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Composting Oil Palm Wastes and Sewage Sludge For Use In Potting Media Of Ornamental Plants

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ABSTRACT

The use of oil palm wastes, particularly the empty fruit bunch (EFB), frond and trunk as compost are now receiving greater attention by researchers. Currently, these organic waste materials have not been fully utilized on a large scale, either agriculturally or industrially, for manufacture of useful by-products. Another organic waste that needs to be appropriately disposed of in Malaysia is the sewage sludge. Co-composting these waste materials could potentially convert these wastes into value added product. The objective of this study was to determine the best formulation using oil palm wastes and sewage sludge in producing a composted material to be used as a potting media in horticulture. Composting different oil palm wastes with sewage sludge was carried out in the glasshouse using a polystyrene box. Shredded oil palm wastes (EFB, frond and trunk) were mixed with sewage sludge in 3 different ratios (1:0, 3:1 and 4:1 ratio) and adjusted to 60% moisture content. Based on the temperature, C/N, NH_4^+-N and NO_3^- - N + NO_2^- -N patterns of the oil palm wastes added with sludge during composting, the EFB, frond and trunk added with sludge composts seemed to perform similarly. However, due to the small volume of compost, the temperature did not sustain > 45°C because of dissipation of the heat. Oil palm trunk with sewage sludge at 4:1 ratio was found to be the most optimum compost as potting media for ornamental plants because of its texture suitable for potting media, not stringent or stiff, had high nutrient contents (2.05 % N, 0.640 % P, 1.39 % K, 0.705 % Ca, 0.229% Mg), pH 6.2 and low C/N ratio, 19.

Keywords: potting substrate, co-composts, oil palm empty fruit bunch, oil palm fronds, oil palm trunk

INTRODUCTION

Currently, very limited choices of potting media are available in the market, i.e. mainly peat, coconut coir dust (CCD) and red clay soils. Therefore suitable substitutes or alternatives need to be sought before shortage occurs. Moreover every time a container-grown plant is sold, the rooting substrate is sold with it, necessitating the need for more substrate. Peat is one of the traditional organic materials that have

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been used extensively in ornamental horticultural industries to prepare potting/ planting media. However, peat is a finite resource and large scale of peat extraction causes environmental damage (Barber 1993; Barkham 1993; Buckland 1993). Rising prices and decreased availability of fertilizer have also caused growers to look for renewable and organic sources of nutrients (Roe 1998). Various agricultural and municipal waste materials including municipal solid waste, biosolids, animal manures, yard trimmings, agricultural residues, waste paper, food processing wastes are composted as potting media without any negative effects on a variety of crops raised in these substrates (Inbar *et al.* 1986; Bugbee and Frink, 1989; Beeson 1996; Eklind *et al*. 2001; Hashemimajd *et al*. 2004). Composting is a very popular process in the management of organic solid wastes because (a) it reduces the volume (b) microorganisms are destroyed during composting and (c) the end product is rich in nutrients content (Kulhman *et. al.* 1989).

In Malaysia, agricultural and municipal waste materials including oil palm wastes, yard trimmings, agricultural residues, waste paper, paddy straw, sewage sludge and animal manures are increasing each year leading to disposal problems. Malaysia as a major exporter of oil palm with a wide planted area of more than 3.9 million hectares in year 2005, created more than 51 million tonnes of oil palm wastes particularly the empty fruit bunch (EFB), frond and trunk (MPOB, 2006). Oil palm wastes, particularly the empty fruit bunches (EFB), fronds and trunks composts were reported to have many characteristics that are equal or superior to peat in growing media (Lin and Ratnalingam 1980). Another organic waste that needs to be disposed off is the sewage sludge. Malaysia produces 5 million cubic meters of domestic sludge. By the year 2022, the amount will be increased to 7 million cubic meters per year (Indah Water 1997). Recently in Malaysia, there has been a great interest in converting oil palm wastes into composts with other organic materials. Sewage sludge has been reported to have significant amounts of primary nutrient, N, and other macro and micronutrients and is suitable for composting, for agricultural purposes (Akhtar and Malik 2000; Lazzari *et al*.,2000; Barrena et al. 2005), due to high organic matter content (50% to 70%) of the total solids content and as potting media for horticulture plants (Smith 1992 and Ingelmo 1998; Zubillaga 2001 and Perez *et. al.* 2006). Due to high moisture content, sewage sludges need to be mixed with dry materials (such as sawdust, vegetal remains, straw), which act as bulking agents, absorbing the moisture and providing the composting mass with an appropriate degree of sponginess and aeration (Sanchez Monedero *et al.* 2001; Iranzo *et al.* 2004; Tremier *et al.* 2005). Therefore there is a potential for composting oil palm wastes with sludge to produce composts, physically similar to peat.

Currently, these organic waste materials have not been fully utilized on a large scale either agriculturally or industrially, for manufacture of useful by-products. Research in recycling of oil palm wastes and sewage sludge is important in reducing waste management problems and conserve plant nutrients. However, the amount of sludge added need to be restricted due to its content of heavy metals. The resulting compost would be suitable in potting media for growth of ornamental plants in Malaysia due to prohibited use of sewage sludge for food crops. Presently, no work has yet been done on composting of oil palm wastes with sewage sludge. Therefore, this study was conducted to determine the optimum mixture of oil palm wastes (EFB, frond and trunk) and sewage sludge that will produce compost suitable for use in potting media of ornamental plants. The resulting compost should be fine textured, odourless, rich in macro- and micronutrients and with acceptable levels of heavy metals. It may partially or fully substitute peat in the normally used potting media for ornamental plants.

MATERIALS AND METHODS

Several whole EFB's trunk chips and fronds were collected from an oil palm plantation, Durian Estate, Golden Hope Sdn Bhd, Selangor. They were first manually chopped into small pieces and then shredded with a mechanical shredder into smaller pieces of 6-10 cm to hasten composting process. Dewatered sewage sludge was collected from Indah Water Konsortium (IWK) wastewater treatment plant. The chemical compositions of the oil palm wastes and sewage sludge used in this experiment were as given in Table 1. The pH of oil palm wastes was almost neutral, whilst the sludge had a pH of 5.24. Total nitrogen content in oil palm wastes ranged from 0.75 to 1.10 % N and C/N ratio of 46.25 to 69.71, whereas the sludge had 2.82 % N and C/N ratio of 13.26. The Ca and P contents in the sewage sludge were higher than the oil palm wastes. However P content in the trunk was lower than the EFB and frond. Magnesium content in sludge was lower than the oil palm wastes. The micronutrient contents (Pb, Cd, Mn, Zn, Fe and Cu) in sludge was higher than in the oil palm wastes, however the concentrations did not exceed the maximum permitted concentration in sludges according to the CEC (1986). The treatments for this experiment consisted of types of oil palm wastes (EFB, frond and trunk) which were mixed with sewage sludge in 3 ratios (v:v), i.e. 1:0 (control), 4:1 and 3:1 and 5 replicates. The experiment was conducted in a glasshouse (28 - 31^{o}C) and laid-out in a randomized complete block design using a white polystyrene box measuring 0.6 m (length), 0.5 m (width) and 0.4 m (height). The shredded oil palm wastes were mixed manually with sewage sludge according to the treatments and then placed in a polystyrene box up to 75% volume of the box. Water was sprinkled onto the compost to keep the mixture moist to about 60 % moisture content and composted for 12 weeks. During composting, the mixture was turned every three days and water was sprayed when there was lost in moisture. The composting process was completed when the temperature at the center of the compost heap had cooled down to the ambient air temperature, 29^{o}C. The composting materials were monitored for changes in physical (colour, odour, temperature) and chemical properties (total C, total N, mineral N) during the composting process. A sample of the compost from each box was taken weekly during turning, and divided into two portions. One of which was immediately frozen for NH_4^+-N and (NO_3^- - N + NO_2^- -N) analysis, while the other was air-dried and ground for other chemical analysis. At the end of 12 weeks of composting, volume reduction were calculated and samples were analysed for chemical properties (pH, total N, total C and macronutrients and heavy metals concentration)

The presences of obnoxious odour in the compost were recorded. Compost colour (white or gray colour), due to the growth actinomycetes was also monitored through visual observation during weekly sampling of the compost. Percentage of volume reduction was calculated by taking the difference between the volume of the composting material at the beginning and volume of the compost after the composting process of 12 weeks. The pH was determined in the suspension of 1:5 (w/v) compost: deionized water using pH-meter (Mettler MP 225). Compost moisture content was determined by gravimetric method whereby 10 g of air-dried compost was placed in the oven at 105^{o}C for 24 hours. The samples were then removed from the oven and placed at room temperature to cool off. The weight of the oven-dried compost was recorded.

Table 1
Chemical characteristics of the raw materials used for the composting experiment (n=3).

Parameter	**EFB**	**Frond**	**Trunk**	**Sludge**
pH	7.30 a	6.70 a	6.80 a	5.24 b
C %	50.87 a	52.28 a	52.18 a	37.41 b
N %	1.10 b	0.75 c	0.77 c	2.82 a
C/N	46.25 b	69.71 a	67.77 a	13.26 c
Ca %	0.17 b	0.17 b	0.15 b	0.83 a
Mg %	0.13 a	0.12 a	0.13 a	0.09 b
K %	2.06 a	1.63 b	1.46 c	0.08 d
P %	0.11 b	0.08 b	0.05 c	0.63 a
Pb (mg.kg^{-1})	7.67 b	7.37 b	5.33 b	68.00 a
Cd (mg.kg^{-1})	1.30 b	1.33 b	0.56 c	3.50 a
Mn (mg.kg^{-1})	42 b	47 b	39 b	257 a
Zn (mg.kg^{-1})	37 b	38 b	94 b	1322 a
Fe (mg.kg^{-1})	1076 b	1090 b	951 b	19000 a
Cu (mg.kg^{-1})	8 b	9 b	13 b	178 a

Means with different letters within the row indicate significant differences (p<0.05) using Duncan's Multiple Range Test.
EFB- Empty fruit bunch

Organic C was determined according to the combustion method (McKeague, 1976). One gram of compost was placed in a crucible and put into a furnace at 350 ^{o}C for an hour. The temperature was then raised to 550^{o}C and left for 4 hours. The remaining ash was weighed and organic C was calculated from the loss in weight during ashing. Total N was determined using the Kjeldhal method (Bremner and Mulvaney, 1982). Total analysis of the heavy metals and macronutrients were determined using the aqua-regia method. The extraction solution was made using HCl and HNO_3 solution (3:1). Heavy metals (Pb, Cd, Cu, Ni, Mn, Zn, and Fe) and macronutrients (Mg, Ca and K) in the solution were determined using atomic absorption spectrophotometer, Model PE 5100. Mineral N (NH_4^+-N and NO_3^- -N + NO_2^- -N) was determined according to Bremner (1965). A sub-sample of 10 g was removed for extraction of mineral N with 40 ml of 2 M KCl. The sample was shakened for an hour, then 10 ml of the filtered extract was distilled with MgO for NH^+_4-N and Devarda's alloy for NO^-_3-N and NO^-_2-N, and collected in boric acid. Titration was done with 0.0025 M HC1. All experimental data were analysed statistically using analysis of variance (ANOVA). Duncan's multiple range test (DMRT) was used for comparison of treatment means when F values were significant at $p<0.05$.

RESULTS AND DISCUSSION

Compost Characteristics during Composting

Temperature Patterns: The temperature pattern shows the microbial activity and the occurrence of the composting process (Bernal *et al*. 2009). The optimum temperature range for composting is 40–65°C (de Bertoldi *et al.* 1983), temperatures above 55°C are required to kill pathogenic microorganisms. In this study, it was observed that the compost did not reach thermophilic stage (> 45 °C) (Fig. 1). This could probably be due to the dissipating of heat due to small volume. Moreover, the materials, especially the EFB, were light and spongy and easily compacted. However the addition of sewage sludge increased the temperature compared to the control EFB, frond and trunk represented as ($E_{1:0}$, $F_{1:0}$ and $T_{1:0}$). Generally, temperatures in all the compost mixture were in the range of 28.1 °C to 43.3 °C. There were similar patterns of temperature variations during composting in all the treatments. In this study, it was found that the EFB mixtures resulted in a more rapid rise in temperature within 48 hours compared to the trunk and frond mixtures and reached a maximum temperature of 41.5°C after 1 week similar to those reported by Thambirajah (1988). This rapid increase indicates an intensive microbial activity reflecting a higher degradation rates occurring during the first stage. Finally, temperature decreased and stabilized at 28.0 °C to 30.2 °C after 60 days, during the maturation phase. At this stage, the bio-oxidation phase of composting was considered completed (Hachicha *et al*. 2008).

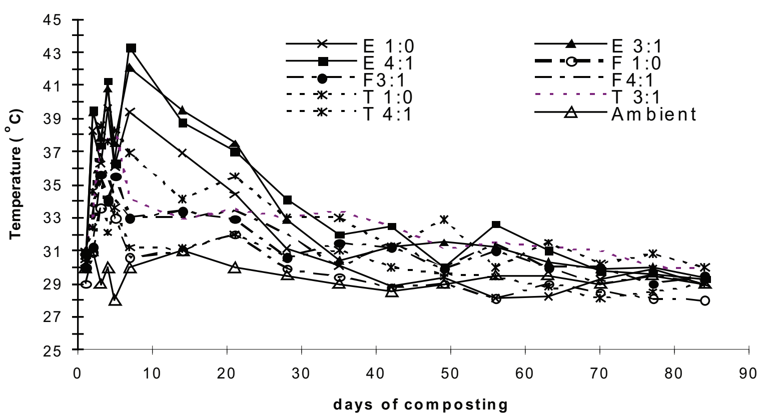

Fig. 1. Changes in temperature of the composting blends of oil palm wastes (E=EFB, F=frond and T=trunk) and sewage sludge at different ratios (1:0, 3:1 and 4:1) during 12 weeks of composting.

C/N Dynamics: Initial C/N ratios of the compost mixture were higher than 30 (Fig. 2). However C/N ratio decreased in each treatment as time progressed and this is due to the mineralization of organic matter by microorganisms (Bernal *et al.* 1998; Brewer and Sullivan, 2003; Grigatti *et al.* 2004; Tognetti, *et al.* 2007). Initial values (C/N of 34.0 to 69.7) dropped to 18.96 to 41.50 at the end of biological process (12 weeks). Addition of sewage sludge showed significant differences (p<0.05) in C/N ratios among the treatments during composting period. The frond and trunk composts ($F_{1:0}$ and $T_{1:0}$) still had high C/N ratio even after 12 weeks of composting. The possible reason for the C/N ratio to go up in the intermediate stage of the composting period could be due to greater nitrogen loss than carbon. According to Hutchings (1985), the evolution of nitrogen content during composting would be conditioned not only by the quantity of total nitrogen and its mineralization rate, but also by the loss of this element through volatilization, denitrification and immobilization process that may occur in the compost. The EFB and trunk + sludge composts had C/N ratio ranging from 18.96 to 22.16. This is within the recommended value by the Council of European Communities (CEC 1986) for compost (C/N< 22).

Mineral N (NH_4^+-N and NO^{3-} - N + NO_2^- -N)

Fig. 3 shows changes in NH_4^+ - N concentration in the different compost mixture over a period of 12 weeks. In general, NH_4^+-N concentration in the various mixtures increased with time. The compost in $E_{3:1}$ and $E_{4:1}$ exhibited a distinct increase in the concentration of NH_4^+-N from 2 to 6 weeks and drop in the concentration of NH_4^+-N after week 6 in treatments $E_{1:0}$ and $E_{3:1}$. In treatment $E_{4:1}$ the drop in ammonium concentration was after week 8. Whereas, treatment $F_{4:1}$ and $F_{3:1}$ showed an increase in NH_4^+-N up to week 8 and 10, respectively, and then decreased. Decreased NH_4^+-N concentrations towards stable values at the end of the thermophilic phase have also been reported by other authors (Laos *et al.* 2002; Levanon and Pluda, 2002; Banegas *et al*. 2007). However, the rate of ammonification in compost mixtures $T_{1:0}$, $T_{3:1,}$ and $T_{4:1}$ showed a slow increase in the initial 6 weeks period and a distinct increase there after, without a drop in NH_4^+-N up to the 12th week .

Fig. 4 shows the changes in NO_3^--N + NO_2^--N concentration in the various treatments. The compost mixtures initially contained low nitrates (i.e 0.6 to 3.6 mg/kg), but at the maturation phase, where temperature decreases to mesophilic and subsequently, ambient levels, nitrification reactions, in which ammonia (a by-product from waste stabilization) is biologically oxidized to become nitrite (NO_2^--N) and finally nitrate (NO_3^- -N) take place. Generally, all the treatments in this study exhibited an increasing trend in NO_3^-- N + NO_2^--N concentration throughout the 12 weeks. This was also observed by other authors (Parkinson et al. 2004; Huang *et al.* 2004; Banegas *et al*. 2007).

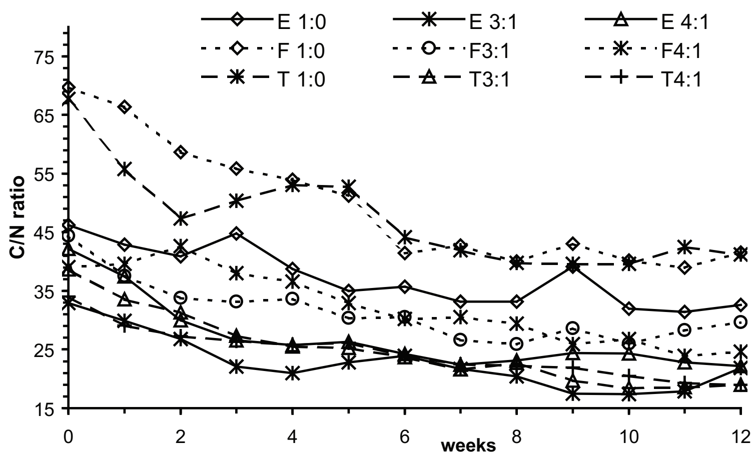

Fig. 2. Changes in C/N ratio of the composting blends of oil palm wastes (E=EFB, F=frond and T=trunk) and sewage sludge at different ratios (1:0, 3:1 and 4:1) during 12 weeks of composting.

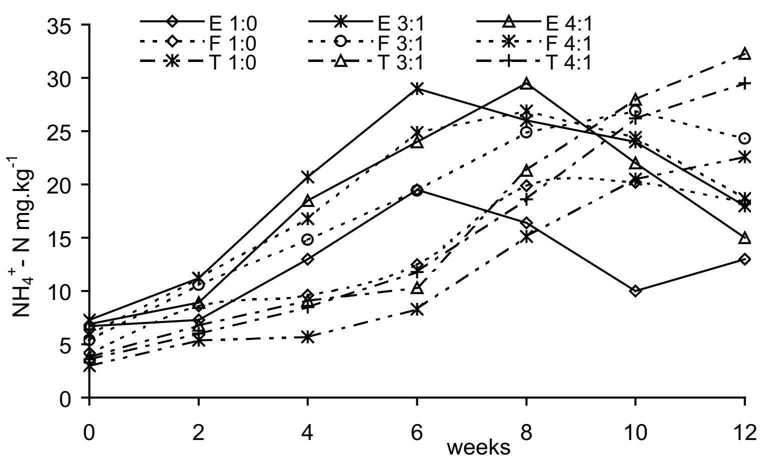

Fig. 3. Changes in NH_4^+ - N concentration of the composting blends of oil palm wastes (E=EFB, F=frond and T=trunk) and sewage sludges at different ratios (1:0, 3:1 and 4:1) during 12 weeks of composting.

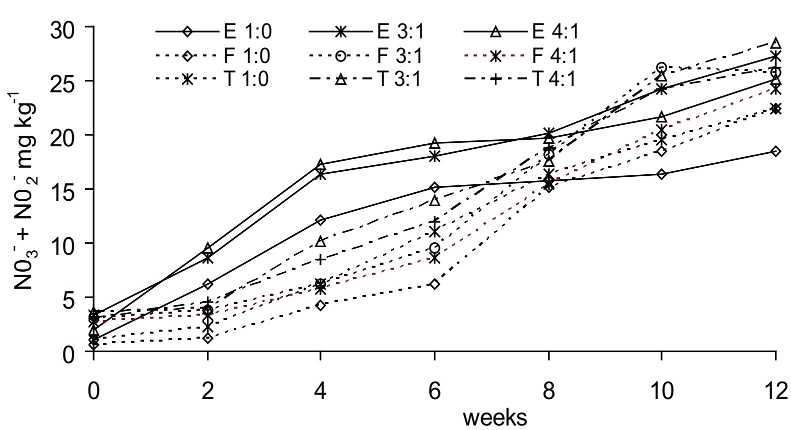

Fig. 4. Changes in NO_3^- -N and NO_2^- -N of the composting blends of oil palm wastes (E=EFB, F=frond and T=trunk) and sewage sludges at different ratios (1:0, 3:1 and 4:1) during 12 weeks of composting.

Changes in Composts Characteristics

Physical Changes: At the beginning of the composting process, putrefaction odours occurred in the oil palm wastes with sewage sludge mixtures. Nitrogen and sulfur compounds (amines and H_2S) are the cause of malodour. However, this odour decreased and produced humus-like odour as the composts matured with time. After 12 weeks, composts with added sludge had darker colour compared to the controls. Mathur *et al.* (1993), reported that the C=O group of quinones and ketones in conjugation caused the dark colour of humic subtances. The trunk + sludge composts had finer particle size similar to peat (< 20 mm). This is within the recommended level of CEC (1986). The EFB and frond + sludge composts were still fibrous with long strands (> 40 mm) and did not look matured. Therefore, these composts would need to be composted more than 12 weeks to achieve finer particle size.

Volume Reduction: The percentage of volume reduction of compost mixtures after 12 weeks of composting process varies widely from 10.6 to 47.0 % (Table 2), depending upon the initial moisture content of the particular compost volume and starting materials used. According to Bernal *et al.* (2009), during the active phase of the composting process the organic-C decreases in the material due to decomposition of the OM by the microorganisms. This loss of OM reduces the weight of the pile and decreases the C/N ratio. There were significant differences (p<0.05) in volume reduction between the treatments compared to the control. The higher percentage of volume reduction was seen in the EFB compost $E_{4:1}$ and $E_{3:1}$ (44.9 and 47.0%, respectively) compared to trunk and frond compost. According to Hashim *et al*. (1993) decomposition of EFB during 12 months resulted in loss of physical structure and showed an inferior growth of plants due to poor water holding capacity and poor anchorage in plants as a potting media. The lower percentage of volume reduction for frond and trunk were characterised by a more compacted and bulky initial material than the EFB which was spongy.

Table 2.
Chemical characteristics of the oil palm wastes (E=EFB, F=frond and T=trunk) and sewage sludge at different ratios (1:0, 3:1 and 4:1) after 12 weeks of composting (n=5).

Parameter	$E_{1:0}$	$E_{3:1}$	$E_{4:1}$	$F_{1:0}$	$F_{3:1}$	$F_{4:1}$	$T_{1:0}$	$T_{3:1}$	$T_{4:1}$
pH	6.9 a	6.7 a	6.9 a	6.1 b	5.8 c	6.0 bc	6.3 b	6.1 b	6.2 b
Vol. rdn.	19.7 b	44.9 a	47.0 a	12.6 c	18.2 b	18.8 b	10.6 d	15.6 b	14.8 bc
N %	1.48 c	1.78 c	1.93 b	1.22 f	1.63 d	1.45 e	1.18 f	2.04 a	2.05 a
C/N	32.6 b	21.83 cd	22.16 cd	41.5 a	29.67 b	24.6 c	41.24 a	19.0 d	18.98 d
Ca %	0.320 g	0.440 e	0.420 e	0.350 f	0. 520 c	0.489d	0.287 h	0.645 b	0.702 a
Mg %	0.260 c	0.40 a	0.330 b	0.180 f	0.220 e	0.180 f	0.160 f	0.250 d	0.230 d
K %	2.11 bc	4.03 a	2.46b	1.89 cd	2.21 bc	2.05 bc	1.32 f	1.66 de	1.39 ef
P %	0.428 c	0.585 d	0.469 e	0.444 e	1.025 a	0.808 c	0.330 f	0.885 b	0.64 d
Pb ($mg.kg^{-1}$)	9.35 h	62 a	34.73 b	9.97 h	29.0 d	26.35 f	15.33 g	33.19 c	26.35 e
Cd ($mg.kg^{-1}$)	1.53 e	3.9 a	3.43 b	2.0 d	3.32 b	2.97 c	0.96 f	2.78 c	1.63 e
Mn ($mg.kg^{-1}$)	46.1 c	108 a	99.43 ab	52.8 c	98.46 ab	84.85 b	46.88 c	87.97b	92.64 bb
Zn ($mg.kg^{-1}$)	112 g	881 a	723 c	66 h	675 d	495 e	188 f	829 b	671 d
Fe ($mg.kg^{-1}$)	3163 cd	7335 a	5322 ab	1201 d	5239 ab	4692 bc	1205 d	6794 ab	6310 ab
Cu ($mg.kg^{-1}$)	17.88 d	68.31 b	67.63 b	9.5 f	53.33 b	52.33 b	14.67 e	78.6 a	68.83 b

Vol. rdn - volume reduction
Means with different letters within the row indicate significant differences ($p<0.05$) using Duncan's multiple range test

pH: According to Zucconi *et al.* (1987), organic substrates having a wide range of pH levels (pH 3 to 11) can be composted. Availability of plant nutrients is affected to a great extent by the pH of the growth medium. Although the composting process is relatively insensitive to pH, because of the wide range of organisms involved (Esptein *et al.* 1977), the optimum pH range for compost appears to be 6.5 to 8.5 (Jeris and Regan 1973: Willson 1993). Compost mixtures with high pH however can lead to loss of N as NH_3 and odour problems (Miller *et al.* 1991). In this study, initially the compost mixture had pH ranging from 6.2 to 7.3. As bacteria and fungi digest organic material, they release organic acids. In the early stages of composting, these acids often accumulate. According to Hachicha *et al*. (2008), the resulting drop in pH encourages the growth of fungi and breakdown of lignin and cellulose. The pH of the compost mixtures after 12 weeks of composting ranged from 5.8 to 6.9 were within the recommended level by CEC (1986) for compost (5.5 to 8.0).

C/N ratio: There were significant ($p<0.05$) differences in the C/N ratio between the compost mixtures (Table 2). The frond and trunk composts in control, $F_{1:0}$ and $T_{1:0}$ still had high C/N ratio even after 12 weeks of composting. The EFB and trunk + sludge composts had C/N ratio ranging from 18.96 to 22.16. This is within the recommended value by CEC (1986) for compost. Addition of sludge to the oil palm wastes resulted in significantly ($p<0.05$) lower C/N ratio in the final compost than the control. However, there were no differences in C/N ratio in the final compost of EFB and trunk added with sludge (3:1 and 4:1).

Total Macronutrients Content

Total N content was significantly ($p<0.05$) higher in the trunk + sludge composts, $T_{3:1}$ and $T_{4:1}$ followed by the EFB + sludge composts, $E_{4:1}$ and $E_{3:1}$ and frond + sludge composts, ($F_{3:1}$ and $F_{4:1}$). Addition of sludge to the oil palm wastes resulted in significantly higher ($p<0.05$) total N in the final compost than the control. Kulhman, (1989) reported that total N content of composts is from 0.5 to 2.7 %. In this study the final compost of oil palm wastes + sludge had total N content ranging from 1.18 to 2.05 % (Table 2) which was more than the recommended level by CEC (1986) for compost (0.6 % N). Phosphorus concentration was highest in the frond composts, $F_{3:1}$ (1.025 %) followed by trunk compost, $T_{3:1}$ (0.885 %). All the composts had more than the recommended P content (0.5 %) by CEC (1986), compared to $E_{1:0}$, $F_{1:0}$, $T_{1:0}$ and $E_{4:1}$. Compost + sludge ratio 3:1 had higher P concentration than 4:1 ratio, obviously due to the higher P content of sludge compared to the oil palm wastes. According to Taiz and Zeiger (1991) P plays an important role in ATP buildup in plants. Phosphorus is the main component in the production of nucleic acids, nucleotides, co-enzymes, phospholipids and phytic acids. According to Morgan (1998), insufficient P concentration in plants could lead to stunted growth and stem and leaves turning to purple. Generally, K concentration in this study was more than the recommended level by CEC (1986) in compost (0.3 % K). The percentage of K was highest in the EFB compost $E_{3:1}$ (4.026 %). This could be due to the initial higher K in EFB than the frond and trunk. The frond compost, $F_{3:1}$ and $F_{4:1}$ had higher K concentrations than the trunk compost, $T_{3:1}$ and $T_{4:1}$. Calcium concentration was higher in composts with sewage sludge than the controls. This could be due to higher Ca content of sludge compared to the oil palm wastes. The Ca content was significantly higher ($p<0.05$) in the trunk + sludge composts, $T_{3:1}$ and $T_{4:1}$ (0.705 and 0.635%, respectively) followed by the frond + sludge compost, $F_{3:1}$ and $F_{4:1}$ (0.523 and 0.477%, respectively). However, the Ca content in this study was less than 2.0%, which is the recommended level by CEC (1986). According to Eysinga *et al.*, (1980), Ca deficiency in plants could lead to smaller flower, stunted growth and deformation of petals. The concentration of Mg was highest in the EFB compost, $E_{3:1}$ followed by $E_{4:1}$. The Mg content in this study was less 0.3% which is the recommended level in compost by CEC (1986), except for treatments in $E_{3:1}$ and E4:1. The trunk composts, $T_{3:1}$ and $T_{4:1}$ had Mg concentration of 0.237 and 0.229 %, respectively. The frond compost, $F_{3:1}$ and $F_{4:1}$ had 0.207 and 0.182 % Mg concentration, respectively. The composts, $F_{1:0}$, $F_{4:1}$ and $T_{1:0}$ had lower Mg content than the other composts. According to Bernal *et al.* (2009), as a result of the dry weight loss of the material during composting, the concentration of mineral elements increases. Generally addition of sludge to oil palm wastes had significantly increased the total macronutrient content of the oil palm wastes + sludge composts compared to the control.

Total Heavy Metals Content

Composts added with sludge contained 26.35 to 62.0 mg kg^{-1} Pb, 495.0 to 881.0 mg kg^{-1} Zn, 4692 to 7335 mg kg^{-1} Fe, 87.97 to 107.99 mg kg^{-1} Mn, 1.63 to 3.90

mg kg^{-1} Cd and 52.33 to 76.45 mg kg^{-1} Cu (Table 2). Generally, addition of sludge to oil palm wastes had significantly increased the heavy metal contents of the oil palm wastes + sludge composts compared to the control due to the higher heavy metal contents in sewage sludge. Compost mixtures with 3:1 ratio had higher Pb, Zn and Cd concentrations than 4:1 ratio but were within the recommended level by CEC (1986), for compost.

CONCLUSION

After 12 weeks of composting oil palm wastes with sewage sludge, most of the biodegradable fraction of EFBs, fronds and trunks had decomposed and the most resistant fraction remained. Compared to EFBs and trunks, the fronds had higher percentage of C/N ratio after 12 weeks, which ranged from 18.96 to 41.40. Supply of microorganism from the addition of sewage sludge and higher N availability had hastened the composting process. The high amounts of available micronutrients released in the oil palm wastes with sewage sludge compost could be good source of nutrients for plants and could be used as slow release nutrient source for a long duration, throughout the whole vegetative and flowering stages in plants. At week 12, the trunk composts had finer particle size similar to peat. However the EFB and frond + sludge composts were still fibrous with long strands and did not look matured and may need to be composted more than 12 weeks to achieve finer particle size.

Generally, the trunk + sludge composts seemed to be better than the EFB + sludge and frond + sludge composts. Total N and Ca contents were highest in the trunk + sludge compost at week 12. The P and K contents were also fairly high. The pH, C/N, macronutrients and micronutrients were within the recommended levels of CEC (1986) in compost. Since heavy metals content were higher in the 3:1 than 4:1 compost ratio, the trunk + sludge compost ($T_{4:1}$) was selected to be the most ideal for use as a potting media for ornamentals as a complete or partial substitute for peat. This would convert oil palm waste, especially the trunk into a value-added product and provide an alternative disposal method for sewage sludge produced by IWK.

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