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Long rotation swidden systems maintain higher carbon stocks than rubber plantations

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ABSTRACT

Conversion of shifting cultivation to rubber (*Hevea brasiliensis*) plantations is one of the dominant land use changes in montane mainland areas of Southeast Asia, with the area of rubber expected to quadruple by 2050. However, the impacts of this transition on total ecosystem carbon stocks are poorly quantified. We undertook a chronosequence study to quantify changes in ecosystem carbon stocks following conversion from swidden agriculture to rubber plantations in Northern Laos. We measured above-ground biomass stocks and collected volume specific soil samples across rubber plantations established between 2 and 18 years prior to the study, and fallows used in a swidden system. The carbon stock in the upper 40 cm of the soil was almost 20% lower after 18 years of rubber than in the swidden system fallows, suggesting a SOC loss of 0.74 ± 0.2 Mg C ha^{-1} yr^{-1}. Rates of biomass accumulation in fallows were 1.5 ± 0.12 Mg C ha^{-1} yr^{-1} and 1.9 ± 0.14 Mg C ha^{-1} yr^{-1} in rubber plantations. When comparing time-averaged carbon stocks of swidden systems to rubber plantations with 30 year rotation periods, the stocks of swidden systems with rotation times of 5 and 10 years were 19% and 13% lower respectively; the stock of swidden systems with a rotation time of ~15 years was approximately equal to rubber; and the stock of swidden systems with a rotation time of 30 years was 11% higher than in rubber. Therefore, we conclude that the replacement of swidden agriculture with rubber leads to soil carbon losses, but the overall effects on ecosystem carbon stocks depend on the rotation intensity of the swidden system that is being replaced.

1. Introduction

Today 9–11% of anthropogenic CO_2 emissions are derived from land use change and 90% of these changes are taking place in the tropics, with Southeast Asia as a hotspot (Houghton et al., 2012; IPCC, 2014). One of the most dominant land use changes in montane mainland areas of Southeast Asia is the transition from secondary forest and traditional swidden agriculture to monoculture rubber (*Hevea brasiliensis*) plantations (Dressler et al., 2016; van Vliet et al., 2012). By 2012 rubber plantations covered more than 1 million hectares of non-traditional rubber growing areas, principally in the montane regions of mainland Southeast Asia (China, Laos, Myanmar, Cambodia and Thailand), and 97% of the world's supply of natural rubber was derived from this region (Fox et al., 2014a). By 2050 the area of rubber in the region is predicted to increase fourfold – and this expansion will largely be replacing secondary forest and swidden agriculture (Fox et al., 2014a). These large scale transitions have had documented negative effects on biodiversity and a range of ecosystem services (Ziegler et al., 2009) while effects on carbon storage are contested (Bruun et al., 2009; Fox et al., 2014b; Ziegler et al., 2012).

Numerous studies have addressed biomass carbon stocks in rubber plantations in mainland Southeast Asia (e.g. Cheng et al., 2007; Petsri et al., 2013; Yang et al., 2016) and studies that have investigated carbon accumulation in above-ground biomass (AGB) in swidden fallows are also available (e.g. Fukushima et al., 2008; Chan et al., 2013; McNicol et al., 2015). However, to date only one study has quantified changes in soil organic carbon (SOC) stocks as a result of a conversion of secondary forest to rubber monoculture (de Blécourt et al., 2013). This study was carried out in Xishuangbanna, Southern China, and documented a 20% decline in the carbon stock of the upper 120 cm of

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soils converted from secondary forest after 46 years of rubber cultivation.

Due to the absence of studies of the impacts of these land use conversions on the SOC pool, a recent review by Ziegler et al. (2012) relied on a pan-tropical meta-analysis to calculate relative changes in soil carbon stocks after land use changes, and to estimate total ecosystem carbon (TEC) stocks of various land use systems. According to this review, the TEC stock of rubber plantations in Southeast Asia ranges from 93 to 376 Mg C ha^{-1} while the TEC stock of swidden systems ranges from 62 to 329 Mg C ha^{-1}. The calculations are based on 100 cm soil profiles hence values are rather high, furthermore these values are based on relatively few studies that are difficult to compare due to lack of methodological standardization and lack of information about site specific differences, such as soil properties, elevation, climate and land use history (Ziegler et al., 2012). The paucity of studies that provide empirical data on TEC stocks in rubber plantations at the pan-tropical level was also noted in a recent review by Blagodatsky et al. (2016).

The carbon storage potential of rotational land use systems like swidden agriculture and rubber plantations is not determined by the carbon stock at any point in time, but by the average amount of carbon stored in the system during its entire rotation – referred to as the time-averaged carbon stock. While some studies have provided data that makes it possible to assess the time-averaged AGB carbon stocks of rubber plantations in mainland Southeast Asia (Petsri et al., 2013; Yang et al., 2016), no studies allow for a direct comparison of the time-averaged TEC stocks in rubber plantations and swidden systems at various levels of intensity.

In spite of the uncertainties of the carbon outcome of changes from swidden agriculture to rubber, it is often taken for granted that the transition will lead to increased carbon storage (Dressler et al., 2016; Fox et al., 2014a). For example in Laos, projects that convert land from a swidden system to rubber monocultures have been granted carbon credits under the clean development mechanism (CDM) (UNFCC, 2010), and in general the use of IPCC Tier 1 carbon accounting effectively assumes no change in carbon stocks when forests are converted to rubber plantations. Ensuring that land use decisions are made with full understanding of the carbon consequences requires more data on carbon stocks in these systems, but as Ziegler et al. (2012) demonstrate, comparing stocks across different locations introduces too much variation to draw any useful conclusions. Progress will only be made through long term observations or alternatively through careful selection of chronosequences. The rapid rates of land use change in Southeast Asia mean that long term observations will not be able to contribute meaningfully to contemporary land use change decisions, so the development of good chronosequence studies is critical for informed debate about the impacts of land use change on carbon stocks.

To fill this gap, we performed a chronosequence study of the conversion of a swidden system with upland rice to rubber plantations in Northern Laos and quantified the changes in time-averaged carbon stocks in soil and above- and below-ground vegetation. The specific aims of the study are to: I) examine how carbon stocks in soil and vegetation change as rubber plantations mature; and II) determine the difference between time-averaged carbon stocks in rubber and swidden agriculture under various rotation intensities.

2. Materials and methods

2.1. Description of study area

The study was carried out in three villages (Ban Had Nyao, Ban Nam Dee and Ban Hong Luay) in Luang Namtha district, Luang Namtha province, in Northern Laos (20°57′30 N, 101°24′00 E). The province borders China (Xishuangbanna) to the northeast and Myanmar (Shan State) to the northwest (Fig. 1). Luang Namtha district is inhabited by a variety of ethnic groups and the inhabitants of the villages included in this study were of Hmong and Lanten ethnicity. The study is based on three fieldwork campaigns: A pilot study in December 2012 and two sampling and measuring campaigns in May-June 2013 and November-December 2013.

The study area is characterized by a mountainous landscape with elevations between 570 and 980 m above sea level (the selected plots were located between 600 and 800 m above sea level). Luang Namtha has a subtropical monsoon climate with a pronounced dry season from October to April and a wet season from May to the end of September. Annual precipitation is about 1400 mm with 75% of this falling between May and September (Global Weather, 2016). The upland areas are dominated by Ferric Acrisols (GMS, 2014) which translates into Ultisols in the USDA soil taxonomy (USDA, 2014).

Luang Namtha district is known for being the first district in Laos to introduce rubber, which happened at a small scale in five different villages in 1994 (Shi, 2008). Since then, the expansion of rubber plantations has taken place in different 'waves', with large areas being converted to rubber in the years between 2005 and 2008 (Shi, 2008) and after 2012 in response to government programs supporting planting of rubber and to high farm gate prices of latex (Vongvisouk and Dwyer, 2016). The current area under rubber in Luang Namtha is estimated to be about 34,000 ha (Vongvisouk and Dwyer, 2016). The dominant land use trajectory in Luang Namtha over the last decades has been a change from: a) primary forest to swidden agriculture with fallow periods between five and 15 years; and then b) the transition from swidden to rubber (Fujita et al., 2007). Rubber in Luang Namtha is mainly grown in smallholder systems, without any mechanization and with very limited use of external inputs (Shi, 2008; Vongvisouk and Dwyer, 2016).

2.2. Sampling design and plot selection

We used a chronosequence (space for time substitution) method to quantify changes in TEC stocks following a conversion from swidden agriculture to rubber plantations. We estimated AGB stocks and collected soil samples across a chronosequence of different aged rubber plantations (2–18 years, n = 10) and in areas of secondary forest that had been under fallow for 7–10 years (n = 3) which were used as pre-conversion reference plots. The rubber plantations were grouped as 'young rubber' of 2–4 years (n = 3), 'medium aged rubber' of 7–10 years (n = 4) and 'old rubber' of 17–18 years (n = 3).

An important assumption of the space for time substitution method is that the converted plots were once similar to the reference plots with regards to land use history, inherent soil properties and SOC stocks, so that any measured differences can be attributed to land use changes (Bruun et al., 2013). In order to comply with this assumption, detailed information about land use history and management was collected from the land owners, and triangulated with information from the village headmen, prior to plot selection. These interviews were conducted in Lao and translated to English by a native speaker. Plot history was recorded as a timeline upon which the respondent was invited to comment to provide immediate verification of the history of each plot. Recalled dates were anchored against well-known events and triangulated with village history obtained from a separate interview with the village chief.

For the selection of the rubber plots, only plots that had been used for cultivation of upland rice in a swidden system with rotation times of 7–15 years for at least two rotations before they were converted to rubber plantations were targeted. The selected fallow plots had all originally been cleared from old secondary forest and were now used in a swidden system with similar rotation intensity.

To control for variation in inherent soil properties, plots were selected based on similarity of soil colour (as determined by the Munsell soil colour chart), similar texture (as determined by the feel method) and field owners were interviewed about their perception of the soil on their plots. To minimize topographic variation between plots, we restricted our plot selection to areas away from the top or bottom of