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Physico-chemical Changes During Co-composting of Chipped-ground Oil Palm Frond and Palm Oil Mill Effluent

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ABSTRACT

The aim of this study was to investigate the physico-chemical changes during co-composting of chipped-ground oil palm frond (CG-OPF) and palm oil mill effluent (POME). Results showed that co-composting of CG-OPF and POME was completed within 60 days with average C:N ratio of 23. Temperature of the compost observed in thermophilic phase was at 53.5°C after four days of composting (DOC). The highest temperature observed during thermophilic phase was 56°C at 21 DOC. The oxygen level, moisture content and pH of the compost were maintained at 1.7%-12.2%, 60.6%-70.7% and 7.9-8.5, respectively, throughout the 60 DOC. The total bacteria count observed was 55 x 10^{10} cfu ml^{-1} at the initial stage and decreased to 14.7 x 1010 cfu ml^{-1} on 25^{th} DOC and 3.7 x 10^{10} cfu ml^{-1} on 60^{th} DOC. The C:N ratio observed was 63.9 at the initial stage and decreased to 24 on 60^{th} DOC.

ABSTRAK

Kajian ini bertujuan adalah untuk mengenalpasti perubahan fiziko-kimia semasa proses kompos dijalankan menggunakan pelepah sawit keping terkisar (CG-OPF) dan enapcemar kilang sawit (POME). Hasil kajian mendapati proses kompos menggunakan CG-OPF dan POME ini telah dijalankan sepenuhnya selama 60 hari dengan purata nisbah karbon:nitrogen pada paras 23. Suhu kompos yang dicatatkan pada fasa termofilik ialah 53.5°C selepas empat hari proses kompos dijalankan. Suhu tertinggi yang dicerap semasa fasa termofilik ialah 56°C selepas 21 hari proses kompos dijalankan. Paras oksigen, kandungan lembapan dan pH kompos pelepah sawit keping terkisar yang dicerap ialah masing-masing, 1.7%-12.2%, 60.6%-70.7% dan 7.9-8.5, sepanjang 60 hari proses kompos. Jumlah kiraan bakteria yang dicerap ialah 55 x 10^{10} cfu ml^{-1} pada hari permulaan dan menurun kepada 14.7 x 10^{10} cfu ml^{-1} pada hari ke-25 proses kompos dan seterusnya, 3.7 x 10^{10} cfu ml^{-1} pada hari ke-60 proses kompos. Nisbah karbon:nitrogen yang dicatat ialah 63.9 pada hari permulaan dan menurun kepada 24 pada 60 hari proses kompos.

Keywords: chipped-ground oil palm frond (CG-OPF), palm oil mill effluent (POME), composting.

INTRODUCTION

Malaysia is one of the largest palm oil producers, and it was estimated that around 100.4 million tonnes of fresh fruit bunch (FFB) was processed in 2013 (MPOB, 2013). The oil palm industry is the major agriculture-related industry in Malaysia, and it produced around 19.2 million tonnes of crude palm oil from 5.23 million hectares of land in 2013 (MPOB, 2013). Due to a big demand for palm oil in food and oleochemical industries, the production of palm oil is expected to increase rapidly. The oil palm fronds (OPF) is a by-product available during oil palm pruning and harvesting at about 45.49 million tonnes per year (MPOB, 2011).

The OPF dry matters during oil palm replanting and pruning were estimated at about 14.47 t ha^{-1} and 10.40 t ha^{-1}, respectively (Astimar and Basri, 2006; Najib *et al*., 2011; MPOB, 2011). In the current practice, all of this biomass is not being treated, but instead being left to rot in the plantations to provide some nutrients. This massive amount of OPF should be treated to hasten decomposition and to get a higher value-added product. Moreover, a growing awareness on the green environment has encouraged this industry to look more closely at the milling operation. Composting is a method that is increasingly used for treatment of organic waste (Kabbashi *et al*., 2006). Palm oil mill effluent

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(POME), which has a high nitrogen content and a high population of effective microbes, can be used for co-composting with OPF.

According to Baharuddin *et al*. (2009a), composting is considered as one of the best methods to convert organic wastes into beneficial products for plant growth. The major goal of composting is to provide a stable product that consists of high nutrients, as fertiliser as well as efficient soil conditioner. Although considerable research on composting of empty fruit bunch (EFB), mesocarp fibre and various organic wastes has been conducted (Baharuddin *et al*., 2009a; Lim *et al*., 2009), little information on physico-chemical characteristics during co-composting of chipped-ground oil palm frond (CG-OPF) and POME was published, especially in pilot scale operation. Due to the abundance of OPF during harvesting and replanting, it is crucial to find an alternative method for the disposal of OPF, instead of leaving them to rot in the plantations. In this article, composting methods have been suggested for the utilisation of OPF in the plantation, and the treatment was accomplished by the addition of POME.

The aim of this study is to investigate the physico-chemical characteristics during co-composting of CG-OPF and POME.

MATERIALS AND METHODS

Pilot Scale Composting Site

The co-composting of OPF-POME was performed in windrow semi-open system, inside a brick blocks. The composting material was located inside a brick blocks (2.1 m length, 1.5 m width and 1.5 m height). The experimental work was carried out under shade and inside the brick blocks on cement base at composting site of the Department of Bioprocess Technology, Universiti Putra Malaysia, Serdang, Selangor.

Raw Materials

About 1000 kg of fresh OPF were collected from the oil palm estate at the Malaysian Palm Oil Board (MPOB)-Universiti Kebangsaan Malaysia (UKM) in Bangi, Selangor. The OPF were chipped into slices with an average width of 2-3 cm using a chipper machine at the Biomass Pilot Plant, Agro Product Unit, MPOB-UKM. The chipped fronds were placed and segregated on the cement floor for drying. Then, the dried chipped fronds were further ground using a hammer-mill machine at the Biomass Pilot Plant to reduce to a smaller size with length of 0.2-0.5 cm. The CG-OPF was used for the co-composting process.

POME anaerobic sludge was obtained from 500 m^3 closed anaerobic digesting tank system, located at FELDA Serting Hilir Palm Oil Mill, Negeri Sembilan. The thick POME anaerobic sludge from the settling tank was used in the present study (Najib *et al*., 2011). Only the thick POME was taken from the settling tank within the sludge recycling system as recommended by Yacob *et al*. (2006). About 2000 litres of POME was transported to the composting site.

Co-composting Process

One tonne of the CG-OPF was loaded manually into the brick block. POME, 50 litres, containing beneficial microorganisms for co-composting was sprayed using a centrifugal pump to the composting pile at every three-day interval, to maintain the optimum moisture content, within the range of 55% to 65%. After adding POME, the composting material was turned manually for mixing in order to aerate the system, to maintain the optimum moisture content as well as to control the generated heat produced during composting. During the curing stage, which was about a week before harvesting, addition of POME was stopped and the material was turned frequently in order to obtain a final compost product with a good texture and size. Throughout the composting period, the composting material was covered at the middle of the heap using 1 m x 1 m hard plastic to avoid drastic fluctuation in humidity and temperature during the process. The composting cycle was completed within 40-60 days, depending on the maturity of the composting material based on C:N ratio.

Sampling and Analysis Method

Oxygen and temperature were analysed using a digital temperature-oxygen probe meter, Demista Instrument, (CM2006, USA). Moisture and pH were analysed using a moisture analyser, (MX-50, USA) and a pH meter, (DELTA 320, Mettler Toledo, USA), respectively. These analyses were performed throughout the composting process. CHNS 2000 analyser (Leeco, USA) and Inductively Coupled Plasma (ICP)-OES, (Perkin Elmer, USA) were used to analyse carbon, nitrogen, nutrients and heavy metal elements in the composting material. The total colony forming unit (CFU) of microbes was determined by serial dilution methods on nutrient agar plates. The plates were incubated at 30°C for 48 hr and the bacteria colonies were counted and expressed in CFU ml^{-1}.

The analysis of oil-grease on POME was carried out according to the APHA (1998) method as reported by Baharuddin *et al*. (2009a). Biological oxygen demand (BOD) and chemical oxygen demand (COD) were determined by using standard method APHA (2005) (Najib *et al*., 2011). Cellulose, hemicelluloses, and lignin content in OPF were determined using acid detergent fibre (ADF), acid detergent lignin (ADL), and neutral detergent fibre (NDF) analysis (Goering and Van Soest, 1970; Najib *et al*., 2011). Proximate analysis was performed to analyse ash and crude protein in OPF according to APHA (2005) standard method using Fibertec I & M Systems (USA).

RESULTS AND DISCUSSION

Characteristic of Raw Materials and Final Compost

Physical changes such as colour and texture of the composts were observed during the composting (*Figure 1*). The final compost was blackish, with soil texture and earthy smell. The analysis results shown in *Table 1* reveal that raw OPF has high cellulose content (37.9%), high fibre content (46%), lignin (8.1%) and carbon (42.1%). The raw CG-OPF has low nutrients content such as potassium, phosphorus and nitrogen. This analysis revealed that OPF might require longer composting time due to high content of cellulose, fibre and lignin.

The analysis also provides some useful information regarding C:N ratio in OPF and POME. In order to obtain the optimum C:N ratio for the final compost, which is less than 20 (Heerden *et al.,* 2002) and less than 15 (Jimenez and Perez, 1992), POME is the key co-substrate to maximise and accelerate the decomposition process by supplying beneficial microorganisms. Co-composting of CGOPF with POME was recommended since the POME contains a high level of moisture but with a low C:N ratio, and, has an opposite physical properties. The combination of CG-OPF with POME would produce the final compost with acceptable C:N ratio. In this study, the CG-OPF functioned as a carbon source for growth of the microorganisms and also as a bulking agent for composting.

The N, P and K level in the final compost product were 1.2%, 0.1% and 0.9%, respectively (*Table 1*). The NPK were slightly higher (2.2% N, 1.5% P and 2.8% K) in the previous study by Baharuddin *et al*. (2009a) using EFB and POME. According to Suhaimi and Ong (2001), the use of a combination of EFB, raw POME, fermentation liquid waste and chicken manure for composting would result in the final compost containing higher NPK values (2.4% N, 0.7% P and 2.6% K). In this study, the NPK level in the final compost product was lower than the final EFB compost due to low NPK level in raw OPF (0.85% N, 0.05% P and 1.73% K) as compared to raw EFB (1.2% N, 0.08% and 1.73% K). Unlike EFB which underwent steam treatment, no pre-treatment was carried out on raw CG-OPF, which led to difficulty of degrading the materials (Najib *et al*., 2011). Although POME was used to supply nitrogen, the physical treatment such as chipping and grinding alone was not sufficient enough to lower the carbon and increase the nitrogen contents to achieve the desired C:N ratio of the compost (Najib *et al*., 2011).

Moreover, since the thick POME was used as the microbial seeder and nutrient source, the amount of POME added onto the CG-OPF compost was slightly lower than that reported by Baharuddin *et al*. (2009b). In the previous study using chipped OPF as a raw substrate (Najib *et al*., 2011), it was revealed that the texture of chipped OPF was too weak to hold the moisture for a long period. But, such a texture has an advantage in that only a low level of heavy metals was detected in the final compost product, at lower than 1 ppm.

Physico-chemical and Bacterial Changes in Composting

Temperature. Temperature is the main parameter which determines the efficiency of a composting process (Baharuddin *et al*., 2009a). In fact, the rate of composting and compost maturity is determined by temperature. According to Bazrafshan *et*

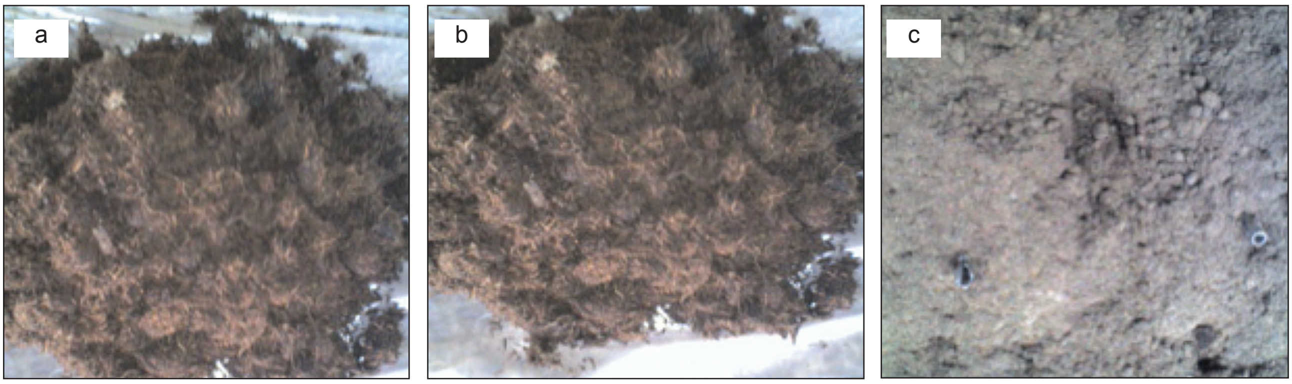

Figure 1. Physical observation of compost at 10th (a), 30th (b) and 60th (c) day of composting.

TABLE 1. PROPERTIES OF OIL PALM FROND (OPF), PALM OIL MILL EFFLUENT (POME) AND FINAL COMPOST AT DAY 60 ANALYSED ACCORDING TO APHA 2005

Parameters	OPF	POME	Final compost
Moisture (%)	-	95.4	-
pH	-	7.4	-
C (%)	42.13	32.5	20.37
N (%)	0.85	3.9	1.19
C:N	49.56	8.3	17.0
Ammonium (%)	-	-	-
Oil and grease (mg litre^{-1})	-	183.0	-
Electrical conductivity (Mmhos cm^{-1})	-	-	-
Total solid (mg kg^{-1})	-	55 884.0	-
COD (mg litre^{-1})	-	40 563.0	-
BOD (mg litre^{-1})	-	15 100.0	-
Cellulose (%)	37.9	-	-
Hemicellulose (%)	-	-	-
Lignin (%)	8.1	-	-
Fibre (%)	46	-	-
Composition of Nutrients and Metal Elements			
Phosphorus (%)	0.1	1.2	0.1
Potassium (%)	1.1	2.0	0.9
Calcium (%)	0.6	1.6	0.6
Sulphur (%)	0.3	4.6	0.4
Magnesium (%)	0.1	0.9	0.2
Zinc (ppm)	25	157.8	38
Manganese (ppm)	65	549.6	72
Ferum (ppm)	20 246	1.9	27 926
Copper (ppm)	13	243.1	24
Boron (ppm)	9	180.4	9
Molybdenum (ppm)	nd	nd	0.08
Cadmium (ppm)	nd	nd	nd
Chromium (ppm)	0.44	23.3	0.43
Plumbum (ppm)	0.39	0.1	0.54
Nickel (ppm)	nd	nd	0.14

Note: nd - not detectable.

al. (2006), temperatures higher than 55ºC will maximise sanitation, between 45ºC and 55ºC will maximise the biodegradation rates, and between 35ºC and 40ºC will maximise microbial diversity in the composting process. Based on this study, the temperature on the first two days of composting (DOC) reached 34ºC to 38ºC. Then, it increased to 50ºC - 56ºC on 21 DOC and remained within this range for 30 days (*Figure 2*), indicating the thermophilic phase and existence of indigenous bacteria in raw materials. These indigenous bacteria were capable of oxidising degradable carbohydrate and peptin at the initial thermophilic phase, whereas more stable material such as lignin would be oxidised in prolonged thermophilic stage (Baffi *et al.*, 2006). Most studies reported that the optimum temperature range for effective decomposition was 50ºC -70ºC (Baharuddin *et al.*, 2009a).

Although the POME was used as the microbial source and to maintain the moisture content, the temperature of the compost heap remained at 56ºC due to the compactness nature of CG-OPF. The highest temperature recorded during composting was 56ºC. Fernandez *et al.* (2008) reported that high compaction in composting material and high environmental temperatures would result in the formation of larger compost particles. The large particle size could reduce the mass transfer of oxygen and evaporated water in the composting process and limit heat generation. Therefore, composting temperature in this case never exceeded 56°C. However, microbial decomposition was still active in the compost pile because the temperature was maintained at around 53ºC±3ºC for 30 days.

The fine texture of the CG-OPF led to a low aeration level in the compost pile and subsequently affected microbial activity in the compost. According to Khalil *et al.* (2001), well aerated composts often attained temperatures of 50ºC-65ºC, and could even reach 80ºC, because of the microbial activity in decomposition of carbohydrates and proteins. The temperature of the composting pile dropped

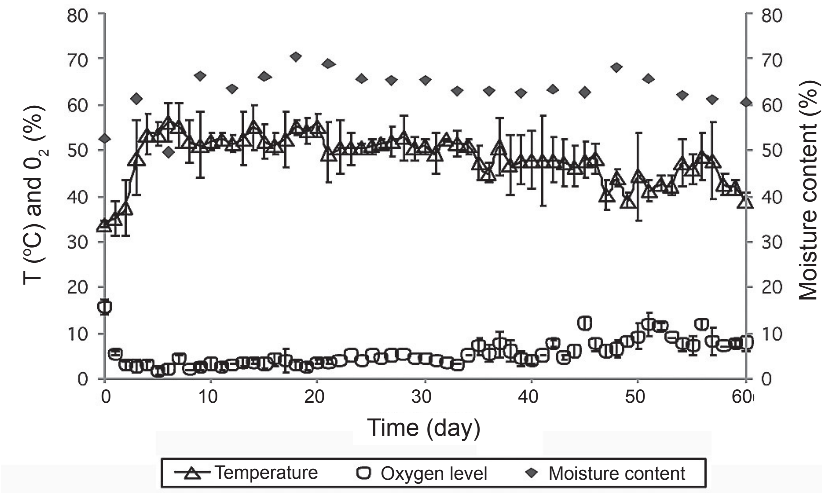

Figure 2. Profiles of compost temperature, oxygen level and moisture content during co-composting of chipped-ground oil palm frond (CG-OPF) and palm oil mill effluent (POME).

to 47°C at 35 DOC, indicating the end of thermophilic phase. The gradually turned composting pile entered a curing phase on Day 60 and the average temperature inside the pile was maintained at 39°C.

Moisture Content and Oxygen Level

The moisture content was a critical factor in determining the success of composting. Thus, POME was added in the composting system in this study to maintain the moisture content around 55%-65%, resulting in a good aeration for bioactivity of the microorganisms. In this study, low thermophilic temperature, 53°C±3°C with interval aeration-turning in composting, as well as the fine structure of the CG-OPF, led to water being trapped that increased the moisture inside the pile.

Although pile turning was done at every three-day interval, the low thermophilic temperature led to almost consistent moisture content. In fact, this condition provided maximum microbial activities as reported by Baharuddin *et al.* (2009b). In this study, the initial moisture content was 53% (*Figure 2*) and could be maintained around 60%-70% for 25 days. At a later stage, the water content of the piles gradually decreased to 61%. This could probably be due to generation of metabolic heat from degradation of easily degradable material which could accelerate water loss. According to Tiquia *et al.* (2002), the moisture content of around 50%-60% was ideal for optimum composting process. However, in this study, the moisture content was higher than 60%, implying over wetting condition during the composting process.

As shown in *Figure 2*, the oxygen level in the piles was around 16% at the initial stage and dropped to 2%-5% due to indigenous bacteria consumption for 30 days. However, due to the compactness nature of the CG-OPF, the oxygen level was still maintained at 3%-7% after the completion of the thermophilic phase. According to Baharuddin *et al.* (2009b), a high oxygen level will accelerate the decomposition. Therefore, the low rate of decomposition in this study was probably attributed to a low oxygen level.

pH

As indicated in *Figure 3*, the pH value was slightly decreased on the fourth DOC due to the addition of POME into the compost materials which contributed to the acidic condition. The pH during composting was in the range of 7.9-8.5 (*Figure 3*). It was increased when the temperature increased on the sixth DOC during the initial stage of the treatment. Moreover, this condition was contributed by the biochemical reactions of nitrogen-containing materials (Baharuddin *et al.*, 2009a). At the end of composting, the pH was stabilised at 8.1, which was probably due to buffering nature of humic substances and domination of thermophilic bacteria, which are not acid tolerant.

Bacterial Count

A bacteria population profile throughout the process reflects microbial activity, state of compost maturity and degree of decomposition of the compost substrate. In this study, the initial population was 55 x 10^{10} cfu ml^{-1} (*Figure 3*). As the composting process reached the thermophilic phase at temperature > 50°C, it was observed that the population of the thermophilic bacteria increased sharply on the fifth DOC, indicating 66 x 10^{10} cfu ml^{-1}. This was probably due to availability of easily degradable materials (Lim *et al*., 2009). However, between the 10^{th} and the 60^{th} DOC, the microbial population decreased gradually.

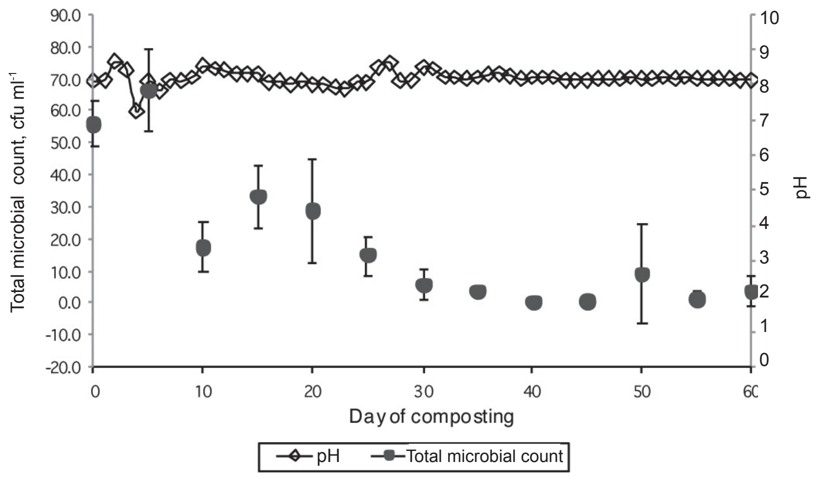

Figure 3. Total microbial count and pH profiles throughout co-composting of chipped-ground oil palm frond (CG-OPF) and palm oil mill effluent (POME).

This condition happened due to a long period of thermophilic temperature, loss of moisture content (Baharuddin *et al*., 2009b), low oxygen level and ash formation (Lim *et al*., 2009), which indirectly prohibited microbial growth during the process. Furthermore, on the 50th DOC, the microbial population increased to 90 x 10^9 cfu ml^{-1}. In the later stage of composting, the mesophilic bacteria might become dominant with respect to a decrease in temperature of the composting pile.

C:N Ratio

As illustrated in *Figure 4*, nitrogen content increased constantly, while carbon content gradually decreased throughout the composting process. At the initial stage, the nitrogen content increased from 0.7% to 1.9% until 60th DOC. This was attributed by the activity of microbial cellulolytic degradation and microbial proliferation which could retain nitrogen content from POME (Lim *et al*., 2009) and increased microbial protein and humic substances (Baharuddin *et al*., 2009b). The addition of POME could reduce the initial C:N ratio to the acceptable level. The C:N ratio dropped to 35 on the 15th DOC, which was due to compactness of the composting material, CG-OPF, which contributed to low degradation.

According to Baharuddin *et al*. (2009a), C:N ratio of less than 20 could be considered as a satisfactory level of compost maturation. In this study, the C:N ratio of the compost was around 26 on the 40th DOC, whilst in the curing phase the C:N ratio was around 17 on the 45th to 50th DOC. However, the C:N ratio for compost product was increased

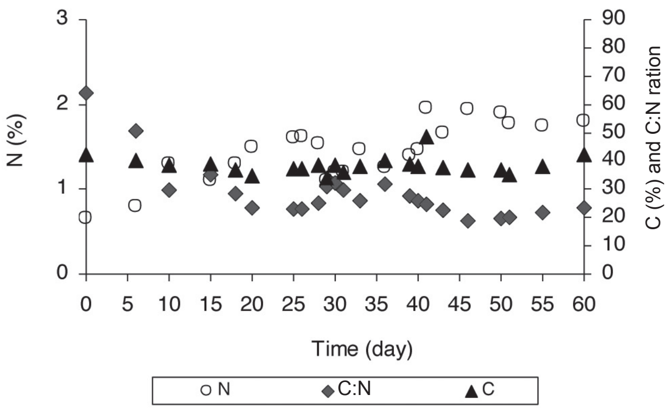

Figure 4. Changes of carbon, nitrogen and C:N ratio throughout co-composting of chipped-ground oil palm frond (CG-OPF) and palm oil mill effluent (POME).

from 17 up to 24 at the 60^{th} DOC. This is considered as not a good compost product as compared to EFB which could achieve the C:N ratio of 12 on 60^{th} DOC.

Macro and Micro Nutrients

In general, a good compost product should contain a considerable amount of nutrients namely N, P, K, calcium (Ca), iron (Fe) and magnesium (Mg). As illustrated in *Table 1*, the critical nutrients in the final compost such as P (0.1%) and K (0.9%) were slightly lower compared to compost made from the mesocarp fibre (P,-0.3% and K,-1.2%) (Lim *et al*., 2009) and EFB (P,- 0.6% and K,-2.4%) (Baharuddin *et al*., 2009b). The content of Ca, Mg, Fe and sulphur increased slightly after 60^{th} DOC due to the addition of POME throughout the composting process as compared to the compost made from EFB (Ca, - 1.0%; Mg,-0.6%; Fe,-1.0% and sulphur,-1.1%) (Baharuddin *et al*., 2009b). The final concentration of Ca (1.0%) was comparable to the result obtained from the EFB-compost (Baharuddin *et al*., 2009b). The micronutrients (zinc, manganese, copper, boron) detected in the compost are very important elements for plant's growth, plant's health and rejuvenation of microorganisms (Lim *et al*., 2009).

Heavy Metals

As shown in *Table 1*, the content of heavy metals such as Cr (0.43 ppm), Pb (0.54 ppm) and Ni (0.14 ppm) in the final compost was low and in acceptable level of < 20 ppm. This level was much lower than oily sludge compost (>70 ppm) (Lim *et al*., 2009). According to US EPA (Moldes, 2006), the maximum allowable level in exceptional quality compost is 1200 ppm (Cr), 300 ppm (Pb) and 420 ppm (Ni). Furthermore, cadmium (Cd) was not detectable in the final compost. The results indicated that the final compost was environmentally safe and non- toxic.

CONCLUSION

As a conclusion, co-composting of CG-OPF and POME needs further improvement in terms of substrate structures and texture to maximise the aeration and optimise the moisture content within the compost pile. The final C:N ratio for compost obtained in this study was 24 with a considerable amount of macro and micronutrients. Besides, the final compost contained very low level of heavy metals.

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