Rubber plantations act as water pumps in tropical China

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[1] Whether rubber plantations have the role of water pumps in tropical Southeast Asia is under active debate. Fifteen years (1994–2008) of paired catchments water observation data and one year paired eddy covariance water flux data in primary tropical rain forest and tropical rubber plantation was used to clarify how rubber plantation affects local water resources of Xishuangbanna, China. Both catchment water observations and direct eddy covariance estimates indicates that more water was evapotranspired from rubber plantation (1137 mm based on catchment water balance, 1125 mm based on eddy covariance) than from the rain forest (969 mm based on catchment water balance, 927 mm based on eddy covariance). Soil water storage during the rainy season is not sufficient to maintain such high evapotranspiration rates, resulting in zero flow and water shortages during the dry season in the rubber plantation. Therefore, this study supports the idea that rubber plantations act as water pumps as suggested by local inhabitants.
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1. Introduction

[2] Anthropogenic impacts on structure and function of terrestrial ecosystem have effects far beyond global climate change [*Vitousek et al.*, 1997]. These impacts are particularly prominent in developing countries. Booms of population and rapid economic development have led to environmental sacrifices in these countries. Though the ecological and environmental consequences of converting rain forest into rubber plantation are uncertain, more than 1,000,000 hectares of non-traditional rubber-growing areas have been planted in rubber to satisfy market demand in tropical southeast Asia [*Ziegler et al.*, 2009; *Mann*, 2009]. The environmental risks of this large-scale land-use change may be high. In Xishuangbanna (southwest edge of China), dry season surface water shortages, which seldom occurred previously even during the driest year, are faced by local people after several decades of rubber-tree planting [*Qiu*, 2009, 2010]. Rubber plantations were then called "water pumps". Governments, however, argue that rubber plantations exhibit similar hydrology to rain forests and will not cause water shortage, in defense of their forestry policies. Nevertheless, no observational data but only official remarks were provided to support these opinions. Here, fifteen years (1994–2008) of paired-catchment water observation data and one year of paired eddy covariance water flux data in primary rain forest and rubber plantation was used to examine how rubber plantation affects local water resources of Xishuangbanna, China.

2. Methods

[3] The observations were carried out in Menglun town of Xishuangbanna in southwestern China (21°55′39″, 101°15′55″). The tropical seasonal rain forest catchment (51.1 ha) is five km from the rubber plantation catchment (19.3 ha). Eddy-covariance flux towers were located in water catchments. Climate, stand description, catchments details, instruments of eddy covariance tower and quality control of eddy water vapor flux are presented in the auxiliary material.[1] Surface runoff was derived from water-level measurements as follows:

$$q = 0.014h^{2.5} \tag{1}$$

where q is surface runoff ($m^3\ s^{-1}$) and h is the water level (m). At an annual scale, the catchment water balance equation can be described as [*Fleischbein et al.*, 2006]:

$$P = q + ET \tag{2}$$

where P is precipitation (mm), ET is evapotranspiration (mm). Neglecting the small amount of fog and cloud water input, gauge-based rainfall is used as P. At monthly scale, the catchment water balance equation is [*Ward and Robinson*, 1990]:

$$P = q + ET + \Delta S + \Delta G + \Delta L = q + ET + F_{storage} \tag{3}$$

[4] In this study, we defined storage flux ($F_{storage}$) as the sum of the changes in soil moisture (ΔS) and ground water storage (ΔG) and leakage flux (ΔL). Eddy water vapor fluxes were calibrated for energy closure using the Bowen

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[1]Auxiliary materials are available in the HTML. doi:10.1029/2011GL050006.

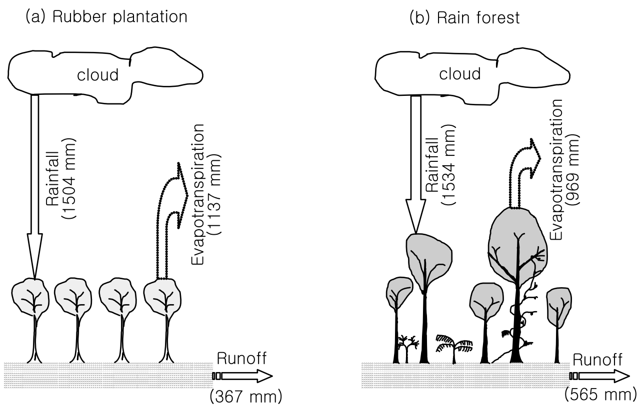

Figure 1. Comparison of annual water balance in (a) rubber plantation and (b) tropical rain forest of Xishuangbanna, China. The results are based on fifteen year (1994–2008) data.

ratio. Data gaps were filled by mean diurnal variation method with windows of 10 days.

3. Results

[5] Fifteen-year mean annual rainfall in the rubber plantation (1504 mm) was slightly lower than in the primary rain forest (1534 mm) (Figure 1). This slight difference may be connected with the temporal and spatial heterogeneity of tropical rainfall events (Figure S1). Annual runoff from rubber plantation (367 mm), however, was only 65% of that in rain forest (565 mm). Perennial runoff was observed in rain forest while zero flow frequently occurred during dry seasons in rubber plantation (Figure S2). Based on catchment water balances, more water was evapotranspired from the rubber plantation (1137 mm) than from the primary rain forest (969 mm). As direct and independent estimates, eddy covariance-based evapotranspiration were consistent with the catchment-derived values: 1125 mm in rubber plantation and 927 mm in primary tropical rain forest (Figure S3).

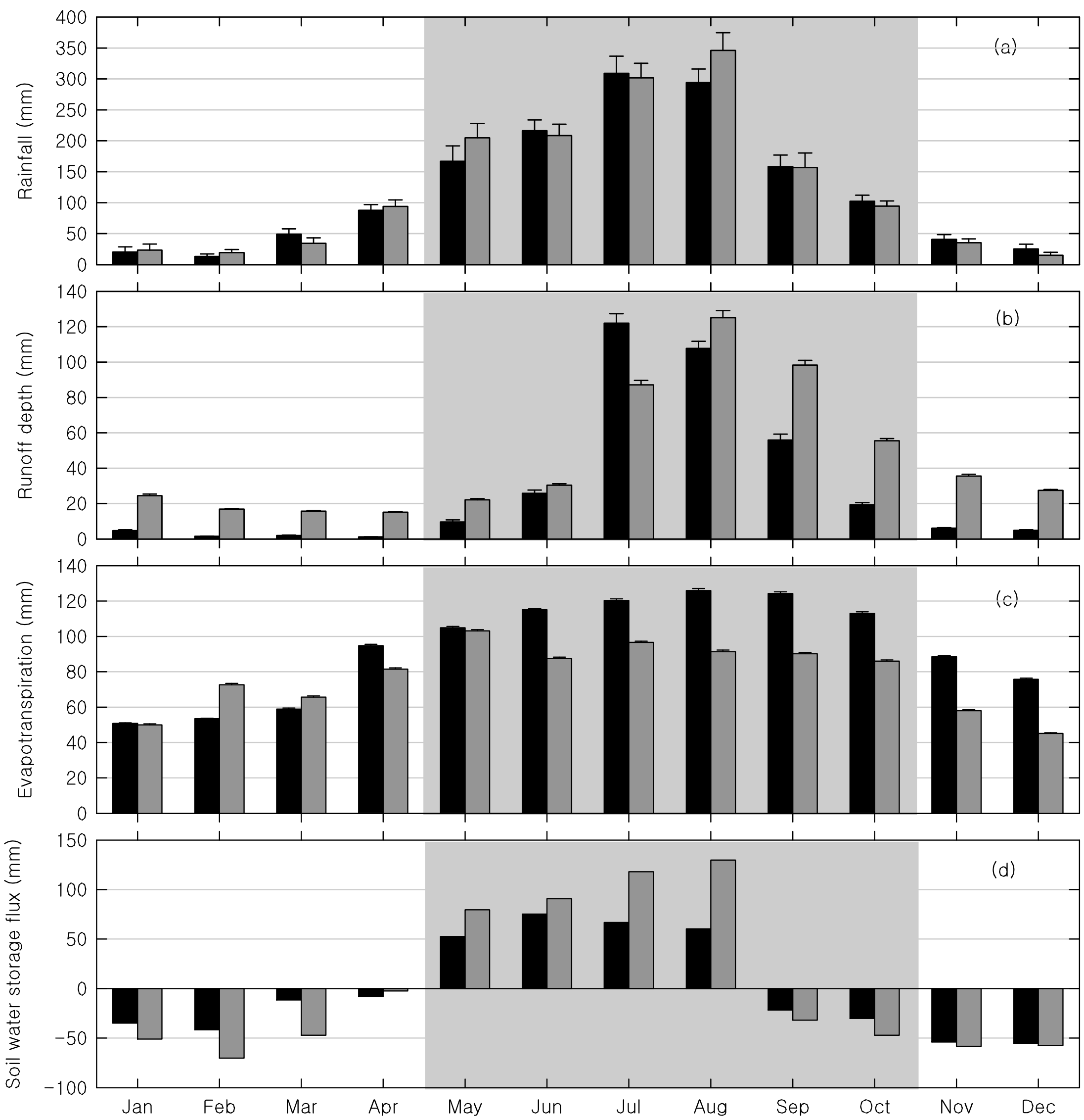

Figure 2. Monthly variation of (a) rainfall, (b) runoff depth, (c) evapotranspiration and (d) derived soil water storage flux in rubber plantation (black bar) and primary tropical seasonal rain forest (grey bar) of Xishuangbanna, China. The shaded area indicate rainy season (May to October). Error bars represent standard error.

[6] Dominated by the Indian monsoon, only 13% of rainfall occurs during the dry half year (Figure 2a). Water storage from the previous rain season was depleted during the dry season and refilled by rainfall in the following rainy season (Figure S4). Water available for plants and local people was mainly controlled by evapotranspiration and water storage during the rainy season. Evapotranspiration in the rubber plantation was larger than which in the rain forest for most months, except February and March when ecologically adaptive leaf shedding occurred (Figure 2c, subplot of Figure S3, and Figure S5). Moreover, the water storage flux (absolute value) of the rubber plantation was less than in the rain forest (Figure 2d). High water evapotranspiration demand encountered with low water storage subsequently led to reduced water yield and water shortage during the dry season. Watershed surface runoff is the main source of river flow in this period. Therefore, river levels will be lower and less water resources available for locals.

4. Discussion

[7] Because rainforest transpires more during drought, it is a bigger consumer of water compared to rubber plantation in the low-rainfall season (when human demand is likely to be high) (Figures 2 and S6). However, rain forest maintains continuous runoff during this period by using water storage from the previous rainy season (Figures 2 and S4). During the rainy seasons, the reverse is true. Rubber plantations are much bigger water consumers than native rain forests in this period (Figure 2). The rubber tree (*Hevea brasiliensis*) is an exotic species originating in the humid Amazon and has large xylem vessels to gain competitive advantages under well-watered conditions [*Ayutthaya et al.*, 2011]. By contrast, the rain forest trees studied here adapt to the seasonally dry environments through long-term evolution and are less sensitive to drought with small xylem vessels (Z.-H. Tan, unpublished data, 2010). This is the main reason why rubber trees consume more water during the rainy season and less during the dry season when compared to rain forest. Because of their sensitivity to drought, the water consumption of rubber plantations on an annual basis remains larger than that of rain forests. The rain forest also creates a cool and moist environment to reduce annual evapotranspiration (Figure S7).

5. Conclusions

[8] Both long-term catchment water observations and direct eddy covariance estimates indicate that more water was evapotranspired from rubber the plantation than from the rain forest. In the rubber plantation, water stored during the rainy season was not sufficient to maintain evapotranspiration, which led to zero flow during the dry season. These factors caused local water resource shortages. This study supports the idea that rubber plantations act as water pumps as suggested by locals. Here, only the water cycle consequences were examined for large-scale planting of rubber trees. Other important environmental issues, such as biodiversity loss, carbon release and soil erosion, should be examined by further studies.

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