Forest Ecology and Management 397 (2017) 67–77

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Tree soil water uptake and transpiration in mono-cultural and jungle rubber stands of Sumatra

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ARTICLE INFO

Article history:
Received 24 March 2017
Received in revised form 19 April 2017
Accepted 22 April 2017
Available online 3 May 2017

Keywords:
Competition
Ecohydrology
Hevea brasiliensis
Poly-cultures
Resource partitioning
Sap flux
Stable isotopes

ABSTRACT

Rubber tree mono-cultural plantations are expanding. Also, there is an increasing search for 'green' rubber production. Rubber tree cultivation in stands with admixed, spontaneously established native trees, referred to as jungle rubber, has a long tradition on Sumatra. For rubber tree monocultures on mainland Asia, concerns have been raised because of potentially very high tree transpiration rates. The objectives of our study were to analyze tree water use rates and tree soil water uptake depths in mono-cultural and jungle rubber stands with a focus on the role of tree diameter. Sap flux measurements suggest similar water use rates for rubber trees in the two cultivation systems. Stand-level transpiration in jungle rubber was 27% higher than in rubber monocultures, which was related to higher stand densities in jungle rubber stands. A water stable isotope ($\delta^{18}O$ and δD) approach suggests different soil water uptake depths for the rubber trees in the two cultivation systems. In a relatively dry period, the main tree water uptake in the monoculture was relatively close to the soil surface, whereas rubber trees in jungle rubber stands mainly took up water from deeper soil strata; here the native trees had their main uptake depth relatively close to the soil surface. This pattern indicates plasticity in rubber tree water uptake and points to competitive displacement. Across rubber trees in both cultivation systems and also among the native trees, there was a clear relationship between tree diameter and soil water uptake depth: bigger trees tended to take up soil water closer to the soil surface. Diameter and density regulation by thinning of big native trees thus appears as a potential management option for influencing water uptake in jungle rubber stands in favor of rubber trees.

1. Introduction

Rubber tree (*Hevea brasiliensis* Müll. Arg.) plantations are widespread in Asia and there is a tendency towards further expansion (Fox et al., 2012; FAO, 2016). The predominant mono-cultural rubber plantations are however associated with a relatively low biodiversity and shifts in ecosystem services (Warren-Thomas et al., 2015; Hu et al., 2008; Kennedy et al., 2017). One potential way of reconciling environmental and latex production needs could be the cultivation of rubber trees in mixed cropping systems (van Noordwijk et al., 2006, 2012; Beukema et al., 2007; Ziegler et al., 2009; Villamor et al., 2014; Warren-Thomas et al., 2015; Kennedy et al., 2017).

In rubber monoculture cultivation, the integrity of the hydrological cycle may be of concern as very high evapotranspiration rates were reported from the Asian mainland based on eddy covariance measurements (Tan et al., 2011; Giambelluca et al., 2016). In contrast to this, substantially lower transpiration rates were found in smallholder plantations in the Sumatran lowlands based on the application of a sap flux method; potential influences of differences in methods, management and climate between the studies on Sumatra and the mainland were discussed in this context (Niu et al., submitted for publication). Compared to forested areas, substantially reduced (evapo)transpiration from transformation systems such as rubber plantations can have potentially severe local, regional and global climatic and hydrological consequences (see review in Ellison et al., 2017). One example are reduced regional precipitation patterns after large-scale deforestation, induced by a disturbance of the cycle of 'recycled moisture' through continuous re-precipitation and re-evapotranspiration (Ellison et al., 2017; Aragão, 2012).

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http://dx.doi.org/10.1016/j.foreco.2017.04.032
0378-1127/

The previously mentioned study in Sumatra also pointed to a strong increase of rubber tree water use with increasing tree diameter among relatively young, up to eight year-old plantations (Niu et al., submitted for publication). For mixed rubber cultivations systems, we are currently not aware of any published studies on transpiration and tree water use. In general, it is not unlikely that mixed stands have higher stand transpiration rates than monocultures (Forrester et al., 2010). A such, mixed stands of *Eucalyptus globulus* and *Acacia mearnsii* in Australia had higher transpiration rates than the respective monocultures; this reflected generally larger tree sizes in mixtures (Forrester, 2015). Likewise, in a Panamanian experimental plantation, increasing tree diversity enhanced stand level transpiration (Kunert et al., 2012). Among the possible explanations for higher transpiration in mixed stands is complementarity in resource uptake, which e.g. has been demonstrated for the mentioned stands in Panama with a water stable isotope (δ^{18}O and δD) approach (Schwendenmann et al., 2015).

There are studies from China applying such an approach in rubber tree mixed cultivation systems. In mixture with *Flemingia macrophylla* rubber trees took up water near the soil surface in the rainy season and from deeper soil strata in the dry period (Wu et al., 2016a). In the dry period rubber trees took up water from lower layers than the *F. macrophylla*, which was interpreted as an effect of competition. Plasticity in water uptake depths and competitive displacement of rubber tree water uptake was also indicated in an intercropping experiment with tea, coffee and cacao plants (Wu et al., 2016b). Reported effects of competition between rubber trees and admixed *Acacia mangium* trees also included differences in water potential in relatively dry periods, which may lead to an allocation of water in favor of *A. mangium* (Khasanah et al., 2006). However, the studied rubber agroforestry cultivation systems (tea, coffee, cacao and *Acacia*) are intensive production systems, while an approach towards 'greener' rubber latex production would probably involve the integration of native tree species (Tomich et al., 1998; van Noordwijk et al., 2012); this would introduce a greater variability in plant size. Various previous isotope studies on soil water uptake partitioning have found influences of tree size on water uptake depth (Meinzer et al., 1999; Meißner et al., 2012; Hombegowda et al., submitted for publication).

Rubber cultivation in mixed stands with native trees is by far not a modern invention and likely dates back several centuries. In its native region, rubber trees occur dispersed as one of the many tree species in the Amazonian lowland rainforest (Porro et al., 2012). On Sumatra, Indonesia jungle rubber cultivation has a long-standing tradition. Smallholders planted rubber trees amid native tree species that naturally regenerated after slashing and burning rainforest (Gouyon et al., 1993). It was a widespread land-use system in the lowlands of Jambi, Sumatra until the mid-20th century (Gouyon et al., 1993; Joshi et al., 2002; van Noordwijk et al., 2012). Today, jungle rubber stands are often replaced by oil palm or rubber mono-cultural plantations (Williams et al., 2001; Drescher et al., 2016). Nonetheless, such stands still exist; they can be considered models of 'green' rubber production.

Our study was carried out in the lowlands of Sumatra in the province of Jambi, where in remote rural areas rubber tree cultivation is a dominant land use. Today, rubber tree cultivation mostly has the form of mono-cultural plantations, but some jungle rubber stands can still be found. The objectives of our study were to compare tree water use rates and tree soil water uptake depths between mono-cultural and mixed jungle rubber stands, with a particular focus on the role of tree diameter. We focused on stands with a relatively similar age structure, i.e. 'mature', commercially productive rubber monoculture and jungle rubber stands, to minimize additional variability in water use characteristics as induced by changing stand characteristics over the course of stand development as e.g. analyzed by Niu et al. (submitted for publication) for rubber monocultures.

2. Methods

2.1. Study area and plots

Our study was carried out in the lowlands of Jambi province, Sumatra, Indonesia. In the past, the lowlands of Jambi province were dominated by forest and jungle rubber but in recent decades monoculture plantations of oil palm and rubber trees expanded. Average annual precipitation in Jambi's lowlands was 2235 mm yr^{-1} and the mean annual temperature was 27 °C (Drescher et al., 2016). The study was implemented in the Harapan landscape as part of the EFForTS project (Drescher et al., 2016,

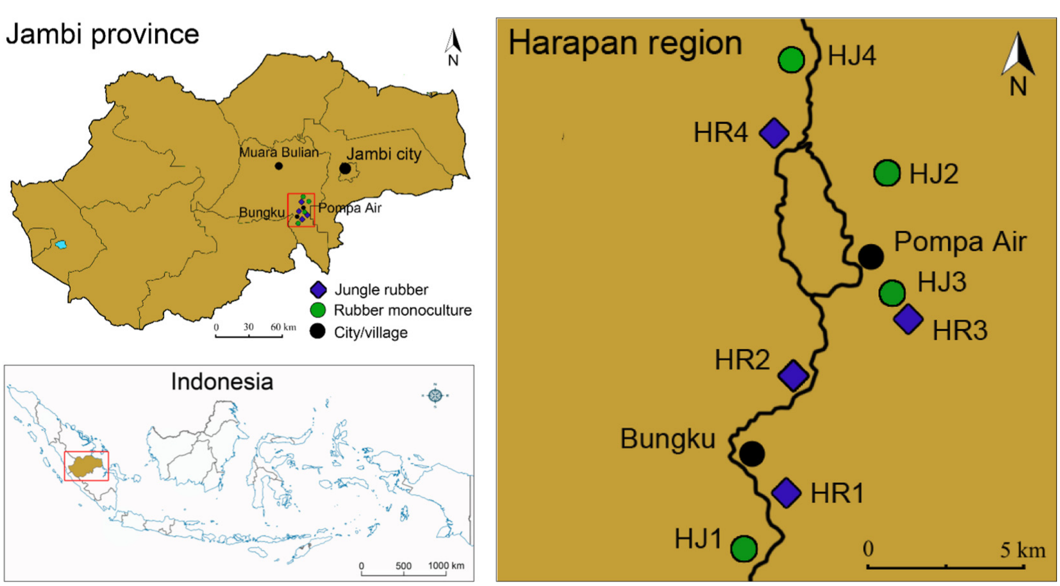

Fig. 1. The study region in Jambi province, Indonesia. The study was conducted in the Harapan region and consists of four plots each in rubber monoculture (HR) and jungle rubber (HJ) stands.