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Dry season water uptake by two dominant canopy tree species in a tropical seasonal rainforest of Xishuangbanna, SW China

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ABSTRACT

Radiation fog has been suggested as an important source of moisture in tropical seasonal rainforest of Xishuangbanna during 6 months of annual drought, yet its importance for the plants which inhabit this ecosystem is virtually unknown. We assessed patterns of water uptake by two major seasonal rainforest canopy tree species in Xishuangbanna, SW China, during two consecutive dry seasons (2005 and 2006). Stable oxygen isotope compositions of water in xylem, soil, fog, rain, and groundwater were analyzed, and soil water content and leaf water potential were measured concurrently in order to determine the proportion of water deriving from shallow soil by mature trees and from fog water by seedlings during the pronounced dry season. Our results indicated that evergreen *Gironniera subaequalis* tree appeared to be acquiring water preferentially from the upper 50 cm of the soil profile, with around 53–72% of its water from shallow soil. In contrast, brevi-deciduous *Pometia tomentosa* tree seemed to be tapping water mostly from depths greater than 60 cm or from groundwater, with about 28–46% of its water from shallow soil, suggesting that it relies predominantly on its deep taproot for water uptake. During the dry season, when fog was most frequent, 23–59% of the water used by *P. tomentosa* seedling came from fog water after it had dripped from tree foliage into the soil, indicating that fog water was an important source for seedling growth, especially at the peak of the dry season. Since both seedlings and shallow-rooted understory species require moisture and cool conditions to regenerate, it might be expected that some other tree seedlings and understory species also partially rely on fog moisture during the pronounced dry season, but further research is needed.

1. Introduction

Water is a critical resource that limits the distribution and abundance of vegetation in the world. Many species-rich tropical forests experience a prolonged dry season during which little or no rain falls and upper soil layers undergo severe drying (Jackson et al., 1995; Meinzer et al., 1999; Goldstein et al., 2008). Therefore, the distribution and accessibility of soil water greatly influences plant growth and survival (Drake and Franks, 2003). A variety of traits allow plants to persist under prolonged dry conditions, such as early flowering, leaf and stem succulence, and deep roots that access permanent water sources (Corbin et al., 2005). It also has been suggested that competition for limited water source may be minimized, and therefore species diversity maximized, by intensive spatial and temporal partitioning of resource utilization (Meinzer et al., 1999). For plants growing together in natural communities, differential use of water resources has been shown across different growth forms (Ehleringer et al., 1991; Canadell et al., 1996; Jackson et al., 1999; Schnitzer, 2005; Goldstein et al., 2008) and within similar growth forms (Thorburn et al., 1993; Field and Dawson, 1998; Meinzer et al., 1999; Pate and Dawson, 1999; Stratton et al., 2000). However, it is difficult to draw inferences about spatial partitioning of soil water in tropical forests based on direct observation of rooting patterns because of the large and intricate root biomass, high species diversity characteristic of these ecosystems, and the uncertain relationship between the presence of roots in a particular soil layer and the magnitude of their contribution to the water budget of a plant (Jackson et al., 1995; Moreira et al., 2000). The stable isotope technique has greatly facilitated the identification and separation of different water sources (rain, fog water, soil water, etc.) that might be used by plants, by comparing the isotope composition of xylem water with that of potential water sources (Sternberg and Swart, 1987; Ehleringer et al., 1991; Lin et al., 1996; Dodd et al., 1998; Dawson et al., 2002).

Water from fog has been shown to constitute a significant portion of the total hydrologic inputs in a number of terrestrial

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ecosystems (Bruijnzeel, 2001). However, few studies have quantified the degree to which vegetation relies on fog water (but see Ingraham and Matthews, 1995; Dawson, 1998; Field and Dawson, 1998; Burgess and Dawson, 2004; Corbin et al., 2005). One of the best studies is Dawson's research on coastal redwood forests in California, where 8–42% of the water obtained by redwood trees and 6–100% of the water obtained by understory species was derived from fog (Dawson, 1998).

Within the tropical seasonal rainforest of Xishuangbanna, SW China, most plants remain evergreen and continue to transpire during dry season months (November–April) when rain is sparse. Previous study (Liu et al., 2004) showed that in this forest stand the absolute average amount of annual fog water dripping was 89.4 mm, which contributes an estimated 5% of the annual rainfall, with 86% of the fog water dripping occurring in the dry season. This means fog in Xishuangbanna is of particular ecological significance, because the period of most frequent fog occurring coincide with the dry season drought. While it is reasonable to expect that plants inhabiting the tropical seasonal rainforest might use fog water and that fog plays an important role in the existence of the rainforest in this area (Cao et al., 1996), no work had been done to test if this was true and to quantify the extent to which fog water dripping is used by plants.

The objective of this study was to determine the dry season patterns of water source use for two dominant canopy tree species, *Pometia tomentosa* and *Gironniera subaequalis*, in a tropical seasonal rainforest of Xishuangbanna, by sampling the stable O isotope ratios of water in soil, fog, rain, groundwater and non-photosynthetic tissue, and measuring gravimetric soil water content and leaf water potential, during two consecutive dry seasons (2005 and 2006). Specifically, we tested the use of fog water dripping by *P. tomentosa* seedlings. We hypothesized that: (i) mature canopy trees utilize water primarily from greater depths in the soil profile, (ii) evergreen *G. subaequalis* taps deeper sources of water whereas brevi-deciduous *P. tomentosa* obtains water from shallower soil layers, and (iii) tree seedlings, whose roots are limited to the uppermost soil layer, would use much more water from fog, thus circumventing the problem of limited water supply from the uppermost soil during the dry season.

2. Materials and methods

2.1. Study site

The study was conducted at a tropical seasonal rainforest site (21°55′39′N, 101°15′55″E, 750 m a.s.l.) in Menglun town of Xishuangbanna in southwestern China. This site is located on a small flat area between two hills extending from east to west, and is a permanent plot (dominated by *P. tomentosa* and *Terminalia myriocarpa*) dedicated to the long-term ecological research managed by the Tropical Rainforest Ecosystem Station, the Chinese Academy of Sciences. This type of forest is primarily formed in wet valleys, lowlands and on low hills where heavy radiation fogs frequently occur (Cao et al., 1996). A stream (about 1 m wide) winds through the study site. Slope to the south and north of the site is about 15°. The soil under the forest is yellow a latosol developed from purple sandstone. This forest is a kind of tropical rainforest, which, however, differs from lowland tropical rainforest in that some of its tree species are deciduous under the monsoon climate, although they do not shed leaves in the same season. More detailed information about the forest is provided by Cao et al. (1996).

The Hengdwan Mountains to the north of the region act as a major barrier keeping out cold air coming from the north in the winter. Between May and October (rainy season), the tropical Southwest Monsoon from the Indian Ocean delivers about 85 percent of the annual rainfall, whereas the dry and cold air of the southern edges of the subtropical jet streams dominates the climate between November and April (dry season). The dry season includes a foggy sub-season from November to February, which is characterized by highest frequency of radiation fogs during the night and morning, and a hot sub-season from March to April, which is characterized by dry and hot weather during the afternoon and with radiation fogs during the morning only (Fig. 1B). Thus, radiation fogs occur nearly every day from November to April and are heaviest from midnight (23:00–02:00) until mid-morning (09:00–11:00) when the daily temperature difference is greatest. This area has fog about 37% of the time during the dry season period, with a maximum of 46% during foggy season (Liu et al., 2004).

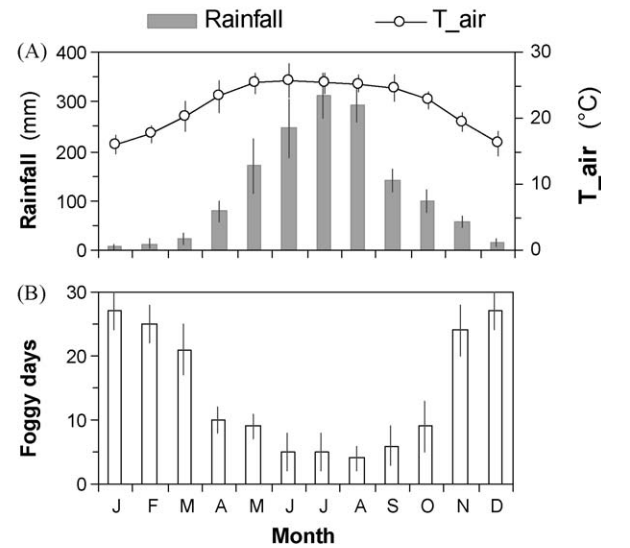

Fig. 1. Average monthly rainfall and air temperature (A), and foggy days (B) at a weather station nearby the experimental site. Each vertical bar represents an average (±1 SE) for that month calculated from records during 1965–2004 for rainfall and temperature, and during 1998–2004 for foggy days.

Long-term climate records as measured at a nearby weather station 5 km southeast from the study site in the past 40 years shows that the mean annual air temperature is 21.7 °C with a maximum monthly temperature of 25.7 °C for the hottest month (June) and a monthly minimum of 15.9 °C for the coldest month (January). Temperatures exceeding 38 °C often occur during March and April, and are always associated with a low relative humidity (less than 40%). The mean annual rainfall is 1487 mm, of which 87% occurs in the rainy season vs. 13% in the pronounced 6-month dry season (Fig. 1A). Class A pan annual evaporation varies between 1000 and 1200 mm. The mean monthly relative humidity is 87%. The mean annual wind speed is 0.7 m s^{-1} (Liu et al., 2004).

2.2. Water, vegetation, and soil sampling

Water samples for isotope analysis were collected from fog water dripping, rain, groundwater, plant xylem water and soil water. Six v-shape troughs (0.3 m × 2.0 m), each connected to a plastic bottle, were mounted 0.7 m above the forest floor and were placed in a random pattern to collect fog water dripping from the canopy. Fog water dripping sampling was performed weekly at predawn, at or near the peak of a fog water dripping event, but before isotopic fractionation had occurred from re-evaporation (Dawson, 1998). During the dry season, only 10% of the annual rainfall occurs from relatively few storms, and days with night rain generally do not have radiation fog the following morning (Liu et al., 2004). Hence, water collected by the troughs comes from fog water dripping only. Three hand-dug wells were installed near the