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PARTICULATE ORGANIC MATTER AS A SOIL QUALITY INDICATOR OF SUGARCANE PLANTATIONS IN EAST JAVA

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ABSTRACT

The research tested the degree of independence of two soil quality indicators for sugarcane plantations: the particulate organic matter (POM) content and earthworm density across five sites in Malang district, East Java. Sites reflected a gradient in average annual rainfall (1400-2500 mm/year) and two types of soil management: with and without organic input. Soil samples taken from a depth of 0-20 cm were analyzed for total organic C (TOC), total N (TN), POM-C, and POM-N and earthworm density and biomass. The TOC was corrected by the clay content using *pedotransfer* equations, so TOC_{ref} was obtained. The soils treated with organic input had higher TOC (18%), TN (28%), POM-C (70%), POM-N (64%), earthworm density (89%) and biomass (92%) than the soils without organic input. A statistically significant interaction was found between variation in annual rainfall and soil management types in their influence on TOC, TN, POM-C, POM-N, earthworm density and biomass. Increase in TOC, TOC/TOC_{ref}, and POM-C tend to be associated with increase in earthworm density (r=0.590;0.667;0.738) and biomass (r=0.622;0.732;0.581). As an easily measured indicator of biological soil health, POM-C is suited for monitoring soil quality in sugarcane plantations: earthworm density does provide additional information that may justify its regular measurement.

Keywords: total C, particulate organic matter, earthworm, soil quality, sugarcane plantation

INTRODUCTION

Soil organic matter (SOM) content is seen as an important indicator of soil fertility and quality in addition to other indicators such as soil structure, nutrient balance and the population density of biota such as earthworms (Gregorich *et al.,* 1994). Total C-organic content relates to soil chemical, physical and biological properties, and processes in the soil, but more dynamically sensitive indicators may be needed as part of management and monitoring systems. Total C-organic content responds to soil physical characteristics (e.g. clay content) as well as soil management practices (Van Noordwijk *et al.,* 1997; Haynes, 2005). It consists of various fractions with varying turn-over time and function. The CENTURY model of soil organic matter dynamics (Parton *et al.,* 1987), distinguishes SOM pool with fast turn-over (<2 years) such as the metabolic, structural and active SOM, and slow turn-over pool (with a half time of around 8 years) and a passive (stable) pool (half life time about two thousand years) that is not available for soil microorganisms. Labile SOM fractions are more responsive to land use and management practices than the other fractions (Cambardella and Elliot, 1992; Ding *et al.,* 2006): corrections for soil textural variation influencing the slow and passive pools may be needed if total SOM is to be used across sample locations.

Measurements of SOM based on particle size and content of C and N, commonly called POM-C and POM-N (Okalebo and Gathua, 1993), have been used extensively to evaluate the effect of organic fertilizer types in paddy soil (Yan *et al.,* 2007) and in maize land (Mtambanengwe and

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Mapfumo, 2008). In addition the method is also used to study the improvement of marginal agricultural land (Mao and Zeng, 2010) and the land use change of monocropping system to agroforestry (Mao *et al.,* 2011). However, measurements of POM as an important indicator to evaluate the productivity of sugarcane land have so far been limited.

Earthworms are important as part of soil macrofauna that acts as a key regulator of soil structure and dynamics of the SOM in the agro-ecosystem. However, in conducting their activities in soil, worms are influenced by various factors that regulate populations such as climatic conditions, soil characteristics and availability of organic materials as their food source (Kale *et al.,* 2010). Therefore, the earthworm population density has been used to evaluate the impact of application of manure and NPK fertilizer in the long-term (Estevez *et al.,* 1996), the effect of various land management practices (Reddy *et al.,* 1997), assessing the productivity of rubber plantations (Chaudhuri *et al.,* 2008) and as bio-indicator of agricultural land management practices (Suthar, 2009). It is even used as an indicator of heavy metals and pollutants from agrochemical residues (Mahmoud, 2008).

To improve soil fertility of sugarcane land, inorganic and organic fertilizer inputs are needed. However, the evaluation of its success is still limited. Evaluation of soil quality of sugarcane land using simple indicators of POM and the population density of earthworms needs to be done. The purpose of this study was to test the hypothesis that the soil quality of sugarcane plantation is closely linked with decreased content of POM-C and earthworm population.

MATERIALS AND METHODS

Study Site and Time

The research was conducted at five sites (Wagir, Tumpang, Ngajum, Karangploso, and Kalipare) of monoculture sugarcane plantation area in Malang district, East Java, Indonesia. The selected plots were established as sugarcane plantation for more than 10 years under conventional soil management with Inceptisol soil type. The five sites were selected based on differences in average annual rainfall ranges from high to low annual rainfall. Environmental characteristics of each site are presented in Table 1. The research was conducted during the growing season of sugarcane in November 2010 to July 2011.

Treatment

Two factors that were interacting in this study were rainfall and soil management. The five sites differed in mean annual rainfall (Table 1). The second factor is the type of soil management, namely the organic fertilizer input of sugar agro-industry waste (5-10 Mg ha^{-1}) at least once in three years, and inorganic fertilizer only with a dose of 800 kg ha^{-1} ammonium sulfate and 200 kg ha^{-1} NPKas compound fertilizer 15:15:15. Based on crop performance, sampling sites in each location included good, average and poor crop with two replicates and 4 sampling points per replicate.

Soil Sampling and Analysis

Soil sampling was carried out between two rows of sugarcane at a depth of 0-20 cm. Four soil samples were taken from each plot, where the distance between the sampling points was 10 m. The soil samples were mixed evenly and air-dried, crushed and sieved to 100-mesh sieve size. Furthermore, the soil samples were analyzed for total organic carbon (TOC) (Walkley and Black, 1934), total soil N (TN) with the Kjeldahl method (Jackson, 1973), soil pH, soil texture by the pipette method of mechanical analysis. Undisturbed soil sample was used to measure the soil bulk density (BD) by calculating the ratio of the mass of soil by volume of soil (Okalebo and Gathua, 1993).

The Corrected Total Organic Carbon (TOC_{ref})

The obtained data of TOC was corrected with soil depth, soil pH, clay and silt content and altitude, in order to obtain soil TOC_{ref} using pedotransfer equation (Van Noordwijk *et al.,* 1997). For Inceptisol, the following equation was used :

$$TOC_{ref} = (Z_s / 7.5)^{-0.42} \exp(1.333 + (0.00994+0.011)^{*} \%\,clay + 0.00699^{*} \%\,silt - 0.156^{*} pH_{KCl} + 0.000427^{*} H)$$

where:
Zs = depth of soil sampling, cm
H = altitude (meter above sea level)

(Van Noordwijk *et al.,* 1997; Hairiah *et al.,* 2000)

Table 1. Location and soil characteristics of the study sites

Environmental Parameters	Sites				
	Wagir	**Tumpang**	**Ngajum**	**Karangploso**	**Kalipare**
Altitude (m)	478-679	580-698	407-592	584-720	522-583
Latitude (S) and Longitude (E)	7^{o} 52'52"- 8^{o}00'50" S and 112^{o}35'9"- 112^{o}37'4" E	8^{o}00'58" – 8^{o}2"50' S and 112^{o}40'5"- 112^{o}50'8" E	7^{o}52'50"- 8^{o}7'50" S and 112^{o}30'15"- 112^{o}37'50" E	8^{o}8'25"- 8^{o}10'26" S and 112^{o}27'7"- 112^{o}32'38" E	8^{o}7'50"-8^{o}15'5" S and 112^{o}25'54"- 112^{o}30'8" E
Mean Annual rainfall (mm)	2514	2031	1904	1644	1413
Mean Annual Temp. (^{o}C)	23.8	23.5	25.1	23.4	25.3
Soil Texture	Loam-clayey loam	Loam	Loam-clayey loam	Loam-clayey loam	Loam-clayey loam
% sand	18-35	38-49	15-37	12-40	18-38
% silt	40-54	33-45	37-55	40-51	41-52
% clay	22-35	14-20	18-37	18-34	20-34
% Soil C-organic	1.13-1.78	1.24-1.58	1.27-1,62	1.04-1.85	0.46-0.98
Soil pH (H_2O)	4.8-6.0	4.8-6.5	4.5-5.6	4.8-5.5	4.5-5.0

Source : Nurhidayati *et al.* (2011)

POM-Fractionation

The processed samples from each plot were taken for Particulate Organic Matter (POM) analysis. POM analysis was done by separating the SOM fractions based on wet sieving technique developed by TSBF (Hairiah, 1996). The air-dry soil (500 g) which has been re-wetted, was separated by using a wet sieve with a size of 2000, 250, 150, and 50 µm diameter. The materials which retained on >50, 150, 250 µm sieves were dried in the oven at 65^{o}C for 24 hours, weighted, and referred as a POM-coarse fraction (>250µm-2 mm), POM-intermediate fraction (150-250µm), and POM-fine fraction (>50-150µm). Total organic carbon (Walkley and Black) and total N (Kjehldahl) were determined by every fraction as a particulate organic matter-C (POM-$C_{C,I,F}$) and a particulate organic matter-N (POM-$N_{C,I,F}$) (Okalebo and Gathua, 1993).

Earthworm Sampling and Assessment

The population density (D) of earthworms was determined from soil monoliths (25cm x 25cmx 20cm size), at 120 point measurements of the 10 m x 10 m transect, according to a sampling procedure described by Huising *et al*., (2008). Earthworm samples were collected by hand sorting and weighed for fresh weight (biomass, B g indiv.$^{-1}$) measurement. Weight per individual was estimated by earthworm biomass and density ratio (B/D).

Statistical Analysis

The obtained data were subjected to analysis of variance (ANOVA) using program Minitab Version 14.12 to compare the interaction effects of sites with different annual rainfall and soil management on the measured parameters. The Duncan t-test (5%) procedure was used to separate the means of selected parameters at p=0.05. For statistical analysis of data (regression, correlation, and charts) Microsoft Excel was used. The Pearson correlation was used to relate earthworm variables with the soil variables.

RESULTS AND DISCUSSION

RESULTS

Total Soil C and N

Interaction between the sites with different rainfall and the type of soil management did not significantly (p<0.05) influence the total organic carbon (TOC_{org}) and total N (TN) of soil. Separately, the effect of different characteristics of sites and type of soil management significantly (p<0.05) affected the TOC and TN in the soils. At all sites of the selected sugarcane plantations, the soils treated with organic input were higher than the treatments without organic input (Figure 1).

The soils of sugarcane plantation with organic input treatment contained an average of 18.3 % C and 27.2 % N more than the soils of sugarcane plantation without organic input. Wagir site, the wettest areas (2514 mm per yr), had the highest average of TOC (16.23 g per kg) for the treatment with organic input, but was not significantly different from three other sites that had lower annual rainfall such as Tumpang (14.51 g per kg), Ngajum (15.53 g per kg), and Karangploso (14.27 g per kg) with an average annual rainfall as 2031, 1904, and 1644 mm per yr, respectively. Kalipare site had the lowest TOC (8.5 g kg^{-1}), while the highest TN due to the addition of organic matter was found in sugarcane land at Tumpang site (1.62 g per kg), but not significantly different from Ngajum (1.58 g per kg) and Karangploso (1.53 g per kg).

The Corrected Soil Organic Matter (TOC/TOC_{ref})

The addition of organic matter into soil of sugarcane plantations did not significantly influence ($p<0.05$) the corrected SOM (TOC_{ref}). The differences in TOC_{ref} were only significantly influenced ($p<0.05$) by the site's factor which had various altitude and soil properties. The highest TOC of 59.49 g kg^{-1} was found at Kalipare site and the lowest value was found at Tumpang site (Figure 2).

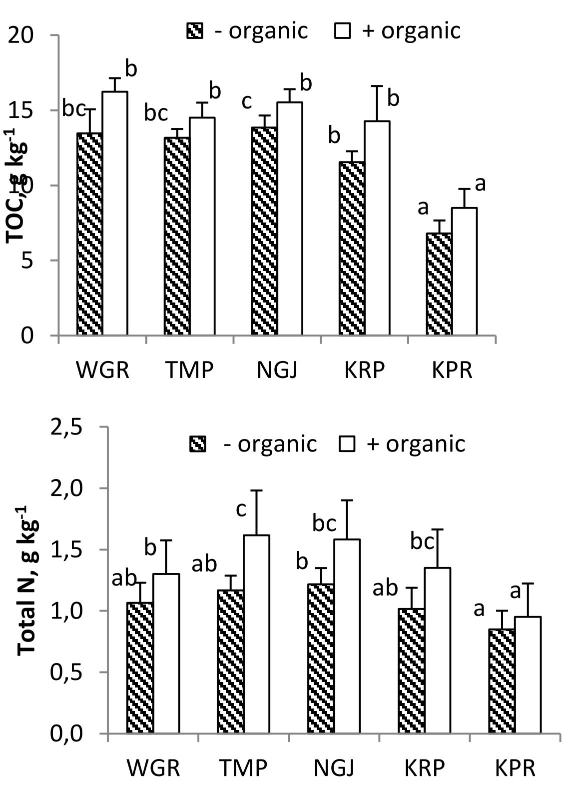

Figure 1. The effect of organic matter input to the average total organic C (TOC) and total soil N (TN) at five sites of sugarcane plantations. The magnitude of the bar shows the standard deviation (n = 6). Bar values followed by different letters are significantly different ($p<0.05$). (Remarks: WGR = Wagir; TMP = Tumpang ; NGJ = Ngajum; KRP = Karangploso; KPR = Kalipare.)

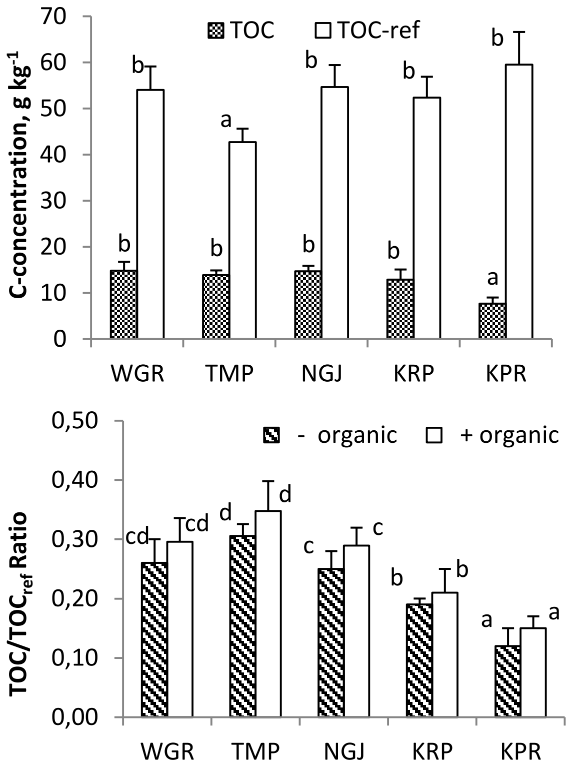

Figure 2. Average TOC and TOC_{ref} (A) and the effect of organic input to the TOC / TOC_{ref} (B) at five sites of sugarcane plantations. The magnitude of the bar shows the standard deviation (n = 6). Bar values followed by different letters indicate significant differences ($p<0.05$). (Remarks: WGR = Wagir; TMP = Tumpang = Ngajum; KRP = Karangploso; KPR = Kalipare)

The results of calculation of TOC/TOC_{ref} from all sites showed an average value of less than 0.5 (Fig.2), which means that the sugarcane lands of the five sites can be regarded as less healthy soil. According to Van Noordwijk *et al.,* (1997), the soil is classified as a healthy soil when the TOC /TOC_{ref} is close to 1.0, such as in natural forest soils. The soils of sugarcane plantation at Tumpang site showed the highest TOC /TOC_{ref}, but were not significantly different from Wagir. The soil of sugarcane plantations with organic input treatment had 14% TOC/TOC_{ref} higher than the soil of sugarcane plantations treated without organic inputs (0.23). The highest increase in TOC /TOC_{ref} was found at Kalipare site (25%), while the lowest increase at Karangploso site (10.5%) (Figure 2).

POM-C and POM-N

The interaction between sites with different annual rainfall and the type of soil management in sugarcane cultivation significantly ($p<0.05$) affected the C concentration of coarse fraction (POM-C_C) and total POM-C (POM-C_T). However, the interaction effect did not affect the POM-C_I and POM-C_F. Separately, the influence of differences in annual rainfall and type of soil management significantly ($p<0.05$) affected POM-C_I and POM-C_F. The addition of organic matter in the sugarcane lands increased POM-C_C- POM-C_I, and POM-C_F by 94.2, 61.4, 66.4%, respectively compared to sugarcane lands without organic inputs, except for POM-C_C at Kalipare site (Table 2).

Table 2. The effect of organic matter input on the C concentration of each fraction and its proportion of the POM-C_T at five sites of sugarcane plantation

Site	Treatment	POM-C (g per kg soil)			POM-C_T	POM-C (% of POM-C_T)		
		C	I	F	(g per kg soil)	C	I	F
Wagir	- Organic	1.01 a	0.46	0.52	1.99 a	49.2 bc	23.6 cd	27.2 ab
	+Organic	1.59 b	0.86	0.92	3.38 cd	47.5 b	25.9 cde	26.6 ab
Tumpang	- Organic	0.71 a	0.61	0.84	2.17 ab	33.8 a	27.3 de	38.9 c
	+Organic	2.29 cd	0.89	1.12	4.29 e	52.8 bc	30.2 de	27.0 ab
Ngajum	- Organic	1.70 b	0.35	0.75	2.80 bc	62.6 c	12.1 a	25.3 a
	+Organic	2.74 d	0.66	1.09	4.50 e	61.2 c	14.4 ab	24.4 a
Karangploso	- Organic	1.50 b	0.54	0.55	2.59 ab	58.9 c	20.2 c	20.9 a
	+Organic	2.03 bc	0.79	1.10	3.92 de	52.6 bc	20.1 bc	27.3 ab
Kalipare	- Organic	1.62 b	0.61	0.55	2.78 bc	58.8 c	21.9 cd	19.3 a
	+Organic	0.94 a	0.85	0.98	2.77 bc	33.3 a	31.9 e	34.7 bc
Duncant 5 %		s	ns	ns	S	s	s	S

Remarks: Means followed by the different letter are significantly different ($P<0.05$). s significant ($P<0.05$) ; ns non-significant; C coarse fraction , I intermediate fraction, F fine fraction

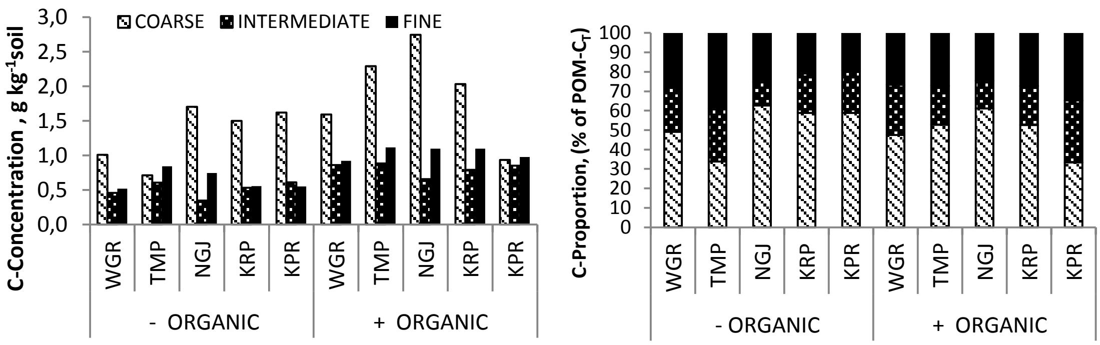

Figure 3. The effect of organic matter input on the C concentration of each fraction and its proportion of total POM-C at five sites of sugarcane plantations (Remarks: WGR = Wagir; TMP = Tumpang ; NGJ = Ngajum; KRP = Karangploso; KPR = Kalipare)

POM-C proportions of each fraction were influenced by the interaction between site and type of soil management. Ngajum site showed the largest average proportion of POM- C_C to POM-C_T, but was not significantly different from Kalipare and Karangploso site. The largest proportion of the POM-C_I relative to POM-C_T was found in the soil of sugar cane plantation at Tumpang, Wagir and Kalipare sites, while the largest proportion of POM-C_F was found at Tumpang and Kalipare sites. The addition of organic matter only increased the proportion of POM-C_C relative to POM-C_T in the soil of sugarcane plantation at Tumpang site. However, the addition of organic matter increased the proportion of POM- C_I relative to POM- C_T at all sites (Table 2 and Figure 3), but not for the proportion of POM- C_F to POM- C_T. Overall POM-C_T for the soils of sugar cane plantations treated with the organic input at five sites were higher than the soils treated without organic input (Table 2), except at Kalipare site. The soil of sugarcane plantations treated with organic input had 70 % POM-C_T higher than the soil treated without organic input (2.46 g per kg).

Similar results are shown in POM-N. The highest average of POM-N_C was found in the soil of sugarcane plantation at Ngajum site with organic inputs, but it was not significantly different from Karangploso site with organic input (Table 3). The N proportion of each fraction was influenced by the interaction between site and type of soil management. Ngajum site shows the largest proportion POM-N_C of POM-N_T, but it was not significantly different from Karangploso site. The addition of organic matter increased the proportion POM-N_C of POM-N_T at Tumpang site. The largest proportion POM-N_I of the POM-N_T was found at Wagir, Tumpang, Karangploso, and Kalipare, while Ngajum had the lowest proportion of POM-N_I of POM-N_T. However, the addition of organic matter does not increase the proportion of POM-N_I of POM- N_T at all sites. The addition of organic matter increased the proportion of POM-N_F of POM- N_T significantly ($P<0.05$) at Kalipare site (Table 3). Overall POM-N_T for the treatment with the organic input at five sites was higher than the treatment without organic input (Table 3), except at the Kalipare and Wagir sites. Sugarcane lands with organic inputs had POM-N_T 63.8% higher than the sugarcane lands without organic inputs (0.26 g per kg). The highest increase in POM-C_T and POM-N_T as the result of the addition of organic matter was found at Tumpang site by 97.7% and 96.0%, respectively.

Table 3. The effect of organic matter input on the N concentration of each fraction and its proportion of the POM-NT at five sites of sugarcane plantation

Site	Treatment	POM-N (g kg^{-1}soil)			POM-N_T (g kg^{-1}soil)	POM-N (% of POM-N_T)		
		C	I	F		C	I	F
Wagir	- Organic	0.13 ab	0.06	0.05	0.24 a	51.2 bcd	25.2 bc	23.6 ab
	+Organic	0.15 bc	0.06	0.08	0.29 a	52.6 bcd	21.8 bc	25.6 abc
Tumpang	- Organic	0.08 ab	0.06	0.11	0.25 a	32.6 a	25.5 bc	41.9 d
	+Organic	0.21 cd	0.11	0.17	0.49 b	43.3 bc	22.0 bc	34.7 cd
Ngajum	- Organic	0.16 bc	0.04	0.08	0.28 a	56.2 de	14.3 a	29.5 bc
	+Organic	0.29 e	0.06	0.11	0.46 b	64.4 e	12.0 a	23.5 ab
Karangploso	- Organic	0.14 b	0.07	0.06	0.27 a	54.1 cde	26.6 c	19.3 a
	+Organic	0.25de	0.09	0.12	0.47 b	54.2 cde	20.6 bc	25.1 abc
Kalipare	- Organic	0.17 bc	0.05	0.04	0.27 a	64.0 e	20.0 b	16.0 a
	+Organic	0.11 ab	0.07	0.09	0.27 a	42.2ab	25.6 bc	32.1 bc
Duncant (5%)		s	ns	ns	s	s	s	S

Remarks: Means followed by the different letter are significantly different ($P<0.05$). S significant ($P<0.05$) ; ns non-significant; C coarse fraction , I intermediate fraction, F fine fraction

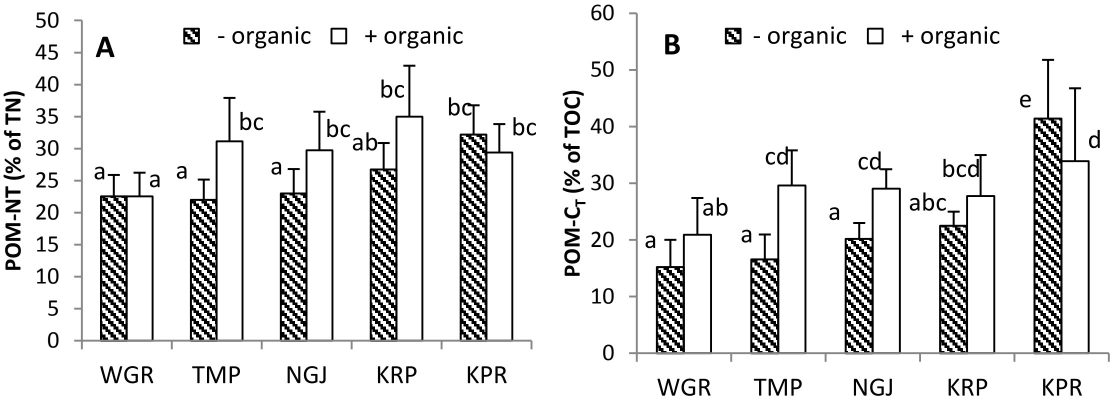

Figure 4. The effect of organic matter input on POM-C_T relative to TOC (A) and POM-N_T relative to total N (B). The magnitude of the bar shows the standard deviation (n = 6). Bar values followed by different letters indicate significant differences ($p < 0.05$). (Remarks: WGR = Wagir; TMP = Tumpang; NGJ = Ngajum; KRP = Karangploso; KPR = Kalipare)

Figure 4 shows that the sugarcane land with organic input treatment had a higher percentage of POM-C_T relative to TOC and POM-N_T relative to TN than the soils of sugarcane plantation without organic input. The average of increase rate accounted for 45.9% (POM-C_T) and 25.4% (POM-N_T). The highest percentage of the increase in POM-C_T of TOC and POM-N_T of TN was the sugarcane land at Tumpang site as 78.8% and 41.5%, respectively.

Earthworm Density and Biomass

The interaction between the sites with different annual rainfall and the type of soil management in sugarcane cultivation significantly ($P<0.05$) affected the earthworm density and biomass. Table 4 and Figure 5 show that the sugarcane land at Tumpang site with organic input treatment had the highest population density of earthworms (269.3 individuals m^{-2}), while the sugarcane land at Kalipare site had the lowest population density of earthworms either with organic inputs (33.3 individuals m^{-2}) or without the input of organic (13.3 individuals m^{-2}). Organic input into sugarcane lands improved the earthworm density and biomass. The average increase in population density of earthworms in the treatment with organic input compared to the treatment without organic input at Wagir was 163.8% and Tumpang was 169.3%, Ngajum was 63.5%, Karangploso was 12 % and Kalipare was 38.8 %. The average increase in earthworm biomass in the treatments with organic input compared to the treatments without organic input at Wagir was 77.8%, Tumpang was 102% and Ngajum was 103.6%, Karangploso was 140% and Kalipare was 34.8%.

The interaction between the sites with different annual rainfall and the type of soil management significantly ($P<0.05$) affected the average weight per individual earthworm (B/D). However, separately, the addition of organic matter did not significantly affect the average weight per individual earthworm. The highest average weight per individual earthworm was found at Wagir site with treatment without the input of organic matter (Table 4).

DISCUSSION

The soil of sugarcane plantation with the organic matter input of the five sites studied had higher total organic C (TOC) (18.3%), TOC/TOC_{ref} (14%) and POM-C_T (70%) than without organic inputs (TOC = 11.77 g per kg; TOC/TOC_{ref} = 0.30; POM-C_T = 2.47). However, the greatest improvement was obtained in the POM-C_T compared with other measurements. The relationship between the three measurements and variable earthworms are presented in Figure 6.

Table 4. The effect of organic matter input on the population density, biomass and weight per individual (B/D) of earthworms at five sites of sugarcane plantations

Site	Treatments	Earthworm density (D) (individual m^{-2})	Earthworm biomass (B) ($g\ m^{-2}$)	B/D ($g\ individual^{-1}$)
Wagir	- Organic	64.7 ab	28.3 b	0.41 d
	+ Organic	170.7 d	50.3 c	0.31 c
Tumpang	- Organic	100.0 bc	30.1 b	0.30 c
	+ Organic	269.3 e	60.8 c	0.23 bc
Ngajum	- Organic	113.3 c	16.5 a	0.16 ab
	+ Organic	185.3 d	33.6 b	0.17 bc
Karangploso	- Organic	104.7 bc	12.5 a	0.11 ab
	+ Organic	117.3 c	30.0 b	0.27 c
Kalipare	- Organic	24.0 a	4.6 a	0.18 ab
	+ Organic	33.3 a	6.2 a	0.18 ab
Duncant 5%		s	s	s

Remarks: Means followed by the different letter are significantly different ($P<0.05$). S significant ($P<0.05$) ; ns non-significant

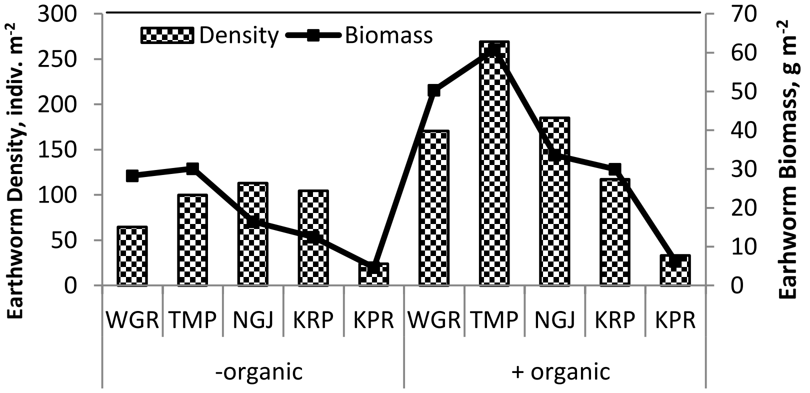

Figure 5. The effect of organic matter input on the population density and biomass of earthworms. (Remarks: WGR = Wagir; TMP = Tumpang; NGJ = Ngajum; KRP = Karangploso; KPR = Kalipare)

Regression analysis showed that the variables TOC, TOC/TOC_{ref}, and $POM\text{-}C_T$ were closely related and significant ($p < 0.05$) with population density and biomass of earthworms, however, there is no significant relationship with an average weight per individual (B/D) earthworms (Fig. 6). Third of the correlation analysis between these variables, $POM\text{-}C_T$ was more closely related to the earthworm population density compared with other variables. Variable TOC/TOC_{ref} was more closely associated with earthworm biomass (Table 5). Based on the increase in variable TOC, TOC/TOC_{ref} and $POM\text{-}C_T$ in the treatment of organic inputs compared with the treatment without organic input, correlation, and regression analysis indicated that the indicators of $POM\text{-}C_T$ and TOC/TOC_{ref} were more sensitive to assess changes in soil quality and productivity in sugarcane plantations.

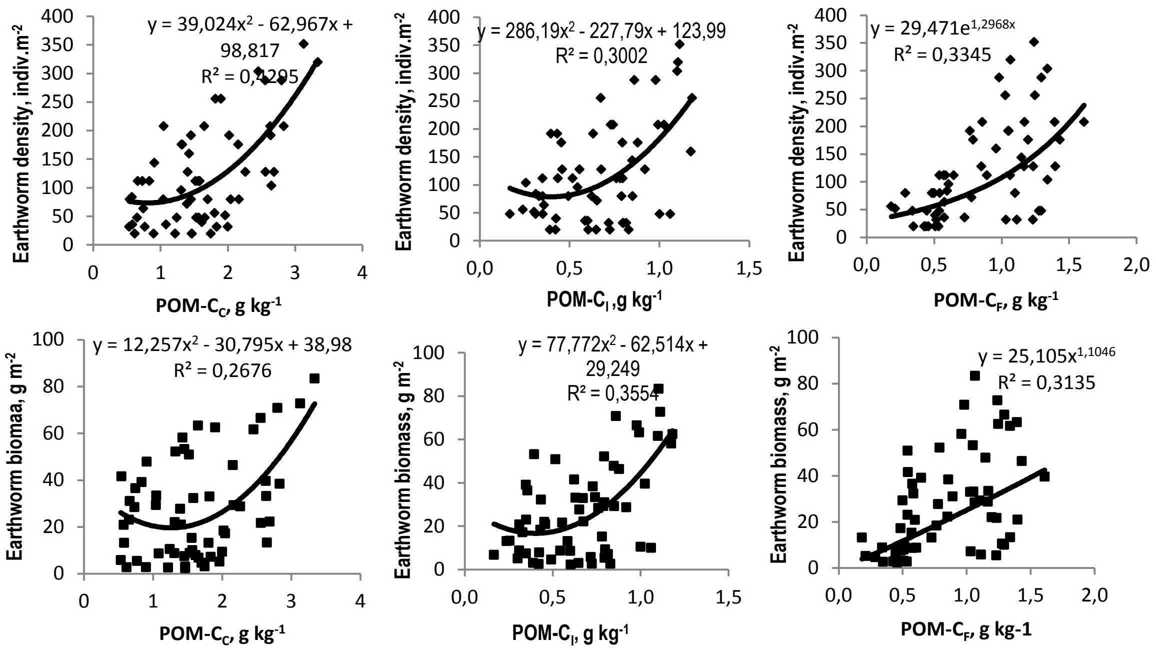

Figure 6. The relationship between POM-C_C, POM- C_I, and POM-C_F with the earthworms variables

POM is labile fraction of soil organic matter. It is a major fraction of the SOM in surface soil and more sensitive to changes of land management (Cambardella and Elliott 1992; Zhang *et al.,* 2006). In addition, POM is uncomplexed fraction of the SOM so that it can be a substrate for microbial activity, and it is also an important agent in the formation macro-aggregate (Franzluebber, 2002; Causarano *et al.,* 2008). POM is also an intermediate fraction of litter (with a rapid turnover) and mineral associated with SOM (with a slow turnover). Active fraction of organic matter plays an important role in the plant nutrient supply, decomposition of organic residues, and the development of soil structure (Franlzluebbers, 2002). Heightened levels of POM-C and POM-N will increase the potential availability of C and N, thus, they will increase soil fertility and quality (Handayani *et al.,* 2010).

The measurement of POM-C on sugarcane lands at five sites with two types of soil management ranged from 1.99-4.50 g kg^{-1} soil. The values were considered slightly higher compared to the results from Handayani *et al.,* (2010) for monoculture land as much as 2.24 g kg^{-1} soil, while on mixed plant land as much as 4.02 g kg^{-1}soil. These values were in the range as reported by Koutika *et al.,* (2001) and Oedraogo *et al.,* (2006) which ranged from 15-22 g kg^{-1} and 1.1-2.7 g kg^{-1}. Difference in the values can be caused by several factors such as differences in the soil management, climate condition and soil characteristics.

The relationships between TOC/TOC_{ref} and biomass of earthworms and the high correlation coefficient were also provided (Table 5). This suggests that the measurement of these indicators can be used to assess the soil quality and health in sugarcane plantations. Ortiz-Ceballos and Fragoso (2004) reported that in 33% soil moisture conditions, abundance and biomass of earthworms were higher in the soil receiving organic matter input compared to conventional soil management without the organic matter input. This is caused by the amount of organic matter and N content is higher.

Sugarcane land with the low TOC/TOC_{ref} ratio showed low population density and biomass of earthworms too, which indicated an unhealthy soil. Healthy soil as forest land usually shows TOC /TOC_{ref} about 1.0 (Van Noordwijk *et al.,* 1997; Hairiah *et al.,* 2003). Every year, treatment of organic input may increase TOC/TOC_{ref} ratio and earthworm density and biomass. This suggests that to maintain the soil quality and health in sugarcane plantations in East Java, the addition of organic material has to be done every year. These results are consistent with those reported by Hairiah *et al.,* (2000) suggesting that in order to maintain soil productivity in the tropics, the SOM content should be maintained between 2.5 - 4.0%. It required the organic matter input as much as 8 to 9 Mg ha^{-1} yr^{-1}. Organic matter input combined with N fertilizer every year on the sugarcane land in North Lampung can improve soil organic matter status in the fourth year (Hairiah *et al.,* 2003).

Regression and correlation analysis between the C concentration of each fraction (POM-$C_{C,I,F}$) indicated that the POM-C_C, POM-C_I, and POM-C_F were closely related and were significant (p <0.05) with population density and biomass of earthworm. However, there was no significant relationship with an average weight per individual (B/D) of earthworms (Table 5 and Figure 5). Third of the correlation analysis between these variables, POM-C_C were more closely related to the earthworm population density compared with other variables. This means that earthworm in the sugarcane plantation is more responsive to the addition of new organic matter. Coarse fraction is the labile fraction and is a matter that has not decomposed yet (Bossuyt *et al.,* 2004; Pulleman *et al.,* 2005.). This organic matter is an energy source of soil microorganisms and is easily degraded (Gregorich *et al.,* 2006). Similarly, earthworms prefer the new organic matter, but are partially decomposed to be particle with intermediate size (> 50 µm) (Lavelle and Spain, 2001).

Table 5. Correlation coefficient of the relationship between soil properties and earthworm variables

Variables	ED	EB
TOC	0.590*	0.622*
TOC/TOC_{ref}	0.667**	0.732**
POM-C_C	0.603*	0.402*
POM-C_I	0.494*	0.536*
POM-C_F	0.588*	0.500*
POM-C_T	0.738**	0.581*
ED	1	0.863**
EB	0.863**	1

Remarks: ns = non-significant ; *= Significance level P < 0.05 ; **= Significance level P< 0.01 ED = Earthworm density ; EB = Earthworm biomass ; BD = Soil bulk density ; BD_{ref}= the corrected BD

These results explain that the presence of earthworms as bio-indicator of soil quality is largely determined by changes in soil C- organic content, total soil N, the labile fraction of organic matter (particulate organic matter), and the availability of N released by the particulate organic matter. Topoliantz *et al.,* (2002) reported that earthworm population density was positively correlated with total soil N through the positive influence of earthworms (*Pontoscolex corethrurus*) of N mineralization (González and Zou, 1999).

CONCLUSIONS AND SUGGESTIONS

Soil quality of sugarcane plantation can be measured by several indicators of the TOC, the TOC/TOC_{ref} ratio and POM-C. Among the indicators, the TOC/TOC_{ref}, POM-C, population density and biomass of earthworms show high sensitivity to assess changes in soil quality of sugarcane plantation due to the addition of organic matter; the indicators show a large increase when compared with the soil of sugarcane plantation without organic input (conventional) mainly on sugarcane plantations with high relatively rainfall and low clay content. It is suggested that to facilitate the assessment of soil quality of sugarcane plantation based on these indicators can be done by observing the population density of earthworms in the field. For further study, the addition of organic matter and earthworms on the productivity of sugarcane needs to be tested.

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