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RESEARCH ARTICLE

INTEGRATED WASTE MANAGEMENT IN PALM OIL MILLS IN SOUTH-WESTERN CAMEROON

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ABSTRACT

Palm oil is one of the most important vegetable oils and sustainable waste management remains a challenge in its production. Most of the nutrients are retained in the crop residues and vast potentials exist to tap the biomass waste and high organic-content of palm oil mill effluent (POME) as nutrient and renewable energy sources. This work was aimed at developing an integrated waste management scheme for multiple or value-added products for palm oil mill wastes using Green Valley Oil Palm Plantation as a case study. The work was done through field surveys, sampling, characterization, and anaerobic digestion of palm oil mill wastes from the plantation. The feasibility of anaerobic digestion of POME and empty fruit bunches (EFB) in the presence of boiler ash was investigated using laboratory-scale experiments. Single stage batch anaerobic digesters were operated with a retention time of 25 days under mesophilic conditions. Biogas generated burned with a blue/yellow flame, indicating a methane content of at least 50%. Anaerobic digestion of EFB and POME for energy and nutrient recycling is feasible with optimal compositions of EFB to POME ranging from 1:4 to 1:5. The EFB, POME and boiler ash contain nutrients: nitrogen (N), phosphorus (P), potassium (K) that would supplement fertilizer inputs for greater productivity.

INTRODUCTION

Oil palm (Elaeis guineensis) is the most productive oil producing plant in the world (Igwe and Onegbado, 2007). With an average of 3.5 tons of oil/ha/year (Frank *et al*., 2011), it provides about a third of all vegetable oils used worldwide (Mahlia *et al*., 2001; Singh *et al*., 2013). Besides its numerous uses, palm oil is becoming an important raw material for transport biofuels (Basiron, 2007; UCS, 2013). This has led to increasing production of palm oil and has raised concerns about its production sustainability, particularly as world demand keeps rising (Panapanaan *et al*., 2009; UCS, 2013). Palm oil production leads to negative impacts such as deforestation, carbon dioxide emission, and pollution of the environment (Anderson, 2008), especially when inadequate and unsustainable management strategies are employed. The institution of sustainable production practices remains a challenge in successful palm oil production with regard to meeting the nutrient requirements of the oil palms. Most of these nutrients are retained in the crop residues (Chan *et al*., 1980). Palm oil production involves many stages and generates large quantities of residues and wastes in the form of leaves, empty fruit bunches (EFB), palm kernel shells (PKS), mesocarp fibre (MF), and palm oil mill effluent (POME) (Sridhar and Adeoluwa, 2009). The milling process generates substantial quantities of wastewater, produces, 0.23 t of EFB, 0.13 t of MF and 0.55 t of kernel shells per ton of FFB (Yeoh, 2006).

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Approaches to waste management in Cameroonian palm oil mills have not effectively made use of the nutrient-rich boiler ash which is simply dumped in most cases, despite the considerable reliance on high external fertilizer input requirements of the oil palms. An integrated waste management approach combines different waste streams for multiple or value-added products and presents a better option for sustainable waste management for the oil palm sector. In Cameroon, with an annual production of crude palm oil estimated at 270,000 tons by 2013 (USDA, 2014), the recycling of energy through the use of wastes as fuel for the boiler is common practice. However, little attention has been paid to the treatment of POME and an integrated approach to use different waste streams for nutrient recycling and energy recovery brings an innovation in palm oil waste management. The purpose of this work was to evaluate the potential for an integrated waste management scheme for palm oil mill waste management for nutrient and energy recycling, using Green Valley Oil Mill as a case study.

MATERIALS AND METHODS

The site of the study was Green Valley Oil Palm Plantation in Bakingili, located between latitudes 4˚2'0"N and 4˚4'0"N and about longitudes 9˚2'0"E and 9˚4'0"E. Rich in volcanic soils and with an average annual temperature and rainfall of 25^{o}C and 11,000mm, this site greatly favours the growth of the oil palm. This study was carried out through surveys, sampling and measurement of some parameters of selected waste streams, anaerobic digestion of different waste compositions and measurement of some attributes of the products of digestion that were analyzed in the laboratory.

Method of Data Collection

Interview of mill management personnel, study of production records and observation of mill practices were carried out to establish generation and management patterns of EFB, MF, PKS, and POME. Quantities of each waste stream generated were estimated according to Schuchardt1 *et al.* (2002), Yeoh (2006) and Sridhar and Adeoluwa (2009), that from every ton of FFB, 0.6 to 1.2 m^3 of wastewater, 0.23 t of EFB, 0.13 t of MF and 0.55 t of PKS are produced. The EFB and POME were characterized by analyzing for their water content, solid content, BOD, COD and N, P, K composition. Nitrogen (N) was determined through kjeldahl procedure, K by dry ashing, dissolving in nitric acid and determined by flame photometry and P by colorimetry. Boiler ash was analyzed for its N, P, and K content. Digestion trials were done with semi-solid mixtures, used as feed substrate, for anaerobic digestion at mesophilic temperature of 32 ± 0.5˚C and detention time of 25 days. Both feed substrate samples and digester content samples after anaerobic digestion were sun dried and analysed. The materials used in this study were single stage batch anaerobic digesters filled with waste blends, some up to about 4/5 of the total volume, and incubated at 32±0.5^{o}C. Waste blends were fed into the anaerobic digesters with the ratio of POME to EFB varied thus: 2:1, 3:1, 4:1, and 5:1. The rate of biodegradation and biogas production was determined daily by measuring the loss in mass of each digester after biogas release. Digesters with the greatest number of waste streams that produced outstanding waste losses were selected and rerun for biogas sampling. Biogas collection was done using an SKC gas sampling pump, tubing and tedlar bags. The presence of methane was verified by flaring experiments.

Samples and Sampling Techniques

A sample size of 60 EFB was collected and sub-sampled using the lottery method to obtain six EFB that were weighed and air-dried to determine water and solid contents. Fresh POME was collected from the mill and sub-sampled for laboratory analysis. Fully digested sewage from C.D.C. rubber factory in Tiko was collected and used as inoculums to initiate the anaerobic digestion process. Boiler ash collected from the oil mill was used in the digesters to raise the pH of the POME to about neutral (favourable pH for anaerobic digestion). The boiler ash/POME mixture was standardized by mixing different quantities of the ash in 100 ml of POME and measuring the pH.

EFB were de-fibred using a local de-fibring machine, air-dried and a sample used for laboratory analysis. The de-fibred EFB was further chopped to a length of about 1cm, mixed with the boiler ash and boiled in water for 10 minutes before injecting the inoculums and mixing it with the POME when cold. Samples used in the digesters were constituted according to Table 1. The feeding ratio of POME and EFB was varied while keeping a digester fed with POME alone as control. The effects of boiler ash and inoculums were each investigated on the digestion of POME alone as well as on the digestion of a combination of POME and EFB.

RESULTS

Waste Generation and Management Patterns at Green Valley Palm Oil Mill: Green Valley Oil Palm Plantation covers over 200 ha and has a production capacity of between 3,000 to 6,000 t of FFB a year. Quantities of each waste stream generated estimated according to Schuchardt1 *et al.* (2002), Yeoh (2006) and Sridhar and Adeoluwa (2009) are presented in Table 2.

The EFB and MF are mainly used as boiler fuel while some EFB are used to mulch young palms. The PKS are simply dumped and boiler ash is used for fertilization of young palms. POME is simply discharged into a stream without treatment. Table 3 shows the results of six EFB used to determine the average water and solid contents.

Table 1. Combinations of Wastes Used in the Anaerobic Digesters at Green Valley Palm Oil Mill in Southwestern Cameroon

Experiment	EFB/g	POME/(ml)	Boiler Ash/g	Inoculum/(ml)
Control	0	1,000	0	0
Digester 1	0	1,000	100	0
Digester 2	0	1,000	0	100
Digester 3	200	1,000	0	0
Digester 4	200	1,000	100	0
Digester 5	200	1,000	0	120
Digester 6	200	1,000	100	130
Digester 7	200	800	80	110
Digester 8	200	600	60	90
Digester 9	200	400	40	70

Table 2. Annual Production and Waste Generation Patterns at Green Valley Oil Palm Plantation in Southwestern Cameroon

FFB/tons	EFB/tons	MF/tons	PKS/tons	Wastewater/m^3
3,000-6,000	700-1,400	400-800	1,700-3,000	2,000-7,000

Table 3. Water and Solid Content of EFB from Green Valley Palm Oil Mill in Southwestern Cameroon

Parameter	EFB 01	EFB 02	EFB 03	EFB 04	EFB 05	EFB 06
Weight (Wet) / Kg	4.8	3.4	5.2	2.7	2.4	4.2
Weight (Dry) / Kg	1.8	1.4	2.0	1.0	0.9	1.6
Weight Loss /Kg	3	2	3.2	1.7	1.5	2.6
% Water	62.5	58.8	61.5	63.0	62.5	61.9
Average Water Content				61.7 %		
Average Solid Content				38.3 %		

Table 4. Some Physicochemical Properties of EFB, POME and Boiler Ash from Green Valley Palm Oil Mill in Southwestern Cameroon

Parameter	Units	EFB	POME	Boiler ash
Water Content	%	61.7	91.5	-
Solid Content	%	38.3	9.48	100
Biochemical Oxygen Demand (BOD)	mg/l	nd	25,960	nd
Chemical Oxygen Demand (COD)	mg/l	nd	54,390	nd
Nitrogen, N	mg/l	-	899	-
Nitrogen, N	g/Kg	3.20	-	0.6
Phosphorus, P	mg/l	-	164	-
Phosphorus, P	g/Kg	0.28	-	1.3
Potassium, K	mg/l	-	1,790	-
Potassium, K	g/Kg	21.30	-	469

nd = not determined

Table 5. Digester Feed Substrate and Residue Characteristics after Anaerobic Digestion of Waste from Green Valley Palm Oil Mill

	Experiment	BOD /(mg/l)	COD /(mg/l)	N/(g/Kg) or /(mg/l)	P/(g/Kg) or /(mg/l)	K/(g/Kg) or /(mg/l)	pH
Before Digestion	Control	25,960	54,390	[a] 864	[a] 156	[a] 1,720	4.7
	Digester 6	nd	nd	1.63	0.72	8.60	7.2
	Digester 7	nd	nd	1.60	0.70	8.43	7.2
After Digestion	Control	23,980	49,209	[a] 899	[a] 164	[a] 1,790	4.5
	Digester 6	nd	nd	1.79	0.81	10.61	6.2
	Digester 7	nd	Nd	1.69	0.77	10.42	6.3

[a] *Values in mg/l, nd = not determined*

Table 6. Annual Estimates of Nutrient Content of the EFB and POME from Green Valley Palm Oil Mill in South Western Cameroon

Waste	N / Kg	P / Kg	K / Kg
EFB	2,240 - 4,480	196 - 392	14,910 - 29,820
POME	1,798 - 3,596	328 - 656	3,508 - 7,160

Table 7. Percentage Weight Losses and Waste Streams in the Digesters for Anaerobic Digestion at Green Valley Palm Oil Mill

Digester	Control	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9
Total % Weight Loss	10.6	20.6	12.2	4.7	5.5	4.2	3.6	3.8	3.2	2.8
No. of Waste Streams	1	2	1	2	3	2	3	3	3	3
Ratio of EFB : POME	-	-	-	1:5	1:5	1:5	1:5	1:4	1:3	1:2

Table 4 shows the nutrient content of the waste components (EFB, POME and boiler ash) used to compose the blends that were anaerobically digested. It shows remarkable N, P, K values that make the wastes a nutrient supplement for application in the palm plantation.

Digester Feed Substrate and Residue Characteristics: The characteristics of the digester feed substrates and residues after anaerobic digestion are shown in Table 5. From the table, the nutrient content of the digester residues remains an important aspect of the added value of the waste blends.

Nutrient Content of the Wastes Generated at Green Valley Palm Oil Mill: Table 6 shows estimates of nutrients (N, P, and K) retained annually in EFB and POME established from the physicochemical properties of waste components (Table 4).

From these estimates, thousands of tons of N, P, and K nutrients are retained in EFB and POME alone. From table 4, boiler ash contains N, P and K nutrients even though annual estimates were not established. Hence, a combination of EFB, POME and boiler ash will yield greater amounts of nutrients than the quantities presented in Table 6.

Optimal Composition of Wastes for Nutrient and Biogas Yields: Variation of the ratio of EFB to POME for the different digester blends resulted in varying consistencies, increasing from D_6 to D_9. Table 7 shows the total percentage digester weight losses at the end of the digestion period and the number of waste streams involved. Digesters with the largest number of waste streams that produced outstanding waste losses were D_4, D_7 and D_6, with D_7 being remarkable amongst those treated with inoculums. The biogas sampled burnt with a blue/yellow flame, indicating methane presence of at least 50 % content (Steffen *et al.,* 1998; NOVAVIRO Technology, 2009). Digester weight losses with time due to biodegradation and biogas production over the anaerobic digestion period were used to plot graphs that compare the performance of the different digesters. Fig.1-3 compare their performance in terms of cumulative percentage weight losses over the 25 day retention time.

DISCUSSION

It can be depicted that daily generation of wastes at Green Valley Palm Oil Mill ranges from 2 to 4 tons of EFB and 5 to 19 tons of POME on the average. This means that the mills' generation of wastes can steadily supply enough raw materials for running an anaerobic digestion facility for waste management. POME is 95% water (Sutanto, 1981; Adapalm, 1992) and approximating $1m^3$ of POME to 1 ton, the proportion of EFB to POME generated by the Oil Mill is in the range of 1:3 to 1:5, giving an average of 1:4.

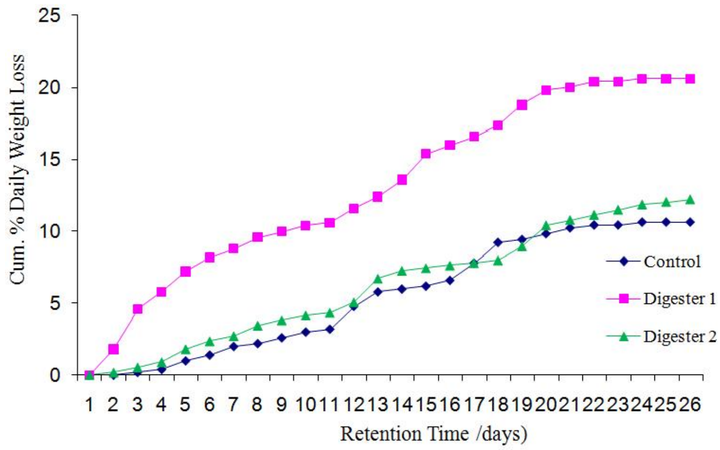

Fig. 1. Cumulative Percentage Weight Loss against Retention Time for POME Digestion

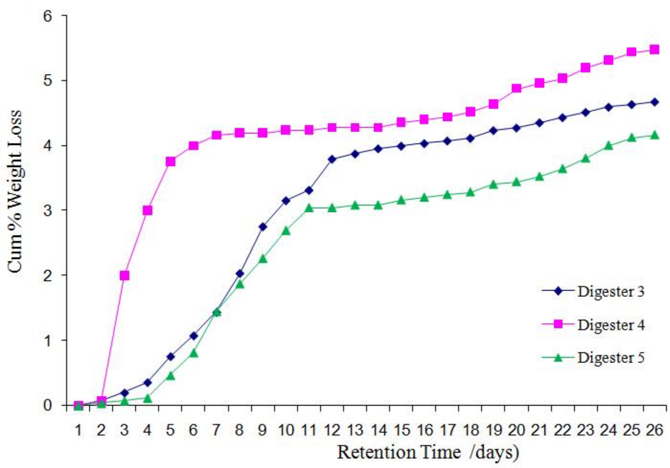

Fig. 2. Cumulative Percentage Weight Loss against Retention Time for EFB and POME Digestion

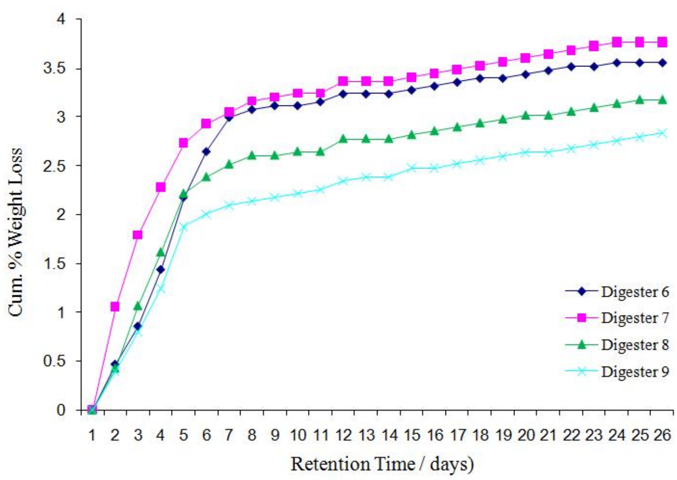

Fig. 3. Cumulative Percentage Weight Loss against Retention Time for EFB and POME Digestion

From Table 7, the optimal composition for an integrated waste management system has an EFB to POME proportion of 1:4, which ties with the waste generation patterns in the mills. The average water and solid contents of the EFB were found to be 61.7 % and 38.3 % respectively and agree with the findings of Saletes *et al.* (2004). The measured characteristics of fresh POME and EFB collected from the oil mill (table 4) also agree with the findings of Chan *et al.* (1980), Zin *et al.* (1988), Caliman *et al.* (2001a), and Menon *et al*. (2003). They show that EFB and POME contain nutrients that can be used to supplement fertilizer inputs in the palm plantations if the wastes are well managed. The different digesters investigated produced biogas whose release led to loss in weight of the digesters. Biogas is 55-65 % methane and 35-45 % CO_2 (Steffen *et al.*, 1998; NOVAVIRO Technology, 2009) depending on the type of waste stream. Biogas yield from the digestion of EFB and POME depends on the proportions of the waste streams used, the optimum being 1:4. All the digesters show remarkably higher weight losses and biogas release in the first week than in subsequent weeks. This could be ascribed to changes in other conditions such as pH since the feed substrate was not buffered to maintain the optimum pH of the range 6.8-7.4 (van Haandel and Lettinga, 1994) for a sustained activity of the microorganisms. The anaerobic digestion of EFB and POME does not reduce the nutrient content of the waste. So, a field application of these digester residues with the nutrient value trends indicated will impose nutrient recycling in the plantations.

It has been calculated that EFB mulching at about 27 tons/ha is equivalent to manuring practices without inorganic fertilizers, with some adjustments for imbalance (Loong, 1987). Digester residues are richer in nutrients than EFB alone. Hence, the application of digester residues to the plantations would be less than 27 tons/ha to replace present needs of inorganic fertilizers. This will cut down on fertilizer inputs and reduce capital investment in the field. Since the breakdown of organic matter by microorganisms is a slow process and leads to slow release of nutrients, recycling plant nutrients is one of the best means of maintaining soil productivity. This application of digester residues to the field will not only improve vegetative growth but will lead to improvement in soil structure, due to better aeration, increased water holding capacity, and even increase in soil pH (Chan *et al.,* 1980; Loong *et al*., 1987). It would as well prevent rain splash, soil wash and reduce erosion and nutrient losses as well as moderate soil temperature. The digestion of POME alone, POME with boiler ash or with inoculums yields higher percentage weight losses than the digestion of a mixture of EFB and POME, EFB and POME with boiler ash or with inoculums. This can be attributed to the difficulty with which lignocellulosic materials undergo biodegradation and the requirement of their pretreatment for greater digestibility (Angelidaki and Ahring, 2000; Houghton *et al*., 2006). Therefore, the digestibility and rate of biodegradation of EFB is lower than that of POME. Biodegradation and biogas yield increase with increase in the ratio of POME to EFB up to an optimum between 4:1 and 5:1.

Conclusion

The oil mill waste generation estimates show an adequate supply of wastes to run an anaerobic digestion waste management scheme. The present waste management methods in the mill are environmentally unsound and there is inadequate use of wastes as a resource for energy and nutrient supply. Hence, the economic advantage provided by a better waste management option like anaerobic digestion here investigated is missing. Anaerobic digestion of EFB and POME for energy and nutrient recycling is feasible with optimal composition for nutrient and biogas yield for this mill being the combination with EFB to POME ratio ranging from 1:4 to 1:5. The anaerobic digestion of EFB and POME provides a better option for waste management in the mill that is environmentally friendlier than the present practices.

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