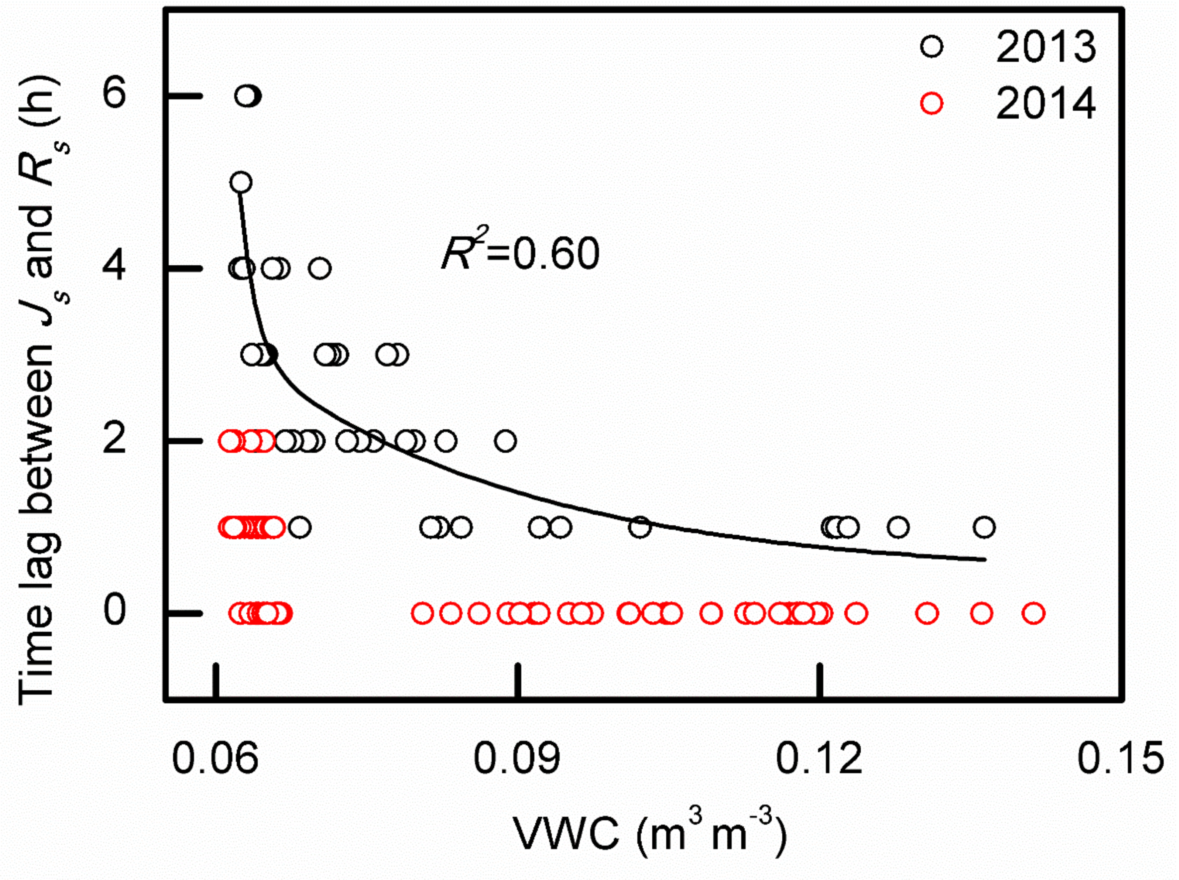

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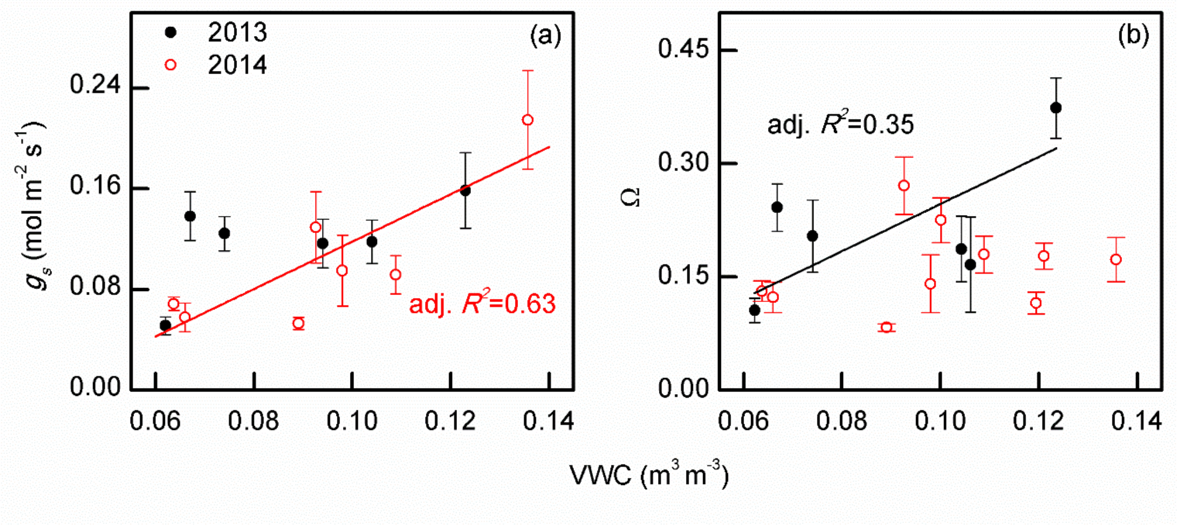

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