International Journal of Agricultural Research

ISSN 1816-4897

Academic Journals Inc.

www.academicjournals.com

International Journal of Agricultural Research 4 (2): 69-78, 2009
ISSN 1816-4897

Co-Composting of Empty Fruit Bunches and Partially Treated Palm Oil Mill Effluents in Pilot Scale

[1]A.S. Baharuddin, [1]M. Wakisaka, [1]Y. Shirai, [2]S. Abd-Aziz,
[2]N.A. Abdul Rahman and [2]M.A. Hassan
[1]Department of Biological Functions and Engineering,
Graduate School of Life Science and System Engineering, Kyushu Institute of Technology, 2-4 Hibikino, Wakamatsu-Ku, Kitakyushu, Fukuoka 808-0916, Japan
[2]Department of Bioprocess Technology,
Faculty of Biotechnology and Biomolecular Sciences, Universiti Putra Malaysia,
43400 UPM Serdang, Selangor, Malaysia

Abstract: The main objective of this study is to investigate the physicochemical changes of the co-composting Empty Fruit Bunch (EFB) with partially treated palm oil mill effluent (POME) in pilot scale. The partially treated POME from anaerobic pond was sprayed onto the shredded EFB throughout the treatment. The composting materials were turned over one to three times per week for aeration. Temperature and oxygen were monitored at different depths of the composting piles. Parameters such as C, N, pH, nutrients, heavy metals and total bacteria count were also determined. The temperature was increased up to 58.5°C at day three of treatment, after that fluctuated between 50 to 62°C and then decreased in the latter stage of the process. The pH of the system (7.75-8.10) did not vary significantly during the treatment period while moisture content was reduced from 65-75% to about 60% at the end of the treatment. The initial C/N ratio of 45 was significantly reduced to 12 after 60 days of composting. The final cured compost contained a considerable amount of nutrients (carbon, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur and iron) and trace amounts of manganese, zinc, copper. In addition, very low levels of heavy metals were detected in the compost. The number of bacteria involved in the composting process was decreased at the end of the composting period. The results obtained indicated that pilot scale of co-composting EFB with partially treated POME gave acceptable quality of compost and ease in operation. The compost product may useful in palm oil plantation as fertilizer and soil amendment.

Key words: Empty fruit bunch, partially treated palm oil mill effluent, composting

INTRODUCTION

Malaysia is one of the top producers of palm oil in the world and at present, the total area under oil palm cultivation is about 4.05 million ha, with the total palm oil production of 16.8 million tonnes (Astimar and Wahid, 2006). In 2004, it was estimated that 26.7 million tonnes of solid biomass and average of 30 million tonnes of POME were generated from 381 palm oil mills in Malaysia (Yaacob *et al*., 2005). The biomass was made up of 53% Empty Fruit Bunch (EFB), 32% mesocarp and 15% fiber and palm kernel shell (Yaacob *et al*., 2006). It is believed that this will continuously increase in proportion to the world demand of edible oils.

Corresponding Author: Dr. Suraini Abd-Aziz, Department of Bioprocess Technology,
Faculty of Biotechnology and Biomolecular Sciences, Universiti Putra Malaysia,
43400 Serdang Selangor, Malaysia Tel: +6-03-89467479 Fax: +6-03-89467510

In the past, with the high content of nutrients, the EFB are burnt to produce ash, which is later used as fertilizer. However, the burning of EFB has been stopped due to the environment issue and nowadays most EFB are recycled and applied as mulch in the field (Astimar and Wahid, 2006). Yaacob *et al*. (2005) reported that one of the major sources of Green House Gas (GHG) in Malaysia was contributed from the palm oil mill wastewater treatment system. It was estimated that for every tonne of POME treated, an average of 12.36 kg of methane was emitted from the anaerobic ponds. Thus, bioconversion of these biomass (EFB and POME) into valuable product and minimize the pollution generated from the palm oil mill are crucial. The utilization of EFB and POME that available in a huge amount at palm oil mills, offer the best prospect of commercial exploitation and could be integrated with the palm oil mill industry.

Co-composting of EFB with partially treated POME was investigated to be one options for the waste utilization and could offer many environmental and economic benefits. Compost is safe to be used in agricultural, however it depends on the production of good quality compost; matured and low in heavy metals and salt content. These materials (EFB and POME) could be composted and used for oil palm plantation purposes and substitute for an inorganic fertilizer. Successful compost stabilization process however depends on maintaining a suitable environment for process control including moisture content, oxygen level, carbon-nitrogen ratio, nutrients and temperature (Ekinchi *et al*., 2006; Liang *et al*., 2006). In this study, co-composting of EFB and partially treated POME was conducted to investigate the performance of windrow composting piles of these materials in the pilot scale. Feasibility of the composting procedure and characterization of the compost product were also evaluated and determined.

MATERIALS AND METHODS

Field-Scale Composting Plant

This research was conducted at field-scale composting plant in FELDA Maokil, Johor, Malaysia. A total of 202 windrows were incubated at the composting site which consists of two field area (13 ha). The experiment was conducted from April 2007 to March 2008.

Raw Materials

The composting materials were obtained from the oil palm processing mill. The shredded Empty Fruit Bunch (EFB) and Partially Treated Palm Oil Mill Effluent (POME) were mixed at 40 tonnes and 120 tonnes, respectively.

Empty Fruit Bunch (EFB)

Empty fruit bunches (EFB) were obtained after oil palm fruits removed from the fresh fruit bunch (FFB) during the milling process (threshing). EFB constitutes about 20-25% of FFB. After threshing process, the empty fruit bunches were shredded into loose fibrous material by using a shredder machine and applied directly onto the composting site.

Palm Oil Mill Effluent (POME)

Wastewater treatment facility in Maokil palm oil mill comprises of ponding system (cooling pond, mixing pond, anaerobic ponds, facultative ponds and algae ponds) constructed to treat POME before safely discharge. POME used in this study was collected from anaerobic pond (partially treated) and sprayed directly onto the composting piles.

Composting Establishment

The tipper lorry was used to lay down the shredded EFB on the composting ground to form a long conical shaped of windrow (40 mL×3 m W×1.5 mH). Each windrow has 1-3 m clearance in between to allow turning process. Leachates or run-off after raining was collected in special constructed drains to prevent the loss of added nutrients. Partially treated POME (anaerobic pond) was added to each of the piles every three days interval to adjust the final moisture content of 65-75%. The addition of POME was stopped one to two weeks prior to harvesting in order to avoid the final product from being too wet. The windrow was covered throughout the composting period except during spraying of POME and turning process. The composting materials were turned over one to three times per week to maintain an even distribution of moisture and prevent the build-up of heat. The composting process was repeated for five times over one year period. Each composting cycle was completed in 60 days.

Sampling

A 2 kg samples was collected at different locations of the windrow; bottom, core and surface. The samples were divided into two parts. One part was stored at 4°C while the other part was air dried and then passed through 2 mm sieve. All experiments were done in triplicates.

Sample Analysis

Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), oil and grease and total solid were measured according to APHA (1998) methods. CNHS analyzer and Inductively Coupled Plasma (ICP) were used to measure carbon, nitrogen, nutrients and heavy metal element. Plate count method was used to obtain viable bacterial count.

RESULTS AND DISCUSSION

Characteristics of Raw Materials and Final Compost

The results indicated the shredded EFB contain relatively large amounts of cellulose and lignin, so that longer composting period is needed as compared to other compost materials (Table 1). Different color and texture of the composts was also observed during the composting period as shown in Fig. 1. The matured compost was exhibited blackish in color, soil texture and has an earthy smell. Based on the results shown in Table 1, it is suggested that co-composting of EFB with partially treated POME was a suitable approach, because POME has high moisture content but lower carbon to nitrogen ratio (C/N) while EFB has the opposite characteristics. Thus, by mixing these two materials could provide better moisture content and adequate nutrients for microorganism growth and degrade the compost materials. The partially treated POME also consisted of high nitrogen content and would complement the shredded EFB that has high carbon content for co-composting. There were

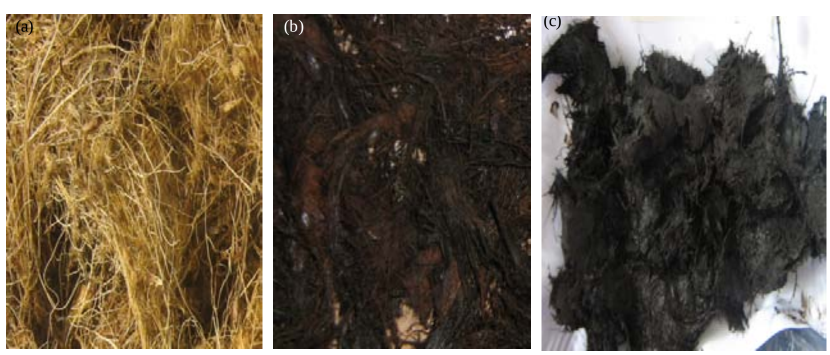

Fig. 1: Physical changes during composting (a) shredded EFB; (b) compost (day 20) and (c) final compost (day 60)

Table 1: Properties of shredded EFB, partially treated POME and final compost at day 60 (*dewatered POME sludge)

Parameters	Shredded EFB	Partially treated POME	Final compost
Moisture (%)	24±5.8	95±3.3	61±4.6
pH	6.7±0.2	7.5±0.5	8.1±0.7
C (%)	53.0±1.5	19.0±1.6*	28.0±1.7
N (%)	0.9±0.1	2.3±0.2*	2.2±0.3
C/N	58.9	8.3	12.7
COD (mg L^{-1})	-	26000-37000	-
BOD (mg L^{-1})	-	1000-2600	-
Oil and grease (mg L^{-1})	-	20-34	-
Total solid (mg L^{-1})	-	32000-62000	-
Cellulose (%)	52.5±6.5	-	-
Hemicellulose (%)	28.8±1.1	-	-
Lignin (%)	17.1±3.6	-	-
Composition of nutrients and metal elements			
Phosphorus (%)	0.6±0.1	1.3±0.6	1.3±0.2
Potassium (%)	2.4±0.4	2.0±0.9	2.8±0.3
Calcium (%)	0.6±0.3	0.5±0.4	0.7±0.2
Ferrum (%)	1.0±0.2	0.8±0.5	1.2±0.3
Magnesium (%)	0.6±0.2	1.0±0.3	1.0±0.1
Sulphur (%)	1.1±0.3	0.7±0.1	1.2±0.4
Manganese (mg kg^{-1})	230.3±40.8	180.2±50.1	250.4±25.1
Zinc (mg kg^{-1})	16.6±2.6	120.1±14.1	90.7±10.0
Copper (mg kg^{-1})	13.5±1.6	95.6±17.2	70.4±21.6
Plumbum (mg kg^{-1})	0.8±0.2	5.5±2.5	4.2±1.6
Cadmium (mg kg^{-1})	0.7±0.3	5.8±0.9	4.1±0.5
Chromium (mg kg^{-1})	9.2 ±1.0	6.0±3.0	9.3±0.2
Nickel (mg kg^{-1})	nd	nd	nd

nd: Not determined

variations of value for parameters detected in the partially treated POME such as COD, BOD, oil and grease and total solids content as shown in Table 1. This might be due to the weather condition and mill operation as reported by Yaacob *et al.* (2005). Moreover, the aging of POME sludge from the anaerobic pond may also contribute to the variation characteristics. Therefore, maintaining partially treated POME at the same characteristics was challenging.

In this study, the nitrogen and nutrient content in the final compost (Table 1) was found comparable to Suhaimi and Ong (2001) that used the combination of EFB, raw POME, fermentation liquid waste and chicken manure for composting process. The final compost consisted of N, P and K at 2.4, 0.7 and 2.6%, respectively while in this study the final compost composition were 2.2% N, 1.5% P and 2.8% K. It can be suggested that with proper control conditions in an open system, the co-composting of EFB can be accomplished with only the addition of partially treated POME as a seeding and nutrient sources to give an acceptable quality of compost product (Table 1). It is also suggested that the high content of phosphorus and potassium detected in the final compost might be due to the high content of these elements existing in the shredded EFB and partially treated POME. Moreover, low level of heavy metals was detected for the all samples tested (< 10 mg kg^{-1}).

Physicochemical and Biochemical Changes in Composting

Temperature Variation

Temperature is the most important indicator of the efficiency of the composting process (Xiujin *et al*., 2008). The ambient temperature measured in the composting site was around 30 to 35°C throughout this study (Fig. 3). The partially treated POME used in this study contained high level of organic matter was indicated by its high BOD (Table 1). Therefore, when it mixed with EFB, the piles generated more heat. It was observed that the temperature of the compost increased sharply to about 58°C within the first three days of treatment reflecting active microbial decomposition in the composting piles (Fig. 2). The pile dimension of 1.5 m height×3 m wide×40 m length could escaped the released of energy and allowed temperature to be increased rapidly.

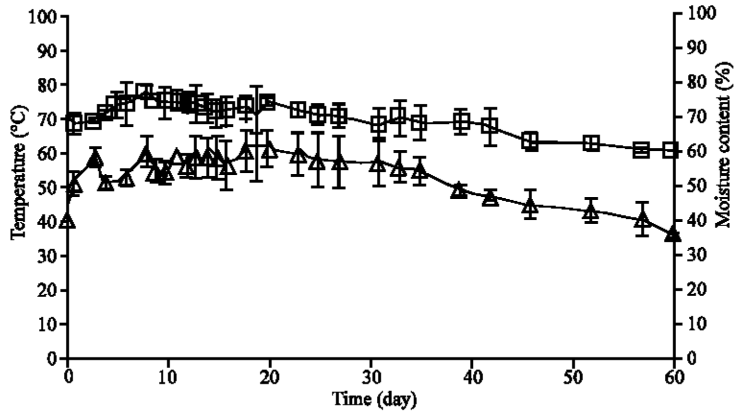

Fig. 2: Profiles of compost temperature (Δ) and moisture content (□) during co-composting of EFB and partially treated POME

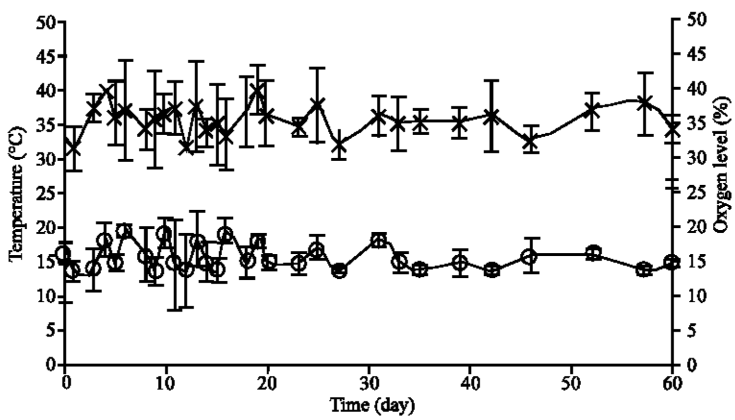

Fig. 3: Profiles of ambient temperature (x) at the composting site and oxygen level (o) during co-composting of EFB and partially treated POME

From day 4 to day 40, the temperature was maintained around 50-62°C indicating the thermophilic phase. Most study reported that the optimum temperature range for effective decomposition was 50-70°C, with 60°C being the most satisfactory level (Wong *et al*., 2001). The thermophilic phase for the composting piles occurred after two days of treatment and this might be due to the high numbers of indigenous bacteria as shown in Fig. 4. During this phase, the dominant micro-organisms might attack rapidly the soluble, readily degradable compounds, high content of available nutrients and relatively small size of organic fraction particles (Wong *et al*., 2001; Olfa *et al*., 2008).

It was reported that composting temperature above 55°C could kill pathogens and sanitize the compost (Gea *et al*., 2005). Stentiford (1996) also stated that a maximum temperature of 55-65°C is necessary to destroy pathogens, but temperature of 45-55°C must be maintained for maximum biodegradation. Thus, the temperature profile obtained in this study (Fig. 2) meet the sanitary requirements, without requiring extra heat energy for the composting process. The temperature of composing piles with frequent turning was decreased gradually after the thermophilic phase and

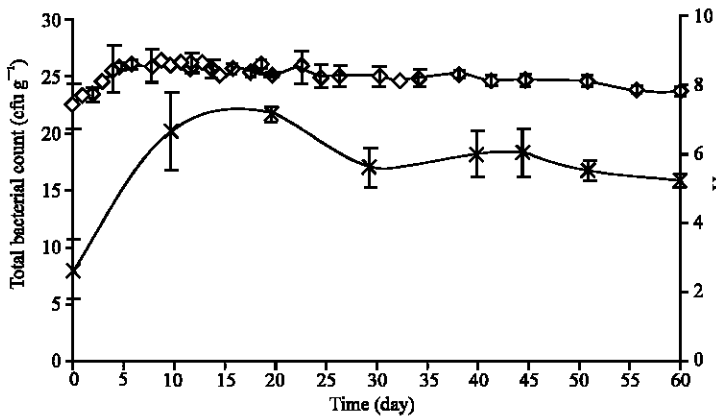

Fig. 4: Total bacterial count (x) and pH (◇) profiles throughout composting process

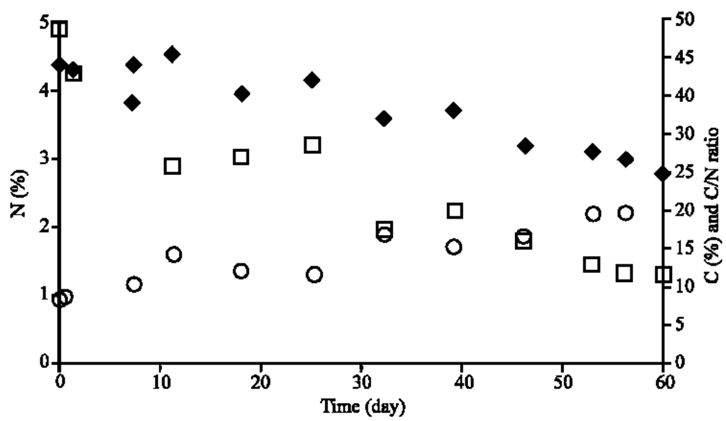

Fig. 5: Changes of nitrogen content and C/N ratio throughout composting process (o: nitrogen; ♦: carbon; □: C/N ratio)

entered a curing phase at day 40 with C/N ratio of 20. During this phase, the C/N ratio tends to stabilize and maintained (Fig. 5). At the end of composting, the average temperature inside the windrows marked a significant decreased (34°C). The temperature remained no change in spite of turning of the windrows for another 10 days.

Moisture Content and Oxygen Level

The moisture level was the critical factor that determined the decomposition rate in composting. In this study, POME was added onto the composting materials (EFB) to keep the moisture content at 65-75% (Fig. 2). Thus, high bioactivity of the micro-organisms and a good aeration capacity could be maintained. The high ambient temperature (30-35°C) followed by frequent turning resulting in water from the compost pile constantly evaporated. Therefore, a proper amount of water from POME was replenished to overcome the water loss, so that microbial activities could be sustained. Turning was continued in the curing phase to achieve moisture content of 60% in the final compost (60 days) and about 52% after another 10 days (data not shown) before distributing the compost to the oil palm plantation. Although the range of 50-60% is generally recommended for composting. Liang and Das Mcclendon (2003) reported that range of 60-75% provided the maximum microbial activities. In this study, water content of the piles gradually decreased in the latter stage of composting process as shown in Fig. 2. Partially treated POME added onto the composting piles could also maintain an aerobic condition as indicated by oxygen level profiles (Fig. 3). It is suggested that turning over one to three times per week was appropriate to control the aeration of the composting piles (>10%). The low oxygen levels will slow the decomposition and increases opportunity for adsorption of ammonia onto solid materials leading to immobilization.

Effect of pH

Figure 4 shows the pH values during composting process were gradually increased and remained in the range of 8.3-8.5. The pH value was increased when the temperature increased during initial treatment. This phenomenon might be due to an increase in ammonia generated by the biochemical reactions of nitrogen-containing materials. Moreover, additional of partially treated POME to enrich the EFB compost may also contributed to the slightly alkaline condition. In present study the pH was decreased to 7.8-8.1 at the end of the composting process. This phenomenon was in agreement with Sundberg *et al*. (2004) that reported for fully developed composting, the pH often rises to 8-9. In addition, the thermophilic phase of composting is dominated by bacteria, which are generally not as acid tolerant.

Bacterial Count

A total bacterial count throughout the process could be an indicator to the state of compost maturity (Khalil *et al*., 2001). In this study, the number of colony forming units (cfu) was around 6.4×10^{-10} cfu g^{-1} wet substrate at the initial composting process (Fig. 4). As the temperature increased to 50°C or above after day three of composting (Fig. 2), thermophilic bacteria might dominant. It can be noticed that after 10 days of treatment, the number of total viable bacteria was sharply increased. However the number of colony decreased gradually after day 20 until day 30. The decreased in the number might be due to the longer thermophilic temperature or loss of moisture during the thermophilic phase. At this stage, the C/N ratio was about 20 (Fig. 5) indicating the curing stage was occurred. In the latter stage of composting, mesophilic bacteria might active. The number of total mesophilic bacteria at the end of composting process was about 16.4×10^{-10} cfu g^{-1}. It has been reported that the number of mesophilic and thermophilic microorganism fluctuated with respect to the changes in temperature of the composting piles (Thambirajah *et al*., 1995).

C/N Ratio

Figure 4 shows that the nitrogen content in this study was gradually increased throughout the composting process. The nitrogen content of 1.0% at the beginning of the composting was increased to 2.2% at the end of the process (Table 1). In addition, C content of the composting materials was gradually decreased throughout the treatment (Fig. 5). This phenomenon may be attributed from the microbial activity on the cellulosic substrate and nitrogen, which increased the microbial protein and humic substances (Thambirajah *et al*., 1995).

Compost maturity and stability are the key factors during composting. C/N ratio is always used as an indicator of compost maturation and should be stable with time (Wong *et al*., 2001). The C/N ratio of shredded EFB used in this study was high (58.5), but it can be reduced to a more appropriate level by the addition of supplements such as partially treated POME. In present study, the C/N ratio of composting material was around 45 at initial treatment. Then, the C/N ratio was dropped to less than 30 after two weeks of composting process and continued decreasing afterwards. According to Heerden *et al*. (2002), a value of C/N ratio less than 20 could be considered as a satisfactory maturation level of compost. However, Jimenez and Perez (1992) reported the ratio of 15 or less is more preferable. In present study, the C/N ratio less than 20 occurred after day 40 during curing phase while, C/N ratio

Table 2: Characteristic changes of nutrients and heavy metal element from compost sample throughout the composting process

Compost elements	Time period (days) 0	10	20	30	40	50	60
Nutrients							
P (%)	0.83±0.29	0.87±0.30	0.89±0.36	0.97±0.45	1.27±0.56	1.28±0.31	1.28±0.25
K (%)	2.10±0.64	2.20±0.60	2.42±0.37	2.70±0.07	2.80±0.16	2.81±0.11	2.79±0.15
Ca (%)	0.43±0.12	0.50±0.26	0.67±0.48	0.68±0.16	0.71±0.25	0.72±0.12	0.72±0.20
Fe (%)	0.78±0.14	0.86±0.28	0.98±0.34	1.07±0.29	1.20±0.41	1.18±0.27	1.16±0.29
Mg (%)	0.50±0.08	0.61±0.17	0.64±0.35	0.75±0.24	0.90±0.06	0.92±0.18	0.91±0.10
S (%)	0.87±0.12	0.94±0.10	0.95±0.18	1.04±0.25	1.06±0.11	1.10±0.18	1.10±0.05
Mn (mg kg^{-1})	186.30±17.6	195.20±20.2	201.60±21.1	223.80±15.3	245.30±13.1	246.00±12.4	244.60±16.3
Zn (mg kg^{-1})	61.20±13.8	62.90±24.4	71.80±19.2	80.00±45.5	87.30±16.0	87.50±12.2	87.20±11.0
Cu (mg kg^{-1})	30.50±3.10	48.60±7.80	55.00±2.10	58.70±10.3	67.60±2.50	68.00±5.20	686.60±5.30
Heavy metal							
Pb (mg kg^{-1})	2.80±0.40	3.20±0.70	3.60±0.80	3.80±0.50	4.20±1.00	4.00±0.30	3.90±0.60
Cd (mg kg^{-1})	3.00±0.30	3.40±1.50	3.50±0.80	3.70±1.40	3.90±2.00	3.80±0.90	3.60±0.20
Cr (mg kg^{-1})	5.00±0.60	5.80±2.10	6.30±1.70	7.00±2.00	9.30±1.80	9.10±1.70	9.10±1.90
Ni (mg kg^{-1})	nd	nd	nd	nd	nd	nd	nd

nd: Not determined

with less than 15 was obtained after day 48. At this stage, POME was not added and the pile was continued turning until it reached C/N ratio of 12.7 at the end of composting process. During the composting process, the biologically degradable organic matter is converted into volatile CO_2 and H_2O and is removed from the compost. The total N content increases resulting in decreasing of C/N toward the end of composting (Vuorinen and Saharinen, 1997).

Nutrient Changes (Macro and Micro Nutrient)

Phosphorus, potassium, calcium, iron and magnesium were the major nutritive elements for microbes in the compost. Therefore, the changes in all major elements throughout the composting process were recorded (Table 2) to verify whether the treatment procedure is essential. Phosphorus had relatively little variation during the composting process. Potassium content was gradually increased at the initial stage of treatment and stabilized with a final concentration of 2.8 % (Table 2) at the end of the composting process. The concentration of calcium, magnesium, sulphur and iron were gradually increased during the thermophilic phase and remained stable (Table 2) after the piles reached C/N less than 20 after day 40 of composting. The range of Fe and S detected in this study was about 1.2%, respectively (Table 2) at the end of the process. The presence of this element is really important to avoid plant illness, especially in basic grounds where iron is not available (Virginia *et al*., 2008). Calcium (Ca) was also found as one of the major elements in the final compost (<1.0%). Its concentration was comparable to the results obtained in municipal solid waste compost, which was 1% (He *et al*., 1995). While the concentration of Mg in the final compost (Table 1) was higher than municipal solid waste compost (<0.5%) (He *et al*., 1995).

Micronutrients are essential for the growth and development of microorganisms (Alidadi *et al*., 2007). The element of micro-nutrients detected in this study were manganese (<200 mg kg^{-1}), zinc and copper (< 90 mg kg^{-1}) as shown in Table 2. These elements were found slightly varied during the thermophilic phase and remain unchanged in the latter stage of composting period. It is suggested that most of the nutrients in this process (Table 2) was derived from the POME sludge as high nutrients concentration were detected in the dewatered partially treated POME (Table 1).

Metal Element

The levels of heavy metals (Ni, Pb, Cd and Cr) in the compost were very low as shown in Table 2. This is due to the use of EFB biomass and POME which derived of plant materials (oil palm residue). The concentration of heavy metal detected in this study was below the levels of toxicity and no nickel was detected throughout the composting. After day 40 (C/N <20) and when the amount of

POME added was reduced, the concentration of these heavy metals was reduced gradually until the end of the treatment. The slow reduction of heavy metals might be attributed to the stabilization phase where the humid substances increased in the latter stage of the process. The results obtained in this study indicated that the final compost product was suitable for plant nutrients, safe and no detrimental effect.

CONCLUSIONS

In summary, the above results showed that co-composting of empty fruit bunch with partially treated POME can be used as an alternative method for converting of these materials using a simple and traditional windrow composting pile. The temperature obtained in the pilot-scale composting met the sanitary requirement for pathogen-killing. The compost obtained in this study has a C/N ratio of 12 with a considerable amount of calcium, magnesium, phosphorus, potassium and other micronutrients. Beside that, the compost product contained very low levels of heavy metals. Thus, the compost might be suitable to be used as fertilizer for the oil palm plantation or as a soil amendment.

ACKNOWLEDGMENTS

The study was sponsored by Kyushu Institute of Technology, Japan and Felda Palm Industries Sdn. Bhd., Malaysia. The authors would like to thank the management of Maokil Palm Oil Mill for their cooperation throughout the study. This study was financially supported by FELDA grant (67001) and Japan Society for Promotion of Science (JSPS).

REFERENCES

APHA, 1998. Standard Methods for Examination Water and Wastewater. 20th Edn., American Public and Health Association, Washington D.C. American Public Health Association, ISBN: 0-87553-235-7.

Astimar, A.A. and M.B. Wahid, 2006. Supply outlook of oil palm biomass in Malaysia. Proceeding of the Seminar on Ecomat Research and Promotion, July 24-25, Beijing, China, pp: 13-26.

Ekinchi, K., H.M. Keener and D. Akbolat, 2006. Effect of feedstock, airflow rate and recirculation ratio on performance of composting system with air recirculation. Bioresour. Technol., 97: 922-932.

Gea, T., A. Artola, X. Sort and A. Sanchez, 2005. Composting of residuals produced in the Catalan wine industry. Compost Sci. Util., 13: 168-174.

He, X., T. Logan and S. Traina, 1995. Physical and chemical characteristics of selected US municipal solid waste composts. J. Environ. Qual., 24: 543-552.

Heerden, I.V., C. Cronje, S.H. Swart and J.M. Kotze, 2002. Microbial, chemical and physical aspects of citrus waste composting. Bioresour. Technol., 81: 71-76.

Jimenez, E. and V. Perez, 1992. Determination of maturity indices for city refuse compost. Agric. Ecosyst. Environ., 38: 331-343.

Khalil, A.I., M.S. Beheary and E.M. Salem, 2001. Monitoring of microbial populations and their cellulolytic activities during the composting of municipal solid wastes. World J. Microbiol. Biotechnol., 17: 155-161.

Liang, C. and K.C. Das Mcclendon, 2003. The influence of temperature and moisture content regimes on the aerobic microbial activity of a biosolids composting blend. Bioresour. Technol., 86: 131-137.

Liang, L., J.J. Leonard, J.J.R. Feddes and W.B. McGill, 2006. Influence of carbon and buffer amendment on ammonia volatilization in composting. Bioresour. Technol., 97: 748-761.

Olfa, F., N. Jedidi and A. Hassen, 2008. Behaviour of main microbiological parameters and of enteric microorganisms during the composting of municipal solid wastes and sewage sludge in a semi-industrial composting plant. Am. J. Environ. Sci., 4: 103-110.

Stentiford, E.I., 1996. Composting Control: Principle and Practice. In: The Science of Composting, Part 1, de Bertoldi, M., P. Sequi, B.P. Lemans and T. Papi (Eds.). Blackie Academic and Professional, Blackie, Glasgow, ISBN: 0751403830,.

Suhaimi, M and H.K. Ong, 2001. Composting empty fruit bunches of oil palm. The Food and Fertilizer Technology Centre (FFTC), 1st November 2001. http://www.agnet.org/library/eb/505a/.

Sundberg, C., S. Smars and Jonsson, 2004. Low pH as an inhibiting factor in the transition from mesophilic to thermophilic phase in composting. Bioresour. Technol., 95: 145-150.

Thambirajah, J.J., M.D. Zulkafli and M.A. Hashim, 1995. Microbiological and biochemical changes during the composting of oil palm empty fruit bunches. Effect of nitrogen supplementation on the substrate. Bioresour. Technol., 52: 133-144.

Virginia, S.A., J.F. Francisco, V. Jose and R. Lourdes, 2008. Enhancing the co-composting of olive mill wastes and sewage sludge by the addition of an industrial waste. Bioresour. Technol., 99: 6346-6353.

Vuorinen, A.H. and H.V.M. Saharinen, 1997. Evolution of microbiological and chemical parameters during manure and straw co-composting in a drum composting system. Agric. Ecosyst. Environ., 66: 19-29.

Wong, J.W.C., K.F Mak, N.W. Chan, A. Lam and M. Fang *et al*., 2001. Co-composting of soybean residues and leaves in Hong Kong. Bioresour. Technol., 76: 99-106.

Xiujin, L., R. Zhang and Y. Pang, 2008. Characteristics of dairy manure composting with rice straw. Bioresour. Technol., 99: 359-367.

Yaacob, S., Y. Shirai, M.A. Hassan, M. Wakisaka and S. Subash, 2005. Baseline study of methane emission from open digesting tanks of palm oil mill effluent treatment. Chemosphere, 59: 1575-1581.

Yaacob, S., Y. Shirai, M.A. Hassan, M. Wakisaka and S. Subash, 2006. Baseline study of methane emission from anaerobic ponds of oil palm oil mill effluent treatment. Sci. Total Environ., 366: 187-196.