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Waste Management: Waste Reduction and Nutrient Recovery During the Co-composting of Empty Fruit Bunches and Palm Oil Mill Effluent*

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Palm oil is the most consumed edible oil in the world. Roughly half of the production originates from Indonesia, where the expansion of the crop has been criticised from an environmental perspective. Reducing the environmental impact of plantations through better waste management practices is critical to achieve cleaner production. In this context, this study is focused on composting, a practice increasingly adopted by agro-industries. This trial was designed to test co-composting of the main palm oil mill by-products viz: empty fruit bunches (EFB) and palm oil mill effluent (POME) – under different POME/EFB ratios and mixing frequencies. After 60 days, the compost was found to be still in a mesophilic phase that could not be considered as mature compost due to the high C/N ratio and elevated temperatures. High weight and volume reduction were achieved (-40% and -60% respectively), as well as significant water evaporation from the POME and EFB (-60%). It was found that a POME to EFB ratio of 1 to 1.5 m^3 per tonne was optimal when the EFB moisture content was in the region of 65 per cent to70 per cent. with large air pockets often exceeding 50 per cent for nutrient recovery, showing that in our experimental conditions the composting process was not suitable for treating the entire POME produced by the mill (3m^3/tonne of EFB). The nutrient recovery rate was close to 100 per cent for phosphorus, potassium and magnesium. For nitrogen, 30-35 per cent loss was observed. Composting on a concrete platform with a roof, without over-spraying on the piles and recycling all the leachates are critical points to achieve high nutrient recovery efficiency and to control final compost quality.

Keywords: *Composting, empty fruit bunch, palm oil mill effluent, nutrient recovery, oil palm, sustainability.*

With a growing global demand for oil and fats (Corley, 2009) oil palm production has been increasing exponentially over the last 30 years and is now the world's most consumed edible oil. The prevalence of Indonesia in this expanding global market provided the country with significant benefits for both agro-industries and smallholders (Rist *et al.*, 2010; Euler *et al.*, 2016). However, the high environmental impact associated with specifically the oil palm development has been pin pointed by various governmental and non-governmental organisations in recent years. This unprecedented expansion of oil palm

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plantations has been recognised as a major driver of deforestation in addition to the pulp and paper plantations, mining concessions and logging concessions (Abood *et al.*, 2015). Environmental pollutions and emissions of greenhouse gases (GHG) during the process of palm oil production became targets of global concerns (Bessou *et al.*, 2014; Schmidt, 2010).

The transition towards agro-ecological food systems has been identified as one way to improve the sustainability of agricultural production (Altieri & Nicholls, 2005). In an agro- ecological framework, farming systems are not only assessed on the sole criteria of productivity and profitability but also on their ability to achieve "a series of ecological services such as conservation of agrobiodiversity, soil and water conservation and enhancement, improved biological pest control etc., regardless of scale or farm size" (Altieri & Nicholls, 2005). Agro-ecological practices in palm oil plantations reviewed by Bessou *et al.* (2017), stressed the importance of recycling organic waste. Soil health, as defined by Kibblewhite *et al.* (2008) plays a key role in agro-ecological farming systems, and feeding the soil with compost can be a way to maintain productivity while increasing other ecosystem functions (Dislich *et al.*, 2016). These claims are confirmed by studies evaluating the effect of fertilisation practices on water quality and soil quality at the watershed level (Comte *et al.*, 2013; Comte *et al.*,2015), as well as evidence on the risks associated with excessive use of mineral fertilisers (Dubos *et al.*, 2016). In terms of sustained productivity, Tohiruddin and Foster (2013) showed that 10 tonnes per hectare (70 kg/palm/year) of compost can be used as an effective substitute for mineral fertilisers in terms of nitrogen (N) and phosphorus (P) nutrition. Several studies documented the effect of organic matter application in the form of empty fruit bunches (EFB). Carron *et al.* (2015) showed that EFB application would increase soil fertility and biological diversity for at least two years after application. Tao *et al.* (2016) showed that EFB application increased soil microbial activity while maintaining high productivity levels (Tao *et al.*, 2017). Other tests in oil palm plantations observed that composted EFB are less attractive for *Oryctes* spp. than fresh EFB (Supriatna *et al.*, 2018) suggesting that compost could also contribute towards the reduction in the use of pesticides.

Composting palm oil mill by-products for the fertilisation of commercial blocks could improve the recycling of nutrients, reduce the cost of fertilisation, increase nutrient efficiency through a slower release and increase of soil quality from a physical and biological point of view. Better waste management aims to avoid contamination of surface and ground water due to soil run-off, nutrients or chemicals, or as a result of inadequate disposal of waste including palm oil mill effluent (POME) (Singh *et al.*, 2010; Zarhim, 2014). The use of compost can also be linked to climate change mitigation (Stichnothe & Schuchardt, 2010; Nasution *et al*, 2018), by avoiding anaerobic digestion of the POME that results in high methane emissions (Choo *et al.*, 2011).

Composting is a complex biological transformation of organic matter carried out by a succession of microbial communities under controlled environmental conditions. Composting occurs in the solid state and is strictly aerobic under a thermophilic phase. The amount of EFB produced per tonne of processed fresh fruit bunch (FFB) is quite stable (about 23 t EFB / 100 t FFB). For POME the quantity and the composition can vary from 45 m^3 to 65 m^3 POME per 100 tonnes FFB according to the technology or machinery used for processing FFB (Schuchardt *et al.*, 2007).

The composting processes is to be accelerated by adding nitrogen in the form of urea (Salètes *et al.*, 2004) or solid decanter cake with high N content (Yahya *et al.*, 2010). In most of the studies considered, EFB were pretreated (shredded or chopped). Mesophilic digestion of the ligneous fraction by various fungi has also been studied as a pretreatment for EFB (Perwitasari *et al.*, 2018) but has never been implemented in agro-industries. Salètes *et al.* (2004) showed that with an open composting system almost 50 per cent of the phosphorus, 70 per cent of the potassium, 45 per cent of the magnesium and between 10 per cent and 20 per cent of the calcium originally present were lost after 10 weeks of composting. The study stressed the importance of protecting the windrows from rain and leachate recycling to minimise K losses. Excessive leaching resulting in nutrient losses during open composting process were confirmed in a case study made in an oil palm plantation in Kalimantan (Baron *et al.*, 2018).

Research questions

The authors chose to study the composting process taking into account its environmental and agronomical impacts to answer the following questions:

- i. How much POME can be utilised through composting?
- ii. What is the optimum turning (mixing) frequency of the compost?
- iii. What is the efficiency of nutrient recovery under controlled conditions?
- iv. What is the standard nutrient content that can be expected from the compost?

In order to answer these questions, the authors studied the general kinetics involved in the EFB composting as well as the impact of turning frequency and the POME to EFB ratio on the weight reduction and nutrient recovery rate during composting. This study did not focus on identifying the changes in the microbial community during the composting process, but measured the physical and chemical changes in organic matter resulting from microbial activity.

MATERIALS AND METHODS

Local conditions

This experiment was conducted in a palm oil mill belonging to the ANJ Group, located on the island of Belitung (Bangka Belitung, Indonesia). It was carried out in May-June-July 2016, when the average air temperature varied from 28°C to 35°C and the relative air humidity ranged from 75 per cent to 95 per cent.

Experimental design

The effluents used for this experiment were pre-digested POME from biogas production ponds. The duration of pre-digestion of POME used was one day after cooling ponds. The POME to EFB ratio chosen were 1, 3 and 4 m^3 POME per tonne of fresh EFB, corresponding to a daily dose of 28, 85 and 112 L of effluent per tonne of EFB, respectively. Those treatments will be hereafter referred to as R1, R3 and R4. R3 is considered as the current average used by agro-industries and also a target ratio, as it is the proportion of POME and EFB produced by the plant.

The turning treatments chosen were: every 3 days, every 10 days, every 20 days and every 10 days with passive aeration (perforated metal tubes inserted vertically in the compost heaps). These treatments will be referred to as T3, T10, T20 and TP10. TP10 was the current industrial operating procedure at the time of the experiment.

The experimental layout consisted of 12 treatments (4 turning modalities * 3 ratios) repeated two times. The 24 experimental compost piles followed a split-plot design with two blocks. Each block was divided into three plots of four compost piles each receiving the same POME/EFB ratio. Each one of the four piles within one plot received a different turning treatment. This specific design was chosen to facilitate the daily application of POME on the piles.

Composting process

Fresh EFB coming directly from the plant were used for composting (no chopping, no shredding, no delay between processing and composting). Each compost pile weighed approximately 3.8 tonnes heaped to form a trapezium having a volume of about 10 m^3 (*Figure 1*). The experimental composting piles were placed on a concrete floor, having draining canals and a zinc roof, to ensure adequate draining of the leachate and to avoid exposure to rainfall.

After the formation of the piles, the EFB were inoculated with BAR formula's commercial microbial mix, containing strains from the genus *Bacillus subtilis, Azotobacter, Nitrobacter, Nitrosomonas*, as well as fungi such as *Trichoderma viride, Phanerochaete chrysosporium, Neurospora*, and *Actinomycetes (Actinobacteria), Kocuria rhizophila.* EFB discharged from the mill have already been sterilised followed by microbial inoculation to avoid variability in the process by ensuring a quick and homogenous start of the microbiological process. The microbial example: *Actinomycetes (Actinobacteria)* and *Azotobacter* are some of the dominant strains in thermophilic compost (Partanen *et al.*, 2010). Others such as *Nitrobacter* and *Nitrosomonas* are involved in the fixation of atmospheric nitrogen and mineralisation of organic N (Sanchez *et al.*, 2017), and fungi are decomposers of cellulose and lignin (Xi *et al.*, 2012).

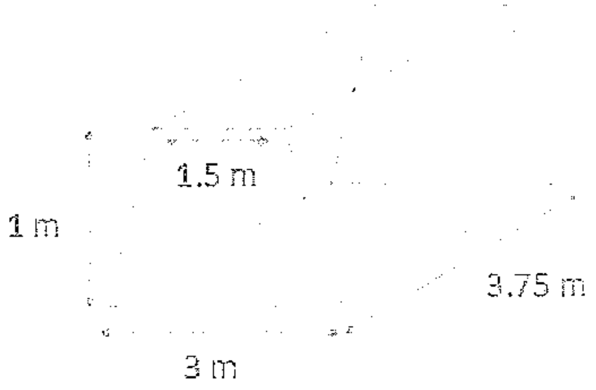

Figure 1 Dimensions of the standard composting pile

Pre-treated POME from the biogas plant was stored in a 5 000 L tank and sprayed on to the shredded EFB heap using a pump and hose system. Each heap was sprayed six times a week at a constant rate to complete the ratio in 40 days (see daily doses in *Table 1*). The leachates from the windrows were collected through drainage canals and were pumped back to the POME tank. This means that all the leachates from the piles were mixed up and recycled to be sprayed again, and after the first days the compost piles received a mix of POME straight from the POME anaerobic digestion pond and recycled leachates. The total volume of leachates was measured each day for all plots, and the amount for each plot was estimated visually. Spraying was stopped after 40 days of composting and the compost was harvested after 60 days (drying period of 20 days). Turning (mixing and piling) was executed using an excavator.

Measurements and sampling

The core temperature of each pile was measured before spraying every morning with

TABLE 1
AVERAGE CHEMICAL PROPERTIES OF EFFLUENTS USED FOR COMPOSTING AND COMPOST LEACHATES

	N	*P*	*K*	*Mg*	*C organic (% DM)*	*pH*
	(mg/L)					
POME (Post biogas)	336	33	3 193	128	19.8	7.5
Compost leachates	443	58	4 173	188	16.2	8.0

Note: DM = dry matter

a thermic probe Prosensor SCI 1500. Every 20 days, each pile of compost was loaded onto a small truck and weighed using the mill weigh bridge, then put back into place. Pile volume was measured after weighing by measuring the height and width of the pile at three points across and three points along the pile. The 24 measurements per pile were used to make a three dimensional model of the pile to estimate the total volume.

A composite sample (8 points) of compost was taken from each pile every 20 days. The samples were dried in an oven at 80°C until constant weight was reached (24 h to 48 h) to determine moisture content. POME and leachate samples were also collected during the experiment to determine their composition.

Chemical and biochemical analysis

All analyses were performed on dry samples. Ash content was determined by calcination at 550°C during 4 hours. Nitrogen content was measured with the Kjeldahl distillation method. Organic carbon was determined by the Walkley and Black titration. pH was determined through electrometric pH measuring device.

Mineral content was measured by extracting minerals from the ashes. P content was then determined by Spectrophotometry. K and Mg content were determined by Flame photometry.

Data analysis

Free air space was calculated from the volume, weight and moisture of the pile. Density of water is 1 tonne per cubic metre and the density used for ligno-cellulosic organic matter was 1.6 tonne per cubic metre (Abd El Kader *et al.*, 2007). The actual POME/EFB ratio is the amount of POME coming from the plant that is actually absorbed by the pile and degraded during composting. It is calculated by subtracting the amount of compost leachates that are recirculated daily and sprayed on the compost. The nutrient recovery efficiency (NRE) is calculated for each element (N, P, K, Mg) as the ratio between the final stock of nutrient and the original stock of nutrient contained in the EFB and the POME, using the actual POME/EFB ratio.

RESULTS AND DISCUSSION

General kinetic of the composting process

The EFB fresh from the plant were still warm, around 40°C (*Figure 2*). The temperature increased quickly after the formation of the pile to reach 60°C after three days. A thermophilic peak followed from day 4 to day 12, with temperatures averaging 65°C. After day 12, the temperature stabilised and remained around 50°C to 55°C for the rest of the composting

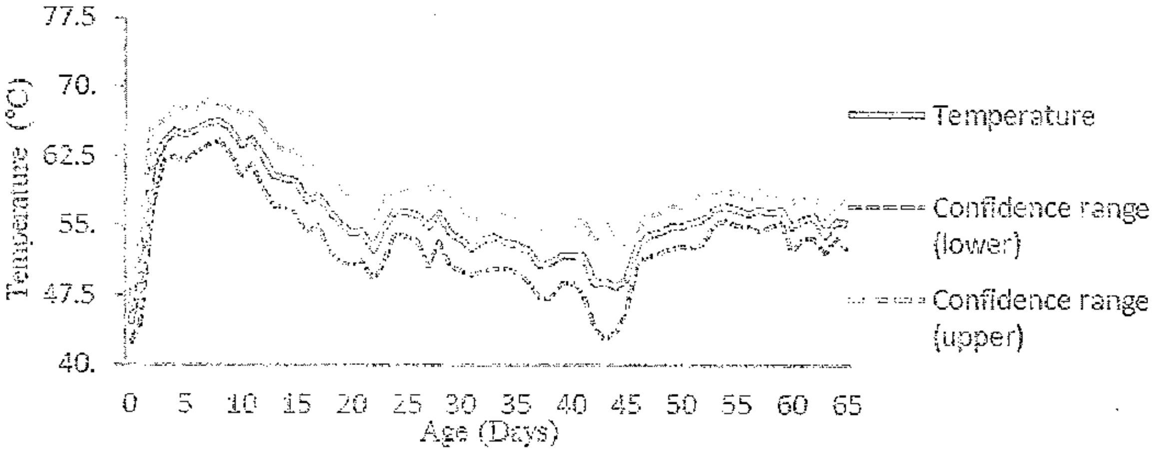

Figure 2 *Temperature trend during the composting process. The lower and upper ranges represent the standard deviation of temperature*

process. No significant effect of treatments on the average temperature or C/N ratio was observed. The C/N ratio decreased from 50 to 30 during the composting process (*Figure 3*). The compost still had a high C/N ratio and temperature at day 60 and could therefore not be considered as a completely mature or stable product. The biological activity of compost was sustained by daily sprayings of POME containing biodegradable organic matter until day 40.

The overall loss in dry matter observed from composting was -45 per cent after 60 days. Most of the degradation occurred between days 0 and 20 (-30%). The POME/EFB ratio did not affect the reduction of dry weight throughout the composting process. The turning process had an effect on dry weight reduction at day 20 (D20) and day 40 (D40) (*Figure 4*), with a significant difference between T20 and T3 treatments (with the lowest and highest reduction respectively). At D60, the only significant difference was between T3 and TP10, which were the highest and lowest

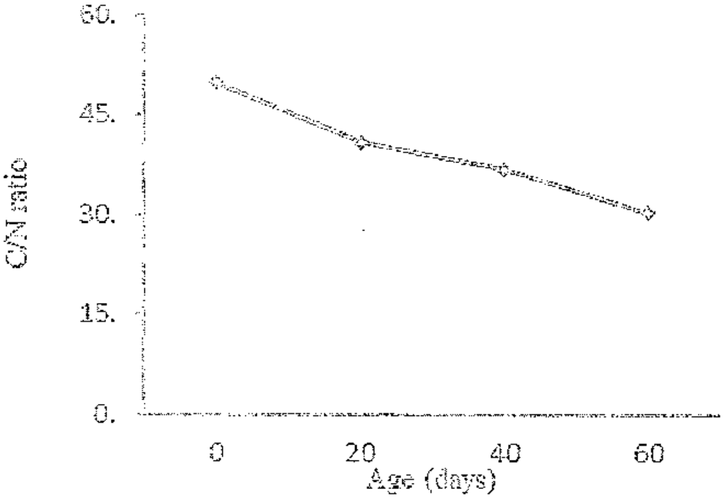

Figure 3 *Evolution of C/N ratio during composting. Error bars represent the 95 per cent confidence interval from the ANOVA analysis*

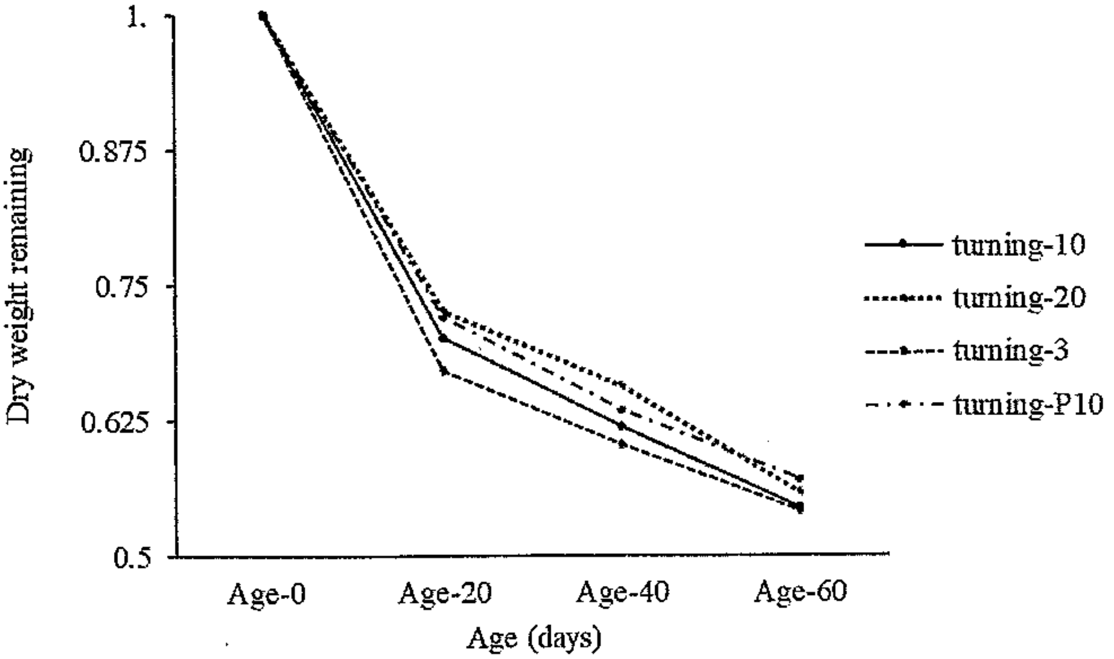

Figure 4 Effect of the turning frequency on the dry weight reduction during composting, expressed as a fraction of the original dry weight of the EFB piles. Error bars represent the 95 per cent confidence interval from the ANOVA analysis

weight respectively. The fresh weight ratio of compost to fresh EFB ranged from 49 per cent to 62 per cent. The treatments had no effects on the final fresh weight reduction. The volume reduction occurred primarily at the beginning of the composting process, between day 0 and day 20, and then slowed. After 60 days, the volume of the pile was about 40 per cent of the original volume, a result similar for all treatments.

The turning frequency produced no significant impact on compost moisture throughout the composting process, but the POME/EFB ratio had a significant effect on moisture at D20 and D40, with the R1 ratio having a lower moisture (*Figure 5*). The final moistures of the compost piles were between 62 per cent and 70 per cent. Overall, the thermophilic composting process led to the evaporation of 60 per cent to 65 per cent of the water contained in EFB and POME. The raw EFB (non-shredded) have a very bulky structure, resulting in a lot of free air space inside and between bunches at the beginning of composting (>60%). The free air space had reduced due to changes in EFB structure caused by microbial degradation, turning operations and uptake of water by the pile (*Figure 6*). Additional water coming from POME spraying occupied the free space inside the piles. The percentage of free air space remained high throughout the process, the lowest point being 40 per cent, which was considered low but still aerobic conditions for composting (Abd El Kader, 2007). The effect of POME on free air space was significant at D20 and D40, as R1 maintained a higher proportion of free air space.

Leaching and actual absorption of POME

The amount of leachates varied with time and with the POME to EFB ratio. Toward D40 it was close to 90 per cent of the effluent

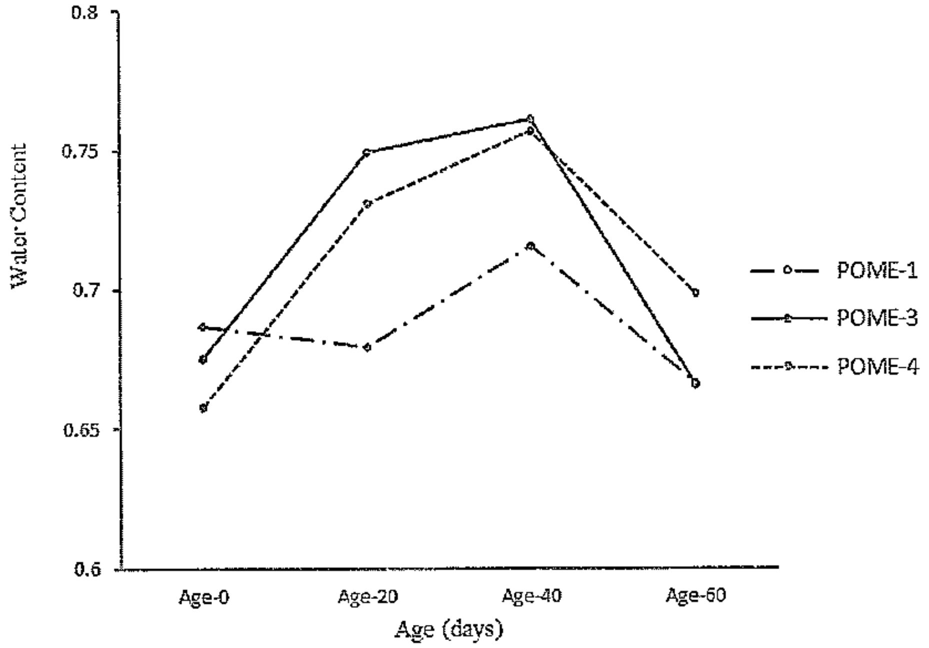

Figure 5 *Effect of the POME to EFB ratio on moisture of the compost. Error bars represent the 95 per cent confidence interval from the ANOVA analysis*

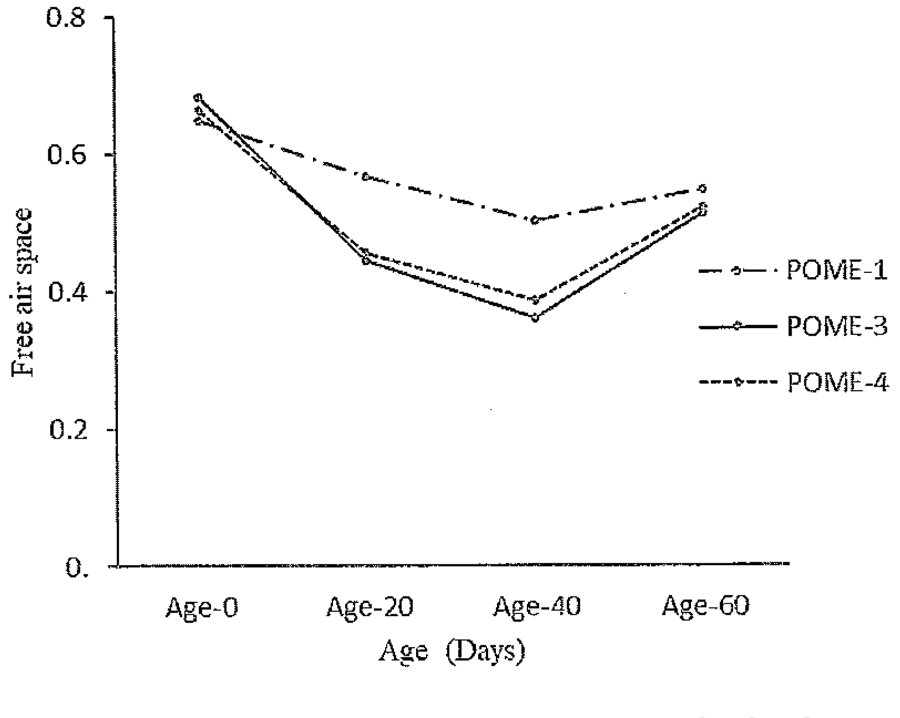

Figure 6 *Effect of the POME/EFB ratio on the free air space within the piles, expressed as a fraction of the total volume of the pile. Error bars represent the 95 per cent confidence interval from the ANOVA analysis*

sprayed daily, for the R4 treatment. The actual POME/EFB ratio, i.e. the amount of POME from the mill that can be recycled with zero discharge of leachates, was limited to 0.7 m^3 to 1.7 m^3 per tonne of fresh EFB, according to the treatment (*Table 1*). Leachates had a higher nutrient content than the POME sprayed onto the piles, but a lower content of organic matter (*Table 2*), confirming that when effluents percolate through the piles organic matter is deposited and some nutrients are washed away.

Nutrient content and recovery efficiency

Only the POME/EFB ratio had an effect on chemical properties, with the R1 treatment having a more alkaline pH and higher potassium content (*Table 3*). Overall, the reduction of organic matter during the composting process led to a concentration of nutrients and a net increase for all nutrients (*Figure 7*). This increase was particularly sharp for potassium.

The average nutrient recovery efficiency showed that the composting process studied was very efficient for recycling minerals contained in the palm oil mill by-products (91% potassium, 96% magnesium and 100% phosphorus). Nitrogen losses were more conspicuous with only 65-70 per cent of recovery. The authors hypothesise that higher losses for nitrogen were mostly due to ammonia volatilisation at high temperature and free air space (Sánchez-Monedero *et al.,* 2001; Abd El Kader *et al.*, 2007; Jiang *et al.*, 2011). The contribution of POME and EFB to the original nutrient stock and the NRE for each element is shown in *Figure 7*. Recycling POME is critical for enriching the compost; the effluent provides 47 per cent of the K stock and 22 per cent of the Mg stock.

Reducing leaching and nitrogen losses

The high leaching observed also attributed to

TABLE 2
FINAL POME/EFB RATIO (ESTIMATES).

	R1	*R3*	*R4*
Daily spraying dose (L/tonne EFB)	28	85	112
Real POME/EFB ratio (L/tonne)	750	1 400	1 500

TABLE 3
EFFECT OF THE POME/EFB RATIO ON THE CHEMICAL CHARACTERISTICS OF COMPOST AT DAY 60

Treatment	*Moisture (%)*	*pH*	*Corg*	*N*	*P*	*K*	*Mg*
			(%) DM				
R1	67 a	9.08 a	46.96 a	1.52 a	0.23 a	5.97 a	0.40 a
R3	67 a	8.75 b	46.93 a	1.65 a	0.27 a	3.68 b	0.44 a
R4	70 b	8.50 b	47.66 a	1.56 a	0.29 a	3.81 b	0.49 a
Average	68	8.77	47.18	1.58	0.26	4.49	0.44

Note: Different letters in column indicate a statistically different value between the treatments (Tukey test)

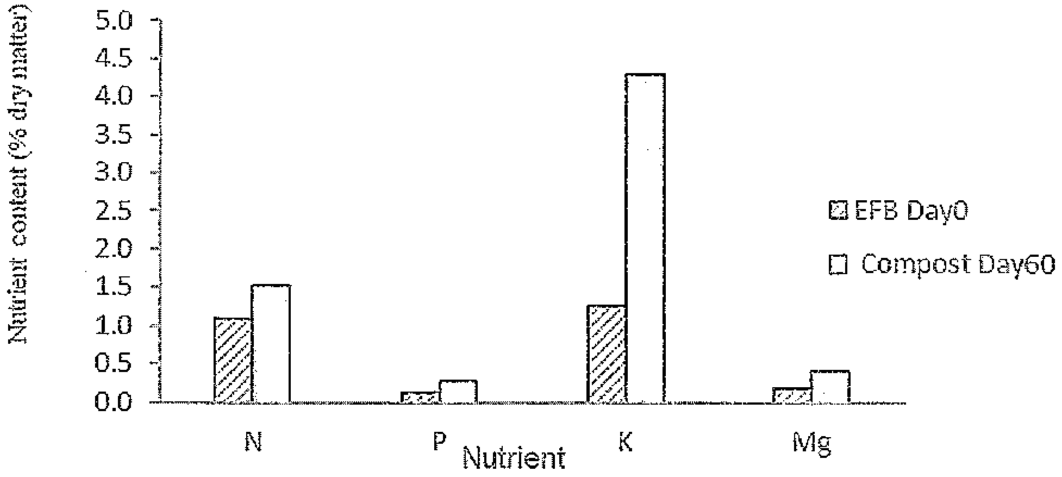

Figure 7 Evolution of nutrient content during composting. Error bars represent the 95 per cent confidence interval from the ANOVA analysis

the compost structure, which had high free air space between bunches. Pre-treatments of EFB (shredding and compacting) to reduce the size of fibre aggregates could reduce leaching and increase POME uptake. Some other researchers suggested higher POME/EFB ratios, up to 3 m^3 per tonne, but they did not estimate the real ratios as they did not take into account the proportion of leachates (Baharuddin *et al.*, 2009; Salètes *et al.*, 2004). Most leaching happens after D20, and it is suggested that spraying programmes be adapted to match the different composting phases. The daily dose of POME should also be highest at the beginning of the process (0-20 days) and then decreased progressively.

Compost can improve the environmental footprint of palm oil production due to methane avoidance, but it is unlikely that all of 0.55-0.65 m^3 per tonne FFB can be used up through composting. Compost is one part of the solution for methane avoidance, but increased water efficiency at the mill is also necessary. Improved systems can bring POME production to 0.25 m^3 per tonne of FFB (Schuchardt *et al.*, 2007). This is a realistic number to recycle 100 per cent of POME through composting (1.1 m^3/tonne EFB). The composting process will evaporate 65 per cent of the waste water using only biological energy, and the use of nutrient rich POME will significantly increase the final quality of compost regarding plant nutrition (*Figure 8*).

Regarding nitrogen losses, Abd El Kader *et al.* (2007) showed that compacting piles and maintaining high moisture can help reduce NH_3 emissions, which represent the majority of N losses during composting (Jiang *et al.*, 2011). This treatment together with intermediate turning frequency (10 days) could reduce NH_3 losses during the thermophilic phase by lowering the aeration rate of the pile (Jiang *et al.*, 2011). However, the data of the authors shows that the difference between treatments in terms of moisture did not result in difference in N losses in the final compost. During the mesophilic/drying phase of the compost, piles could be turned and/or spread to decrease their temperatures below 40°C in order to favour the nitrifying process of ammonia and reduce risk of losses (Sánchez-Monedero *et al.*, 2001). Those two practices – reduced free air space in thermophilic phase and quick cooling in mesophilic phase – could be tested to improve

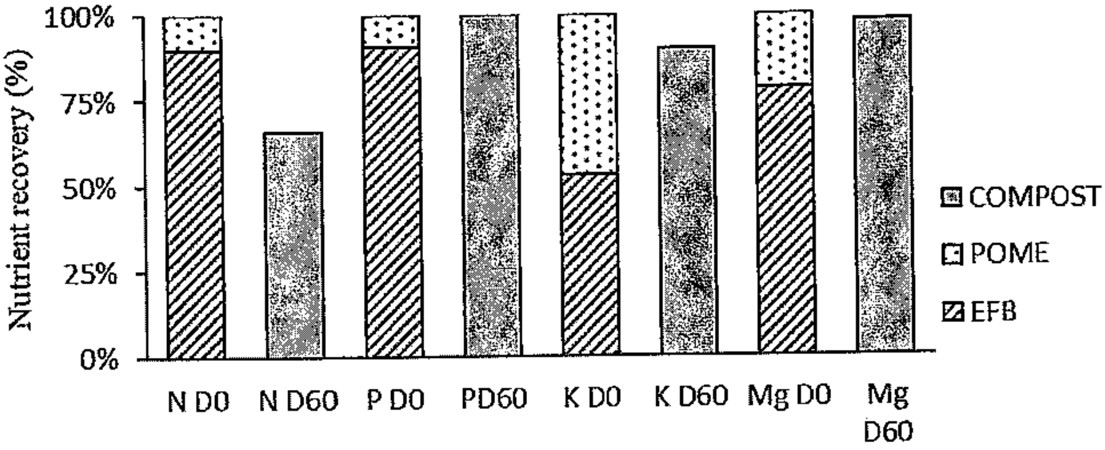

Figure 8 *Nutrient recovery during the composting process.*
(Note: *The graph plots the original stock of nutrients at day 0 (POME+EFB=100%) against the final stock of nutrients in the compost at day 60, expressed as a fraction of the original stock. The values come from the average case scenario presented in* Table 5, *but corrected with a coefficient of 0.91. This correction factor is applied to compensate for potential overestimates and is calculated so that NRE= 100 per cent for phosphorus. Corrected NRE values are N: 66 per cent; P: 100 per cent; K: 91 per cent; Mg: 96 per cent)*

the NRE for nitrogen. An optimum has to found to reduce NH_3 emissions, but a very low aeration rate of the compost pile can increase emissions of CH_4 and N_2O (Yuan *et al.*, 2016).

CONCLUSION

The composting process efficiently reduced the amount of waste in palm oil mills and recycled nutrients contained in POME and EFB. A 60 days composting process with a drying period of 20 days was sufficient to fully recycle 0.75 m^3 to 1.5 m^3 of POME per tonne of fresh EFB, which represented all EFB and 25 per cent to 50 per cent of the POME produced by the palm oil extraction process. During this period, the loss of 50-60 per cent of organic carbon and the evaporation of 60-65 per cent of the water contained in those by-products significantly reduced the amount of solid and liquid waste. Composting on a concrete platform with a roof and recycling all leachates guaranteed an efficient recovery of minerals. 30-35 per cent of nitrogen was lost through volatilisation. The composting process led to an increase in mineral content and provided a final product that can be used in mature oil palm plantations. The high potassium content of the compost matches the oil palm's demand in nutrients.

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