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Assessing Soil Biological Properties of Natural and Planted Forests in the Malaysian Tropical Lowland Dipterocarp Forest

[1]Daljit Singh Karam, [1,2]Arifin Abdu, [3,4]O. Radziah, [3]J. Shamshuddin,
[1,2]Hazandy Abdul-Hamid, [1]Nik M. Majid, [1]Mohanaselvi Panicker
and [5]Nor Halizah Abd. Halim
[1]Department of Forest Production, Faculty of Forestry,
[2]Laboratory of Sustainable Bioresource Management,
Institute of Tropical Forestry and Forest Products,
[3]Department of Land Management, Faculty of Agriculture,
[4]Laboratory of Food Crops and Floriculture, Institute of Tropical Agriculture,
University Putra Malaysia, 43400 UPM Serdang, Selangor
[5]Forestry Department Peninsular Malaysia, 50660 Kuala Lumpur, Malaysia

Abstract: Problem statement: A study was conducted to evaluate and compare the soil biological properties of a natural forest and an 18-year-old stand of *Shorea leprosula* in Chikus Forest Reserve, Perak, Malaysia. **Approach:** Soils were sampled at depths of 0-15 cm (topsoil) and 15-30 cm (subsoil) in six subplots (20×20 m) of natural forest (C1) and of a planted *S. leprosula* (C2) plot. Fresh composite soil samples were kept in UV-sterilized polyethylene bags prior to analysis in the laboratory. The microbial population count was determined using a spread-plate count technique. The microbial enzymatic activity was elucidated using a Fluorescein Diacetate (FDA) hydrolysis assay; microbial biomass was extracted using a rapid chloroform fumigation extraction method. The Microbial Biomass C (MBC) was determined by wet dichromate oxidation; Kjeldahl digestion and a distillation method were used for evaluation of Microbial Biomass N (MBN). **Results:** Results indicate that only the microbial biomass N and the population count in the soil at the 0-15 cm depth were found to be higher in C1 compared to C2. The higher microbial population count in the soil at the 0-15 cm depth of C1 compared to C2 was enhanced by the large amount of organic matter that serves as a suitable medium for soil microbial growth. The higher MBN in the C1 soil was also influenced by the high content of organic material available that encourages activities of decomposing bacteria to take place. Similarities in the soil biological properties of the plots with regard to enzymatic activity and microbial biomass Care believed to be influenced by the same topographic gradient. The higher MBC/MBN ratios found in soils of C2 compared to C1 were due to the low availability of N compared to C, might result from N utilization by soil microbes for organic material decomposition. **Conclusion:** There are similarities in microbial enzymatic activity and biomass C, but not in microbial population counts and biomass N, between a natural forest and an 18-year-old stand of *S. leprosula* in Chikus Forest Reserve, Perak, Malaysia.

Key words: Natural forest, planted forest, microbial population, enzymatic activity, biomass C and N, Fluorescein Diacetate (FDA), Forestry Department Peninsular Malaysia (FDPM), Soil analyses, soil fertility

INTRODUCTION

Forest rehabilitation is one of the vital strategies used to restore a degraded forest to its initial state (Singh *et al*., 2011; Arifin *et al*., 2008; Hamzah *et al*., 2009; Zaidey *et al*., 2010: Heryati *et al*., 2011a; 2011b). Rehabilitation also helps to reduce the demand for woody and non-woody products from natural forest. Therefore, it is crucial to carry out soil fertility evaluations of rehabilitated forests to evaluate the success of rehabilitation efforts.

It is undeniable that soil biological activity plays a key role in the catalyzing cycles of nutrients in the soil. Bollard and Stotzky (1990) found that the sensitive

Corresponding Author: Arifin Abdu, Department of Forest Production, Faculty of Forestry, University Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia Tel: +603-89467177 Fax: +603-89432514

nature of microbial activity to environmental changes made it a good indicator of soil fertility. Islam and Weil (2000) also justified the importance of including soil biological parameters in determining soil fertility; these parameters can show how land management affects soil microbial biomass. In addition, Van Dobben and McConnell (1975) found that 90% of the energy cycle in the soil was induced by microbial decomposition activity, which provided a preview of soil organic matter turnover in a particular area.

The Chikus Forest Reserve, Perak, Malaysia is considered to be a lowland dipterocarp forest and it was subjected to a forest rehabilitation program by the Forestry Department of Peninsular Malaysia (FDPM) and the Japan International Cooperation Agency (JICA) via the Multi-Storied Forest Management System (MSFMS) (Arifin *et al.*, 2008). Many soil fertility evaluations were carried out, focusing on the physico-chemical and mineralogical properties of the soil in these forests (Arifin *et al.*, 2008; Abdu *et al.*, 2007; Saga *et al.*, 2010); however, no information on the soil biological properties was collected. Hence, this study was carried out to evaluate and compare the soil biological properties of natural and rehabilitated forests.

MATERIALS AND METHODS

Study site and soil sampling: The study was carried out in a natural forest (N 04.10076° E101.19411°, ± 28 m) and an 18-year-old stand of *Shorea leprosula* (N 04.09197° E 101.19499°, ± 28 m) in January, 2011. The area has an average annual precipitation of 3223 mm and a mean temperature of 27.7°C. *S. leprosula* was planted in 1992 through collaborative work of the Multi-Storied Forest Management System involving the Forestry Department Peninsular Malaysia, the Perak State Forestry Department and the Japan International Cooperation Agency (JICA). The planting distance was 10 m x 3 m. Natural forest and planted *S. leprosula* plots were marked as C1 and C2, respectively. Six subplots were established at each plot and a composite sample was randomly collected from depths of 0-15 cm (topsoil) and 15-30 cm (subsoil). The fresh composite soil samples were kept in UV-sterilized polyethylene bags under 0-4°C in ice-filled polystyrene boxes prior to analysis.

Soil analyses: The spread-plate technique described by Sleytr *et al*. (2007) was used for microbial population counts. The microbial enzymatic activity was evaluated using the Fluorescein Diacetate (FDA) hydrolysis assay (Sanchez-Monedero *et al.*, 2008). Microbial biomass was extracted via a rapid ethanol-free chloroform fumigation extraction technique (Witt *et al.*, 2000). Microbial Biomass C (MBC) was analysed by wet dichromate oxidation (Vasquez-Murrieta *et al.*, 2007; Vance *et al.*, 1987) and microbial biomass N (MBN) was elucidated through Kjeldahl digestion and a distillation technique (Simmone *et al*., 1997; Brookes *et al.*, 1985). The loss-on-ignition method used in Ahmadpour *et al.* (2010) was used for soil organic matter and organic carbon determination. Kjeldahl digestion was used for total N evaluation and soil acidity was determined using a glass electrode and a soil: water suspension ratio of1:2.5 (Akbar *et al.*, 2010).

Data analyses: Mean values were compared using the Student's t-test. Linear regression analysis using SPSS ver. 16.0 was performed to determine any correlations or relationships derived from comparisons between microbial biomass C and organic matter and between microbial biomass N and total N at the same soil depths.

RESULTS

Microbial population: Microbial population counts were significantly higher ($P \leq 0.05$) in the soil of C1 (3.45 ± 0.12 $\log_{10}$ g^{-1} soil) compared to C2 (2.90 ± 0.06 $\log_{10}$ g^{-1} soil) at the 0-15 cm depth; no significant differences ($P \leq 0.05$) were detected in the soils at the 15-30 cm depth for either plot (Fig. 1). Microbial population counts in the soils at the 15-30 cm depth for C1 and C2 were3.13 ± 0.13 $\log_{10}$ g^{-1} soil and 2.75 ± 0.16 $\log_{10}$ g^{-1} soil, respectively.

Microbial enzymatic activity: The C1 and C2 plots exhibited no significant differences ($P \leq 0.05$) in microbial enzymatic activity at the same soil depths (Fig. 2). Means of microbial enzymatic activity for C1 at the 0-15 cm and 15-30 cm soil depths were 26.51 ± 0.63 μg g^{-1} soil $0.5h^{-1}$ and 25.74 ± 1.13 μg g^{-1} soil $0.5h^{-1}$, respectively; for C2, the means were 24.89 ± 1.22 μg g^{-1} soil $0.5h^{-1}$ and 22.92 ± 0.76 μg g^{-1} soil $0.5h^{-1}$, respectively.

MBC: No significant differences in soil MBC ($P \leq 0.05$) were found between C1 and C2 at the same soil depths (Fig. 3). Means of MBC for C1 and C2 at the 0-15 cm soil depth were 824 ± 34 μg g^{-1} soil and 542 ± 329 μg g^{-1} soil, respectively. The means of MBC for C1 and C2at the 15-30 cm soil depth were 524 ± 115 μg g^{-1} soil and 337 ± 233 μg g^{1} soil, respectively.

MBN: The MBN was higher ($P \leq 0.05$) in C1 compared to C2 at both soil depths (Fig. 4). In C1, the means of the MBN were149 ± 20 μg g^{-1} soil at the 0-15 cm soil depth and 113 ± 29 μg g^{-1} soil at the 15-30 cm soil depth. In contrast, the means of MBN in C2 were 37 ± 4 μg g^{-1} soil and 9 ± 4 μg g^{-1} soil at the0-15cmand 15-30 cm depths, respectively.

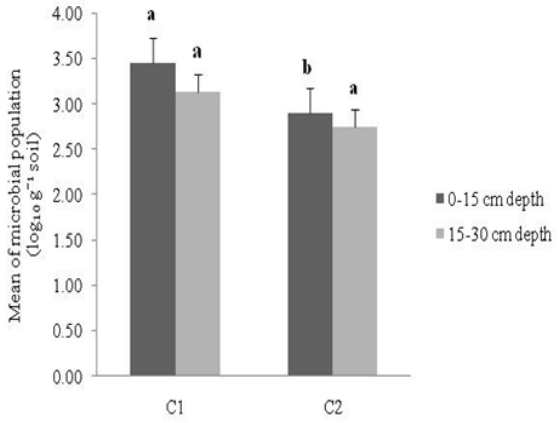

Fig. 1: Total means of soil microbial populations in the natural forest (C1) and *S. leprosula* (C2) plots. The different letters indicate significant differences between the means of the same soil depths in the natural forest (C1) and *S. leprosula* (C2) plots using the Student's t-test (P≤0.05)

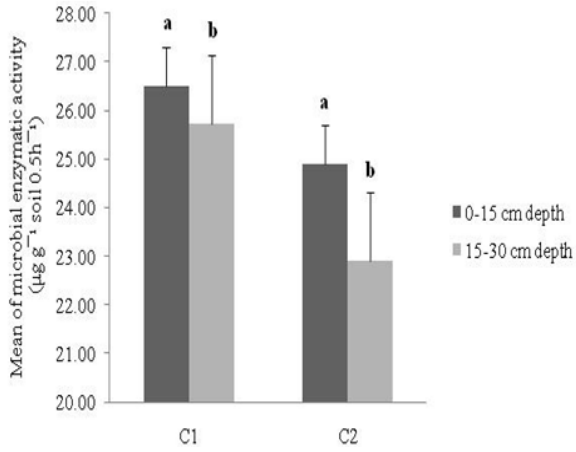

Fig. 2: Total means of soil microbial enzymatic activity in the natural forest (C1) and *S. leprosula* (C2) plots. The different letters indicate significant differences between means of the same soil depths in the natural forest (C1) and *S. leprosula* (C2) plots using the Student's t-test (P≤0.05)

Microbial biomass C to microbial biomass N (MBC/MBN) ratio: The ratio of MBC/MBN was found to be higher in C2 compared to C1 (Fig. 5). The MBC/MBN ratio for C1 was 6.35 ± 1.38 and 6.39 ± 2.46 at the 0-15 cm and 15-30 cm soil depths, respectively. On the other hand, the MBC/MBN ratio for C2 at the 0-15 cm and 15-30 cm soil depths were 16.79 ± 9.72 and 37.84 ± 22.36, respectively.

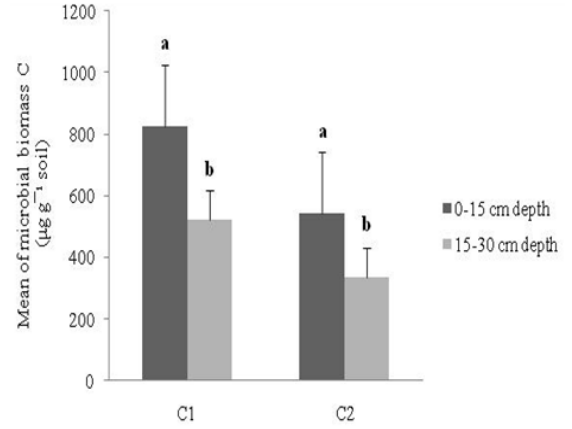

Fig. 3: Total means of soil Microbial Biomass C (MBC) in the natural forest (C1) and *S. leprosula* (C2) plots. The different letters indicate significant differences between means of the same soil depths in the natural forest (C1) and *S. leprosula* (C2) plots using the Student's t-test (P≤0.05)

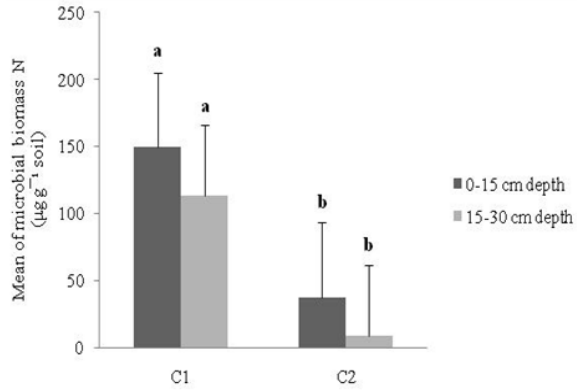

Fig. 4: Total means of soil Microbial Biomass N (MBN) in the natural forest (C1) and *S. leprosula* (C2) plots. The different letters indicate significant difference between means of the same soil depths at the natural forest (C1) and *S. leprosula* (C2) plots using the Student's t-test (P≤0.05)

Organic matter, organic C, total N and soil acidity: The soil organic matter and organic C were significantly higher (P≤0.05) in C1 compared to C2 at the same soil depth (Table 1). In addition, total N was also found to be significantly different (P≤0.05), except at the 15-30 cm soil depth. No significant difference was found in soil acidity at the 0-15 cm soil depth, but the soil of C2was significantly more acidic (P≤0.05) at the15-30 cm soil depth than the soil of C1.

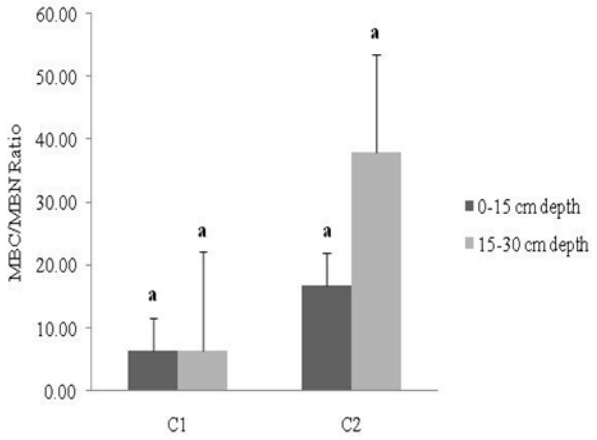

Fig. 5: Ratios of soil microbial biomass C to microbial biomass N (MBC/MBN) in the natural forest (C1) and *S. leprosula*(C2) plots. The different letters indicate significant difference between means of the same soil depths at the natural forest (C1) and *S. leprosula* (C2) plots using the Student's t-test (P≤0.05)

Table 1: Selected soil physico-chemical properties of the natural forest (C1) and *S. leprosula* (C2) plots

	0-15 cm	15-30 cm
	Organic matter (%)	
C1	12.31 ± 1.47a	9.63 ± 1.62a
C2	8.52 ± 0.55b	8.07 ± 0.45b
	Organic C (%)	
C1	7.14 ± 0.85a	5.58 ± 0.94a
C2	4.94 ± 0.32b	4.68 ± 0.26b
	Total N (%)	
C1	1.66 ± 0.20a	1.26 ± 0.25c
C2	1.10 ± 0.15b	0.87 ± 0.06c
	pH-H_2O	
C1	4.16 ± 0.08a	4.65 ± 0.10a
C2	4.22 ± 0.03a	4.30 ± 0.04b

Note: The different letters within columns indicate significant differencesbetween means of the same soil depths at the natural forest (C1) and *S. leprosula (*C2) plots using the Student's t-test (P≤0.05)

No linear relationships were found between microbial biomass C and organic matter or between microbial biomass N and total N in the soils of C1 and C2 at either soil depth.

DISCUSSION

Higher microbial population counts in soil of natural forest compared to the *S. leprosula* plot could be due to the high content of organic matter and humic substances in the soil at the 0-15 cm depth. The high content of organic material in the soil would trigger soil microbial activities and, thus, could subsequently result in a larger population in the C1 soil.

The similarities between the plots in soil microbial enzymatic activity and MBC could be due to the fact these plots are located at the same elevation; both plots were located about 28 m above sea level, which is considered to be lowland forest area. Furthermore, both areas are classified as tropical rainforest and receive heavy rainfall; hence, these factors promote the same range of microbial diversity and activity (Barbhuiya *et al.*, 2004). Arunachalam and Pandey (2003) found that soil microbial biomass could be a more reliable indicator of ecosystem recovery than other ecological approaches because it is the most labile and sensitive portion of organic matter and determines soil fertility.

Arifin *et al.* (2008) and Carter (2002) reported that the distribution of soil organic biodiversity is also influenced by the type and carrying capacity of soil, the weather and how the land at a particular site was managed. The soil MBN was found to be significantly different between the plots for both soil depths. This is could be due to low availability of total N in the *S. leprosula* plot. In the field, the natural forest area was waterlogged, whereas the *S. leprosula* plot was well-drained. In the natural forest, adequate supply of water or suitable humidity leads to enhanced growth of nitrogen-fixing bacteria and allows increases in the decomposition of biomass N to take place. In addition, Behera and Sahani (2003) found that optimum microbial activity occurs when there is an adequate supply of growth substrates. Hence, drought or inadequate supply of water itself will inhibit or slow down nutrient cycling and the decomposition of organisms by affecting the microbial activity in the soil. However, the lower level of MBN compared to MBC in both plots could be due to the loss of MBN from the ecosystem that is caused by low N mobilization (Maithani *et al*., 1998).

Differences in the MBC/MBN ratio between the natural forest and *S. leprosula* plots indicate that qualitative changes take place in microbial biomass; these changes are believed to be enhanced by the cycling and turnover processes of micro flora in soils (Behera and Sahani, 2003). The MBC/MBN ratios found at the 0-15 cm and 15-30 cm depths in the natural forest were within the optimal range of 5-8 (Joergensen *et al*., 1995). However, the higher MBC/MBN ratio in the *S. leprosula* plot compared to the natural forest could be due to a higher ratio in the C2 soil of fungi to bacteria or actinomycetes (Behera and Sahani, 2003; Campbell *et al*., 1994). Furthermore, fungal domination of microbial biomass also contributes to the higher MBC/MBN ratio we observed in soil of the *S. leprosula* plot; the higher MBC/MBN ratio in the lower soil layer of both the natural forest and *S. leprosula* plots

indicates a low level of accumulation of organic matter and fine roots (Bremer and Van Kessel, 1992; Maithani *et al.*, 1996). The higher MBC/MBN ratio in soil of the *S. leprosula* plot could be caused by the higher organic matter and organic C content compared to the availability of total N in the soil at natural forest. The low N in the soil of the *S. leprosula* plot also could be due to the available N being utilized by microbes during the decomposition of soil organic matter or humus. This result indicates that reforestation of a particular site requires more time to populate adequate detrital medium for microbial growth (Arunachalam and Pandey, 2003).

The dynamics of soil biological properties provide us with data regarding the current conditions and early effects of land management, monitoring and sustainability status in a particular area. Furthermore, the abundance of microbial communities, which catalyze numerous enzymatic cycles of nutrients in the soil, will subsequently increase and maintain the soil fertility and productivity (Behera and Sahani, 2003).

CONCLUSION

Analysis of the biological activities of the soils in a natural forest and the *S. leprosula* plantation in Chikus Forest Reserve, Perak showed no significant differences, with the exceptions of microbial biomass N and the microbial population counts at the 0-15 cm soil depth. Hence, the data prove that rehabilitation of degraded forestland helps restore soil biological activities to their original state or to the extent seen in natural forests.

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