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Improvement of Physical and Biological Quality of Soil in a Sugarcane Plantation through the Management of Organic Matter Input

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Abstract: Changes in soil quality of sugarcane plantation as a result of changes in land management can not be measured directly, but must be demonstrated by measuring the change in the properties of the ecosystem as an indicator. This research aimed to study the effect of the addition of various quality and quantity of organic matter on soil biology (earthworms) and physical quality (aggregate stability, macroporosity and infiltration rate). There were 15 treatment combinations tested. The first factor is the type of organic matter: (1) cattle manure (CM), (2) filter cake (FC), (3) sugarcane trash (ST), (4) a mixture of CM + FC and (5) a mixture of CM + ST. The second factor is the application dose of organic matter, which consists of three levels—5, 10 and 15 Mg/ha. The treatments were arranged in a factorial randomized block design with three replicates and one control treatment (without organic matter input). The result of this research showed that the highest population density of earthworms was found in the treatment of ST (78 individuals/m^2) and a mixture of CM + ST (84 individuals/m^2). The type of organic matter with C/N ratio ranged from 15.5 to 34.7 and cellulose content in 33.3%-40.1% gave better growth of earthworm. The effect of increase in earthworm growth on soil physical improvement is more apparent in the treatment of mixture of low quality and high quality organic matter. The increase of earthworm density and biomass enhanced soil macroporosity (from r = 0.683 to r = 0.606) and infiltration rate (from r = 0.669 to r = 0.756). The results of this study suggest a mixture of CM + ST or ST alone as organic matters, which is recommended to improve soil physical and biological quality of sugarcane land, with the dose application ranged from 10 Mg/ha to 15 Mg/ha.

Key words: Quality and quantity of organic matter, earthworms, physical and biological quality of soil.

1. Introduction

Managing soil organic matter content is very important for maintaining nutrient cycling in agroecosystem, improving soil physical condition and maintaining a healthy environment [1]. Organic matter plays an important role in regulating of nutrient flux and microbial biomass [2] and improving soil physical properties [3, 4], chemical properties [5] and biological properties [6]. Increase of soil C-organic content can directly improve soil structure as shown by water-stable aggregates [3, 4]. However, improvement of soil structure can also be caused by the indirect effect of organic matter through increasing population density of soil dweller type of earthworm and plant roots density resulting a better soil structure, soil porosity and water infiltration [7, 8]. Therefore, low input management in agroecosystems got a lot of attention from sugarcane farmers in Indonesia, especially in East Java. Hairiah et al. [9] reported their research result in an ultisol in North Lampung that the application of 16 Mg/ha bagasse (sugarcane processing waste) and 8 Mg/ha sugarcane trash (harvest residue) increased sugarcane production of 18-21 Mg/ha with the average sugar content of 7%-8% (relative to total dry weight), and the sugar production was about 1.5 Mg/ha. Some findings also had been reported that the applications of organic

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matter, such as cattle manure, crop residues and compost, can improve the status of soil organic matter, soil structure and soil fertility [10, 11]. The soil quality of the agricultural land that received anorganic input is better than conventional farming systems [12]. However, the effects of organic matter on soil quality are differed depending on its quality. According to Palm and Sanchez [13], organic materials with low C/N ratio (< 25), low concentrations of lignin (< 15%) and polyphenolics (< 3%) are considered to be high-quality, meaning material decomposes and nutrients are released rapidly. Research about the effect of different quality organic material on soil quality improvement in sugarcane plantation, however, is rather limited.

This research aimed to study the effect of different quality of organic material on the soil quality as measured by changes in the biological (earthworms) and physical soil quality (aggregate stability, soil macroporosity and soil infiltration rate). Hypotheses of this study are: (1) the application of a mixture of high and low quality organic matter will give better earthworm growth than a single quality of organic matter, (2) the increase of the application rate of organic matter will increase the growth of earthworms and (3) the increase of earthworms growth gives the improvement of soil physical properties.

2. Materials and Methods

2.1 The Experimental Site, Climate and Soil Characteristics

The field experiment was conducted on an inceptisol soil type for one year (during planting season) at Sempol village, Pagak sub-district, Malang regency (08°16.837′ S and 112°30.453′ E, 424 m above sea level). It was initiated in November 2010 to December 2011 in rainy season until dry season of 2010-2011. The climate of the experimental site is tropical with rainy season (November-May) and dry season (June-October). The average annual rainfall was 1,199 mm, while the average annual temperature was 25.3 °C. The soil of the experimental site is loam and has the following properties: 26% of clay, 48% of silt and 26% of sand. It is well drained and flat, and has bulk density of 1.24 Mg/m^3. The soil is very low in organic carbon (1.06%), with pH (H_2O) = 5.2 and pH (KCl) = 4.5, low in total N (0.16%), low in available P (9.17 mg/kg), medium in exchangeable K (0.54 meq/100 g) and medium in cation exchange capacity (CEC, 23.23 meq/100 g).

2.2 Treatments

The treatments were arranged in factorial block randomized design. The first factor is organic matter source that consists of five different quality of organic matter, i.e., cattle manure (CM), filter cake of sugar mill (FC), sugarcane trash (ST), mixture of cattle manure + filter cake (CM + FC), and mixture of cattle manure + sugarcane trash (CM + ST). The second factor is three application rates of the organic matter which are 5, 10 and 15 Mg/ha. The combination of two factors made 15 combinations of treatments plus one treatment (no organic input) as a control. Each treatment was replicated three times.

2.3 Preparation of Organic Matter and Analysis of the Organic Matter Quality

The used organic matter was two weeks been composted. Sugarcane trash was collected after harvesting and then was ground (< 2 mm). All organic matter samples were analyzed in laboratory for total N (by Kjeldahl digestion), C-organic content (by Walkley Black), lignin, cellulose and ash content by Goering and Van Soest [14], polyphenols content (by Folin-Denis) and gross energy (by Bomb calorimeter method). The results of these analysis were presented in Table 1.

2.4 Earthworms Inoculation

Earthworm *Pontoscolex corethrurus* obtained from coffee plantation, was inoculated into the planting hole in one week after organic matter application.

Table 1 The chemical composition of organic matter on dry weight basis.

Organic matter	Total C-organic (%)	Total N (%)	C/N	Lignin (%)	Ash (%)	Cellulose (%)	Polyphenol (%)	Gross energy (kcal/kg)
CM	16.7	1.94	8.30	12.3	13.3	30.3	0.26	1,011
FC	20.2	1.98	10.2	19.9	20.5	40.2	1.14	1,090
ST	28.1	0.81	34.7	13.3	10.2	40.1	2.01	3,028
CM + FC	19.2	1.68	11.4	16.5	11.5	37.5	1.42	1,120
CM + ST	20.4	1.32	15.5	12.0	8.22	33.3	1.12	1,354

Before the inoculation, a plastic barrier was installed among experimental plots to avoid any movement of inoculated earthworm. Each plot was inoculated by 125 individuals of earthworm with average weight per individual ranged from 0.2 g to 0.4 g. After the inoculation of earthworm, the soil surface was covered by sugarcane trash to avoid direct sunlight.

2.5 Crop Culture

The plots size of 10 m × 1 m was prepared by hoeing for all treatments uniformly. The sugarcane cultivar Bululawang-red with one bud and 10 cm length was planted in seedling beds for a month to obtain uniform seedlings. Subsequently, they were transplanted into the soil beds with planting distance of 40 cm inter-plants. During growing season, there were no chemicals (herbicide, pesticide or insecticide) applied. All the organic amendments were manually applied to field plots one month before planting. In addition to organic matters used for the treatments, the soil also received basic fertilizers NPK (15:15:15) of 200 kg/ha and ammonium sulfate of 800 kg/ha. The fertilizers were applied one month after transplantation by band application on distance of 10 cm from the plant.

2.6 Earthworm Sampling and Measurement

The population density of earthworms was determined by taking 48 soil monoliths (25 × 25 × 20 cm size) samples, each point was chosen in between two sugarcane plant of each plot, at soil depths of 0-10, 10-20 and 20-30 cm, according to a sampling procedure described by Huising et al. [15]. The earthworm samples were collected by hand sorting and calculated on population density (*D*, individuals/m^2), and weighed for its fresh weight (biomass, g/m^2). Weight per individual was estimated by the earthworm's biomass and density ratio (*B/D*). The earthworm measurement was conducted in April, July and December (during rainy and dry season).

2.7 Soil Sampling and Soil Physical Analysis

Soil samplings were taken in each treatment of each plot at one, three, six and nine months after planting. The measurements of stable aggregate were done using aggregate soil sample with diameter of > 5 mm, while for soil macroporosity measurement, an undisturbed soil sample was taken using a ring sample (4.5 cm diameter, 5 cm height). Aggregate stability was determined by wet sieving method and calculated it mean weight diameter of the aggregate (mm). The macroporosity was obtained by calculating soil water content in $pF = 0$ minus $pF = 2.5$ [16]. Infiltration rates were measured using a falling head single ring infiltration with diameter of 20 cm that was inserted to a depth of approximately 10 cm. The infiltration tests were conducted for at least 3 h until the infiltration rates were found to become constant. Cumulative infiltration was plotted against time and the data were fitted the Philip's infiltration equation [17].

2.8 Statistical Analysis

The collected data were statistically analyzed by using analysis of variance (ANOVA) (*F*-test) at level $P \leq 0.05$ and differences in each treatment were adjudged by least significant difference (LSD) test ($P \leq 0.05$) using program Minitab version 14.12. For statistical analysis of data (charts), Microsoft Excel was employed.

3. Results and Discussion

3.1 Effect of Quality of Organic Matter on Earthworm

The result of this study showed that the addition of different quality of organic matter has significantly ($P < 0.05$) affected the earthworm population densities (Table 2). The average increase of earthworm population density compared to control (no organic input) were 90% for CM, 106% for FC, 118% for ST, 65% for CM + FC and 135% for CM + ST. Mean weight per individual of earthworm (g/individual) calculated from the ratio earthworm biomass to population density tends to increase with increasing the applicated doses of organic matter. The application of the mixture of CM + ST and ST alone at a dose of 5-15 Mg/ha gave the highest population density (Fig. 1).

The increase of earthworm biomass on the plots which received the addition of organic matter to control were 165% for CM, 235% for FC, 273% for ST, 212% for CM + FC, 358% for CM + ST (Table 2). The increase of organic matter application rates increases earthworm biomass, except in the plot which received the mixture of CM + FC (Fig. 1). This result indicates that the organic matter input was needed to increase earthworm biomass, and differences of organic matter quality will affect the increase of earthworm biomass, when environmental conditions are less suitable for the growth of earthworms. It caused the different increase patterns of earthworm biomass with increase of the application rates. The addition of organic residues into the soil is a source of food and energy for soil biota [18, 19]. The result of this research is in line with which reported by previous researchers confirmed that the residue management either the mulch or the cover crop increased

Table 2 Effect of addition of various organic matter on earthworm population density (*D*), earthworm biomass (*B*), mean weight diameter of aggregate (*MWD*), macroporosity and infiltration rate.

Treatments	*D* (individuals/m^2)	*B* (g/m^2)	*B/D* (g/individual)	*MWD* (mm)	Macroporosity (%)	Infiltration rate (cm/h)
Control	35.6^a	2.60^a	0.073^a	0.65^a	8.65^a	31.2^a
CM	67.6^{bc}	6.90^b	0.102^{ab}	0.99^b	9.87^b	35.4^b
FC	73.5^{cd}	8.70^{bc}	0.118^{bc}	1.20^c	9.84^b	39.6^c
ST	77.6^{cd}	9.50^c	0.122^{bc}	1.31d	10.50^c	43.7^e
CM + FC	58.7^b	8.10^{bc}	0.138^c	1.28^{cd}	10.20^{bc}	42.2^d
CM + ST	83.6^d	11.90^d	0.142^c	0.99^b	10.30^c	43.6^e
LSD (P = 0.05)	10.7	1.90	0.030	0.08	0.44	1.01

LSD = least significant difference; $^{a-e}$means followed by the same letters at each column are not significantly different (P = 0.05).

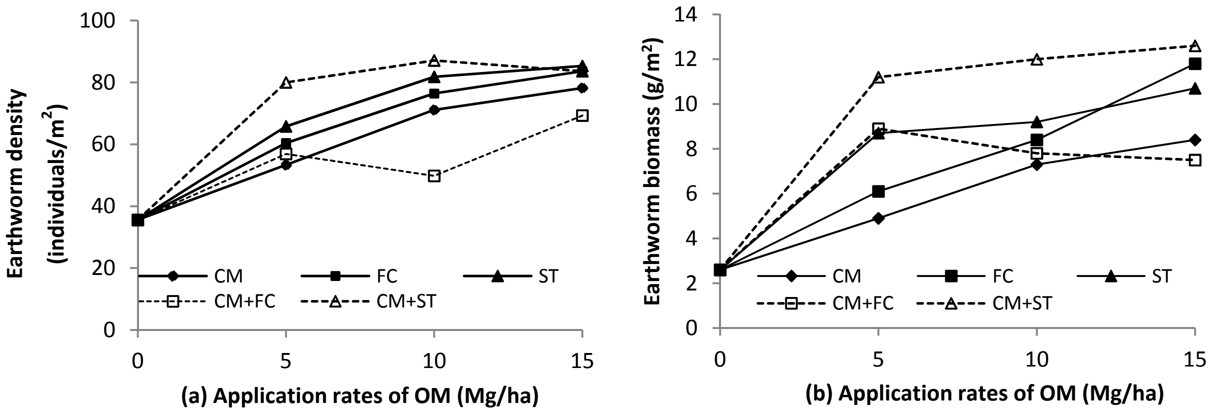

Fig. 1 Effect of application dose of various organic matter (OM) on the average earthworm density (a, LSD = 18.40) and biomass (b, LSD = 3.42).

population density earthworms ranging from 18.5 individuals/m^2 to 451.2 individuals/m^2, and earthworm biomass ranged from 1.3 g/m^2 to 142.3 g/m^2. The residue left on the soil surface can increase the biomass of earthworms 2.9 fold in fallow soil [20-22].

The palatability of earthworm food determines the growth and development of earthworms. Schönholzer et al. [23] reported that the organic matter quality that measured by C/N ratio greatly determined palatability of organic matter consumed by earthworms. The residue consumption level of earthworm was positively correlated with the C/N ratio on the range of 12-39. Residues with C/N ratio of 12.3 are preferred than C/N ratio of 8. Neilson and Boag [24] and Valckx et al. [25] reported that the grasses residue with the same palatability on the C/N ratio of 11.4 to 15 is more consumed by earthworms. Increase in the application rates of organic matter increases the population density and biomass of earthworms. García and Fragoso [18] reported that the growth and biomass of earthworms, including *P. corethrurus*, was influenced by the quality and quantity of food available in the soil. The higher the quantity of applied organic matter is, the larger the amount of energy and food resources is available to earthworms, thereby increasing earthworm populations and activity.

3.2 Effect of the Organic Matter Quality on Soil Physical Properties

The quality of organic matter influenced significantly ($P < 0.05$) *MWD* of soil aggregate. The average increase of soil aggregate *MWD* of each the organic matter quality in comparsion with the control were 52% for CM, 85% for FC, 101% for ST, 97% for CM + FC and 52% for CM + ST. Increase of organic matter application rates can increase average *MWD* of soil aggregate, except on application of mixture of CM + FC (Fig. 2). This result suggests that the organic matter input even though low quality can enhance the formation of stable aggregates. It probably caused by that organic input enhanced soil biota activity in the organic matter decomposition process as well as earthworms. The result of organic matter decomposition process and biota activity can play an important role as a granulator in stable aggregate formation. Earthworms prefer the low quality of organic matter and high C/N ratio and cellulose content [22]. The results of decomposition

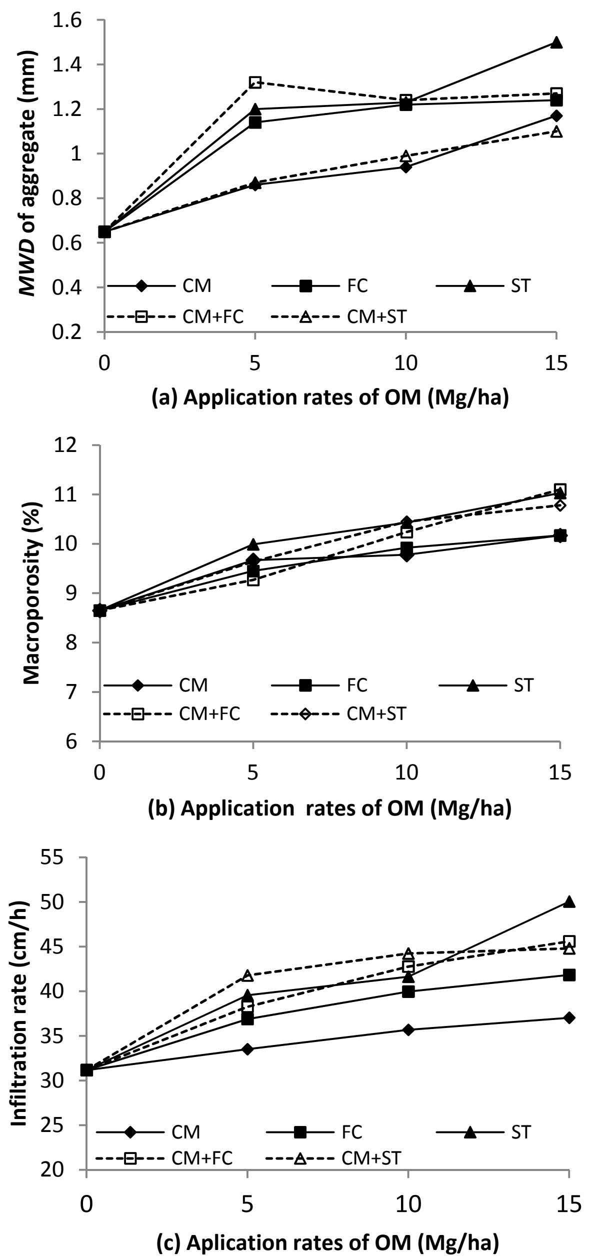

Fig. 2 Effect of application rates of various organic matter (OM) on *MWD* of aggregate (a, LSD = 0.14), macroporosity (b, LSD = 0.76) and infiltration rate (c, LSD = 1.76).

and cast formation can increase soil aggregate stability.

The results of this research also showed that the addition of various organic matter with different rates gave higher macroporosity than the control. The increase of organic matter application rates increases macroporosity with similar increasing pattern for each treatment (Fig. 2). The average macroporosity increase of the addition of various organic matter were 14% for CM, 14% for FC, 27% for ST, 18% for CM + FC and 19% for CM + ST, respectively (Table 2). These results suggest that the application of low quality of organic matter can increase the activity of soil biota to produce greater amounts macropore. It is caused by the low quality of organic matter, which has a high gross energy (Table 1). Availability of more food and energy resources can increase earthworm activity in burrowing and formation of holes and channels in the soil.

The difference of organic matter quality influenced significantly ($P < 0.05$) the soil infiltration rate. The increase of infiltration rate of each treatment compared to the control were 14% for CM, 27% for FC, 40% for ST, 35% for CM + FC and 40% for CM ST, respectively (Table 2). This result indicates that the application of low quality of organic matter with larger particle size due to more porous soil and higher soil infiltration rate. The higher organic matter application rate is, the higher soil porosity is, especially in the upper layers of soil. It caused increase of soil infiltration rate (Fig. 2). These results also suggest that input of low quality of organic matter can increase the infiltration rate due to increasing earthworms activity in formation of soil macropore.

Organic matter is the main agent of aggregate stabilization in some form, such as (1) the decomposition products of plant, animal and microbial residues, (2) itself microorganism and (3) the products of microbial synthesis, such as polysaccharide and gums that are formed during the decomposition of organic residues [26, 27]. The quality and quantity of residue affect the aggregate formation and stabilization [28].

The results of this study showed that the application of sugarcane trash (low quality of organic matter) at a rate of 15 Mg/ha gave a high *MWD* of soil aggregate. The increase in aggregate stabilization can occur because of stimulation of micro- and macro-fauna activity and soil microflora [27]. This study is in line with the one reported by Coq et al. [29] that the effect of earthworm activity on the formation of stable aggregates is larger in the treatment with the addition of low quality of organic matter than high quality of organic matter, such as legume crops residue. The increase in growth and population density of earthworm can stimulate the activity of other soil microorganisms [30], so it assists in the stabilization of aggregates. Earthworms' activity through their burrowing and casting activities also affected the soil porosity. Also known as "ecosystem engineers" [31], earthworms produce structural features at three different scales of soil porosity. They live and are active in the soil, and consume litter available in the soil or on the soil surface [8, 32, 33]. Earthworm activity can alter pore spaces between mineral and organic particles to influence the soil macroporosity and soil structure stability [34].

Lamande et al. [7] reported that the difference of land management will produce a different earthworm community. It will further influence the structure of the soil pore morphology to influence the water movement in the soil, as measured from hydraulic conductivity and soil infiltration rate. A good soil structure will help the movement and retention of water in the soil and improve crop rooting environment. Thus, maintaining organic matter inputs is needed to increase earthworm activity and improve the development of plant roots due to maintenance of soil porosity [8].

3.3 The Relationship between the Variables of Soil Biological and Physical Properties

The results of correlation analysis showed that the

Table 3 Correlation coefficient between earthworm variables and soil physical properties.

Variables	Earthworm population density (individuals/m^2)		Earthworm biomass (g/m^2)	
	r	*P*-value	*r*	*P*-value
MWD aggregate (mm)	0.416	0.110	0.416	0.110
Macroporosity (%)	0.683	0.004*	0.606	0.010*
Infiltration rate (cm/h)	0.669	0.005*	0.756	0.001*

*Means statistically significant difference at $P < 0.05$.

earthworms variables were positively correlated with the variables of soil physical properties (Table 3). This suggests that the greater the population density and biomass of earthworms are, the higher the average aggregates *MWD*, macroporosity and soil infiltration rate are. These results indicate that the addition of organic matter into the soil provides a direct influence on the population and activity of earthworms. Increased population and earthworm activity improved soil physical properties. The significant influence of the increase in population and activity of earthworm was shown in soil macroporosity and infiltration rate. This suggests the role of *P. corethrurus* endogeic earthworms group through their burrowing and casting activity in the subsurface layer is clearly visible.

The earthworms can improve soil aggregation through amendmenting biological and physico-chemical soil [34], as well as the direct effect and indirect effect on soil structure and content of soil organic matter [34, 35]. However, impact of earthworms on the aggregation varied depending on the quality of the organic matter residue added to the soil [36], because the population and diversity of earthworms were affected by the quality and quantity of organic residues [37]. The *P. corethrurus* earthworm (geophagus earthworm) can digest soil. It can destroy soil aggregates to make them become unstable. However, the biochemical process of soil digesting activity can stabilize soil aggregates [38]. Rearrangement of soil particles affected the water movement into soil (infiltration) [35]. Thus, earthworm activity increases soil aggregate stability, soil macroporosity and soil infiltration rate [36].

4. Conclusions

The addition of various quality of organic matter increased earthworm population density, respectively, 90% for CM, 106% for FC, 118% for ST, 65% for CM + FC and 135% for CM + ST, and earthworm biomass, respectively, 165% for CM, 235% for FC, 273% for ST, 212% for CM + FC and 358% for CM + ST compared with the control. It also increased soil macroporosity, respectively, 14% for CM, 14% for FC, 27% for ST, 18% for CM + FC and 19% for CM + ST, and the rate of infiltration by 14% for CM, 27% for FC, 40% for ST, 35% CM + FC and 40% for CM + ST than in the control. The addition of sugarcane trash with a ratio of C/N = 15.5, alone or mixed with high quality organic matter (CM + ST) with a ratio of C/N = 34.7 is likely to provide the improvement of biological and physical soil quality higher than the other treatments. The recommended application rate based on the results of this study was 10-15 Mg/ha. Increasing population density and biomass of earthworms improves soil macroporosity and infiltration rate. Thus, the addition of organic matter derived from sugarcane harvest residue alone or mixed, is recommended in the sugarcane land management for maintaining the existence and activity of earthworms in the sugarcane land. It is an important factor in the improvement of soil physical properties of sugarcane land.

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References

[1] Mapfumo, P., Mtambanengwe, F., and Vanlauwe, B. 2007. "Organic Matter Quality and Management Effects on Enrichment of Soil Organic Matter Fractions in Contrasting Soils in Zimbabwe." *Plant Soil* 296 (1): 137-50.

[2] Goyal, S., Chander, K., Mundra, M. C., and Kapoor, K. K. 1999. "Influence of Inorganic Fertilizers and Organic Amendments on Soil Organic Matter and Soil Microbial Properties under Tropical Conditions." *Biol. Fertil. Soils* 29 (2): 196-200.

[3] Six, J., Feller, C., Denef, K., Ogle, S. M., De Moraes Sa, J. C., and Albrecht, A. 2000. "Soil Organic Matter, Biota and Aggregation in Temperate and Tropical Soils—Effects of No-tillage." *Agronomie* 22 (7-8): 755-75.

[4] Chenu, C., Le Bissonnais, Y., and Arrouays, D. 2000. "Organic Matter Influence on Clay Wettability and Soil Aggregate Stability." *Soil. Sci. Soc. Am. J.* 64 (4): 1479-86.

[5] Bellakki, M. A., Badanur, V. P., and Setty, R. A. 1998. "Effect of Long-Term Integrated Nutrient Management on Some Important Properties of a Vertisol." *J. Ind. Soc. Soil. Sci.* 46 (2): 176-80.

[6] Marinori, S., Masciandaro, G., Ceccanti, B., and Grego, S. 2000. "Influence of Organic and Mineral Fertilizers on Soil Biological Properties." *Biores. Technol*. 72 (1): 9-17.

[7] Lamande, M., Hallaire, V., Curmi, P., Peres, G., and Cluzeau, D. 2003. "Changes of Pore Morphology, Infiltration and Earthworm Community in a Loamy Soil under Different Agricultural Managements." *Catena* 54 (3): 637-49.

[8] Hairiah, K., Sulistyani, H., Suprayogo, D., Widianto, Purnomosidhi, P., Widodo, R. H., and Van Noordwijk, M. 2006. "Litter Layer Residence Time in Forest and Coffee Agroforestry Systems in Sumberjaya, West Lampung." *Forest Ecology and Management* 224 (1-2): 45-57.

[9] Hairiah, K., Purnomosidhi, P., Khasanah, N., Nasution, N., Lusiana, B., and Van Noordwijk, M. 2003. "Utilization of Sugarcane Bagasse and Trash for Improving the Soil Organic Matter Status and Production of Sugarcane in North Lampung: Measurement and Estimation with WaNuLCAS Simulation." *Agrivita.* 25 (1): 30-40. (in Indonesian)

[10] Parham, J. A., Deng, S. P., Raun, W. R., and Johnson, G. V. 2002. "Long-Term Cattle Manure Application in Soil: Part 1, Effect on Soil Phosphorus Levels, Microbial Biomass C and Dehydrogenase and Phosphatase Activities." *Biol. Fertil. Soils* 35 (5): 328-37.

[11] Saviozzi, A., Bufalino, P., Levi-Minzi, R., and Riffaldi, R. 2002. "Biochemical Activities in a Degraded Soil Restored by Two Amendments: A Laboratory Study." *Biol. Fertil. Soils* 35 (2): 96-101.

[12] Droogers, P., and Bouma, J. 1996. "Biodynamic Versus Conventional Farming Effects on Soil Structure Expressed by Simulated Potential Productivity." *Soil Science Society of America Journal* 60 (5): 1552-8.

[13] Palm, C. A., and Sanchez, P. A. 1991. "Nitrogen Release from the Leaves of Some Tropical Legumes as Affected by Their Lignin and Polyphenolic Contents." *Soil Biol. Biochem.* 23 (1): 83-8.

[14] Goering, H. K., and Van Soest, P. J. 1970. *Forage Fiber Analysis (Apparatus, Reagents, Prosedures and Some Applications).* US: USDA.

[15] Huising, E. J., Coe, R., Cares, J. E., Louzada, J. N., Zanetti, R., Moreira, F. M. S., Susilo, F. X., Konate, S., Van Noordwijk, M., and Huang, S. P. 2008. *A Handbook of Tropical Soil Biology: Sampling Strategy and Design to Evaluate Below-Ground Biodiversity,* edited by Moreira, F. M. S., Huising, E. J., and Bignell, D. E. London: Earthscan Publishing, 17-41.

[16] Okalebo, J. R., and Gathua, K. W. 1993. *Laboratory Methods of Soil and Plant Analysis: A Working Manual.* Nairobi, Kenya: UNESCO, 89.

[17] Landon, J. R., ed.. 1984. *Booker Tropical Soil Manual: A Handbook for Soil Survey and Agriculture Evaluation in the Tropics and Sub-tropics*. New York: Longman, 213-8.

[18] García, J. A., and Fragoso, C. 2003. "Influence of Different Food Substrates on Growth and Reproduction of Two Tropical Earthworms (*Pontoscolex corethrurus* and *Amynthas corticis*)." *Pedobiologia* 47 (5-6): 754-63.

[19] Suthar, S. 2007. "Influence of Different Food Sources on Growth and Reproduction Performance of Composting Epigeics: *Eudrilus eugeniae*, *Perionyx excavatus* and *Perionyx sansibaricus*." *Applied Ecology and Environmental Research* 5 (2): 79-92.

[20] Kladivko, E. J., Akhouri, N. M., and Weesies, G. 1997. "Earthworm Populations and Species Distributions under No-till and Conventional Tillage in Indiana and Illinois." *Soil Biol. Biochem.* 29 (3-4): 613-5.

[21] Chan, K. Y., Bowman, A., and Oates, A. 2001. "Oxidizable Organic Carbon Fractions and Soil Quality Changes in an Oxic Paleustalf under Different Pasture Leys." *Soil Sci.* 166 (1): 61-7.

[22] Fonte, S. J., Winsome, T., and Six, J. 2009. "Earthworm Populations in Relation to Soil Organic Matter Dynamics and Management in California Tomato Cropping Systems." *Applied Soil Ecology* 41 (2): 206-14.

[23] Schönholzer, F., Kohli, L., Hahn, D., Daniel, O., Goez, C.,

and Zeyer, J. 1998. "Effects of Decomposition of Leaves on Bacterial Biomass and on Palatability to *Lumbricus terrestris* L." *Soil Biol. Biochem.* 30 (13): 1805-13.

[24] Neilson, R., and Boag, B. 2003. "Feeding Preferences of Some Earthworm Species Common to Upland Pastures in Scotland." *Pedobiologia* 47 (1): 1-8.

[25] Valckx, J., Pina, A. C., Govers, G., Hermy, M., and Muys, B. 2011. "Food and Habitat Preferences of the Earthworm *Lumbricus terrestris* L. for Cover Crops." *Pedobiologia* 54: S139-44.

[26] Martens, D. A., and Frankenberger, W. T. 1992. "Modification of Infiltration Rates in an Organic-Amended Irrigated Soil." *J. Agron.* 84 (4): 707-17.

[27] Schlecht-Pietsch, S., Wagner, U., and Anderson, T. H. 1994. "Changes in Composition of Soil Polysaccharides and Aggregate Stability after Carbon Amendments to Different Textured Soils." *Applied Soil Ecology* 1 (2): 145-54.

[28] Bossuyt, H., Denef, K., Six, J., Frey, S. D., Merckxb, R., and Paustian, K. 2001. "Influence of Microbial Populations and Residue Quality on Aggregate Stability." *Applied Soil Ecology* 16 (3): 195-208.

[29] Coq, S., Barthes, B. G., Oliverb, R., Rabaryc, B., and Blanchart, E. 2007. "Earthworm Activity Affects Soil Aggregation and Organic Matter Dynamics according to the Quality and Localization of Crop Residues—An Experimental Study (Madagascar)." *Soil Biol. Biochem*. 39 (8): 2119-28.

[30] Bohlen, P. J., Parmelee, R. W., Edwards, C. A., and McCartney, D. M. 1997. "Earthworm Effects on Carbon and Nitrogen Dynamics of Surface Litter in Corn Agroecosystems." *Ecol. Appl.* 7 (4): 1341-9.

[31] Jones, C. G., Lawton, J. H., and Shachak, M. 1994. "Organisms as Ecosystem Engineers." *Oikos* 69: 373-86.

[32] Capowiez, Y., Pierret, A., Daniel, O., Monestiez, P., and Kretzschmar, A. 1998. "3D Skeleton Reconstructions of Natural Earthworm Burrow Systems Using CAT Scan Images of Soil Cores." *Biol. Fert. Soils* 27 (1): 51-9.

[33] Brown, G. G., Barois, I., and Lavelle, P. 2000. "Regulation of Soil Organic Matter Dynamics and Microbial Activity in the Drilosphere and the Role of Interactions with Other Edaphic Functional Domains." *Eur. J. Soil Biol.* 36 (3-4): 177-98.

[34] Chauvel, A., Grimaldi, M., Barros, E., Blanchart, E., Desjardins, T., Sarrazin, M., and Lavelle, P. 1999. "An Amazonian Earthworm Compacts More than a Bulldozer." *Nature* 398: 32-3.

[35] Jegou, D., Hallaire, V., Cluzeau, D., and Trehen, P. 1999. "Characterization of the Burrow System of the Earthworms Using X-Ray Computed Tomography and Image Analysis." *Biol. Fert. Soils* 29 (3): 314-8.

[36] Winsome, T., and McColl, J. G. 1998. "Changes in Chemistry and Aggregation of a California Forest Soil Worked by the Earthworm *Argilophilus papillifer* Eisen (Megascolecidae)." *Soil Biol. Biochem*. 30 (13): 1677-87.

[37] Flegel, M., and Schrader, S. 2000. "Importance of Food Quality on Selected Enzyme Activities in Earthworm Casts (*Dendrobaena octaedra*, Lumbricidae)." *Soil Biol. Biochem*. 32 (8-9): 1191-6.

[38] Schrader, S., and Zhang, H. Q. 1997. "Earthworm Casting: Stabilization or Destabilization of Soil Structure?" *Soil Biol. Biochem.* 29 (3-4): 469-75.