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Water Budget of the Surumoni Crane Site (Venezuela)

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Abstract. Since 1997, the authors have examined the main components of the water budget within a primary Amazonian rain forest in southern Venezuela at the Surumoni Crane Project site. Annual interception loss determined from the forest amounts to 17% of gross annual precipitation. Transpiration was measured for eight different tree species, using the constant-heating method. Monthly values of transpiration loss were remarkably lower compared to reports from other study sites in tropical South America. Although further analysis is needed to prove the reliability of the calculated total amounts, these data already provide valuable information about the physiological response of the trees to various environmental parameters.

Key words: water budget, transpiration, interception, Surumoni crane, Venezuela

Introduction

Partial or complete clearance of tropical rain forests affects the hydrologic cycle, at least on a regional scale. Progress in assessing the environmental impact of changes in vegetation is limited by the current lack of reliable data. Thus, in 1996, a multidisciplinary research project of the Austrian Academy of Science and the Venezuelan government was implemented in the center of the state of Amazonas in southern Venezuela (Figure 1). At the experimental site, the structure and function of the rain forest are being studied, using a mobile crane system 42 m in height.

During the first field campaign in 1996, microclimatic conditions and the entire energy balance of the forest were investigated. Results of this micrometeorological monitoring conducted within the project are being published elsewhere (Szarzynski & Anhuf in press). In summer 1997, additional measurement configurations were installed at the study site to determine the transpiration loss of several tree species, as well as the main components of the water budget. This article reports on preliminary results of the transpiration measurements and the partitioning of gross precipitation into throughfall, stem flow, and interception loss (Figure 2).

Material and Methods

The crane plot is located at 3°10′N, 65°40′W, 105 m above sea level, near the river banks of the Rio Surumoni, a small tributary of the upper Rio Orinoco. Long-term annual precipitation data are available from La Esmeralda (2700 mm a^{-1}), a small village 15 km upstream on the Orinoco and from Tama-Tama (3250 mm a^{-1}), ca. 20 km downstream from the Surumoni crane (1970–1995, Dirección de Hidrología y Meteorología, Caracas). The average annual temperature in the study area is ca. 26°C, usually with slight variations between the coolest month (25°C) and the warmest month (26.5°C), whereas a daily range of 5–10°C frequently occurs.

The following data are being collected at the Surumoni plot as part of water budget examinations:

1) Precipitation—measured using a tipping-bucket rain gauge at the crane tower 10 m above the forest canopy;
2) Throughfall—recorded by six half-tubes each of them connected with a tipping-bucket gauge;
3) Stem flow—determined by plastic collars wrapped around the trunks of trees;
4) Transpiration—calculated from sap-flow measurements, consisting of continuously heated temperature probes; and
5) Soil moisture, ground water level, and surface runoff—recorded by six subsurface sensors in three wells and by a 50° notch-weir.

Sensors were installed to measure transpiration for selected tree species representing the floristic composition of the research plot. Throughfall and stemflow were recorded within the investigated runoff-basin in the southwestern part of the plot. Groundwater and soil moisture was measured with sensors placed along the main runoff channels in the test basin. All data were stored on four 21X datalogger (Campell Scientific, U.K.), computing 10-minute averages from 30-second sampling intervals.

These data will serve to develop a physical simulation model for precipitation and runoff. A precise digital elevation model, already created

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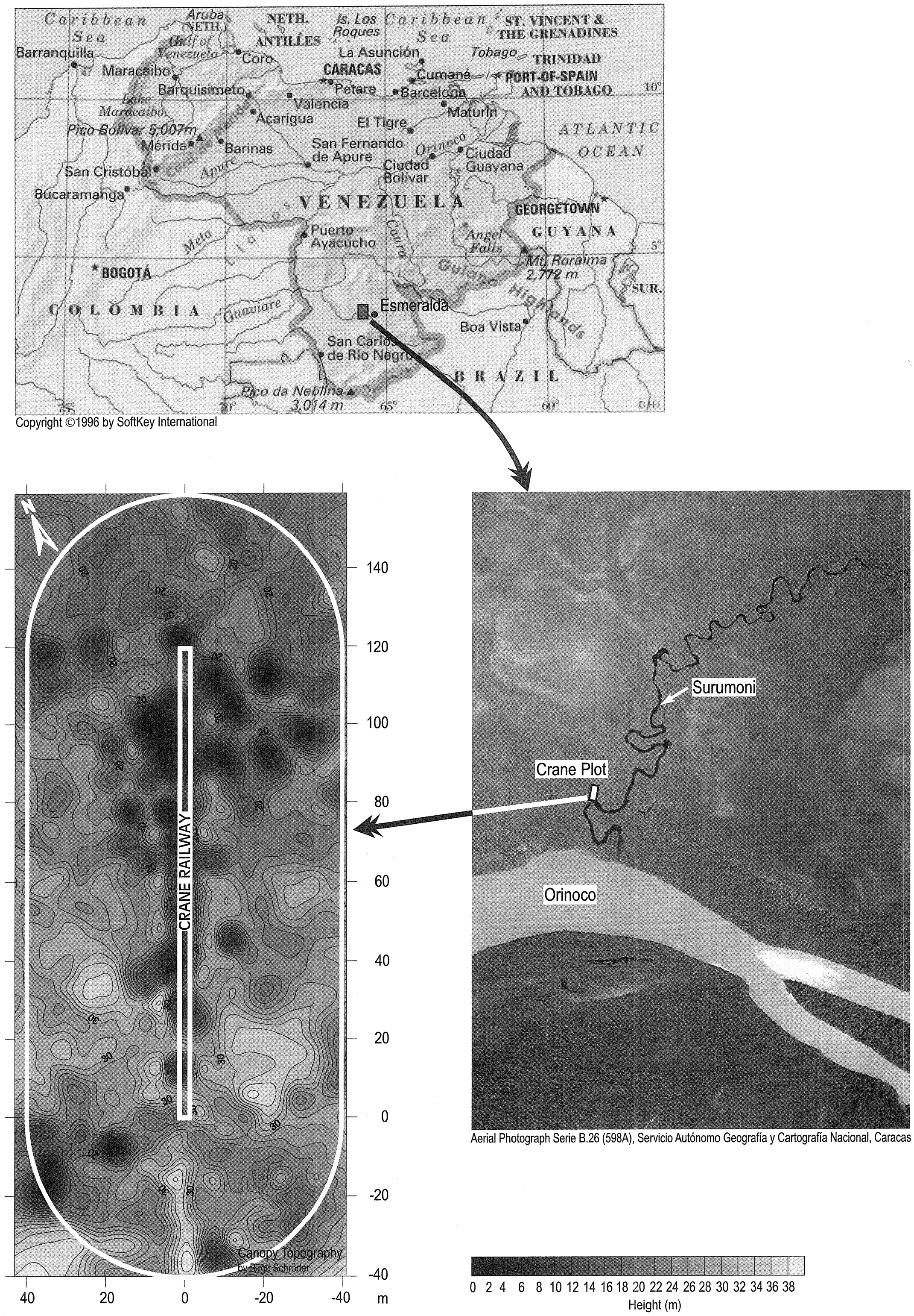

FIGURE 1. The Surumoni Crane Project research plot, Venezuela.

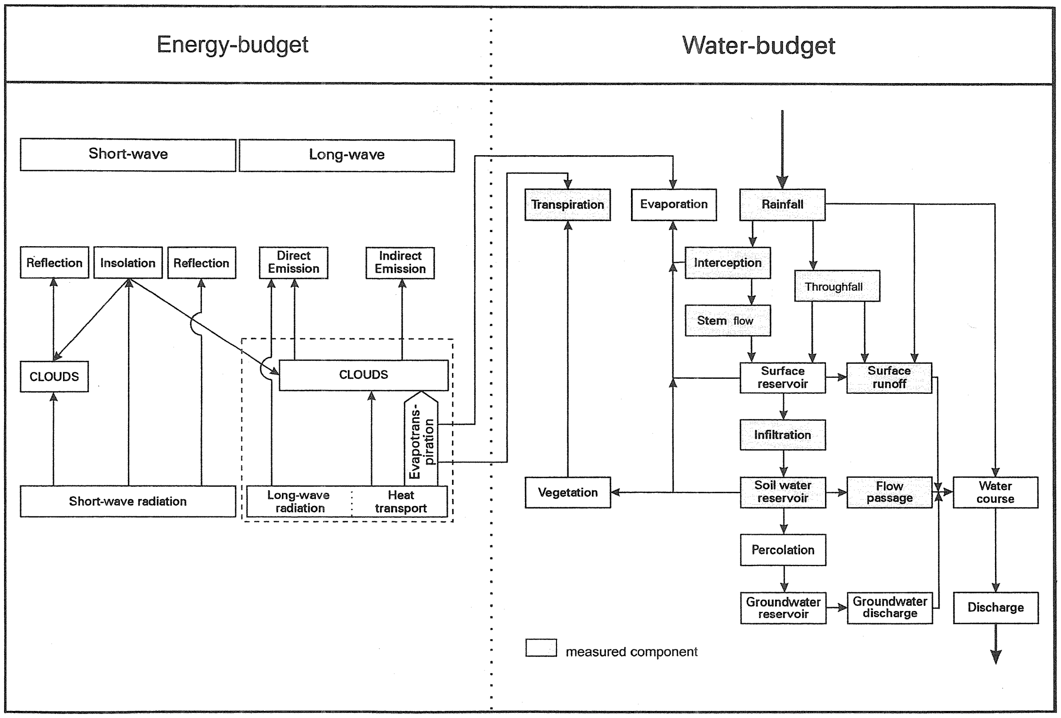

FIGURE 2. Components of the energy budget and water budget of the Surumoni study site.

for the research plot, was the basis for calculation of the hydrological model (FIGURE 3).

RESULTS

Sap Flow Measurements

Sap flux density was measured using a method developed by Granier (1985) (also see Motzer 1998). Several sap flow meters, each consisting of two temperature probes, were inserted horizontally into the sapwood of the tree trunks. The upper probe is continuously heated, and the lower one records the reference temperature of the wood. The temperature difference between the two probes is inversely correlated with the sap flux density u (kg dm^{-2} h^{-1}):

$$u = 4.28 * [(T_{max.})/(T_{actual}) - 1]^{1,231} \quad (1)$$

which represents the sap flow per unit sapwood area. ($T_{max.}$) = (T_{actual}) describes the state when the xylem flow is at its lowest. This state is usually reached during the early morning hours. (T_{actual}) is the voltage difference at the moment of measurement, by which 45 μVolt correspond to 1°C. The sapwood cross sectional area SA is calculated from the difference between the total cross sectional area and the heartwood area according to the equation:

$$SA = \pi r^2 - \pi(r - d_x)^2 \quad (2)$$

where r is the radius and d_x is the xylem depth. Sap flow meters were installed at 1.5 m height. Total sap flow F (kg h^{-1}) was calculated as the product of the sap flux density and the sapwood cross sectional area:

$$F = u\ SA \quad (3)$$

Sapwood cross-sectional area was estimated from cores, which were drilled horizontally into the trunk near the measuring probes.

Within the primary forest at the Surumoni site, eight tree species were chosen for measurements (TABLE 1). *Goupia glabra* (Celastraceae), *Qualea trichanthera* (Vochysiaceae), and *Ocotea cf amazonica* (Lauraceae), with a height of 26 m, 28.5 m, and 25 m respectively, represent the highest treetop level. A specimen of *Dialium guianense* (Caesalpiniaceae), at only 23 m high, belongs to the upper treetop stratum because of its location within a canopy depression. The chosen canopy trees are the most abundant species of the Surumoni forest. Chosen as representatives of the sub-canopy were an Arecaceae (*Oenocarpus bacaba*) and a young specimen of *Goupia glabra* (Celastraceae).

A sequence of two consecutive days (20–21 June 1997) provides a first insight into the di-

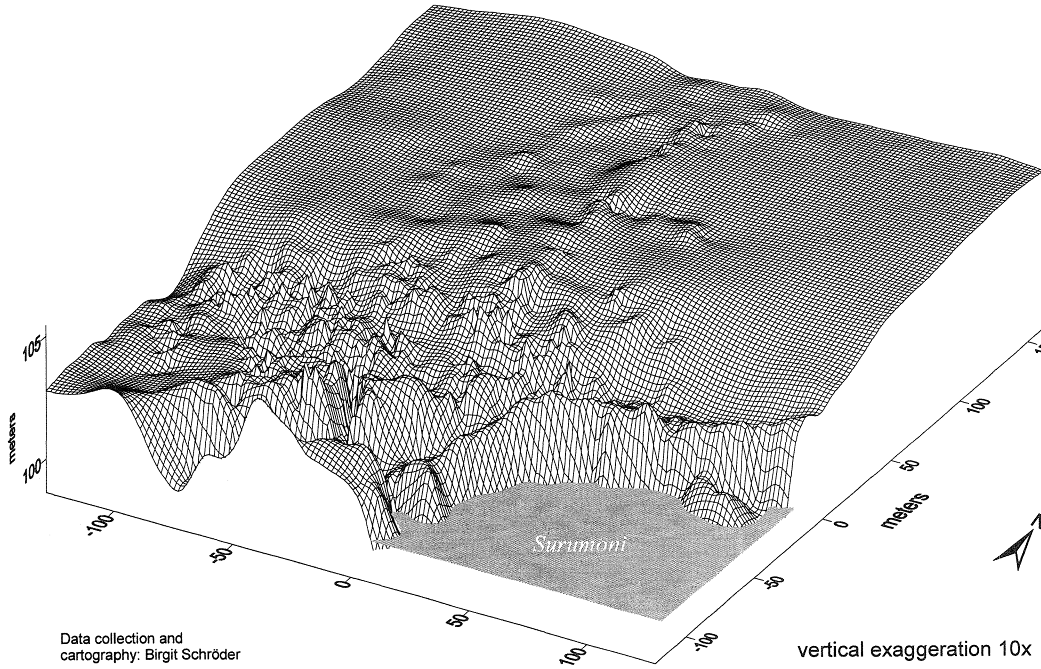

FIGURE 3. Digital elevation model (DEM) of the Surumoni study site.

urnal cycles of sap flux density (FIGURE 4). A clear day was followed by a cloudy day, during which a short convective rainstorm occurred. Sap flow usually starts about two hours after sunrise. This delay is caused by the water storage capacity of the trees and evaporation of dew occurring in the early morning hours. Subsequently, the sap flux density increases in accordance with higher atmospheric vapor pressure deficit and accelerated photosynthetically active radiation (PAR). During the midday hours, the sap flow rate is obviously reduced, although the atmospheric saturation deficit is still increasing. This reduction can be attributed to a decrease in transpiration through stomatal regulation to avoid high transpiration loss (20 June 1997 at 2 p.m.). A pronounced midday depression is recognizable, to various degrees, at all trees of the upper canopy. In contrast, trees of the sub-canopy do not usually show this stomatal response. At the start of the rain on the second day, all curves decline, indicating that transpiration had stopped, and free water was evaporating directly from the wetted leaf surfaces.

The data suggest that examined trees exhibit different physiological strategies to maintain their individual water balance. Species that tend towards hydro-instability (e.g., *Dialium guianense*) do not reduce transpiration, until soil water availability is restricted. In this situation,

TABLE 1. Trees from evergreen forest investigated at the Suromoni Crane Project site in Venezuela.

Species	Family	Height (m)	Circumference at 1.5 m (cm)	Xylem depth (cm)	Sapwood cross-sectional area (dm^2)
Goupia glabra (adult)	Celastraceae	26	212	3.2	6.462
Qualea trichanthera	Vochysiaceae	28.5	170	3.0	4.817
Dialium guianense	Caesalpiniaceae	23	90	2.0	1.674
Ocotea cf. *amazonica*	Lauraceae	25	84	3.0	2.237
Oenocarpus bacaba	Arecaceae	8.5	32	—	0.268*
Nr. 212	Myristicaceae	14	44	3.5	1.155
Goupia glabra (young)	Celastraceae	22.5	78	3.0	2.057
Nr. 206	?	16.5	32	3.5	0.735

* SA was estimated to be 30–40% (maximum) of the total cross-sectional area.

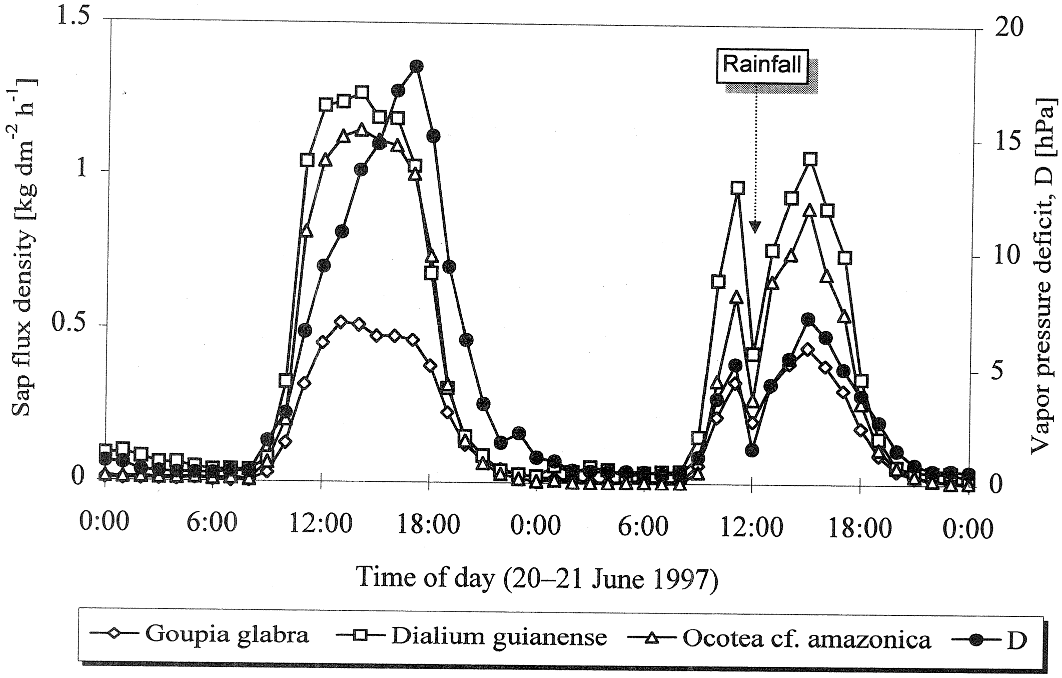

FIGURE 4. Vapor pressure deficit (D) and sap flux density for three tree species at the Surumoni study site for two consecutive days in 1997.

they are prone to adopt a more hydro-stable behavior. Species with extensive, deep-reaching roots, such as *Qualea trichanthera* (W. Morawetz pers. comm.), show relatively high transpiration intensity, for they are able to absorb a sufficient amount of water from the soil. With regard to water-balance strategies, the general behavior of sub-canopy trees is more similar. Even during the dry season, they demonstrate low transpiration rates in association with pronounced hydro-stable reactions. The cause is the higher values of humidity and lower radiation intensities within the forest, when compared to conditions of the upper canopy layer (Motzer 1998).

Highest values of daily transpiration are reached by the trees of the canopy group, for instance, *Goupia glabra* and *Qualea trichanthera* (50–60 kg/day) (FIGURE 5). Daily totals for trees of these two species growing in the understory, however, are remarkably lower; they range from 2.4 kg/day (*Oenocarpus bacaba*) to 23 kg/day (*Goupia glabra,* young). In general, canopy trees contribute 70–80% of total stand transpiration. At the Surumoni crane plot, the highest amounts of transpiration loss were recorded at the beginning of the dry season in 1997. Following that period, changes in soil water storage were responsible for a decrease in transpiration. Immediately after the first rains in March 1998, transpiration rates again increased.

Water Budget of the Forest

Since 1996, greatly variable precipitation has been observed in the study area (FIGURE 6), obviously triggered by the El Niño event of 1997–1998. With regard to interannual cycles in 1996, total precipitation amounted to 3700 mm, which reflected local floods in June and July. In 1997, gross rainfall was 2435 mm, which is 265 mm below the average annual total. Data on the water budget of the Surumoni forest, available for November 1997–September 1998, will be discussed in this section.

The gross rainfall (measured on top of the crane) recorded during this period (3100 mm) and the partition into throughfall and interception are illustrated in FIGURE 7. Measured stem flow, which only amounted to 2% of total precipitation, is not shown. The dry months, December 1997–February 1998, received 188 mm precipitation. Total throughfall was 93 mm for the same period, with the average interception loss of 51% of gross precipitation. During the months of the rainy season, April–August 1998, precipitation was measured at 2250 mm. Of this, 1956 mm reached the forest floor, which corresponds to an interception

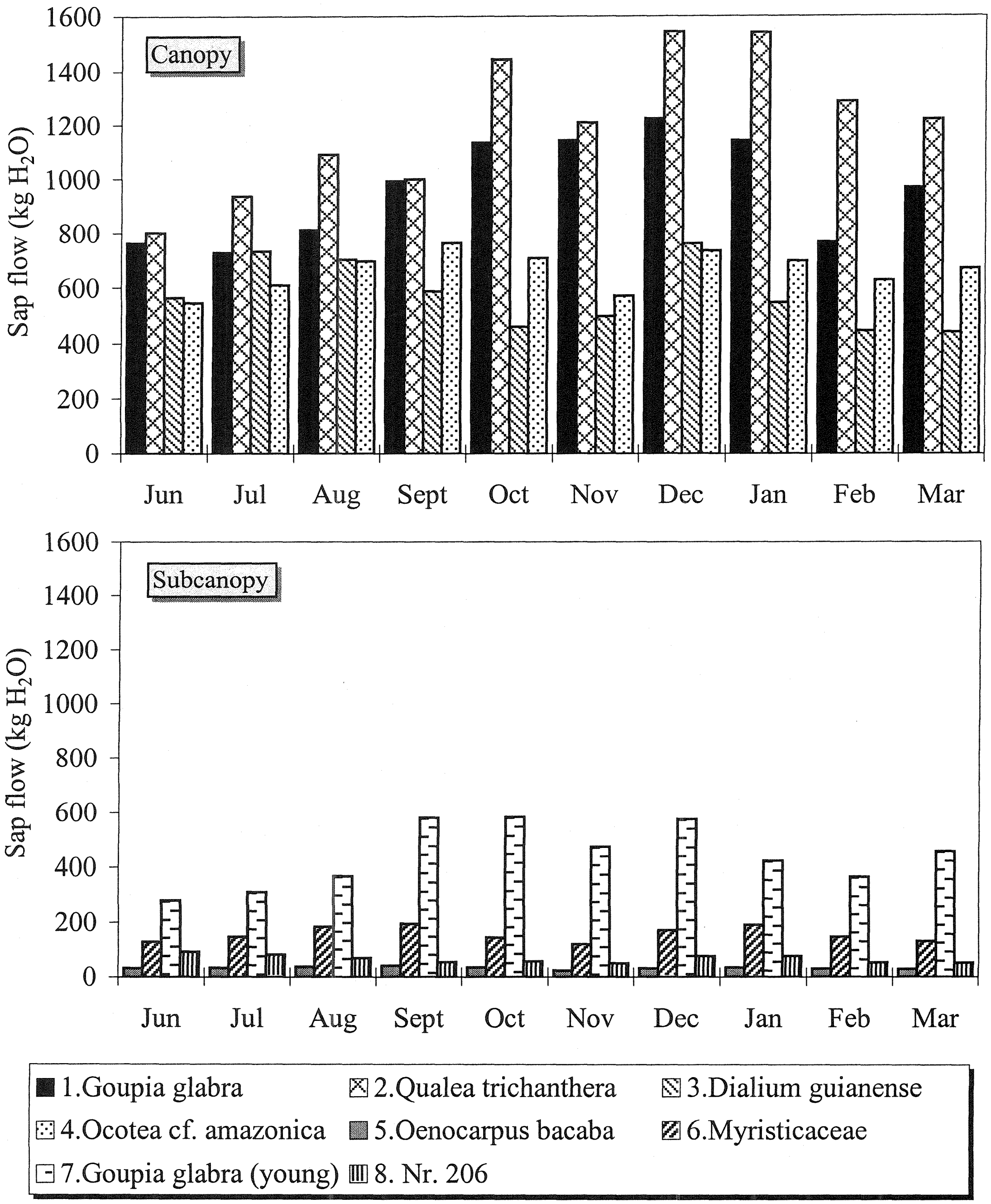

FIGURE 5. Monthly sum of transpiration (sap flow) for eight trees at the Surumoni study site, June 1997–March 1998.

loss of ca.13% (FIGURE 7). The transitional month of March exhibited 268 mm precipitation and an interception loss of 43%.

In summary, during the observed period (November 1997–September 1998), gross rainfall amounted to 3100 mm, of which 2539 mm occurred as throughfall. Average interception loss was 17%, characterized by a great monthly variability that ranged between 5% in June 1998 and 56% in January 1998.

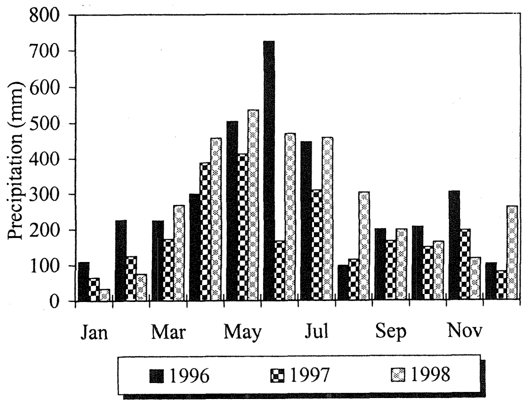

FIGURE 6. Monthly precipitation totals at the Surumoni study site, 1996–1998.

DISCUSSION

Although measurements of the main components of the water budget at the Surumoni research plot reveal an annual interception loss of 17%, this value was subject to a high monthly variability. During the dry month of January 1998, precipitation was only 34 mm. The prevailing climatic conditions—indicated by high amounts of incident solar radiation in combination with high values of air temperature and vapor pressure saturation deficit—were a prerequisite to support enhanced evaporation immediately after the canopy surface was wetted. In contrast, in June 1998, the area received ca. 470 mm of rainfall. In this situation, neither the lower amount of radiative energy nor the reduced vapor pressure deficit was sufficient to sustain great interception loss from the forest. Interestingly, the average value of 17% exceeds results reported for the Reserva Ducke forest near Manaus, Brazil, by 7% (Shuttleworth 1988). The monthly amounts of transpiration, however, distinctly range below comparable values of other authors (Granier et al. 1996, Roberts et al. 1993). Only Oren et al. (1996) found similarly low results as recorded for the Surumoni forest. Some caution is thus necessary in interpreting the Surumoni data. To explain the described discrepancy, the authors will re-inspect the sapwood cross-sectional areas of the trees under investigation. Furthermore, they are determining both leaf area index (LAI) and appropriate canopy area to evaluate whether study data might represent underestimations of the transpiration amount.

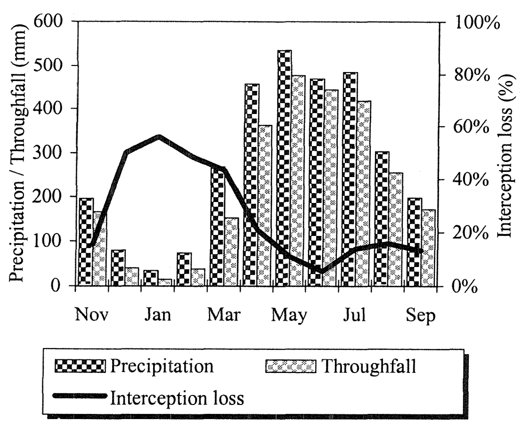

FIGURE 7. Monthly totals of precipitation, throughfall, and interception loss, November 1997–September 1998.

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