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Earthworm Populations and Cast Properties in the Soils of Oil Palm Plantations

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ABSTRACT

Oil palm plantations generate a substantial amount of agricultural by-products, such as oil palm empty fruit bunches (EFB) and fronds. These by-products are commonly recycled in the oil palm plantations in order to obtain plant nutrients through decomposition. Information on earthworm species and populations and their cast properties in oil palm plantations in different soil types and oil palm tree ages is still lacking. The population and diversity of earthworms, casts and soils were surveyed in 10 m transects using 5 of 25 cm^2 quadrat. In all sampling sites, only an endogeic species, *Pontoscolex corethrurus* Müller discovered. The earthworm population densities were influenced by the age of the oil palm trees and soil types. Under similar soil types and different oil palm ages, the earthworm population densities were inversely related. Four major factors which dictated the heterogeneity of earthworm population in oil palm plantation were: (i) food and soil physical habitat, (ii) exchangeable calcium, (iii) pH, and (iv) exchangeable potassium as determined by principal component analysis (PCA). The earthworm population was positive significantly related to the CEC and exchangeable Ca in the soil (R^2=0.66*, n=100). With the exception of the soil C: N ratio, all other soil chemical properties (pH, C, N, total P, plant available P, total K, total Mg, CEC, exchangeable- K, Ca and Mg) were significantly correlated with the earthworm cast properties. Available P was 509 % higher in casts than in the surface soil (r=0.63*, n=100). The cast CEC and exchangeable Ca were strongly correlated with the soil CEC and exchangeable Ca in soil. However, the increase in CEC and exchangeable Ca were 67 and 98%, respectively. The earthworm population was highly correlated with soil CEC and exchangeable Ca.

Keywords: Oil palm, earthworm, *Pontoscolex corethrurus*, **soil factors, principal component analysis**

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INTRODUCTION

Oil palm (*Elaeis guineensis Jacq*) is a major plantation crop in Malaysia. The total oil palm plantation area was about 4.01 million ha in 2005 and is expected to increase to 5.10 million ha in 2020 (Anon. 2005). The oil palm tree is a highly demanding crop for nutrients both for early growth and production, hence requiring high inherent soil fertility status. When planted on soils with low inherent fertility, oil palm requires more agronomic inputs to ensure adequate yields. The addition of nutrient-rich palm oil mill by-products and agricultural by-products to replace some of these inorganic nutrients is an environmentally friendly option.

Oil palm plantations churn out a huge amount of by-products. An average of 24 fronds is pruned per plant per year which is equivalent to 11.7 tonnes ha^{-1} $year^{-1}$ (Chan *et al.* 1980; Chan *et al*. 1984). The empty fruit bunches constitute 6-7 tonnes per 10 tonnes of fresh fruit bunch. Palm oil mills also generate additional industrial by-products. For every tonne of crude palm oil produced, three tonnes of palm oil mill effluent cake are generated during the oil extraction process. This huge amount of oil palm by-products are potential sources of nutrients to the oil palm trees. However, oil palm by-products are difficult to manage as they decompose slowly. Soil micro and macro-organisms are required to enhance the decomposition process. Soil macro-organisms such as earthworms have considerable potential to increase the decomposition, thus, increasing soil productivity in oil palm plantations. Furthermore, application of agricultural by-products and earthworms are economically and ecologically feasible in the plantations.

Earthworms contribute to soil turnover, structure formation and serve as a fertility enhancer in various ways. Earthworms and their casts are useful in land improvement, reclamation and in organic waste management (Edwards and Baker 1992; Johnson 1997; Lavelle and Martin 1992; Villenave *et al.* 1999). Soil productivity can be improved by manipulating the community of earthworms in the soil (Brown *et al.* 1999).

The distribution and population density of various species of earthworm have been correlated with soil type, and agricultural land use (El-Duweini and Ghabbour 1964; Haynes *et al*. 2003). In oil palm plantations, the earthworm population and the diversity are expected to differ with soil type and palm tree age, with the cast properties also being affected by soil properties.

This research was done in oil palm plantations in Malaysia with the aim of (i) identifying earthworm diversity and density and its cast properties in different soil types and oil palm ages and (ii) studying the relationships between soil properties and earthworm populations in the oil palm plantations.

MATERIALS AND METHODS

Study Location

The study was carried out at five oil palm plantations with different soil types. These plantations enjoy a warm and humid climate, with a mean annual rainfall of 2,141 mm and a mean annual temperature of 26^0C. Five soil series were chosen for this study. They were Rengam, Serdang, Jerangau, Bungor and Munchong, which are the common soil series in the oil palm plantations (Department of Agriculture 2004). General properties of the soils are summarised in Table 1. For each soil type, the samples were collected from oil palm of 3 different ages: (i) <7 years old, (ii) 7-14 years old, and (iii) >14 years old. These ages correspond to the growing phase of the oil palm tree (Henson 2003). During the first six years after planting, the growth of the palm tree is extremely fast. The age of 6 to 12 years is a period of steadily rising yield, and the peak of FFB production. Thereafter, the yield stabilises and then slows down.

TABLE 1
Some physico-chemical characteristics of the soils used in this study and their classifications

Soil characteristics	Soil series				
	Serdang	Rengam	Jerangau	Bungor	Munchong
pH	4.8 ± 0.8	4.9 ± 0.7	5.1± 0.8	4.7 ± 0.8	4.6 ±0.5
C (%)	1.15 ± 0.71	1.25 ± 0.25	1.90 ± 0.32	1.22 ±0.94	1.97 ±0.97
N (%)	0.12 ± 0.06	0.13 ± 0.01	0.18 ± 0.09	0.12 ±0.06	0.18 ±0.07
CEC (cmol (+) kg^{-1} soil)	3.69 ± 0.96	4.33 ± 1	7.98 ± 1.25	6.04 ±1.00	9.28 ±1.2
Texture	sandy loam	sandy loam	clay loam	sandy loam	heavy clay
Soil taxonomy	Typic Kandiudults	Typic Kandiudults	Typic Hapludox	Typic Paleudults	Haplic Hapludox
FAO classification	Haplic Nitisols	Haplic Nitisols	Geric Ferrasols	Haplic Nitisols	Haplic Ferrasols

Sampling Technique

Earthworm casts, earthworm and topsoil (depth 0-25 cm) were sampled in February to July 2004. At each location, five quadrats of 25 cm^2 were taken randomly from a 10 m transect, along palm rows or palm inter-rows or across the palm inter-row with the frond heaps being included.

At each sampling site, the surface casts were removed. After collecting the top soil, sampling sites were poured with 500 mL 10% of formalin in order to induce the worms to come up to the surface of the soil for easy collection and then taken back to the laboratory. Also, the soil was dug to 25 cm depth and the aggregates broken up for earthworm collection. The earthworms were identified following the procedure of Bouché (1977) and the checklist was made according to Blakemore (2002).

At every site, soil samples were also taken for soil chemical and physical analyses. Soil and cast samples were air-dried, ground and sieved to pass through a 2 mm sieve size. Soil pH was determined in water using a soil (cast) to solution ratio of 1:2.5; organic carbon was analysed using the Walkley and Black method (1934); total nitrogen was determined by the Kjeldahl method (Bremner, 1960); total P, K, Ca and Mg were measured after digesting the sample using the aqua-regia method (1:3 ratio of HNO_3 to HCl) (Mehlich, 1953); available P in soil and cast were analysed using the Bray 2 method (Bray and Kurtz, 1945); and exchangeable Na, K, Ca, Mg and CEC were determined after leaching the sample with neutral 1 M ammonium acetate (Blakemore *et al*. 1987). Concentrations of N, P and K in solution were determined using the Lachat QuickChem FIAT auto-analyser, and Ca and Mg was measured using the Perkin Elmer PE 5100 atomic absorption spectrophotometer in the presence of 1000 mg $Sr(NO_3)_2$ L^{-1}, as an ionisation suppressant.

Statistical Analysis

The effects of soil type and palm age on earthworm population were examined using a factorial design, soil type and palm age as a factor. The soil physical and chemical properties affecting the heterogeneity of earthworm population were identified using the principal component analysis. Soil properties extracted from PCA were used as independent variables and earthworm population as the dependent variable. Stepwise multiple regression analysis was used to investigate relationships between soil properties and population of earthworms. The relationship between the soil and the cast properties was determined by simple correlation analyses. The data were analysed using the statistical analysis system (SAS) version 8e (SAS 1999).

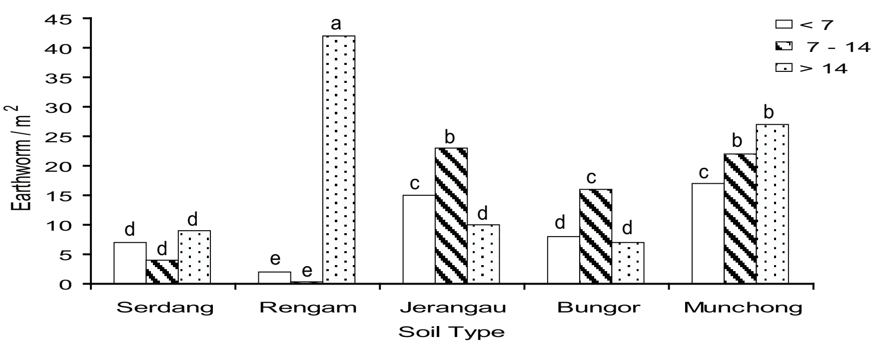
RESULTS AND DISCUSSION

Distribution and Population of Earthworms

Only one endogeic species *Pontoscolex corethrurus* Müller was found at all the sampling sites. This earthworm species is a pigmentless geophagus type from the Glossoscolecidae family. The population of earthworms varied significantly ($P \leq 0.01$) with soil type and oil palm age. The highest population found was 42 individual m^{-2} in Rengam soil in areas of oil palm > 14 years (Fig. 1). This was significantly higher than the population of earthworms for oil palm age of <7 and 7-14 years in the same soil. In Rengam and Munchong soils, with an increase in the age of the oil palm trees, there was an increase in the abundance of earthworms. The patterns of earthworm density under Jerangau, and Bungor soils were similar, with the highest number of earthworm being found under 7–14 year old trees. The number of earthworms in the oil palm plantation >14 years was significantly ($P \leq 0.01$) different from those in plantations <7 and 7–14 years old. The young oil palm tree field contained relatively low organic matter (2.22%) compared to an old palm oil tree field (3.29%), thus, contributing to the lower density of earthworms (Table 2).

TABLE 2
The number of earthworm and organic matter content under fronds heap and open soil surface

Soil Type	Palm age	Earthworm number		Organic matter	
		Under fronds	Open surface	Under fronds	Open surface
	Year			%	
Serdang	< 7	5	2	2.56	2.01
	7 - 14	2	1	1.78	1.74
	> 14	6	3	2.10	1.73
Rengam	< 7	1	0	1.96	1.69
	7 - 14	8	7	2.49	2.30
	> 14	24	18	2.39	2.25
Jerangau	< 7	8	7	2.60	2.43
	7 - 14	13	10	4.14	3.37
	> 14	5	5	2.96	3.37
Bungor	< 7	5	3	2.10	1.96
	7 - 14	8	8	2.34	2.06
	> 14	4	3	2.32	2.32
Munchong	< 7	10	7	2.35	2.23
	7 - 14	12	10	4.02	3.61
	> 14	14	13	3.10	3.23



Common letters within soil types and palm age indicate no significant differences according to Duncan test α≤0.05

Fig. 1: Earthworm population in five soil types (Serdang, Rengam, Jerangau, Bungor, Munchong) and three different palm oil age (< 7, 7 – 14, > 14).

Pontoscolex corethrurus is a native species in these oil palm plantations. The lack of earthworm population diversity in oil palm plantations might be due to the intensive management systems. *Pontoscolex corethrurus* exhibits wide climatic and edaphic tolerances (Fragoso *et al.* 1999a). The difference in survival of Malaysian species and/or the invasion of exotic species in India compared to Africa or to Mexico-Central America may be related to management practices (Fragoso *et al.,* 1999b). Schmidt *et al*. (2003) emphasised that land use is a factor that influences the diversity and populations of earthworms. Soil management affects the chemical and physical properties of soils. The effect of organic matter removal during land preparation of the young oil palm plantation is more apparent than in the older oil palm plantation. Mostly, the young oil palm plantations consist of low organic matter, except for the sites that are fully maintained with cover crops. Organic matter content in the development of sustainable earthworm populations is very important especially in the restored site (Lowe and Butt 2002). Furthermore, the crown of the younger oil palm tree do not fully cover the soil surface, thus, the sunlight may directly radiate on the soil surface which results in a lower soil moisture content (11.5-20.9%) compared to the soil under older palm tree (14.1-32.1%). During the phase of fast growth or the first six years after planting, oil palm trees absorb more water and nutrients compared to those trees which are steadily growing. The oil palm by-products from young oil palm tree are also less than the older trees. Therefore, the effect of oil palm by-products were excluded as a factor for a fewer number of earthworms in the oil palm plantation. Populations of *P. corethrurus* in tropical tree plantations in Hawaii are influenced strongly by tree species, particularly the palatability of leaves to earthworms. Although Eucalyptus trees produce more litter, Albizia trees produce finer litter fall and earthworm densities are correlated positively with the nitrogen content and concentration of fine litter fall (Zou 1993). The young oil palm tree received less organic matter compared to the old oil palm tree, a factor which might affect the population of earthworms. The influence of organic matter in the development of sustainable earthworm populations is of vital importance, especially in the restored site (Lowe and Butt 2002). The abundance and biomass of earthworms were higher in the improved maize with a *Mucuna prupriens* cover crop than in continuous conventional maize, which was caused by the amount of organic matter and N content (Otiz-Ceballos and Fragoso, 2004). However, this study found that not all the species of earthworms prefer the high organic matter and nitrogen; one of the native species, *Balanteodrilus pearsei*, was found to have a negative correlation with nitrogen content in the soil. Besides, the other possibility is that the crowns of the young oil palm trees do not fully cover the soil surface; hence direct sunlight contact with the soil surface contributes to higher soil temperature. Higher soil temperature might be the cause of lower earthworm population (Edwards and Bohlen 1996). The management of a young oil palm tree differs from that of a old or mature tree, which also has an effect on the population of earthworms beside the diversity mentioned earlier. Curry *et al*. (2002) found that the impact of intensive cultivation for potato production resulted in a drastic reduction in the earthworm population.

Microclimate may be a further reason for low earthworm diversity. Earthworm communities in the tropics are dominated by endogeics, while in the colder environment epigeics predominate (Fragoso *et al.* 1999b). The number of *P. corethrurus* was higher under the oil palm frond heaps compared to the open soil surface. Soil under frond heaps is moist and humid where plenty of food is available for the earthworms. Even though *P. corethrurus* is classified as endogeic and geophagus, the endogeics communities in the tropical regions can shift to epigeic communities if soil nutrients and seasonality of rains are low

(Fragoso and Lavelle 1992). However, according to field observations during this study, the presence of termites under the frond heaps and wild boar (recognized from its footprint) might have reduced the population of earthworm drastically.

Organic matter content in the development of sustainable earthworm populations is very important especially in the restored site (Lowe and Butt 2002). The effect of organic matter removal during land preparation for the young oil palm plantation has not yet been investigated.

Soil Factors Affecting the Distribution of Earthworm Population

Soil properties can affect the distribution of earthworm population in soil under different oil palm ages. Six soil factors have been identified by principal component analysis which explained 71% of total variance (Table 3). The first factor (27.9%) comprised of C, N, CEC, clay, silt and water content; and bulk density and sand content. This first principal component was considered to be a 'physical habitat and food' factor. The second component involved the concentration of calcium in the soil (Fig. 2). The signs of coefficients of total and exchangeable Ca were opposite to each other. Increments of exchangeable Ca in the soil probably caused a reduction in total Ca. The close relationships between Ca content in the soil and population of *P. corethrurus* may be because earthworms need Ca to produce their calciferous glands. The third component was related strongly to pH and total Mg, and moderately to total P and available P. The soil pH and total Mg exhibited a negative correlation, while total P, available P and pH were positively correlated. The availability of P in the soil is controlled by soil pH. The fourth component is apparently the 'K' factor (Fig. 3). Clay content in the study area appeared to be a factor influencing earthworm populations. The fifth and sixth component contributed 7% and 6% of the total variation (Table 3). The factors that caused a higher variation in the principal component 1 and 2 were used as an independent variable for regression analysis. They were organic C, N, CEC, clay, sand, bulk density, water content, total Ca and exchangeable Ca. The most appropriate model obtained at a 5% significant level was:

$$Y = 1.42\, X_1 + 0.006\, X_2 \qquad (R^2=0.66^{*}\ n=100)$$

where

Y = earthworm/m^2
X_1 = CEC
X_2 = exchangeable calcium

The PCA produced some probable answers in the variation of earthworm populations in term of soil type and oil palm age. Although *P. corethrurus* is an endogeic earthworm species, which is a soil feeder, our survey showed that organic C and N caused the variability in earthworm population. Soil physical conditions have been shown to affect the activities of earthworms. For example, Stovold *et al*. (2004) showed that earthworm burrows were longer in the loose soil than in compact soil. Our study showed that the physical habitat/soil conditions influenced populations of earthworms in the same proportion as food. The limited areas for earthworms to move or burrow in order to obtain food might serve as a disturbance for the reproduction capability of the earthworms. There was a positive linear correlation between soil CEC and organic C content and clay content, which indicates that the effect of CEC on earthworm populations was similar to the effects of organic C and clay.

TABLE 3
Eigenvalues and proportions of variance to the total variance for derived principal component

Principal component	Eigenvalue	Proportion	Cumulative percentage
PC1	5.02	0.28	28
PC2	2.90	0.16	44
PC3	1.92	0.11	55
PC4	1.68	0.09	64
PC5	1.20	0.07	71
PC6	1.11	0.06	77
PC7	0.83	0.05	82
PC8	0.65	0.04	85
PC9	0.60	0.03	89
PC10	0.55	0.03	92

Relationship between Soil Properties and Earthworm Cast

Earthworm casts significantly affect plant growth through their effects on micro-organisms, aggregation of soil, and nutrient supply (Table 4). The amounts of cast varied from 0 to 262 g dry weight m^{-2} (Table 5). Earthworms ingest selected soil particles, soil organic matter, dead plant material, seeds or seedlings, and micro-organisms. This may affect the chemical and physical properties of cast as compared to the surrounding soils.

The cast pH was higher than the soil pH. This might be due to the difference in Ca content and OM. Calcium and OM of certain residue are able to correct the acidity of cast, thus the pH of cast becomes higher. The 69% increase in organic C in casts compared to soil showed that *P. corethrurus* consumes organic C. A similar trend in the amounts of total N in earthworm casts occurred in comparison to the N in the associated soils. Carbon and nitrogen are major nutrients for earthworms, so the utilisation of C and N by earthworms gave the lowest value of 69 and 52% in the cast compared to other nutrients (Table 4).

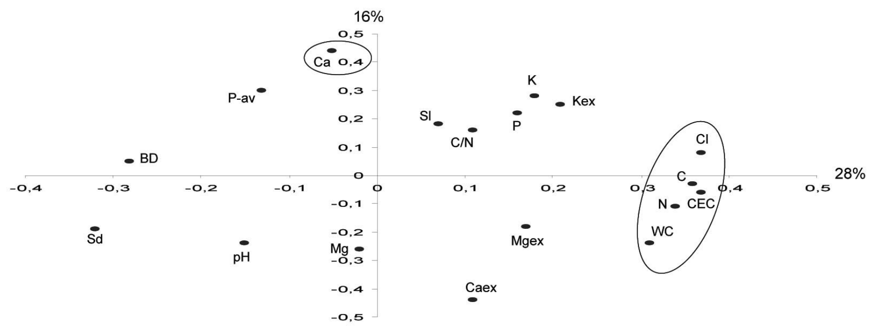


Fig .2: Principal component analysis 1 (horizontal) and 2 (vertical) of earthworm distribution pattern related to soil properties.

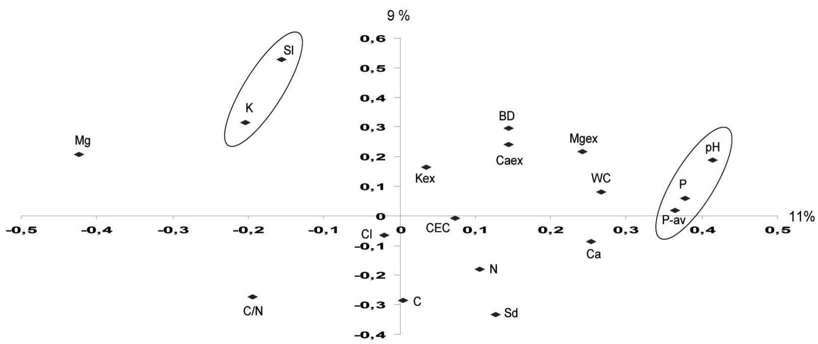


Fig.3: Principal component analysis 3 (horizontal) and 4 (vertical) of earthworm distribution pattern related to soil properties.

TABLE 4

Relationships between soil and earthworm cast properties and its relative percentage increase in value between cast and soil properties (n=100)

Properties	Linear regression equation	Correlation coefficient (r)	Relative increase
			%
pH	pH cast = 2.05 + 0.65 pH soil	0.61**	5
Organic C	Org-C cast = 1.27 + 0.63 org-C soil	0.57**	69
N	N cast = 0.05 + 1.11 N soil	0.66**	52
C/N	------	-0.03^{ns}	---
P_{total}	P_{total} cast = 165 + 1.18 P_{total} soil	0.55*	302
$P_{available}$	$P_{available}$cast = 55.4 + 1.21 $P_{available}$ soil	0.63*	509
K_{total}	K_{total}cast = 96.2 + 1.32 K_{total} soil	0.57*	116
Ca_{total}	Ca_{total} cast = 838 + 0.46 Ca_{total} soil	0.42*	117
Mg_{total}	Mg_{total}cast = 303 + 0.26 Mg_{total} soil	0.60*	110
CEC	CEC cast = 4.31 + 0.84 CEC soil	0.72**	67
$K_{exchangeable}$	$K_{exchangeable}$ cast = 0.23 + 1.36 $K_{exchangeable}$ soil	0.66**	165
$Ca_{exchangeable}$	$Ca_{exchangeable}$cast = 195 + 1.66 $Ca_{exchangeable}$soil	0.82**	98
$Mg_{exchangeable}$	$Mg_{exchangeable}$cast = 41.6 + 1.43 $Mg_{exchangeable}$ soil	0.71**	241

Most of the chemical properties of the casts were greater than in the surrounding soils, except for the C:N ratio. Earthworms ingest dead plant materials of varying but relatively wide C:N ratios and convert them to earthworm tissues with lower C:N ratio, which are released on the death of the earthworm. Earthworms ingest the selected soil particles, soil organic matter, dead plant material, seeds or seedlings, and microorganisms. Surface casts usually have lower C:N ratios than associated soils, and no correlations were obtained between the C:N ratio in soil and C/N ratio in cast (Syers and Springett 1984). The amounts of total P and available P were higher by 302% and 509%, respectively, than in soils. However, the correlation coefficients between these P properties and corresponding cast and soil were low ($r=0.55^{*}$ and $r=0.63^{*}$). As for the P status in soil, the increases in total P and available P in casts were probably caused by modifications of the pH (5% improvement) in earthworm casts. The percentage of plant-available P in casts was nearly twice that of the percentage increase in total P. This indicates that the P produced by earthworms in their casts was the labile P in inorganic fractions. Increases in activity of microorganisms in the casts were probably responsible for increases in phosphatase activity in earthworm casts compared to the underlying soil (Jiménez *et al.* 2003). The total K and exchangeable K contents in casts were 116 and 165% greater than the surrounding soil, as reported by Basker *et al*. (1992). They further stated that earthworm activity increased amounts of exchangeable K, and concluded that the increase in exchangeable K in cast must be due to the displacement of K^+ from the wedge sites of clay minerals by NH_4^+ ions generated by enhanced mineralisation of organic N. The amounts of exchangeable Ca in cast were correlated strongly with the amounts of exchangeable Ca in the soil, and the exchangeable Ca in the casts was 98% higher than the exchangeable Ca in the soil. The amounts of total Ca released in earthworm casts were high although earthworms use it in their metabolism (Laverack 1963).

TABLE 5
The weight of surface earthworm casts

	Earthworm casts				
Palm age	Serdang	Rengam	Jerangau	Bungor	Munchong
	g				
< 7	182.02±38.6	90.11±38.6	174.72±18.6	59.61±15.8	116.75±12.2
7 - 14	127.91±8.7	129.95±1.5	95.65±56.6	227.78±6.4	123.62±36.3
> 14	186.04±32.9	84.80±18.3	389.39±7.1	273.07±23	223.17±31.8

Mean and standard error of unequal replicates

Total Mg and exchangeable Mg in the cast were significantly ($p \leq 0.05$) correlated with the content of total Mg and exchangeable Mg in the soil. The concentration of exchangeable Ca, Mg and K are usually significantly greater in earthworm casts than in undigested soil (Tiwari *et al.* 1992). The effects of soil Mg on earthworms is unknown; however, the increasing concentrations of total Mg and exchangeable Mg in the casts were probably caused by the modification of pH and P content in the cast.

The clay content in the casts was greater than in soil, and the sand and silt contents were lower than in the soil (Table 6). Soil particles in the earthworm gizzard are ground up, thus increasing the clay content.

TABLE 6
Soil and earthworm cast particles components

Sample	Clay	Sand	Silt
		%	
Earthworm cast	30.6	15	52.1
Surface soil	28.3	18	53.4
T test , Pr>t	0.3558	0.1145	0.7161
Standard error, cast	2.51	2.89	1.33
Standard error, soil	2.20	2.93	2.15

CONCLUSIONS

The CEC and exchangeable Ca were the most important factors influencing earthworm populations in soils of oil palm plantations. Most of the chemical and physical properties of earthworm casts under oil palm plantations were closely related to those of the soil. Overall, nutrient avaialability was higher in casts than in the surrounding soils. The content of available P in earthworm cast was five-fold higher compared to that of the soil.

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