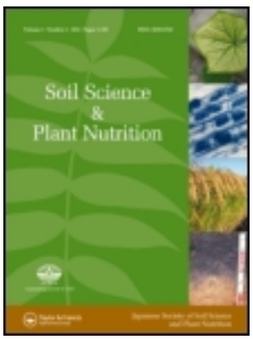

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Effect of Land Degradation on Soil Microbial Biomass in a Hilly Area of South Sumatra, Indonesia

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We investigated the impact of land-use changes on the soil biomass at several soil sites in Indonesia under different types of land-use (primary forest, secondary forest, coffee plantation, traditional orchard, and deforested area), located within a small geographical area with similar parent material and climatic conditions. Various parameters of soil microbial biomass (biomass C, biomass N, content of anthrone-reactive carbohydrate carbon, and soil ergosterol content) were examined. Our results suggested that the removal of the natural plant cover did not cause any appreciable decrease in the amount of microbial biomass; on the contrary it led to a short-time increase in the amount of microbial biomass which may be due to the availability of readily decomposable dead roots and higher sensitivity to the decomposition of residual litter in recently deforested soils. However, the amount of microbial biomass tended to decrease in proportion to the duration of the land history in coffee plantation soils. This may be ascribed to the effect of the loss of available substrates associated with soil erosion in the long term. Lower ergosterol contents in recently deforested areas reflected a reduction in the amount of fungal biomass which may be due to the destruction of the hyphal network by the slash and burn practice. On the other hand, the higher soil ergosterol content at the sites under bush regrowth indicated that microbial biomass was able to recover rapidly with the occurrence of a new plant cover.

Key Words: **anthron reactive carbon, ergosterol content, microbial biomass, soil degradation.**

Indonesia is one of the many countries feeling the burden of a large population concentrated in a relatively small area. Soil degradation has become a major problem due to drastic land-use changes associated with the transmigration policy. In the past two decades, the area covered by primary forest decreased by 44% whereas coffee-planted areas increased by 60% in hilly areas in Lampung province, south Sumatra, Indonesia (Syam et al. 1997). A large number of studies have been carried out on the changes in soil chemical properties (Lumbanraja et al. 1998), organic matter content (Tsutsuki et al. 1999), humus composition (Watanabe et al. 1999), soil enzyme activities (Salam et al. 2001), and also water run-off and soil erosion (Afandi et al. 1999) in disturbed areas of Lampung province, Sumatra island. However, there is still a lack of information on micro-fauna scale. As an active fraction of soil organic matter, microbial biomass can provide a functional indication of slow changes, less easily detectable alterations in soil quality and accurate information on soil degradation in tropical soils (Henrot and Robertson 1994). Furthermore, biological degradation of soil is related to the deterioration or elimination of various populations of soil microorganisms that can cause changes in biochemical processes within the associated system (Sims 1990). We therefore examined various fractions of microbial biomass, e.g., biomass C, biomass N, anthrone-reactive carbohydrate carbon, and also ergosterol content as an indication of living fungal biomass (Stahl and Parkin 1996), in deforested soils and also in soils under primary and secondary forests, coffee plantations, traditional orchards etc. Our objective was to investigate the effect of intensive land-use changes on the soil microbial biomass in hilly areas of Lampung province, south Sumatra, Indonesia.

Materials and Methods

Soil sampling. Soil sampling was carried out at eight soil sites including a primary forest (PF), a secondary forest (SF), previously deforested bush regrowth (BR), 2, 3, and 15 years old coffee plantations (CP-2, CP-3, CP-15), traditional orchard (TO), and finally a

deforested area (DA) at the end of the dry season in September 2001. All of the sites were on the same slope located in a hilly area of the Bukit Barisan mountain range (4°55′–5°10′ S and 104°19′–104°34′ E) in Lampung province, South Sumatra, 780–2,155 m above the sea level. In the sampling area the wet season extends over 7–9 months while the dry season over less than 2 months. Annual rainfall is approximately 1,500–2,000 mm and mean temperature is 22–25°C (Lumbanraja et al. 1998). Primary forest was located in the upper part of the slope, between 800–1,200 m above sea level. Secondary forest was located next to the primary forest between 500–800 m above sea level. The area, which was under bush regrowth, had been covered by secondary forest until the forest was slashed in 1999 and since then this area has been left to bush regrowth. Deforested area, which had also been covered by secondary forest, was slashed and burned 6 months before soil sampling. All the coffee-planted sites were located on the lower part of the slope, adjacent to bush regrowth and secondary forest sites. At each site, cubical soil samples (100 g approximately) were taken randomly from 20 points, within a 20–40 m circular area, from a 0–10 cm depth of A horizon after the plant cover was carefully removed from the soil surface. The samples of each soil site were combined and mixed well in a polythene bag. All the samples were stored at 4°C before being brought to Japan.

Measurement of soil chemical characteristics. Soil pH was measured in H_2O and KCl with a soil to solution ratio of 1 : 2.5. Total C and N contents were determined with a C-N corder (MT-700, Yanaco).

Measurement of soil microbial biomass. For microbial biomass measurements, two sets (fumigation and control groups) of triplicated soil samples (15 g on a dry basis) were moistened to 50% of their WHC and incubated at 25°C for 21 d prior to the biomass measurements. The amount of soil microbial biomass (SMB) was determined by the chloroform fumigation-extraction method as indicated by Vance et al. (1987). The content of organic C in the extracts was measured by using a total organic carbon analyzer (5050, Shimadzu). The amount of microbial biomass carbon (MBC) was calculated from the relationship: biomass C = 2.22 × E_C (Wu et al. 1990) where E_C is {(the amount of organic C extracted from fumigated soils) − (the amount of organic C extracted from non-fumigated soils)}. The amount of ninhydrin-reactive nitrogen in the soil extracts was measured according to the method of Joergensen and Brookes (1990) and converted to microbial biomass N (MBN) by multiplication with the factor 3.1 (Zeller et al. 2000), as previously indicated by Amato and Ladd (1988). The amount of anthrone-reactive carbohydrate carbon (ARC) in the soil extracts was measured and the amount of anthrone-reactive carbohydrates included in the microbial biomass (B-ARC) was calculated according to method of Badalucco et al. (1990). The amount of anthrone-reactive carbohydrates in the non-fumigated extracts was assumed to consist of the free carbohydrate pool (F-ARC) in soil (DeLuca and Keeney 1993).

Measurement of soil ergosterol content. The ergosterol assay was performed as soon as the samples were brought to Japan. Fifteen milliliters of MeOH was added to 5 g of field moist samples and these solutions were stored at −20°C prior to the ergosterol measurement. Extraction of soil ergosterol and preparation of spiked samples were performed as indicated by Eash et al. (1996) and the ergosterol content of the samples was determined by using a gas chromatograph (GC-14B, Shimadzu) equipped with a hydrogen flame ionization detector and a megapore column, 30 m in length (0.542 mm inside diameter). Ergosterol recovery evaluated by the spike-recovery experiment ranged from 76 to 98% for 8 soils.

The results presented are the arithmetic means of the measurements of triplicate samples and are expressed on an oven-dried basis (24 h, 105°C). Statistical analyses were performed by using MINITAB software (Minitab Inc.).

Results and Discussion

Some of the soil characteristics are shown in Table 1. Total C and N contents decreased in the order of PF > SF > CP, TO, and BR soils. No significant relationships between the total C, N, and microbial biomass parameters were evident (Table 2). Soil pH values in the DA, BR, and CP soils were higher than those in the PF and SF soils, suggesting that wood ash which appeared after burning had released a high amount of basic cations and thus raised the pH (Pietikainen and Fritze 1995).

The data of MBC, MBN, carbohydrate content, and soil ergosterol content (SEC) of the study sites are shown in Fig. 1. Across the sites, MBC ranged from 286 to 1,176.9 μg C g^{-1} soil (Fig. 1a) and accounted for 0.9 to 4.4% of the total C content with 2.3% as a mean. There was no statistical relationship between the amount of MBC and other microbial parameters (Table 2). PF soil showed the largest value of MBC (1,176.9 μg C g^{-1}). In contrast, the DA soil showed a smaller value of MBC (952.4 μg C g^{-1}). The BR soils contained 1,084.9 μg biomass C g^{-1} soil. In Indian tropical soils, Sahani and Behera (2001) reported that the amount of biomass C ranged between 901 and 150 μg C g^{-1} in natural forest and deforested soils, respectively. Kirchman and Eklund (1994) stated that the amount of biomass C ranged from 816 μg C g^{-1} in the surface layer of African tropical soils. Our values were close to the data

Table 1. Chemical characteristics of the soils collected from areas differing in land-use.

Soils	Botanical characteristics	Soil type	pH (in water)	Moisture content (%)	Total C (mg g^{-1} soil)	Total N (mg g^{-1} soil)	C / N ratio
PF	*Shorea* spp. *Hopeamengarawan* *Dipterocarpus* spp. *Dryobalanops* spp.	Inceptisol[a]	4.43	39.7	64.7	4.7	13.6
SF	*F. ampelas, F. variegata* *Hibiscus* spp. *H. ficus* *H. calamus*	Inceptisol	4.85	24.3	46.6	3.2	14.56
DA		Inceptisol	6.15	31.2	33.2	2.75	12.0
BR	*Imperata cylindrical*	Inceptisol	5.73	25.7	24.5	2.31	10.6
CP-2	*Coffea robusta*	Inceptisol	5.13	25.1	35.9	2.80	12.8
CP-3			5.81	20.9	30.8	2.52	12.2
CP-15			4.89	22.4	27.5	2.55	10.8
TO	*Carica papaya* L. *Musa papientum, Artocarpus heterophylus* L. *Gossypium arboreum* L.	Inceptisol	5.19	29.7	30.6	2.67	11.5

PF, primary forest; SF, secondary forest; DA, deforested area; BR, bush regrowth; CP-2, 2 years old coffee plantation; CP-3, 3 years old coffee plantation; CP-15, 15 years old coffee plantation; TO, 20 years old traditional orchard. [a] Soil Survey Staff (1998).

Table 2. Correlation coefficients among chemical and microbial parameters of the soils under different types of land-use.

Parameters	pH	Soil moisture	Total C	Total N	Biomass C	Biomass N
Soil moisture	−0.33					
Total C	−0.67	0.71*				
Total N	−0.68	0.80*	0.98***			
C / N	−0.46	0.29	0.80*	0.66		
Biomass C	−0.20	0.72*	0.32	0.43		
Biomass N	0.65	0.25	−0.40	−0.33	0.52	
B-ARC	0.14	0.56	−0.01	0.03	0.65	0.79*
F-ARC	−0.76*	0.09	0.28	0.35	−0.03	−0.64
Ergosterol	−0.34	0.05	0.46	0.34	0.04	−0.35

$n = 8$. B-ARC, anthrone-reactive carbohydrate carbon in microbial biomass; F-ARC, non-biomass (free) anthrone-reactive carbohydrate carbon. $^{*}p < 0.05$; $^{***}p < 0.001$.

obtained by Luizao et al. (1992) in various tropical soils in South America. Under similar climatic conditions to those of our study, they found that the biomass C values were 1,287 and 829 μg C g^{-1} in the soils from the forest and burned areas, respectively. The range of MBN was estimated to be 48–138.2 μg N g^{-1} soil and accounted for 1.5 to 6% of the soil total N content with 3.4% as an average value. In contrast to biomass C, the amount of biomass N was higher in the DA (131.5 μg N g^{-1}) and the BR (138.2 μg N g^{-1}) soils than in the PF (78.6 μg N g^{-1}) and the SF (48 μg N g^{-1}) soils. It decreased in the CP soils along with the increasing age of the plantation (Fig. 1b). Sahani and Behera (2001) stated that in Indian tropical soils, the amount of biomass N was higher in natural forest (104 μg N g^{-1}) than in deforested barren (35 μg N g^{-1}) soils. The observations of Smolander et al. (1998), who showed that MBN increased in the first summer after clear-cutting in spruce forest soils in Norway, are in agreement with the results of our study. Our data obtained from the DA and CP soils indicated that the microbial biomass tended to decrease after deforestation in the long term. This trend was more obvious, especially in the case of MBN, which consistently decreased with the increasing age of the CP soils (Fig. 1b), presumably due to the effect of drastic soil erosion especially in hilly areas in western Lampung (Afandi et al. 1999). The removal of significant amounts of surface soil materials by erosion has been found to result in a loss of microbial biomass (Sims 1990). A close relationship between biomass C and N was not revealed in our study. Studies on agricultural soils showed that the microbial C pool largely parallels the microbial N pool, which is probably due to the small variations in pH and nutrient availability and regular

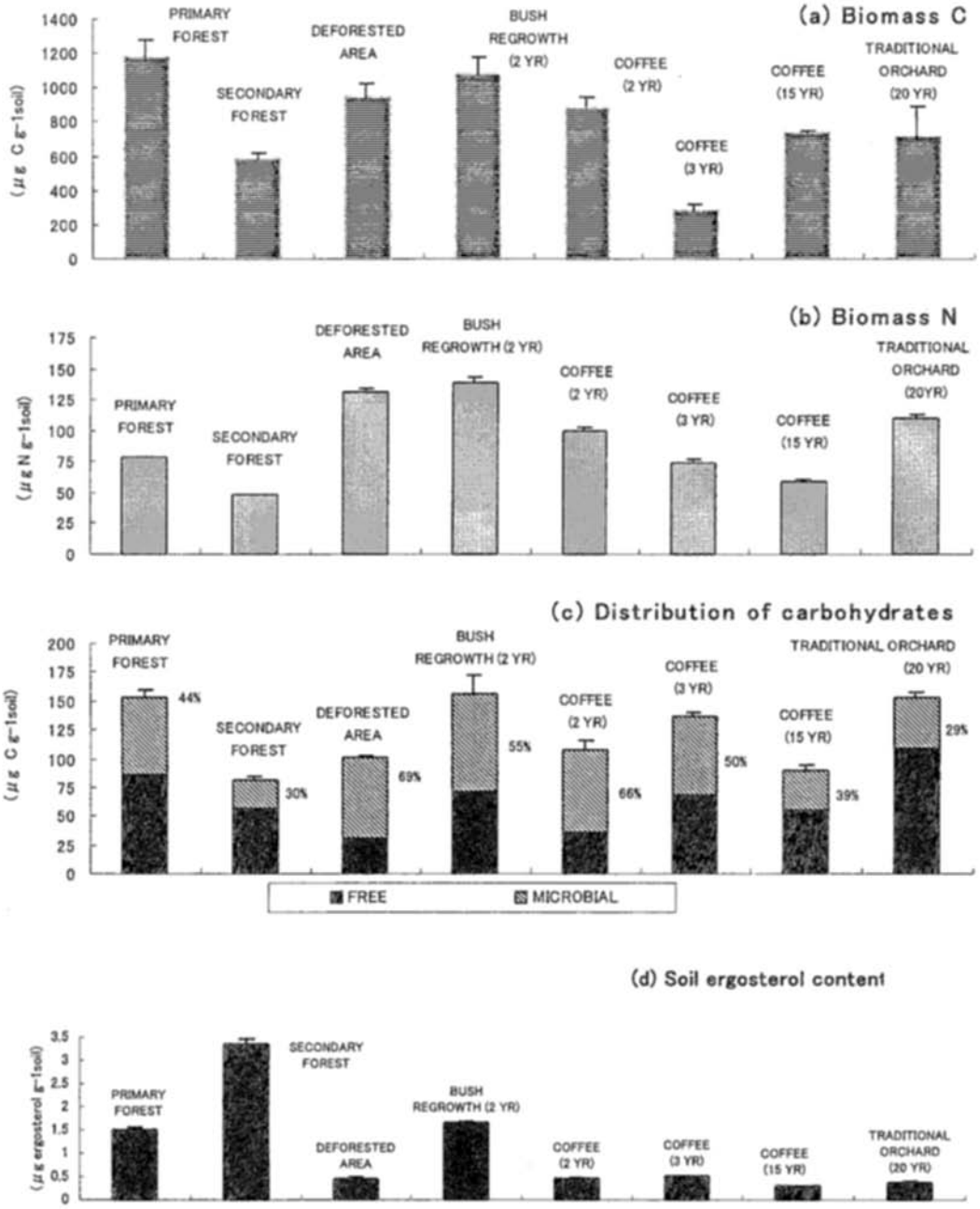

Fig. 1. Changes in values of biomass C (a), biomass N (b), anthrone-reactive carbohydrate content (c), and soil ergosterol content (d) at different times after deforestation. Bars in figures denote SD values ($n = 3$) and percentages in (c) indicate the amount of carbohydrates included in microbial biomass.

management practices (Kaiser et al. 1992). However, this is questionable in forest soils in which the activity and growth of the soil microflora are often limited by nutrient availability. For example, microbial N incorporation is significantly affected by C and N availability (Joergensen et al. 1995). Lower values of carbohydrates in the microbial biomass compared to those of free carbohydrates in the PM, SF, CP-15, and TO soils (Fig. 1c) and the significant correlation between B-ARC and biomass N (Table 2) in our study support this assumption. Moreover, the lower ergosterol values in the CP-2, CP-3, CP-15, TO, and DA soils compared to the PF and SF soils (Fig. 1d) showed that deforestation ended the dominance of fungi. The difference in the trends in biomass C and N can therefore be explained by the changes in the composition of the microflora at different sites in our study.

Carbohydrate content determined from the extracts of biomass assay showed that the amounts of free and microbial carbohydrates (F-ARC and B-ARC) ranged

from 31.3 to 108.3 and 24.7 to 85.5 μg glucose C g^{-1}, respectively (Fig. 1c). No statistical relationships were found between the contents of soil carbohydrates and MBC or SEC. However, there was a significant correlation between the amounts of microbial carbohydrates and biomass N (Table 2), presumably due to the degree of availability of C which may affect microbial N incorporation (Joergensen et al. 1995). The amount of B-ARC was lower than that of F-ARC in the forest and also in the CP-15 and TO soils, which had been subjected to deforestation long time ago (Fig. 1c) because in forest soils, plant litter penetrates into the soil above ground where it forms a humus layer and carbohydrates are preferentially mineralized and accumulated in the course of humification (Kogel-Knabber et al. 1988). This may be related to the accumulation of relatively inert soil organic matter against a relatively small and constant input of microbial biomass in natural ecosystems. In contrast, we observed that the amount of B-ARC was higher than that of F-ARC in the DA and BR soils (Fig. 1c). This may be due to the effect of deforestation that leads to the decomposition of high molecular weight C compounds (e.g. lipids and lignin) to carbohydrates by microbial synthesis (Gregorich et al. 1996).

Ergosterol is a fungal membrane component and its amount has been shown to be correlated with the fungal surface area (West et al. 1987). A decrease in SEC therefore reflects a reduction in the fungal biomass. In the present study, the SEC ranged from 0.30 to 3.35 μg ergosterol g^{-1} soil (Fig. 1d). There was no significant relationship between SEC and other parameters (Table 2). The SEC was considerably lower in the DA, CP, and TO soils than in the PF, SF, and BR soils (Fig. 1d). These results are consistent with previous findings (Bååth 1980; Pietikainen and Fritze 1995) indicating that the number of soil fungi decreased with clear-cutting and burning treatments. In our study, the amount of fungal ergosterol was approximately 80% less in the DA, CP, and TO soils than in the PF, SF, and BR soils. This severe decrease probably resulted from the interruption of root growth and exudation due to the removal of the natural plant cover (Bååth 1980).

Pietikainen and Fritze (1995) stated that a reduction in the number of mycorrhizal fungi could be reflected by observing the decrease in SEC and they showed that the amount of fungal ergosterol decreased by 56% after burning treatment in northern Finland soils. Our data of SEC are consistent with those of Arif et al. (1999) who reported that the number of genera and species of arbuscular mycorrhizal fungi were low in the CP soils compared to the PF and SF soils in the same area as that of our study in southern Sumatra. Although SEC drastically declined after deforestation (Fig. 1d), the amounts of biomass C and N showed higher values in the DA soil than in the adjacent SF soil (Fig. 1a and b), which may indicate a shift in the bacterial and fungal communities. Bacteria are more tolerant to fire and clear-cutting than fungi and they show a higher ability to survive during burning or to proliferate in burned soils and thus dominate the soil microbial biomass after clear-cutting or burning (Bååth 1980; Pietikainen and Fritze 1995). Despite the severe effect of the slash and burn practice on the soil fungi, the comparatively higher SEC in the BR soil (Fig. 1d) suggests that burned soil is always gradually recolonized by surviving microorganisms in soil (Theodorou and Bowen 1982) or microorganisms introduced from adjacent areas (Jalaluddin 1969). Zeller et al. (2000) also noted a relatively higher ergosterol content in abandoned soils in their study.

In conclusion, our results suggest that the amount of microbial biomass may slightly decrease or increase in recently deforested soils. This is not surprising because in most studies, it was reported that the amount of biomass of the micro-fauna and flora increased during the first few years and sometimes persisted as long as 5 to 15 years after clear-cutting or controlled burning. This may be due to the availability of readily decomposable dead roots and greater sensitivity to decomposition of residual litter associated with more favorable moisture and temperature conditions in deforested soils (Paul and Clark 1996). However the fungal biomass is highly vulnerable to tropical forest clearing indicating that microbial diversity was adversely affected by land-use changes in Sumatra, Indonesia.

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