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Research Paper

Soil respiration in sloping rubber plantations and tropical natural forests in Xishuangbanna, China

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ABSTRACT

Soil respiration (SR) plays an important role in the global carbon cycle. The widespread and continued conversion of tropical forests to plantations is expected to drastically alter CO_2 production in soil, with significant consequences for atmospheric concentrations of this crucial greenhouse gas. In Southeast Asia, rubber plantations are among the most widespread monoculture tree plantations. However, knowledge of how SR differs in rubber plantations compared to natural forests is scarce. In this study, surface CO_2 fluxes and soil CO_2 concentrations (at 5 cm, 10 cm, 30 cm and 70 cm depths) were measured at regular intervals over a one-year period along slopes at three sites in paired natural tropical forests and mature rubber plantations. Annual surface soil CO_2 fluxes were 15% lower in the rubber plantations than in natural forest. This difference was due to substantially lower SR during the dry season in rubber plantations compared to natural forest. During the wet season, SR did not differ significantly between rubber plantations and natural forests. In rubber plantations, soil moisture increased from lower and middle to upper slope positions, but this did not significantly impact SR. Throughout the year, net CO_2 production per unit volume in the topsoil (2.5–7.5 cm) exceeded by 2–3 orders of magnitude net CO_2 production in the subsoil (7.5–50 cm). However, CO_2 originating from 5 cm depth and below in both land cover types could only explain up to 30% of the aboveground measured CO_2 flux, indicating that > 70% of the total CO_2 respired and emitted to the atmosphere originated from the uppermost few cm of the soil. Net CO_2 production at different soil depths did not differ significantly between rubber plantations and natural forests. Our results indicate that SR characteristics in mature rubber plantation and natural forest were broadly similar, although dry season soil surface CO_2 fluxes were lower in rubber plantations. However, further information on the drivers of CO_2 production in the uppermost topsoil layers which are responsible for most CO_2 emissions is needed to understand the extent to which these results are generalisable.

1. Introduction

Soil respiration accounts for up to 80% of total terrestrial respiration and is the largest flux of CO_2 from terrestrial ecosystems to the atmosphere (Hanson et al., 2000; Raich et al., 2002). Processes in the soil that contribute to the emission of CO_2 into the atmosphere include respiration of heterotrophic and autotrophic microorganisms and roots (Hanson et al., 2000; Schlesinger and Andrews, 2000). Compared to forests in other climate zones, tropical forests have the highest soil respiration rates (Raich and Potter, 1995) but at the same time act as an important sink for CO_2 due to their high productivity (Ahlström et al., 2015). The worldwide conversion of tropical forests into agricultural land therefore has critically important consequences for the global carbon cycle (Drescher et al., 2016; Yang et al., 2016) as well as numerous other negative impacts on ecosystem services.

In Southeast Asia, large areas of rain forest have been converted into rubber plantations, which were estimated to account for 84% of total global rubber plantation area in 2012 (Ahrends et al., 2015; Warren-

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Thomas et al., 2015). Through further expansion the area of rubber monoculture plantations is predicted to reach 4.3–8.5 million ha by 2024, in order to meet the global demand for natural latex (Warren-Thomas et al., 2015). This land use conversion has significant environmental consequences such as declines in regionally important biodiversity (Warren-Thomas et al., 2015), reduced annual water discharge (Ziegler et al., 2009), and increased soil erosion (Liu et al., 2016). Regarding soil nutrient cycling, rubber plantations have been shown to reduce leaf litter input, fine root biomass, carbon stocks and soil microbial activity (de Blécourt et al., 2013; Martius et al., 2004; Pransiska et al., 2016; Sahner et al., 2015; Zhang et al., 2013; Abraham and Chudek, 2008) and therefore most likely have reduced SR in comparison to natural forests. However, the number of studies on annual SR in rubber plantations is low (Fang and Sha, 2006; Satakhun et al., 2013; Zhou et al., 2008).

Over the past 50 years, rubber has become an increasingly common crop in areas previously thought unsuitable for rubber cultivation, i.e. regions with distinct dry and wet seasons and in montane regions (at elevations above 300 masl and on slopes > 15°) (Ahrends et al., 2015; Warren-Thomas et al., 2015). In Xishuangbanna prefecture, Yunnan province, the area covered by rubber plantations increased to 22% (424,000 ha) of the total land cover in 2010 (Xu et al., 2014). Most of the rubber plantations in this area are on sloping land of up to 24° incline and 900 m elevation. Rubber plantations at higher elevations and on steeper slopes are not profitable (Ahrends et al., 2015; Yi et al., 2014). This topography causes gradients of soil physical and chemical parameters, such as soil moisture and soil organic matter distribution that in turn can result in differing soil respiration rates along the slope (Garrett and Cox, 1973; Hanson et al., 1993; Kang et al., 2003). However, only a few studies have investigated the effect of topography on soil respiration in tropical regions (Epron et al., 2006; Fang et al., 2009; Li et al., 2008; Takahashi et al., 2011; Wood and Silver, 2012) and to our knowledge no one has studied the impacts of topography on soil respiration in rubber plantations. In order to be able to upscale SR measurements from landscape to regional levels and on an annual scale, it is essential to improve our understanding of the temporal and spatial patterns of SR in complex topographic landscapes. Furthermore, land-use conversion from tropical forest to a monoculture plantation will most likely differently affect CO_2 production at different depths. It is therefore essential to analyze CO_2 production at various soil depths in these different land cover types in order to explain differences in soil CO_2 emissions that are measured aboveground.

In this study, we compared annual SR in tropical natural forests and mature rubber plantations on land converted from natural forest in Xishuangbanna, China. Furthermore, we investigated the effect of slope position (upper, middle and lower) in rubber plantations and forests. Through CO_2 concentration measurements in soil air at different soil depths we aimed to identify net CO_2 production at different depths for the two land cover types and different topographic positions.

2. Materials and methods

2.1. Study sites description

The study was conducted in the Naban River Watershed National Nature Reserve (22°04′–22°17′ N, 100°32′–100°44′ E) in the Dai Autonomous Prefecture of Xishuangbanna, Yunnan Province, China. The area has a tropical monsoon climate with distinct dry (November–April) and wet seasons (May-October). The annual mean (1960–2000) temperature is 19 °C and the annual precipitation is 1490 mm (Xu et al., 2005). Three different sites were chosen for the monitoring: Mandian (22°07′ N, 100°40′ E), Manlü (22°08′ N, 100°41′ E), and Manfei (22°09′ N, 100°41′ E). All sites were at an elevation ranging between 600 and 800 masl, and at slopes between 22 and 28°. For all sites, lower slopes were steeper than higher slopes. The distance between the sites was between 5 and 10 km. At every site, one natural tropical seasonal rain forest and one rubber plantation were chosen in close proximity (distance < 1 km). During our study, from November 2014 to November 2015, mean annual temperature was 21.1 °C and annual precipitation was approximately 1320 mm, of which the majority (1050 mm) fell during the wet season. Climatic data were obtained from a local weather station in one of the three sites (Mandian; Fig. 1).

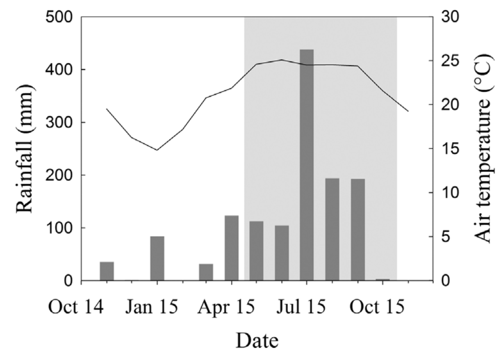

Fig. 1. Monthly mean rainfall (bars) and air temperature (line) of the study area in Xishuangbanna, China. The grey box indicates the wet season.

The sizes of the rubber plantations were 1 ha–2 ha, as is typical for this region, with an approximate length of 150–200 m. In each site and land cover type, three plots (10 m diameter) were established along the topographic gradient: upper slope, middle slope and lower slope. The difference in elevation between 2 plots was around 25 m. All plots were selected at least 20 m away from the forest edge to avoid edge effects. Soils of all sites were Ferralsols, according to FAO classification. Rubber plantations were first established in this nature reserve in 1970 after forest clearance and the age of the rubber plantations in this study was 20–25 years at the time of the observations. Sampling sites in this study were selected based on similar land use history and management practices. Management practices in rubber plantations include terrace establishment, fertilization, pest control, removal of understorey vegetation and rubber tapping. The terrace benches in the rubber plantations were constructed using a hoe. The mean tree spacing is 2.5 m in a row, and 6 m between rows. According to the local farmers, rubber plantations were fertilized with 45% compound fertilizer (N–P–K = 15–1–15) at a rate of 1.5 kg per tree in July. Rubber trees in this area are severely affected by powdery mildew disease. To control this disease, 10 kg ha^{-1} of 99% sulphur powder was applied once during January to March. Herbicides (30% glyphosate) were applied at a rate of 6 kg ha^{-1} twice a year in July and December and there was no groundcover throughout the year. Rubber trees are tapped after they are 6–7 years, and farmers tap from April to October, according to the onset and ending of the rainy season. Rubber latex is harvested every second day.

The tropical monsoon forests had tall emergent trees of up to 40 m height with epiphytes, lichens and a rich herbaceous layer. Forests in this region can have over 100 tree species per hectare and dominant trees families include Burseraceae, Annonaceae and Euphobiaceae (Cao and Zhang, 1997). In the rubber plantations, mean tree height was 20 m.

2.2. Surface soil CO_2 fluxes

SR was measured using a closed dynamic system. Every plot was equipped with three PVC collars, 20 cm in diameter and 20 cm in height, that were installed haphazardly in September 2014; but at least 2 m away from trees. The collars were driven 5 cm into the soil. SR measurements were performed from end of November 2014 until November 2015. Measurements were made twice a month during the year. For each measurement, the collars were manually closed with a plastic lid and connected to a portable infra-red gas analyzer (LI-8100,