VERMICOMPOSTING OF DIFFERENT TYPES OF OIL PALM FIBRE WASTE USING *Eudrilus eugeniae*: A COMPARATIVE STUDY

Z NAHRUL HAYAWIN*; ASTIMAR, A A; M HAKIMI IBRAHIM‡; WAN HASAMUDIN, W H** and H P S ABDUL KHALIL***

ABSTRACT

*Earthworms (*Eudrilus eugeniae*, the African Nightcrawler) were tested as inoculants in the vermicomposting process in relation to their capacity to compost the various types of oil palm biomass. The different types of oil palm biomass used were empty fruit bunches (EFB), oil palm fronds (OPF) and oil palm trunks (OPT). The oil palm biomass was composted and vermicomposted for 84 days under controlled conditions. In the study on the effects of earthworm digestibility towards the major lignocellulosic components (cellulose and lignin) of EFB in the vermireactors (EFB WORM), results showed a significant degradation rate of the cellulose. A similar trend was also observed for lignin degradation. Meanwhile, lower rates of the lignocellulosic degradation were observed for EFB, OPF and OPT in the control reactor (without earthworms). Vermicompost obtained showed an increase in heavy metal contents in EFB WORM, OPF WORM and OPT WORM, but the contents were still within the range of limits allowable. A significant decrease in C/N ratio and increases in total Kjeldahl nitrogen, total available phosporous and total potassium were recorded for EFB WORM over the control (EFB, OPF and OPT). EFB fibre was found to be the best oil palm fibre for vermicomposting as compared to OPT and OPF fibre.*

Keywords: vermicomposting, oil palm biomass, bio-fertilizer, cellulose degradation, earthworm.

Date received: 26 February 2010; **Sent for revision:** 31 March 2010; **Received in final form:** 2 November 2010; **Accepted:** 6 January 2011.

INTRODUCTION

Malaysia with a large land area dedicated to the agricultural plantations of crops such as banana (34 000 ha) and pineapple (15 000 ha) generates large quantities of cellulosic and non-cellulosic raw materials during harvests (MOA, 2006). The total planted area for oil palm recorded in 2009 was 4.69 million hectares, and based on the components of biomass per hectare that have been formulated and widely accepted (Gurmits, 1996), the availability of total oil palm biomass (made up of empty fruit bunches or EFB, oil palm trunks or OPT, and oil palm fronds or OPF) in that year was estimated at about 65.46 million tonnes (dry weight). In the early years, there were problems and challenges faced by oil palm industry in exploiting these waste products, but in recent years, the oil palm biomass has been exploited for wood-based products (Nor Yuziah and Paridah, 2008), bio-energy (Sansubari, 2008), and for bio-fertilizer (Khalid and Ahmad Tarmizi, 2008). *Table 1* shows the proximate analysis of oil palm biomass compared to that of hardwood and of softwood. Oil palm biomass has a comparable content of the major lignocellulosic components, *i.e.* hemicellulose, cellulose and lignin.

Lignocellulosic materials are the most abundant polymer in nature, and constitute a large carbon pool

* Division of Bio-resource, Paper and Coatings Technology, School of Industrial Technology, Universiti Sains Malaysia, 11800 Minden, Pulau Pinang, Malaysia.
E-mail: nahrul.hayawin@mpob.gov.my
** Malaysian Palm Oil Board, P. O. Box 10620, 50720 Kuala Lumpur, Malaysia.
‡ Division of Environmental Technology, School of Industrial Technology, Universiti Sains Malaysia, 11800 Minden, Pulau Pinang, Malaysia.

TABLE 1. PROXIMATE CHEMICAL ANALYSIS OF THE OIL PALM, HARDWOOD AND SOFTWOOD (%, dry weight basis)

Constituents	EFB	OPF	OPT	Hardwood	Softwood
Ash	3.5	2.5	2.5	<1.5	<1.5
Extractives Hot Water	3.5	4.5	5.5	0.1-8.0	0.2-8.5
Alcohol-toluene	2.3	1.7	1.3	1.3	2.9
Klason Lignin	17.0	21.0	25.0	14.0-35.0	21.0-36.0
Holocellulose	80.0	83.0	73.0	71.0-75.0	60.0-75.0
Alfa cellulose	50.0	56.0	41.0	31.0-65.0	30.0-65.0
Hemicellulose	30.0	27.0	32.0	10.0-40.0	10.0-30.0

Note: EFB – empty fruit bunches.
OPF – oil palm fronds.
OPT – oil palm trunks.
Source: Abdul Khalil *et al*. (2008). Malaysian oil palm fibres: the cell wall ultra structure and physiology characteristics. *Utilization of Oil Palm Tree: Strategizing for Commercial Exploitation*.

for microorganisms, the main agents responsible for soil organic matter decomposition. Cellulolysis occurs as the result of the combined action of fungi and bacteria on the lignocellulosic materials, with different requirements during composting. During decomposition, earthworms act either indirectly by affecting the microbial population structure and dynamics, or directly by the cellulolytic activity of the cellulose enzymes secreted by earthworm species (Aira *et al*., 2006). Degradation of cellulose in the soil is a slow process that is limited by several factors influencing the activities of the cellulases, such as concentration, location and the mobility of the enzymes (Sinsabaugh and Linkins, 1988). Moreover, the production of cellulases is regulated by the speed of accumulation of enzyme products during the process. Hemicellulose and lignin contents and the degree of cellulose crystallization also determine the rate at which the cellulose is metabolized (Lynd *et al*., 2002).

Theoretically, the decomposition of lignocellulosic materials is directly mediated by extracellular enzymes; therefore, analysis of the dynamics may be needed to understand the mechanisms relating to the rate of decomposition, which could be related to the substrate quality and nutrient availability (Sinsabaugh and Linkins, 1993).

With the increase in the prices of chemical fertilizers, the oil palm industry is taking steps to convert oil palm biomass, especially EFB, into bio-fertilizers. Vermicomposting is one of the attempts at increasing the nutritive value of the bio-fertilizers. Earthworms have been used as an alternative tool to convert a great proportion of organic residues into a product with relatively higher concentrations of plant nutrients, microbial population, soil enzymes and humic acids. Vermicomposting is the stabilization of organic waste materials involving the joint action of earthworms and microorganisms (Suthar, 2009).

The objective of this study was to determine the potential of using the earthworm species, *Eudrilus eugeniae* (African Nightcrawler), for vermicomposting of the various types of oil palm biomass (EFB, OPF and OPT) and the quality of vermicompost thus produced. In relation to their high nutritive value and potential utilization, this study subsequently determined the factors that could contribute to optimizing the vermicomposting process on a large scale.

MATERIALS AND METHODS

Materials

Fibre samples of EFB, OPT and OPF were shredded and refined into loose fibrous material by using a thermo mechanical refiner (Andritz) at the MPOB pilot plant. The EFB fibres were collected from the Tian Siang Oil Mill (Perak) Sdn Bhd, while the OPT and OPF fibres were collected from FELDA Keratong 1, Pahang and MPOB plantation, Bangi Lama, respectively, in Malaysia. The earthworm species used was *Eudrilus eugeniae*, commonly known as the African Nightcrawler, which was obtained from a local worm breeder in Malaysia. The breeding stock was maintained at a temperature of 25 ± 1°C, and only matured clitellate earthworms were used for this investigation. The duration of experiment was 84 days.

Experimental Set-up

The EFB, OPT and OPF fibres were refined into fine fibres with a length <5.18 mm. About 150 g (dry weight) of each type of fibres were placed in 1.6-litre circular plastic containers (diameter 11 cm, depth 12 cm) called vermicomposters. The fibre samples were kept moist using distilled water up to 80% by weight for two weeks, in order to soften the fibre and to accelerate the degradation process. Five grams of mature clitellate worms of *E. eugeniae* (live weight of each individual being 0.35-1.90 g) were added to every vermicomposter. The same set-up for a vermicomposter was established without worms, which acted as the control. The moisture content of the substrate in each container was kept at 60%-80% throughout the experimental period, and the vermicomposters were kept in the dark at a temperature 26.3ºC ± 0.39ºC (mean of the temperatures recorded during the experimental duration ± SE). Samples were collected every week from each vermicomposter for earthworm processing, taking the top layer of the vermicomposter once the waste had been processed by the earthworms, and the samples (vermicast) sent to the laboratory for analysis. The experimental samples were prepared in triplicate for each vermicomposter.

Chemical Analysis

The nutrient contents of the oil palm biomass fibres were determined prior to the vermicomposting process, and also at every interval of the vermicomposting period. Total organic carbon (TOC) of the vermicompost was estimated using the standard dichromate oxidation method of Nelson and Sommers (1982). Total kjeldahl nitrogen (TKN) content from the vermicompost was analyzed by the Kjeldahl method using a Technican Auto Analyser II. The C/N ratio was calculated from the measured values of C and N. Total phosphorus (TP) was analyzed by using the spectrophotometric method with molybdenum in sulphuric acid. The K and heavy metal contents (Cu, Fe, Mn and Zn) in the vermicompost were determined by the double-acid method and analyzed using an atomic absorption spectrophotometer (Analyst 100, Perkin Elmer) with a graphite furnace (Model: HGA-850). Cellulose content of the fibre was determined using the method of Updegraff (1969). Changes in lignin content were followed by using the method of Zadrazil and Brunnert (1980). The pH of the media was determined using a double-distilled water suspension of each mixture in the ratio of 1: 10 (w/v).

RESULTS AND DISCUSSION

Loss of Lignocellulosic Components during Vermicomposting

After 84 days of vermicomposting, the contents of the main components of the lignocellulosic fraction (cellulose and lignin) were analyzed, and are shown in *Figures 1* to *6*. The percentages of cellulose at the initial stage were 60.00 ± 0.25% for EFB, 59.20 ± 4.00% for OPF, 58.82 ± 2.00% for OPT, 50.00 ± 0.45% for EFB WORM, 59.53 ± 2.01% for OPF WORM and 55.38 ± 4.12% for OPT WORM. These percentages decreased with composting time, and after 84 days were 38.00 ± 0.49% in EFB, 40.00 ± 2.75% in OPF, 40.60 ± 1.30% in OPT, 20.07 ± 3.21% in EFB WORM, 30.00 ± 1.50% in OPF WORM and 32.00 ± 0.45% in OPT WORM. In the controls, the OPT fibre (*Figure 3*) did not show much of a decrease in cellulose content as compared to the EFB fibre (*Figure 1*) and the OPF fibre (*Figure 2*). Despite cellulose degradation, there was still some cellulose content at the end of the process, which probably was due to less weight loss during the process, as it has been previously reported (Haruta *et al*., 2002) especially for EFB WORM. The presence of earthworms in the vermicomposter

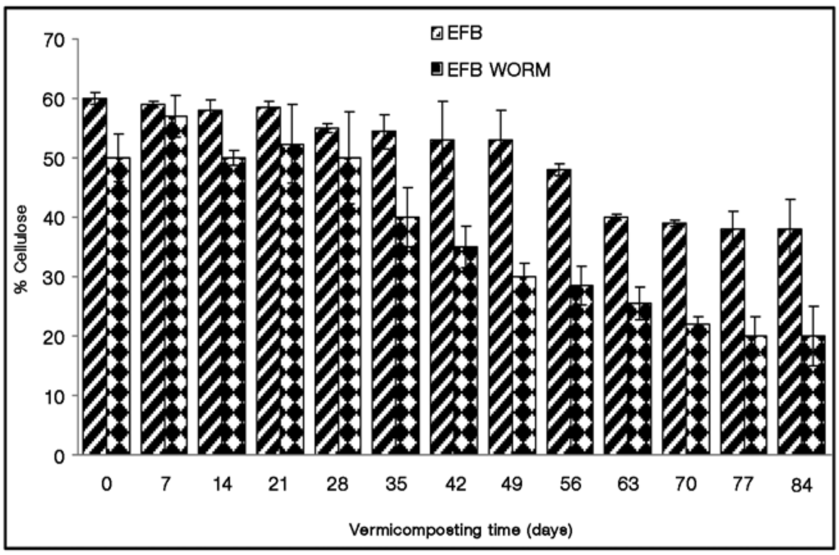

Figure 1. Trends in empty fruit bunches (EFB) cellulose degradation during vermicomposting (with and without earthworms).

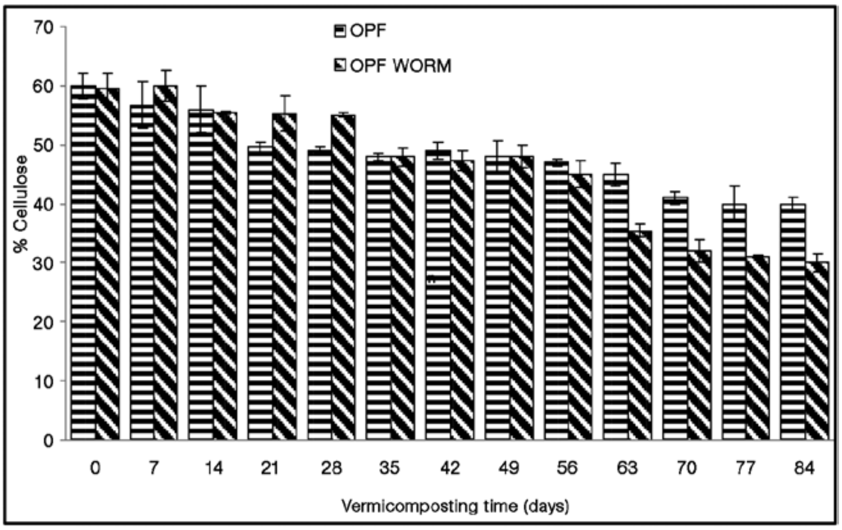

Figure 2. Trends in oil palm fronds (OPF) cellulose degradation during vermicomposting (with and without earthworms).

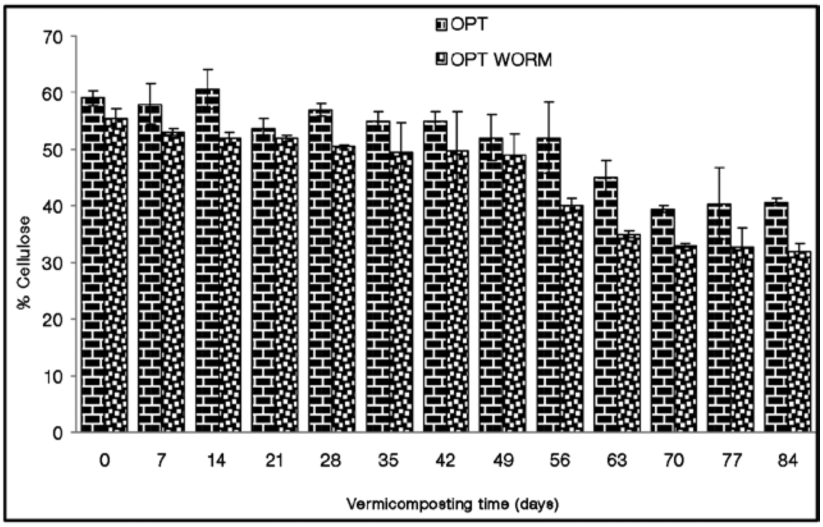

Figure 3. Trends in oil palm trunks (OPT) cellulose degradation during vermicomposting (with and without earthworms).

caused the loss of cellulose (*Figures 1* to *3*). Thus, this study shows that decomposition of cellulose in the vermicomposters was significantly faster in those with earthworms. Degradation of the cellulosic biomass represents an important part of the biosphere's carbon cycle. Consequently, the use of microorganisms or earthworms in order to remove, reduce or ameliorate these potentially polluting materials is a real environmental challenge, which can be solved by research focused on efficient methods applied in the biological degradation processes. Degradation of the cellulose component of the biomass sample, with reference to oil palm biomass, mostly during the composting or vermicomposting process has also been recorded by other researchers (Thambirajah and Kuthubutheen, 1989; Thambirajah *et al.*, 1995).

The least amount of lignin content (15.00 ± 2.00%) was observed at day 84 in EFB WORM, followed by OPF WORM (18.00 ± 1.75%) at day 49 and OPT WORM (19.00 ± 1.00%) at day 63. The maximum decrease in lignin from the initial day until the final day was observed in EFB WORM at 21.05 ± 0.69% (*Figure 4*), followed by OPF WORM at 8.69 ± 1.52% (*Figure 5*) and OPT WORM at 4.56 ± 2.01% (*Figure 6*). No consistent changes in lignin content were observed for EFB, OPT and OPF (*Figures 4*, *5* and *6*, respectively). It would appear that even though composting or vermicomposting occurred in all of the oil palm biomass samples, the breakdown of lignin was not obvious. The most evident changes were in cellulose degradation for all the biomass samples. Thus, lignin is not totally mineralized during composting. Saiz-Jeminez *et al*. (1989)

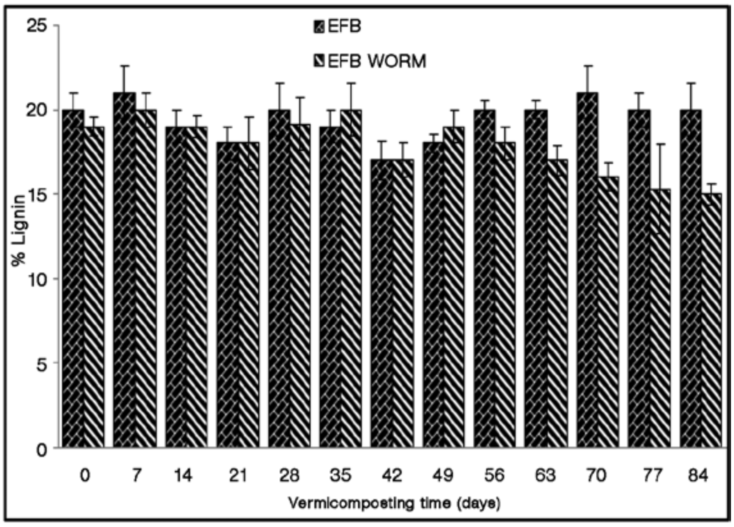

Figure 4. Trends in empty fruit bunches (EFB) lignin degradation during vermicomposting (with and without earthworms).

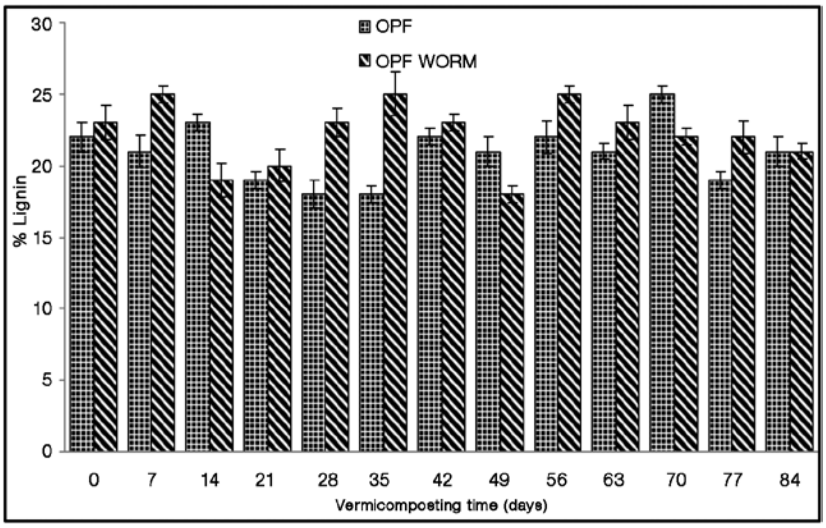

Figure 5. Trends in oil palm fronds (OPF) lignin degradation during vermicomposting (with and without earthworms).

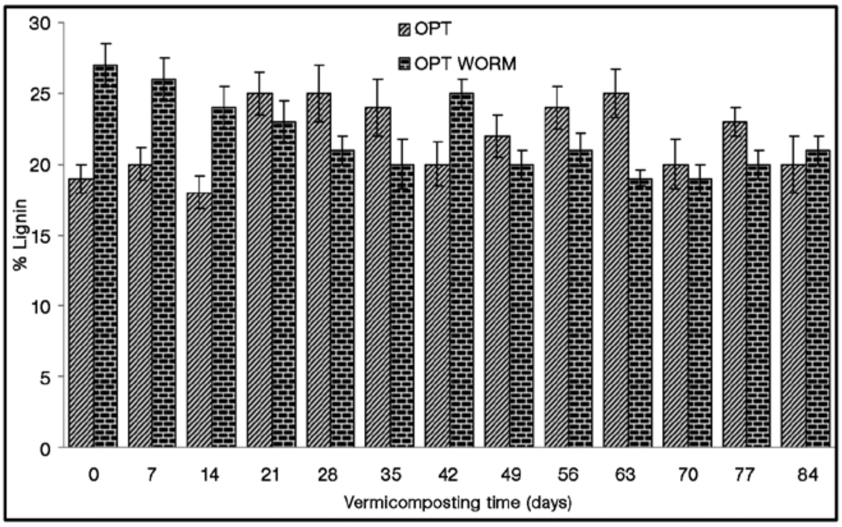

Figure 6. Trends in oil palm trunks (OPT) lignin degradation during vermicomposting (with and without earthworms).

and Malherbe and Cloete (2002) have suggested that the difficulty in degrading lignocellulose during composting is because the lignin fraction is most resistant towards biodegradation. The content of this polymer determines not only its own decomposition but also influences the decomposition of hemicellulose (Vikman *et al.*, 2002). The macromolecular properties and structural characteristics of lignin make biodegradation studies difficult. According to Vikman *et al.* (2002), biodegradability seems to be limited when the lignin content is greater than 20% because of the higher initial proportion of lignin.

pH, Nutrient Quality and Heavy Metal Concentration

Vermicomposting shifted the pH towards neutrality (*Table 2*), irrespective of the initial pH of the substrates. Most reports on vermicomposting (Gunadi and Edwards, 2003; Garg and Kaushik, 2005) showed a decrease in pH of all the feed mixtures during vermicomposting. The initial pH of the control for EFB was 6.55 ± 0.05, for OPF 5.15 ± 0.02 and OPT 5.35 ± 0.15. The pH then shifted towards neutrality at day 84 for EFB to 7.30 ± 0.15, OPF to 7.47 ± 0.50 and OPT to 7.24 ± 0.02. For the vermicomposting treatments, OPT WORM recorded the lowest pH at day 0 at 5.58 ± 0.25, followed by OPF WORM at 6.50 ± 0.05 and EFB WORM at 6.52 ± 0.02. The pH shifted towards neutrality at day 28 for EFB WORM to 7.15 ± 0.25 and for OPF WORM to 7.10 ± 0.05, and at day 56 for OPT WORM to 7.07 ± 0.50 (*Table 2*).

These results are in agreement with some other observations (Datar *et al.*, 1997; Pramanik *et al.*, 2007; Mainoo *et al.*, 2009) which reported an increase in pH during vermicomposting. This may be due to the decomposition of organic matter leading to the formation of ammonium (NH^{4+}) ions and humic acids (Komilis and Ham, 2006) although these two components have exactly opposite effects on pH. The presence of carboxylic and phenolic groups in humic acids will reduce pH while ammonium ions would increase pH of a system. The combined effect of these two oppositely charged ions probably regulates pH of vermicompost, leading to a shift of pH towards neutrality.

Table 2 shows the increase in total phosphorus (TP) and total potassium (TK) contents in the resulting vermicompost as compared to the initial substrates and the controls. The highest increase in TP occurred in EFB WORM where the initial TP content was $0.2 \pm 1 \times 10^{-2}$ while the final content was $1.1 \pm 1 \times 10^{-2}$. Meanwhile, the least increase occurred in OPT WORM where the initial content was $1 \times 10^{-2} \pm 1 \times 10^{-3}$ while the final content was $0.4 \pm 2.5 \times 10^{-2}$. In the control, EFB showed the highest increase with the initial content of TP being $2 \times 10^{-2} \pm 1 \times 10^{-3}$ and final being $0.3 \pm 1 \times 10^{-3}$. The OPT control showed the least increase with the final content of TP at $0.2 \pm 2 \times 10^{-2}$. Total phosphorus content increased by the end of the vermicomposting process, probably because of mineralization of the organic matter. The contents of P and K were substantially higher in vermicompost than in compost by 20% and 38%, respectively. The presence of a large number of microflora in the gut of the earthworm might

TABLE 2: CHEMICAL ANALYSIS OF THE COMPOST PREPARED FROM DIFFERENT OIL PALM WASTE AT DIFFERENT TIME PERIOD

Days	EFB WORM			OPF WORM			OPT WORM		
	pH	TP (%)	TK (%)	pH	TP (%)	TK (%)	pH	TP (%)	TK (%)
0	6.5 ± 0.1 (6.6 ± 0.5)	$0.2\pm1\times10^{-2}$ ($2\times10^{-2}\pm1\times10^{-3}$)	$2\times10^{-2}\pm1.2\times10^{-3}$ ($0.1\pm1\times10^{-3}$)	6.5 ± 0.5 (5.2 ± 0.2)	$1\times10^{-2}\pm1\times10^{-3}$ ($0.02\pm2\times10^{-3}$)	$4\times10^{-2}\pm1\times10^{-3}$ ($3\times10^{-2}\pm1\times10^{-3}$)	5.6 ± 0.3 (5.4 ± 0.2)	$1\times10^{-2}\pm1\times10^{-3}$ ($1\times10^{-2}\pm2\times10^{-3}$)	$3\times10^{-2}\pm1\times10^{-3}$ ($1\times10^{-2}\pm2\times10^{-3}$)
14	6.7 ± 0.2 (6.6 ± 0.2)	$0.5\pm1\times10^{-2}$ ($2\times10^{-2}\pm2\times10^{-3}$)	$4\times10^{-2}\pm1.1\times10^{-3}$ ($1\times10^{-2}\pm4\times10^{-3}$)	7.0 ± 0.1 (6.2 ± 0.5)	$4\times10^{-2}\pm1\times10^{-3}$ ($2\times10^{-2}\pm1\times10^{-3}$)	$4\times10^{-2}\pm3\times10^{-3}$ ($3\times10^{-2}\pm2\times10^{-3}$)	5.9 ± 1.2 (5.7 ± 0.2)	$1\times10^{-2}\pm1\times10^{-3}$ ($3\times10^{-2}\pm2\times10^{-3}$)	$3\times10^{-2}\pm1\times10^{-3}$ ($2\times10^{-2}\pm1\times10^{-3}$)
28	7.2 ± 0.3 (6.7 ± 0.1)	$0.6\pm1\times10^{-3}$ ($3\times10^{-2}\pm5\times10^{-3}$)	$5\times10^{-2}\pm4\times10^{-3}$ ($3\times10^{-2}\pm2\times10^{-3}$)	7.1 ± 0.1 (6.5 ± 0.2)	$0.2\pm3\times10^{-2}$ ($0.1\pm1\times10^{-3}$)	$5\times10^{-2}\pm1\times10^{-3}$ ($3\times10^{-2}\pm1\times10^{-3}$)	6.2 ± 2 (6.1 ± 0.4)	$1\times10^{-2}\pm3\times10^{-3}$ ($3\times10^{-2}\pm2\times10^{-3}$)	$4\times10^{-2}\pm2\times10^{-3}$ ($2\times10^{-2}\pm2\times10^{-3}$)
42	7.3 ± 0.1 (6.9 ± 0.1)	$0.9\pm2\times10^{-2}$ ($0.2\pm1\times10^{-3}$)	$8\times10^{-2}\pm2\times10^{-3}$ ($3\times10^{-2}\pm5\times10^{-3}$)	7.1 ± 0.3 (6.8 ± 1.0)	$0.3\pm1\times10^{-2}$ ($0.2\pm2\times10^{-3}$)	$6\times10^{-2}\pm1\times10^{-3}$ ($4\times10^{-2}\pm1\times10^{-3}$)	6.9 ± 1 (6.3 ± 0.5)	$3\times10^{-2}\pm1.2\times10^{-3}$ ($4\times10^{-2}\pm1\times10^{-3}$)	$5\times10^{-2}\pm1\times10^{-3}$ ($3\times10^{-2}\pm1\times10^{-3}$)
56	7.4 ± 0.1 (7.0 ± 0.1)	$0.9\pm1\times10^{-2}$ ($0.2\pm1\times10^{-3}$)	$0.2\pm1\times10^{-2}$ ($0.1\pm3\times10^{-2}$)	7.2 ± 0.8 (6.8 ± 0.3)	$0.3\pm1\times10^{-2}$ ($0.2\pm1\times10^{-2}$)	$7\times10^{-2}\pm2.1\times10^{-3}$ ($0.1\pm1\times10^{-3}$)	7.1 ± 0.5 (6.9 ± 0.05)	$8\times10^{-2}\pm1\times10^{-3}$ ($1\times10^{-2}\pm2\times10^{-3}$)	$6\times10^{-2}\pm1.2\times10^{-3}$ ($3\times10^{-2}\pm1\times10^{-3}$)
70	7.5 ± 0.3 (7.3 ± 0.1)	$1.0\pm1\times10^{-2}$ ($0.2\pm2\times10^{-3}$)	$0.2\pm3\times10^{-2}$ ($0.2\pm2\times10^{-3}$)	7.2 ± 0.8 (7.1 ± 0.6)	$0.8\pm3\times10^{-2}$ ($0.3\pm2\times10^{-2}$)	$7\times10^{-2}\pm1\times10^{-3}$ ($5\times10^{-2}\pm2\times10^{-3}$)	7.3 ± 0.1 (7 ± 0.1)	$0.1\pm2\times10^{-2}$ ($0.1\pm2\times10^{-2}$)	$6\times10^{-2}\pm1\times10^{-3}$ ($5\times10^{-2}\pm2\times10^{-3}$)
84	7.5 ± 0.1 (7.3 ± 0.2)	$1.1\pm1\times10^{-2}$ ($0.3\pm1\times10^{-3}$)	$0.3\pm1\times10^{-2}$ ($0.2\pm3\times10^{-3}$)	8 ± 0.1 (7.5 ± 0.5)	$8\pm1\times10^{-3}$ ($0.6\pm2\times10^{-2}$)	$8\times10^{-2}\pm1\times10^{-3}$ ($5\times10^{-2}\pm1\times10^{-3}$)	7.7 ± 0.1	$0.4\pm2.5\times10^{-2}$ ($0.2\pm2\times10^{-2}$)	$0.1\pm1\times10^{-3}$ ($5\times10^{-2}\pm2\times10^{-3}$)

Note: All values are the mean and standard deviation of three replicates; all values are given in the percentage except pH. The values given in the parentheses are the control values.
TP – total phosphorus.
TK – total potassium.

play an important role in increasing P and K contents during the process of vermicomposting (Kaviraj and Sharma, 2003). Selective feeding of earthworms on organically rich substances results in their breakdown during passage through the gut, where biological grinding together with enzymatic influence on finer soil particles occurs. These processes are likely to be responsible for increasing the different forms of K (Rao *et al*., 1996).

All the vermicomposters showed a similar trend of change in TOC, which decreased from the initial value of TOC_t/TOC_0 = 1.00 to TOC_t/TOC_0 = 0.73 in EFB WORM (R^2 = 0.99), to TOC_t/TOC_0 = 0.77 in OPF WORM (R^2 = 0.95) and to TOC_t/TOC_0 = 0.80 in OPT WORM (R^2 = 0.95) (*Figures 3* to *7*). The maximum reduction in TOC was observed in EFB WORM. Organic C was lower in the final product when compared to the initial level in the vermicomposting treatments EFB WORM, OPF WORM and OPT WORM. The decrease in TOC shows that the earthworms consumed the wastes and converted them into vermicompost at a faster rate than by normal composting, as has been reported by Kaushik and Garg (2004). The TOC content on all the sampling days varied significantly (p<0.05). The vermicomposting process accelerated microbial decomposition after inoculation of the waste materials with earthworms. These combined activities of earthworms and microorganisms bring about C loss from the substrates in the form of CO_2 (Kaushik and Garg, 2004; Suthar, 2006; 2007).

It may be seen from *Figure 8*, that stabilization of $(C/N_t)/(C/N_0)$ was observed from week 0 until week 12 of vermicomposting. All the vermicomposters showed a similar pattern of change in C/N, which decreased from the initial value of $(C/N_t)/(C/N_0)$ = 1.00 to $(C/N_t)/(C/N_0)$ = 0.26 in EFB WORM (R^2 = 0.97), to $(C/N_t)/(C/N_0)$ = 0.31 in OPF WORM (R^2 = 0.99) and to $(C/N_t)/(C/N_0)$ = 0.34 in OPT WORM (R^2 = 0.96). The

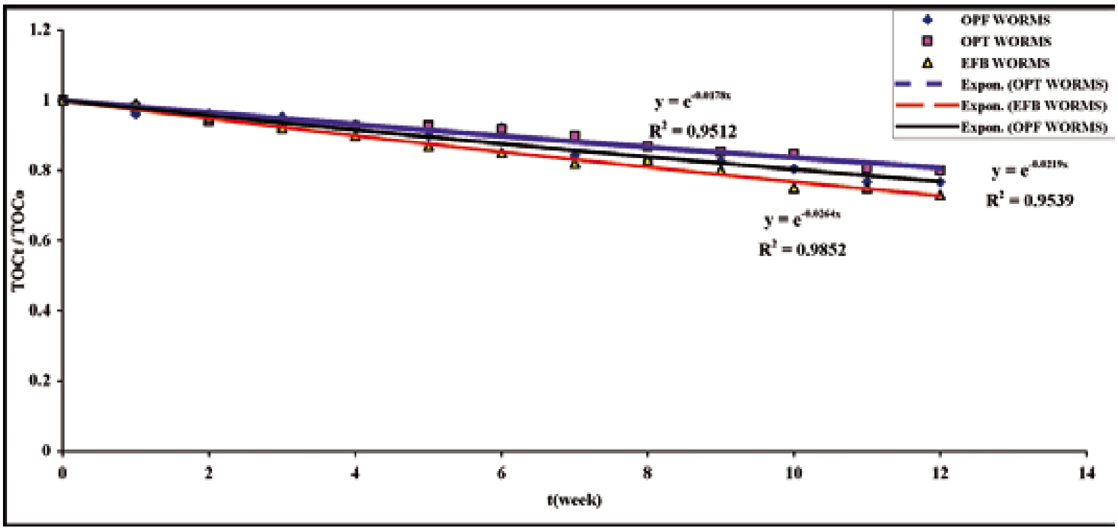

Figure 7. Changes in total organic carbon (TOC) content during vermicomposting of oil palm biomass fibre.

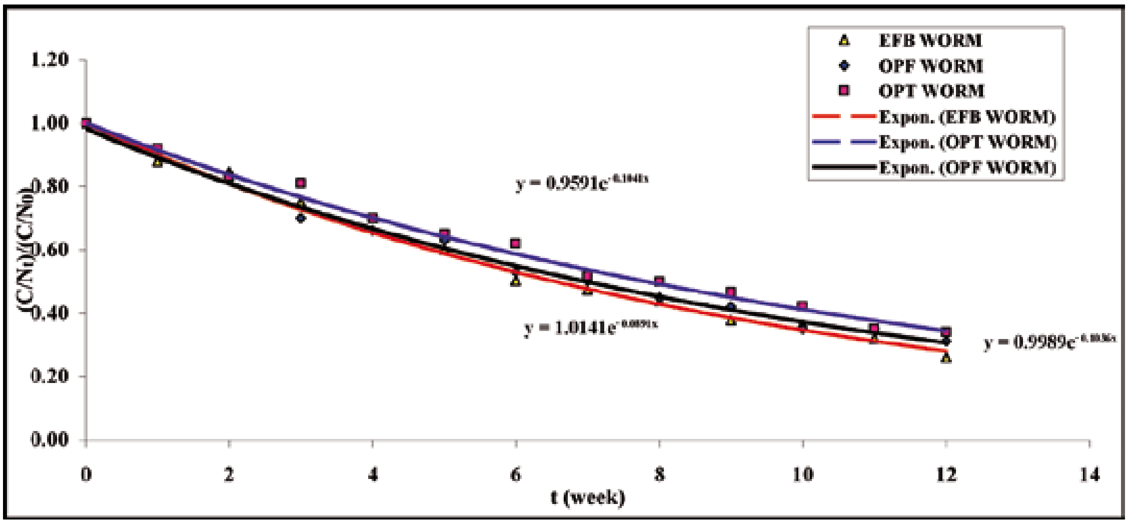

Figure 8. Changes in C/N ratio during vermicomposting of oil palm biomass fibre.

maximum reduction in C/N ratio was in EFB WORM (74.44% of the initial value), followed by OPF WORM (68.88%) and OPT WORM (65.92%). The loss of C as CO_2 in the respiration process and production of mucus and nitrogenous excreta enhance the level of nitrogen, which reduces the C/N ratio (Suthar, 2007).

Total nitrogen consists of the inorganic forms of nitrogen, *i.e.* ammonium (NH_4^+) and nitrate (NO_3^-), and organic nitrogen (N_{org}). Total nitrogen as shown in *Figure 9* was higher in the final products than in the initial substrates with increases by 2.5-2.7, 2.3-2.4 and 1.7 times in EFB WORM, OPF WORM and OPT WORM, respectively. The maximum increase in N occurred in EFB WORM (76.54% of initial value, $R^2 = 0.98$), followed by OPF WORM (55.49%, $R^2 = 0.99$) and OPT WORM (36.20%, $R^2 = 0.98$). The maximum TKN content was in EFB WORM after day 84 compared to other substrates. The increase in TKN was greater in the vermicomposting treatments (EFB WORM, OPF WORM and OPT WORM) than in the composting (wormless) treatments or controls, probably because of the higher mineralization of organic matter. Losses in organic carbon might have been responsible for the additional N. The reduction in dry mass (loss in organic carbon in terms of CO_2) due to substrate utilization by microbes and the earthworms, and the metabolic activities of these organisms, as well as water loss by evaporation during mineralization of the organic matter, might have led to the relative increase in nitrogen. However, in general the final content of nitrogen in the vermicomposts was dependent on the initial nitrogen present in the wastes and the extent of decomposition. Earthworm activity enriches the nitrogen profile of vermicompost through microbe-mediated nitrogen transformation, and through the addition of mucus and nitrogenous wastes secreted by the earthworms. The decrease in pH may be an important factor in nitrogen retention as N is lost as volatile ammonia at high pH values. Studies reveal that the decomposition of organic materials by earthworms accelerates the N mineralization process and subsequently changes the N profile of the substrate (Suthar, 2007). In addition, Satchell (1967) reported that over 70% of the N in the tissues of dead earthworms was mineralized in less than 20 days.

Heavy metal pollution can be from many sources but most commonly arises from the heavy use of chemicals in the plantation. From this study, it was found that the contents of heavy metals (Cu, Fe, Zn and Mn) were higher in the vermicomposts than in the controls (*Table 3*), but were still below the allowable limits in the vermicomposts (*Table 4*). The Mn, Zn, Fe and Cu concentrations in EFB after composting for 10 days were $9.3 \pm 1 \times 10^{-2}$, $0.6 \pm 4 \times 10^{-3}$, $0.3 \pm 1.1 \times 10^{-2}$ and $1 \times 10^{-2} \pm 2 \times 10^{-3}$ mg kg^{-1}, respectively, whereas in the vermicompost of EFB WORM, the concentrations were $7 \pm 1 \times 10^{-2}$, $0.6 \pm 3 \times 10^{-2}$, $0.7 \pm 1 \times 10^{-3}$ and $7 \times 10^{-2} \pm 1 \times 10^{-3}$ mg kg^{-1}, respectively (*Table 3*). After 84 days of composting and vermicomposting, the Mn, Zn, Fe and Cu concentrations in the EFB control were 16.78 ± 0.96, 2.82 ± 0.32, 1.62 ± 0.39 and 2.18 ± 0.49 mg kg^{-1}, respectively, while in EFB WORM they were 18.75 ± 0.75, 3.56 ± 0.08, 3.29 ± 1.64 and 5.58 ± 0.29 mg kg^{-1}, respectively. The Mn, Zn, Fe and Cu concentrations in OPF WORM after vermicomposting for 10 days were $8.4 \pm 5 \times 10^{-2}$, $1.1 \pm 1 \times 10^{-3}$, $0.9 \pm 1 \times 10^{-3}$ and $0.3 \pm 2 \times 10^{-3}$ mg kg^{-1}, respectively. After 84 days of vermicomposting the levels rose to 25.25 ± 1.01, 5.73 ± 1.22, 6.70 ± 0.20 and 5.27 ± 1.24 mg kg^{-1} for Mn, Zn, Fe and Cu, respectively. The Mn, Zn, Fe and Cu contents were three, five and a half, seven and a half and 16 times respectively higher in OPF WORM than the initial contents. Even if

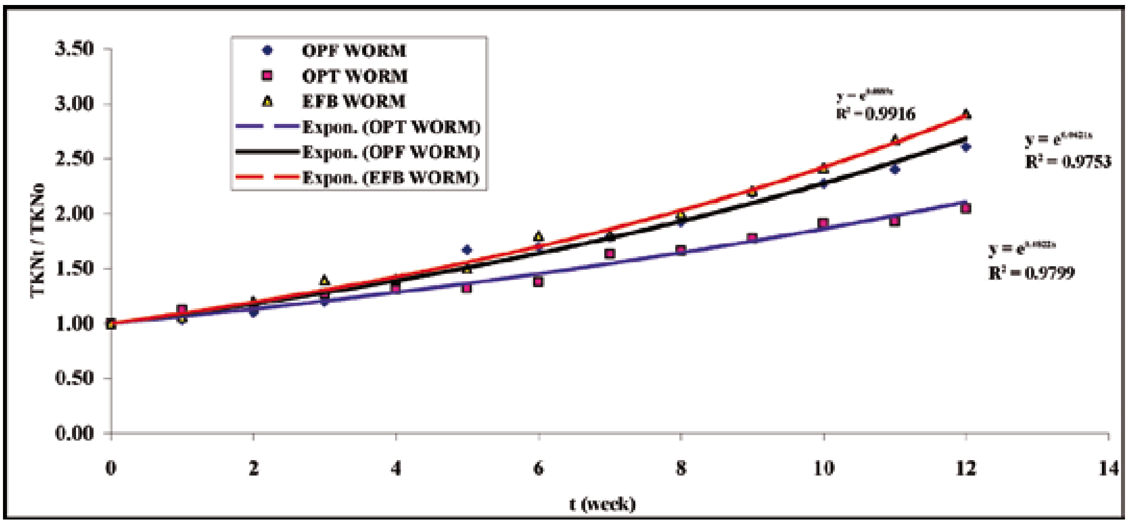

Figure 9. Changes in total kjeldahl (TKN) content during vermicomposting of oil palm biomass fibre.

TABLE 3. HEAVY METAL CONTENT (ppm) IN THE OIL PALM BIOMASS, VERMICOMPOSTS AND THE CONTROLS OF THE COMPOSTING PERIOD OF 84 DAYS (mean ± SE, n= 3) (dry basis)

Vermicomposter medium	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})
EFB control	2.18 ± 0.49	2.82 ± 0.32	1.62 ± 0.40	16.78 ± 0.96
OPT control	1.10 ± 0.47	2.53 ± 0.23	1.45 ± 0.35	40.47 ± 0.83
OPF control	2.92 ± 1.10	4.05 ± 0.45	1.29 ± 0.33	18.90 ± 0.57
EFB WORM	5.58 ± 0.29	3.56 ± 0.08	3.29 ± 1.64	18.75 ± 0.75
OPT WORM	1.16 ± 0.42	4.55 ± 0.10	4.59 ± 0.31	42.00 ± 1.08
OPF WORM	5.27 ± 1.24	5.73 ± 1.22	6.70 ± 0.20	25.25 ± 1.01

Note: EFB – empty fruit bunches.
OPT – oil palm trunks.
OPF – oil palm fronds.

TABLE 4. THE LIMITS OF ALLOWABLE HEAVY METALS CONTENT IN THE VERMICOMPOST

Calcium and magnesium (meq/100 g)	22.67-47.60
Copper (ppm)	2.00-9.50
Iron (ppm)	2.00-9.30
Zinc (ppm)	5.70-11.50
Available sulphur (ppm)	128.00-548.00

Source: Kale (1998).

earthworms do not absorb all the micronutrients from the feed material, those that are absorbed tend to accumulate in their bodies (Sharma *et al.*, 2005).

The Pb, Cd, Zn, Mn and Cu accumulate and, under some environmental conditions, bioconcentrate in earthworms (Cortet *et al.*, 1999). The Zn has been found to accumulate in the peritoneal epithelium in nerve cells of the ventral nerve chord of the chlorogogen cells that form the outer layer of the earthworm's intestine (Padmavathiamma *et al.*, 2008). However, these minerals are incorporated into the compost upon the death of the worms. Earthworms may serve as bioindicators of soil contaminated with pesticides, *i.e.* polychlorinated biphenyls, polycyclic hydrocarbons and heavy metals (Spurgeon and Hopkin, 1999). In many cases, Zn is a critical toxic metal in these organisms (Spurgeon and Hopkin, 2000). Mortality and fecundity of earthworms as bioindicating organisms may serve as reliable, albeit time-consuming, indices of environmental pollution (Morgan *et al.*, 1999).

The high contents of heavy metals in vermicompost, which may accumulate in the earthworms, could pose a problem if worm fecundity is a consideration (Flechenstein and Graff, 1983). Deolalikar *et al.* (2005) suggested that the weight and volume reduction due to breakdown of the organic matter during vermicomposting may be the reason for the increase in heavy metal concentrations in vermicompost (in terms of calculation). Suthar (2008) revealed that earthworms can accumulate heavy metals in their tissues if reared in contaminated soils for long durations.

CONCLUSION

Our trials have demonstrated that EFB was the best substrate for vermicomposting when using the African Nightcrawler, as compared to OPT and OPF, and that the cellulose component was the most degraded portion during vermicomposting. No significant difference was observed for changes in lignin. There was a shift in pH towards the neutral condition as vermicomposting progressed. The C/N ratio decreased with time in all the vermireactors indicating a stabilization of the vermicomposting process. The vermicomposts obtained showed an increase in heavy metal content but the levels were still within the allowable range for vermicompost. Larger increases in the TKN, TK and TP were recorded in EFB as compared to OPT and OPF, and these nutrient contents were comparable to the nutrient contents of vermicompost from other lignocellulosic materials. Further research in this area will help in fine-tuning the technological aspects of using earthworms in composting oil palm biomass.

ACKNOWLEDGEMENT

The first author would like to thank MPOB for providing financial assistance under the Graduate Students Assistantship Scheme (GSAS) to conduct this work. Heartfelt appreciation is also dedicated to Universiti Sains Malaysia, Pulau Pinang, for approval to the first author to pursue this study at the Master's degree level. The author is also grateful to all MPOB staff, and to the reviewers for their valuable comments and careful revision of this manuscript.

REFERENCES

AIRA, M; MONROY, F and DOMINGUEZ, J (2006). *Eisenia fetida* (Oligochaeta, Lumbricidae) activates fungal growth, triggering cellulose decomposition during vermicomposting. *Microb. Eco., 52*: 738-746.

CORTET, J; GOMOT-DE VAUFLERY, A; POINSOT-BALAGUER, N; GOMOT, L; TEXIER, C H and CLUZEAU, D (1999). The use of soil fauna in monitoring pollutants effects. *Eur. J. Soil Biol., 35*: 115-134.

DATAR, M T; RAO, M N and REDDY, S (1997). Vermicomposting – a technological option for solid waste management. *J. Solid Waste Technol. Manage., 24(2)*: 89-93.

DEOLALIKAR, A V; MITRA, A; BHATTACHARYEE, S and CHAKRABORTY, S (2005). Effect of vermicomposting process on metal content of paper mill solidwaste, *J. Environ. Sci. Engg., 47*: 81-84.

FLECHENSTEIN, J and GRAFF, O (1983). Heavy metal uptake from municipal waste compost by earthworm *Eisenia foetida* (Savigny 1826). *Anim. Res. Devel., 18*: 62-69.

GARG, V K and KAUSHIK, P (2005). Vermistablisation of solid textile mill sludge spiked with poultry droppings by an epigeic earthworm *Eisenia foetida*. *Bioresour. Technol., 96*: 1063-1071.

GUNADI, B and EDWARDS, C A (2003). The effect of multiple applications of different organic wastes on the growth, fecundity and survival of *Eisenia foetida* (Savigny) (Lumbricidae). *Pedobiologia. 47(4)*: 321-330.

GURMITS, S (1996). United Plantations Berhad's experiences in the development of peat soils for oil palm. *Proc. of the 1996 Sem. on Pros. of Oil Palm Planting on Peat in Sarawak* (Mohd Tayeb, D ed.). PORIM, Bangi. p. 17.

HARUTA, S; CUI, Z; HUANG, Z; LI, M; ISHII, M and IGARASHI, Y (2002). Construction of a stable microbial community with high cellulose-degradation ability. *Appl. Microbiol. Biotechnol., 59*: 529-534.

KAUSHIK, P and GARG, V K (2004). Dynamics of biological and chemical parameters during vermicomposting of solid textile mill sludge mixed with cow dung and agricultural residues. *Bioresour. Technol., 94*: 203-209.

KAVIRAJ, B and SHARMA, S (2003). Municipal solid waste management through vermicomposting employing exotic and local species of earthworms. *Bioresour. Technol., 90*: 169-173.

KHALID, H and AHMAD TARMIZI, M (2008). Efficient use of inorganic and organic fertilizers for oil palm and potential utilization of decanter cake and boiler ash for biofertilizer production. *Proc. of the 2008 National Seminar on Biofertilizer, Biogas and Effluent Treatment in the Oil Palm Industry: Waste to Wealth.* 14-15 August 2008. MPOB, Bangi. p. 21-30.

KOMILIS, D P and HAM, R K (2006). Carbon dioxide and ammonia emissions during composting of mixed paper, yard waste and food waste. *Waste Management, 26*: 62-70.

LYND, L R; WEIMER, P J; VAN ZYL, W H and PRETORIUS, I S (2002). Microbial cellulose utilization: fundamentals and biotechnology. *Microbiol. Mol. Biol. Rev., 66*: 506-577.

MAINOO, N O K; BARRINGTON, S; JOAN, K W and LUIS, S (2009). Pilot-scale vermicomposting of pineapple wastes with earthworms native to Accra, Ghana. *Bioresour. Technol., 3*: 1-4.

MALHERBE, S and CLOETE, T E (2002). Lignocellulose biodegradation: fundamentals and applications. *Envion. Sc. Biotechnol., 1*: 105-114.

MOA (MINISTRY OF AGRICULTURE) (2006). Hectarage of industrial crops by type, Malaysia. http://www.doa.gov.my/doa/main.php?Content = article & ArticleID=5. Accessed on 18 January 2006.

MORGAN, A J; STURZENBAUM, S R; WINTERS, C and KILLE, P (1999). Cellular and molecular aspects of metal sequestration and toxicity in earthworms. *Invertebr. Reprod. Dev., 6*: 17-24.

NELSON, D W and SOMMERS, L E (1982). Total carbon and organic carbon. *Methods of Soil Analysis* (Page, A L; Miller, R H and Keeney, D R eds.). Amer. Soc. Agron. Inc., Madison, W.I. p. 539-579.

NOR YUZIAH, M Y and PARIDAH, M T (2008). Bonding of oil palm fiber biomass for wood-based panels industry. *Utilisation of Oil Palm Tree, Strategizing for Commercial Exploitation.* Institute of Tropical Forestry and Forest Products (INTROP), UPM Serdang, Selangor. p. 25.

PADMAVATHIAMMA, P K; LORETTA, Y L and USHA, R K (2008). An experimental study of vermi-biowaste composting for agricultural soil improvement. *Bioresource Technology, 99*: 1672-1681.

PRAMANIK, P; GHOSH, G K; GHOSAL, P K; and BANIK, P (2007). Changes in organic-C, N, P and K and enzyme activities in vermicompost of biodegradable organic wastes under liming and microbial inoculants. *Bioresour. Technol.*, *98*: 2485-2494.

RAO, S; SUBBA RAO, A and TAKKAR, P N (1996). Changes in different forms of K under earthworm activity. *Proc. of the National Seminar on Organic Farming and Sustainable Agriculture.* South India, 9-11 October. p. 50.

SAIZ-JIMENEZ, C; SENESI, C and DE-LEEUW, J W (1989). Evidence of lignin residues in humic acids isolated from vermicompost. *Anal. Appl. Pyrol.*, *15*: 121-128.

SANSUBARI, C M (2008). Latest development on supply of renewable energy to the national grid. *Proc. of the 2008 National Seminar on Biofertilizer, Biogas and Effluent Treatment in the Oil Palm industry: Waste to Wealth.* 14-15 August 2008. MPOB, Bangi. p. 234-252.

SATCHELL, J E (1967). Lumbricidae. *Soil Biology* (Burger, A and Raw, F eds.). Academic Press, London. p. 259-322.

SHARMA, S; PRADHAN, K; SATAN, S and VASUDEVAN, P (2005). Potentiality of earthworms for waste management and in their uses – a review. *J. Am. Sci.*, *1*: 107-111.

SINSABAUGH, R L and LINKINS, A E (1988). Adsorption of cellulose components by leaf litter. *Soil Biol. Biochem.*, *20*: 927-931.

SINSABAUGH, R L and LINKINS, A E (1993). Statistical modelling of litter decomposition from integrated cellulase activity. *Ecology.*, *74*: 594-1597.

SPURGEON, D J and HOPKIN, S P (1999). Comparisons of metal accumulation and excretion kinetics in earthworms (*Eisenia foetida*) exposed to contaminated field and laboratory soils. *Appl. Soil Ecol.*, *11(3)*: 227-243.

SPURGEON, D J and HOPKIN, S P (2000). The development of genetically inherited resistance to zinc in laboratory – selected generation of the earthworm *Eisenia foetida. Environ. Pollut.*, *109*: 193-201.

SUTHAR, S (2006). Potential utilization of guar gum industrial waste in vermicompost production. *Bioresour. Technol.*, *97*: 2474-2477.

SUTHAR, S (2007). Vermicomposting potential of *Perionyx sansibaricus* (Perrier) in different waste materials. *Bioresour. Technol.*, *98*: 1231-1237.

SUTHAR, S (2008). Development of a novel epigeic-anecic-based polyculture vermireactor for efficient treatment of municipal sewage water sludge. *Int. J. Environ. Waste Manage.*, *2(1/2)*: 84-101.

SUTHAR, S (2009). Vermistabilization of municipal sewage sludge amended with sugarcane trash using epigeic *Eisenia fetida* (Oligochaeta). *Hazard. Material*, *163*: 199-206.

THAMBIRAJAH, J J and KUTHUBUTHEEN, A J (1989). Composting of palm press fibre. *Biol. Wastes*, *27*: 257-269.

THAMBIRAJAH, J J; ZULKALI, M D and HASHIM, M A (1995). Microbial and biochemical changes during the composting of oil palm empty fruit bunches. Effect of nitrogen supplementation on the substrate. *Bioresour. Technol.*, *52(2)*: 133-144.

UPDEGRAFF, D M (1969). Semimicro determination of cellulose in biological materials. *Anal. Biochem.*, *32*: 420-424.

VIKMAN, M; KARJOMAA, S; KAPANEN, A; WALLENIUS, K and ITA¨VAARA, M (2002). The influence of lignin content and temperature on the biodegradation of lignocellulose in composting conditions. *Appl. Microbiol. Biotechnol.*, *59*: 591-598.

ZADRAZIL, R F and BRUNNERT, H (1980). The influence of ammonium nitrate supplementation on degradation and *in vitro* digestibility of straw colonized by higher fungi. *Eur. J. Appl. Microbiol. Biotechnol.*, *9*: 37-44.