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LONG-TERM IMPACT OF CONVENTIONAL SOIL MANAGEMENT TO EARTHWORM DIVERSITY AND DENSITY ON SUGARCANE PLANTATION IN EAST JAVA, INDONESIA

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Abstract - This study highlighted the effect of soil management on earthworm diversity and density and related the soil properties in sugarcane plantation areas with different annual rainfall. This research was conducted at five sites in East Java, Indonesia. The sites were selected based on differences in average annual rainfall from high to low that were equal to 2514, 2031, 1904, 1644, and 1413 mm as the first factor. The two treatments of soil management, that is without and with organic matter input are the second factor. The maize land and forest with the same agro-ecosystem condition were used as a comparison in this research. Earthworm samples were taken using the monolith (25 cm x 25 cm x 20 cm). Earthworm was assessed using parameters: density (indiv.m^{-2}), biomass (g m^{-2}), the average weight per individual (g), the number of earthworm species and Shannon diversity index. The results of earthworm assessments were influenced by differences in annual rainfall and treatment. The treatment without organic matter input had lower earthworm assessments. The results of assessments in the sugarcane lands were still better than the maize land. Organic matter input increased the earthworms' density and biomass in the sugarcane land, but they were lower than the forest. Earthworm density and biomass were not only influenced by annual rainfall and treatment, but also by soil properties such as total soil N and soil C-organic. Increasing C-organic content by 25% increased earthworm's density by 64%, and biomass by 83%. Increasing the total soil N content by 25% increased the earthworms' density by 79% and biomass by 75%. The lowest C- organic is 0.4 % and the lowest total soil N content is 0.065 % that still found earthworms in the sugarcane land. Two earthworm species found in sugarcane land were *Pontoscolex corethrurus* (Glossoscolecidae) and *Pheretima minima* (Megascolecidae).

Keywords: earthworms, diversity, density, sugarcane land, conventional soil management, annual rainfall and soil factors.

INTRODUCTION

East Java is one of the center areas for sugar production in Indonesia, which annually supplies about 45% of the total national sugar requirement. The sugarcane plantation area of East Java is 172,942 ha, or 43.5% of the total area of sugarcane in Indonesia with total production of 14,666,500 tons of sugarcane, or 48.5% of total sugarcane production of Indonesia (Purwanto, 2009).

In Indonesia, sugarcane is usually grown in monoculture cultivation, although it is sometimes intercropped with annual crops in the farmer's sugarcane plantation area. As with other conventional farming systems, N, P, and K fertilizers were applied in the cultivation of sugarcane with high doses between 1000-2000 kg ha^{-1} Ammonium Sulfate and compound fertilizer P and K with a dose of 200-300 kg ha^{-1}. Sub-soil tillage accompanied by land clearing, and removal or burning of harvest residues were also practices in sugarcane production. Thus, the long-term impacts of the conventional sugarcane cultivation system will be followed by a decline in soil health, characterized by the rapid decline in soil organic matter content and soil biodiversity which can accelerate the decline in soil productivity (Wood, 1985; Garside, 1997; Haynes and Hamilton, 1999; Hairiah *et al*., 2003). Soil C-organic content in monoculture sugarcane lands lowered by about 40-56% when compared with the C-organic content prior to forest conversion to sugarcane lands. The decline occurred in the past 10 years after forest conversion (Mahabharata, 1996; Dominy *et al*., 2002.). The negative effect mainly results from changes in soil temperature, soil moisture and organic matter quantity or quality. However, the problem of decreasing soil organic matter (SOM)

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did not receive serious attention from managers because SOM did not directly influence the sugarcane productivity. Decreasing the SOM directly impacts on the soil quality. This can be measured from changes in physical and chemical properties and the level of soil biodiversity. Thus, there is a relationship between soil C-organic content with soil biodiversity, especially among earthworms. In general, the greater the intensity and frequency of disturbances that caused the decrease in the SOM, the lower the density and biomass of earthworms (McKay, Kladivko, 1985; Hendrix *et al.,* 2004). Studies conducted in the semiarid northern India showed that the presence of earthworms to the maximum level wherever the farmers followed integrated farming practice (100%) followed by organically managed (70%) and conventional agro-ecosystems (18.9%) (Suthar, 2009).

Earthworms' distribution and abundance are dependent not only on management related to crop production, but also on local soil and climate factors. Earthworms density and biomass are higher in areas with higher annual rainfall and inversely correlated with soil sand content (Buckerfield *et al.,* 1996). Earthworms density and diversity were reduced in conventionally managed soils, because earthworms are very sensitive to changes in microclimate and food availability and their populations in cultivated soil generally were lower than in undisturbed habitats or forests (Paoletti, 1999 ; Lavelle and Spain, 2001; Curry *et al.,* 2002). In the dry-land cropping area in southern Australia, generally there are fewer than four species of earthworms (Baker *et al.,* 1994). There are 10 species found in various land-use systems in areas of West Lampung, Indonesia, however two species only were found in land that is managed for crops. Natural forests have a density of 32 individuals per m^2 with an average weight per individual 0.48 g. The population density in the disturbed forest is greater than the natural forest that is equal to 296 individual per m^2 with an average weight per individual 0.32 g (Dewi *et al.*, 2006)

Many studies on earthworm ecology were conducted in subtropical areas (Edwards, 1983; Sautter *et al,* 2006.). Research on earthworms in tropical soils were done by Fragoso *et al.,* (1997), Kale, (1998), Singh, (1997), Kaushal *et al*., (1999), Bisht *et al.*, (2003), and Dewi *et al.,* (2006), however there were not as many as in temperate climate areas. In Indonesia, very few studies were conducted on the role of earthworm communities in sugarcane land, because the researchers assumed that sugarcane grown in dry-land was unsuitable habitat for earthworms. The objectives of this research are to study the effect of management of organic matter inputs on earthworm diversity and density on sugarcane land and to relate the soil properties which affect the density and diversity of earthworms in sugarcane plantation area.

MATERIALS AND METHODS

Study Site and Time

The research was conducted at five sites, namely: Wagir, Tumpang, Ngajum, Karangploso, and Kalipare of monoculture sugarcane planting areas in Malang regency, East Java, Indonesia. The selected sugarcane lands, established more than 10 years ago were used for sugarcane planting areas under conventional soil management. The five sites were selected based on differences in annual rainfall, ranging from high to low. The characteristics of each site are presented in Table 1. The research was conducted during the rainy season, from November 2010 to March 2011.

Table 1. Location and characteristics of the study sites.

Environmental Parameters	Sites			
	Wagir	Tumpang	Ngajum	Karangploso
Altitude (m)	478-679	580-698	407-592	584-720
Latitude and Longitude	7° 52'52"-8°00'50" S and 112°35'9"-112°37'4" E	8°00'58" – 8°2"50' S and 112°40'5"-112°50'8" E	7°52'50"-8°7'50" S and 112°30'15"-112°37'50" E	8°8'25"- 8°10'26" S and 112°27'7"-112°32'38" E
Mean Annual rainfall (mm)	2514	2031	1904	1644
Mean Annual Temp. (°C)	23.8	23.5	25.1	23.4
Soil Texture	Loam-clayey loam	Loam-clayey loam	Loam-clayey loam	Loam-clayey loam
	18-35	15-44	15-37	12-40
% sand	40-54	34-53	37-55	40-51
% silt	22-35	18-37	18-37	18-34
% clay				
% Soil C-organic	1.13-1.78	1.24-1.58	1.27-1,62	1.04-1.85
Soil pH (H_2O)	4.8-6.0	4.8-6.5	4.5-5.6	4.8-5.5

Research Methods

The study evaluated two factors. The first factor was the five sites with different rainfall. Data on the annual rainfall was presented in Table 1. The second factor was the kind of soil management. There were two kinds of soil management that were tested : with the input of organic fertilizer for at least 3 years (10 tons ha^{-1}) and without the input of organic fertilizer (using only inorganic fertilizer with a dose of 1000 kg ha^{-1} ammonium sulfate and 200 kg of P-K (15:15) ha^{-1}). Sampling strategy was based on three performances of plant growth which were: the good, average, and bad growth performance, with four replications. In each location there were 24 sampling points with a total of 120 samples. A forest located nearby the sugarcane fields with the same agro-ecosystem was considered to represent a reference with relatively favorable conditions for earthworms and maize (annual crops) fields with intensive farming as a comparison with relatively unfavorable condition for earthworms. The forest had been undisturbed for more than 20 years at th e time of sampling.

Earthworm sampling

Monolith sampling of earthworms was conducted in accordance with the method of measuring point of Conservation and Sustainable Management of Below-Ground Biodiversity (CSM – BGBD) project modified in accordance with the purposes of research and field conditions (Huising *et al.,* 2008.). Soil monoliths (25 cm x 25 cm x 20 cm) were taken randomly within each plot with 4 replications (r = 4). Soil was extracted from two depth layers (0-10 cm and 10-20 cm). Earthworms were collected by hand, sorted and placed in plastic trays (Swift and Bignell, 2001). Earthworms sampling in the field was carried out between rows of sugarcane crop.

Earthworm preservation process and its assessment

Earthworms were killed in 70% alcohol, and then inserted in 4% formalin and stored in sealed bottles containing 70 % alcohol before being sent to the laboratory for identification, counting and weighing. Earthworms were identified up to species in the Soil Biology Laboratory, Brawijaya University, using the appropriate key. Specimens that could not be identified were simply counted and weighed. Biological assessment consisted of several parameters of earthworm diversity, density (number of individual per m^2), earthworm biomass (fresh weight of earthworms, g m^{-2}) and the estimated average weight of an individual (ratio biomass/density, g). Diversity was measured by determining the types of earthworms recovered from the sampling point. Types of earthworms were identified up to a level of species according to the manual provided by James (2004) and based on external characteristic (Paoletti, 1999; Fragoso and Csuzdi, 2004). Diversity was also calculated using the Shannon-Wiener diversity index (H '), calculated as $H' = \Sigma (p_i \ln p_i)$, where p_i is the proportion of taxonomic groups to i, which is estimated by n_i / N, where n_i is the number of individual species to i , N is the total number of individual of species in the sample.

Parameters for soil properties and soil analysis

Several soil properties were measured as support parameters, including soil C- organic, total soil N, soil pH, % sand, % silt, and % clay. The extracted soils from two depth layer (0-10 and 10-20 cm) compositely were analyzed for their soil pH, total C-organic, total N, soil texture and water holding capacity (WHC). Soil pH was measured in a 1:2.5 soil : water and soil : KCl using a glass electrode. C-organic was analyzed by the Walkley and Black dichromate oxidation method. Total N was based on a Kjeldahl oxidation, followed by either distillation and titration or by colorimetry. Soil texture was analyzed by pipette method. Water holding capacity was expressed as the moisture content of a freely drained, oven dried soil and was held at pF=0. (Okalebo and Gathua, 1993).

Statistical analysis

The obtained data were subjected to analysis of variance (ANOVA) to compare the effects of sites with different annual rainfall and soil management on earthworms' assessment variables. The LSD procedure was used to separate the means of earthworm parameters at p = 0.05. For statistical analysis of data (correlation and charts) Microsoft Excel was used.

RESULTS AND DISCUSSION

Effects of organic matter input on earthworms diversity in sugarcane planting areas

One hundred twenty (120) specimens of earthworms were sorted from soil samples taken from sugarcane planting areas in the five study sites in Malang, East Java, Indonesia with different annual rainfall. Long-term conventional soil management without the organic matter input had a significant negative effect on earthworms in the dry-land sugarcane planting area. However, there was no significant difference observed in the number of species found in sugarcane lands, with or without organic matter input. Only two earthworms species endogeic *Pontoscolex corethrurus* (Glossoscolecidae) and *Pheretima minima* (Megascolecidae) were found in all sampling sites (Table 3). Four earthworms species *Pontoscolex corethrurus* (Glossoocolecidae), *Pheretima minima* (Megascolecidae), *Polypheretima elongata* (Megascolicidae), and *Drawida barwelli*

Table 2. Earthworm taxonomic richness and functional diversity based on monolith method in sugarcane field of five sites, maize field and forest.

Taxonomic Group	Functional group [a]	Sites of Sugarcane Land					Maize field	Forest
		Wagir	Tumpang	Ngajum	Karang ploso	Kalipare		
Megascolecidae								
Polypheretima elongata	Endogeic	-	-	-	-	-	-	+
Pheretima minima	Endogeic	+	+	+	+	+	+	+
Moniligastridae								
Drawida barwelli	Endogeic	-	-	-	-	-	-	+
Glossoscolecidae								
Ponthoscolex corethrurus	Endogeic	+	+	+	+	+	+	+
Taxonomic richness (S)		2	2	2	2	2	2	4
Shannon diversity index		0.41	0.47	0.54	0.54	0.19	0.34	0.91

[a] Based on classification by Fragoso *et al.*,(1997) ; Swift and Bignell (2001)
+/- denotes presence or absence, respectively

(Moniligastridae) were found in the forest soil samples (Table 2.).

The average number of species totalled 1.72 for the sugarcane lands. These results are higher than the average number of species found on the maize land (1.4) and less than the species found in the forests (2.9) (Table 2).

The average SDI for each site was presented in Table 3. There were significant differences in average SDI among sites with different annual rainfall. However, between the two plots with and without organic input, there were no significant differences observed (Table 3). This means the application of organic matter cannot increase earthworm diversity. However, the average SDI for the sugarcane lands is 0.43 higher, than the maize land (0.34), but lower than the forest which is 0.91. This means that the sugarcane land is better able to maintain the earthworm diversity than the maize land. This may be related to the sugarcane cultivation in Malang. Oftentimes, the farmers leave the dry leaves on the sugarcane field which provides food supplies for earthworms and maintains a good soil environment for them.

Rana *et al.,* (2006) noted the diversity of soil macrofauna in the sugarcane land with high-input intensive farming (cultivation using pesticides and chemical fertilizers) and low-input farming systems (cultivation using low doses of chemical fertilizers and organic inputs) in Faisalabad, Pakistan. They reported that organic input affected significantly the whole diversity of macrofauna. Six earthworms species were found in the cultivated land with low input and five earthworms species in the high input land. Significant difference was found in earthworm abundance. According to the measurement of SDI, the whole macrofauna SDI was 2.93, evenness 0.81 and dominance 0.19. Baker *et al.,* (1994) recorded species of earthworms less than four (4) in the areas of dry-land cropping in southern Australia.

Effects of organic matter input on earthworms density, biomass and average weight per individual in sugarcane planting areas

The ANOVA results confirmed that the sites with different annual rainfall and two kinds of treatment significantly affected the earthworms density, biomass and average weight per individual. This suggests that different annual rainfall has a large effect on the activity and population of earthworm at each point of observation. The effect of the site-treatment interaction was also significant (Table 3). Rainfall water infiltrated into soil determined the soil water content. There was a positive correlation between earthworm parameters and water holding capacity (WHC) (Table 4). Soil moisture positively correlated with population density (Ismail, Ramakrishnan and Anzar, 1990). Thus, earthworm activity increased in high rainfall areas (Buckerfield *et al.,* 1996 ; Joshi and Aga (2009). Earthworms can live in the soil with moisture ranging from 30 to 50% (Lavelle, 1988; Ganihar, 1996; Kale and Karmegam, 2010). Soil moisture also determines the distribution of earthworms because water is a major part of its body weight. Water makes up 75-90 percent of earthworm's body weight. Prevention of water loss is the main factor for their survival and

Table 3. SDI, number of species and earthworm density and biomass, mean weight per individual across the treatments with organic input and without organic input of five sites in East Java, Indonesia.

Site	SDI		Number of Species		Earthworm Density (ind.m^{-2})		Earthworm biomass (g.m^{-2})		Mean weight per ind.	
	O	I	O	I	O	I	O	I	O	I
WGR	0.44 b	0.38 b	1.75 b	1.58 b	B 174.67 c	A 67.00 b	B 48.96 c	A 27.75 c	A 0.29 b	B 0.40 d
TMP	0.58 c	0.35 b	2.00 d	1.67 a	B 300.00 d	A 101.33 c	B 64.10 d	A 28.87 c	A 0.22 a	B 0.29 c
NGJ	0.44 b	0.63 c	1.83 bc	2.00 a	B 173.33 c	A 105.33 c	B 31.34 b	A 17.01 b	A 0.18 a	A 0.18 b
KRP	0.56 c	0.53 c	1.92 cd	1.92 a	B 112.00 b	A 100.00 c	B 25.16 b	A 13.58 b	B 0.23 a	A 0.12 a
KPR	0.23a	0.16 a	1.33 a	1.25 a	B 32.00 a	A 23.00 a	B 6.06 a	A 4.00 a	A 0.18 a	A 0.17 ab
Mean	0.45	0.41 b	1.77 bc	1.68	158.40	79.33	35.13	18.24	0.22	0.23
LSD	0.10		0.15		20.14		6.77		0.05	
SV	Df	F-ratio	Df	F-ratio	Df	F-ratio	Df	F-ratio	Df	F-ratio
R	2	7.3784*	2	7.3636*	2	29.3837*	2	21.2946*	2	3.0574^{ns}
T	1	1.1768^{ns}	1	2.2727^{ns}	1	113.3346*	1	45.7396*	1	0.3669^{ns}
S	4	12.9135*	4	18.0909*	4	56.6621*	4	33.9057*	4	11.2375*
SxT	4	3.4940^{ns}	4	2.2727^{ns}	4	22.3458*	4	4.8925*	4	3.5934^{ns}
Residual	18		18		18		18		18	

Means of earthworm parameters followed by the same lowercase letters within the same columns are not statistically significant at $p<0.05$.
Means of earthworm parameters followed by the same uppercase letters within the same rows are not statistically significant at $p<0.05$.
O = with organic input ; I= without organic input ; S= Site ; T = Treatment ; R= Replication ; ns = non-significant ; * = significant ($P\leq 0.05$)

maintenance of their life processes (Kretzschmar and Bruchou, 1996; Karmegam and Daniel, 2007).

Figure 1 presents the results gathered on the earthworm's density, biomass, average weight per individual, and the number of earthworm species from five sites with and without organic inputs compared to maize and forest land. One general observation from this study is that the plots with organic input have higher density and biomass than without organic input at each site. This indicates that earthworms are sensitive to disturbance associated with the agrochemical inputs, and that their role can be significantly improved by implementing management practices that increase soil C-organic in the sugarcane land (Fonte *et al.*, 2007; Ayuke, 2010). Other studies in tropical regions also showed that organic farming maintains higher earthworm density and diversity when compared to conventional farming with inorganic inputs (Tian *et al.*, 1997, Nunes *et al.*, 2006; Fonte *et al.*, 2007.). This could be caused by a higher soil C-organic content found in sugarcane planting area managed with the organic manure input when compared with the areas which has inorganic fertilizer.

Average weight per individual was higher at Wagir and Tumpang site without organic input treatment

Table 4. Correlation Matrix (pearson) between selected variables measured on soil samples (0-20 cm and n = 120 samples) in five sites.

Variables	Density	Biomass	Mean weight per ind.	SDI
Total Soil C-organic	0.595**	0.624**	0.316**	0.381**
Total Soil N	0.875**	0.787*	0.056^{ns}	0.395**
C/N ratio	0.281*	0.141^{ns}	0.310**	0.032^{ns}
% Sand	-0.480**	-0.527**	-0.262**	-0.197**
% Silt	-0.104^{ns}	-0.027^{ns}	-0.076^{ns}	-0.004^{ns}
% Clay	0.593**	0.638**	0.277**	0.217**
WHC	0.514**	0.480**	-0.006**	0.142^{ns}
Soil pH H_2O	0.762**	0.738**	0.245**	0.418**

**Correlation is significant at the 0.01 level (2-tailed) ; ns Correlation is not significant at the 0.01and 0.05 level (2-tailed)

than with organic input treatment (Fig.1d).
This is due to the presence of juvenile earthworms (weight <0.3 g) in both sites with organic input. In the plots with organic inputs, Tumpang had the highest average earthworms density and biomass of 300 individuals per m^2 and 64.11 grams per m^2, even when compared with the earthworm density of forest 182.57 per indiv. m^2. However, the forest had the highest earthworm biomass of 185.65 g m^{-2} (Fig.1b & 1c). These findings were slightly higher than the results recorded by Dlamini *et al*., (2001). Their results showed the earthworms density of 250 individual per m^2 in sugarcane land with pre-harvest burning, and 500 individual per m^2 under conditions of harvest residual left at the soil surface of the sugarcane land in an area Eshowe, north Kwazulu-Natal coast. Maftu'ah *et al.,* (2002) recorded an earthworm density of 160 individual per m^2 in the sugarcane land in Pagak, Malang, Indonesia.

Overall, the study has shown that the sugarcane lands have a higher average for the earthworm density (116.6 indiv.m^{-2}), biomass (25.35 g m^{-2}), average weight per individual (0.22 g), SDI (0.43), and number of species (1.7) when compared with data on the maize land and forest land (Fig. 1). The maize land is under disturbed conditions because of intensive farming and high input of inorganic fertilizer. In contrast, the forest is under relatively undisturbed conditions with permanent soil cover, where soil mechanical disturbance is minimal and high organic matter is accumulated. The forest soil contains a relatively high C-organic (3.10%) when compared with the organic carbon in the sugarcane lands (1.49% in WGR, 1.38% in TMP, 1.44% in NGJ, 1.30% in KRP and 0.77 % in KPR) and when compared with the 1.17% organic carbon in the maize land. Thus, the low organic carbon contributed to the low density and biomass of earthworms. In contrast, the high C-organic content of soil is a favorable condition for macrofauna activity, resulting into a porous soil with well-developed structure. According to Paoletti (1999) and Curry *et al*., (2002), earthworm populations in cultivated land are generally lower than those found in undisturbed habitats. Agricultural activities such as plowing, soil treatment, fertilization and application of chemical pesticides have a dramatic effect on invertebrates.

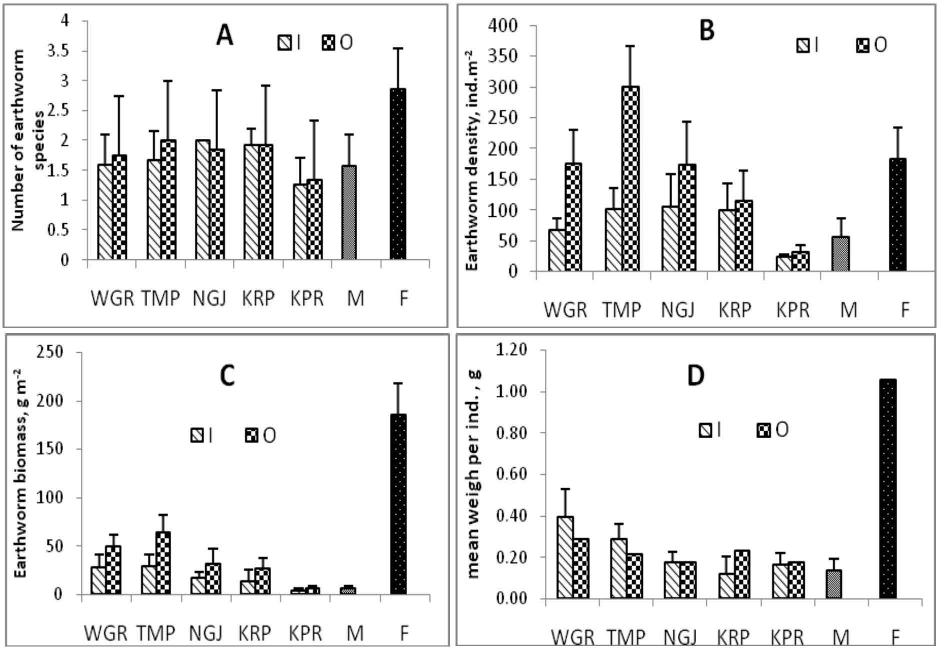

Fig. 1. Earthworm density (a) earthworm biomass (b) mean weight per indiv.(c) and number of species (d) in five sites, maize land and forest.

I= without input organic ; O = with input organic M= maize land ; F = forest
WGR = Wagir ; TMP = Tumpang ; NGJ = Ngajum ; KRP = Karangploso ; KPR =

The measurement results of soil C-organic and total N content for each sampling point indicated a significant positive correlation with earthworm's parameters (Fig.2). The higher C-organic and total N content of soil, the higher earthworm density and biomass. Based on the regression equation, the lowest C-organic was 0.4 % and the total N content was 0.065% were still found in earthworms in the sugarcane land. The earthworms in the rubber plantations of Tripura in India were found in the soil with organic matter and represent a relatively good condition. The conventional practices without organic manure represent conditions that are not favorable to the growth of earthworms. Evaluation of the number of species, diversity, density, and biomass of earthworm can be an effective method to assess the long-term impact of conventional soil management on their populations in sugarcane lands. Higher earthworm's assessment have been recorded in the sugarcane lands in five sites than the maize land, but lower than the forest data. Variation in soil C-

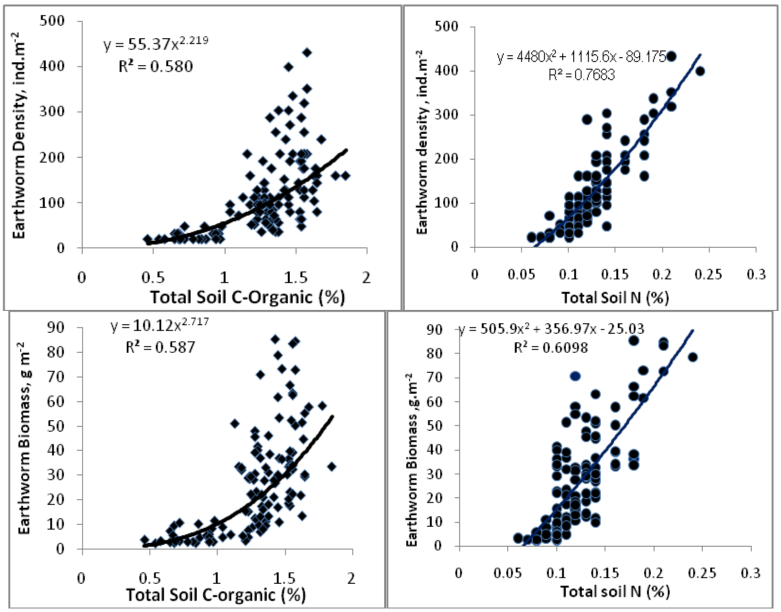

Fig.2. Relationship between earthworm density and biomass and total soil C-organic and soil N in the sugarcane land of five sites.

content of 1.8%, and soil pH of 4.85, a 24.8% soil moisture and soil temperature of 25.9% (Chaudhuri *et al.*, 2008). An increase in C-organic content of 25% from 1% to 1.25% can increase the density of earthworms by 64 %, and biomass by 83 %. The increase in total N content of 25% (from 0.1 to 0.125 %) also caused an increase in the density by 79% and biomass by 75% (Fig.2).

The results of this study is in line with that recorded by Suthar (2009), that the higher the nitrogen content of organic substrates of earthworms, the higher the growth of earthworms. They respond more quickly to the low-input practices associated with organic farming when compared to high agrochemical inputs (Paoletti *et al.*, 1998).

CONCLUSION

Management of organic inputs were found to have beneficial effects on earthworm communities organic and total soil N content contributed to the variation of earthworm density and biomass. It is concluded that conventional soil management using synthetic chemical fertilizers, without organic matter input in the long-term, provided some negative effects on earthworm communities. It is recommended that soil management with organic matter input is needed to maintain better earthworm communities in sugarcane lands.

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