

Impact of Palm Oil Mill Effluent (POME) on Soil Quality in Evwreni Town, Ughelli North LGA, Delta State

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Abstract—Palm Oil Mill Effluent (POME), a by-product of palm oil processing, has drawn attention due to its potential impact on soil quality and plant growth. This study investigated the impact of POME application on key soil quality. Experimental treatment involved three concentrations of POME (100ml/kg, 200ml/kg, 400ml/kg) applied to agricultural soil over a defined period. The pH gradually decreased from approximately 6.0 at 100 ml to 5.5 at 400 ml, demonstrating a consistent trend of acidification with increasing effluent volume. In contrast, electrical conductivity (EC) increased steadily from about 0.11 mS/cm to 0.33 mS/cm, signifying a progressive rise in ionic concentration and a potential risk of salinity build-up. Similarly, the total organic carbon (TOC) content rose markedly from roughly 2.5% at 100 ml to 5.7% at 400 ml, confirming substantial organic enrichment of the soil. The nutrient profile also reflected considerable augmentation, as nitrate concentrations increased steadily from around 9 mg/l to 23 mg/l, indicating significant nutrient accumulation. Among the exchangeable cations, potassium (K) recorded the sharpest increase, rising from about 104 mg/l to 303 mg/l, underscoring its dominance in the mineral composition of POME and its potential influence on crop responses. Moreover, microbial activities intensified, as evidenced by the total heterotrophic bacteria (THB) count, which almost doubled from approximately 6.0×10^8 cfu/ml to 10.8×10^8 cfu/ml, reflecting strong microbial stimulation and enhanced nutrient cycling in the amended soils. With these findings realized from the average value across all data set, it can be drawn conclusively that palm oil mill effluent (POME) has a direct effect on the soil physicochemical and microbial properties and it affects plant growth potential. It also serves as an effective organic amendment. Hence its use should be carefully managed to prevent negative environmental effects by treating or diluting it before application. This study highlights the dual potential of POME as both a pollutant and a resource in sustainable agriculture.

Keywords— POME, soil quality, nutrient dynamics, soil microbes, crop growth, environmental management.

I. INTRODUCTION

The environment is fundamental to the survival and well-being of humans, plants, animals, and other living organisms, yet anthropogenic activities continue to degrade this shared ecological system. Among the contributors to this degradation is the generation of Palm Oil Mill Effluent (POME), a high-strength industrial wastewater produced during the extraction of palm oil. Rising global demand for palm oil—used in food, cosmetics, pharmaceuticals, and increasingly for biofuel—has accelerated the expansion of oil palm plantations across Asia, Africa, and Latin America (Kumar et al., 2018; Schneider et al.,

2020). However, this expansion has generated substantial environmental concern due to the improper disposal of POME, which is characterized by high organic load, elevated BOD and COD, abundant suspended solids, and significant concentrations of oil and grease (Chai et al., 2017; Yusoff et al., 2019; Suhaila et al., 2020).

POME is widely recognized as one of the most environmentally challenging agricultural waste streams due to its extremely high pollutant strength. It consists of 95–96% water, 0.6–0.7% oil, and 4–5% total solids, with pollutant concentrations far exceeding those of typical municipal effluent (Ahmad et al., 2018). Although rich in nutrients such as nitrogen, phosphorus, and potassium, which may have agronomic relevance, uncontrolled discharge leads to significant environmental degradation. When applied to soil, untreated POME alters physicochemical properties—including pH, texture, organic matter content, and nutrient balance—and may result in nutrient toxicity or acidification (Okwute & Isu, 2007; Sharifah et al., 2021). Heavy metals present in POME (Ohimain et al., 2012) further pose long-term ecological and public health concerns due to their persistence and potential for bioaccumulation.

Microbial communities are equally affected. The high organic load of POME stimulates microbial respiration by supplying readily degradable substrates (Wu et al., 2017), yet oxygen depletion in POME-amended soils may shift microbial communities toward anaerobic species, including methanogens and denitrifiers (Adegbola & Olatunde, 2020). These shifts disrupt nutrient cycling processes and may increase greenhouse gas emissions. While some studies report improvements in soil structure and water retention due to organic matter additions (Nannipieri et al., 2017), the balance between beneficial and harmful effects remains dependent on concentration, soil type, and treatment status of the effluent.

Given these environmental risks, significant research has been directed toward POME treatment technologies. Biological methods such as anaerobic digestion reduce BOD and COD effectively while generating biogas as a renewable energy source (Md Maniruzzaman et al., 2020). Aerobic treatments offer enhanced effluent polishing though they are energy-intensive (Chan et al., 2011). Physicochemical approaches—including coagulation, flocculation, and membrane filtration—aid in solid removal and stabilization (Sharifah et al., 2021; Tan

et al., 2019), while advanced oxidation processes such as ozonation and photocatalysis target recalcitrant compounds for further degradation (Ponce-Robles et al., 2020). Hybrid systems integrating these methods have shown improved overall performance (Madaki & Seng, 2013).

In regions such as Delta State, Nigeria, where palm oil processing is a major economic activity, the discharge of untreated or poorly treated POME has become a pressing environmental issue. Studies indicate that POME contamination alters soil physicochemical and microbial properties—including pH, nutrient balance, organic matter content, and heavy metal concentrations—resulting in reduced soil fertility and disrupted soil ecological processes (Eze et al., 2017; Akintoye et al., 2021). Runoff into water bodies further threatens aquatic ecosystems through oxygen depletion, biodiversity loss, and eutrophication driven by high nutrient loading (Adewumi et al., 2019). These impacts reflect broader global concerns regarding agricultural intensification, soil degradation, and environmental pollution (Aayushma, 2019).

Given that palm oil accounts for 34% of global vegetable oil consumption, with approximately 64.6×10^3 million kg produced in 2017 (Raghu, 2017), the volume of POME generated is substantial. Each ton of fresh fruit bunches processed yields about one tonne of effluent, with pollutant levels up to 100 times higher than municipal sewage (Zafar, 2024). When discharged on land, POME causes soil clogging, waterlogging, and vegetation die-off; when discharged into aquatic systems, it results in severe pollution and loss of biodiversity (Sharifah et al., 2021). These challenges underscore the necessity of effective effluent management and strict regulatory compliance.

In the Niger Delta which is Nigeria's primary palm-oil-producing belt and one of its most environmentally stressed regions—industrial and agricultural activities, including palm oil milling, have heightened concerns over soil and water quality. As Nigeria is the fifth-largest global producer of palm oil, with most production concentrated in this region, increased milling activity has correspondingly intensified POME generation. Raw POME is typically acidic upon discharge but becomes alkaline as biodegradation proceeds, influencing soil chemistry and biological activity (Ohimain et al., 2012). Understanding these dynamics is critical for assessing environmental risks and guiding sustainable palm oil production practices.

Consequently, this study examines the impact of POME on soil physicochemical and microbial properties in Evwreni community, Ughelli North LGA, Delta State. By comparing contaminated and uncontaminated soils and evaluating the influence of varying POME concentrations, the study aims to elucidate POME's impact on soil quality, nutrient availability, and crop growth potential. This evidence is essential for developing environmentally sound POME management strategies and promoting sustainable agricultural production in palm-oil-producing regions.

II. MATERIALS AND METHODS

2.1 Materials and Equipment

2.1.1 POME Collection and Preservation

Fresh Palm Oil Mill Effluent (POME) was sourced from a palm oil processing facility in Evwreni, Ughelli North LGA, Delta State, Nigeria. To minimize biochemical alteration, the effluent was immediately transferred into sterile airtight containers and stored in an ice-packed cooler prior to laboratory use.

2.1.2 Soil Sampling and Analytical Instruments

The study utilised standard laboratory-grade materials and equipment, including:

- Measuring cylinders (50 mL and 100 mL): For precise volumetric application of POME and water.
- Pipettes/watering cans: For uniform daily moisture application.
- Digital pH meter: Used for in situ and laboratory determination of POME and soil pH after calibration.
- Electrical Conductivity (EC) meter: For quantifying soluble salt concentrations in saturated soil extracts.
- Digital weighing balance: For accurately weighing soil and analytical samples.
- Spectrophotometer/Colorimeter: Employed to analyse available phosphorus using the molybdenum blue method.
- CEC Analytical Kit: Used to determine exchangeable cations via chemical extraction and spectrometric quantification.
- Walkley–Black reagents: Applied to determine soil organic matter and organic carbon through wet oxidation.
- Titration apparatus: For measuring Chemical Oxygen Demand (COD) via dichromate oxidation and Biochemical Oxygen Demand (BOD) after five-day incubation at 20°C.

2.1.3 Crop Nutrient Reference Chart

A comprehensive nutrient requirement chart for major food crops in Delta State was developed to support interpretation of findings and evaluate the agronomic implications of POME-induced soil changes (see Table 1)

2.2 Methodology

2.2.1 Study Area and Soil Sample Collection

The study was conducted in Evwreni (5.4000°N, 6.0667°E), located in Ughelli North LGA of Delta State. Soil samples were collected from a cassava farm using a soil auger at four separate points to ensure representative sampling. A control soil sample was collected approximately 1 km from any known contamination source. All samples were stored in sterile polyethylene bags and sealed to avoid alteration of moisture content or microbial structure prior to laboratory analysis.

2.2.2 Experimental Design

A Completely Randomized Design (CRD) was adopted with four treatment levels of POME applied to 1 kg of soil:

- T0 (Control): 0 mL POME
- T1: 100 mL POME
- T2: 200 mL POME
- T3: 400 mL POME

Each treatment was replicated twice, resulting in eight (8) experimental units. Following treatment application, the soils were placed in perforated plastic pots and transferred to a greenhouse to maintain controlled environmental conditions and eliminate interference from rainfall or surface runoff.

2.2.3 Treatment Application and Experimental Monitoring

Fresh POME was thoroughly mixed into each soil unit at the designated volumes. The control treatment received no effluent. All pots were irrigated daily with 50 mL of clean water to maintain optimal moisture for microbial and biochemical activity. The pots were monitored routinely to ensure uniform watering, prevent anaerobic conditions, and sustain consistent temperature and humidity throughout the experimental period.

2.2.4 Physicochemical Soil Analysis

Both pre-treatment and post-treatment soils were analysed for the following parameters:

- pH: Determined using a calibrated digital pH meter in a 1:2.5 soil–water suspension.
- Electrical Conductivity (EC): Measured from saturated soil extracts to estimate soluble salt accumulation.
- Cation Exchange Capacity (CEC): Evaluated using ammonium displacement and quantified via spectrometric analysis.
- Organic Matter and Organic Carbon: Determined using the Walkley–Black wet oxidation procedure.
- Nitrogen, Phosphorus, and Potassium (NPK):
 - Total nitrogen was quantified using colorimetric/spectrophotometric techniques following chemical extraction.
 - Available phosphorus was analysed via the ammonium molybdate (blue color) method using a spectrophotometer.
 - Exchangeable potassium was measured in soil extracts using spectrophotometric methods.

2.2.5 Microbial Analysis

Microbial quality and biological activity were assessed as follows:

- Total Heterotrophic Bacteria and Fungi (THB/THF): Determined using the spread plate technique on appropriate media to estimate viable microbial populations.
- Rhizobium/Rhizobacteria Enumeration: Conducted using Yeast Extract Mannitol Agar (YEMA) to quantify nitrogen-fixing and plant-growth-promoting rhizobacteria.

2.2.6 Statistical Analysis

Data were analysed using SPSS or R at a significance threshold of $p \leq 0.05$.

- One-way ANOVA was used to assess significant differences among treatments.
- Tukey’s HSD was applied for post-hoc multiple comparisons to identify specific treatment effects. Results were presented using tables, charts, and descriptive statistical summaries.

2.2.7 Safety and Ethical Considerations

All procedures followed laboratory safety standards. Personal protective equipment (PPE) including gloves and face masks were used when handling POME and chemical reagents. Waste materials, including excess effluent and extraction residues, were disposed of according to environmental safety guidelines to prevent secondary contamination.

TABLE 1: Crop Nutrient Requirement Reference

Crop	Nutrient Requirements	Soil/Physicochemical Properties	Microbial/Biological Roles
Maize	N 120–180 kg/ha; P 10–20 mg/kg; K 150–240 kg/ha; Zn 1.5–3 mg/kg (CIMMYT & IITA, 2009; FAO, 2006)	pH 6–7; loam/silty loam; SOM $\geq 2.5\%$; EC < 1.7 dS/m (Soluap, 2023)	AMF; PSB (Bacillus/Pseudomonas); decomposers; siderophore bacteria (Sylvia et al., 2005)
Rice	N 90–150; P 8–15 mg/kg; K 120–200; Zn 1–2 (AfricaRice, 2010; FAO, 2006)	pH 5–6.5; clay/silt loam; SOM $\geq 2\%$; EC 2–3 dS/m tolerant	Anaerobic N-cyclers; Fe-reducers; limited AMF under flooding (Kennedy & Islam, 2001)
Cassava	N 80–120; P 8–20; K 120–200; Mg, B (Howeler, 2002; IITA, 2009)	pH 5.5–7; sandy loam; SOM $\geq 2\%$; EC < 1.5	AMF; PSB; K-solubilizers; endophytes (Sylvia et al., 2005)
Yam	N 90–130; P 15–25; K 150–250 (Asiedu & Sartie, 2010)	pH 5.5–6.8; sandy loam; SOM $\geq 2.5\%$	Mycorrhiza enhances tuber growth; Trichoderma protects roots (Sylvia et al., 2005)
Sweet Potato	N 60–100; P 10–20; K 100–150 (FAO, 2006)	pH 5.5–6.8; sandy loam; SOM 2–3%	AMF aids P uptake; Bacillus promotes rooting (Kennedy & Islam, 2001)
Cocoyam	N 60–90; P 15–20; K 100–150 (FAO, 2006; Soluap, 2023)	pH	

III. RESULTS AND DISCUSSION

3.1 Physicochemical and Microbiological Characteristics of POME

The physicochemical and microbiological properties of the Palm Oil Mill Effluent (POME) used for this experiment are presented in Table 2. The effluent was acidic (pH 4.61 ± 0.028) and exhibited high organic loading, with biochemical oxygen demand (BOD) and chemical oxygen demand (COD) values of 4919.33 mg/L and 10268.53 mg/L respectively. Nutrient concentrations including potassium, sodium, calcium, magnesium, nitrate, and phosphate were also elevated. These values reflect the characteristic composition of effluent from palm oil mills and establish the baseline impact potential on soil systems.

3.2 Baseline Soil Properties

Table 3 presents the properties of the uncontaminated soil used as the control. The soil had an initial pH of 5.80 ± 0.028 and low electrical conductivity (0.042 mS/cm), indicating minimal soluble salt content. Organic matter ($3.68 \pm 0.035\%$) and organic carbon ($2.13 \pm 0.020\%$) were moderate. Initial microbial counts were low (THB: 2.31×10^8 cfu/mg; THF:

1.35×10³ cfu/mg), indicating limited microbial enrichment prior to POME application.

TABLE 2: Mean of Physicochemical and Microbiological Parameters of Palm Oil Mill Effluent (POME) from Two Replicate Tests

Parameters	Unit	Test 1	Test 2	Mean	Standard Deviation (SD)
pH		4.63	4.59	4.61	0.028
Temperature	°C	25.7	26.1	25.9	0.283
Dissolved Solids	mg/l	1780.00	1815.00	1797.50	24.75
Electrical Conductivity	µS/cm	3530.00	3478.00	3504.00	36.77
Total Organic Carbon	%	2.37	2.32	2.35	0.035
Dissolved Oxygen	mg/l	0.60	0.63	0.615	0.021
Biochemical Oxygen Demand (BOD)	mg/l	4960.46	4878.20	4919.33	58.26
Chemical Oxygen Demand (COD)	mg/l	10324.29	10212.76	10268.53	78.83
Nitrate	mg/l	34.93	35.15	35.04	0.155
Sulphate	mg/l	248.07	245.62	246.85	1.73
Phosphate	mg/l	41.26	40.89	41.08	0.26
Chloride	mg/l	305.69	308.33	307.01	1.86
Potassium	mg/l	721.237	728.864	725.05	5.39
Sodium	mg/l	238.912	241.303	240.11	1.69
Calcium	mg/l	114.385	116.029	115.21	1.16
Magnesium	mg/l	54.096	53.744	53.92	0.25
THB ×10 ⁸	cfu/ml	9.42	9.56	9.49	0.099
THF ×10 ³	cfu/ml	4.8	4.6	4.7	0.141

TABLE 3: Mean Concentrations of Physicochemical parameters and Microbial count of Uncontaminated Soil

Parameters	Unit	Test 1	Test 2	Mean	Standard Deviation (SD)
% Sand	%	56.2	55.9	56.05	0.212
% Silt	%	39.2	39.5	39.35	0.212
% Clay	%	4.6	4.6	4.60	0.000
Texture		Sandy loam	Sandy loam	-	-
pH		5.82	5.78	5.80	0.028
Electrical Conductivity	mS/cm	0.041	0.043	0.042	0.0014
Total Organic Carbon	%	2.14	2.11	2.13	0.021
Total Organic Matter	%	3.70	3.65	3.68	0.035
Nitrate	mg/kg	4.69	4.74	4.72	0.035
Sulphate	mg/kg	16.17	16.09	16.13	0.057
Phosphate	mg/kg	1.86	1.88	1.87	0.014
Potassium	mg/kg	47.19	46.93	47.06	0.184
Sodium	mg/kg	34.28	34.11	34.20	0.120
Calcium	mg/kg	42.67	42.81	42.74	0.099
Magnesium	mg/kg	26.09	25.94	26.02	0.106
THB ×10 ⁸	cfu/mg	2.29	2.33	2.31	0.028
THF ×10 ³	cfu/mg	1.3	1.4	1.35	0.071

3.3 Effects of POME on Soil Physicochemical Properties

3.3.1 Soil pH and Electrical Conductivity (EC)

POME application induced significant modification of soil reaction (pH) and ionic strength (EC). Table 4 shows a progressive increase in soil pH from Day 0 to Day 21 across all

treatments, with the highest rise observed in the 100 mL (5.68 → 6.38) and 200 mL treatments (5.30 → 6.18). EC increased sharply by Day 14—indicating elevated soluble salt concentrations due to the nutrient load in POME—and partially stabilized by Day 21. This finding aligns with the acidic nature of POME and its high ion content, which initially acidifies but later buffers the soil as decomposition progresses.

TABLE 4: shows the variation in soil pH and electrical conductivity (EC) of POME

Treatment	Day 0 (pH)	Day 7 (pH)	Day 14 (pH)	Day 21 (pH)	Day 0 EC (mS cm ⁻¹)	Day 7 EC	Day 14 EC	Day 21 EC
100 mL POME	5.68	5.90	6.15	6.38	0.09	0.18	0.26	0.20
200 mL POME	5.30	5.85	6.10	6.18	0.09	0.21	0.28	0.21
400 mL POME	4.99	5.80	6.05	6.03	0.09	0.23	0.28	0.25

3.3.2 Total Organic Carbon (TOC) and Total Organic Matter (TOM)

TOC and TOM values increased proportionally with POME volume. Two-way ANOVA revealed significant main effects of day and volume on TOC and TOM (p < 0.001). Tukey post-hoc tests indicated strong volume-dependent increases, with 400 mL > 200 mL > 100 mL (p < 0.01). Temporal differences, however, were mostly non-significant, demonstrating stability of organic inputs over the 21-day period. Figure 1 further shows a gradual decline from Day 0 to Day 21—indicating biodegradation—yet TOC levels in the 400 mL treatment remained well above baseline (2.13%). This suggests persistent organic enrichment attributable to POME amendment.

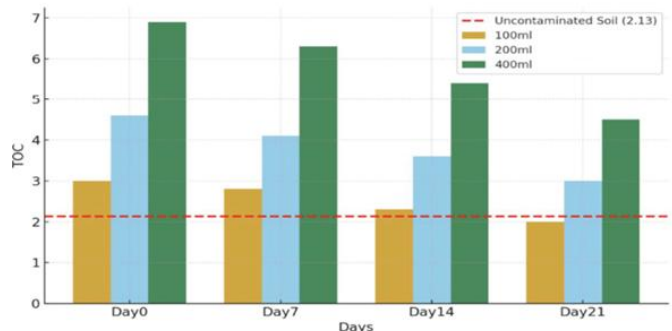


Figure 1: Mean Soil TOC Variation Across Treatment Volumes and Days Compared with Uncontaminated Soil Baseline.

3.3.3 Soil Macronutrients (Nitrate, Phosphate, Potassium)

Two-way ANOVA results indicated highly significant effects of both day and volume on nitrate, phosphate, and potassium (p < 0.001). Volume consistently had the strongest influence.

- Phosphate: Tukey post-hoc comparisons revealed significant differences across volumes, with 400 mL exhibiting the highest enrichment, followed by 200 mL and 100 mL (p < 0.01). Temporal differences were not significant, indicating relative stability of P across 21 days

- Potassium: Potassium experienced the highest degree of enrichment. ANOVA results showed extremely high F-values for volume ($F = 15429.35$), confirming POME as a dominant source of K. Tukey tests showed significant differences among all treatment volumes ($p < 0.001$)

Trends for nitrate demonstrated progressive accumulation at higher POME volumes, contributing to improved soil fertility.

3.4 Microbial Response to POME Application

3.4.1 Total Heterotrophic Bacteria (THB)

THB populations increased significantly with both POME volume and incubation time ($p < 0.001$). The 400 mL treatment showed the highest bacterial activity, followed by 200 mL and 100 mL, establishing a dose-dependent relationship. Tukey post-hoc tests confirmed significant pairwise differences among all volumes ($p < 0.01$), suggesting that higher POME levels provide more organic substrate for microbial growth. Figure 2 shows a consistent upward microbial trajectory from Day 0 to Day 21 compared to the baseline count of 2.31×10^8 cfu/mg, illustrating enhanced biodegradation potential.

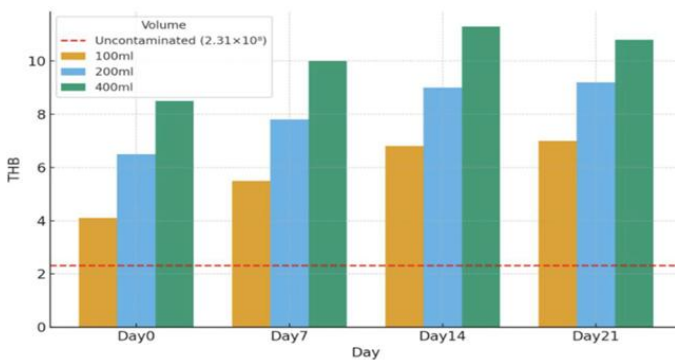


Figure 2: Mean Soil THB x 108 Variation Across Treatment Volumes and Days Compared with Uncontaminated Soil Baseline

3.4.2 Total Heterotrophic Fungi (THF)

THF levels were significantly influenced by volume ($p < 0.001$) but not by time (Table 5). Tukey post-hoc tests showed no significant differences across days; however, fungal counts increased sharply with higher POME volumes, again indicating dose-dependent stimulation of fungal activity. The interaction effect (Day x Volume) was not significant, implying fungal response remained stable across incubation periods.

TABLE 5: Two-way ANOVA (Day x Volume) for Soil Parameter THF x 10³

Effect	sum_sq	df	F	PR(>F)
C(Day)	4.3746	3.0	89.735	0.0
C(Volume)	13.6358	2.0	419.5641	0.0
C(Day):C(Volume)	0.1242	6.0	1.2735	0.3387
Residual	0.195	12.0	nan	nan

3.5 Multivariate Analysis (Principal Component Analysis)

PCA results (Table 6) revealed two dominant components:

- PC1 (Nutrient Enrichment Axis): Strong positive loadings for Ca, K, Mg, Na, nitrate, phosphate, sulphate, TOC, and TOM (all > 1.02), indicating that POME application significantly enriched the soil in essential nutrients.
- PC2 (Biological Activity Axis): Strong associations with microbial counts—THB (0.769) and THF (0.783)—

reflecting increased microbial activity due to organic substrate availability.

Soil pH exhibited opposing loadings on PC1 and PC2, suggesting acidification under nutrient enrichment but increased microbial stimulation concurrently. These findings confirm that POME impacts both biochemical and biological soil processes simultaneously.

TABLE 6: PCA of Soil Properties and Microbial Parameters

Parameter	PC1	PC2
Ca	1.0276	-0.0843
K	1.0409	0.0598
Mg	1.0213	-0.2091
Na	1.0391	-0.0512
Nitrate	1.0407	-0.0753
Phosphate	1.0414	-0.0289
Sulphate	1.0329	0.0562
THB	0.6903	0.7694
THF	0.6848	0.7828
TOC	1.0384	-0.1041
TOM	1.0384	-0.1041
pH	-0.8218	0.6200

3.6 Heavy Metal Content of POME and Soil

3.6.1 Heavy Metals in POME Wastewater

Heavy metal concentrations in POME were low, with Fe (4.40 mg/L) and Zn (1.42 mg/L) being the most abundant. Cd and Ni values were below detection limits (< 0.001 mg/L). These results indicate minimal risk of heavy-metal accumulation in soils receiving POME application.

3.6.2 Heavy Metals in Uncontaminated Soil

Baseline soil exhibited typical tropical soil metal composition, dominated by Fe (2627.98 mg/kg) with trace amounts of Pb, Ni, Cd, and Cr. Values were well below contamination thresholds, confirming the soil's natural geochemical background and suitability for agricultural use.

3.7 Comparison with Crop Nutrient Requirements

Using nutrient benchmarks for crops such as maize, cassava, yam, rice, and groundnut, POME-treated soils—particularly at 200 mL and 400 mL—approached or exceeded the nutrient thresholds for K, Ca, Mg, nitrate, and organic matter. Cassava and yam aligned most closely with the enriched nutrient profile, while maize and pepper may require supplemental N and P to optimize growth (Kennedy & Islam, 2001; Soluap, 2023; AVRDC, 2010)

Across the 21-day incubation, POME consistently enhanced soil nutrient status, organic content, and microbial activity. Higher application volumes yielded greater improvements, following the pattern: 400 mL $>$ 200 mL $>$ 100 mL. Nutrient enrichment peaked between Day 0 and Day 7, decreased slightly by Day 14 due to immobilization, and stabilized by Day 21 as mineralization processes advanced.

The cumulative findings suggest that POME can serve as an organic soil amendment with minimal heavy-metal risk and significant fertility-enhancing potential when applied in controlled quantities.

3.8 Discussion of Findings

The study demonstrates that POME application induces rapid, dose-dependent changes in soil chemical and biological

properties, enhancing fertility while posing potential risks. Higher POME volumes (100–400 ml) immediately increased TOC/TOM, major nutrients (NO_3^- , PO_4^{3-} , K^+ , Ca^{2+} , Mg^{2+}), and exchangeable Na, with pH and EC shifting predictably during the 21-day incubation. These responses reflect the rapid mineralization of POME's organic inputs by soil biota (Osman et al., 2020). The nutrient and organic matter increases, particularly under the 400 ml treatment, followed by stabilization, align with earlier observations that POME and other organic wastes raise soil organic matter and exchangeable cations (Ipinmoye & Dayo-Olagbende, 2023; Ikott et al., 2025). The initial acidification and gradual pH recovery parallel findings from organic manure studies (Khalil et al., 2020).

Relative to the baseline sandy-loam soil (TOC 2.13%, pH 5.80), POME treatment led to marked increases in TOC/TOM, K, P, EC, and Na, confirming both soil enrichment and potential salinity/sodicity risks if application becomes excessive (Mohammad et al., 2021). Statistical analyses showed strong effects of POME volume and time on most soil parameters, with significant Day \times Volume interactions linked to microbial decomposition and nutrient mineralization. The observed stimulation of microbial counts (THB, THF) with increasing POME dosage is consistent with responses reported for various organic amendments (Elizabeth et al., 2023; Cong et al., 2024; Yang et al., 2023).

Heavy-metal levels in POME were low (Zn, Fe detectable; Pb, Cr minimal; Ni/Cd negligible), and baseline soils already contained moderate Fe and Zn. Although short-term risk is low, literature cautions that repeated POME application may lead to gradual metal accumulation, particularly Pb and Cd (Njoku et al., 2022; Osman, 2020; Ipinmoye & Dayo-Olagbende, 2023). Agronomically, POME substantially improves nutrient supply—especially K and P—supporting crops such as cassava, maize, rice, and groundnut, but excessive or untreated application may elevate EC, Na, and acidity, necessitating pre-treatment and regular monitoring (Mohammad et al., 2021; Zhao et al., 2022; Ngone et al., 2023).

Comparisons with crop nutrient requirements show that POME-amended soils meet or exceed benchmarks for major crops, confirming strong growth potential. However, short-term acidity, rising EC, and the possibility of long-term metal buildup underscore the need for sustainable management, as excessive salinity or metal uptake can impair crop performance and pose food-safety risks (Njoku et al., 2022; Ngone et al., 2023).

IV. CONCLUSION

POME has both beneficial and adverse impacts on soil properties and crop growth potential. When applied in moderate quantities, POME enhances soil fertility by increasing organic carbon, nutrient availability, and microbial activity, making it suitable for sustainable crop production. However, excessive or uncontrolled application may result in soil acidification, salinity build-up, and potential long-term heavy metal accumulation, which could compromise soil health and crop productivity. Therefore, POME should be regarded as both an agricultural resource and an environmental liability depending on its management. Proper application rates, pre-treatment before

land use, and continuous monitoring of soil pH, salinity, and heavy metals are essential to maximize its benefits while minimizing environmental risk

V. RECOMMENDATIONS

1. Treat POME before use or disposal to reduce acidity, BOD, COD, and prevent oxygen depletion and toxic anaerobic microbial activity.
2. Apply POME in controlled quantities to avoid salinity buildup, nutrient imbalance, and potential declines in crop productivity.
3. Conduct routine soil testing to monitor pH, salinity, and heavy-metal accumulation in soils receiving POME.
4. Implement best management practices for POME handling and land application to ensure environmental safety and sustainable soil fertility.

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