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Soil properties and gross nitrogen dynamics in old growth and secondary forest in four types of tropical forest in Thailand

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ABSTRACT

To understand the changes in soil properties and function due to human-induced disruption of mature tropical forest cover in differing climatic zones and forest types, we investigated soil properties and gross soil N dynamics in the top 5 cm of mineral soil in old-growth and young secondary (<30 years) stands of four contrasting forest types (dry dipterocarp, dry evergreen, mixed deciduous, and moist evergreen) in Thailand. In all four forest types, soil total carbon (C) and nitrogen (N) pools were not different between old-growth and young secondary forests. In contrast, soil N turnover rates, such as the gross and net mineralization and nitrification rates, were different depending on forest type (e.g., gross mineralization rate was faster in old-growth than in secondary moist evergreen forest, but faster in secondary than in old-growth for the other three forest types). Although the response of soil N turnover rate to forest succession was inconsistent among the four forest types, the gross nitrification ratio (gross nitrification rate as a proportion of gross mineralization rate) was smaller in secondary than in old-growth forest in all forest types. This shift in the inorganic N production balance by reducing NO_3-N production relative to NH_4-N production in Southeast Asia warrants further investigation, including the extent of the phenomenon and its effect on plant productivity and species composition.

1. Introduction

Tropical forests are the most diverse and carbon-rich forests in the world; they are critical for biodiversity conservation, carbon (C) storage, and climate regulation. The rate of deforestation (mainly due to conversion of forest to agricultural land) is alarmingly high in tropical regions, especially in Southeast Asia and South America (FAO, 2010). Deforestation often severely reduces ecosystem services such as C sequestration, watershed protection, and biodiversity conservation. In South and Southeast Asia, less than 30% of primary forests remain, and over 70% of all forests are secondary forest, having been either naturally regenerated or planted (FAO, 2010). Secondary forests therefore play an increasingly important ecological role in tropical areas (Letcher and Chazdon, 2009). Thus, to build an understanding of the sustainability of ecosystem services in future tropical forest landscapes, it is vital to understand how ecosystem functioning recovers during tropical forest secondary succession (Lohbeck et al., 2014).

Land-use conversion from forest to agriculture often results in changes in soil properties such as soil bulk density, C storage, nitrogen (N), and other nutrients (Murty et al., 2002). Removal of biomass causes nutrient losses and changes in N dynamics (mineralization rate, nitrification rate) (Hornbeck et al., 1990; Steudler et al., 1991). In addition, the close relationship between forest productivity and N supply from the soil (Reich et al., 1997) means that an understanding of changes in soil N dynamics is essential to evaluate the ecosystem functions of secondary forests. Although phosphorus rather than N is generally considered the most common limiting nutrient for productivity of mature tropical forests, N loss during human land use change can alter the stoichiometric balance of nutrient cycling and cause N limiting conditions during secondary succession, even in the tropics (Davidson et al., 2007).

Despite their importance, relatively little information is available about soil N dynamics (e.g., gross and net mineralization and nitrification rates) in tropical forest soils, especially in disturbed ecosystems (Mo et al., 2003). Net rates are consequences

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of production and consumption processes. On the other hand, gross rates are the indicators of total N turnover in the soil. Gross N transformations in tropical lowland soils remain under-studied, and most of what is known comes from studies in South America (Hamilton et al., 2016). To the best of our knowledge, only two studies have been conducted in Southeast Asian lowland tropical forests; these are Allen et al. (2015) and Hamilton et al. (2016), which investigated gross N transformations in moist natural and plantation forests in Indonesia. Thus, there is a large knowledge gap with respect to gross N dynamics of disturbed tropical forest in Southeast Asia, especially in dry forests. To add to the knowledge of this region and uncover any general patterns across dry to moist forest types, we explored how human use of tropical forests affects soil properties and gross soil N dynamics across four common forest types within Thailand.

Deforestation and land degradation in Thailand dates back to the mid-1890s (FAO, 2016). Thailand had mostly experienced severe forest degradation and conversion to agricultural land in Southeast Asian countries. From 1961 to 2006, forest cover was decreased from 53.5% to 30.9% of total country land (Royal Forest Department, 2006). The government, therefore, has issued a nationwide promotion of reforestation and rehabilitation of degraded land. Thailand has various types of forests due to various climates such as wide range of precipitation. Thus, for the nationwide forest recovery management, it is essential to understand both general recovery pattern among various forest types and forest-type-specific recovery patterns of soil processes those tightly link with vegetation recovery.

We compared soil properties and gross N dynamics between old-growth and young secondary forests of four types with contrasting functional vegetation types and climates—dry dipterocarp, dry evergreen, mixed deciduous, and moist evergreen—along a precipitation gradient in Thailand. In the present study, old-growth forest is a natural, mature forest whose forest structure is quite close to intact, primary forests but had been experienced a few human activities such as selective loggings by local people at some point (>30 years ago), but not as clear cut for land-use change. Young secondary forest is the forest at their early successional stage (<30 yeas) after the agricultural land was abandoned.

The main aim of this study was to compare soil properties and N dynamics between young secondary and old-growth forests. In addition, we measured reactive forms of N concentration. Ammonium (NH_4-N), nitrate (NO_3-N), and dissolved organic N (DON) are the dominant forms of reactive N in soil, and thus are the key components of biogeochemical N cycling. We addressed two overarching questions: (1) Do soil properties and N dynamics change with successional stage? (2) Are there any general patterns among the four forest types in how they differed between old-growth and secondary forest? We aimed to find consistent or forest-type-specific differences between successional stages among the four contrasting forest types.

2. Materials and methods

2.1. Study sites

We investigated the four typical forest types in Thailand (Table 1, Fig. 1). Each forest type studied included young secondary forests (<30 years since reforestation) and old-growth forests. The four forests were as follows:

Dry dipterocarp forest (DDF) and dry evergreen forest (DEF) were located at Sakaerat Biosphere Reserve in Nakhon Ratchasima Province in northeast Thailand (14°25′–14°33′N, 100°48′–100°56′E, 300–400 m a.s.l., 19.4–34.9 °C, annual rainfall 900–1200 mm, Fig. 1a) (Sakaerat Environment Research Station, 2015). The station area is surrounded by agricultural areas and human settlements (Trisurat, 2009). Vegetation covering the area is DDF and DEF (Sahunalu and Dhanmanonda, 1995). Soils are classified as Ultisols and are formed from sandstone parent material (Sakurai et al., 1998). Secondary forests were regenerated after local agricultural land use such as abandoned swidden cultivation areas (not commercial plantations).

Mixed deciduous forest (MDF) was located at the Mae-Klong Watershed Research Station in Khuansrinakarin National Park (14°34′N, 98°50′E, 200–800 m a.s.l., 11.9–40.2 °C, annual rainfall 1200–2300 mm, Fig. 1a) (Thai Meteorological Department, 2015) in Kanchanaburi Province. The soils are Ultisols developed on alluvium with residual sandstone, limestone, and quartzite (Suksawang, 1993; Marod et al., 1999). Secondary forests were regenerated after local agricultural land use such as abandoned swidden cultivation areas (not commercial plantations).

Moist evergreen forest (MEF) was located in Khao-Pu and Khao-YaNational Park (5°18′N, 102°03′E, 0–200 m a.s.l., 19.2–37.8 °C, annual rainfall 1700–2500 mm, Fig. 1a) (Thai Meteorological Department, 2015) between Trang and Patalung Province along the limestone dominated Nakhon Si Thammarat Range. The soils here are also Ultisols (Baldeck et al., 2013). Secondary forests were regenerated after local agricultural land use such as abandoned swidden cultivation areas (not commercial plantations).

2.2. Soil sampling

At each site, three 10 m × 10 m replicate plots were established in each of the secondary and old-growth forests (Fig. 1b and c). The distance between each pair of secondary and old-growth plots varied from 100 to 3000 m. In mid-August 2015 (rainy season), soil samples were collected using a core sampler (5 cm depth; 100 cm^3) to obtain the top 5 cm. For each plot, five soil core samples (Fig. 1c) were composited. Soil samples were kept in plastic bags on ice for transport to the laboratory and then kept at 4 °C. The soil samples were passed

Table 1
Main attributes of the four sites used to study the effects of forest successional stage on soil properties in Thailand.

Site name	Forest type	Succession stage	Land-use	Clay Sand	Soil	Elevation Temperature	Rainfall Drought period
Sakaerat Environmental Research Station	Dry dipterocarp forest (DDF)	Old-growth		19 ± 1%	Ultisol	300–400 m	900–1200 mm/y
		Secondary (30 years)	Local agriculture	56 ± 3%		19.4–34.9 °C	November–April
	Dry evergreen forest (DEF)	Old-growth		25 ± 2%			
		Secondary (30 years)	Local agriculture	50 ± 3%			
Maeklong Watershed Research Station	Mixed deciduous Forest (MDF)	Old-growth		27 ± 2%	Ultisol	200–800 m	1200–2300 mm/y
				54 ± 3%		11.9–40.2 °C	November–April
		Secondary (30 years)	Local agriculture				
Khao-Pu Khao-Ya National park	Moist evergreen forest (MEF)	Old-growth		27 ± 2%	Ultisol	0–200 m	1700–2500 mm/y
		Secondary (15 years)	Local agriculture	62 ± 2%		19.2–37.8 °C	January–April