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Evaluation of Palm oil mill effluent to maize (*Zea mays.* L) crop: yields, tissue nutrient content and residual soil chemical properties

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Abstract

Palm oil mill effluent (POME) is produced in large quantities in Nigeria and is amenable to microbial degradation. Thus, represents a low-cost source of plant nutrients. This paper presents the data from two years experiments concerned with the application of aerobically-fermented POME to soils for maize (*Zea mays.* L) Production at Owerri. Nigeria. Maize grain yield, height, dry matter, tissue nutrient and soil residual chemical properties were evaluated. The experimental design consisted of completely randomized block in factorial arrangement. The paper describes the results of crop yields, stover and grain N, P and K content and residual organic C, N, P and pH as influenced by soil-amendment. The research demonstrated the organic-fertilizer produced higher grain yield, dry matter, and tissue nutrient content and leaves consider- able residual organic C, N and P than plots that received no amendment (control). Fermented POME could enhance maize crop production and can promote sustainable agriculture.

Keywords: Fermentation, organic-amendment, performance, tissue-nutrient, waste-management

Introduction

Oil palm production in Nigeria has risen from 8.2 million tonnes in 1990 to 9 million metric tonnes in 2001 (FAO, 2002). About 43-45 % of this is always a mill residue in the form of Empty Fruit Bunches (EFB), Shell, Fibre and Palm Oil Mill Effluent (POME). These residues will continue to accumulate with increasing production. Efforts are geared towards converting these waste materials into useful products in energy production, animal feedstock and organic fertilizer.

The process to extract the oil requires significant large quantities of water to steam sterilize the palm fruit bunches and clarify the extracted oil. The separated wastewater sludge commonly referred to as POME is a brown slurry, which is composed of 4-5 % solids, (mainly organic), 0.5-1% residual oil and about 95% water and high concentration of organic nitrogen (Onyia et al., 2001). This effluent is a serious land and aquatic pollutant when discharged immediately into the environment. Besides the presence of lipids and volatile compounds, the inhibitory effects of POME on living tissues, could also be due to presence of water-soluble phenolic compounds (Radzia 2001; Perez et al., 1992). The discharge of effluent containing ammonia is undesirable because it causes excessive oxygen demand in the receiving waters. Although POME is a pollutant as far as the palm oil industry is concerned, it has enormous potentials for animal feed improvement and soil amendment (Binder et al., 2002).

Palm oil mills release POME in tremendous volumes with its attendant polluting potential. Therefore POME requires proper management and handling strategies by the industries and government authorities. Proper management of POME has been poorly practiced in Nigeria as many oil mills dispose their POME within their vicinity or dump them in special pits that could later drain to surface and ground waters. POME with very high organic content is easily amenable to biodegradation. Developing a low–cost approach towards facilitating efficient mineralization of the organic nitrogen content of POME will be helpful in the environmental management of waste from palm oil mills as well as in boosting organic farming. This present work evaluated the fertilizer value of fermented POME in a field trial experiment using maize (*Zea mays*. L) as a test crop.

Table 1. Physicochemical Characteristics of POME and soil (0-15cm)

Parameter (fresh POME)	mean of three determinations+ std deviation	Soil Parameters		
			2006	2007
		Sand (%)	85	86
BOD_5 mg/l	16307.2 ±13.9	Silt (%)	64	63
COD mg/l	13452.0 ±4.5	Clay (%)	4	5
TSS mg/l	11977.5± 2.6	pH (H_20)	5.7	5.6
Total N (mg/l)	698.5 ±1.37	Org. C (%)	1.68	1.63
Magnesium (mg/l)	202.7± 0.5	Total N (%)	0.28	0.28
Phosphorus mg/l	212.8±0.6	Avail. P (ppm)	7.6	7.4
pH	4.5± 2.0	ECEC	4.52	4.78

Materials and methods

Physicochemical characteristics of POME

A composite POME sample obtained from government owned palm oil mill plant ADAPALM Ltd Owerri Nigeria was analyzed for COD, $BOD_{5,}$ TSS, pH, total nitrogen, phosphorus and magnesium. The above measurements were performed on raw POME. COD determineation was based on closed reflux dichromate oxidation colorimetric method and was read out in DR 2000 spectrophotometer as explained in detail in APHA (1992). Samples for BOD_5 measurements were prepared according to a modified method explained in APHA (1992). 2-Chloro-6 trichloro-methyl pyridine was used to inhibit nitrification as stipulated by the procedure. The apparatus used was the Lovibond BOD IR-sensomat, which consists of an IR-pressure sensor acting as the measurement device, BOD- sensomat and stirring system. Each sample was collected in a 500 ml BOD flask and was filled completely and covered satisfactorily with foil cap and left for a 5-day period. The resultant carbondioxide from microbial respiration is absorbed with potassium hydroxide (KOH), which creates a decrease of the air pressure in the BOD flask. The pressure decrease is detected by the IR-sensor, logged into the BOD-sensor and converted directly in mg/L of BOD. Suspended solid was determined gravimetrically by evaporating to dryness 100 ml of unfiltered sample (effluent) and heating to constant weight. Total org. N was determined using micro-kjeldahl method described by Bremner (1965). pH of POME was determined using a Hach-one pH Meter. Magnesium and phosphorus determination was carried out using wet oxidation method as described in Association of analytical chemists (A.O.A.C) (1965).

POME fermentation

POME fermentation involved the use of 6 plastic bowls of 80 litres in volume and diameter 0.5 m. The plastics were fed each with fresh POME + 0.8 g/L of urea to facilitate microbial activity and N mineralization. Temperature was maintained at 30^{o}C, pH; 8.5 using 2NaOH. This mixture was allowed to ferment for 10, 15 and 20 days respectively. The content stirred at least once a day to provide aeration.

Soil-plant experiment

Field experiments were conducted in the Federal University of Technology, Owerri (FUTO) agricultural farm during 2006 and 2007 early cropping seasons. The University is situated between latitudes 5^{o}29^1 N and longitudes 7^{o}02^{1}E within the Nigeria humid (rain) forest zone. The experiment was laid out as a 3 x 4 factorial treatment combination in a randomly complete block design (RCBD) with 3 replications. The experimental area was 730 m^2. A plot size of 4 x 4 m^2 separated by a 1 m wide alley and 2 m between blocks (replicates). Each of the twelve (12)+ 3 NPK treatment combinations was randomly assigned to plots and planted maize grain (Oba supper) at a spacing of 75 x 25 cm at 2 seeds per hole and was thinned to 1 plant per stand at 3 weeks after planting achieving a density of 53000 plants/ha. Inorganic fertilizer (NPK) was used as standard check. The fermented POME was applied at rates of 0 m^3ha^{-1} (control), 2.0 m^3ha^{-1}, 3.2 m^3ha^{-1}, and 4.7 m^3ha^{-1}. POME was applied 3 WAP in a ring pattern on each maize stand except in the control and NPK plots. Data on maize growth, dry matter and grain yields were collected at harvest.

Pre-soil analysis was based on composite samples (0-15 cm) from the experimental farm. This was subsampled and analyzed for parameters such as soil pH, organic carbon, total nitrogen, available P and exchangeable calcium (ca) magnesium (mg), Sodium (Na), Potassium (K) and total exchangeable acidity. pH (1:1) was determined using pH meter. Organic carbon was determined by dichromate oxidation method of Walkley and Black, (1945). Available P was measured using Bray no 1 solution of Murphy and Riley, (1972). Exchangeable bases were measured by extracting known quantities of the soils with neutral ammonium acetate (1N NH_40-

Table 2. Nutrient NPK content of fermented POME before soil application

POME (Nutrient Content)	Duration of fermentation	2006 mgl^{-1}	2007 mgl^{-1}
N	$Dferm_{10}$	41.4 ±2.0	38.2 ±1.31
	$Dferm_{15}$	78.4 ±2.13	92.3 ±1.64
	$Dferm_{20}$	126.4±1.4	126.5 ±1.43
P	$Dferm_{10}$	38.5±2.1	37.8±2.4
	$Dferm_{15}$	41.3±1.7	43.9±1.8
	$Dferm_{20}$	44.7±3.2	45.2±2.9
K	$Dferm_{10}$	35.9±2.7	36.8±2.3
	$Dferm_{15}$	41.3±1.9	38.6±3.7
	$Dferm_{20}$	42.3±2.2	44.5±1.8

Dferm= Duration of POME fermentation.

Ac: pH=7) solution (Bray and Kurtz, 1945). Exchangeable Potassium and sodium contents were estimated on the flame photometer while Calcium and Magnesium contents were determined by the Versnate (0.1 M EDTA) titration method. The exchangeable acidity was determined by 1N KCl extraction procedure as outlined by Mclean (1965). Effective cation exchange capacity (ECEC) was obtained by summation of exchangeable cations and acidity. Nitrogen in POME before application was determined using method of Greweling and Peech (1965). Phosphorus was determined using the Bray No 1 method (Bray and Kurtz, 1945) while the Potassium was determined using the flame photometer method.

A post harvest soil chemical analysis and plant tissue analysis were carried out to evaluate the current and residual effects. Random samples of maize stalk and grain based on treatment were obtained oven (model Gallenkamp 100) dried, ashed in furnace (Elle 200) and chemically analyzed for org. N content using the modified micro kjeldahls method. The available P was determined using the Bray No 2 method (Bray and Kurtz 1945) while the Potassium contents was determined using the flame photometer. These were carried out for each treatment combination.

Statistical analysis

One way analysis of variance (ANOVA) and least significant difference (5 %) comparison procedure were carried out using the statistical software GenStat discovery edition 3. Regression analysis was used as appropriate.

Results and discussion

High levels of BOD_5, COD and TSS observed in POME (Table 1) suggest that it could be a serious aquatic pollutant and also amenable to biodegradation. Dhouib et al., (2006) noted similar results from olive mill effluents (OME) and suggested anaerobic digestion with white rot fungi to decrease the COD/BOD_5 ratio and toxicity. Presence of organic N, Mg and P in POME point to its possibility for use as organic amendment to improve soil fertility. This observation is consistent with the works of Onyia et al., (2001), Kittikun et al., (2000) on POME. The low pH noticed in POME could be as a result of presence of phenolic acids and oxidation of other organic acid compounds.

The pre-planting soil physical and chemical analysis of (Table 1) indicated acidic nature of the soil, low nitrogen and low organic carbon which implies low soil fertility. POME characterized before application revealed appreciable level of $N0_3$-N, Phosphorus and avail. K (Table 2). Organic matter mineralization in wastewater such as POME may be enhanced by providing favourable conditions for microbial and enzymatic activity. Reduced C: N ratio, O_2 availability, optimum pH and favourable temperature are likely essential factors in organic matter mineralization (Pascual et al., 2007, Piotrowska et al., 2006). The main factors that influence N availability from wastewater are its inorganic N content (Hutchings, 1984), digestion process (aerobic vs anaerobic) Amundson and Jarrell, 1983, Hutching, 1984, Serna and Pomares, 1992), C: N ratio (Sims, 1990), pH, the method and timing of application and soil type and properties (Hutchings, 1984).

At physiological maturity, varied results emerged from the different treatments. There were significant differences in maize height as affected by both Dferm and rate of application. $Dferm_{20}$ enhanced maize growth parameters (Table 3). From the results, there were up to 1.03, 1.08 folds maize height increases in 2006 as Dferm increased 10-20. In 2007, 1.10, 1.11 folds maize height increases relative to Dferm $_{10}$. Similar results were obtained in dry matter production and grain yield where there were 1.03, 1.15-folds dry matter increases in 2006, 1.10, and 1.22 in 2007 and grain yield 1.07, 1.10-folds in 2006, 1.08, 1.25 in 2007. These results were consistent with result of Yeop and Poop (1983) who observed that land application of palm oil mill effluent improved soil fertility and plant growth. Orhue, et al., 2005 also reported positive growth response in maize after brewery effluent

Table 3. Mean growth , yield and tissue nutrient of maize as affected by POME in 2006 and 2007

Year	Treatment	Plant height	Dry matter	Grain yield	Stover N	Stover P	Stover K	Grain N	Grain P	Grain K
	Dferm (D)	cm	tha^{-1}	tha^{-1}	Mgg^{-1}	Mgg^{-1}	Mgg^{-1}	Mgg^{-1}	Mgg^{-1}	Mgg^{-1}
2006	10	88.5	1.38	2.93	32.9	2.9	22.1	11.7	2.30	2.30
	15	91.3	1.43	3.16	33.9	3.0	22.3	11.8	2.20	2.30
	20	96.4	1.59	3.25	47.6	3.0	22.6	11.6	2.20	2.30
	LSD $_{0.05}$	7.34	0.14	0.19	13.6	0.51	0.33	0.32	0.08	0.12
	Rate of application (R))of POME (m^{3}ha^{-1})									
	0	76.6	1.10	2.15	34.0	2.2	19.8	10.2	1.70	2.0
	2.0	92.9	1.54	3.02	36.4	3.0	22.4	11.4	2.00	2.2
	3.2	95.6	1.67	3.15	39.4	3.0	22.7	11.5	2.10	2.2
	4.7	93.4	1.52	3.14	42.7	3.1	22.6	11.7	2.10	2.2
	Npk(90kgha^{-1})	100.8	2.13	4.22	42.9	3.3	24.2	13.7	3.10	2.9
	LSD $_{0.05}$	9.47	0.16	0.24	7.7	0.7	0.42	0.41	0.10	0.2
	D x R	ns	ns	Ns	ns	ns	1.0	ns	ns	ns
2007	10	81.1	1.59	3.21	39.6	3.20	21.9	11.30	2.3	2.20
	15	89.3	1.75	3.47	39.9	3.30	22.6	11.00	2.3	2.20
	20	90.4	1.94	4.00	46.0	3.30	22.4	11.50	2.4	2.20
	LSD $_{0.05}$	7.29	0.16	0.15	8.4	0.55	0.36	0.64	0.16	0.11
	Rate of application (R) of POME (m^{3}ha^{-1})									
	0	66.3	1.17	2.70	36.7	2.6	19.7	9.60	1.4	1.3
	2.0	86.8	1.66	3.17	33.8	3.3	22.5	11.00	2.2	2.3
	3.2	89.0	1.74	3.50	35.1	3.0	22.7	11.30	2.2	2.3
	4.7	85.7	1.67	3.40	42.6	3.1	22.8	11.30	2.2	2.3
	Npk (90kgha^{-1})	106.8	2.64	5.00	61	4.6	24.0	13.30	3.6	2.8
	LSD $_{0.05}$	9.41	0.21	0.19	10.8	0.7	0.5	0.83	0.2	0.14
	D x R	ns	ns	ns	0.9	ns	ns	ns	ns	ns

Dferm = Duration of POME fermentation

amendment. Regression equations indicated strong positive relationship between Dferm, application rate and maize growth and grain yield in this experiment (Table 5)

Increased maize growth parameters recorded in Dferm $_{20}$ may be as a consequence of longer period of fermentation of POME which may have provided enough time for microbial activity and ultimately mineralize micronutrients for maize growth. Cereti et al., (2004) reported that beneficial effects of Olive mill waste were highest when fermented repeatedly. Organic matter mineralization has been previously described as a first order reaction kinetics with functional relation to time (Cabrera et. al., 2005, Nevens and Reheul, 2005 and Paredes et al., 2005). Cordovil et al., (2005) also reported that increasing the amount of waste applied to soils always lead to a greater amount of potentially available N present in the soil waste mixture. POME-amended plots gave maize height that significantly differed from the control. NPK- plots gave the overall highest maize height in the entire experiment indicating the superiority of inorganic fertilizer to positively affect the growth of crops. NPK fertilizer are readily dissolved and absorbed by plant root system. Application rate of 3.2 m^{3}ha^{-1} gave the highest maize height of 95.6 cm and 89.0 cm, dry matter: 1.67 t ha^{-1}, 1.74 t ha^{-1}, grain yield: 3.15 t ha^{-1}, 3.50 t ha^{-1} in 2006 and 2007, respectively (Table 3). This application rate may have provided the optimum hydraulic load for effective soil reactions essential for crop growth. Excess application of wastewater to agricultural soils could lead to undesirable effects such as salinity (Meek, 1970), O_2 depletion and nutrient loss due to immobilization, denitrification and leaching (Searl et al., 1981). Reduced maize growth in the control plots could be attributed to poor nutrient availability and other soil factors. Maize grain yield was significantly affected by the treatments in the two trials (Table 3). On the average, maize grain yield as affected by Dferm increased in the following order Dferm $_{20}$> Dferm$_{15}$> Dferm$_{10}$. Similarly, grain yield increases as affected by rate of application of POME was in the order of 0 m^{3}ha^{-1} < 2.0 m^{3}ha^{-1} < 4.7 m^{3}ha^{-1} < 3.2 m^{3}ha^{-1}. It is obvious that the enhanced yields recorded in NPK and POME amended plots were direct consequences of the provision of adequate doses of organic and inorganic nutrients as well as sound agronomic management practices. Nutrients accumulated for growth and development are

Table 4. Mean residual soil chemical properties as affected by POME application in 2006 and 2007

Year	Treatment Dferm (D)	% org. N	% org. C	P (ppm)	pH
2006	10	0.03	1.11	4.52	5.8
	15	0.03	1.42	4.63	5.9
	20	0.04	1.81	4.63	6.0
	LSD $_{0.05}$	0.004	0.18	0.11	0.12
	Rate of application (R)of POME (m^3/ha)				
	0.0	0.03	0.83	4.24	5.6
	2.0	0.03	1.44	4.57	6.0
	3.2	0.03	1.45	4.51	6.0
	4.7	0.03	1.60	4.52	6.1
	Npk(90kgha^{-1})	0.04	1.91	5.13	5.7
	LSD $_{0.05}$	0.005	0.23	0.11	0.16
	D x R	ns	0.4	ns	ns
2007	Dferm (D)				
	10	0.03	0.93	4.29	5.9
	15	0.03	1.03	4.47	6.0
	20	0.03	1.16	4.43	6.0
	LSD $_{0.05}$	0.004	0.070	0.26	
	Rate of application (R)of POME (m^3/ha)				
	0.0	0.03	0.87	3.44	5.9
	2.0	0.03	1.03	4.36	6.0
	3.2	0.03	1.01	4.51	6.0
	4.7	0.03	1.06	4.50	6.1
	Npk(90kgha^{-1})	0.04	1.22	5.13	5.7
	LSD $_{0.05}$	0.006	0.09	0.33	0.11
	D x R	ns	0.16	ns	ns

Dferm = Duration of POME fermentation

translocated for grain filling. Paredes, et al., (2005) also observed that Olive mill wastewater (OMW) produced Swiss chard crop yield similar to both compost without OMW and inorganic fertilizer. Other authors Zhou, et al., (2000), Warman and Termeer, (2005) reported yield increases in crops following fermented waste application. This high yield response may be predicated on the fact that longer days of POME fermentation provided enough period for microbial activity which cumulated into nutrient mineralization. Consequently, POME application with resultant positive yields may be attributed to the ability of POME to stimulate the decomposition of native organic matter in the subsisting soil/plant environment.

Dferm did not significantly affect K-grain content in this experiment. However, application rate significantly affected K-grain content. K-grain content was highest in NPK plots followed by POME amended plots and the least was in the control. This trend suggests that K absorption closely related to the quantity of k-ions present in the soil matrix. NPK plots gave the highest N-grain and P-grain content followed by POME amended and control plots (Table 3) indicating poor release of N and from POME as against the inorganic fertilizer but better than the control. Zhou et al., (2000) reported increased N-grain accumulation following fertilizer application. Oikeh et al., (2003) noted also that N-application increased N-uptake by 30 % at all sampling dates of maize plant.

K-stover increased as Dferm increased (Table 3). NPK plots recorded highest K-stover content as against POME amended plots. Inorganic fertilizer was readily ionized and absorbed into plant tissues more than POME amended and control plots. Warman and Termeer, (2005) reported that stover and grain–K varied greatly following sewage water application. Significant increase in N-stover content observed in Dferm $_{20}$ could be linked to the efficient mineralization recorded with longer days Dferm which also resulted in the yield increases recorded in the treatment. Greater percentage of tissue N accumulated during active growth is drawn to the ears for grain filling. This observation was also noted by previous authors

Table 5. Coefficient of determination and simple linear regression equation for plant height, dry weight and grain yield as affected by rate of application of POME and duration of fermentation.

	Parameters	Coefficient of determination (r^2)	Linear regression equation
1.0	Plant height as affected by rate of application.	0.7827	Y=7.099 x + 59.1
2.0	Plant height as affected by duration of POME fermentation	0.9726	Y= 7.855 x + 63.5
3.0	Dry weight as affected by rate of application.	0.7517	Y= 0.2627 x + 0.8767
3.0	Dry weight as affected by duration of POME fermentation	0.8899	Y= 0.1715 x + 1.27
4.0	Grain yield as affected by rate of application.	0.7677	Y= 0.4272 x + 1.55
5.0	Grain yield as affected by duration of fermentation.	0.9998	Y= 0.2385 x + 2.26

(Warman and Termeer, 2005; Davis et al., 1985; Sikora and Enkiri, 1999).

There was poor variation in percentage residual N as influenced by Dferm (Table 3). However, rate of application significantly affected residual soil nitrogen and org. C. NPK plots recorded the highest residual percentage N and org. C. while the control plots gave the least (Table 4). The org. C and N contents provide a measure of organic matter status of soil, which is the net function of crop management practices in any agro-ecosystem (Gregorich et al., 1994; Manjaiah and Dhyan, 2001). Amongst the treatments applied, NPK plots recorded highest soil organic C and N, followed by POME amended plots, consequently narrow C: N ratio recorded in these plots indicates build up of N pool in the soil. POME amendment may have provided the needed microbes and $N0_3$-N that stimulated soil organic matter (SOM) degradation (Douglas, et al., 2003). Longer days for which POME was fermented provided quality time for microbial build up which ultimately increased residual org. C and N. The differences in the rates of residual org. carbon and N are indicative of the variable amounts of labile org. C accumulated in different treatments (Kanchikerimath and Singh 2001).

This study showed that fermented POME could enhance the growth and yield of maize and leaves considerable level of soil organic Carbon, N and P residues.

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