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Soil changes induced by *Acacia mangium* plantation establishment: Comparison with secondary forest and *Imperata cylindrica* grassland soils in South Sumatra, Indonesia

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Abstract

Acacia plantation establishment might cause soil acidification in strongly weathered soils in the wet tropics because the base cations in the soil are translocated rapidly to plant biomass during *Acacia* growth. We examined whether soils under an *Acacia* plantation were acidified, as well as the factors causing soil acidification. We compared soils from 10 stands of 8-year-old *Acacia mangium* plantations with soils from 10 secondary forests and eight *Imperata cylindrica* grasslands, which were transformed into *Acacia* plantations. Soil samples were collected every 5–30 cm in depth, and pH and related soil properties were analyzed. Soil pH was significantly lower in *Acacia* plantations and secondary forests than in *Imperata* grasslands at every soil depth. The difference was about 1.0 pH unit at 0–5 cm and 0.5 pH unit at 25–30 cm. A significant positive correlation between pH and base saturation at 0–20 cm depth indicated that the low pH under forest vegetation was associated with exchangeable cation status. Using analysis of covariance (ANCOVA), with clay content as the covariate, exchangeable Ca (Ex-Ca) and Mg (Ex-Mg) stocks were significantly lower in forested areas than in *Imperata* grasslands at any clay content which was strongly related to exchangeable cation stock. The adjusted average Ex-Ca stock calculated by ANCOVA was 249 kg ha^{-1} in *Acacia* plantations, 200 kg ha^{-1} in secondary forests, and 756 kg ha^{-1} in *Imperata* grasslands at 0–30 cm. Based on a comparison of estimated nutrient stocks in biomass and soil among the vegetation types, the translocation of base cations from soil to plant biomass might cause a decrease in exchangeable cations and soil acidification in *Acacia* plantations.

Keywords: *Acacia mangium*; Cation; Chronosequence study; Fast wood plantation; Humid tropics; *Imperata cylindrica*; Soil acidification

1. Introduction

Acacia species have been introduced in commercial plantations in Southeast Asia. The total area of tree plantations is now approaching 2 million ha and the largest of these plantations (about 1.2 million ha) is located in Indonesia, where the major planted species is fast-growing *Acacia mangium* Wild. Currently, *A. mangium* wood is primarily used for pulp, paper, and other wood products (Arisman and Hardiyanto, 2006; Potter et al., 2006). *A. mangium* has high nitrogen-fixing ability by symbioses with nodule forming bacteria and produces leaves that are more nitrogen-rich than native tropical leguminous trees (Tilki and Fisher, 1998; Akinnifesi et al., 2002).

The characteristics of *A. mangium*, a fast-growing nitrogen fixer, may lead to soil acidification because base cations rapidly accumulate in its biomass; these base cations are matched by the extrusion of H^+ from roots, and base cation loss from the soil profile is associated with high leaching of nitrate anions (Binkley and Giardina, 1997). The concentration of nitrate anions is high in soils under nitrogen-fixing trees because of their nitrogen-rich leaves. In *Albizia falcataria* and *Eucalyptus saligna* plantations in Hawaii, soil pH decline is driven by the accumulation of nutrient cations in plant biomass, with increasing aluminum saturation of the soil exchange complex (Rhoades and Binkley, 1996). Although soil acidity might compromise plantation performance by affecting the availability of essential soil nutrients and the solubility of potentially toxic elements, little is known about soil acidification in *A. mangium* plantations.

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Table 1
Representative soil properties in *Acacia mangium* plantations in South Sumatra, Indonesia

Layer	Depth (cm)	$pH_{(H_2O)}$[a]	$pH_{(KCl)}$[b]	ECEC[c] ($cmol_{(+)}\ kg^{-1}$)	Clay (%)	BS[d] (%)
Veti-hyperdystric acrisol						
Ah	0–6	4.4	3.7	4.7	22	12
EA	6–21	4.2	3.8	3.5	26	9
BEt	21–40	4.2	3.7	3.7	39	5
B1	40–60	4.3	3.7	3.5	41	4
B2	60–90	4.4	3.8	3.5	47	4
Bw1	90–120	4.5	3.8	4.1	54	3
Bw2	120–145	4.5	3.8	4.3	56	4
CB1	145–180	4.5	3.7	4.2	56	3
CB2	180–	4.5	3.7	4.5	51	3

[a] 2.5:1 in H_2O.
[b] 2.5:1 in 1 M KCl.
[c] Effective cation exchange capacity.
[d] Base saturation (exchangeable cations/effectivecation exchange capacity).

Because *Imperata cylindrica* grasslands and secondary forest were the major land-cover types prior to *A. mangium* plantation establishment, the current status and mechanisms of soil acidification induced by *A. mangium* plantations can be determined by comparing the soil pH and related soil parameters among these vegetation types. Our objectives were to clarify whether soils under *A. mangium* plantations have been acidified and to determine the factors that cause soil acidification in *A. mangium* plantations.

2. Materials and methods

2.1. Comparative approach

We used a soil comparative approach known as a chronosequence study. *Imperata* grasslands were a major land-cover type before plantation establishment, and secondary forests were present prior to *Imperata* grassland establishment. Thus, we compared soils from these different vegetation types to clarify soil acidification processes during the conversion from secondary forest to *Imperata* grassland and from *Imperata* grassland to *A. mangium* plantation.

2.2. Site descriptions

We studied an industrial *A. mangium* plantation area in South Sumatra Province, Indonesia (3°00′–4°00′S, 103°00′–104°30′E). About 190 kha of *A. mangium* plantation have been established on the undulating land (60–200 m above sea level) in this area.

At the study site, the annual mean temperature was 29 °C and annual precipitation was 2520 mm in 2004. There is rainfall throughout the year, with weak seasonality, i.e., low rainfall from June to September and high rainfall from November to April. The geology is Tertiary sedimentary rocks, with alternate layers of sandstone, claystone, and mudstone (FAO-UNESCO, 1979). The soils in this area are Acrisols (FAO-UNESCO, 1979). A representative soil profile in the *A. mangium* plantation was classified as Veti-hyperdystric acrisol (Table 1). This soil is characterized by deep weathering, low-activity clays, and low base saturation. The clay content ranged from 22% in surface layers to over 55% at 150 cm in depth. The pH_{H_2O} exceeded the pH_{KCl} in all layers. The effective cation exchange capacity (ECEC) was very low (3.5–4.5 $cmol_{(+)}\ kg^{-1}$ in the B layer), whereas the cation exchange capacity (CEC) with ammonium acetate at pH 7.0 was relatively high (7–14 $cmol_{(+)}\ kg^{-1}$ in the B layer). Base saturation by ECEC decreased with depth, but was 12% in the surface layer; the soil exchange complex was dominated by exchangeable acidity, mainly Al.

I. cylindrica grasslands and secondary forests were located around the plantation area. Almost all secondary forests were fallow forests of shifting cultivation. The fallow age was 20–30 years, based on interviews with the local people. *I. cylindrica* grasslands have spread in south Sumatra (Gouyon et al., 1993) after repeated disturbances such as slash and burn agriculture, extensive cattle grazing or natural fires in primary or secondary forests (Seth, 1970; Otsamo et al., 1995). In the study area, *A. mangium* plantations were established in the early 1980s. *A. mangium* was typically planted on *I. cylindrica* grassland after mechanized plowing and initial fertilization. The plantations are maintained on an 8-year rotation for pulp wood production.

2.3. Soil sampling

We collected soil samples at 28 locations, 10 in 8-year-old *A. mangium* plantations (hereafter *Acacia* plantations), 10 in secondary forests, and 8 in *I. cylindrica* grasslands (hereafter *Imperata* grasslands), from March to September in 2003. *A. mangium* plantations in first rotation phase were selected by referring the map of forest compartment belonging to the plantation company.

A 20 m × 20 m plot was created in each of the 28 locations. In each sampling plot, soil samples were collected every 5 cm from 0 to 30 cm in depth using three 100-mL sampling cylinders at six different sampling points. These points were placed randomly in each plot. We mixed the samples from the same depth from the six sampling points in each plot. Thus, we prepared 6 composite layer samples for each of the 28 locations.