Journal of Hydrology 515 (2014) 81–89

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Tropical tree water use under seasonal waterlogging and drought in central Cambodia

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ARTICLE INFO

Article history:
Received 8 October 2012
Received in revised form 28 February 2014
Accepted 20 April 2014
Available online 26 April 2014
This manuscript was handled by Konstantine P. Georgakakos, Editor-in-Chief, with the assistance of David J. Gochis, Associate Editor

Keywords:
Flooding
Ground water
Inter-species comparison
Monsoon Asia
Sap flux
Soil drought

SUMMARY

In central Cambodia, rapid growing non-endemic species are planted for future timber production. However, less is understood about the impact of the introduction of non-endemic species on the transpiration characteristics of the forest, which has been composed of native species that adapted to the highly seasonal environments. Sap flux of two native and one non-endemic tree species in central Cambodia was measured to reveal its seasonal trends and variability in the Monsoon Asia region. Measurements were carried out in a 10- to 15-year-old forest in the dry and rainy seasons that were defined by differing rainfall patterns. The seasonal trend in depth to water table differed from that of rainfall; groundwater table depth reached zero late in the rainy season and increased gradually after the onset of the dry season. The ratio of sap flux to an equilibrium evaporation condition of the native species, Popel (*Shorea roxburghii*), showed a sharp decline at the end of the dry season, whereas that of a non-endemic species, eucalyptus (*Eucalyptus camaldulensis*), decreased in the mid rainy season while Tbeng (*Dipterocarpus obtusifolius*) did not show a clear trend. The ratio of sap flux to an equilibrium evaporation was negatively correlated with the depth to water table in Popel, but was positively correlated in eucalyptus, possibly because of the negative effects of flooding. In addition to the large seasonal variation, intra-species variation in sap flux was also large and was a major controlling factor for tree-level water uptake at this young forest site in both dry and rainy seasons. In conclusion, the transpiration characteristics of this forest were species-specific and were controlled more by the fluctuating depths to groundwater rather than the onset of the rainy/dry seasons defined by rainfall events.

1. Introduction

Monsoon Asia experiences seasons of contrasting precipitation, i.e., a rainy season and a dry season with long periods of dry days without rain. Seasonal trends in transpiration rate are thought to differ among trees and sites because of the site-specific environmental conditions (Tanaka et al., 2003, 2004, 2008) and species-specific ecophysiological traits (Kelliher et al., 1995; Eamus et al., 2001; O'Grady et al., 2006, 2009), which have evolved to minimize the risk of excessive water loss and physiological damage during the dry season (e.g., Law et al., 2001; McDowell et al., 2008). Transpiration and its relationship with species and environmental conditions has been intensively investigated in seasonally drought-affected regions owing to the possible threat to local water resources from plantations of fast-growing species (Calder et al., 1993; Hornbeck et al., 1993; Mielke et al., 2000; Bruijnzeel, 2004; Whitehead and Beadle, 2004).

Transpiration in the dry season is strongly influenced by the trees' access to the water source deep underground (Pinker et al.,

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http://dx.doi.org/10.1016/j.jhydrol.2014.04.049
0022-1694/

1980; Tanaka et al., 2004; Kume et al., 2007). If trees have non-limiting water access in the dry season (Meinzer et al., 1999; Eamus et al., 2000; Hutley et al., 2000; Prior et al., 2004; Zeppel et al., 2004; Cleverly et al., 2006; Fisher et al., 2006; O'Grady et al., 2006, 2009; Pfautsch et al., 2011), the transpiration rate is not reduced in the mid dry season and reaches the annual maximum under the highest atmospheric evaporative demand in the dry season (Tanaka et al., 2003). However, access to groundwater does not ensure unlimited water use (Teskey and Sheriff, 1996; Franco, 1998; Meinzer et al., 1999; Leuning et al., 2005). On the Indochina Peninsula, the relationship between transpiration and tree access to groundwater sources was investigated in the montane region of Thailand (Tanaka et al., 2004), where appreciable base flow conditions are observed in the stream even in the mid dry season and the deep soils offer access to water for overlying trees (Tanaka et al., 2003, 2004). If a given tree species introduced to or removed from a stand has higher water uptake than other stand species of similar size, changes in forest species composition due to afforestation or logging could cause changes in stand-level transpiration. Similarly, if the introduced species reduces its transpiration in dry periods while other species do not, stand-level transpiration could be influenced by changes in species composition. In the central Cambodia plain information on deep soil water sources is lacking and, correspondingly, knowledge of the influence of soil water variations on tree transpiration is limited. Therefore, *in situ* measurements are required for the evaluation of forest transpiration in this region.

In this study, we measured the atmospheric evaporative demand (equilibrium evaporation, E_{eq}, Table 1), soil water environment (soil water content and depth to water table) and sap flux of three tree species in the dry and rainy seasons in central Cambodia. The objective of the study was to address the following three questions. First, what are the seasonal trends in soil water environment, precipitation and sap flux? Second, does sap flux decline in the dry season because of soil drought or simply track the seasonal trends of evaporative demand? Third, are there inter-species differences in the seasonal trends of sap flux in response to the variable environment that reflect species-specific ecophysiological traits?

2. Materials and methods

2.1. Study site

The study was carried out at the Svay Bakav water cycle study site (11°59′20″N, 104°44′27″E), Kampong Chhnang province, Cambodia. In March 2008, the site was located in a reforested area, which was established on heavily degraded land in 1998. The Cambodian government designated the area as 'community forest', which is managed by the villagers for the purpose of forest conservation. Community forests are used by villagers for the production of non-timber forest products and timber cutting is forbidden.

The forest is composed of 10 woody species, with basal area 8.62 m^2 ha^{-1} and mean tree height 10.8 m. We studied two native species, Tbeng (*Dipterocarpus obtusifolius* Teijsm. ex Miq.) and Popel (*Shorea roxburghii* G.Don.), and one artificially introduced non-endemic species, eucalyptus (*Eucalyptus camaldulensis* Dehnh.), which accounted for 19.8%, 27.7% and 13.4% of the total basal area of the stand, respectively. These species are evergreen broadleaved trees according to the observations by the villagers and Williams et al. (2008). Litter fall data showed a peak in leaf fall occurred in February to April. However, a decline in leaf area index (LAI) in these months was not detected by the periodic LAI monitoring (Fig. 1e). For eucalyptus, Popel and Tbeng, seven trees of each species were selected for sap flow measurements (Table 2). An additional non-endemic species, acacia (*Acacia auriculiformis* A.Cunn. ex Benth.), was also monitored. However, because of its narrow sapwood area, sap flux was not successfully measured and hence was not included in our analysis.

The climate at the study site is a typical Monsoon Asian climate (Tanaka et al., 2008), with a distinct dry season for 4–5 months (from the end of November to early–mid April) and a rainy season (from the end of April to November), in which nearly 90% of the annual precipitation falls. The annual precipitation in this region is 1700–1800 mm and the annual average air temperature is 23.7°, which was measured at a weather station 23 km east of the study site without major topographical changes between them (SCW, 2006). In this study site, the daytime air temperature reaches the annual maximum in March and April (33.7 ± 0.7 °C for the hottest months in 2008–2011), and the annual minimum in December and January (29.1 ± 0.9 °C for the coldest months in 2008–2011). The soil of this region is a red-yellow podzol (SCW, 2006). In the 0–3 m depth at the study site, the soil is a sandy soil with less silt and clay soil.

A weather station for the study site was established in an open site in April 2008 equipped with a pyranometer (LP PYRA 03, Delta Ohm, Padua, Italy), photosynthetically active radiation (PAR) sensor (PAR-02, Prede Co., Ltd., Tokyo, Japan), rainfall gauge (TK-1, Takeda Keiki Co., Ltd., Tokyo, Japan) and air temperature–humidity sensors (HMP45D, Vaisala, Helsinki, Finland). An anemometer (Model 05305, R.M. Young, Traverse City, MI, USA) monitored wind speed and direction. Volumetric soil water content (θ_{soil}) was monitored using time domain reflectometry (TDR) sensors (ThetaProbe ML2x, Delta-T Devices, Cambridge, UK), which were installed at soil depths of 10, 20, 80 and 100 cm. A groundwater-level meter (HM-900-02-10, Sensez Co., Ltd., Tokyo, Japan) was installed in an observation well. Sensors were connected to a data logger (CR1000, Campbell Scientific, Logan, UT, USA), which collected data every 10 s. Averages were recorded at 10 min intervals except for rainfall, which was recorded as pulse counts.

LAI (m^2 m^{-2}) was periodically measured for each tree selected for sap flow measurements from March 2009 at 3- to 4-month intervals using a fish-eye lens (FC-E8, Nikon Corporation, Tokyo, Japan) attached to a digital camera (CoolPix 990, Nikon Corporation). One to three hemispherical photographs were taken at fixed points below the canopy of each tree and were used for calculation of LAI with HemiView canopy analysis software version 2.1 (Delta-T Devices, Cambridge, UK). Because the stand is a mixture of several species, the calculated LAI of each tree represents the LAI of the tree and the surrounding overstory trees, except for Tbeng, which formed a relatively monospecific stand.

Because of technical problems, monitoring of rainfall from April to October 2010 was not successful (Fig. 1). We could not obtain data for depth to water table from July 2008 to April 2009, and soil water content sensors failed periodically.

Table 1
List of abbreviations.

Abbreviations	Unit	
A_s	m^2	Sapwood area
dbh	cm	Diameter at breast height
ΔT	°C	Temperature difference between heater and reference sensors
E_{eq}	mm day^{-1}	Equilibrium evaporation
F_d	g m^{-2} s^{-1}	Sap flux measured by a sap flux sensor
J_s	mm day^{-1}	Sap flux weighted by the sapwood area
LAI	m^2 m^{-2}	Leaf area index
PAR	μmol m^{-2} s^{-1}	Photo synthetically active radiation
Q_{soil}		Volumetric soil water content
R_n	MJ m^{-2} day^{-1}	Net radiation
SLA	m^2 g^{-1}	Specific leaf area
VPD	kPa	Atmospheric vapor pressure deficit