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Soil chemical and microbial properties after disturbance by crawler tractors in a Malaysian forest plantation

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Abstract

Extracting timber with heavy machinery on humid tropical soils degrades the soil structure and decreases plant growth. We investigated how disturbance by crawler tractors affected soil chemical and biological properties in a second-generation plantation in Sabah, Malaysia. Total N, total P, and anion resin-extractable P contents were analyzed. N- and P-limited microbial respiration kinetics were bioassayed (by measuring them before and after the addition of glucose + P and glucose + N, respectively), to assess changes in the soil's biological properties. Three months after planting, the soil's organic content were 25% lower on tracks compared to control plots that had not been affected by crawler tractors, while microbial indices of N and P availability were about 50% lower. Two years after planting acid-digestible P, N, and anion resin-extractable P contents were still lower along the tracks, as was one of two indices of microbial P and N availability, respectively. Therefore, the results indicate that soil conservation needs to be improved during the establishment phase to maintain the fertility of forest plantations such as the one studied. If crawler tractors are used, skid-tracks should be designated and their coverage minimized.

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1. Introduction

Timber extraction with heavy machinery on humid tropical soils has adverse effects on plant growth and soil structure along the skid-tracks used to transport the harvested logs (Nussbaum et al., 1995; Woodward, 1996). This degradation is caused mainly by removal of the upper, organically rich, porous soil (Woodward, 1996; Malmer et al., 1998) down to the denser, organically poor B horizon. Skid-tracks commonly cover 20–40% of the operational area of commercial forests after selective logging or clear-cutting (see, for instance, Fox, 1969; Malmer and Grip, 1990).

In contrast to their effects on tree growth and the soil's physical properties, the effects of skid-tracks on the soil's chemical and biological properties have received little attention. Soil micro-organisms exert a major influence on ecosystem functions by regulating carbon and nutrient cycling, litter decomposition and nitrification. The pool of nutrients in the microbial biomass is a major source of labile nutrients in most soils (Myrold and Tiedje, 1986; Binkley and Vitousek, 1989), which is important since the nutrient supply generally limits plant growth, although the microbial communities in most ecosystems are constrained by carbon availability (Gallardo and Schlesinger, 1990; Wardle, 1992; Paul and Clark, 1997). The microbial biomass is generally smaller than that of higher plants, but it may contain a similar amount of P, per unit area, to the vegetation (Hayman, 1975).

Since the turnover of soil microbial biomass is much higher than that of plant biomass, the microbes' demands for, and uptake of, nutrients are often high (Cole et al., 1977; Paul and Clark, 1997). Thus, changes in the nutrient status of the microbial community might explain much of the variation in plant nutrient availability and productivity. Nordgren (1992) developed a nutrient status bioassay based on the respiratory responses of soil samples treated with glucose and nutrients. When the soil samples were supplied with glucose and excess levels of all nutrients except one (the ‘‘limiting’’ nutrient), the respiratory rate response was shown to be proportional to the added amount of the limiting nutrient (hereafter called ‘‘calibration addition’’). Analyses based on this method have shown that the microbial N availability in a tropical soil was affected by fire (Ilstedt et al., 2003) and the microbial P

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availability in a boreal soil was related to the Al and Fe concentrations in the organic layer (Giesler et al., 2004).

The objective of the present study was to examine how total N, total P and anion-extractable P contents, and indices of microbial N and P availability, were affected by skid-tracks in a tropical plantation in Sabah, Malaysia.

2. Materials and methods

2.1. Site description

The study site (4°55′N, 115°47′E) was situated close to the Mendolong research area at an altitude of 580–620 m in the foothills of Mt. Lumako 35 km southeast of the coastal city of Sipitang, Sabah, Malaysia (Northern Borneo). The average precipitation was 3383 mm (1985–2000). During this study, the mean annual precipitation was 1840 and 3290 mm in 1997 and 1998, respectively. An area with Haplic Acrisols – US Soil taxonomy equivalent, Ultisol – (FAO, 1988; Soil Survey Staff, 1996), developed on sandstone and shale, was chosen because this soil type predominates in large areas of South East Asia, and is common all over the humid tropics. Mineral topsoil (0–5 cm) textures in Acrisols of the research area ranged from sandy loam to clay loam. The porosity in nearby undisturbed forest soil was high, up to 60–70% (Malmer and Grip, 1990), and the bulk density was 0.83 (standard deviation, S.D., 0.09) Mg m^{-3} in the uppermost 5 cm of the soil (Malmer and Grip, 1990). Below this topsoil, a 5–20 cm deep transitional A/E horizon is generally found with lower organic matter contents, and bulk densities ranging between 1.0 and 1.2 Mg m^{-3}. Below the A/E horizon, there is a massive argillic Bt horizon, extending to a depth of about 1–2 m. These changes with depth in the soil profile are accompanied by increases in exchangeable Al, and reductions in N and P (Ilstedt and Sing, 2005). In order to increase stability and traction, crawler tractors normally remove the topsoil and parts of the A/E horizon already during the first passage.

2.2. Experimental design

The original vegetation was hill dipterocarp forest (Whitmore, 1984), which was logged in 1988 and in the same year *Acacia mangium* was planted. The resulting stands were logged, the residues were burned and a second generation of *A. mangium* was planted in early 1998. In October 1998, in an approximately 5 ha plantation area, 10 experimental plots (each covering 10 m × 4 m) were laid out on the tracks caused by skidding with crawler tractors (Caterpillar; size class D6). An additional set of 10 control plots, of the same size as those on the tracks, were laid out at random on surfaces that were not covered by tracks. All treatments were stratified for two types of plot surface (convex to flat, or concave) to account for topographic effects. This resulted in five replicates per treatment combination and surface type.

2.3. Establishment and maintenance

Following the routine nursery practices of the local forest company (Sabah Forest Industries Sdn. Bhd.), seedlings were raised in seedling trays and planted 3 months later, when 25–30 cm tall. In the nursery, 5 g (NPK, 10:26:10) Agroblen (Scotts, Marysville, USA) per seedling was mixed into the mineral soil used as the potting medium. Agroblen is a slow release fertilizer that is effective for about 7 months. In the field, planting was carried out only on consecutive rainy days. On tracks a spade was used to dig the planting holes (8 cm diameter, 10 cm deep). Planted seedlings were examined 2 weeks after planting and dead seedlings were replaced. On each plot, five trees were planted with a spacing of 2 m. Plots were manually weeded using machetes at 3-monthly intervals throughout the study. All plots were fenced to avoid human disturbance. Because of a misunderstanding with field personnel, plots outside the tracks were planted a month after the plots on the tracks.

2.4. Soil sampling

Soils were sampled in January 1999 and August 2000. On each occasion two samples from a depth of 0–5 cm were collected from the side of four soil pits (0.2 m × 0.2 m), dug between the planted trees near the centre of each plot, using a cylindrical sampling device (diameter 7.2 cm, height 5 cm). The resulting four samples were bulked into one composite sample. All samples were immediately placed in plastic bags and kept shaded before being transported to the laboratory (within 3 h of sampling). In the laboratory the samples were weighed and homogenized by hand. The samples were not sieved, but visible roots were removed manually. Samples were placed in the freezer within 6 h of sampling for subsequent processing. Water content (105 °C, 14 h) and loss on ignition (LOI; 500 °C, 4 h) from one sub-sample of each bulk soil sample were determined, and a second sub-sample was used for acid digestion (see below). Acid digests and a third sub-sample for chemical extractions and microbial analyses were transported by air to Sweden (inside a foam-box cooler). Upon arrival in Sweden most of the samples were still frozen, indicating that temperatures had stayed below or close to 0 °C inside the box. The soil samples were then kept in a freezer until analysis. Freezing tropical soils is likely to induce changes in their properties, but this disturbance was considered unavoidable because the alternative (storing samples for a prolonged time at temperatures above 0 °C) would have been even more detrimental (Stenberg et al., 1998; Verchot, 1999). However, despite the disturbance the results should provide valid comparisons of relative (if not absolute) differences among treatments.

2.5. Microbial growth kinetics

Microbial respiration kinetics was measured within 2 months of each sampling occasion. Before soil respiration was measured, the soils were adjusted to −15 kPa water potential (Klute, 1986) to optimize conditions for microbial respiration (Ilstedt et al., 2000). Then, 20 g wet-weight of moisture-adjusted soil, from four plots representing each treatment, was weighed into 300 ml plastic jars used for the

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