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Waste reduction and nutrient recovery during the co-composting of empty fruit bunches and palm oil mill effluent

Pengurangan limbah dan pemulihan nutrisi selama proses pengomposan tandan kosong dan limbah cair pabrik kelapa sawit

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Abstrak

Minyak kelapa sawit adalah minyak nabati yang paling banyak dikonsumsi dunia. Setengah dari produksinya berasal dari Indonesia, walaupun perluasannya telah dikritik dari sudut pandang lingkungan. Pengurangan dampak lingkungan perkebunan melalui praktik pengelolaan limbah yang lebih baik sangat penting untuk mencapai produksi yang lebih bersih. Dalam konteks ini, penelitian difokuskan pada pengomposan, praktik yang semakin banyak diterapkan di agroindustri. Penelitian bertujuan untuk menguji pengomposan produk samping pabrik kelapa sawit yaitu tandan kosong kelapa sawit (TKKS) dan limbah cair pabrik kelapa sawit (LCPKS), pada rasio LCPKS/TKKS dan frekuensi pembalikan yang berbeda. Setelah 60 hari, kompos masih dalam fase mesofilik dan tidak dapat dianggap sebagai kompos matang karena rasio C/N dan suhu yang tinggi. Penurunan bobot dan volume yang tinggi telah dicapai masing-masing sebesar 40% dan 60%, serta penguapan air yang signifikan dari LCPKS dan TKKS (60%). Rasio LCPKS terhadap TKKS pada 1 – 1.5 m^3/ton adalah optimal untuk mencapai kelembaban (65-70%), ruang udara bebas (>50%) dan pemulihan nutrisi, juga menunjukkan bahwa dalam kondisi percobaan ini proses pengomposan tidak dapat menggunakan semua LCPKS yang diproduksi oleh pabrik (3m^3/ton TKKS). Tingkat pemulihan nutrisi mendekati 100% untuk fosfor, kalium dan magnesium, sedangkan untuk nitrogen terjadi kehilangan sekitar 30-35%. Pengomposan dengan platform beton dan beratap, tidak melakukan penyemprotan pada tumpukan secara berlebihan, dan mendaur ulang semua limbah cair merupakan hal penting untuk mencapai efisiensi pemulihan nutrisi yang tinggi dan untuk mengontrol kualitas kompos akhir.

[Kata kunci: pengomposan, tandan kosong, pemulihan nutrisi, kelapa sawit, limbah cair pabrik kelapa sawit, keberlanjutan]

Abstract

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 criticized from an environmental perspective. Reducing the environmental impact of plantations through better waste management practices is critical to achieve cleaner production. In this context, our study was focused on composting, a practice increasingly adopted among agro-industries. Our trial was designed to test co-composting of the main palm oil mill by-products – empty fruit bunches (EFB) and palm oil mill effluent (POME) – under different POME/EFB ratios and turning frequencies. After 60 days the compost was still in a mesophilic phase and could not be considered as mature compost due to high C/N ratio and temperature. High weight and volume reduction were achieved (40% and 60% respectively), as well as significant water evaporation from the POME and EFB (60%). We found that a POME to EFB ratio of 1 to 1.5 m^3/ton was optimal for moisture (65-70%), free air space (>50%) and nutrient recovery, showing that in our experimental conditions the composting process could not use all the POME produced by the mill (3m^3/ton of EFB). The nutrient recovery rate was close to 100% for phosphorus, potassium and magnesium. For nitrogen we observed 30-35% of losses. Composting on a concrete platform with a roof, not over-spraying the piles and recycling all the leachates are critical points to achieve high nutrient recovery efficiency and to control final compost quality.

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[Keywords: composting, empty fruit bunch, nutrient recovery, oil palm, palm oil mill effluent, sustainability]

Introduction

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 on this expanding global market provided the country with important benefits for both agro-industries and smallholders (Rist *et al.*, 2010; Euler *et al.*, 2016). However, the high environmental cost of this agricultural development was pointed out by various governmental and non-governmental organizations in recent years. Indonesia has lost an important part of its primary forest cover in the last decades (Margono *et al.*, 2014) and the expansion of oil palm plantations is recognized to be a major driver of deforestation together with 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 are also important 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 agroecological framework, farming systems are not 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). Agroecological practices in palm oil plantations have been reviewed by Bessou *et al.* (2017), stressing 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 fertilization 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 fertilizers (Dubos *et al.*, 2016). In terms of sustained productivity, Tohiruddin & Foster (2013) showed that 10 t/ha (70 kg/palm/year) of compost can be used as an effective substitute for mineral fertilizers regarding 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 ssp.* than fresh EFB (Supriatna *et al.*, 2018) suggesting that compost could also contribute to reduce the use of pesticides.

Composting palm oil mill by-products for the fertilization of commercial blocks could improve the recycling of nutrients, reduce the cost of fertilization, increase nutrient efficiency through a slower release and increase 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 and its high methane emissions (Choo *et al.*, 2011).

Composting is the 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 with a thermophilic phase. The amount of EFB produced per ton of processed fresh fruit bunch (FFB) is quite stable (about 23t EFB /100t FFB). For POME the quantity and the composition can vary from 25 to 65 m^3 POME/100t FFB according to the technology used for processing FFB (Schuchardt *et al.*, 2007). The composting processes will 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% of the phosphorus, 70% of the potassium, 45% of the magnesium and between 10% and 20% of the calcium originally present were lost after 10 weeks of composting. The study stressed the importance of protecting the windrows from rain and recycling the leachates to minimize K losses. Important leaching and losses in nutrients with an open composting process were confirmed by a case study made in an oil palm plantation in Kalimantan (Baron *et al.*, 2018).

We chose to study the composting process taking into accounts its environmental and agronomical impacts, and listed the following questions:

1. How much POME can be recycled through composting?
2. What is the best turning frequency for EFB composting?
3. What is the efficiency of nutrient recovery in controlled conditions?
4. What is the standard nutrient content that can be expected for compost?

To answer these questions, we studied the general kinetic of EFB composting as well as the effect of turning frequency and the POME to EFB ratio on the weight reduction and nutrient recovery from 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.

Material and Method

Local conditions

This experiment was conducted in an industrial palm oil mill belonging to the ANJ Group, located on the island of Belitung (Bangka Belitung, Indonesia). The experiment was conducted during month of May-June-July 2016, with average air temperature varying from 28-35°C and air moisture 75-95%.

Experimental design

The effluents used for this experiment were pre-digested POME from biogas production ponds. The POME to EFB ratio chosen were 1, 3 and 4 m^3 POME per ton of fresh EFB, corresponding to a daily dose of 28, 85 and 112 L of effluent per ton of EFB, respectively. Those treatments are hereafter referred 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 are referred 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 frequencies x 3 ratios) repeated 2 times. The 24 experimental compost piles followed a split-plot design with two blocks. Each block was divided into 3 plots of 4 compost piles each receiving the same POME/EFB ratio. Each one of the 4 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 metric ton and was given a trapezoidal shape with a volume of about $10m^3$ (Figure 1). The experimental composting piles were placed in a platform with a concrete floor, draining canals and a tin roof, to ensure adequate draining of the leachate and to avoid contamination by rainfall.

After the formation of 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 coming from the mill have been sterilized and microbial inoculation was done to avoid variability in the process by ensuring a quick and homogenous start of the microbiological process.

Pre-treated POME from the biogas plant was stored in a 5000 L tank and sprayed using a pump and hose system. Each heap was sprayed 6 times a week at a constant rate to complete the ratio in 40 days (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 methane plant 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 was executed using an excavator to mix and turn the piles.

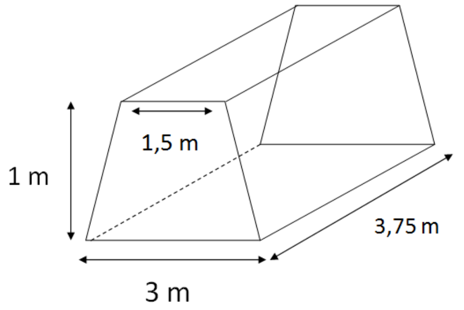

Figure 1. Dimensions of the standard composting pile
Gambar 1. Dimensi sungkup pengomposan standar

Table 1. Average chemical properties of effluents used for composting and compost leachates
Tabel 1. Rerata sifat kimia limbah cair yang digunakan untuk pengomposan dan pencucian kompos

	N (mg/L)	P (mg/L)	K (mg/L)	Mg (mg/L)	C organic (% DM)	pH
POME (Post biogas)	336	33	3193	128	19.8	7.5
Compost leachates	443	58	4173	188	16.2	8.0

Measurements and sampling

The core temperature of each pile was measured before spraying every morning with 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 for 3 points across and 3 points along the pile. The 24 measurements per pile were used to make a 3 dimensional model of the pile and 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 (24h to 48h) 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 electrometry.

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 phothometry.

Data analysis

Free air space was calculated from the volume, weight and moisture of the pile. Density of water is 1 and the density used for ligno-cellulosic organic matter was 1,6 (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 3 days. A thermophilic peak followed from day 4 to day 12, with temperatures averaging 65°C. After day 12, the temperature stabilized and remained around 50°C to 55°C for the rest of the composting process. We observed no significant effect of treatments on the average temperature or C/N ratio. 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 fueled by daily sprayings of POME containing biodegradable organic matter until day 40.

The overall loss in dry matter observed from composting was 45% 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 D20 and 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 weight respectively. The fresh weight ratio of compost to fresh EFB ranged from 49% to 62%. 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% of the original volume, a result similar for all treatments.

There was no significant effect of the turning frequency on compost moisture throughout the composting process, but the POME/EFB ratio had a significant effect on moisture at day 20 and day 40, with the R1 ratio having a lower moisture (Figure 5). The final moistures of the compost piles were between 62% and 70%. Overall, the thermophilic composting process led to the evaporation of 60 to 65% 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 was decreased 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 free space inside the piles. The percentage of free air space remained high throughout the process, the lowest point being 40%, 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 number of leachates varied with time and with the POME to EFB ratio. Toward day 40 it was close to 90% of the effluent 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 to 1,5m^3 per ton 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.

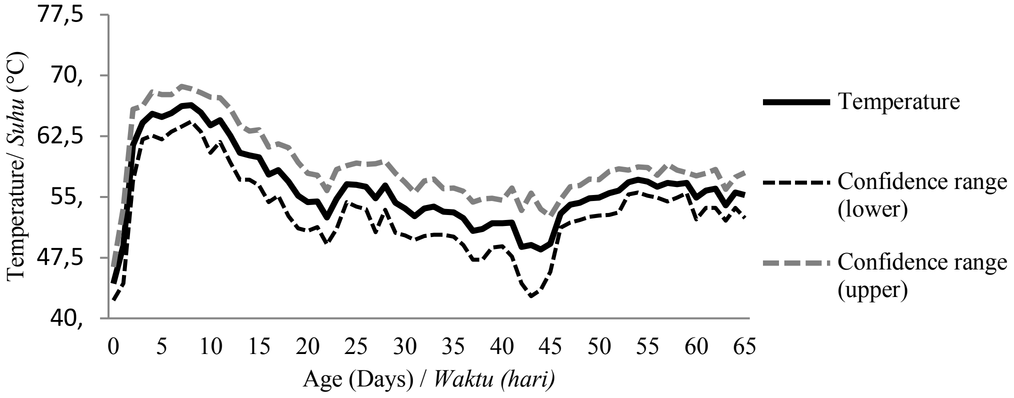

Figure 2. Temperature trend during the composting process. The lower and upper ranges represent the standard deviation of temperature

Gambar 2. Perkembangan suhu selama proses pengomposan. Angka kisaran batas bawah dan batas atas menunjukkan standar deviasi suhu

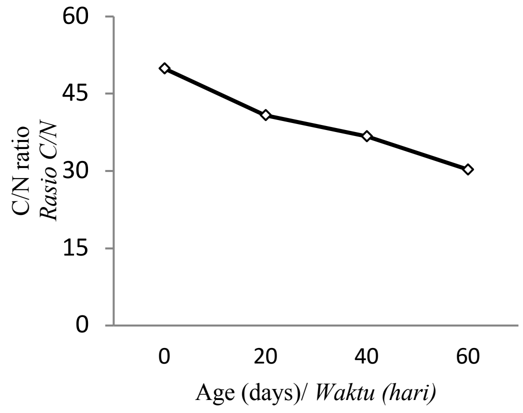

Figure 3. Evolution of C/N ratio during composting. Level of confidence is 95% based on ANOVA

Gambar 3. Evolusi rasio C/N selama pengomposan. Tingkat kepercayaan pada interval 95% berdasarkan analisis ANOVA

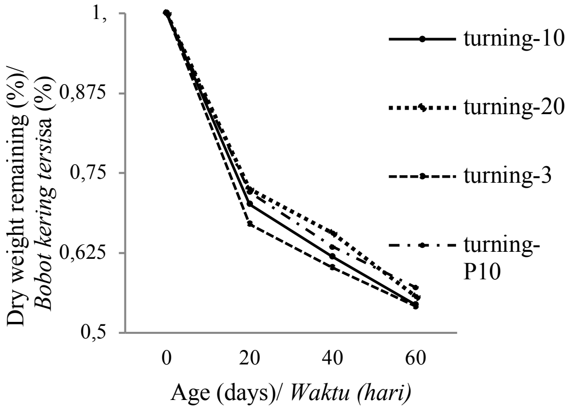

Figure 4. Effect of the turning frequency on the dry weight reduction during composting, expressed as a fraction of the original dry weight of the EFB piles. Level of confidence is 95% based on ANOVA

Gambar 4. Pengaruh frekuensi pembalikan terhadap berat kering selama pengomposan, dinyatakan sebagai fraksi dari berat kering awal. Tingkat kepercayaan pada interval 95% berdasarkan analisis ANOVA

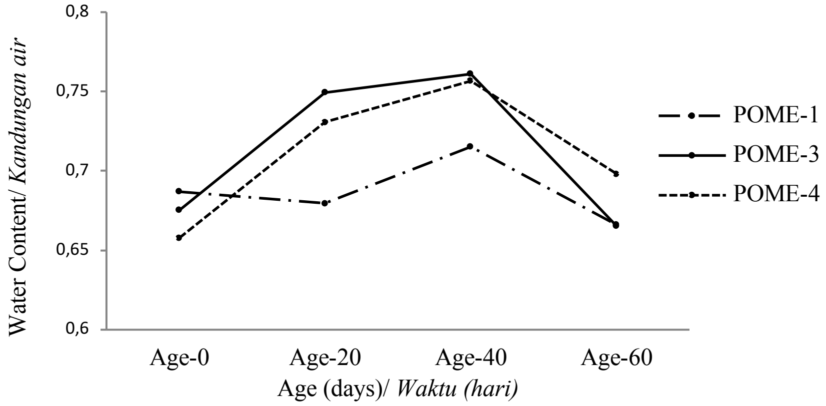

Figure 5. Effect of the POME to EFB ratio on moisture of the compost. Level of confidence is 95% based on ANOVA

Gambar 5. Pengaruh rasio LCPKS terhadap TKKS pada tingkat kelembaban kompos. Tingkat kepercayaan pada interval 95% berdasarkan analisis ANOVA

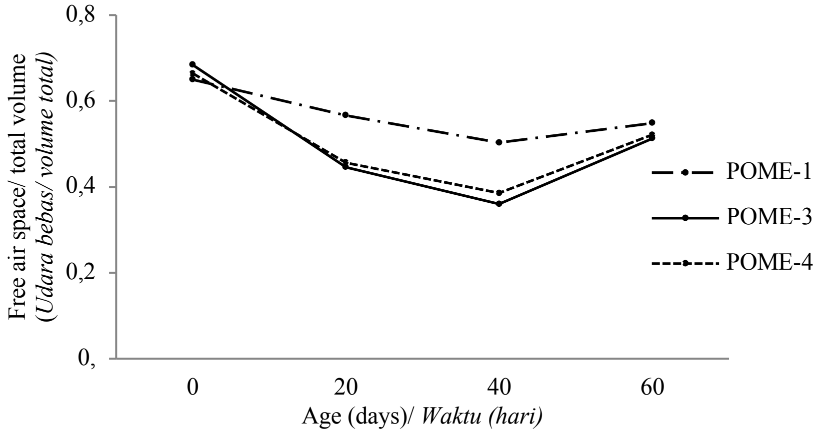

Figure 6. Effect of the POME/EFB ratio on the free air space within the piles, expressed as a fraction of the total volume of the pile. Level of confidence is 95% based on ANOVA

Gambar 6. Pengaruh rasio LCPKS/TKKS pada ruang udara bebas diantara tumpukan, dinyatakan sebagai fraksi dari total volume tumpukan. Tingkat kepercayaan pada interval 95% berdasarkan analisis ANOVA

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 important, with only 65-70% of recovery. We hypothesize that higher losses for nitrogen were mostly due to ammonia volatilization at high temperature and free air space (Sánchez-Monedero *et al.,* 2001; Abd El Kader *et al.*, 2007 and Jiang *et al.*, 2011). Figure 7 shows the contribution of POME and EFB to the original nutrient stock and the NRE for each element. Recycling POME is critical for enriching the compost; the effluent is providing 47% of the K stock and 22% of the Mg stock.

Reducing leaching and nitrogen losses

The high leaching observed was also attributed to the compost structure, which had high free air space between bunches. Pre-treatments of EFB (shredding and compacting) to reduce the size of fiber aggregates could reduce leaching and increase POME uptake. Some other studies argued for higher POME/EFB ratios, up to 3m^3/ton, but these did not estimate the real ratios by considering the proportion of leachates (Baharuddin *et al.*, 2009 and Salètes *et al.*, 2004). Most leaching happens after day 20, and we suggest that spraying programs 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.

Table 2. Final POME/EFB ratio (estimates)
Tabel 2. Rasio akhir LCPKS/TKKS (perkiraan)

	R1	R3	R4
Daily spraying dose (L/ton EFB) *Dosis semprot harian (L/ton TKKS)*	28	85	112
Real POME/EFB ratio (L/ton) *Rasio LCPKS/TKKS (L/ton)*	750	1400	1500

Table 3. Effect of the POME/EFB ratio on the chemical characteristics of compost at day 60. Different letter in column indicate a statistically different value between the treatments (Tuckey test)
Tabel 3. Pengaruh rasio POME/EFB terhadap kandungan dan sifat kimia kompos pada hari ke-60. Perbedaan huruf pada kolom yang sama menunjukkan perbedaan secara statistik antar perlakuan (Uji Tuckey)

Treatment/ *Perlakuan*	Moisture/ *Kelembaban* (%)	pH	Corg (%)	N (%)	P (%)	K (%)	Mg (%)
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/ *Rerata*	68	8.77	47.18	1.58	0.26	4.49	0.44

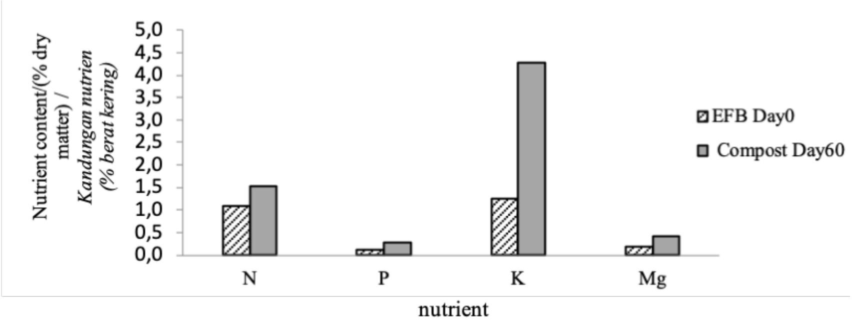

Figure 7. Evolution of nutrient content during composting. Level of confidence is 95% based on ANOVA
Gambar 7. Evolusi kandungan nutrisi selama pengomposan. Tingkat kepercayaan pada interval 95% berdasarkan analisis ANOVA

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 /ton FFB can be recycled 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 0,25m^3 per ton of FFB (Schuchardt *et al.*, 2007). This is a realistic number to recycle 100% of POME through composting (1.1m^3/ton EFB). The composting process will evaporate 65% 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 reduced NH3 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, our data shows that the difference between treatments in terms of moisture did not results 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 favor 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 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_20 (Yuan *et al.*, 2016), Noctor *et al.* (2014). The roles of reactive oxygen metabolism in drought: Not so cut and dried.

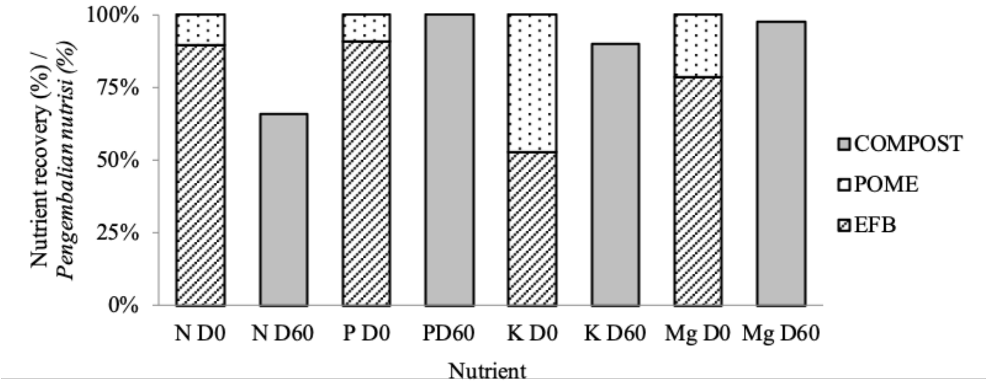

Figure 8. Nutrient recovery during the composting process. The graph plots the original stock of nutrients at day 0 (POME+EFB=100%) against the final stock of nutrients in the compost at day 60, expressed as a fraction of the original stock. The values come from the average case scenario presented in 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% for phosphorus. Corrected NRE values are N: 66%; P: 100%; K: 91%; Mg: 96%

Gambar 8. Pemulihan nutrisi selama proses pengomposan. Grafik menunjukkan stok nutrisi pada hari ke-0 (POME+EFB=100%) terhadap stok nutrisi akhir pada hari ke-60, dinyatakan sebagai fraksi stok nutrisi. Nilai-nilai tersebut merupakan rerata yang disajikan pada Tabel 5, tetapi dikoreksi dengan koefisien 0,91. Faktor koreksi ini diterapkan untuk mengkompensasi potensi perkiraan dan perhitungan yang berlebih, sehingga NRE =100% untuk fosfor. Nilai NRE yang diperbaiki adalah N: 66%; P: 100%; K: 91%; Mg: 96%

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 to 1.5m^3 of POME per ton of fresh EFB, which represented all EFB and 25%-50% of the POME produced by the palm oil extraction process. During this period, the loss of 50-60% of organic carbon and the evaporation of 60-65% 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. About 30-35% of nitrogen was lost through volatilization. The composting process led to an increase in mineral content (P, K, Mg) 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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