



Simulating canopy conductance of the *Haloxylon ammodendron* shrubland in an arid inland river basin of northwest China

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ABSTRACT

Accurate estimates of canopy conductance (g_c) are essential for quantifying the carbon, water and energy fluxes of ecosystem and understanding the patterns of water utilization of vegetation in arid regions. To this end, g_c of *Haloxylon ammodendron* community, dominated by three desert shrub species, was calculated using the inversed Penman-Monteith equation from measurements of sap flow and concurrent microclimate over two main growing seasons (2014–2015). Then, it was used to examine the Jarvis-Stewart (JS) models which comprised different response functions and the simplified process-based model (BTA) to select the best one for our study species and climate. Photosynthetically active radiation and vapor pressure deficit typically covary throughout the day and are known to have opposite effects on g_c . When this effects was taken into account, both the JS model and the BTA model produced better g_c fittings. Selection of proper vapor pressure deficit function and air temperature function significantly improved the performance of the JS model. The best JS model given a correlation coefficient of 0.89, RMSE of 1.99 mm s^{-1} and average percent error of 19% in comparison with the PM-calculated g_c , while the best BTA model outperformed this model, reflected by higher correlation coefficient (0.90), and lower RMSE (1.93 mm s^{-1}) and average percent error (9%). The average decoupling coefficient was 0.28, indicating canopies of *H. ammodendron* community were well coupled from the atmosphere. These findings addressed the importance of selection of stress function and consideration of air temperature for improving g_c estimation in arid region, and gain new knowledge on the environmental control on canopy conductance.

1. Introduction

Canopy conductance (g_c) that couples photosynthesis and transpiration is a key parameter in climate, hydrology and ecology models for quantifying the biosphere-atmosphere interactions (Leuning, 1995; Sitch et al., 2008). Accurate estimation of g_c , therefore, is critical for improving our understanding of the way g_c responds to environmental variables, and predicting the long-term ecosystem carbon, water and energy fluxes; this is especially important for arid and semi-arid regions, which cover 40% of the Earth's terrestrial surface but receive little attention on g_c simulating (Reynolds, 2000).

Among approaches of quantifying g_c , the inverted physically-based

Penman-Monteith (PM) equation (Monteith, 1981) has been widely used to derived g_c using observed water/heat fluxes and meteorology (Zhang et al., 2009, 2010; Wang et al., 2014). The sap flow method is well suited for determining species effects and other types of variability that occur in highly heterogeneous environments (Vrugt et al., 2002; Yu et al., 2014). The g_c in PM equation, which considers both climatic factors and their interactions with surface vegetation characteristics, represents bulk stomata behavior as canopy resistance and assumes that stomata and canopy resistance have the same influencing factors.

Alternatively, there have been several attempts to estimate g_c directly from environmental variables using mechanistic or empirical approaches. For example, Ball et al. (1987) linked stomatal

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conductance (g_s) to CO_2 assimilation using a function of intercellular CO_2 concentration and leaf-level relative humidity. White et al. (1999) related g_s of *Eucalyptus globulus* and *Eucalyptus nitens* with incoming-shortwave radiation, air temperature and vapor pressure deficit. More relevant studies can be found in a recent review paper by Damour et al. (2010). Buckley et al. (2003) developed a process-based canopy conductance model with clear physiological interpretations and later simplified it (Buckley et al., 2012) for canopy conductance as well as transpiration modeling. The simplified models are driven only by incoming-shortwave radiation and vapor pressure deficit and have two to four parameters that represent sums and products of biophysical parameters. They are an advance in predicting g_c in desert region where long-term exhaustive field measurement is difficult to implement.

In addition, the multiplicative Jarvis-Stewart (JS) model (Jarvis, 1976; Stewart, 1988) has been largely used at the field level and incorporated into land surface models for transpiration estimate (Churkina et al., 1999; Dickinson et al., 1998; Noilhan and Planton, 1989; Sellers et al., 1986), due to its simpler model structure and lower requirements on measurement. The JS model was initially designed to describe g_s from a maximum rate by applying different stress functions related to influencing factors. While it has been extended to canopy scales by assuming that g_c is analogous to g_s (Harris et al., 2004). The stress of each influencing factor on g_c is site specific and has been expressed differently among studies (Damour et al., 2010). However, selection of response functions in many studies is somewhat arbitrary, without specific explanation on why they, not others, were chosen. We hypothesize that selecting the appropriate functions will lead to better simulations of g_c .

The JS approach assumes the environmental factors have independent effects on g_c . However, some of the meteorological variables that affect g_c are typically highly correlated with one another. For example, photosynthetically active radiation (PAR) is known to have positive direct and indirect effects on g_s/g_c , while many investigations of water use in trees have shown a decrease in g_s/g_c as vapor pressure deficit increases (D) (Meinzer et al., 1995; Motzer et al., 2005; O'Brien et al., 2004). To our knowledge, the influence of PAR and D on g_c is less understood and considered in g_c estimates for desert species. The effect of air temperature (T) on g_c is often neglected without quantitative evidence (Lhomme et al., 1998). For example, Whitley et al. (2009) modeled g_c of an Australian native forest without consideration of T . Significance of the T effect on g_c is specifically examined in this study.

In arid regions, desert ecosystems play a crucial role in stabilizing sand dunes and protecting oases from desertification (Xu et al., 2017a). As one of the important morphological characteristics, the predominantly deep root system enables desert species to maximize use of deeper soil water for adapting to the frequent aridity and other environmental stresses (Schwinning and Ehleringer, 2001; Smith et al., 2000; Xu et al., 2017b). Considering plant water uptake is affected by both root distribution and soil hydraulic conductivity and occurs through the whole root zone, a single measurement of the soil-water content at shallow or a given depth can only provide limited information, and may lower the accuracy of estimated g_c values. In present study, we use root-zone soil moisture to simulate g_c .

Based on concurrent measurements of stem sap flow on three dominant shelterbelt shrub species and microclimate over two main growing seasons in 2014 and 2015, this study calculated g_c of *Haloxyylon*

ammodendron community using the inversed PM equation, and made a comparison with the results of Jarvis-Stewart model (JS) and simplified process-based model (BTA). We aim to address (1) whether photosynthetically active radiation and vapor pressure deficit have offsetting effect on g_c , and correspondingly affects the performance of the selected models, (2) whether air temperature is critical for g_c estimates using the JS approach. For quantifying the environment control on g_c , the dimensionless decoupling coefficient between the canopies and the atmosphere was also calculated.

The paper is structured as follows. Section 2 describes the study area, followed by the vegetation, environment, sap flow, and leaf-scale gas exchange measurements. Section 3 introduces the methods of stand transpiration and canopy conductance estimates, calculation of decoupling coefficient, and model construction of the JS and the BTA models. Results, Discussion and Conclusion are presented in Sections 4, 5 and 6, respectively.

2. Study site and material

2.1. Site description

We conducted our experiments near the Linze Inland River Basin Research Station (LIRBRS), Chinese Academy of Sciences. LIRBRS is located in the middle reaches of Heihe River Basin, northwest China (39°22'07"N, 100°08'48" E, elevation 1386 m). This region is characterized by a typical continental arid temperate climate with hot and dry summers and cold winters. LIRBRS meteorological station data for 2005–2014 showed the daily average sunshine duration of about 8.3 h and average annual global radiation of 6254 MJ m⁻²; the annual mean temperature is about 8.9 °C, with the lowest temperature of -26.2 °C occurring in January and the highest temperature of 38.6 °C occurring in July; the annual mean precipitation is about 125 mm, with approximate 80% of the annual total occurring from June to September. Soil at the site is loamy sand (sand 73.5%, silt 22.5% and clay 1.4%) (USDA texture class) with little organic matter and few mineral nutrients.

2.2. Vegetation measurement

A plot of *H. ammodendron* community (50 m × 50 m) was selected within which a stand vegetation survey was conducted during intensive field experiments (from 15 July to 10 August 2014). *H. ammodendron* is the dominant species, comprising approximately 87% of the canopy cover, with subdominant *Nitraria tangutorum* (ca. 6.8%), *Calligonum mongolicum* (ca. 3.2%) and other shrubs species (e.g. *Hedysarum Scoparium*, *Tamarix ramosissima*) and subshrubs (e.g. *Suaeda glauca*, *Agriophyllum squarrosum*, *Bassia dasyphylla*, *Halogeton arachnoideus*) constituting smaller portions of the vegetation. The species-specific locations, stand density, basal diameter (5 cm above ground level), height and crown area of sampling shrub stems for three dominant shrubs in the plot were surveyed. Detailed information on vegetation survey can be found in previous study (Ji et al., 2016). The average stand characteristics and the frequency distribution of stem diameter for three dominant species were presented in Table 1 and Fig. 1, respectively.

Table 1
Average stand characteristics of the three dominant desert shrubs.

Species	Average plant height (m)	Average crown area (m ²)	Average stem diameter (cm)	Stem density (stems m ⁻²)	Stem cross-sectional area per ground (cm ² m ⁻²)
<i>H. ammodendron</i>	1.87 ± 0.04	3.56 ± 0.18	1.40 ± 0.03	1.26 ± 0.29	3.92 ± 0.14
<i>C. mongolicum</i>	0.96 ± 0.06	1.45 ± 0.25	0.83 ± 0.03	0.16 ± 0.09	0.14 ± 0.004
<i>N. tangutorum</i>	0.45 ± 0.14	2.05 ± 0.71	0.32 ± 0.01	2.43 ± 0.19	0.31 ± 0.02

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