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V. SOIL MACRO-ORGANIC MATTER IN NATURAL FOREST AND CACAO AGROFORESTRY SYSTEMS

INTRODUCTION

Changes in soil management practices influence the amount, quality and turnover of soil organic matter (SOM) (Glaser et al. 2000). Soil organic matter is a key of nutrients for plant growth essential for the maintenance of soil structure, and contributes to the ability of soil to retain nutrients and water (Liu et al. 2003). It is a critical component of soil resource base, which affects the biological, chemical, and physical processes of the soil and through the effect on these processes, fulfils a very wide range of functions (Wild 1995, Craswell and Lefroy 2001).

It is generally accepted that SOM contains fractions with rapid turnover rate and fractions with a slower turnover rate (Cambardella and Elliot 1992). The fractions with a rapid turnover (active fractions) are assumed to play a dominant role in soil nutrient dynamics (Janzen et al. 1992). The "active" fraction (light fraction) has been found to be more sensitive to differences in management and inputs of residues than total organic matter (Janzen et al. 1992).

Size-density fractions have been shown to be more useful to characterize land use changes compared with whole SOM (Hairiah et al. 1995). Fractionation by size and density was shown to be more powerful approach for separating SOM fractions than fractionation based on density alone (Magid et al. 2002). From a density perspective, SOM can divided into: (1) light fraction (LF), which consist of mineral-free organic matter composed of partly-decomposed plant debris and less stable, it has a relatively high C-to-N ratio, low ash concentration, a rapid turnover and a specific density considerably lower than that of soil minerals; and (2) intermediate fraction (MF) of partly humified material, and (3) heavy fraction (HF), composed of organic matter adsorbed or deposited by microorganisms on aggregate surfaces and sequestered within organo mineral aggregates, more stable, it has a narrow C-to-N ratio, a slower turnover rate and higher specific density than the light fraction due to its intimate association with soil minerals (Strickland and Sollins 1987, Christensen 1992, Meijboom et al. 1995, Golchin et al. 1995, Gregorich et al. 1996).

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Light and intermediate fractions of the macro-organic matter (> 150 μm) respond much faster to changes in C input than smaller size fractions. This shows that the light and intermediate macro-organic matter fractions can be used as early indicators of effects of soil management on changes in SOM (Hassink et al 1997). The LF has been considered part of the biologically active or labile SOM pool (Janzen et al. 1992, Woomer et al. 1994, Meijboom et al. 1995, Coolson et al. 2005). The light fraction is rapidly depleted when soils are brought under cultivation, whereas organic matter associated with silt is most stable after extended periods of cultivation. The examination of light fraction is to develop sensitive indicators that can detect changes in soil fertility before soil degradation becomes severe (Liu et al. 2003). Although the various light fraction or labile fractions represent only a small proportion of total SOM, they are very dynamic and account for much of the organic matter fluctuations over time (Cambardella and Elliott 1992). Furthermore, these fractions have been closely linked to soil productivity because of their capacity to furnish plant nutrients such as nitrogen (Biederbeck et al. 1994).

In the buffer zone of Lore Lindu National Park (LLNP), there are many different land-use types ranging from natural forest to agroforestry systems with cacao and shade trees. There are six different land-use types: (1) Natural forest with traditional use only (NF), (2) Natural forest with rattan extraction, (3) Natural forest with canopy gaps from selective logging or local forest gardening, (4) Agroforestry system (cacao) under a remaining forest cover (CF1), (5) Agroforestry system (cacao) under local shade trees (CF2), (6) Agroforestry system (cacao) without forest cover but with planted shade trees (CP). In these work only type (1), (4), (5), and (6) were studied.

The aims of this research are that to determine the amount SOM fractions in various land use types, from natural forest to cacao agroforestry with shade trees, and their carbon and nitrogen content.

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MATERIALS AND METHODS

Size and density fractionation of soil macro-organic matter

Twenty-five soil samples were collected from each subplot in each plot down to 10-15 cm depth. Soil samples were collected four times in a year. Air dried soil samples (500 g, < 2 mm) were washed on two sieves (top sieve, mesh size 250 µm; bottom sieve, mesh size, 150 µm). The mineral fraction was discarded by decantation, and after combining the organic fraction from both sieves it was fractionated in silica suspensions (LUDOX solution) with a density of 1.13 and 1.37 g cm^{-3}. The organic fraction recovered on both sieves (diameter > 150 µm) were referred to as macro-organic matter. The macro-organic matter was separated into three fractions: a light fraction (LF) (density < 1.13 g cm^{-3}), an intermediate fraction (MF) (density between 1.13-1.37 g cm^{-3}), and a heavy fraction (HF) (density > 1.37 g cm^{-3}). Each fraction was dried into a constant dry weight at 60º C (Hassink 1995, Meijboom et al. 1995).

The nitrogen and carbon of each fraction of soil macro-organic matter were determined. Nitrogen was determined by the Kjeldahl, whereas organic carbon content was determined by using Walkley and Black method.

Statistical analyses

Data on amount as well as organic carbon and nitrogen content of soil macro-organic matter among land-use types were analyzed by using general linear models (GLMs). All post hoc tests were carried out by using Tukey-tests. All analyses were done by using SPSS 13.0 software. The relationship between parameters was analyzed using regression and Pearson’s correlation analysis.

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RESULTS

Table 5.1 shows the amount of soil macro-organic matter (LF-, MF-, and HF-SOM), was significantly different between natural forest (NF) and cacao agroforestry systems (CF1, CF2, and CP). Intermediate soil macro-organic matter fraction (MF-SOM) was the highest proportion of soil macro-organic matter, except in the cacao agroforestry system CF2. Light soil macro-organic matter fraction (LF-SOM) was the highest in NF. Among cacao agroforestry systems, the CF2 was the highest LF-SOM. The natural forest had the highest total soil macro-organic matter (6.1 g kg^{-1} DW soil), while CF2 (3.9 g kg^{-1} DW soil) was the highest among cacao agroforestry systems. Quality of soil macro-organic matter could be determined by nitrogen, and organic carbon content. Quality of soil macro-organic matter fractions (organic carbon and nitrogen) was significantly different ($p < 0.05$) between natural forest (NF) and cacao agroforestry systems (CF1, CF2, and CP). Organic carbon and nitrogen content in fractions of soil macro-organic matter decrease with the changing of land use from natural forest into cacao agroforestry systems. The NF has highest organic carbon and nitrogen content.

Because of LF-SOM is an active fraction, hence, in this research only focus in LF-SOM. The amount of LF-SOM was related to annual litterfall production and decay rate coefficient of leaf-litter decomposition (k). The average of decay rate coefficient of leaf-litter decomposition (k) in this study was NF=2.47, CF1=1.68, CF2=1.18, and CP=1.68. Correlation between dry weight LF-SOM with annual litterfall production and decay rate coefficient (k) were positively significant in all study sites (Pearson's r = 0.46 and 0.42, respectively, $p < 0.01$). It means that the increasing of dry weight of LF-SOM was affected by increasing annual litterfall and decay rate coefficient of leaf-litter decomposition.

Table 5.1. The dry weight of soil macro-organic matter fractions and their fractions (light fractions - LF, intermediate fractions - MF, heavy fractions – HF) in various land use types.

	NF	CF1	CF2	CP
Dry weight of soil macro-organic matter and their fractions (g kg^{-1} DW soil)				
LF	1.4 ± 0.2^{ab}	0.8 ± 0.1^{a}	1.0 ± 0.2^{a}	0.7 ± 0.1^{a}
MF	2.8 ± 0.4^{c}	1.3 ± 0.2^{ab}	1.2 ± 0.1^{ab}	1.3 ± 0.2^{ab}
HF	1.9 ± 0.2^{b}	1.0 ± 0.3^{a}	1.7 ± 0.2^{b}	0.7 ± 0.1^{a}
Total	**6.1^{c}**	**3.1^{a}**	**3.9^{b}**	**2.7^{a}**
Organic C and N content of fraction of soil macro-organic matter (mg kg^{-1} DW soil)				
C in LF	428.9 ± 10.7^{c}	265.7 ± 5.4^{ab}	313.8 ± 6.6^{b}	228.3 ± 4.6^{ab}
C in MF	651.3 ± 0.8^{d}	359.2 ± 2.1^{b}	309.0 ± 1.5^{b}	311.2 ± 1.3^{b}
C in HF	353.3 ± 2.1^{b}	202.3 ± 1.3^{a}	182.3 ± 1.6^{a}	153.1 ± 0.9^{a}
N in LF	17.7 ± 0.5^{b}	11.5 ± 0.3^{a}	14.4 ± 0.4^{ab}	11.9 ± 0.4^{a}
N in MF	36.2 ± 0.1^{d}	19.9 ± 0.1^{b}	18.5 ± 0.1^{b}	22.9 ± 0.2^{c}
N in HF	22.9 ± 0.1^{c}	10.5 ± 0.1^{a}	13.1 ± 0.2^{ab}	11.2 ± 0.2^{a}

Numbers followed by different superscript(s) indicate significantly different. Values are mean ± SE. Significance of Tukey-test given at $p < 0.05$.

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DISCUSSIONS

Using size and density fractionation of soil macro-organic matter in this study, size of soil organic matter between 150 to 250 µm and density between 1.13 to 1.37 g cm^{-3} was chosen. Based on the nomenclature of soil organic matter aggregate (Degryze et al. 2004), these particle included in total light particulate organic matter (POM). The POM is a better indicator of soil fertility than total SOM content, because the POM is more sensitively influenced by management practices than total SOM (Kaya and Nair 2004).

The land-use type in Toro village affected the amount and quality of soil macro-organic matter, since the different land use types in this study had different tree density and diversity (Ramadhanil 2006). Therefore, land use types contributed to different amount and quality of litterfall, hence; the total of soil macro-organic matter fractions were significantly different (Table 5.1). The total of soil macro-organic matter fractions under NF was the highest due to the highest litterfall. In this work, the fractions of soil macro-organic matter apparently were affected by land-use type. The order of the dry weight of total soil macro-organic matter fractions was MF > HF > LF (Table 5.1). This result was different from the reported by Barrios et al. (1996) and Hassink (1995). Barrios et al. (1996) observed the order of soil macro-organic matter fractions was HF > LF > MF after 4-yr-old maize legume systems on Alfisol in Kenya, but Hassink (1995) resulted the order HF > MF > LF on sandy arable soils in the Netherlands that received various organic input for 25 yr. In both situations their finding reflected condition in annual crops, which is different from the tropical forest and cacao agroforestry system studied here. The amount of LF-SOM in the soil at any time is small due to its rapid turnover (Paul and Juma 1981). The dry weight of LF-SOM and MF-SOM content decreased as changing land use from natural forest into cacao agroforestry systems in this study. The HF-SOM was not affected by land-use change. This is consistent with finding of Hopkins et al. (1993) that SOM tend toward chemical homogeneity as it decreases in size and increases in density through decomposition.

The differences in LF-SOM at the various sites can be attributed to two factors: the amount and quality of residue applied and the rate of substrate decomposition (Janzen et al. 1992, Biederbeck et al. 1994). In the NF had the highest annual litterfall as an amount residue applied (1367.4 g m^{-2}) and the fastest

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rate of decomposition ($k = 2.47$); both produced the highest total soil macro-organic (6.1 g kg^{-1} soil). The LF-SOM in cacao agroforestry systems in this study did not differ significantly. It showed that factors influencing LF-SOM formation was quite similar among cacao agroforestry systems. In this present study, the correlation between LF-SOM and annual litterfall was significant, as well as that with the decay rate coefficient ($p < 0.01$). It means that the LF-SOM was the influenced by amount of litterfall and rate of leaf-litter decomposition. The amount of LF-SOM was high when the amount of annual litterfall was also high, or when the rate of decomposition was faster. Quality of litterfall and microclimate in each site might influence the amount of LF-SOM as reported by Barrios et al. (1996) that quality of organic residues such as litter determined the proportion of LF-SOM. The study conducted by Janzen et al. (1992) in line with this study, particularly in the NF. Decomposition and biodegradation of litter produces POM (Cambardella and Elliot 1994, Shang and Tiessen 1998, Six et al. 1998) which includes soil macro-organic matter. The proportion of LF-SOM in the present study ranged between 22.9 to 25.9% in line with the results reported by Barrios et al. (1996) that LF-SOM of 10-30 % of SOM is responsible for maintaining soil microorganisms. The active fraction of organic matter is most susceptible to soil management practices. The proportion of LF-SOM in cacao agroforestry under CF2 was contributed by grass roots decomposition. Cacao agroforestry under CF2 showed a considerable grass weed infestation much more than either CF1 or CP agroforestry systems. Therefore, the cacao agroforestry CF2 had much more organic matter such as roots and leaves of grass weed, which contributed to soil macro-organic matter.

Quality of soil macro-organic matter fractions in this study was represented by nitrogen and organic carbon contents. Hassink (1995) reported that the quality and amount of the residues input had the strongest effect on the nitrogen and organic carbon content of the soil macro-organic matter particularly LF-SOM. Land use change from natural forest into cacao agroforestry systems decreased organic carbon and nitrogen in soil macro-organic matter fractions. The nitrogen and organic carbon content in the LF-SOM fractions indicate that the LF-SOM consists of mineral free, partly decomposed plant debris. The HF-SOM fraction includes the organomineral complexes soil macro-organic matter (Hassink 1995) with much lower carbon content (Golchin et al. 1995). This result was in line with Hassink (1995) and Meijboom et al. (1995). The amount of organic carbon and nitrogen

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content in three fractions of soil macro-organic matter in this study was higher than that reported by Barrios et al. (1996) and Hassink (1995). Even though LF-SOM contains only a small fraction of the total soil carbon and nitrogen, the amount of nitrogen in LF-SOM reportedly correlated with nitrogen mineralization in the whole soil (Barrios et al. 1997). The amount of carbon in soil macro-organic matter is controlled by soil management, while the amount of carbon protected by clay and silt particles is controlled mainly by soil texture (Hassink et al. 1997). Nitrogen in total soil macro-organic matter represented only a fraction of total soil nitrogen. Vanlauwe et al. (1998) indicated that it contributed more to crop nitrogen uptake than nitrogen from the other pools, and that it might be an important indicator of soil fertility.

According to Tumpal et al. (2005) organic residues are important for cacao plantation to increase its growth. The concentration of organic matter for soil requirement in cacao plantation is 3.5 % (Wood and Lass 1985). Organic residues in cacao plantation come from the compost of leaf-pruning and cacao pod husk. About 1,990 kg ha^{-1} year^{-1} of leaf-litter from *G. sepium,* as a shade trees, contribute 40.8 kg ha^{-1} N, 1.6 kg ha^{-1} P, 25 kg ha^{-1} K, and 9.1 kg ha^{-1} Mg into soil. About 900 kg ha^{-1} of cacao pod husk is equivalent to 29 kg N, 9 kg P, 56.6 kg K, and 8 kg Mg (Tumpal et al. 2005). Because cacao plantations in Toro village were local people's plantation, never fertilized chemically, and planted under shade trees, therefore, input of organic residues is important to maintain soil fertility.

CONCLUSIONS

Land use types ranging from natural forest to cacao agroforestry systems produced different soil macro-organic matter. Fractions component of soil macro-organic matter under natural forest was higher (6.1 g kg^{-1} DW soil) than those under cacao agroforestry systems. Under CF2 however showed a high soil macro-organic matter among cacao agroforestry systems. Light fraction of soil macro-organic matter under natural forest was highest (1.4 g kg^{-1} DW soil). The amount of light fraction of soil macro-organic matter was influenced by annual litterfall and rate of leaf-litter decomposition. The light fraction of soil macro-organic matter in cacao agroforestry CF2 was higher than the other cacao agroforestry systems.

Organic carbon and nitrogen content in fractions of soil macro-organic matter the highest in intermediate fraction of soil macro-organic matter.

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