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VERMICOMPOSTING OF EMPTY FRUIT BUNCH WITH ADDITION OF PALM OIL MILL EFFLUENT SOLID

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ABSTRACT

The aim of the present study was to evaluate the quality of the nutrients of the vermicompost produced from oil palm empty fruit bunches (EFB) mixed with palm oil mill effluent (POME) solid employing an epigeic earthworm Eisenia fetida. *The vermicomposting of EFB and in supplementation with POME solid differed in the resulting C/N ratios. The initial C/N ratios (178.1, 114.5, 153.3, 73.1, 123.1 and 38.6) for the six vermicomposters were significantly reduced to 54.0, 20.1, 19.5, 12.1, 15.5, and 10.5, respectively, after 84 days of vermicomposting. A significant increase in pH, TKN, TP and TK content was recorded in all the vermicomposters (V_1, V_2, V_3, V_4, V_5 and V_6). From this study, we can conclude that of the six compositions studied, the best ratio for vermicomposting of EFB with additional POME is V_6 (50% EFB + 50% POME solid).*

Keywords: vermicomposting, empty fruit bunch, palm oil mill effluent, *Eisenia fetida*.

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INTRODUCTION

Elaeis guineensis is a species under the family of *Palmacea* which originated from the tropical forests of West Africa (Yusof, 2000). Oil palm is well-known as one of the most economical perennial oil crops. Oil palm by-products including oil palm fronds (OPF), oil palm trunks (OPT) and empty fruit bunches (EFB) are produced in large quantities throughout the year and during the replanting process.

The by-products of oil palm are not efficiently utilised and have also caused problems to the environment. Malaysia has vast resources of such plant fibres that are currently under utilised. Therefore, the economic utilisation of these fibres will be beneficial (Abdul Khalil and Rozman, 2004). The chemical composition of EFB is given in *Table 1*. In a palm oil mill, besides palm oil and palm kernel, large quantities of liquid waste commonly known as palm oil mill effluent (POME) are generated. POME, when fresh, is a thick brownish

TABLE 1. COMPOSITION OF EMPTY FRUIT BUNCH (EFB)

Parameter	Dry matter basis		Fresh wt. basis* (mean)
	Range	Mean	
Ash (%)	4.8-8.7	6.3	2.52
Oil (%)	8.1-9.4	8.9	3.56
C (%)	42.0-43.0	42.8	17.12
N (%)	0.65-0.94	0.80	0.32
P_2O_5 (%)	0.18-0.27	0.22	0.09
K_2O (%)	2.0-3.9	2.90	1.16
MgO (%)	0.25-0.40	0.30	0.12
CaO (%)	0.15-0.48	0.25	0.10
B (mg litre^{-1})	9-11	10	4
Cu (mg litre^{-1})	22-25	23	9
Zn (mg litre-$^{-1}$)	49-55	51	20
Fe (mg litre^{-1})	310-595	473	189
Mn (mg litre^{-1})	26-71	48	19
C/N ratio	45-64	54	54

Note: * Moisture content 60%-65%.
Source: Gurmit Singh *et al*. (1990).

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colloidal slurry of water, oil and fine cellulosic fruit residues. It is hot (80ºC-90ºC) and acidic (pH 4-5). It is characterised by a very high biological oxygen demand (BOD), which is 100 times that of domestic sewage. The suspended solids in the POME are mainly cellulosic material from the fruits. N, P, K, Mg and Ca which are essential nutrient elements for plant growth present in POME (*Table 2*) (Ma, 2009).

The traditional disposal methods such as open dumping and/or land filling of these materials are not only increasingly expensive, but are also impractical, as open space becomes limited. Low input eco-friendly technologies have been developed in recent years to manage industrial waste resources. A large amount of plant nutrients are contained in some agro-industrial wastes. By converting the waste to a resource, these materials can be utilised efficiently as a soil conditioner for sustainable soil fertility management (Suthar, 2007).

Biofertilizers can be produced from the vermiconversion of urban, industrial and agro-industrial wastes using earthworms (Elvira *et al*., 1998; Gupta and Garg, 2008; Suthar, 2006). A large number of organic wastes can be ingested by earthworms and egested as a peat like material termed as vermicast. It is much more fragmented, porous and microbially active than the parent material (Edwards *et al*., 1998; Edwards and Bohlen, 1996) due to humification and increased decomposition. Kaushik and Garg (2003; 2004) have reported the vermicomposting of textile mill sludge using *E. fetida*. Butt (1993) showed that solid paper mill sludge was a suitable feed for *Lumbricus terrestis* under laboratory conditions. Elvira *et al*. (1998) have reported the vermicomposting of paper mill sludge using *Eisenia andrei* under laboratory as well as field conditions.

The objective of this study was, to determine the feasibility of vermicomposting to stabilise the EFB mixed with POME solid in different ratios using earthworms *E. fetida*. The level of metals in the end products were also monitored so that the value of the vermicompost as an environmentally safe product could be determined.

TABLE 2. CHARACTERISTICS OF PALM OIL MILL EFFLUENT (POME)

pH	4.7
Phosphorus	180
Potassium	2 270
Magnesium	615
Calcium	439
Boron	7.6
Iron	46.5
Manganese	2.0
Nitrogen	750
Copper	0.89
Zinc	2.3

Note: All parameters in mg litre^{-1} except pH.
BOD_3 - after incubation for three days at 30ºC.
Source: Ma (2000).

MATERIALS AND METHODS

Eisenia fetida

Healthy unclitellated hatchlings weighing 100-160 mg live weight were randomly picked up for the experiment from a local worm breeder, AZR Agro Resources Sdn Bhd in Olak Lempit, Banting, Selangor. This species of earthworm was selected based on its tolerance to a wide range of temperature and a high metabolic rate.

Empty Fruit Bunch (EFB) and Palm Oil Mill Effluent

A fibre samples of EFB were shredded and refined into loose fibrous material (length ≈ 3.68 mm, width ≈ 165.45 μm) using a thermo mechanical refiner (Andritz) at the MPOB pilot plant (*Figure 2*). The EFB fibres were collected from the Tian Siang Oil Mill (Perak) Sdn Bhd. POME solid was obtained from the wastewater treatment plant of MPOB's Palm Oil Mill Technology Centre, located at Labu, Negeri Sembilan.

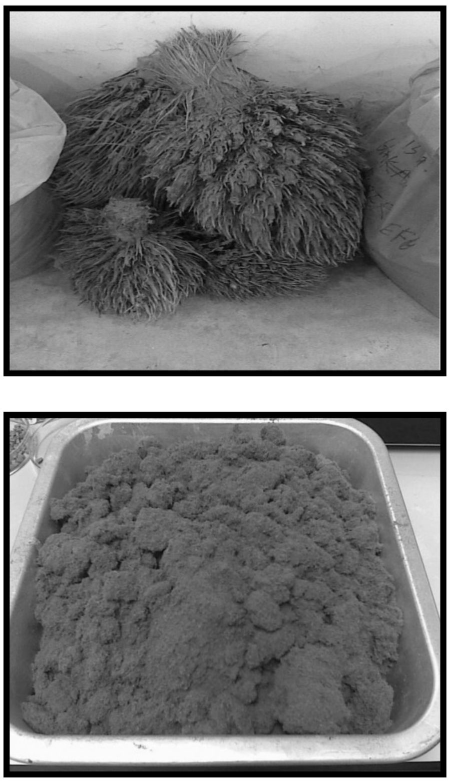

Figure 2. Fibre sample of empty fruit bunches (EFB) before and after shredded and refined into loose fibrous material.

Experimental Set-up

Six vermicomposting units (vermicomposters) were established having different content of EFB and POME. The 80 g of each feed mixture were filled in 1.2 litres rectangular plastic containers (length 14 cm, width 12 cm, height 7 cm). The vermicomposters in different compositions of feed are shown in *Table 3*. After 15 days of pre-composting, 5 g unclitellated *E. fetida* were released into each rectangular plastic container containing substrate material. The moisture level of the substrates was maintained around 80 ± 10%, throughout the study period by periodic sprinkling with distilled water. All the vermicomposters were placed in a dark room with a temperature of 25 ± 3ºC. Each vermicomposter was established in triplicate.

Physico-chemical Analysis of Vermicompost

Homogenised samples of all feed mixtures were drawn at 0, 7, 14, 21, 28, 35, 42, 49, 56, 63, 70, 77 and 84 days. The 0 day refers to the day of inoculation of earthworms after pre-composting of 15 days. The physico-chemical analysis was done on a dry weight basis. Double distilled water was used for analytical work. All the samples were analysed in triplicate and results were averaged. The pH was determined by pH meter Cyberscan 510 using double distilled water suspension of each mixture in ratio of 1:10 (w/v).

Total organic carbon (TOC) was measured using the method of Nelson and Sommers (1982), total Kjeldhal nitrogen (TKN) was determined by digesting the samples with conc. H_2SO_4 and $HClO_4$ (9:1, v/v) by Bremner and Mulvaney (1982) procedure. Total available phosphate was analysed using the spectrophotometric method with molybdenum in sulphuric acid. Total potassium (TK) and total calcium (TCa) were determined by flame photometer after digesting the sample in diacid mixture (conc. HNO_3; conc. $HClO_4$, 4:1, v/v) (Pansu *et al*., 2001). Total heavy metals were determined by atomic absorption spectrophotometer (AAS) after digesting the samples with conc. HNO_3 and conc. $HClO_4$ (4:1, v/v) (Pansu *et al*., 2001).

Statistical Analysis

The results obtained were analysed by ANOVA using the Statgraphics v. 5.0 software packages (Statistical Graphics Corporation, 1991) and considering the treatment as the independent variable. The means were separated by the Tukey's test, considering a significance level of $p < 0.05$ throughout the study.

RESULTS AND DISCUSSION

C/N Ratio of the Vermifertiliser

As evident from *Table 4*, C/N ratios decreased with time in the entire worm worked vermicomposters. The C/N ratio was lower in those feed mixtures (V_2, V_3, V_4, V_5 and V_6) which had POME compared to pure EFB feed (V_1). In this study, the maximum reduction in C/N ratio was in V_5 (87.4% of initial

TABLE 3. COMPOSITION OF TREATMENTS

Vermicomposter	Composition of feed (%)	Empty fruit bunch (EFB) (g)	Palm oil mill effluent (POME) (g)
V1	EFB (100)	80	0
V2	EFB (90) + POME (10)	72	8
V3	EFB (80) + POME (20)	64	16
V4	EFB (70) + POME (30)	56	24
V5	EFB (60) + POME (40)	48	32
V6	EFB (50) + POME (50)	40	40

TABLE 4. VARIATION IN C/N RATIO DURING VERMICOMPOSTING OF THE VERMIFERTILISER (mean ± S.E, n= 3)

Vermicomposter	C/N ratio					
	0 Day	15 Days	30 Days	45 Days	60 Days	84 Days
V1	178.1±0.5	165.1±0.3	125.2±2.8	100.6±4.8	75.9±0.3	54.0±0.4
V2	114.5±1.5	88.5±1.3	79.6±0.5	66.5±0.7	44.5±1.2	20.1±0.2
V3	153.3±0.2	94.8±0.9	65.0±0.4	54.0±0.2	32.6±0.2	19.5±0.8
V4	73.1±0.3	56.8±1.2	46.1±1	36.9±0.3	18.4±4.5	12.1±0.5
V5	123.1±1.5	79.3±0.1	61.6±0.1	51.5±0.2	20.9±3.7	15.5±0.7
V6	38.6±0.3	28.2±0.4	22.4±1.1	20.6±1.6	17.0±2.8	10.5±0.1

value) followed by V_3 (87.3%), V_4 (83.4%), V_2 (82.5%), V_6 (72.8%) and V_1 (69.7%). The C/N ratio is used as an index for the maturity of organic wastes as well as a very important parameter because plants cannot assimilate N unless the ratio is in the order of 20 or less (Edwards and Bohlen, 1996). Furthermore, the decline in C/N ratio to less than 20 indicates an advanced degree of organic matter stabilisation and reflects a satisfactory degree of maturity of organic wastes (Senesi, 1989). So, in the present study, a high degree of organic matter stabilisation was achieved in all the reactors. The decrease in C/N ratio over time might also be attributed to the increase in the earthworm population (Ngedwa and Thompson, 2000), which led to rapid decrease in organic carbon due to enhanced oxidation of the organic matter. The release of part of the carbon as carbon dioxide (CO_2) in the process of respiration, production of mucus and N excrements, increases the level of N and lowers the C/N ratio (Senapati *et al*., 1980).

Fertiliser Quality of the Vermicompost

Table 5 shows that the pH values increased gradually during vermicomposting process and remained in the range 7.9-8.5. The increase in pH value might be due to an increase in ammonia generated by the biochemical reactions of nitrogen-containing materials. An addition of partially treated POME to enrich the EFB compost may also contribute to the slightly alkaline condition. Sundberg *et al*. (2004) reported that for fully developed vermicomposting, the pH often rises to 8-9. Ngedwa and Thompson (2000) reported that different substrates could result in the production of different intermediate species and different feed substrates show a different behaviour in pH shift. It is concluded that the shifting in pH could be attributed to microbial decomposition during the process of vermicomposting. Gunadi and Edwards (2003) reported that the pH of feed could be the limiting factor for the survival and growth of *E. fetida*. Mitchell (1997) reported that *E. fetida* was unable to survive in the cattle solids with pH of 9.5.

There was an increase in the TKN in all vermicomposters *(Table 5*). The TKN content was 1.33, 1.20, 1.40, 1.60, 1.67 and 1.42 times the initial content in vermicomposters No. 1 to 6, respectively. The maximum increase was in V_5 (66.7%) where the initial TKN concentration was 0.6 ± 3x10^{-3} mg kg^{-1} and the final concentration was 1.0 ± 9x10^{-2} mg kg^{-1} followed by V_4 (60.0%), V_6 (41.7%), V_3 (40.0%), V_1 (33.3%) and V_2 (20.0%) (*Table 5*). The difference in the TKN contents of the vermicomposts obtained from different vermicomposters was statistically significant ($p<0.05$). The TKN concentration during the vermicomposting process was in the order: $V_5 > V_4 > V_6 > V_3 > V_1 > V_2$. The increase in TKN content was higher in feed mixture rather than pure feed. According to Viel *et al*. (1987) losses in organic carbon might be responsible for nitrogen increase. It is suggested that in addition to releasing N from compost material, earthworms also enhance nitrogen levels by adding their excretory products, mucus, body fluid, enzymes, *etc*. to the substrate. Suthar (2006) suggested that decaying tissues of

TABLE 5. PHYSICO-CHEMICAL CHARACTERISTICS OF INITIAL FEEDS AND VERMICOMPOSTS OBTAINED FROM DIFFERENT RATIO OF EMPTY FRUIT BUNCH (EFB) + PALM OIL MILL EFFLUENT (POME) FEED MIXTURES

Feed mixtures	pH	TKN	TP	TK
Initial physico-chemical characteristics of initial feed mixtures[a]				
V_1	5.9 ± 0.1	0.3 ± 2x10^{-3}	0.1 ± 1x10^{-3}	3x10^{-2} ± 1x10^{-3}
V_2	6.6 ± 0.2	0.5 ± 1x10^{-3}	0.2 ± 8x10^{-3}	3x10^{-2} ± 1x10^{-3}
V_3	5.5 ± 0.3	0.5 ± 4x10^{-3}	0.2 ± 6x10^{-3}	5x10^{-2} ± 1x10^{-3}
V_4	6.3 ± 0.2	0.5 ± 4x10^{-3}	0.2 ± 1x10^{-3}	6x10^{-2} ± 1x10^{-3}
V_5	6.3 ± 0.1	0.6 ± 3x10^{-3}	0.3 ± 1x10^{-3}	7x10^{-2} ± 1x10^{-3}
V_6	6.3 ± 0.2	1.2 ± 6x10^{-3}	0.3 ± 3x10^{-3}	9x10^{-2} ± 1x10^{-3}
Physico-chemical characteristics of final vermicomposts obtained from different vermicompostersb (mean ± S.E., n=3)				
V_1	7.9 ± 0.2	0.4 ± 6x10^{-3}	0.2 ± 2x10^{-3}	6x10^{-2} ± 8x10^{-3}
V_2	8.1 ± 6x10^{-2}	0.6 ± 2x10^{-3}	0.4 ± 3x10^{-3}	7x10^{-2} ± 1x10^{-3}
V_3	8.1 ± 0.1	0.7 ± 9x10^{-3}	0.7 ± 4x10^{-3}	0.13 ± 1x10^{-3}
V_4	8.5 ± 0.2	0.8 ± 5x10^{-3}	0.8 ± 8x10^{-2}	0.2 ± 2x10^{-3}
V_5	8.3 ± 0.1	1.0± 9x10^{-2}	0.9 ± 8x10^{-2}	0.23 ± 2x10^{-3}
V_6	8.2 ± 0.2	1.7 ± 5x10^{-2}	1.4 ± 5x10^{-2}	0.5 ± 4x10^{-3}

Note: [a] Initial physico-chemical characteristics of the feed in the vermicomposters have been calculated based upon the percentage of the EFB and POME.
[b] Mean value followed by different letters is statistically different (ANOVA; Tukey's test, $P< 0.05$). Units of all the parameters, mg kg^{-1} except pH value.

dead worms also add a significant amount of N to the vermicomposting sub-system. In general, nitrogen enrichment patterns and mineralisation activities mainly depend upon the total amount of N in the initial waste material (*e.g*. sludge) and on the earthworm activity in the waste decomposition sub-system (Kale, 1998; Suthar, 2007). It is also suggested that the differences in N content in the end product (vermicompost) could be related to the availability of metals in vermibeds, which directly affect the N mineralisation rate. Recently, Suthar (2008) demonstrated a significant impact of high metal contents on the mineralisation rate during the vermicomposting of sewage sludge.

The available phosporus content was significantly higher in feed mixture than pure feed (t-test: $p<0.01$, for all treatments). The highest increase for TP concentration occurred in V_6 where the initial TP concentration was $0.3 \pm 3x10^{-3}$ mg kg^{-1} and final concentration was $1.4 \pm 5x10^{-2}$ mg kg^{-1}. This shows an increase of four times the initial concentration. The lowest increase occurred in V_1 where the initial TP concentration was $0.1 \pm 1x10^{-3}$ mg kg^{-1} and final concentration was $0.2 \pm 2 x10^{-3}$ mg kg^{-1}. This shows a doubling of the initial concentration (*Table 5*). The mineralisation rate for TP content during the vermicomposting process was in the order: $V_6 > V_5 > V_4 > V_3 > V_2 > V_1$. Studies have revealed that during vermicomposting the release of available TP content from organic waste is performed partly by earthworm gut phosphatases, and further release of TP might be attributed to the P-solubilising microorganisms present in worm casts. TP mineralisation increased with increasing proportion of POME in the vermicomposters.

TK content in the end material was higher than the initial contents (Suthar and Singh, 2008) (*Table 5*). The highest increase for TK occurred in V_6 where the initial TK concentration was $9x10^{-2} \pm 1x10^{-3}$ mg kg^{-1} and final concentration was $0.5 \pm 4x10^{-3}$ mg kg^{-1}. This shows an increase by a factor of five times the initial value. The lowest increase occurred in V_1 where the initial TK concentration was $3x10^{-2} \pm 1x10^{-2}$ mg kg^{-1} and final concentration was $0.06 \pm 8x10^{-3}$ mg kg^{-1} which was two times the initial concentration. However, when organic waste passes through the gut of the worms, the nutrients are converted from unavailable forms to available forms, which consequently enrich the worm cast with higher quality plant nutrients (Suthar and Singh, 2008). Similarly, Delgado *et al*. (1995) have reported higher TK content in vermicomposts prepared using sewage sludge as feed mixture. In addition, Suthar (2007) suggested that earthworm processed waste material contains higher concentration of exchangeable K due to enhanced microbial activity during the vermicomposting process.

Heavy Metal Concentrations in Final Vermicomposts

The total metal contents in vermicomposted material are shown in *Table 6*. The heavy metals' (Cu, Fe, Zn and Mn) content was higher in the feed mixture than the pure feed. The Cu content in the final vermicompost was 2.33, 2.56, 4.28,

TABLE 6. HEAVY METAL CONTENT (mg kg^{-1}) IN INITIAL FEED SUBSTRATES AND VERMICOMPOSTS OBTAINED FROM EMPTY FRUIT BUNCH (EFB) + PALM OIL MILL EFFLUENT (POME) VERMICOMPOSTERS

Feed mixtures	Cu	Fe	Zn	Mn
Heavy metal content in initial feed mixtures[a]				
V_1	$3x10^{-2} \pm 3x10^{-3}$	$1.6 \pm 1x10^{-3}$	$0.56 \pm 2x10^{-2}$	1.3 ± 0.1
V_2	$0.18 \pm 2x10^{-3}$	18.2 ± 2.3	0.59 ± 0.1^{-2}	1.5 ± 0.2
V_3	$0.18 \pm 6x10^{-2}$	23.9 ± 0.1	$0.79 \pm 1x10^{-2}$	2.1 ± 0.3
V_4	$0.19 \pm 1x10^{-2}$	23.6 ± 0.6	$0.78 \pm 2x10^{-2}$	2.3 ± 0.3
V_5	$0.3 \pm 8x10^{-3}$	25.6 ± 1.2	$0.8 \pm 2x10^{-2}$	2.5 ± 0.1
V_6	$0.4 \pm 2x10^{-3}$	23.9 ± 1	$1.1 \pm 8x10^{-2}$	2.6 ± 0.3
Heavy metal content in final vermicomposts obtained from different vermicomposters[b] **(mean ± S.E., n=3)**				
V_1	$7x10^{-2} \pm 4x10^{-3}$	2.8 ± 1.4	$0.7 \pm 2x10^{-2}$	2.0 ± 0.5
V_2	$0.46 \pm 3x10^{-2}$	27.2 ± 1	$1.4 \pm 3x10^{-2}$	2.8 ± 0.9
V_3	$0.77 \pm 5x10^{-2}$	27.9 ± 1.9	$1.7 \pm 4x10^{-2}$	3.6 ± 0.6
V_4	$0.8 \pm 2x10^{-2}$	28.7 ± 0.9	$1.8 \pm 6x10^{-2}$	4.1 ± 0.5
V_5	$0.82 \pm 2x10^{-2}$	29.5 ± 0.8	$2.0 \pm 4x10^{-2}$	4.8 ± 0.4
V_6	$1 \pm 3x10^{-2}$	29.8 ± 1	$2.1 \pm 4x10^{-2}$	5.4 ± 1.6

Note: [a] Initial physico-chemical characteristics of the feed in the vermicomposters have been calculated based upon the percentage of the EFB and POME.
[b] Mean value followed by different letters is statistically different (ANOVA; Tukey's test, $P< 0.05$). Units of all the parameters, mg kg^{-1}.

4.21, 3.28 and 2.40 times the initial content in vermicomposters No. 1 to 6, respectively. The initial Fe content in different ratios of feed was in the range (0.6 ± 1 mg kg^{-1}) to (23.9 ± 1 mg kg^{-1}). The Fe content in the final vermicompost was 1.75, 1.49, 1.16, 1.21, 1.14 and 1.25 times the initial content in vermicomposters No. 1 to 6, respectively. The maximum increase was in V_1 (75%) followed by V_2 (49.5%), V_6 (24.7%), V_4 (21.6%), V_3 (16.7%) and V_5 (15.23%).

The initial Zn content in different ratios of feed was in the range (0.56 ± 2x10^{-2} mg kg^{-1}) to (1.1 ± 8x10^{-2} mg kg^{-1}). Final Zn concentrations in all vermicomposter were in the range (0.7 ± 2x10^{-2} mg kg^{-1}) to (2.1 ± 4x10^{-2} mg kg^{-1}). The highest increase for Zn concentration occurred in V_5 where the initial Zn concentration was 0.8 ± 2x10^{-2} mg kg^{-1} and final concentration was 2 ± 4x10^{-2} mg kg^{-1}. This shows an increase to 2.42 times the initial value. The smallest increase for Zn concentration was V_1 where the initial Zn concentration was 0.56 ± 2x10^{-2} mg kg^{-1} and final concentration was 0.7 ± 2x10^{-2} mg kg^{-1}. The pattern of Zn increase was recorded in the order: $V_5 > V_2 > V_4 > V_3 > V_6 > V_1$.

The initial Mn content in different ratios of feed was in the range (1.3±0.1 mg kg^{-1}) to (2.6±0.3 mg kg^{-1}). Final Mn concentrations in the vermicomposters were in the range (2 ± 0.5 mg kg^{-1}) to (5.4 ± 1.6 mg kg^{-1}). The Mn content was 1.59, 1.89, 1.67, 1.76, 1.91 and 2.03 times the initial content in vermicomposters No. 1 to 6, respectively. The pattern of Mn increase was recorded in the order: V_6 (107.7%) > V_5 (92%) > V_2 (86.7%) > V_4 (78.3%) > V_3 (71.4%) > V_1 (53.8%).

The increasing presence of heavy metals in organic waste, which may accumulate in earthworms, could pose a problem if worm fecundity is a consideration (Flechenstein and Graff, 1983). Elvira *et al*. (1998) have reported an increase in heavy metal content in the vermicompost of paper-pulp mill sludge. Malley *et al*. (2006) have reported that copper accumulation occurs within the worm tissues. Deolaliker *et al*. (2005) suggested that weight and volume reduction due to breakdown of organic matter during vermicomposting may be the reason for the increase in heavy metal concentrations in vermicompost. The vermicompost made from oil palm wastes may have higher heavy metal concentrations. In small amounts, many of these elements may be essential for plant growth. However, in higher concentrations they are likely to have detrimental effects upon plant growth (Whittle and Dyson, 2002). So, prior to vermicompost application to the soils, there is a need to determine the heavy metal concentrations in the final vermicomposts.

Similarly, Hartenstein and Hartenstein (1981) have attributed the greater increase in heavy metal in the castings, as opposed to in the sludge without earthworms, to the mineralisation process that earthworms accelerate during sludge decomposition and stabilisation. While considering the risks associated with heavy metal contamination in soils for Cu, Fe and Zn, it was found that the concentrations of heavy metals in the final vermicompost (*Table 6*) obtained from the vermicomposters containing up to 50% composition of POME with EFB were within the limits set for standard composts.

CONCLUSION

Industrial sludge should not be treated as waste material because it has great agronomic potential. In this study, the vermicomposting of EFB with POME, using *E. fetida* has been examined for its suitability for producing a value-added product, *i.e.* vermicompost. The EFB, when mixed with POME was a good growth media for earthworms. The mixing of up to 50% POME in EFB could accelerate the mineralisation of nutrients. From the study, we can conclude that V_6 (50% EFB + 50% POME) showed the best ratio in highest value of TKN, TP and TK. The maximum reduction in C/N ratio was obtained in V_5 (87.4% of initial value). From this study, we can conclude that of the six compositions studied, the best ratio for vermicomposting of EFB with additional POME is V_6 (50% EFB + 50% POME). The vermicomposting process showed a demonstrable impact on total metal concentration of sludge. The increased values of heavy metals in all vermicomposters indicate that earthworms can accumulate a considerable amount of metals in their tissues because no mortality was observed. This study suggested that palm oil sludge could be utilised as an efficient soil conditioner for sustainable land practices, after processing by composting earthworms.

REFERENCES

ABDUL KHALIL, H P S and ROZMAN, H D (2004). *Gentian dan Komposit Lignoselulosik* (Othman, S ed.). Universiti Sains Malaysia Publisher. p. 15-40.

BUTT, K R (1993). Utilisation of solid paper mill sludge and spent brewery yeast as a feed for soil-dwelling earthworms. *Bioresour. Technol., 44*: 105-107.

BREMNER, J M and MULVANEY, R G (1982). Nitrogen total. *Method of Soil Analysis* (Miller, R H and Keeney, D R eds.). American Society of Agronomy, Madison, p. 575-624.

DELGADO, M; BIGERIEGO, M; WALTER, I and CALBO, R (1995). Use of California red worm in sewage sludge transformation. *Turrialba*. p. 33-41.

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.

EDWARDS, C A and BOHLEN, P J (1996). *Biology and Ecology of Earthworm*. Third ed. Chapman and Hall, New York.

EDWARDS, C A (1988). Breakdown of animal, vegetable and industrial organic wastes by earthworm. *Earthworms in Waste and Environmental Management* (Edwards, C A and Neuhauser, E F eds.). SPB, The Hague, p. 21-31.

ELVIRA, C; SAMPEDRO, L; BENITEZ, E and NOGALES, R (1998). Vermicomposting of sludges from paper mill and dairy industries with *Eisenia andrei*: a pilot scale study. *Bioresource Technology, 63*: 205-211.

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.

GUPTA, R and GARG, V K (2008). Stabilisation of primary sewage sludge during vermicomposting. *J. Hazard. Mater., 153*: 1023-1030.

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.

GURMIT SINGH; MANOHARAN, S and TOH, T S (1990). United Plantation's approach to palm oil mill by-product management and utilization. *Proc. of the 1989 International Palm Oil Development Conference - Agriculture (Module II)* (Jalani, B S; Zin Zawawi, Z; Paranjothy, K; Ariffin, D; Rajanaidu, N; Cheah, S C; Mohd Basri, W and Henson, I E eds.). PORIM, Bangi. p. 225-234.

HARTENSTEIN, R and HARTENSTEIN, F (1981). Physicochemical changes effected in activated sludge by the earthworm *Eisenia foetida. J. Environ. Qual., 10*: 372-376.

KAUSHIK, P and GARG, V K (2003). Vermicomposting of mixed solid textile mill sludge and cow dung with epigeic earthworm *Eisenia foetida. Bioresourse Technology, 90*: 311-316.

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. *Bioresource Technology, 94*: 203-209.

KALE, R D (1998). Earthworm ecology. earthworms: nature's gift for utilisation of organic wastes. *Earthworm Ecology* (Edwards, C A ed.). Soil and Water Conservation Society, New York. p. 355-363.

MA, A N (2000). Management of palm oil industrial effluents. *Advances in Oil Palm Research* (Yusof Basiron; Jalani, B S and Chan, K W eds.). Volume II. MPOB, Bangi. p. 1440.

MA, A N (2009). Sustainable production of palm oil: a Malaysian perspective. *Treatment of Palm Oil Mill Effluent* (Singh, G; Lim, K H; Teo Leng and Chan, K W eds.). Malaysia Palm Oil Association. p. 235-237.

MALLEY, C; NAIR, J and HO, G (2006). Impact of heavy metals on enzymatic activity of substrate and on composting worms *Eisenia foetida. Bioresource Technology, 97*: 1498-1502.

MITCHELL, A (1997). Production of *Eisenia foetida* and vermicompost from feedlot cattle manure. *Soil Biol. Biochem., 29*: 763-766.

NDEGWA, P M and THOMPSON, S A (2000). Integrating composting and vermicomposting, the treatment and bioconversion of biosolids. *Bioresource Technology, 76*: 107-112.

NELSON, D W and SOMMERS, L E (1982). Total carbon and organic carbon. *Methods of Soil Analysis, Part 2. Agronomy* (Miller, R H and Keeney, D R eds.). Amer. Soc. Agron. Inc., Madison, W.I. p. 539-579.

PANSU, M; GAUTHEYROU, J and LOYER, J Y (2001). *Soil Analysis*. Taylor and Francis, London, UK.

STATISTICAL GRAPHICS CORPORATION (1991). *Statgraphics 5.0. Statistical Graphics System*. Educational Institution Edition, USA. p. 105.

SENAPATI, B K; DASH, M C; RANE, A K and PANDA, B K (1980). Observation on the effect of earthworms in the decomposition process in soil under laboratory conditions. *Comp. Physiol. Ecol., 5*: 140-142.

SENESI, N (1989). Composted materials as organic fertilizers. *Sci. Total Environ., 81/82*: 521-524.

SUNDBERG, C; SMARS, S and JONSSON (2004). Low pH as an inhibiting factor in the transition from mesophilic to thermophilic phase in composting. *Bioresource Technology, 95*: 145-150.

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 and SINGH, S (2008). Feasibility of vermicomposting in biostabilisation of sludge from a distillery industry. *Science of the Total Environment, 394*: 237-243.

SUTHAR, S (2006). Potential utilisation of guar gum industrial waste in vermicompost production. *Bioresource Technology, 97*: 2474-2477.

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

VIEL, M; SAYAG, D and ANDRE, L (1987). Optimisation of agricultural, industrial waste management through in-vessel composting. *Compost: Production, Quality and Use* (de Bertoldi, M ed.). Elsevier Appl. Sci., Essex. p. 230-237.

WHITTLE, A J and DYSON, A J (2002). The fate of heavy metals in green waste composting. *The Environmentalis, 22*: 13-21.

YUSOF, B (2000). Utilisation of oil palm biomass: strategic progress report. *Utilisation of Oil Palm Tree. Symposium of Oil Palm Biomass: Opportunities and Challenges in Commercial Exploitation.*