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Impact of land use changes on the storage of soil organic carbon in active and recalcitrant pools in a humid tropical region of India

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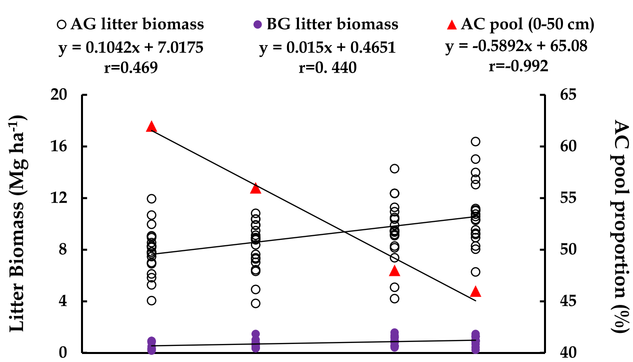
HIGHLIGHTS

- Mature rubber plantation contains 34% lower SOC stock than natural forests.
- Active carbon pool decreases with increase in age of rubber plantation.
- In 50–100 cm soil depth proportion of recalcitrant carbon pool is higher in mature rubber plantations.

GRAPHICAL ABSTRACT



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ABSTRACT

Quantifying soil organic carbon (SOC) dynamics is important in understanding changes in soil properties and carbon (C) fluxes. However, SOC measures all C fractions and it is not adequate to distinguish between the active C (AC) and recalcitrant or passive C (PC) fractions. It has been suggested that PC pools are the main drivers of long term soil C sink management. Therefore, the present study was undertaken with the objective of determining whether or not SOC fractions vary with land use changes under a humid tropical climate in the North East India. A chronosequence study was established consisting of natural forest, *Imperata cylindrica* grassland and 6, 15, 27 and 34 yr old rubber (*Hevea brasiliensis*) plantations to determine changes in the different fractions of SOC and total SOC stock. SOC stocks significantly varied with soil depth in each land use practice. SOC stocks increased from 106 Mg ha^{-1} under 6 yr to 130 Mg ha^{-1} under 34 yr old rubber plantations. The SOC stocks under 34 yr old plantations were 20% higher than that under *I. cylindrica* grassland, but 34% lower than SOC stocks recorded under natural forest soil. The proportion of AC pools decreased with increase in plantation age, AC pools being 59% of SOC stock in 6 yr old stands and 33% of SOC stocks in 34 yr old plantations. In contrast, the proportion of PC pools increased from 41% of SOC stock in 6 yr old plantation to 67% of SOC in 34 yr old plantation. In the 50–100 cm soil depth, the PC pool under 27–34 yr old plantations was comparable with that under natural forest but much higher than in *I. cylindrica* grassland. Therefore, it is concluded that old rubber plantations can play a significant role in long term soil C sink management.

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1. Introduction

The global soil organic carbon (SOC) stock of ~1.5 × 10^3 Pg (1 Pg = 10^{15} g) represents two and three folds higher than that of the atmosphere and vegetation, respectively (Jobbágy and Jackson, 2000; Lal, 2016). Tropical forests have been known for alteration of atmospheric C concentration by acting as C sink or source (Wei et al., 2014). Human induced land use change (LUC) from tropical forests into plantations and croplands may act as a C source (De Blécourt et al., 2013; Guillaume et al., 2015; Fan et al., 2016; Iqbal and Tiwari, 2016) and simultaneously degrade soil properties (Abera and Wolde-Meskel, 2013). Of the total of 350 M ha of tropical forest land that has been converted to different land uses (ITTO, 2002), ~1.5 M ha is under rubber (*Hevea brasiliensis* (Willd. ex A. Juss.) Müll. Arg.) plantations in Southeast Asia (Ziegler et al., 2009; Tan et al., 2011; De Blécourt et al., 2013). In India, 0.80 M ha of land is currently under rubber plantations. This area has been primarily converted from forest land (The Rubber Board, 2011). Conversion of forests to rubber plantations has been associated with biodiversity loss (Ahrends et al., 2015) and SOC losses of 20–40% (Guillaume et al., 2015; De Blécourt et al., 2013). In contrast, establishment of rubber plantations on degraded lands has been shown to provide high carbon sink potential (Brahma et al., 2016, 2017). Numerous studies across the world have also indicated increases in SOC stock with increase in the age of rubber plantations (Wauters et al., 2008; De Blecourt et al., 2014; Zhang et al., 2007).

Quantifying SOC dynamics is important in understanding changes in soil properties and C fluxes in ecosystems. Depending on the residence time of SOC, the C fractions have been categorized as active and passive pools (Chan et al., 2001). The microbial and derivative products, which are very active in recycling within a period of 5 yrs, have been recognized as the active C (AC) pool, while fractions with relatively longer residence time than the AC pool are characterized as recalcitrant or passive C (PC) pool. These major C pools have differential contributions to atmospheric C concentration due to their release and sequestration processes. The AC pool is the chief source of soil nutrients (Mandal et al., 2008), and therefore it greatly influences the productivity and quality of soil (Chan et al., 2001; Mandal et al., 2008). However, due to its low residence time the C sink potential of the AC pool is very low (Luo et al., 2003). In addition to improving soil productivity and quality, the PC pool contributes to the total organic carbon (TOC) stock (Mandal et al., 2008). Therefore, the PC pool can act as a reliable indicator of C sequestration potential of a system (Paul et al., 2001). However, information is scanty on the storage of SOC in AC and PC pools under chronosequences of rubber plantation developed on degraded forest land. Therefore, the first objective of this study is to determine the impact of LUC on storage of SOC in the AC and PC pools. Litter production in aboveground (leaf, twig and branch) and belowground (fine root) plant component depends on land use types, vegetation structure and composition (Freschet et al., 2013). The availability of organic matter and its decay process determines the quality and quantity of SOC (Krull et al., 2003). For example, high lignin content in belowground litter slows down the decomposition process and subsequently regulates carbon in AC pool (Freschet et al., 2013). The litter decomposition rate is linearly related to turnover rate and inversely related to the mean residence time (MRT). The MRT is influenced by the quality and quantity of litter produced (Lui et al., 2009), which further affects SOC lability (Certini et al., 2015). Therefore, correlating MRT of aboveground and belowground litter with AC pool will reveal the role of litter decomposition in SOC lability. Therefore, the second objective of the present study is to assess the role of aboveground and belowground litter production and its decomposition in the lability of SOC pools.

2. Materials and methods

2.1. Study site

The study area is located in the Barak Valley of Assam in North East India (NEI). It falls within the range of the Himalayan foothills and the Barak River Basin. The Barak Valley consists of three districts of Assam (Cachar, Hailakandi and Karimganj) covering an area of ~7000 km^2 (NEDFI, 2016). The valley is characterized by tropical humid climate, and experiences mean annual precipitation of 3500 mm, temperature range of 13-37 °C and relative humidity of 93.5% (NEDFI, 2016). The soil texture of the study area is silty clay loam or clay loam. The pH of soil ranges from 4.5 to 5.3. Total nitrogen ranges from 0.45–0.78 me kg^{-1} (Vadivelu et al., 2004). The dominant soil is classified as the Barak series, which is fine, mixed, hyperthermic family of *Aeric Endoaquepts* (Soil Survey Staff, 2014), which is the equivalent of Inceptisols in the USDA classification. According to the World Reference Base for Soil Resources (WRB) classification and correlation system (IUSS, 2014) the soils correlate with Cambisols.

The natural forest, adjacent grasslands and rubber plantations in Karimganj district (24°40′N, 092°46′E) were selected for the present study. The forest is classified as tropical wet evergreen forest (Champion and Seth, 2005), with the dominant tree species being *Artocarpus chama* (Buch.-Ham. ex Wall.), *Cynometra polyandra* (Roxb. (Harms)), *Ficus hispida* (Linn. f.), *Lindera* sp., *Litsea* sp., *Oroxylum indicum* ((L.) Kurz), and *Syzygium cumini* ((L.) Skeels) etc. The grasslands in Barak Valley originally developed as result of degradation of natural forests and subsequently invaded by *I. cylindrica*. Annual harvesting of above ground parts of the *I. cylindrica* for thatching and roofing purposes are very common in North Eastern India (Pathak et al., 2017). Burning of aboveground residues is also a common managerial system practised annually to maintain the soil nutrients under *I. cylindrica* grasslands (Pathak et al., 2017). The rubber plantations were developed on grassland that developed following degradation of the natural forest. Rubber plantations were established for production of natural rubber latex, which is an important source of monitory income in the region. For the present study, rubber plantations of different ages situated at 200–300 m from each other were chosen. The age of the rubber tree plantations and the history of the land use were confirmed from the forest's official records and interview of local people.

2.2. Soil sampling and analyses

Soil samples were collected from each of the study sites (rubber plantation, natural forest and grassland) during the months of February–March in 2016. Four 250m × 250 m quadrants were selected from each plantation and land uses following the ISRO-GBP/NCP-VCP protocol described in Singh and Dadhwal (2009). The quadrants were chosen on representative sites covering dense to sparse vegetation cover. Since, the selected rubber plantations were situated on slopes of small hillocks, the quadrants were laid in such a way to cover the top, middle and base of the hillock. The distance between any two representatives quadrants within each plantation ranged between 30 and 50 m. Within each quadrant three vertical soil profiles (1 m × 1 m × 1 m) were dug at the top, middle and base of the slope. Thus, for each rubber plantations a total of 12 vertical profiles (4 quadrants × 3 soil profiles) were dug. The natural forest and *I. cylindrica* grasslands were situated on plain landscapes, therefore, two profiles were dug within each of the 250 m × 250 m quadrants. Thus, in case of the natural forest and *I. cylindrica* grassland, eight vertical profiles (4 quadrants × 2 soil profiles) were dug for collecting soil samples.

Soil samples were collected using 10 cm scaled soil cores with 5.6 cm inner diameter from the 0–20 cm, 20–50 cm and 50–100 cm depth of each soil profile. Three samples were collected by inserting the core horizontally up to 10 cm and composite soil samples were prepared for each of the soil depth. In total 36 composite samples were collected for each of the rubber plantation. In case of natural forest and *I. cylindrica* grassland, 24 composite samples each were collected and taken to the laboratory for analysis. The soil samples were air dried and sieved through 150 μm (100 mesh) sieve for determination of SOC stock and C pools. Coarse mineral fragments (>2 mm) were excluded from SOC stock calculation.