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Rubber plantation ageing controls soil biodiversity after land conversion from cassava

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ABSTRACT

The rapid expansion of perennial crops is a major threat to biodiversity in Southeast Asia. The biodiversity losses related to the conversion of forest lands to oil palm or rubber plantations (RP) are well documented by recent studies. However, the impact of the conversion from intensively managed annual crops to perennial crops on soil biodiversity has not yet been addressed. This study aims at assessing the impact on soil biodiversity of a) the short-term effect of land use conversion from cassava crop to RP, and b) the long-term effect of RP ageing. Soil biodiversity (bacterial, fungal and macrofaunal), microbial activities and pedoclimatic characteristics were measured over a chronosequence of 1–25 years old of RP compared to cassava fields, the former crop, in Thailand. The conversion from cassava to young RP (1–3 yr) had a significant effect on microbial biomass and activities and fungal composition, but did not impact the bacterial and macrofaunal diversity. This effect of land use conversion could be explained by the change in land management due to the cultivation of pineapple in the inter-row of the young RP. Canopy closure appeared to be the main driver of soil biota shifts, as most of the biotic parameters, composition, abundance and activities were significantly modified after 7 years of RP. The changes of composition in older rubber plantations originated from the dominance of *Trichoderma* (fungi), Firmicutes (bacteria), and earthworms. Old rubber plantations (23–25 yr) harboured the highest microbial and macrofaunal biomass; however, they were also characterised by a significant decrease in bacterial richness. The change in pedoclimatic conditions across the rubber chronosequence, i.e. increase in soil moisture, litter and organic carbon content, was a stronger driver of soil biota evolution than land use conversion. The macrofaunal composition was more resistant to land use conversion than the bacterial composition, whereas the microbial biomass was sensitive to land use conversion, but showed resilience after 20 years. However, bacterial, fungal and macrofaunal diversity, macrofaunal and microbial biomass and microbial activities were all sensitive to RP ageing.

1. Introduction

Rubber plantations (RP) have expanded faster than all other tree crops in South East Asia (Fox and Castella, 2013), with a 1.8 fold increase in surface area over the last three decades. South East Asia represents more than 83% of the World rubber area (FAO, 2012). In Thailand, the first natural rubber producer (IRSG, 2015), this expansion has lasted for more than a century. In 2015, rubber plantations covered more than 3.5 million ha in Thailand, and represented the second largest area of rubber in the world (IRSG, 2015). Originally, the expansion of RP in Thailand replaced natural vegetation such as forest. However, today RP have replaced many subsistence agriculture or intensive annual cash crops such as sugarcane or cassava, instead of replacing natural vegetation due to forest depletion and protection (Chambon et al., 2016).

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The ability of rubber trees to grow on a wide range of soil types and pedoclimatic conditions, from optimal tropical lowland to suboptimal environments such as low-fertility areas with distinct dry seasons or steep slope (Blagodatsky et al., 2016), partly explains the rapidity and success of RP expansion. However, according to Saengruksawong et al. (2012), only 102,000 ha in Thailand have suitable soil characteristics for RP. Thus, the majority of rubber expansion has taken place on poor soil with low fertility (Chambon et al., 2016). This highlights the need to better determine the environmental impact of RP on the soil compartment. Like any other form of land use conversion, the development of a tree plantation leads to changes in ecosystem characteristics and fluxes (Njar et al., 2011). If RP are considered as one of the top four best land uses in South East Asia for carbon (C) stock (Ziegler et al., 2012), their C balance rarely considers the soil compartment (Blagodatsky et al., 2016). Globally, the effect of rubber trees on soil C balance and nutrient cycle first depends on the previous land use, being positive after conversion of arable land to RP (Njar et al., 2011; Yasin et al., 2010; Herrmann et al., 2016a,b) and negative when forest was converted to RP (Li et al., 2012; de Blécourt et al., 2013; Blagodatsky et al., 2016). However, studies investigating rubber tree plantations impact on soil have focused mainly on the physico-chemical parameters.

Concerns about the impact of RP on soil biodiversity has been growing due to rapid rubber tree expansion in tropical regions associated with high level of biodiversity (Mumme et al., 2015; Warren-Thomas et al., 2015; Xu et al., 2014). Conversion of primary or secondary forest to rubber monoculture results in a severe decrease in species richness of aboveground diversity (Warren-Thomas et al., 2015), mainly in insect and fruit eating species (Aratrakorn et al., 2006) such as birds and bats (19–76%). Belowground diversity has so far been mostly investigated considering the conversion from forest to rubber. This conversion seems to reduce soil macrofauna diversity (Gilot et al., 1995; Lavelle et al., 2014), soil nematodes (Xiao et al., 2014) and soil microbial activities (Gilot et al., 1995; Abraham and Chudek, 2008). Moreover, this conversion modifies the soil microbial biomass and structure (Krashevska et al., 2015; Schneider et al., 2015) and may even increase soil prokaryotic richness (Schneider et al., 2015). The impact of annual crop conversion to rubber on soil biodiversity has only been addressed in one study, focussed on arbuscular mycorrhizal fungi communities (Herrmann et al., 2016b). This study showed that a modification of the arbuscular mycorrhizal fungi communities composition was due to a change in soil texture and nutrient contents in RP after cassava cultivation. A range of different methods with different resolutions were used to determine the microbial composition or diversity (such as PLFA (Krashevska et al., 2015) or pyrosequencing (Schneider et al., 2015; Herrmann et al., 2016b)) and the macrofaunal community (using morphological techniques (Gilot et al., 1995; Lavelle et al., 2014)). However, these methods were not used simultaneously in the same sites and plots and were mostly focused on the effect of deforestation. Assessing the impact of land use and management changes on soil functioning should focus on a set of soil organisms playing major roles (Lavelle et al., 2006, 2014). Soil microbiota as decomposers and nutrients transformers and soil macrofauna as ecosystem engineers contribute to key functions such as carbon transformation, soil structure maintenance and nutrient cycling (Lavelle et al., 2006), which might be directly affected by land use conversion or RP ageing. Therefore, it is important to address the consequences of such specific land use conversion on the soil biota.

Beyond the land use conversion, the temporal dynamics of RP, i.e. canopy closure and ageing of the trees, may also play a critical role on soil biodiversity (Walker et al., 2010). The effect of RP ageing was mainly studied on soil properties, such as C stock (de Blécourt et al., 2013), nutrients concentrations (Aweto, 1987; Gilot et al., 1995), and microclimatic conditions (Gilot et al., 1995; Herrmann et al., 2016a) but not yet on the soil biodiversity. To address the temporal dynamics of soil biodiversity in a long term plant succession, chronosequences are recognised to be an efficient and necessary tool (de Blécourt et al., 2013). Thus, the aim of this study was to assess the effect of land use conversion from cassava and ageing of RP on the soil biodiversity (i.e. bacteria, fungi and macrofauna) and microbial activity. A chronosequence design was used with three replications (blocks) including four age-classes (ranging from 1 to 25 years) and was compared with cassava fields, the former crop systems in the area.

2. Materials and methods

2.1. Study sites, plot setting and rubber management practices

The study was carried out in the rubber growing area of Chachoengsao Province in eastern Thailand (13°41′N, 101°04′E). The site is characterised by a tropical monsoon climate, with a strict dry season between November and April and a rainy season between May and October. The mean annual precipitation and temperature is 1328 mm and 28.1 °C, respectively (source Thai Meteorological Department). The soils in the plots belong to the Kabin Buri series, with 50% sand, 15% silt and 35% clay. Soil depth is limited to 1–1.5 m by a compact layer of ferralitic concretions that strongly limits root growth. These pedoclimatic conditions are considered as a marginal area for rubber cultivation (Webster and Baulkwill, 1989). The soil is classified as isohyperthermic Vertic Endoaquepts soil based on soil taxonomy classification (USDA, 2014). The study was conducted in cassava fields and RP which belong to local farmers. We selected fifteen plots managed under local agricultural practices (Table 1). There were 5 treatments, including four RP age-classes and one cassava plantation (Table 1 and Fig. S1). Twelve rubber (*Hevea brasiliensis,* clone RRIM 600) plantations were chosen to represent four classes of stand-age: 1–3, 5–6, 6–10 and 23–25 years. Three cassava plantations (C) were selected as references since cassava is the main annual crop cultivated in this region previously to RP. In cassava plantations, the soil was ploughed every year and plant materials (tuber and sometimes leaves) were exported. With a distance of 7 m between the rows and 2.5 m between trees, the rubber tree planting density varied from 444 to 667 trees per ha. The first RP age class (1–3 y) represented the beginning of the rubber cycle. The soil was left bare and under direct light exposure. Young pineapples were planted as inter-culture (~4 m, 8 lines of pineapples, 28.000 feet per ha) between rubber rows (inter-row). During this phase, neither rubber nor pineapple were harvested. During the second RP stand-age (5–6 y), pineapple fruits were collected while rubber trees were not yet tapped. Rubber trees started to be tapped for latex harvesting at the beginning of the third RP stand-age (6–10 y) after the canopy closure. The last RP stand-age (old, 23–25 y) represented the end of the rubber culture cycle. In Thailand, rubber trees are usually cut after 25 y. Each treatment was distributed within three blocks (A, B and C), these blocks were approximately 1–1.5 km from each other (Fig. S1).

2.2. Soil physico-chemical analyses

In each plot, eight soil samples were taken, four in tree rows and four at mid-distance between two rows (inter-rows) at a depth of 0–5 cm along a 70 m transects, traced in the centre of the plantation to avoid edge impact (Fig. S1). A total of 120 soil cores were sampled in November 2012 using 100 cm^{-3} cylinders. Fresh soil samples were sieved at 2 mm and dried at 105 °C over 24 h to measure soil moisture. All analyses were performed by the soil laboratory of the Office of Science for Land Development in Land Development Department in Bangkok. The air-dried soil was weighed without coarse particles > 2 mm. The bulk density ($g\,cm^{-3}$) was calculated as the ratio of the dry mass of fine soil (< 2 mm) to the cylinder volume. Soil texture was determined by the Bouyoucos Hydrometer method adapted from Gee and Bauder (1986). Available phosphorus was determined using the Bray II method (Bray and Kurtz, 1945). The pH was determined in distilled water (1:1 soil-water ratio). The cation exchange capacity

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