EFFECT OF PALM OIL MILL EFFLUENT CONDITIONED BY ORGANIC AMENDMENTS ON PHYSICOCHEMICAL PROPERTIES OF SELECTED SOILS IN ALUU, PORT HARCOURT.

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Abstract
Palm Oil Mill Effluent (POME) is a high-strength organic waste that poses significant environmental risks, particularly in regions where untreated discharge into terrestrial ecosystems is common. This study evaluates the impact of POME amended with organic wastes on soil physicochemical properties. The pots each containing 10 kg of soil were laid out in a factorial fitted into a completely randomized design (CRD) - six treatments with six replications giving a total of 36 experimental units. Three seeds of *Amaranthus Spp.* were planted. Six treatments (poultry droppings, pig droppings, cow dung, poultry + cowdung + pig dropping, soil without POME and Soil with POME) were used, each applied at 20 tha^{-1}. The soil samples were assessed for physicochemical properties after amendment. Physicochemical properties analyzed include pH, moisture content, hydraulic conductivity, organic carbon, total nitrogen and available phosphorus. There was a significant ($P<0.05$) increase in soil properties by the application of treatments to the raw POME. These parameters included soil pH (5.1 – 6.2), phosphorus (20.10 – 24.00 mg/kg), organic carbon (0.4 – 1.6 %), hydraulic conductivity (1301.92 – 9598.45 mm/day), moisture content (18.50 – 51.15 %). On average, POME amended with cow dung recorded the highest values among other treatments as follows: hydraulic conductivity = 9598.45, moisture content = 51.15 %, pH = 6.2 and available phosphorus = 24.0 mg/kg. These values buttress the fact that the addition of organic waste to POME soil could improve soil quality and boost its fertility for agricultural productivity.

Keywords: Palm Oil Mill Effluent, Soil Contamination, Soil Physicochemical Properties, Organic amendments

Introduction
Oil palm *(Elaeis guineensis)* is one of the most versatile crops in the tropical world (Corley and Tinker, 2015)). In Nigeria, oil palm production has increased from 12.4 million tonnes in 2010 to 13.5 million metric tonnes in 2020 (FAO, 2021). However, the production of palm oil results in the generation of large quantities of polluted wastewater commonly referred to as palm oil mill effluent (POME). Palm oil mill effluent is rich in solid, oil and grease (O&G) and high in organic content (Mohammad *et al.*, 2021). The continuous discharge of POME

into the environment during the processing of palm oil has become a major concern due to its high organic potential to affect soil properties and plant growth negatively (Ali *et al.*, 2015). POME is often released untreated, leading to environmental issues such as soil acidification, nutrient imbalance, and potential pollution of water bodies (Ahmad *et al.*, 2010).

Besides the presence of lipids and volatile compounds, it has been reported that the physicochemical properties of soil are negatively affected by POME (Okwute and Isu, 2007a) Andrews *et al*. (2021) recommended the use of crop residues and other organic waste as fertilizer supplements. However, when properly managed and amended with adequate organic fertilizers like cow dung, poultry droppings, and pig dung, POME has the potential to enhance soil fertility and improve plant growth performance (Chiew *et al.*, 2018).

Though POME alters the soil physicochemical properties, there is still paucity of information on extent of alteration, and possible improvements when POME is amended with various organic amendments. Therefore, the objective of this study was to assess the effects of POME fortified with various organic amendments on soil physicochemical properties.

Materials and methods

Study Area

The study was conducted between May and August, 2024 in the Screen House of the Department of Crop and Soil Science, University of Port Harcourt, Rivers State, Nigeria. The experiment lasted for three (3) months. Port Harcourt is found in the subequatorial region of Nigeria. Port Harcourt lies between 4º,07 and 5°5°N and longitude 60°56'04"' and 7°3'20"E on an elevation of 14 m above sea level. The mean annual rainfall of Port Harcourt ranges from about 3000 mm – 4500 mm with a bimodal pattern, starting in March and ending in November with peaks in June and September and short period of dry spell in August usually known as August break (Numbere *et al.*, 2016).

Collection of Soil Sample

Composite soil samples were collected using a soil auger behind the Department of Crop and Soil Science, University of Port Harcourt. Each composite sample was obtained by mixing five subsamples collected within a 1 m² quadrat using a stainless-steel auger. The composite samples were then bulked together for homogeneity into 36 buckets prior to spiking with POME.

Sourcing of organic wastes

The deep-litter chicken poultry droppings were collected from the University of Port Harcourt Demonstration Farm in Choba Campus. Fresh pig dung was obtained from the University of Port Harcourt Livestock Farm in Abuja Campus, and fresh cow dung was collected from the Choba community abattoir. The wastes were cured for two weeks before application.

Sourcing of POME

A composite sample of POME was collected from a functional oil mill in Emohua Community, Rivers State, Nigeria. The effluent, usually stored in a plastic drum, was mixed thoroughly and then transferred into clean plastic containers and tightly sealed. It was transported to the laboratory in an ice box.

Spiking of the Soil samples with POME and application of organic amendments

Each experimental bucket was filled with 10 kg of soil and spiked with 100 ml of POME. Three different organic wastes (poultry droppings, cow dung, and pig dung) were each weighed at 1 kg and applied to the buckets. The mixtures were then allowed to compost alongside the applied POME for a period of three weeks.

Experimental Design

The pots, each containing 10 kg of soil, were arranged in a factorial experiment fitted into a Completely Randomized Design (CRD) comprising six treatments with six replications, giving a total of 36 experimental units. The six treatments were: poultry droppings, pig droppings, cow dung, a mixture of poultry droppings + cow dung + pig droppings, soil without POME, and soil with POME.

Planting of Amaranthus

Two weeks after spiking, three seeds of *Amaranthus* spp. were planted in each pot and later thinned to two seedlings. The growing plants were watered at 48-hour intervals.

Physicochemical Analysis of Soil Samples

At the end of four months after planting the experiment was terminated and the following soil physicochemical properties were assessed: organic carbon and mineral assay (Black, 1965), exchangeable cations (Sumner and Miller, 1996), moisture content and total nitrogen (Agbenin,1995) and pH determination by the potentiometric method as described by Brady and Weil (2017). Electrical conductivity (EC), indicating salinity, was measured in the same suspension using a conductivity meter (Okafor *et al.*, 2020). Total nitrogen (TN) was determined using the Kjeldahl digestion technique as outlined by Adeniyi et al. (2019). Available Phosphorus was extracted using the Bray-1 method, suitable for acidic soils, and measured colorimetrically (Nwoko and Ogunyemi, 2010). Soil texture was determined using the hydrometer method.

Statistical Analysis

Data collected from the various parameters after soil analysis were subjected to analysis of variance using SPSS (Version 19.0) (SPSS, 2010) computer package to compare treatment values. Mean difference was compared using the least significant difference at 1 % and 5 % level of probability levels respectively.

Results and discussion

Soil Reaction

The highest pH values were recorded in ‘POME + cow dung’ (6.2), ‘POME + Poultry droppings’ (6.0), ‘POME + pig dung’ (6.2) and ‘POME + pig dung + cow dung + poultry droppings’ (5.7); and these values were statistically the same but higher than values of both Soil alone (4.8) and ‘unamended POME’ (5.1) which showed no statistical difference among each other. Generally, the pH of the POME amended samples was significantly higher than those of unamended soil samples (5.1). This observation is in tandem with the report of Okwute and Ijah (2014b) that the addition of POME to soil had a clear effect on the pH of the polluted soil, as there was a significant difference ($P < 0.05$) between the pH of the unpolluted and polluted soils. This is because raw POME is acidic (Salihu and Alam, 2012; Fitri *et al*., 2022) resulting from the oxidation of organic acids, lipids, volatile compounds and water-soluble compounds (Mohammad *et al*., 2021). The pH values of the studied samples ranged from very strongly acidic, 4.8 (soil alone) to moderately/slightly acidic, 6.2 (soil + POME amended with animal droppings) thus, highlighting a distinct pH buffering due to effluent-derived alkaline organic compounds. These values exceeded the typical baseline pH of acid forest soils in southeastern Nigeria, which ranges from 3.9 – 4.8, as reported by Osodeke and Eze (2011).

The increase in pH, though modest, is ecologically significant. Acidic soils, particularly below pH 5.0, often suffer from aluminum toxicity, phosphorus fixation and microbial inhibition. Therefore, the slight elevation in pH at effluent-impacted samples could foster improved microbial activity and nutrient availability, supporting findings by Okonokhua *et al*. (2007), who observed enhanced microbial respiration and enzyme activities at mildly acidic conditions post-effluent treatment. However, these benefits are contingent on controlled effluent dosing; excessive or chronic effluent exposure may disrupt pH balance or induce salinity-related antagonism.

Exchangeable Cations

The highest value of Mg was recorded in 'POME + cow dung' (1.60 cmol/kg), 'POME + pig dung' (1.51 cmol/kg) and 'POME + Poultry droppings' (1.32 cmol/kg) which were statistically the same but higher than 'Soil alone' (0.48 cmol/kg), 'POME + pig dung + cow dung + poultry dropping' (0.46 cmol/kg) and 'unamended POME' (0.27 cmol/kg) which were statistically the same. The highest value of K was recorded in 'unamended POME' (0.27 cmol/kg) and was significantly higher than other treatments. There was no significant difference among the other treatments. The highest values of Ca were recorded in 'POME + pig dung + cow dung + poultry dropping' (8.5 cmol/kg), 'POME + Poultry droppings' (8.3 cmol/kg) and 'POME + cow dung' (7.4 cmol/kg). There is no significant difference among the aforementioned values. However, they are significantly higher than values of 'POME + pig dung' (5.9 cmol/kg), Soil alone (6.50 cmol/kg) and 'unamended POME' (4.90 cmol/kg). Similar to the observations obtained in soil reaction, Nwoko and Ogunyemi (2010) observed a moderate increase in soil pH following POME application in Ibadan, attributed to the hydrolysis of organic acids and release of basic cations such as Ca^{2+}, K^{+}, and Mg^{2+} during decomposition.

Total Nitrogen (TN)

The highest Total Nitrogen value was recorded in 'unamended POME' (1.6 %), 'POME + pig dung' (1.6 %) and 'POME + Poultry droppings' (1.4 %). These values were statistically amongst themselves but higher than those of 'POME + cow dung' (1.3 %) and 'POME + pig dung + cow dung

+ poultry dropping' (1.3 %), while the least value was recorded in soil alone (0.6 %). The nutrient and organic content data from the study clearly demonstrates the profound influence of palm oil mill effluent (POME) discharge on soil fertility parameters. Total nitrogen values of soil amended with animal waste were higher than of the control (0.6 %), suggesting a high deposition of organic-rich effluent and subsequent nitrogen mineralization. These values are considerably higher than those reported by Nwoko and Ogunyemi (2010), who recorded nitrogen values between 0.15 % and 0.88 % in POME-treated soils in Ibadan, Nigeria, pointing to more intense contamination or prolonged effluent exposure in the Umuapu region (Nwoko and Ogunyemi, 2010).

Total Organic Carbon (TOC)

The highest TOC value was recorded in 'POME + pig dung + cow dung + poultry dropping' (1.6 %) which was significantly higher among the treatment combinations. The values of 'POME + cow dung' (1.1 %), 'POME + Poultry droppings' (1.0 %) and 'POME + pig dung' (0.8 %) were significantly lower than 'POME + pig dung + cow dung + poultry dropping' but higher than 'unamended POME' (0.4) which had the least value. Total organic carbon concentrations were markedly elevated in POME-impacted soils with range – 0.7 % (Soil alone) to 1.6 % (Soil + POME + cow dung). These values reflect an abundance of undecomposed or partially decomposed organic residues from the effluent. Such enrichment mirrors the findings of Okwute *et al*. (2023), who reported a TOC range of 14.2 % – 18.5 % in POME-polluted soil amended with compost, emphasizing that effluent alone is capable of elevating carbon stocks in soils. The Total organic carbon follows a similar pattern and these figures are consistent with studies conducted in the Niger Delta, where POME application increased TOM by over 40 % within three weeks (Anoliefo and Edegbai, 2000). Organic matter plays a vital role in nutrient retention, soil aggregation, and microbial activity. However, excessive accumulation can also result in oxygen deficiency and reduced nitrification in poorly drained soils.

Available Phosphorus

The highest value of available phosphorus was shown in 'POME + cow dung' (24.0 mg/kg), 'POME + pig dung' (23.3 mg/kg) and Soil alone (23.1 mg/kg) respectively, and were statistically the same. The above values were all significantly higher than that of 'unamended POME' (20.1 mg/kg) while the statistically least value was that of 'POME + pig dung + cow dung + poultry dropping' (17.9 mg/kg). This deviation suggests potential phosphorus immobilization or fixation in certain microenvironments. Similar phosphorus inconsistency was reported in Afangide *et al*. (2022), where microbial uptake and chemical precipitation in acidic soils limited bioavailable phosphorus despite high organic input.

Hydraulic conductivity (-Ksat)

There was no regular pattern in distribution of -Ksat among the treatments. The -Ksat recorded the highest value in 'POME + cow dung' (9598.45 mm/day), 'POME + pig dung' (8970.25 mm/day) and 'POME + pig dung + cow dung + poultry dropping' (8822.45 mm/day) and there was no significant difference among the aforementioned values. However, they were higher than those of 'POME + Poultry droppings' (6574.76 mm/day) and 'soil alone' (5693.79 mm/day).

Generally, the hydraulic conductivity across POME-inoculated samples with animal droppings (6574.76 mm/day – 9598.45 mm/day) significantly surpassed that of the control (1301.92 mm/day). This may be due to the intermittent mixing of the soil for proper aeration and porosity due to impact of increased organic matter introduced by the animal droppings. This is in tandem with the findings of (Aluko and Oyeleke, 2005; Lal, 2011) who reported that organic matter is known to improve the physical properties of soil such as the porosity (Aluko and Oyeleke, 2005; Lal, 2011). Similarly, Farooqi et al., (2020) made similar observation and reported that organic matter content is said to affect soil fertility by increasing the availability of plant nutrients, improving the soil structure and water holding capacity, and acts as an accumulation phase for toxic heavy metals in the soil environment.

Moisture content (MC)

The MC did not record regular pattern across the treatments. However, POME + cow dung' (51.15 %), 'POME + pig dung + cow dung + poultry dropping' (48.88 %) and 'POME + Poultry droppings' (49.77 %) showed no significant different from each other but were higher than other treatments. On the other hand, POME + pig dung' (45.54 %) and soil alone (39.60 %) were significantly the same, but lower than 'POME + cow dung', 'POME + pig dung + cow dung + poultry dropping' and 'POME + Poultry droppings' and higher than 'unamended POME' (18.50 %) which was significantly lower across other treatments.

Moisture content across POME-impacted the soil samples were higher (45.54 % – 51.15 %) than that of control (39.60 %). This reflects the hydrophilic nature of residual organics and oil in effluents, which could enhance water retention. Similar outcomes were reported in Maduwuba (2024), with moisture of 21 % – 35 % in POME treated soils. While higher moisture may benefit plant growth in dry seasons, elevated residual moisture content combined with oil films risks pore clogging, reduced aeration, and anaerobic microzones potentially impairing root respiration and microbial nitrification processes (Maduwuba, 2024).

The high moisture level observed in the polluted soil was probably due to the mulching effect of the applied POME. However, the soil moisture was greatly enhanced ($p<0.05$) with the application of chicken droppings and cow dung as it increased from 18.50 % to 49.77 % for poultry droppings after 2 months of bioremediation and from 18.50 to 51.15 % for cow dung (Table 1). This is in line with the findings in Adeleye *et al*. (2010) and Haque et al. (2021) reported that the application of organic wastes significantly increased soil moisture content. Similarly, Khaleel *et al*. (1981) and Haque *et al*. (2021) reported that soil water retention capacity due to application of animal manure could cause structural improvement in soil; that is, increase in porosity and the amount of porosity involved in soil water storage. In addition, the improvement of soil moisture by poultry droppings may be due to the colloidal and hydrophobic nature of the droppings as previously reported by Mbah and Mbagwu (2006) and Mau *et al*. (2018).

Conclusion

This study has demonstrated that the indiscriminate discharge of POME significantly alters the physicochemical properties of soils within the study location. The application of organic amendments (cow dung, poultry droppings and pig dung) in POME contaminated soil increased pH values from 5.1 (unamended soil) to 6.2 in amended soil samples thereby reducing the acidity of the POME contaminated soil. It also improved the Organic carbon content from 0.4 % (unamended sample) to 1.6 % in amended samples thereby improving the soil structure and water holding capacity. It increased the total nitrogen, thereby suggesting a high deposition of organic-rich effluent and subsequent nitrogen mineralization. It equally increased the soil moisture content from 18.50 % in unamended soil to 51.15 % in amended soil samples. It increased the value of available phosphorus from 20.1 mg/kg in unamended soil samples to 24.0 mg/kg in amended soil samples. In all, the organic amendments enrich the POME contaminated soil for agricultural production. However, these findings underscore the urgent need for regulated effluent management in artisanal palm oil-producing communities.

Recommendations

1. Promote the use of eco-friendly remediation strategies, such as bioremediation and phytoremediation, to rehabilitate impacted soils.

2. Sensitize rural farmers and mill operators on the environmental hazards of POME and the benefits of sustainable waste management.

3. Enforce environmental monitoring and compliance policies targeting soil and water quality near processing sites.

4. Establish localized effluent treatment systems for artisanal palm oil mills to reduce direct discharge of untreated POME.

Contribution to knowledge

This study provides the first field-based empirical evidence of POME-induced soil degradation in Aluu Province, Port Harcourt, Rivers State; contributing to data bank of the region. It highlights the spatial variability of soil impacted with POME effluent discharge and establishes a baseline for future ecological risk assessments and soil remediation strategies in artisanal oil palm zones.

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Table 1: Physical properties of soil before POME inoculation

Sand	Silt	Clay	TC	FC	MC	-Ksat	EC	BD
	⟶		%	⟵		mm/day	-	g/cm
33	38	29	CL	12.93	38.54	5691.82	0.08	1.47

TC = Textural class, MC = Moisture content, EC electrical conductivity, -Ksat = Hydraulic conductivity, BD = Bulk density, CL = clay loam

Table 2: Chemical properties of soil before POME inoculation

pH	Av.P	TN	OC	Ex. Mg	Ex. Ca	Ex. K	Ex. Na	EA
	(mg/kg)	⟶	(%) ⟵	⟶		(cmol/kg)	⟵	
4.6	22.90	0.55	0.67	0.46	6.42	0.13	0.17	0.95

Av.P = Available phosphorous, OC = Organic carbon, Ex. Exchangeable, TN = Total Nitrogen, EA = Exchangeable acidity

Table 3: Physical characteristics of the soil after POME amendment

Parameter	Unit	T1	T2	T3	T4	T5	T6
Sand	%	35[a]	32[a]	30[a]	29[b]	28[b]	26[b]
Silt	%	40[c]	43[c]	45[b]	46[b]	48[b]	51[a]
Clay	%	25[a]	25[a]	25[a]	25[a]	24[a]	23[a]
TC	-	CL	CL	CL	SL	SL	SL
BD	g/cm	1.49[b]	1.62[a]	1.49[b]	1.49[b]	1.38[c]	1.49[b]
MC	%	39.60[b]	18.50[c]	51.15[a]	49.77[a]	45.54[b]	48.88[a]
K_{sat}	mm/day	5693.79[b]	1301.92[c]	9598.45[a]	6574.76[b]	8970.25[a]	8822.45[a]
EC	-	0.10[b]	0.30[b]	0.00[c]	0.00[c]	0.00[c]	0.50[a]
FC	%	13.79[c]	13.79[c]	55.17[a]	41.37[b]	55.17[a]	42.39[b]

T1 = soil alone, T2 = 'unamended POME', T3 = soil + POME + cow dung, T4 = soil + POME + poultry droppings, T5 = soil + POME + pig dung, T6 = soil + POME + cow dung + Poultry droppings + Pig dung. CL = clay loam, SL= sandy loam, ksat = saturated hydraulic conductivity, FC = field capacity, MC = Moisture content. TC = Textural Class. Means followed by the same alphabets within column were not significantly different at $p < 0.05$

Table 4: Chemical characteristics of the soil after POME amendment

Parameter	T1	T2	T3	T4	T5	T6
pH	4.8^{b}	5.1^{b}	6.2^{a}	6.0^{a}	6.2^{a}	5.7^{a}
Av. P (mg/kg)	23.1^{a}	20.1^{b}	24.0^{a}	15.2^{c}	23.3^{a}	17.9^{c}
TN (%)	0.6^{c}	1.6^{a}	1.3^{b}	1.4^{a}	1.6^{a}	1.3^{b}
OC (%)	0.7^{b}	0.4^{c}	1.1^{b}	1.0^{b}	0.8^{b}	1.6^{a}
Ex. Mg^{2+} (cmol/kg)	0.48^{b}	0.27^{b}	1.60^{a}	1.32^{a}	1.51^{a}	0.46^{b}
Ex. Ca^{2+} (cmol/kg)	6.50^{b}	4.90^{b}	7.4^{a}	8.3^{a}	5.9^{b}	8.5^{a}
Ex. K^{+} (cmol/kg)	0.15^{b}	0.27^{a}	0.12^{b}	0.14^{b}	0.16^{b}	0.13^{b}
Ex. Na^{+} (cmol/kg)	0.20^{a}	0.10^{b}	0.20^{a}	0.20^{a}	0.10^{b}	0.10^{b}
EA (cmol/kg)	1.00^{a}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}

T1 = soil alone, T2 = unamended POME, T3 = soil + POME + cow dung, T4 = soil + POME + poultry droppings, T5 = soil + pome + pig dung, T6 = soil + pome + cow dung + poultry droppings + pig dung. EA= exchangeable acidity, EC = Electrical conductivity, OC = organic carbon, TN = Total Nitrogen, Ex. = exchangeable, Av.P = Available Phosphorus. Means followed by the same alphabets within column were not significantly different at $p < 0.05$