Effects of short-rotation harvesting on soil microbial biomass and nitrogen mineralization in *Gmelina arborea* plantations in East Kalimantan

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**ABSTRACT** In order to elucidate the effects of short-rotation harvesting on microbial biomass and nitrogen (N) mineralization in soil, we studied *Gmelina arborea* Roxb. (yemane) plantations and the mixed planting of a legume cover crop in East Kalimantan. The microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) decreased by approximately 40% to 50% in the plantation plots than in a secondary forest plot. The MBC increased with the stand age in the plantation plots, while the MBN remained low. In a mixed plot of yemane and legumes, the MBC, MBN, and N mineralization rate were approximately the same as those in a 10-yr plantation plot without cutting; however, these values were higher than those in a 4-yr coppice plot after the cutting of a 6-yr plantation. Mixed planting of a legume cover crop might influence the soil nutrition by N2 fixation. The percentage of the MBN in the total N in the plantation plots was lower than that of the MBN in the total N in the secondary forest plot because the rate of decrease in MBN was higher than that in the total N due to clear-cutting and plantation.

Key words: tropical plantation, microbial biomass, legume cover crop, nitrogen mineralization

**INTRODUCTION**

In recent years, the deterioration of tropical forests has been one of the main environmental factors that cause alterations in the environment. Tropical deforestation is associated with socio-economic conditions. The plantation of fast-growing trees is one of the options for supplying timber and chip, and for mitigating the environmental deterioration caused by deforestation. Additionally, such plantations contribute to carbon sequestration (Reddy, 2002). However, there is a concern that clear-cutting and short-rotation harvesting of fast-growing trees may adversely affect soil productivity (Agus et al. 2003).

Since natural supplies of nitrogen (N) and phosphorus (P) are often the limiting factors in forest ecosystems, these nutrient elements play an important role in tree growth. Ohta (1994) and Ohta et al. (2000) have reported that the available N and P were concentrated in the surface soil in East Kalimantan, and that soil productivity was considerably affected by the deterioration of these nutrients due to soil erosion and deforestation.

Trees take up mineral nutrients from soil. Organic matter is decomposed and mineralized in soil. Soil microbes play an important role in the decomposition process that occurs in soil (Horwath and Paul, 1994). Due to the considerable amount of litter and the high temperature and humidity of the tropical forest soil, the activity of soil microbes is rather vigorous, and the cycling of nutrients through the decomposition of organic matter proceeds rapidly. The turnover time of microbes is 1 to 2 years (Srivastava and Singh, 1991; Marumoto, 1994; Brookes, 2001); hence, the lifespan of microbes is short. The nutrients contained in the dead microbes, such as N and P, are rapidly released. Therefore, microbial biomass serves as both a decomposer of organic matter and a nutrient pool in soil (Marumoto, 1994; Brookes, 2001). Since the microbial biomass carbon (MBC) reacts sensitively to environmental changes than the soil total carbon (C), MBC serves as an indicator of the changing trends in soil C (Anderson and Domsch, 1989; Horwath and Paul, 1994). Therefore, it is important to investigate the effects of environmental changes on microbial biomass when considering the maintenance of soil productivity in tropical forests.
Agus et al. (2003) have reported that the N content of the ecosystem decreased by approximately 300 kg·ha⁻¹ when a 6-year-old yemane plantation with an intermediate site index was clear-cut. N is an important nutrient for tree growth and exhibits the highest depreciation when clear-cutting is employed in a tropical forest ecosystem. Therefore, we prepared a mixed plot with legume cover crop for soil amelioration in the second rotation of the yemane plantation.

In this research, in order to elucidate the effects of short-rotation plantation system on microbial biomass, which are associated with soil productivity, and the effects of planting a legume cover crop on soil productivity, we investigated the microbial biomass and the net N mineralization rate in East Kalimantan in Indonesia.

Based on the results obtained, we have drawn conclusions regarding the effects of short-rotation harvesting on soil productivity.

**MATERIALS AND METHODS**

The study sites were located at Sebulu (00°0'0"N-00°15'E, 116°33'E-117°00'E) in East Kalimantan in Indonesia. The Sebulu site is situated at an altitude of 20 to 60 m above sea level, and its topography is flat with a slope of 0 % to 8 %.

The climate of the Sebulu site is that of wet tropical rain forest (Köppen classification). The mean annual rainfall at the study site between 1991 and 2000 was 1,938 ± 567 mm, with the minimum rainfall occurring in September (78 ± 38 mm) and the maximum, in December (238 ± 92 mm). The mean annual air temperature was 27.4 ± 5.2 °C.

The soil type of the research area is Typic Hapludults (USDA classification; Dregne, 1976), which commonly extends over large areas in tropical regions. This soil is heavily weathered and acidic. It consists of a thin A layer in the upper horizon and a red-yellow clayey layer in the lower horizon that has a low basicity.

Yemane is a useful species of the plantation trees grown in tropical regions. Since yemane grows rapidly, at this site, harvesting and reforestation were set at a short 6-yr rotation. In the sixth year at the productive plantation sites that exhibited intermediate productivity, the diameter at breast height (DBH), height, and volume of the yemane trees were noted to be 15 cm, 11 m, and 86 m³·ha⁻¹, respectively (Table 1, Agus, 2003).

In the secondary forest, the effects of stand age on microbial biomass were studied before plantation. Further, these effects were studied in 2-, 4-, 5-, 7-, and 9-year-old plots of moderately producing yemane plantations and in a plot that was a clear-cut of the 6-year-old moderately producing yemane plantation.

Next, the effects of mixed planting of legume cover crops were studied in a 4-year-old coppice plot of the second rotation (4-yr coppice plot), 10-year-old yemane plantation plot of the first rotation (10-yr plot), mixed plot of 4-year-old coppice of the second rotation with *Stylosanthes guianensis* (SG) (mixed plot), and only SG planting plot (legume plot). These 4 plots along with the adjoining plots were planted for the first time in 1992. Since the second rotation was mostly coppice, we selected the coppice plot such that it mitigated the workload in this area. The 10-yr plot was established without cutting the 6-year-old yemane. SG was planted after clear-cutting the first rotation in the mixed plot and legume plot. SG is relatively easier to grow and its N₂-fixing ability is approximately 10 kgN·ha⁻¹·year⁻¹ (Agus et al. 2003). It reproduces with little maintenance and only requires the above layer to be mowed every 6 months and returned to the soil as organic matter.

We investigated the first rotation in December 1999 and the second rotation in July 2002. Samples were collected from soil at depths of 0 to 10 cm and 10 to 30 cm for the measurement of their chemical properties (quoted from the data of Agus, 2003). Additional samples were obtained from soil at depths of 0 to 5 cm, 5 to 10 cm, and 10 to 30 cm for the measurement of microbial biomass, and at depths of 0 to 5 cm and 5 to 10 cm for

### Table 1. Tree height and DBH, biomass and litterfall of yemane plantations.

<table>
<thead>
<tr>
<th>Biomass</th>
<th>2-yr</th>
<th>4-yr</th>
<th>6-yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (m)</td>
<td>5</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>DBH (cm)</td>
<td>7</td>
<td>12</td>
<td>15</td>
</tr>
</tbody>
</table>

**Biomass**

| Above ground (Mg ha⁻¹) | 14 | 46 | 86 |
| Ao horizon (Mg ha⁻¹) | 14 | 12 | 14 |

**Fluxes (1 year)**

| Litterfall (Mg ha⁻¹) | – | 8 | 8 |

DBH: the diameter at breast height

\*: no data

These data were quoted from the data of Agus (2003)
the measurement of net N mineralization. All samples were obtained from 3 standard points in each plot. After transporting the fresh soil samples to the laboratory, 1 composite soil sample for each plot was prepared by thoroughly mixing and sieving the sample using a 4-mm mesh. Fresh soil (within 2 weeks after collection) was used for the measurement of microbial biomass and net N mineralization. Air-dried soil was used for the measurement of chemical properties.

The total C and N were measured by using a C-N coder (Yanagimoto MT-500). The pH (H$_2$O) values were measured using a glass electrode (soil : water = 1 : 2.5). The total C and N and pH (H$_2$O) analyses were repeated twice (quoted from a part of the data of Agus, 2003). The cation exchange capacity (CEC) has been quoted from the data of Agus (2003).

The MBC and MBN were measured by using the chloroform fumigation-extraction method (Inubushi, 1992; Horwath and Paul, 1994). After fumigation in an atmosphere of chloroform for 24 h, the soil was extracted with 0.5 M K$_2$SO$_4$. The amounts of C and N were measured by using a TOC meter (Shimadzu TOC-500A) and by the ninhydrin color method. The conversion factor between measured C and microbial C was 2.0 and that between measured N and microbial N was 5.0 (Inubushi, 1992; Horwath and Paul, 1994; Seto, 1999).

The net N mineralization rate was measured by using an incubation method in the laboratory. The soil sample was incubated at 25 °C after adjusting the water content to 60 % of the water-holding capacity of the soil. The inorganic N was measured and calculated at the beginning of incubation and 30 d after incubation. The inorganic N in the soil was extracted with 50 ml of 2 M KCl per 10 g of fresh soil. Ammonium-N (NH$_3$; N) and nitrate-N (NO$_3$; N) were analyzed using the colorimetric method (Keeney and Nelson, 1982). The analyses of microbial biomass and net N mineralization from 1 composite sample were replicated 3 times.

Luizao et al. (1992) reported that seasonal changes in the microbial biomass were unclear in tropical rain forests; therefore, we assumed that the differences associated with the rainy and dry seasons has little influence on the soil sampling. In this study, the factor of seasonal change was not taken into account because we analyzed net N mineralization under controlled water content; furthermore, our objective was to illustrate the differences in net N mineralization between several plots; hence, the factor of seasonal change was not considered.

The significance of the difference between any mean values was analyzed by using Scheffe’s multiple comparison test at the level of 0.05 and the values were expressed using different letters.

RESULTS
Total C and N, CEC, and pH (H$_2$O) of soils in yemane plantations
The total C and N, CEC, and pH (H$_2$O) values are shown in Table 2. The pH (H$_2$O) ranged from 4.1 to 5.2 in the grouped plots at every depth, indicating that the soil was strongly acidic. The CEC of the soil at depths of 0 to 10 cm in the secondary forest and in the 9-yr plantation was approximately 2 times higher than that of the other plots. The association between the stand age and CEC was unclear. With the exception of the 9-yr plantation, the CEC values of the soil in the other plantations ranged from 5.1 to 7.8 cmol·kg$^{-1}$ at depths of 0 to 10 cm. The total C ranged from 13 to 30 g·kg$^{-1}$ in the samples collected at depths of 0 to 10 cm and from 7 to 12 g·kg$^{-1}$ at depths of 10 to 30 cm; the total C was 2 to 3 times higher at depths of 0 to 10 cm than at depths of 10 to 30 cm. The total C was high in the 9-yr plot (30 g·kg$^{-1}$) and low in the 5- and 7-yr plots (15 and 13 g·kg$^{-1}$, respectively) at depths of 0 to 10 cm. The total N ranged from 1.3 to 2.2 g·kg$^{-1}$ at depths of 0 to 10 cm and from 0.8 to 1.6 g·kg$^{-1}$ at depths of 10 to 30 cm. The total N was high in the 4- and 9-yr plots (2.2 g·kg$^{-1}$) and low in the 7-yr and clear-cut plots (1.3 and 1.5 g·kg$^{-1}$, respectively) at depths of 0 to 10 cm. The relationship between the stand age and total C or N was unclear. The C/N ratios were high in the 9-yr and clear-cut plots (1.35 and 1.46, respectively; Agus, 2003).

In soils of the second rotation, the total C ranged from 22 to 31 g·kg$^{-1}$ at depths of 0 to 10 cm and from 8 to 11 g·kg$^{-1}$ at depths of 10 to 30 cm. The total N ranged from 2.0 to 2.4 g·kg$^{-1}$ at depths of 0 to 10 cm and from 1.2 to 1.9 g·kg$^{-1}$ at depths of 10 to 30 cm. The difference in the values of total N among the 4 plots was small. The C/ N ratios of the soil sampled at depths of 0 to 10 cm from the 10-yr and the mixed plots were 1.3 times higher than those from the 4-yr coppice and legume plots.

Microbial biomass in the chronosequence of yemane plantations
The MBC and MBN with regard to stand age are shown in Fig. 1. With the exception of the 5-yr plantation, the MBC at depths of 0 to 5 cm and 5 to 10 cm was 1.2 to 3 times higher than that in the soil from the depths of 10 to 30 cm. The MBC of the plantations from the secondary forest decreased to approximately 40 % in the soil sampled at depths of 0 to 5 cm. It then gradually increased along
with the increase in the stand age of plantations. The changes in the MBC in the soil at depths of 5 to 10 cm were similar to those at depths of 0 to 5 cm. The differences between the secondary forest and plantations were not observed at depths of 10 to 30 cm.

Both MBN and MBC were high in the surface soil. In the soil of the plantations from the secondary forest at depths of 0 to 5 cm, the MBN decreased to approximately a half. Unlike the increase in MBC, that in the MBN along with the stand age was not observed. Although the difference between the soil obtained at depths of 0 to 5 cm and 5 to 10 cm was large in the secondary forest and the clear-cut plots (1.5 to 3 times), the other plots exhibited no difference. In the soil sampled at depths of 10 to 30 cm, the difference in MBN between the secondary forest and plantations was small.

**Microbial biomass and net N mineralization in yemane plantations of the second rotation**

The MBC and MBN in yemane plantations of the second rotation are shown in Fig. 2. At depth of 0 to 5 cm, the MBC and MBN of the mixed and 10-yr plots were higher than those of the 4-yr coppice and legume plots. At depth of 5 to 10 cm, the MBC of the 10-yr plot was the highest and the MBN of the mixed, 10-yr, and legume plots was higher than that of the 4-yr coppice plot. The MBC and MBN in the 4-yr coppice plot were slightly lower than those in the 2- and 4-yr first rotation plots (Fig. 1).

The inorganic N in yemane plantations of the second rotation is shown in Fig. 3. The inorganic N was the highest in the legume plot. The ratio of NO$_3$−N to inorganic N was also higher (65 % to 70 %) in the legume plot than in the other 3 plots (30 % to 55 %). The net N mineralization rate for 30 d in yemane plantations of the second rotation is shown in Fig. 4. The net N mineralization rate in the soil sampled at depths of 0 to 5 cm in the 10-yr and mixed plots was approximately 1.3 times higher than those in the 4-yr coppice and legume plots.

The relationships between MBN and the net N mineralization rate are shown in Fig. 5. Although there were only 4 plots, the MBN and the net N mineralization rate in the soil samples obtained at depths of 0 to 5 cm showed a trend of positive correlation (Fig. 5).

**The percentage of microbial biomass in the total C and N in yemane plantations**

The percentage of MBC in the total C ranged from 1.0 % to 3.7 %, and no clear relationship with regard to the stand age or soil depth was observed (Table 3). The percentage of MBN in the total N was high in the secondary forest.
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**Fig. 1. Microbial biomass C (MBC) and microbial biomass N (MBN) in chronosequence of yemane plantations of the first rotation.**

The name of plots are the same as in Table 2. nd: no data. Values are means (n = 3) with standard error. Different letters for the same depth indicate significant difference at $P < 0.05$ using Scheffe’s test.

**Fig. 2. Microbial biomass C (MBC) and microbial biomass N (MBN) in yemane plantations of the second rotation.**

The name of plots are the same as in Table 2. Values are means (n = 3) with standard error. Different letters for the same depth indicate significant difference at $P < 0.05$ using Scheffe’s test.
Further, with the exception of the mixed and 4-yr coppice plots, the percentage of MBN at depths of 0 to 10 cm was higher than that at depths of 10 to 30 cm.

**DISCUSSION**

According to Agus (2003) and Agus et al. (2004), with the increase in the stand age by 2, 4, and 6 years, the above-ground biomass increased by 14, 46, and 86 Mg·ha⁻¹, respectively (Table 1). It was clear that MBC decreased as a result of clear-cutting and that the influence of soil disturbance decreased with the increase in the stand age. The MBC reacted sensitively to environmental changes, particularly at the surface of the soil at depths of 0 to 10 cm. Although such a decrease in the MBC and MBN was not observed in the clear-cut plot immediately after the clear-cutting, the influence of clear-cutting was observed in the 4-yr coppice plot in the second rotation.

The microbial biomass in temperate forests has been reported to decrease as a result of clear-cutting or burning (Kaneko et al. 1996; Liu et al. 2001). It has also been reported that in soil, the MBC decreased before the total C as a result of the clear-cutting of tropical forests in the Amazon area (Henrot & Robertson, 1994), and that in Thailand, the microbial biomass increased with the increase in the number of fallow years after burning (Hirai, 1994). In the present study, the MBC and MBN decreased markedly due to clear-cutting, and the MBC tended to increase with an increase in the stand age. Conversely, the MBN remained low regardless of the stand age. However, the reason for the difference between the MBN and MBC is not clear although a change in the microflora may have been a contributory factor.

The microbial biomass in soil mostly comprises fungi and bacteria. It has been suggested that the C/N ratio of fungi is higher than that of bacteria (Anderson and Domsch, 1980; Marumoto 1994). It is possible that the ratio of bacteria to microbial biomass might increase in the early stages of plantation by clear cutting or soil disturbances. Thereafter, fungal biomass might increase
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Table 3. The percentage of microbial biomass C, N in the total C, N in yemane plantations.

<table>
<thead>
<tr>
<th>Plot</th>
<th>Depth (cm)</th>
<th>MBC/Total C (%)</th>
<th>MBN/Total N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Secondary forest and yemane plantations of the first rotation</strong>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF</td>
<td>0~10</td>
<td>3.1</td>
<td>8.7</td>
</tr>
<tr>
<td></td>
<td>10~30</td>
<td>2.6</td>
<td>7.0</td>
</tr>
<tr>
<td>4-yr</td>
<td>0~10</td>
<td>1.4</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>10~30</td>
<td>1.0</td>
<td>3.3</td>
</tr>
<tr>
<td>5-yr</td>
<td>0~10</td>
<td>1.6</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>10~30</td>
<td>2.4</td>
<td>5.2</td>
</tr>
<tr>
<td>Cut</td>
<td>0~10</td>
<td>2.9</td>
<td>6.2</td>
</tr>
<tr>
<td></td>
<td>10~30</td>
<td>2.8</td>
<td>4.7</td>
</tr>
<tr>
<td>7-yr</td>
<td>0~10</td>
<td>3.5</td>
<td>4.0</td>
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<tr>
<td></td>
<td>10~30</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>9-yr</td>
<td>0~10</td>
<td>1.7</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td>10~30</td>
<td>2.0</td>
<td>2.5</td>
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<tr>
<td><strong>Yemane plantations of the second rotation</strong>*</td>
<td></td>
<td></td>
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<tr>
<td>4-yr Copi</td>
<td>0~10</td>
<td>1.5</td>
<td>2.5</td>
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<tr>
<td></td>
<td>10~30</td>
<td>3.7</td>
<td>3.6</td>
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<tr>
<td>10-yr</td>
<td>0~10</td>
<td>1.7</td>
<td>4.6</td>
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<td></td>
<td>10~30</td>
<td>2.0</td>
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<td>10~30</td>
<td>2.1</td>
<td>4.3</td>
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<tr>
<td>LC</td>
<td>0~10</td>
<td>1.2</td>
<td>3.4</td>
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<tr>
<td></td>
<td>10~30</td>
<td>–</td>
<td>–</td>
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</tbody>
</table>

The name of plots are the same as in Table 2.
- : no data.
MBC and MBN values were calculated by the weighted average in 0-5 and 5-10 cm.

In the early stages of growth in the 4-yr coppice plot, it appears that the C/N ratio decreased because of a decrease in the supply of organic matter that is usually provided by the canopy trees and the promotion of decomposition by the increased soil temperature. In the legume plot, the C/N ratio decreased probably because of the decrease in the amount of woody litter and N fixation by root nodule bacteria. There were apparent differences in the C/N ratio among the 4 plots, indicating differences in the microbial activity.

In the mixed plot, it appears that the intensity of insolation decreased, resulting in a decrease in the N fixation ability of SG, along with the growth of yemane coppice. The microbial biomass and net N mineralization rate of the mixed plot were similar to those of the 10-yr plot, while they were larger than those of the 4-yr coppice plot. This was because the legume cover crop not only provided nutrition in the form of N but also efficiently served to cover the surface soil. The N uptake of legume cover crop was lower than that of yemane (Noordwijk and Purnomosidi, 1992; Agus, 2003). The standing stock of inorganic N was lower in the mixed plot than in the legume plot. This was because N uptake of the coppice of the second rotation with legume was higher than that of the legume plot. Due to the effect of N fixation and lower N uptake than that in the other plots, the standing stock of inorganic N was the highest in the legume plot.

The microbial biomass and net N mineralization rate in the 10-yr plot were larger than those of the 4-yr coppice plot. In the regeneration of coppice, since the roots remain, it appears that the nutrient storage ability of soil is sustained to a greater extent than that observed in the clear-cut plantations; however, soil erosion and leaching of nutrients should be anticipated. Therefore, soil productivity might be deteriorated by the regeneration of coppice on short rotation.

Although there were only 4 plots, the MBN and the net N mineralization rate in the soil samples obtained at depths of 0 to 5 cm showed a trend of positive correlation. The same correlation was revealed in the data of Kita et al. (2005).

Since microbial biomass not only serves as a decomposer but also as a nutrient pool, which immediately decomposes and mineralizes after the death of microbes, it was considered that MBN and net N mineralization had some correlation.

According to Kita et al. (2005), the percentage of MBN in the total N in natural forests and selectively cut forests was as high as that observed in the secondary forests, the average being 7.5 %. The percentage of MBN in the total N decreased in the yemane plantations due to the influence of environmental changes on MBN, which is sensitive to such changes; this value was greater than that of total N.

In order to establish sustainable fast-growing plantations, continuous monitoring of MBN after the second rotation is necessary.
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