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Water use characteristics of a bamboo species (*Bambusa blumeana*) in the Philippines

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ABSTRACT

We studied water use in a common bamboo species (*Bambusa blumeana* J.A. and J.H. Schultes) in the Philippines with the aim to (1) estimate bamboo water use and its dependence on environmental factors, (2) evaluate internal water storage and water dynamics and (3) compare water use characteristics of this bamboo species with those of co-occurring tree species. Two thermal sap flow methods were applied and complemented with a deuterium tracing experiment. Sap flow measured using the stem heat balance method (SHB) was in agreement with simultaneous flow measurements from thermal dissipation probes (TDP) which were used for long term measurements in this study. Maximal sap flux densities measured at the culm base using the TDP method were up to 25.7 g cm^{-2} h^{-1}, but can be 2–3 times higher at other positions along the culm due to changes in the culm wall cross-section. Maximal water use rates of bamboo culms were on average 12 kg d^{-1}, corresponding to a maximal transpiration rate of 1.4 mm d^{-1} at the clump level. These values are in line with those of co-occurring tree species, but bamboo tends to limit water use more under reduced soil water availability than most co-occurring tree species. Deuterium added to the transpiration stream at the culm base travelled upwards more slowly than in trees, leading to maximal deuterium levels in the canopy at the 3rd or 6th day after labelling, whereas this was the 1st or 2nd day for trees. This may indicate higher water storage capacities in bamboo relative to its water use rates, although diurnal patterns of sap flux density did not support this interpretation.

1. Introduction

Bamboos belong to the true grasses (subfamily Bambusoideae, Poaceae) and are widely distributed in tropical to temperate zones, though the highest species diversity is encountered in the tropics. In many countries, in particular in South and South-East Asia, bamboos are an integral part of daily life, used in various traditional ways (for an overview, see Dransfield and Widjaja, 1995) and lately increasingly for industrial purposes such as pulp and paper (Hammett et al., 2001). Bamboo is also considered a key element in the sustainability of some traditional land use systems in Indonesia (Christanty et al., 1996; Parikesit et al., 2004) and has been put forward for use in land restoration efforts (Virtucio and Roxas, 2003). Bamboo also supports biodiversity as it serves as food source and habitat for diverse groups of organisms (Hyde et al., 2002; Linderman et al., 2005).

Despite the importance of bamboo, plant physiological aspects received little attention in scientific literature and plant–water relations in bamboo are no exception to this. The few available studies provide insight into how water use characteristics in bamboo species – which are perennial woody grasses – may be influenced by their plant architecture, anatomical features and phenology (Cochard et al., 1994; Kleinhenz et al., 2003; Franklin, 2005; Saha et al., 2009). Being monocotyledonous, bamboos lack secondary growth, which implies that the hydraulic system in a bamboo culm is formed during a single phase of rapid culm growth and has to remain functional over the entire lifetime of the culm (Liese and Weiner, 1996). Strategies to restore hydraulic functioning such as development of positive root pressures may therefore be a prominent feature in bamboo species (Cochard et al., 1994; Saha et al., 2009). Bamboo wood anatomy is characterised by the presence of scattered fibro-vascular bundles containing xylem in association with phloem elements and fibre strands. The dimension and density of fibro-vascular bundles varies considerably in radial direction and in function of the position along the culm (Grosser and Liese, 1974) which may influence xylem hydraulic conductivity, while at the same time a relatively high parenchyma content in the culm (50% according to Dransfield and Widjaja, 1995) may influence hydraulic capacity and water dynamics in a culm. Also, morphological features, such as the development of an adventitious

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root system, could influence water use characteristics in bamboo species.

This study presents findings for the species *Bambusa blumeana* J.A. and J.H. Schultes, which is one of the most utilised bamboo species in the Philippines. It is a sympodial species, forming dense clumps with horizontal, spiny branches growing at the lower 4 m of the culms. For a detailed description we refer to Dransfield and Widjaja (1995). Water relations in this bamboo were studied with the objective to (1) estimate bamboo water use and its dependence on environmental factors, (2) evaluate internal water storage and water dynamics and (3) compare water use characteristics of this bamboo species with those of co-occurring tree species. Two thermal methods were used to measure water use in bamboo and complemented with a deuterium tracing experiment. Findings for *B. blumeana* were analysed together with data for five co-occurring tree species that were part of a larger study (Dierick and Hölscher, 2009).

2. Methods

2.1. Study site

Field studies were conducted over a 3-month period between July and September 2007 adjacent to and in a reforestation stand on the island of Leyte, the Philippines. The climate is humid tropical with an average annual temperature of 27.5 °C and precipitation of 2753 mm y^{-1} which is distributed relatively evenly throughout the year with a drier period occurring from March to May (PAGASA, 2007). Species-rich lowland dipterocarp forests form the natural vegetation in this part of the Philippines (Langenberger, 2006), but have largely vanished due to anthropogenic disturbances.

The actual study site is located near the village Patag (10°44′10″ N, 124°48′16″ E) at the edge of the Leyte Cordillera. The reforestation stand is 0.33 ha in size and at an elevation of 40 m asl on a west facing slope with an average inclination of 35%. The soil developed on volcanic parent material and is classified as a Cambisol (Marohn, 2007). The soil can be considered slightly acidic with a pH (KCl) equal to 4.1 (Fisher, personal communication, 2008). The site is part of a pilot study on a novel reforestation approach called ‘rainforestation’ (Margraf and Milan, 1996). Formerly a coconut plantation, it was reforested in 1995 with a mixture of mostly native tree species, including several members of the Dipterocarpaceae family. Several bamboo clumps (in this case *B. blumeana*) were planted by local villagers directly adjacent to the reforestation stand.

2.2. Micrometeorological and soil moisture measurements

Micrometeorological conditions were monitored in open terrain adjacent to the study site. Air temperature (T_{air}, °C) and relative humidity (RH, %) were measured using a thermo-hygrometer with passive radiation shield (MP100A, Rotronic AG, Bassersdorf, Switzerland) and used to calculate the vapour pressure deficit (VPD, kPa). Global radiation (R_g, J m^{-2} s^{-1}) was measured using a pyranometer (SP1110, Campbell Scientific Inc., Logan, UT, USA). All sensors were installed on top of a 5-m high pole. Micrometeorological data and sap flow data (see below) were collected using three data loggers with multiplexer (CR1000 and AM16/32, Campbell Scientific Inc., Logan, UT, USA). Meteorological data were measured every 30 s and 5 min averages were stored. Volumetric soil moisture content (θ, m^3 m^{-3}) was measured at 15 min intervals using time domain reflectometry probes (CS616, Campbell Scientific Inc., Logan, UT, USA). Sensors were installed horizontally in the soil profile at depths of 10 and 40 cm at six locations distributed throughout the study site. The soil moisture probes were calibrated for a similar soil from a nearby site (village Marcos, see Dierick and Hölscher, 2009) following the procedure described by Veldkamp and O’Brien (2000). Precipitation data were taken from a weather station (PAGASA, 2007) located less than 3 km away.

2.3. Bamboo and tree selection

Water use characteristics were studied in four culms of *B. blumeana*. These were selected from two clumps growing on the lower slope at the west and south south-west boundary of the reforestation stand. From each clump, two well exposed and mature culms were selected. Characteristics of the bamboo clumps and individual culms are given in Table 1.

We compared data on bamboo with data on four native dipterocarp species (*Shorea contorta* S. Vidal, *Shorea polysperma* Merr., *Hopea malibato* Foxw., *Hopea plagata* S. Vidal) and the exotic big-leaved mahogany (*Swietenia macrophylla* King) growing in the reforestation stand. Each species was represented by five individuals. These trees were part of a larger study which compared water use characteristics across ten tree species growing in two comparable reforestation sites (Dierick and Hölscher, 2009). Well-exposed tree individuals were studied, except for *H. plagata* which occurred as small stature, partially shaded trees. For stand and species characteristics at the time of study we refer to Dierick and Hölscher (2009).

2.4. Sap flux density measurements, water use and transpiration

Sap flux density J_s (g cm^{-2} h^{-1}) in bamboo and trees was measured continuously for the duration of the field study using thermal dissipation probes (TDP) as developed by Granier (1985). For measurements of sap flux in trees a standard setup was used with two sensors of 25 mm length installed at breast height (1.3 m) at opposite sides of the stem to account for circumferential variability in sap flux densities (Dierick and Hölscher, 2009). This standard installation was not appropriate for bamboo as the wall of the culms is at most positions along the culm only 10–15 mm thick and part of the sensor would protrude into the hollow part of the culm, which is likely to lead to serious underestimation of measured sap flux densities (see Clearwater et al., 1999). It was therefore decided to install sensors in the bamboo at the third or fourth internode (about 0.35 m above ground) where the culm is solid or has only a small lumen at the centre and can thus accommodate the complete sensors (Fig. 1a). Sensors were shielded with a styrofoam box and the installation was covered with reflective foil to limit the influence of incident radiation. A plastic foil attached to the stem with sealant protected the sensors from stem flow and rainfall. Natural temperature gradients were monitored for several days to verify that they were indeed negligible (Do and Rocheteau, 2002). Sap flux sensors were sampled every 30 s and 5 min averages stored. All data from the TDP method were processed using the original calibration function (Granier, 1987) to obtain sap flux densities.

To convert sap flux densities (g cm^{-2} h^{-1}) to water use rates (g h^{-1}), the former need to be scaled by the sapwood area (cm^2). For the tree species this scaling was done by combining measured radial profiles of sap flux density with the area of the respective ring shaped stem cross-section and sap flux density in the outermost sapwood (Meinzer et al., 2005). For bamboo – where sensors cover approximately three fourth of the culm cross-section – it was assumed that sap flux density was uniformly distributed over the solid cross-section of the culm at installation height.

Measured water use rates over the complete study period were used to estimate transpiration rates. For trees, daily water use rates (kg d^{-1}) were referenced to the area of the crown projection (m^2) to obtain a transpiration rate (mm d^{-1}). In bamboo, a different approach was needed because no crown projection area can be