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Stomatal and hydraulic conductance and water use in a eucalypt plantation in Guangxi, southern China

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ABSTRACT

Previous work has demonstrated that constant water use per unit leaf area results from the combined control of stomatal and hydraulic conductance holds for plant water use; however, few studies have ever explored the water use of a popularly planted fast-grown tree species, *eucalyptus*, in southern China. In this study, seasonal variations in hydraulic traits and ecophysiological parameters were monitored via the sap flux, leaf water potential (ψ_{leaf}) and associated environmental variables to investigate the water use of a five-year-old *Eucalyptus grandis* × *Eucalyptus urophylla* plantation in Guangxi province, China, in July and October 2012 and January and April 2013. The results show that predawn ψ_{leaf} was similar among all months, suggesting an abundance of soil water in the study site. There was a significant seasonal variation in midday ψ_{leaf}. Moreover, canopy stomatal conductance (G_s) was higher in July than in October and linearly decreased with the natural logarithm of the vapor pressure deficit ($\ln(VPD)$). Furthermore, the hydraulic conductance from soil to leaves (K) per unit sapwood area in the dry season (October) was relatively high compared to that in the wet season (July). Whole-tree water use per day was estimated to be 7.7 kg d^{-1} and 6.7 kg d^{-1} in July and October, respectively, and linearly increased with leaf area. However, the slope of the regression line between whole-tree water use per day and leaf area was similar in July and October, clearly indicating that this *eucalyptus* stand had a constant water use per unit leaf area, which confirms the generally accepted concept. The findings of this study should help address the increasing ecohydrological and water resource concerns related to the rapid expansion of *Eucalyptus* spp. plantations in southern China, which recently underwent a severe drought.

1. Introduction

Eucalyptus trees, which represent a fast-growing species, have been planted extensively in many parts of the world to meet the increasing demand for timber and fiber. It is reported that the *Eucalyptus* plantation area reached 3.68 million ha in China by the end of 2010 (data from the China *Eucalyptus* Research Centre), most of which are located in southern China. In Guangxi province, the *Eucalyptus* planting area has expanded to 1.8 million ha in the recent 10 years, making this province the largest eucalypt plantation region in China (data from the State Forestry Administration, China). Because plant productivity is typically related to water resource accessibility (Sands and Nambiar, 1984; Hunt et al., 2006), increasing concerns about the water balance in catchments has resulted from the high transpiration rates of *Eucalyptus* species and from uncertain ecohydrological effects on non-native environments (Bari and Schofield, 1992; Bleby et al., 2012). Particularly, the severe drought that began in late 2009 caused serious water shortages and adverse social consequences in Guangxi province (Cao et al., 2012; Guo et al., 2013). Therefore, quantifying water use and understanding ecophysiological factors of local eucalypt plantations appear to be critical issues, especially in an area that has experienced more serious drought conditions in recent years.

A clear understanding of plant water use has been stressed for modeling water fluxes across large spatial scales (Zeppel, 2013). Several previous studies have reported that there is a constant relationship between water use and leaf area (Hatton et al., 1998;

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Meinzer, 2003; O'Grady, 2009). Manzoni et al. (2013b) further demonstrated that transpiration is a conservative process across plant types. As for eucalypt species, Hatton et al. (1998) observed a constant water use per unit leaf area under limited soil water conditions. However, whether such relationship holds for the expanding *Eucalyptus* plantation in southern China remains unclear. Furthermore, to clearly explain this behavior, plant water use and the underlying regulating mechanisms, which range from leaf physiological parameters to the plant hydraulic structure, should be comprehensively studied.

An improved understanding of the roles of stomatal conductance and hydraulic conductance on plant water use will help to understand ecohydrological relationships across large spatial scales because stomatal conductance responds to various environmental stimuli, such as light, vapor pressure deficit and water status at the root (Buckley, 2005). Furthermore, previous work has shown that stomatal closure avoids high transpiration rates that would otherwise occur due to increasing vapor pressure deficits (Saliendra et al., 1995). Whitehead and Beadle (2004) indicated that stomata close in response to a decreasing water potential and an increasing vapor pressure deficit. However, studies have shown that the response sensitivity of stomatal conductance to the vapor pressure deficit varies among tree species (Oren et al., 1999).

Furthermore, adaptation of hydraulic architecture may contribute to survival in dry habitats (Stout and Sala, 2003). Several studies have indicated that plants evolve coordination mechanisms to regulate stomatal aperture and water transport in the xylem (Manzoni et al., 2013a; Domec et al., 2004, 2006, 2012). Bleby et al. (2012) has investigated the water use of *eucalyptus* in a seasonally dry forest and reported that hydraulic and physiological traits vary according to size and growth conditions. As environmental factors change, especially soil water availability, transpiration rates are synergistically affected by stomatal conductance and whole-tree hydraulic conductance (Cruiziat et al., 2002; Manzoni et al., 2013a; Hacke et al., 2000; Katul et al., 2003).

In this study, we examined seasonal variations in leaf water potential, canopy stomatal conductance, soil-to-leaf hydraulic conductance and water use in five-year-old *Eucalyptus grandis* × *Eucalyptus urophylla* trees to explore whether a constant water use per unit leaf area is valid for this widely planted species in southern China. To accomplish his goal, an analysis based on the relationship between whole-tree water use and leaf area was performed in both the wet and dry seasons. The focal point of plant water use, i.e., the sensitivity of canopy stomatal conductance to the vapor pressure deficit, was explicitly investigated to evaluate the environmental control on water loss. Finally, the seasonal changes in canopy stomatal conductance and hydraulic conductance were used to explain characteristics of water use in the studied *Eucalyptus* plantation.

2. Materials and methods

2.1. Site description

The study was conducted in a five-year-old *E. grandis* × *E. urophylla* plantation at Huangmian Forest Farm in Liuzhou, Guangxi province, China (latitude: 24°45.8′N; longitude: 109°53.6′E; altitude: 226 m) in July and October 2012 and January and April 2013. The area is located in the transitional zone from China's low subtropics to tropics, which is characterized by a monsoon climate. Annual rainfall varies from 1750 mm to 2000 mm and is seasonally unevenly distributed; most precipitation falls between April and August. The mean annual temperature is approximately 21 °C; the minimum and maximum mean monthly temperatures are approximately 10 °C in January and 29 °C in July, respectively. A 400-m^2 experimental plot was established in the plantation on a steep northwest-facing slope of 28° for long-term ecological research. The plot density was 1425 trees per hectare, which were planted in a soil of heavy loam and a pH of 3.5; the organic content and total nitrogen content of the soil 2.8% and 0.1%, respectively. The understory vegetation, which primarily included *Miscanthus floridulus* and *Rhus chinensis*, was less developed. A 23.5-m-high tower with a horizontal area of 2 m × 2 m was constructed inside the experimental plot to provide an anchor station to mount various environmental sensors (described below) and as a platform for leaf water potential measurements. During the measurement period, the sampled trees were averaged to be approximately 11.5 m high. The mean leaf area index was estimated to be 1.8 m^2 m^{-2}. Moreover, the maximum photosynthetically active radiation (*PAR*) and the average soil volumetric water content were 1552.6 (±167.8) μmol m^{-2} s^{-1} and 0.32 (±0.03) m^3 m^{-3}, respectively.

2.2. Monitoring of environmental factors and leaf area index

The soil volumetric water content at a depth of 30 cm was monitored using a SM300 sensor (Delta-T Devices, Ltd., Cambridge, UK). A SKP215 quantum sensor (Sky Instruments Ltd., Powys, U.K.), a wind speed sensor (AN4-05, Casella, Ltd., UK) and an AT2&RHT2 sensor (Delta-T Devices, Ltd., Cambridge, UK) were mounted over the tower for monitoring *PAR*, wind speed and both air temperature and relative humidity, respectively. Environmental factors were sampled every 30 s; their 10-min means were recorded in a data logger (DL2e, Delta-T Devices, Ltd., Cambridge, UK). The vapor pressure deficit (*VPD*) was calculated from the measured air temperature and air relative humidity as follows (Campbell and Norman, 1998):

$$VPD = a \exp\left(\frac{bT}{(T+c)}\right)(1 - RH), \quad (1)$$

where T is the air temperature (°C), RH is the air relative humidity and a, b and c are constants set to 0.611, 17.502 and 240.97, respectively. In addition to these climatic variables, the leaf area index (LAI) was measured every month using an LAI 2000 plant canopy analyzer (Li-Cor, Inc., Lincoln, NE). We randomly captured image data using the analyzer at 10–15 sample points within the experimental plot. We subsequently calculated and recorded the average LAI values for the plantation.

2.3. Sap flux and canopy stomatal conductance

The sap flux was monitored using self-made thermal dissipation probes following Granier's prototype (1987). This type of sensor comprises two probes with a length of 20 mm and a diameter of 2.0 mm. The upper probe of the sensor contains a copper-constantan thermocouple and a heating element of constantan, which is continuously heated with a constant power of 0.2 W; the unheated lower probe serves as a temperature reference. During the field campaign, the two probes were typically inserted radially into the stem at 10–15 cm apart and 1.3 m above the ground on the northern side of a sampled tree. The probes were covered with plastic locket and insulated with aluminum film to avoid mechanical disturbance and direct solar heating. 15 trees were selected for sap flux measurements based on the distribution of tree diameters shown in Fig. 1. In addition, the characteristics of each sampled tree are also presented in Table 1. While obtaining the measurements, the voltage outputs of each pair of probes were synchronously recorded with environmental factors.