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Critical parameters for integrating co-composting of POME and EFB into life cycle analysis of palm oil production

Victor Baron [a], Mohamed Saoud [a], Joni Jupesta [b], Ikhsan Rezky Praptantyo[b], Hartono Tirto Admojo [b], Cécile Bessou [a], Jean Pierre Caliman [b]

a- CIRAD, Perennial Cropping System Research Unit, Avenue Agropolis, 34398 Montpellier Cedex 5, France
b- SMART Research Institute, Jl. Teuku Umar No. 19, Pekan Baru, 28112, Indonesia

* Corresponding author: +33686779934 ; victor.baron@cirad.fr.

Abstract

Palm oil mill's co-products (empty fruit bunch – EFB and palm oil mill effluent – POME) management is a matter of concern in Indonesia. Co-composting would allow dealing with them along with a restitution of organic matter to the soil. This project is a part of a Life Cycle Assessment (LCA) study and aims to pinpoint the most environmentally impacting compartments of the palm oil production chain. This study deals more specifically with the Life Cycle Inventory of data on the composting process based on experimental data. Data on the recycled biomass, energy demand and yielded compost properties were recorded over one year. Due to the experimental conditions, excessive nutrient leaching from the compost were recorded and the compost remained very wet and hot (thermophilic phase) at the end of the first trial due to the spraying of compost with raw and hot POME. We identified the following critical parameters to be accounted for to improve the composting process: i) the roofing of the composting platform, ii) the POME/EFB ratio, iii) the turning frequency, and iv) the process duration to reach given final moisture. The nutrient content and the applied doses of the final compost depend on all these connected parameters. The produced data will be used to develop LCA models for CPO production in order to assess the potential net environmental benefits from POME composting.

Keywords: *Palm Oil; LCI; Compost ; EFB ; POME.*

1. INTRODUCTION

Over the last decades palm oil has become unavoidable. It has taken a growing part in the diet of most countries and became the world's most consumed edible oil about more than ten years ago. But besides feeding the world population, the palm oil production has been fueling a vivid controversy over its environmental and social impact. In Indonesia, world leader in palm oil production, high losses of biodiversity and significant greenhouse gas emission are reported because of land clearing and fires, especially on peatlands (FAO, 2015).

As the debate is focused on the issues of land use change and biodiversity conservation, the agricultural practices themselves are often overlooked. Oil palm plantations, as every crop, will have a different effect on their local and distant environment depending on the way they are managed. Therefore, the question is how to minimize environmental impact in existing production area. More specifically, what practices shall be promoted, and according to which criteria.

In this perspective, composting seems to be one of the most promising practices as it allows for recycling mill residues in the field as organic amendments substituting synthetic fertilizers. However, the composting process itself may also directly impact the environment. There is a need to assess potential trade-offs. Life Cycle Assessment (LCA) is the international reference in terms of supply chain environmental analysis. It consists in a systemic and global approach that is highly relevant to evaluate the potential benefits and trade-offs of such a waste-management system.

1.1. What is composting?

Composting is a complex biological transformation process of organic matter carried out by a succession of microbial communities under controlled environmental conditions. Different definitions of composting can be found in the scientific literature, each author stressing a different aspect of composting such as the decomposer involved (Baharuddin et al., 2010), the physico-chemical conditions in which the degradation occurs , the control of the process (Francou, 2003), the emissions of volatiles compounds associated with composting (Elkader et al., 2007; Oudart, 2013), or the end product itself (Ceglie and Adbelrahman, 2014). Some other also focus on the quality of compost (Bernal et al., 1998), its mineralization kinetics and its capacity to increase soil organic carbon stock (Thuriès et Pansu, 2002).

Composting process occurs in the solid state and is strictly aerobic with a thermophilic phase. The three main transformations occurring during composting are: 1) degradation of organic matter through microbial respiration, 2) production of metabolic water and a loss of water through biological drying in the thermophilic phase and 3) the stabilization of organic matter with the production of humus like substances.

The compost is a hygienized product, non-phytotoxic and free of pathogens. Composting leads to a loss of organic matter in the form of volatile compounds such as CO_2, CH_4, N_2O, NH_3, N_2, and H_20. A longer composting process leads to the production of more stable products with a higher potential for increasing soil organic carbon.

We can identify four successive phases in composting. First, the mesophilic phase occurs at the beginning of composting. The microbial degradation of the easily degradable organic matter (fatty acids, soluble sugars) causes an increase in temperature. Second, the thermophilic phase is characterized by a temperature above 50-60°C (sometimes up to 75°C), only thermophilic bacteria are active in the compost pile. It is the most important phase in terms of organic matter degradation and gaseous emissions. Three, the cooling phase is when the temperature of compost slowly decreases below 40-45°C, a temperature at which Actinomycetes, fungus and nitrifying bacterium can develop. Four, the compost maturation is a phase during which the transformation of organic matter occurs at a slow rate, respiration rate is low and temperature close to ambient temperature. Organic matter becomes more and more stable and earth-like under the activity of bacteria, fungus and mesofauna.

1.2. Composting in palm oil plantations

According to the extraction process used in the palm oil mill, various co-products can be available for composting in palm oil industrial estates: EFB, POME, solid decanter cake, mesocarp fibers, boiler ashes. The two most important by-products in terms of quantity are POME and EFB. The amount of EFB produced per ton of processed FFB is quite stable (about 23t EFB /100t FFB) whereas the quantity and the composition can vary greatly according to the technology used for processing FFB, from 25 to 65m3 per 100t of FFB (Schuchardt et al. 2007). There is not one but several composting processes existing within palm oil plantations. The composting process of palm oil by-products has been studied in various scientific studies published in peer review journals or conference proceedings. We have chosen to consider 15 of those publications to provide a scientific background to this study*.The method we used is based on this background and the results we obtained could be compared to those other references. From the review of those studies we summarized the various factors that could influence the kinetics of composting and the final quality of compost:

- The amount of POME and EFB (POME/EFB ratio)
- The frequency of POME spraying
- The quality of POME
- Recycling of POME leachates
- The turning frequency
- Using passive or forced aeration of piles
- Addition of starter or another microbial inoculum
- Addition of urea to lower C/N ratio
- Addition of solid decanter cake
- Pre-treatment of EFB (shredding, chopping)
- The size and the shapes of the compost piles

The composting processes in those studies ranged from 28 to 120 days, with a turning frequency ranging from every 2 days to every 40 days and a POME/EFB ratio ranging from 0,35 to 6,5. The most frequent turning intervals were 3 days and 7 days and most of the studies focused on POME/EFB ratios between 1 and 3. The final dry weight reduction was 40 to 60% after 120 days (Salètes, 2004). The EFB have a very high initial C/N ration (50-70), that is not optimal for composting. Composting process will be accelerated by adding nitrogen in the form of urea

* (Abu Zahrim et Asis 2010) (Ahmad et al. 2011) (Baharuddin et al. 2010) (Baharuddin, Kazunori, et al. 2009) (Hock 2009) (Baharuddin, Wakisaka, et al. 2009) (Mohammad, Alam, et Kabashi 2013) (Goenadi et al. 1998) (Salètes et al. 2004) (Yahya et al. 2010) (Suhaimi and Ong 2001) (Thambirajah, Zulkali, et Hashim 1995) (Schuchardt et al. 2000) (Schuchardt, Darnoko, et Guritno 2002).

(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). Abuh Assan et. al suggested that shredding of EFB led to a quicker formation of stable compost.

Those studies confirmed the variability of compost quality, with important differences in mineral content. Although the composition of EFB was quite constant throughout the bibliography, the POME composition was quite variable due to the fact that it could undergo several treatments before being used for composting (bio-digestion, pounds, aerobic or anaerobic ponds).

Only one study really considered the volume and weight reduction of EFB during composting to asses to global losses in nutrients and estimates the nutrient recovery efficiency. It 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 theoretically applied were lost after 10 weeks of composting. Those losses were explained by a non-covered window system, subject to important rains and without the recycling of leachates from the compost pile. The study stressed the importance of covering the windrows to minimize K losses. The study also suggested that a spraying interval of 3 days was not optimal for POME absorption from the piles, as it means that a lot of POME is sprayed on the piles at once and is not absorbed properly.

Table 1. Composition of EFB (literature review).

Source		Pre-treatment	Moisture(%)	pH	C/N	C (% DM)	N (% DM)	P (% DM)	K (% DM)	Ca (% DM)	Mg (% DM)
Baharuddin	2010	Press shredded	29,3	6,9	54,4	43,49	0,8	0,08	2,01	0,26	0,12
Abu Zharim	2010	Non shredded	61				1,15	0,6665	2,1165		0,27
Baharuddin	2009	Shredded	24	6,7	58,9	53	0,9	0,6	2,4	0,6	0,6
Baharuddin	2009	Shredded	25	6,5	56,5						
Thambirajah	1995	Shredded		6,5	52	45	0,85				
Yahya	2010	Dried	14,28		63,67	54,76	0,86	0,0774	1,992	0,0929	0,138
Schuchardt	2002	-	68	7	57,5	48,5	0,86	0,065	2,09	0,28	0,14
Saletès	2004	Shredded	60		40	49,6	1,25	0,11	2,07	0,42	0,2
Average				**6,72**	**54,71**	**49,06**	**0,95**	**0,27**	**2,11**	**0,33**	**0,24**

Table 2. Composition of various types of POME (literature review).

Source		POME	Water(%)	pH	C/N	C (ppm)	N (ppm)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	S (ppm)
Schuchardt	2000	Raw	-	4,6	-	-	270	22	393	145	82	-
Schuchardt	2001	Raw	-	4,3	-	-	600	110	1500	300	280	-
Baharuddin	2010	Raw	98	4,33	13	6508	485	181	446	279	217	102
Baharuddin	2011	Partially treated	94	7,41	8	22393	2794	746	3081	1522	842	722
Abu Zharim	2010	Fresh	96	-	-	-	32	13,76	398,4	1020	360	484
Baharuddin	2009	Partially treated	95	7,5	8	9500	1150	650	1000	250	500	350
Saletès	2004	Partially treated	-	6,6	-	-	450	310	2090	380	545	-
Ahmad	2011	Partially treated	95	7,4	8	14950	1794	552	920	736	414	2116
Wood	1979	Raw	-	-	-	-	643	110	1620	315	295	-

Table3. Composition of various palm oil mill composts (literature review).

Source		Age (day)	Water (%)	pH	C/N	C (%DM)	N (%DM)	P (%DM)	K (%DM)	Ca (%DM)	Mg (%DM)
Baharuddin	2010	40	51,80	8,12	12	28,81	2,31	1,36	2,84	1,04	0,90
Abu Zharim	2010	30	-	8,20	20	-	1,70	0,22	1,41	-	0,48
Abu Zharim	2010	150	-	8,00	23	-	1,90	0,34	1,66	-	0,48
Baharuddin	2009	60	61,00	8,10	13	28,00	2,20	1,30	2,80	0,70	1,00
Baharuddin	2009	60	60,00	7,80	13	-	-	-	-	-	-
Thambirajah	1995	60	-	9,00	14	37,50	2,65	-	-	-	-
Thambirajah	1995	60	-	9,00	18	36,00	1,90	-	-	-	-
Thambirajah	1995	60	-	9,00	12	27,00	2,20	-	-	-	-
Yahya	2010	51	53,70	8,50	18	47,40	2,50	0,51	2,40	0,83	0,48
Yahya	2010	51	53,46	8,60	28	48,60	1,70	0,43	2,04	0,67	0,48
Schuchardt	2002	70	16,40	7,50	15	35,10	2,34	0,31	5,53	1,46	0,96
Saletès	2004	70	42,00		14	41,60	2,86	0,34	2,30	1,27	0,63
Saletès	2004	70	42,00			41,50	3,25	0,35	2,01	1,37	0,76
Saletès	2004	70	42,00			42,30	2,96	0,34	2,32	1,28	0,70
Saletès	2004	70	42,00			41,70	3,13	0,34	2,08	1,34	0,70

1.3. Agronomical quality of compost

A study showed that 10 t.ha^{-1} (70kg/palm/year) of compost can be used as a substitute for mineral fertilizers regarding N and P nutrition (Tohiruddin et al., 2013). Compost would increase yield by 2 t. ha^{-1} compared to inorganic fertilizers used at the same rate. The maximum yield and leaf content were achieved with a combination of compost (20 t. ha^{-1}) and synthetic fertilizer (2 kg of urea and 1 kg of rock phosphate (RP) per tree).

Regarding the costs, compost-based fertilization with 10t.ha^{-1} of compost halved the cost of fertilization compared to the same nutrient rate with inorganic. The study found an increase in fertilizer efficiency of +66%, +37%, +20% for compost compared to urea, RP, and dolomite, respectively.

Some other trials (Darmosarkoro et Sutarta, 2002) also showed that compost application could increase soil pH and exchangeable cations and organic matter on a short term basis. The results are encouraging but would need to be confirmed by other studies. A trial showed that 7.5 kg of compost mixed with usual topsoil in polybags can replace standard mineral fertilization in nursery. Lower rates of compost can also be proposed, combined with reduced mineral fertilizer regime.

Two trials conducted on different types of soils also demonstrated that compost and empty fruit bunches (EFB) could be a good substitute to mineral fertilizer in the nursery and would improve soil chemical properties (Baron et al, 2018).

The use of compost as a fertilizer in palm oil plantation lacks further documentation but other studies documented the effect of organic matter application in the form of EFB. Caliman (2001) showed that EFB would quickly release significant amount of N and K to the crop. Carron (Carron et al., 2015) showed that EFB application would increase soil fertility and biological diversity for at least two years after application. Tao (2016) showed that EFB application increased soil microbial activity. We believe that compost could have the same effect as EFB with lower cost of application (reduced volume and weight), a higher content in nutrients and a higher potential for increasing soil organic carbon (SOC).

1.4. Composting and LCA

If we set aside the possible GHG (greenhouse gas) emission caused by land use change and the cultivation of peat land, the first source of GHG emission linked to the production of palm oil are the treatment of palm oil mill effluent (POME) in pounds and the use of nitrogen fertilizers ((Bessou et al., 2014) (Reijnders and Huijbregts, 2008). Compared to processing POME in ponds, composting significantly reduces the methane emissions, which is the main contributor to the global warming potential (GWP) of the oil palm mill (Stichnothe and Schuchardt, 2010) . The oxidation of organic carbon in aerobic conditions generates emissions of CO_2 only, whereas the anaerobic fermentation of organic matter will generate emission of methane (CH_4), which as a 28-fold higher global warming potential than carbon dioxide. Stichnothe and Schuchard found that composting, instead of treating POME in pounds and dumping EFB would reduce GHG emission from 2.3 tons of CO_2 equivalent to 0.55 tons of CO_2 equivalent per ton of crude palm oil (CPO). Further emission reduction can also be reached if POME is pre-treated in a continuous anaerobic digester for producing biogas (methane) before using the bio-digester sludge for making compost (Wu et al. 2009; Harsono, Grundmann, et Soebronto 2014; Chin et al. 2013).

From an LCA perspective, the composting process may also lead to further environmental benefit due to the avoided emissions from inorganic fertilizer production. However, the net advantage needs to be investigated in the light of the composting process emissions and potentially enhanced, field emissions. Different studies also point that compost could present other benefit such as "temporary storage of carbon, improved soil quality and protection from soil erosion (R. Singh et al. 2010; R. P. Singh et al. 2011))". Those potential benefits are yet to be included to the life cycle approach, as they lack more site-specific data.

1.5. Research question

Compost palm oil waste seems to be highly beneficial from an environmental standpoint. However, there is a lack of site-specific data for a better integration of the composting as a waste management method in LCA models. The aim of this study is to identify the critical parameters for integrating co-composting of POME and EFB into life cycle analysis of palm oil production; i.e to understand to which extent different composting process and compost quality could affect the result of the LCA. We do so by presenting a case study of an oil palm agro-industry.

2. METHODS

2.1. Industrial case study

We collected data from an agro-industrial production area involving one mill and 4 estates totals 13,485 ha of productive oil palm (*Elaeis guineensis Jacquemard*). The plantation area has been planted between 2006 and 2014 in Central Kalimantan. We collected data for the year 2017:

- Overall yield and production
- Energy and water consumption of the mill
- Energy consumption for fertilizer application
- Fertilizers consumption (organic and inorganic)
- Energy consumption of composting platform
- Quantity and quality of the compost produced
- Quantity and quality of POME produced and discharged.

All the industrial data was verified and validated in collaboration with the mill and estates staff. We also collected information about EFB application and methane production from POME in other estates of the same company, to be able to comment other waste management systems.

2.2. Composting trial

The data on the industrial compost is often incomplete and only a few parameters are measured. There are no thorough protocols to follow physical and chemical parameters during the composting process. A trial was therefore implemented on the composting platform of the same company to provide extensive data sets. The trial comprised thirty piles of 10 tons of EFB that were regularly turned and sprayed with POME using a Backhus ™ compost turner, modified for spraying the compost with POME while turning. The composting process took place on a non-roofed concrete platform surrounded by drains to collect leachates.

The trial was designed to test different composting process existing within the PT. SMART company, with 3 standards (see Table 4). The trial was also sub-divided to test the covering of the compost piles with a semi-permeable tarpaulin (cover/ non-cover).

Table 4. Trial design

	Additionnal Urea (2kg/ ton EFB)	Spraying and turning interval	Dose per spraying (L per ton of EFB)	Final POME/ EFB ratio
1-JLTM	Yes	3	200	3.1
2-KUYM	No	1	100	4.9
3- KWAR	No	2	100	2.9

3 standards * 2 cover * 5 repetitions= 30 piles

The composting process usually last between 40 and 50 days in industrial conditions but was extended to 74 days in our study to see if extra maturation of the compost could be of importance for the LCA analysis.

2.3. Measurements protocol

- Temperature **(**2 measurements/day): 9 measurement points (3 at the top, 3 at the middle and 3 at the base of the heaps).

- Humidity (2 measurements/day): A composite sample of compost is taken from each pile. A handful of compost was collected from 20 sampling points from each pile (for a total of about 5 to 8 kilos of compost). The samples were mixed thoroughly and then divided in two. One half was mixed again and then divided in two, and the operation was repeated until reaching a sample of about 700g. The samples we dried in an oven at 105°C until constant weight is reached (12 to 24 hours).
- Weight (1 measure/week): compost heaps are collected in a 7- 8 t capacity truck and transported to the mill weighing bridge. After weighing, compost is taken back to the platform and the heaps are reshaped.
- Volume (1 measure/week): 9 measurements points (3 measures of length, 3 of width and 3 of height).
- Nitrogen content: measured with the Kjeldahl distillation method
- Phosphorus: determined by acid-base method
- Organic carbon: determined by the gravimetry method
- pH: determined through potentiometry

2.4. Nutrient recovery rate

The nutrient recovery efficiency (NRE) is calculated for a given element as follow NRE =

$$= \frac{Ci70 \ x \ Dw70}{Ci70xDw0 + Ve \ x \ CiE}$$

Where:

Ci60: the concentration of the element in the compost at day 60 (% of dry matter);

Ci0: the concentration of the element in the EFB at day 0 (% of dry matter);

Dw 70: the dry weight of the pile at end of the process (day 70) in kg;

Dw 0: the dry weight of the compost pile at the start of the process (day 0) in kg;

Ve: the real volume of effluent sprayed onto the compost over the whole composting process (m3);

CiE: the concentration of the element in the effluent (ppm).

3. RESULTS AND DISCUSSION

3.1. Overall description of the system

CPO production

More than 90% of 13,816 ha of the area under study have been planted between 2006 and 2009, and the remaining 10% between 2010 and 2014. The precedent land use was a mix of forest, shrubs and a mix agricultural land. The plantation is of young age and planted with high-yielding 100% Tenera hybrids. In 2017 the production achieved was 272,929 tons of fresh fruit bunch, with an average yield of 19.8 t/FFB/ha/year. The CPO production was 68,805 tons with an oil extraction rate of 25.21%.

Waste management

POME and EFB are the main organic waste generated by the extraction process, as shell and mesocarp fibers are entirely burnt to feed the mill's boiler. The POME/FFB and EFB/FFB ratios were 63% and 21% respectively. The average chemical composition of raw POME and EFB is presented hereafter, as well as the chemical properties of the effluent sent to land application after anaerobic digestion in pounds.

The composting platform receives all the EFB from the mill after shredding, which are transported in big green bins (capacity of about 10 to 13 tons of shredded EFB). The prime mover (carrying the bin) comes and goes from the EFB shredder directly to the composting platform. In the platform there are two other operating machines: a loader and a mechanical compost turner (Backhus) which has been modified to allow spraying.

The composting platform (figure 1) receives raw palm oil mill effluents (POME) from the mill that are stored in a temporary open pound (spraying pound, 1,250m^3). From there they are pumped directly to different outlets to which flexible pipes are connected to the combined turning and spraying machine, through different outlets presence every 2 rows in the composting platform. All leachates are collected in the North East corner of the platform to a small run off pond (60m^3) and then to a buffer pond (4,500m^3). Then the leachates are pumped back to the different anaerobic effluents' ponds.

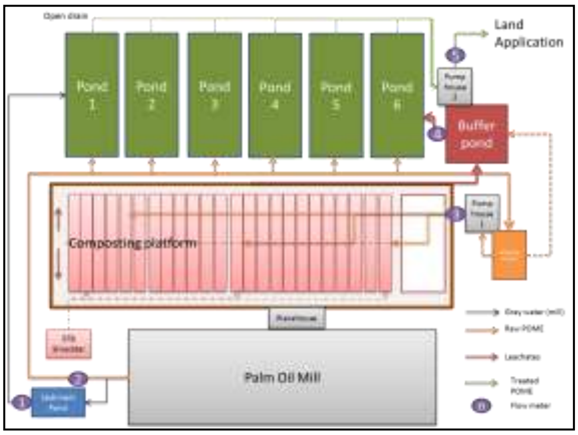

Fig. 1 Framework of the study.

Table 5. Quality of final effluent sent to land application.

BOD5 (mg/L)	COD (mg/L)	pH	Oil and fat (mg/L)	Pb (mg/L)	Cu (mg/L)	Cd (mg/L)	Zn (mg/L)
1748	5985	7,6	352	<0,0017	<0,015	<0,022	0,2125

Table 6. Quality of raw POME.

	Total solid (mg/L)	BOD (mg/L)	COD (mg/L)	N (mg/L)	P(mg/L)	K (mg/L)	Mg (mg/L)
CI95 +	63 918	36 485	90 470	1 216	232	3 017	639
Average	61 180	34 337	87 242	1 166	224	2 912	617
CI95 -	58 443	32 189	84 013	1 117	217	2 807	595

As the composting platform cannot absorb all the POME from the palm oil mill, some portion of it (about 20%) is sent directly to the anaerobic ponds, with an outlet in front of every pond. All pounds are dug directly into the ground (no concrete foundations). The total compost production obtained from the FFB processed in 2017 was about 31,482 tons (from Jan 1st, 2017 to Feb 15th, 2018). This would give us an average compost/EFB and compost/FFB ratios of 51% and 11.2% respectively.

Energy and water consumption

The overall energy and water consumption of the plant is presented in **Table 7**. Electricity used in the plant comes from a boiler using mesocarp fibers as a fuel. The energy surplus for composting is the electricity consumption of the EFB shredder. Diesel fuel is used to power vehicles, backup generators and pumps for handling the effluent. The surplus for composting is only for machines and vehicles operating in the composting platform, 83% of which is consumed by the compost turner.

Table 7. Energy and Water consumption.

	Total Mill	Total Composting platform	Total per ton of CPO	Increase due to composting
Diesel Fuel (L)	422,032	105,175	8	25%
Electricity (kWH)	5,137, 296	526, 454	82	10%
Water Consumption (m3)	266,743	6, 809	4	3%

Compost quality

The average quality of the compost coming out of the composting platform is quite low compared to existing results found in literature.

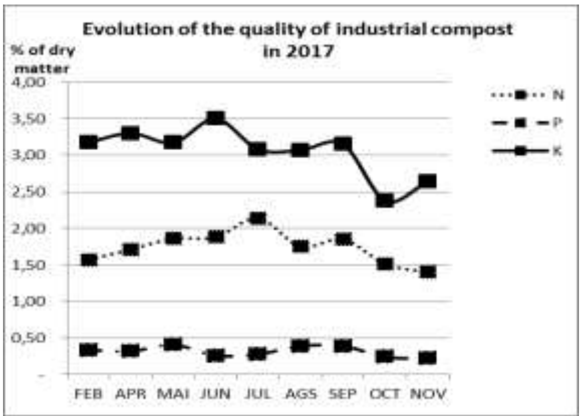

Fig. 2 Industrial compost quality.

Critical points

The critical point in the study of the system is the evolution of effluents quality that are treated successively in the composting platform (aerobic conditions) and in the effluent pound (anaerobic conditions). The key unknown is to know how much of the COD is lost in aerobic conditions and how much is lost in anaerobic conditions, and how to consider dilution by rainwater in an open system. We know that the platform received about 150,000 m^3 of rainfall in addition to the 150,000 m^3 of POME used for spraying compost. It resulted in the leaching of 130,000 m^3 of effluent from the composting platform that had to be evacuated to the anaerobic pound.

However, the quality of those leachates was not analyzed for COD and BOD. They were sent directly to the anaerobic pounds for further biological degradation and dilution by rainwater. Those pounds also received 16,000m^3 of grey water from the mill. With the heavy dilution by water, the final amount of effluent sent to land application was 350,000 m^3. Given the composition of the raw POME and the final effluent, a reduction of 86% of the COD occurred during the two steps of composting and pound treatment. The critical point is to know which part to attribute to the composting platform and which part to the pounds. Further chemical analyses on the leachates collected in the buffer pound are required.

Fertilization practices

The crop's need in essential nutrient is met by application of imported mineral fertilizers or recycled organic waste from the mill. A fully mineral fertilization covers the majority of the plantation while compost is applied on about 20% of the plantations. Land application of POME in flat beds dug in the interrows of oil palm represent a small amount of land around the mill.

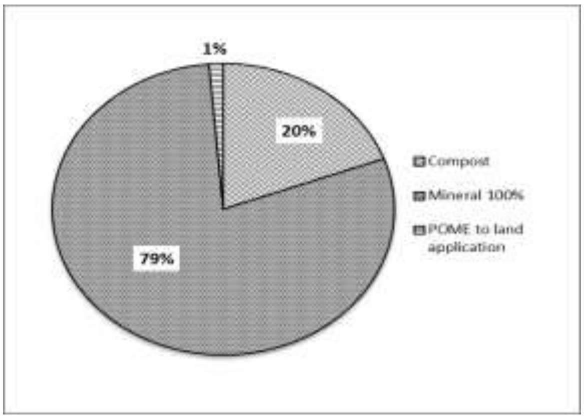

Fig. 3 Fertilization practices proportions.

The crop's need for each element is determined each year for each block (15 to 50ha) through the use of leaf analysis (Caliman, Daniel and Tailliez 1994). Each block therefore receives a specific dose of each fertilizer, which is split in two applications. Compound fertilizers are not used to avoid over-fertilization. Compost is always applied at a dose of two times 65kg per palm and per year, equivalent to 17,5t per year per hectare. Compost is sometimes enough to cover the crop's need in N and Mg but is often complemented with mineral fertilizers for K, P and Br. The table 8 presents the overall average doses of fertilizer applied, for each type of fertilization.

Table 8. Fertilizers applied doses

Average dose (kg/ ha/year)	Mineral and compost	Mineral	Land application of effluent
Urea	12	234	-
DAP	0	200	-
Rock Phosphate	11	31	-
Triple Super P.	189	100	-
KCl	122	471	-
Dolomite	0	29	-
Kieserite	11	145	-
Borax	7	7	-
Compost	17595	-	-
Effluent (m^3)	-	0	375

At the plantation's scale, compost covers a large part of the crop's need, but its nutrient isn't perfectly balanced according to the crop's need and additional mineral fertilizer is added.

3.2 Composting trials

General kinetic of the composting process

The composting process as it is conducted is industrial conditions is purely thermophilic. There is a constant increase in moisture and the temperature is above 65°C. The degradation of organic matter is the highest in the first 10 days of composting, which correspond to the loss of the easily degradable fraction of EFB while the lingo-cellulosic fraction remains. However, the biological reaction of composting is fueled by the frequent spraying of hot and highly fermentable POME and the compost never reaches a mesophilic or maturation phase.

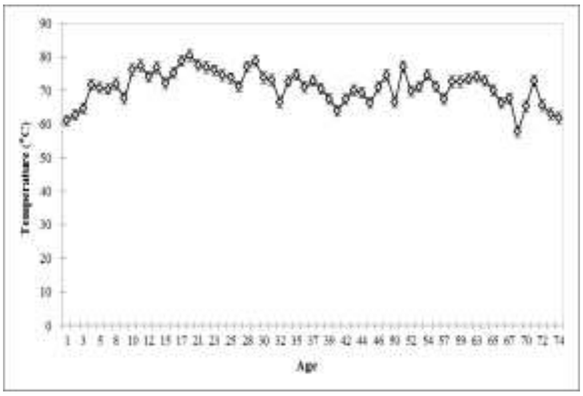

Fig. 4 Temperature general trend.

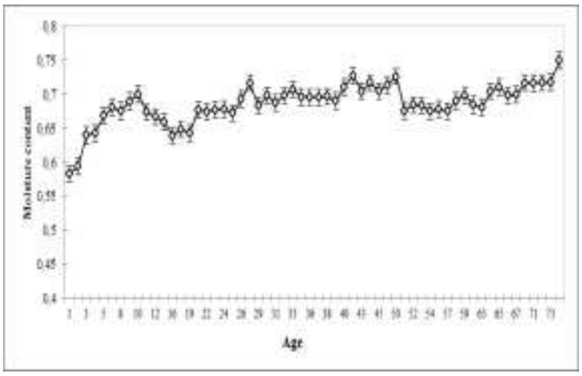

Fig. 5 Moisture general trend.

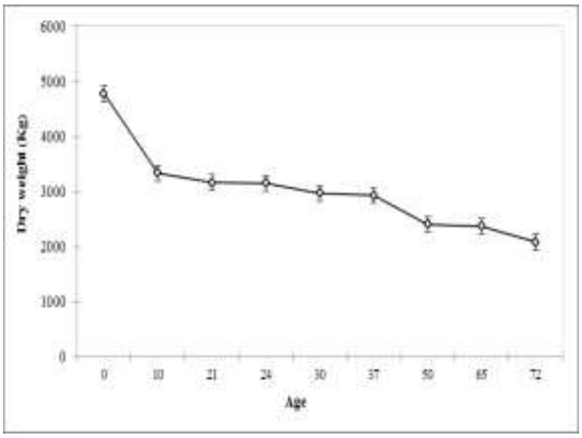

Fig. 6 Dry weight general trend.

The biological degradation of organic matter results in the loss of dry weight of 50% and 56% after 50 and 72 days respectively. However, the compost still had a very high-water content and the fresh weight reduction was only 26% and 34% of the original EFB weight, after 50 and 72 days respectively. This weight reduction leads to an increased nutrient content as shown in **Table 9.** The nutrient recovery rates observed are very low on average and can be explained by the combination of a high POME/EFB and exposition to rainfall which washed away more than 50% of the nutrients contained in compost.

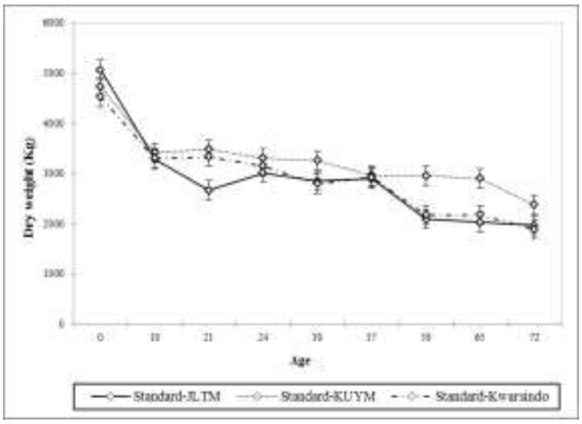

Fig. 7 Dry weight evolution per standard.

Table 9. Nutrient content at different composting ages.

Nutrient	N (%)	P_2O_5(%)	K_2O(%)	MgO(%)
EFB (day 0)	1,0	0,5	3,9	0,5
Compost (day 50)	1,7	0,8	4,0	0,9
Compost (day 72)	2,0	1,3	5,3	1,4

Effect of treatments

The composting process chosen had an effect on the dry weight reduction and the nutrient recovery rate. The standard 2 with a higher turning and spraying frequency had the lower weight reduction at day 50 and a lower nutrient recovery rate for most elements. The standard 2-Kwarsindo with no additional urea and a lower dose of POME per application appears to be the best for maximizing nutrient recovery. No effect of the covers on the nutrient recovery rate or weight reduction was observed.

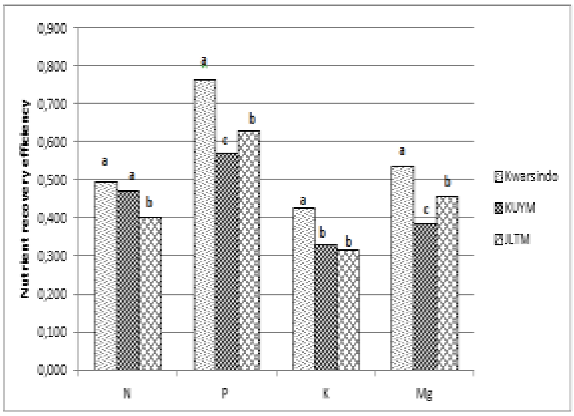

Fig. 8 Nutrient Recovery Effciency for N, P, K and Mg.

3.3 Discussion: Towards different LCA scenarios

The composting of palm residues is a promising way to reduce environmental impacts along the whole palm oil value chain. Mitigation ways include i) the reduction of GHG emissions by avoiding POME anaerobic digestion, ii) the reduction of the impact of residue transport back to the field by reducing the biomass and concentrating the nutrients, and iii) the reduction of the impact of synthetic fertilizers substituted by composted residues. However, those impact savings may be, at least partially, compensated by increased emissions due to i) the building and daily operation of the composting plant, or ii) the potential increase in volatilization of nitrogen compounds in the field. A life cycle approach is needed to investigate potential problem shifting and inform trade-offs.

The collected data will be implemented within an LCA model for CPO. Various scenarios will be compared including POME anaerobic treatment with and without methane capture and raw POME composting and field application. For the baseline scenarios, the experimental data will be used to characterize the composting process fluxes and the final compost. The scenario datasets will be completed with data from the literature to model methane emissions from anaerobic treatment as well as methane capture and flaring. An improved compost scenario will also be developed as benchmark based on best practices recorded in the literature, notably in terms of nutrient recovery.

4. CONCLUSION

This study highlighted different methodological challenge in integrating composting as a waste management option in current LCA models for palm oil. Composting is a biological process that is not always standardized in plantations, and the way in which the process is conducted will potentially affect the result of the LCA. The roofing or absence of roofing of the composting platform is a critical parameter that will affect the amount of effluent to be treated in anaerobic conditions, and therefore methane emissions of the production system. Exposition to rainfall will decrease the nutrient recovery rate and therefore the amount of nutrient available to replace mineral imports at the plantation scale. POME/EFB ratio as well as the spraying frequency of POME will also affect the nutrient recovery rate, with high doses sprayed at once more likely to wash away nutrient.

The final moisture of compost is critical in terms of weight reduction of waste and will impact the cost and fuel consumption for compost application. The final nutrient content will determine the dose of compost necessary to cover the crop's needs and the area where compost is applied, respectively 17.5 t/ha/year and 20% of the plantation in this study. We estimate that with optimized composting and nutrient recovery this dose of compost could be halved, and the area covered doubled. This study could be continuing for the LCA modeling to measure the environment impact of the co-composting.

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REFERENCES

Abu Zahrim, Yaser, et Tahang Asis. 2010. « Production of non shredded empty fruit bunch semi-compost ». http://dspace.unimap.edu.my/xmlui/handle/123456789/13706.

Ahmad, Mohd Najib, Mohd Noriznan Mokhtar, Azhari Samsu Baharuddin, Lim Siong Hock, Siti Ramlah Ahmad Ali, Suraini Abd-Aziz, Nor Aini Adbul Rahman, et Mohd Ali Hassan. 2011. « Changes in physicochemical and microbial community during co-composting of oil palm frond with palm oil mill effluent anaerobic sludge ». *BioResources* 6 (4): 4762‑80.

Baharuddin, Azhari Samsu, Lim Siong Hock, M. Z. Yusof, Nor Aini Abdul Rahman, U. K. Shah, Mohd Ali Hassan, Minato Wakisaka, Kenji Sakai, et Yoshihito Shirai. 2010. « Effects of palm oil mill effluent (POME) anaerobic sludge from 500 m 3 of closed anaerobic methane digested tank on pressed-shredded empty fruit bunch (EFB) composting process ». *African Journal of Biotechnology* 9 (16): 2427–2436.

Baharuddin, Azhari Samsu, Nakamura Kazunori, Suraini Abd-Aziz, Meisam Tabatabaei, N. A. Abdul Rahman, Mohd Ali Hassan, M. Wakisaka, K. Sakai, et Y. Shirai. 2009. « Characteristics and microbial succession in co-composting of oil palm empty fruit bunch and partially treated palm oil mill effluent ». *Open Biotechnol J* 3: 92–100.

Baharuddin, Azhari Samsu, M. Wakisaka, Y. Shirai, Suraini Abd-Aziz, N. A. Abdul Rahman, et Mohd Ali Hassan. 2009. « Co-Composting of Empty Fruit Bunches and Partially treated Palm Oil Mill Effluent in Pilot Scale ». *International Journal of Agricultural Research* 4 (2): 69‑78.

Bernal, M.P., C. Paredes, M.A Sanchez Monedero, et J. Cegarra. 1998. « Maturity and stability parameters of composts prepared with a wide range of organic wastes ». *Bioresource Technology* 63: 91‑99.

Bessou, C., L.D.C. Chase, I.E. Henson, A.F.N. Abdul-Manan, L. Milà i Canals, F. Agus, M. Sharma, et M. Chin. 2014. « Pilot Application of PalmGHG, the Roundtable on Sustainable Palm Oil Greenhouse Gas Calculator for Oil Palm Products ». *Journal of Cleaner Production* 73: 136‑45. https://doi.org/10.1016/j.jclepro.2013.12.008.

Caliman, Jean-Pierre, Claude Daniel, et Benoît Tailliez. 1994. « La nutrition minérale du palmier à huile ». *Plantations, Recherche, Développement* 1 (3): 36‑54.

Carron, M. P., M. Pierrat, D. Snoeck, C. Villenave, F. Ribeyre, Suhardi, R. Marichal, et J. P. Caliman. 2015. « Temporal Variability in Soil Quality after Organic Residue Application in Mature Oil Palm Plantations ». *Soil Research*. https://doi.org/10.1071/SR14249.

Ceglie, Francesco G., et Hamada M. Adbelrahman. 2014. « Ecological intensification through nutrients recycling and composting in organic farming ». In *Composting for sustainable agriculture*, Springer, 2‑22. Sustainable development and biodiversity 3. Dinesh K. Maheshwari.

Chin, May Ji, Phaik Eong Poh, Beng Ti Tey, Eng Seng Chan, et Kit Ling Chin. 2013. « Biogas from Palm Oil Mill Effluent (POME): Opportunities and Challenges from Malaysia’s Perspective ». *Renewable and Sustainable Energy Reviews* 26 (octobre): 717‑26. https://doi.org/10.1016/j.rser.2013.06.008.

Darmosarkoro, W, et E.S Sutarta. 2002. « Application of EFB compost on acidic soil in North Sumatra to increase soil bases and decrease aluminum ». In *Enhancing oil palm industry development through environmentally friendly technology*. Bali, Indonésie.

Elkader, N, P Robin, J Paillat, et P Leterme. 2007. « Turning, Compacting and the Addition of Water as Factors Affecting Gaseous Emissions in Farm Manure Composting ». *Bioresource Technology* 98 (14): 2619‑28. https://doi.org/10.1016/j.biortech.2006.07.035.

Francou, Cédric. 2003. « Stabilisation de la matière organique au cours du compostage de déchets urbains: Influence de la nature des déchets et du procédé de compostage-Recherche d’indicateurs pertinents ». INAPG (AgroParisTech). https://pastel.archives-ouvertes.fr/pastel-00000788/.

Goenadi, D.H, Y. Away, Y. Sukin, H.H Yusuf, Gunawan, et P. Aritonang. 1998. « Pilot-Scale composting of empty fruit bunches of oil palm using lignocellulosic composting ». In . Bali: IOPRI. http://scholar.google.fr/scholar?q=Pilot-Scale+composting+of+empty+fruit+bunches+of+oil+palm+using+lignocellulosic+composting+bioactivator&hl=fr&as_sdt=0&as_vis=1&oi=scholart&sa=X&ved=0ahUKEwjTzLG1qOzNAhWDnRoKHcz8AHYQgQMIHjAA.

Harsono, Soni Sisbudi, Philipp Grundmann, et S. Soebronto. 2014. « Anaerobic treatment of palm oil mill effluents: potential contribution to net energy yield and reduction of greenhouse gas emissions from biodiesel production ». *Journal of Cleaner Production* 64 (février): 619‑27. https://doi.org/10.1016/j.jclepro.2013.07.056.

Hock, Lim Siong. 2009. « Physicochemical changes in windrow co-composting process of oil palm mesocarp fiber and palm oil mill effluent anaerobic ». *Austalian Journal of Basic Applied Science* 3 (3): 2809‑16.

Mohammad, Noor, Md. Zahangir Alam, et Nassereldeen A. Kabashi. 2013. « Development of Composting Process of Oil Palm Industrial Wastes by Multi-Enzymatic Fungal System ». *Journal of Material Cycles and Waste Management* 15 (3): 348‑56. https://doi.org/10.1007/s10163-013-0125-x.

Norhasmillah, Abu Hassan, Chiew Wei Puah, Ibrahim Nor Azowa, Azhari Samsu Baharuddin, et Yuen May Choo. 2015. « Composting of oil palm biomasse: fourrier transformed infrared ». *Journal of Oil Palm Research* 27 (3). https://webmail.cirad.fr/service/home/~/Article_EFB%20compost_Norhasmillah%20et%20al_JOPR_2015.pdf?auth=co&loc=fr&id=8573&part=2.

Oudart, Didier. 2013. « Modélisation de la stabilisation de la matière organique et des émissions gazeuses au cours du compostage d’effluents d’élevage. » Toulouse, INSA. http://www.theses.fr/2013ISAT0044.

Reijnders, L., et M.A.J. Huijbregts. 2008. « Palm Oil and the Emission of Carbon-Based Greenhouse Gases ». *Journal of Cleaner Production* 16 (4): 477‑82. https://doi.org/10.1016/j.jclepro.2006.07.054.

Salètes, Sloan, Fahri Arief Siregar, Jean-Pierre Caliman, et Tony Liwang. 2004. « Ligno-cellulose composting: Case study on monitoring oil plam residuals ». *Compost science and utilization* 12 (4): p.372-382.

Schuchardt, Frank, Sascha Balcke, Friedrich Becker, Purboyo Guritno, T. Herawan, Darnoko, et Erwinsyah. 2000. « Production of compost from EFB ». In *Proceedings of the 2000-II IOPRI Oil Palm Technical Meeting*. Medan: Indonesian Oil Palm Research Institute.

Schuchardt, Frank, D. Darnoko, et Purboyo Guritno. 2002. « Composting of empty oil palm fruit bunch (EFB) with simultaneous evaporation of oil mill waste water (POME) ». In *Proceedings of International Oil Palm Conference*. Bali, Nusa Dua.

Schuchardt, Frank, K. Wulfert, D. Darnoko, et T. Herawan. 2007. « Effect of new palm oil mill processes on the EFB and POME utilisation ». In . Medan, Indonesia: Indonesian Research Institute for Estate Crop, Indonesian Oil Palm Research Institute.

Singh, R., M. Ibrahim, Norizan Esa, et M. Iliyana. 2010. « Composting of waste from palm oil mill: a sustainable waste management practice ». *Reviews in Environmental Science and Biotechnology*. https://doi.org/10.1007/s11157-010-9199-2.

Singh, R.P., A. Embrandiri, M.H. Ibrahim, et N. Esa. 2011. « Management of biomass residues generated from palm oil mill: Vermicomposting a sustainable option ». *Resources, Conservation and Recycling* 55 (4): 423‑34. https://doi.org/10.1016/j.resconrec.2010.11.005.

Stichnothe, Heinz, et Frank Schuchardt. 2010. « Comparison of Different Treatment Options for Palm Oil Production Waste on a Life Cycle Basis ». *The International Journal of Life Cycle Assessment* 15 (9): 907‑15. https://doi.org/10.1007/s11367-010-0223-0.

Suhaimi and Ong. 2001. « Composting Empty Fruit Bunches of Oil Palm ». Malaysian Agricultural Research and Development Institute (MARDI). 2001. http://www.agnet.org/library.php?func=view&id=20110804151206.

Thambirajah, J.J, M.D Zulkali, et M.A Hashim. 1995. « Microbiological and biochemical changes during the composting of oil palm empty-fruit-bunches. Effect of nitrogen supplementation on the substrate ». *Bioresource Technology*, nº 52: 133‑44.

Thuriès, L., et Marc Pansu. 2002. « Classification et modélisation de la décomposition d'apports organiques dans un sol sableux ». https://www.researchgate.net/profile/Laurent_Thuries2/publication/40438346_Classification_et_modlisation_de_la_dcomposition_d%27apports_organiques_dans_un_sol_sableux/links/0a85e537ecb3b7cc3c000000.pdf.

Tohiruddin, L., H. L. Foster, et others. 2013. « Superior effect of compost derived from palm oil mill by-products as areplacement for inorganic fertilisers applied to oil palm ». *Journal of Oil Palm Research* 25 (1): 123–137.

Wu, Ta Yeong, Abdul Wahab Mohammad, Jamaliah Md. Jahim, et Nurina Anuar. janvier. « A holistic approach to managing palm oil mill effluent (POME): Biotechnological advances in the sustainable reuse of POME ». *Biotechnology Advances* 27 (1): 40‑52. https://doi.org/10.1016/j.biotechadv.2008.08.005.

Yahya, Azmi, Chong Puay Sye, Tajudeen Abiodun Ishola, et Hadi Suryanto. 2010. « Effect of Adding Palm Oil Mill Decanter Cake Slurry with Regular Turning Operation on the Composting Process and Quality of Compost from Oil Palm Empty Fruit Bunches ». *Bioresource Technology* 101 (22): 8736‑41. https://doi.org/10.1016/j.biortech.2010.05.073.