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Natural forests maintain a greater soil microbial diversity than that in rubber plantations in Southwest China

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ABSTRACT

The conversion of tropical forests to monoculture rubber plantations throughout Southeast Asia threatens to have widespread negative impacts on ecosystem services. The aim of this study was to identify the impacts of forest conversion to rubber plantations on soil microorganisms, using a space for time substitution design. Soil microbial communities from natural forests, young rubber and mature rubber plantations were investigated using phospholipid fatty acid (PLFA) analysis. Microbial PLFA biomass of all functional groups including actinomycete, arbuscular mycorrhiza, fungi, bacteria and protozoa was lower in rubber plantations as compared to natural forests. This was true for young rubber and mature rubber plantations tested in both dry and wet seasons. The composition of microbial communities differed between natural forests, young rubber and mature rubber plantations. Changes in microbial community composition were strongly correlated with pH, which was lower in mature rubber plantations than in natural forests and young rubber plantations. In addition, our results showed that the variation in soil microbial community composition was strongly affected by seasonality, with higher PLFA biomass recorded in the dry season than in the wet season. The low soil microbial biomass in rubber plantations has long term implications regarding the soil health of rubber plantations.

1. Introduction

The conversion of natural forests to rubber plantations has become common across Southeast Asia region due to increased global demand for natural latex (Fox and Castella, 2013). Intensive expansion of rubber cultivation has occurred throughout montane mainland Southeast Asia (MMSEA), including Cambodia, China, Laos, Myanmar, Thailand and Vietnam. These areas were previously considered as non-traditional rubber growing environments due to their distinct dry and rainy seasons, altitudes above 300 m asl and steeply sloping land (Warren-Thomas et al., 2015). However, increased demand led to expansion of rubber plantations to these areas. By 2011, monoculture rubber plantations in MMSEA covered 1.5 million ha (Li and Fox, 2012). By 2050, the rate of conversion of secondary forests to rubber plantations is predicted to have quadrupled (Fox et al., 2012). Land use change associated with monoculture rubber plantations has major consequences for ecosystem services, including biodiversity loss, declines in carbon pools and increased soil degradation (Ahrends et al., 2015; de Blécourt et al., 2013; Li et al., 2008; Warren-Thomas et al., 2015; Zhang et al., 2007). Several studies have documented the negative impacts of forest conversion to rubber monoculture on soil erosion, quality and fertility (Drescher et al., 2016; Zhang and Zhang, 2003, 2005; Zhang et al., 2007).

Soil microorganisms play a crucial role in decomposition and nutrient cycling in forest ecosystems (Van Der Heijden, 2008). Land use change can cause shifts in the composition, diversity and activity of soil microbial communities (Bossio et al., 2005; Crowther et al., 2014; Lagerlöf et al., 2014; Rodrigues et al., 2013). Therefore, soil microbial communities can function as an indicator of soil health in different land use types (Allen et al., 2011; Cardoso et al., 2013). Nevertheless, the impacts of converting natural forests to rubber plantations on soil microbial communities are still poorly understood. Few studies have

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Table 1
Characteristics and management practices of study sites.

Land cover types	Natural forest (NF)	Young rubber (YR)	Mature rubber (MR)
Canopy closure	Close	Open	Close
Ages	–	6–8 years old	15–20 years old
Latex tapping	–	–	April–October (every 2 days)
Fertilizers	–	July 46% urea (0.5 kg per tree) 45% N-P-K = 15-15-15 (0.75 kg $tree^{-1}$)	July 45% N-P-K = 15-15-15 (1.5 kg $tree^{-1}$)
Herbicides	–	–	July and December 6 kg ha^{-1} of 30% glyphosate
Pesticides	–	–	January–March 10 kg ha^{-1} of 99% sulphur powder

focused on the soil microbial communities associated with rubber plantations (Allen et al., 2015; Guo et al., 2013, 2015; Kerfahi et al., 2016; Krashevska et al., 2015; Puttaso et al., 2015; Schneider et al., 2015). It has been suggested that the conversion of rainforest to rubber plantations greatly affects prokaryotic communities, but has less effect on fungal (including arbuscular mycorrhizal fungal) communities (Krashevska et al., 2015; Schneider et al., 2015). Kerfahi et al. (2016) showed no significant reduction of soil bacterial and fungal diversity in rubber plantations after conversion from rainforest. However, most previous studies were conducted in traditional rubber growing environments (Allen et al., 2015; Kerfahi et al., 2016; Krashevska et al., 2015; Schneider et al., 2015; Wang et al., 2017). Therefore, we still lack a clear understanding of how soil microbial communities are impacted by forest conversion to rubber plantations in non-traditional rubber growing environments. Data from MMSEA is especially lacking. Previous studies have shown that environmental factors such as soil temperature, soil moisture, pH, and organic carbon significantly affect soil microbial communities (Docherty et al., 2015; Evans and Wallenstein, 2011; Feng and Simpson, 2009; Rousk et al., 2010). The increase in both soil temperature and rainfall from the dry to wet season is likely to contribute to changes in the composition of soil microbial communities (Bouskill et al., 2013; Smith et al., 2015). Since all of these factors are themselves affected by conversion from forests to rubber plantations, it is crucial to examine their influence on soil microbial communities when investigating the response of soil microbial communities to land use conversion.

In this study, we examined sites both in natural forests and rubber plantations in Xishuangbanna, Yunnan, Southwest China. Xishuangbanna is a biodiversity hotspot in which environmental conditions are suboptimal for rubber cultivation due to distinct dry and rainy seasons and mountainous terrain, with altitudes above 477 m asl (Wu et al., 2001). By 2010, rubber plantations had rapidly expanded to cover 22% of Xishuangbanna's landscape, replacing forests and other vegetation in the process (Fox and Castella, 2013). The objectives of this study were: (1) to investigate how soil microbial communities respond to the conversion of natural forests into rubber plantations, (2) to investigate how the microbial communities change as the rubber plantations mature, and (3) to identify the main environmental factors through which forest conversion impacts soil microbial communities. We hypothesized that land use conversion from natural forests into rubber plantations will negatively impact soil microbial communities, resulting in reduced microbial biomass in rubber plantations compared to natural forests. Understanding how soil microbial communities are affected by land use conversion to rubber plantations is essential for the sustainable management and restoration of soils in this region.

2. Materials and methods

2.1. Study site and rubber management practices

Our study area was the Naban River Watershed National Nature Reserve (NRWNNR), located in Xishuangbanna, Yunnan Province, China (22° 04′–22° 17′N, 100° 32′–100° 44′E). This nature reserve is a watershed area covering 21,100 ha and is surrounded by hills and mountains. The altitude of our study sites ranged from 600 to 800 m asl. It has a tropical monsoon climate, which is characterized by a dry season from November to April and a wet season from May to October. Mean annual air temperature and cumulative rainfall were 21.3 °C and 1106 mm (data from local meteorological station; September 2014–August 2015). The main forest type in our study sites is tropical monsoon forest (YEPB, 2006). The dominant tree species in the selected tropical monsoon forest were from families Burseraceae, Annonaceae and Euphobiaceae. The forest is characterized by an uneven canopy structure and diverse species composition in different layers (Cao and Zhang, 1997). The soil is classified as Latosols and Ferralsols based on FAO classification (Apel, 1996; YEPB, 2006).

Rubber plantations were first established in this nature reserve in 1990 after some forests were cleared (YEPB, 2006). The rubber plantations are terraced, with a mean tree spacing of 2.5 m in a row, and 6 m between rows. Tapping starts when rubber trees are 6–7 years old and occurs during the rainy season. Sampling sites in this study were selected based on similar land use history and management practices. According to the local farmers, intensive management practices are used in rubber plantations. The characteristics and management practices of our study sites are listed in Table 1.

2.2. Plot setting and soil sampling

Our research was conducted at three sites (Mandian, Manlu and Manfei) in the Naban River Watershed National Nature Reserve (NRWNNR) (Fig. S1). All sites were at elevations of between 600 and 800 m asl, and at slopes of between 22° and 28°. The sites were located approximately 5–10 km apart from each other. In each site, we selected three land cover types: natural forests (NF), young rubber (YR) and mature rubber (MR) plantations (Figs. S1 and S2). Young rubber plantations were 6–8 years old, with pre-canopy closure and untapped latex. The mature rubber plantations were 15–20 years old with post-canopy closure. Latex was tapped each year throughout the rainy season. In each land cover type, three plots positioned along slope gradients (upper, middle and lower slope) were established, giving 27 plots to be used for soil sampling. The difference of elevation between sampling plots along slope gradients varied from 50 m to 80 m. Within a plot, soil samples were collected from a 10 m radius, with sets of 10 soil cores taken from a depth of 0–10 cm; theses soil samples were then bulked into one sample (Fig. S2). The bulked soil samples were sieved through a 2 mm mesh to remove root and plant materials. Soil was then separated into two parts; the first part was air-dried at room temperature prior to physical and chemical analysis, and the second part was kept in a freezer at −20 °C prior to ammonia (NH_4^+-N), nitrate (NO_3^--N) and phospholipid fatty acid analysis (PLFA). Soil samples were collected during two seasons: the wet season (21 September 2014) and the dry season (23 March 2015).

2.3. Soil physical and chemical properties

A data logger system (Hobo U30) was used for daily monitoring of soil moisture (SM) and soil temperature (ST). SM (S-SMC-M005) and ST sensors (S-TMB-M002) were permanently installed at a depth of 5 cm.