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Effects of forest type and environmental factors on the soil organic carbon pool and its density fractions in a seasonally dry tropical forest

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ABSTRACT

Density fractionation is now a potential approach for distinguishing among the functions of different soil organic carbon (SOC) pools in a forest ecosystem. The co-existence of evergreen and deciduous forest types in seasonally dry tropics is favorable for clarifying the effect of contrasting plant functional trait on the size and quality of SOC pools under the high temperature regime. We examined whether forest type (deciduous vs. evergreen), mineral factor (aluminum and iron oxide) and climatic condition (temperature and precipitation) affect the size and quality of SOC pools in bulk soil and density fractions in a seasonally dry tropical forest of continental Southeast Asia. The forest type and mineral factor affected the quality and size, respectively, of SOC pools. The forest type had significant effects on carbon-to-nitrogen (C:N) ratios of leaf litter and free form of light fraction. However, variations in the size of the SOC pools at a depth of 0–30 cm and in each topsoil density fraction were explained exclusively by the mineral factor, i.e., aluminum oxide extractable by acid ammonium oxalate, regardless of variations in forest type and precipitation pattern. It was suggested that the surface area of clay mineral was the dominant factor for the storage capacity of SOC in the study area. The aluminum and related oxides might also increase intra-aggregate space for occluded form of light fraction. The impact of the climatic factor on the SOC pools was not found in a significant level though its effect including humid tropics on the composition of SOC remains a subject of future investigation. The linear models with variables of SOC and soil organic nitrogen favorably estimated the size of the C and N pools in the light fraction independent of the forest type. These regression models help to estimate the wide-area distribution of labile SOC pools of plant detritus form and its digital mapping, combined with a dataset of bulk SOC content. And it will provide incentives for C sequestration practice under forest management in seasonally dry tropical forests through the spatially-defined assessment of reduction effect of C emissions.

1. Introduction

Soil organic carbon (SOC) is a large reservoir of carbon (C) in a forest ecosystem and is a major source of anthropogenic carbon dioxide emissions due to land use change in tropical countries (Ciais et al., 2013). Therefore, there is increasing demand for a standard SOC stock monitoring system on a nationwide scale in tropical forest regions using economically efficient methods (GOFC-GOLD, 2013). In addition, the concepts has been proposed for separating several components of SOC with different stabilities, such as an active or labile C pool with a faster turnover rate than other passive or resistant C pools (Coleman et al., 1997; Liski et al., 2005; Parton et al., 1987) to estimate the potential loss of SOC during land management. To embody the conceptual C pools, the experimental techniques have also been developed based on measureable C pools by either chemical or physical fractionation approaches (Zimmermann et al., 2007). Density fractionation, which divides SOC into two or more components of different particle densities (light fraction [LF], such as fine particles of plant detritus, and a heavy fraction [HF], such as the organo-mineral complex) (Cerli et al., 2012; Christensen, 1992; Golchin et al., 1994; Zimmermann et al., 2007), is now a potential approach for separating the functions of several C pools in forest soils that are rich in fine plant detritus particles. LF can be further divided into "free" and "occluded" or aggregate-protected forms, which are recovered before and after sonication treatment, respectively (Golchin et al., 1994; Wagai et al., 2009). However, the variations in size and quality of these density fractions in a wide area have

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been less examined in tropical forest soils compared with other biomes.

When density fractionation is applied to SOC pools in tropical forests, particularly those that experience severe dry seasons of several months, the effects of forest type and mineral factor (especially content of aluminum and iron oxide) on the size and quality of SOC pools are worth examining closely, though multiple factors such as climate, plant activity, soil texture, mineralogy, and aggregate stability are usually involved in stabilizing C (Feller and Beare, 1997; Oades, 1988; Sollins et al., 1996).

Both deciduous and evergreen forests are distributed under similar climatic conditions in the seasonally dry tropics of Southeast Asia. The leaf life span (and the structure of evergreen and deciduous leaves) is affected by its cost-benefit relationship (Chabot and Hicks, 1982; Orians and Solbrig, 1977; Sobrado, 1991). Consequently, difference in litter-quality between evergreen and deciduous forests leads to the difference in litter decomposition rate in temperate and boreal forests, though there is no evidence from field study that shows a different trend of accumulation pattern of SOC stock between two forest types (Augusto et al., in press). Considering these contexts, the co-existence of two forest types in seasonally dry tropics is favorable for clarifying the effect of contrasting plant functional trait on the size and quality of SOC pools under the high temperature regime. The difference in the sensitivity of SOC pools to future climate change between two forest types, if any, would also be an important implication of this approach.

In evergreen forests, higher moisture content in topsoil than deciduous forest is maintained during the dry season due to the closed canopy (Toriyama et al., 2011), and it might be favorable for microbial activity (Sollins et al., 1996) and decomposition of free forms of LF. The difference in soil moisture conditions between the two forest types could also affect the development of microaggregates, which increases the occluded form of LF and protects soil organic matter from microbial attack due to lower accessibility (Rasmussen et al., 2005; Sollins et al., 1996; Wagai et al., 2009). In contrast, frequent fires on the forest floor, which are observed solely in deciduous forests, might prohibit the development of microaggregates in topsoil (Sakurai et al., 1998). According to these differences between forest types, it is possible that a lower contribution to SOC pools is given by free LF and a greater one by occluded LF in evergreen forest soils compared with deciduous forests, leading to different sensitivities of SOC pools to deforestation in the two forest types.

In addition to forest type, the mineral factor would also provide a single or covariate effect on the size of the SOC pools. The aluminum and iron oxide contents, in both crystalline and amorphous forms, are highly positively correlated with bulk SOC content in Brazilian Cerrado because of their dependence on clay content (Zinn et al., 2007). The aluminum and iron oxides are also dominant stabilizing agents of aggregate in Oxisols and they enhance the stability of aggregates to rapid wetting events (Oades and Waters, 1991), which are frequently observed in the beginning of rainy season in seasonally dry tropics. Therefore, the contents of aluminum and iron oxides could be the primary factor affecting the size of SOC pools in seasonally dry tropical forests rather than the forest type or the other factors.

Because the soil samples are collected on a wide scale in this study, the effect of climatic condition on SOC pools should be considered even under the similar climatic regime. The variation in precipitation in dry season between study sites is expected to affect SOC pools through both plant and microbial activities (Sollins et al., 1996). Accordingly, we examined whether forest type and mineral and climatic factors affect the size and quality of the SOC pool in bulk soil and density fractions in a seasonally dry tropical forest in continental Southeast Asia. To contribute to the methodological development for estimating wide-area distribution of labile SOC pools, we also estimated the size and quality of the SOC pool as the plant-detritus form in this region using simple regression models.

2. Materials and methods

2.1. Study site

The study area was located in Cambodia, central continental Southeast Asia (Fig. 1). In 2005, the forested area of 107,308 km^2 in Cambodia was occupied by 44% deciduous forest and 47% evergreen forest, including mixed forest with deciduous trees (FAO, 2006). We selected eight sites including four each of deciduous and evergreen forests (Table 1; Fig. 1) from Ministry of the Environment monitoring sites, Cambodia (Kiyono et al., 2010). A tree census for estimating forest biomass has been conducted at the monitoring sites since 2005. In this study, we use the new site codes D1-4 and E1-4 (Table 1) for deciduous and evergreen forests, respectively, in relation to the SOC content level. The elevation at eight sites was lower than 700 m a.s.l. Meteorological data for each plot was obtained by reference to the nearest point to the gridded

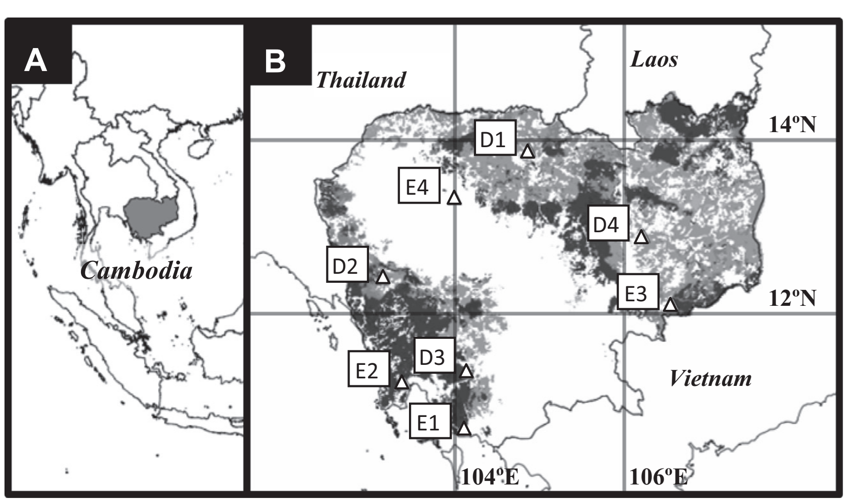

Fig. 1. Map of the study area. (A) Location in Cambodia; (B) location of the forest monitoring sites. The black and grey areas in map B shows the distribution of the evergreen and deciduous forests, respectively.