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RESEARCH ARTICLE

VALORIZATION OF PALM OIL FRUIT SLUDGE FOR SOIL QUALITY AND PLANT GROWTH IN NIGERIA

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ABSTRACT

Palm oil fruit sludge (POFS), a by-product of palm oil processing, is commonly disposed of on surrounding farmlands, yet its effects on soil quality and plant growth remain inadequately documented. This study evaluated the influence of POFS on selected soil physicochemical properties associated with plant growth. A simulated experiment was conducted using POFS applied to soil profiles at 0%, 50%, 100%, and 200% dilutions. Soil samples were collected at 1, 5, and 9 weeks from depths of 0–5 cm, 5–10 cm, and 10–20 cm. Each treatment had nine replicates and was analyzed for pH, moisture content, electrical conductivity (EC), total nitrogen, available phosphorus, organic carbon, organic matter, exchangeable bases (K^+ , Na^+ , Ca^{2+} , Mg^{2+}), total exchangeable acidity, and effective cation exchange capacity. Results showed a marked increase in EC in the undiluted treatment (287–660 µS/cm), while diluted treatments exhibited decreasing EC down the profile: 50% (223–160 µS/cm), 100% (189–160 µS/cm), and 200% (185–80 µS/cm). Overall EC values were relatively high. The undiluted sludge caused the greatest growth inhibition, indicating potential toxicity at high concentrations. Conversely, the 200% dilution produced the best growth response, suggesting improved soil conditions at lower concentrations. The study concludes that dilution of POFS prior to disposal can enhance soil quality and plant growth, whereas direct application may be harmful. It recommends public awareness for POFS-producing communities and further research on sustainable valorization strategies.

Keywords: Palm oil fruit sludge, waste valorization, soil amendment, resource recovery, circular bio-economy, environmental sustainability

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1.0. INTRODUCTION

The palm oil fruit sludge (POFS) refers to the aqueous effluent generated in the oil palm (*Elaeis guineensis*) industry during palm oil processing. Other by-products of the process include empty fruit bunches (EFB), palm oil mill effluent (POME), and palm kernel cake (PKC). POFS is a major product of clarification (separation of oil and sludge) generated locally from the washing of palm fruit and its fiber in the quest for more oil. It contains appreciable levels of organic matter and essential plant nutrients such as nitrogen (N), phosphorus (P), and potassium (K) (Okwute & Isu, 2007; Wu et al., 2010; Ohimain et al., 2012).

Nigeria remains a major producer of palm oil in sub-Saharan Africa, generating substantial quantities of agro-industrial residues during processing (FAO, 2023), with extensive cultivation concentrated in the southern region; Edo state, Abia state, Imo state, Rivers State, etc. Studies on palm oil mill residues have demonstrated their potential to improve soil organic carbon, nutrient availability, and soil structure when properly managed (Okwute & Isu, 2007; Wu et al., 2010). Organic amendments are widely recognized for enhancing soil aggregation, microbial activity, and cation exchange capacity in tropical soils, which are often highly weathered and nutrient-deficient (Lal, 2015). Within the framework of sustainable agriculture and circular bioeconomy, valorization—the conversion of waste materials into value-added products—has gained global attention as a strategy for resource efficiency and environmental protection (European Commission, 2018).

When PFOS is disposed indiscriminately on soils of surrounding processing industries, the bushed slowly die. Some processors say they use the sludge as herbicide to clear their environment (FAO, 2003). For this reason, many of the local processors embrace this method as their strategy for disposal not minding the offensive odour that emanates from the accumulated sludge with time. Indiscriminate disposal on farmlands or into nearby water bodies may lead to soil nutrient imbalance, increased biochemical oxygen demand (BOD), soil acidification, and potential phytotoxic effects (Igwe & Onyegbado, 2007; Chindah et al., 2004). This practice has surpassed soil's natural ability to manage this type of waste, resulting in sludge pools. Sludge pools produce offensive odour, disrupt habitat, destroy biodiversity, make such pieces of land unavailable for uses in agriculture, building, transportation, forestry, and recreational activities.

On the contrary, because of its nutrient-rich composition, POFS may serve as a low-cost organic soil amendment if applied at appropriate rates. Pollution of soil by palm POFS is a serious environmental problem as it renders any piece of land where it accumulates unavailable for use. Even when POFS is commonly disposed of on surrounding farmlands, its effects on soil quality and plant growth remain inadequately documented. Previous study in Nigeria has been done on the pollution potential of palm oil mill effluent (POME) and related residues, with emphasis on water contamination and environmental degradation (Chindah et al., 2004; Ohimain et al., 2012).

There is insufficient data on how treated levels of POFS can influence soil physicochemical parameters that influence plant growth responses. In other to prevent undue environmental degradation as a result of improper disposal of POFS, and enhance plant growth, promote good health and wealth, there is need to be conscious of the method of disposal of POFS generated in the palm oil processing and its management. It is for this reason that this study is undertaken. This study further rethinks waste management by evaluating the sustainable valorization of POFS as a soil amendment to improve soil quality and support plant growth.

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3.0. MATERIALS AND METHODS

3.1. Experimental Design

Two hundred (200ml) of palm fruit oil sludge (PFOS) was collected from the Rivers State Palm Oil Processing Company (RISONPALM Ltd), Nucleus Estate Ubima. Forty-five (45) empty containers, each with a capacity of 25 L were filled with 1,600 cubic centimeter (CC^3) soil from the Rivers State University farm. Then the measured sludge of different dilutions was introduced into the packed soil and allowed to stand for 9 weeks. These treatments were sampled at the 1st week, 5th week and 9th week and analyzed for various physicochemical parameters to determine soil quality.

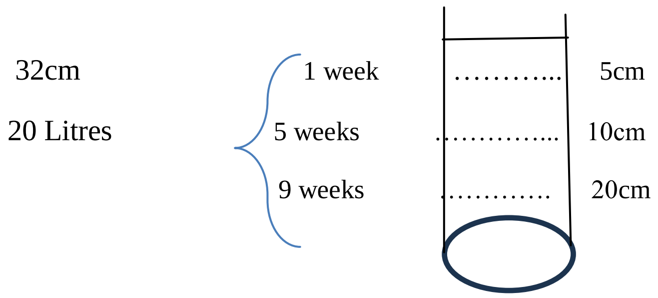
3.2. Sample Preparation

There were 5 different water dilutions of the POFS applied to the set-up as identified by letters A, B, C, D, and E as treatments. Each treatment had 9 replicates for the 3 sampling periods, totaling 45 treatments in all. The essence of having 9 replicates of each treatment was to maintain the quality of the experiment during sampling as each container was sampled once. The air-dried soils were placed into perforated plastic containers to simulate field percolation and aeration processes. Soil moisture content was maintained at approximately 60% of field capacity throughout the nine-week incubation period (Sparks et al., 1996). The treatments were arranged according to sampling depths and dates.

A = Undiluted sludge (100 percent sludge)
B = Sludge diluted on 1:2 water/Sludge ratio (25 percent water + 50 percent sludge)
C = Sludge diluted on 1:1 water/Sludge ratio (50 percent water + 50 percent sludge)
D = Sludge diluted on 2:1 water/Sludge ratio (50 percent water + 25 percent sludge)
E = No Sludge but water applied to soil as per volume used for treatment A.

3.3. Sampling Procedure

Samples were collected from 3 different depths (0 -5cm, 5 - 10cm, and 10-20cm) in triplicate. The 1st sample was collected at one week after treatment application from the depth of (0 - 5cm) using hand shovel. The 2nd sample was collected at five weeks from the depth of (5 - 10cm), while the 3rd sample was collected at nine weeks from the depth of (10 -20cm). The 3 samples collected from treatments of the same quality were mixed up to obtain a composite sample. All samples collected were air-dried at ambient laboratory temperature (25 ± 2°C), gently crushed, and passed through a 2 mm sieve. Subsamples for organic carbon and total nitrogen analysis were further ground to pass through a 0.5 mm sieve (Bremner & Mulvaney, 1982). All prepared samples were stored in properly labeled containers prior to analysis which was determined in duplicate.



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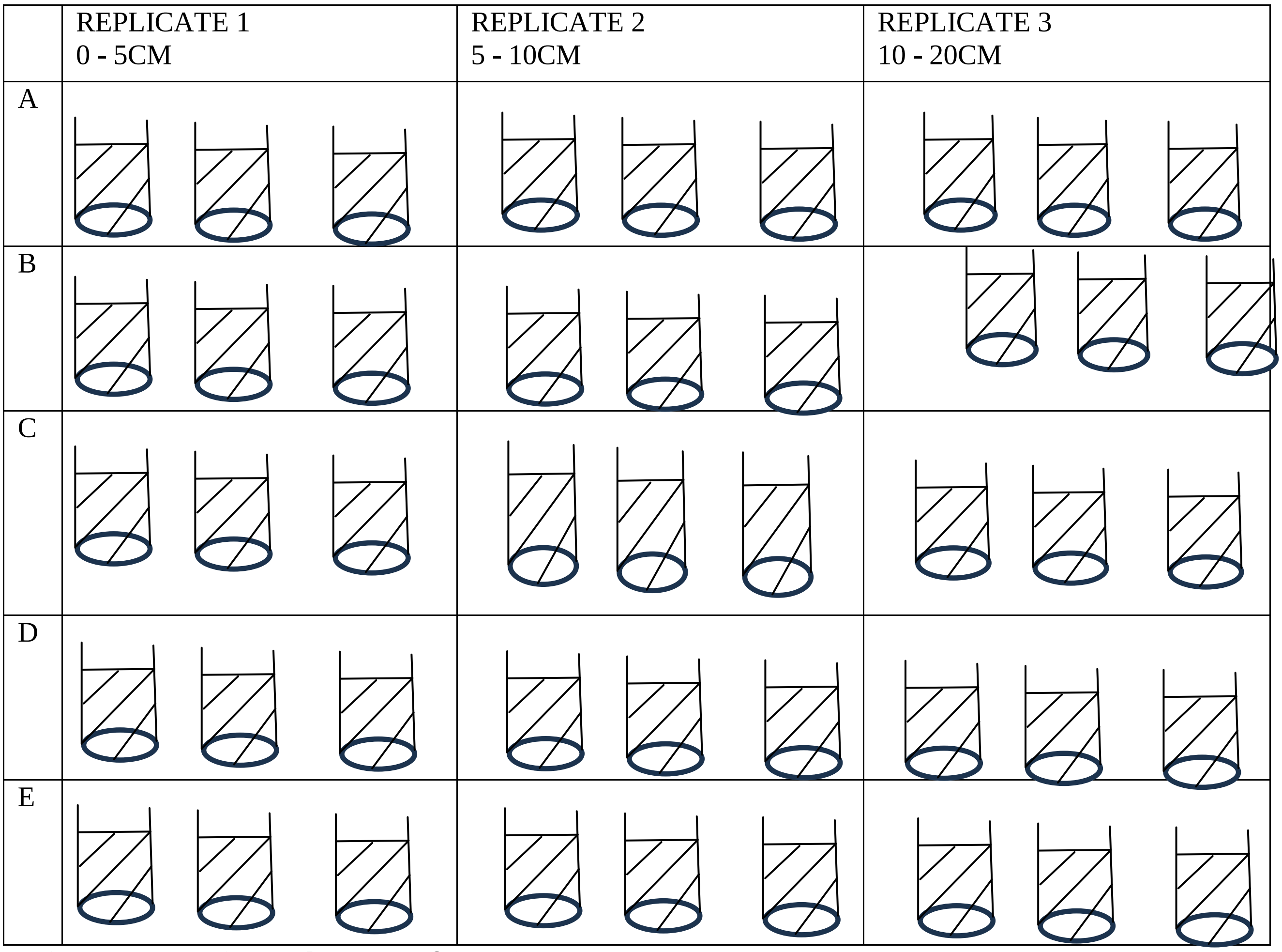

Figure 1: Experimental Layout of containers

3.4. Analytical Methods

Soil pH: The pH was measured electronically using Hanna pH meter model 9812 by dipping the electrode into the soil/water (1:2.5) ratio, using 10g soil, method of (McLean, 1982).

Moisture Content (MC): 5g of air-dried 2mm sieved soil was weighed and put into pre-weighed cans. It was placed in an oven at temperature of 105^0C overnight without lid. It was cooled in desiccator and weighed again. The difference in weight was the moisture content.

Electrical Conductivity (EC): This was determined by using a conductivity cell in a wheatstone bridge arranged as described by (Cottenie, 1980).

Total nitrogen (TN) was analyzed using the semi micro-Kjeldahl of (Bremner & Mulvaney, 1982). This involves digestion-distillation.

Cation exchange capacity (CEC): This was determined by ammonium saturation method of (Rhoades, 1982).

Organic carbon (OC): This was determined using the oxidation method of (Walkley & Black, 1934) principle as described and modified by (Juo, 1979).

Available Phosphorus (AP): AP was extracted using the spectrophotometer method of (Bray & Kurtz, 1945). No 1 method as described by (Olson and Sommer, 1994).

Exchangeable Bases: Exchange Ca and Mg were determined by EDTA complexometric titration as described by (Heald, 1965). While exchangeable K and Na were determined by flame photometry by (Jackson, 1958).

Total Exchangeable Acidity (TEA): This was determined by the KD extraction method as described by (Maclean, 1965). This is a continuation of the cation exchange capacity.

Effective Cation Exchange Capacity (ECEC): The summation of the exchangeable bases and TEA (Al^{3+} and H^{+}) gave the value for the ECEC.

4.0. PRESENTATION OF RESULTS AND DISCUSSION

4.1. Presentation of Results

Physicochemical Parameters

The analytical data of the physico-chemical parameters of the different treatments and the summary are shown in tables 1 - 4. The results show that different palm fruit oil sludge treatments affected the soil properties at different depths 5, 10, and 20 cm respectively.

pH

The pH of the composite sample results demonstrated a decrease from 6.30 in the pure sludge to 4.90 in D (2:1 water/sludge ratio) at the depth of 5cm (Table 4). Treatment C (1:1 water/sludge ratio) just like the control did not show any regular pattern. However, the pH values fall within the normal range for many tropical soils and are generally suitable for plant growth.

Electrical Conductivity (EC)

A remarkable increase was recorded in sample A (pure sludge) from 287 to 660 µs/cm down the profile (Table 4). This suggests more dissolved salts in that treatment. Other treatments including the control recorded a decrease down the profile. The recorded EC values were generally high.

Available Phosphorous (AP)

The recorded values were highest at the 5cm depth in all treatments. There was reduction in value from 141.89mg/kg in treatment A to 100.07mg/kg in treatment D at 0 - 5cm depth (Table 4). There was a general pattern of reduction in value down the profile and as sludge dilution increased. However, the recorded values of the control were generally lower than all the dilutions, but quite higher than the specified standard of 15mg/kg (Landon, 1991) for tropical soils. This shows that nutrients stay mostly in the top soil where plant roots can easily access them.

Total Nitrogen (TN)

TN values were also higher at the O - 5cm depth in treatments A, B, and C, but decreased as POFS dilutions increased from 0.16% in A to 0.02% in D (Table 4). There was no remarkable pattern exhibited by the other dilutions even down the profile. This indicates that sludge application increased soil nitrogen content, which is important for plant growth. Compared to (Landon, 1991), standard ratings for soil parameters, values recorded were low for tropical soils. This could be attributed to the reduction in concentration status of POFS.

Organic Carbon (OC) and Organic Matter (OM)

The OC and OM were highest at 0 -5cm depth, especially in treatment A (Table 4). This shows that sludge improved soil organic matter at the surface. Higher organic matter improves soil fertility, structure, and nutrient holding capacity.

Moisture Content (MC)

The % MC showed a decrease both as the POFS was diluted and down the profile. They decreased from 27.40 to 11.73%, 21.20 to 14.20%, 19.00 to 14.25%, and 20.40 to 12.99% in A, B, C, and D respectively (Table 4). The control was irregular.

Water Holding Capacity (WHC)

The %WHC showed a decrease from 16.30 - 9.19% at 0 - 5cm depth from A - D, from 32.00 - 27.03% at 5 - 10cm depth, and 39.83 - 35.35% at 10 - 20cm depth, but increased down the profile in all the treatments (Table 4). This shows that sludge addition improved the soil's ability to retain water, which is beneficial for plant growth. Values recorded for the control was not regular down the profile.

Total Exchangeable Acidity (TEA)

TEA values decreased down the profile in treatment A (100% sludge) from 0.84 to 0.54cmol(+)/kg, and C (50% water and 50% sludge) from 1.40 to 0.70 cmol(+)/kg. The reverse was the case in treatment D (50% water + 25% sludge), where it increased down the profile from 0.64 to 1.02cmol(+)/kg. The control also increased down the profile. But treatment B did not show a regular pattern.

Effective Cation Exchange Capacity (ECEC)

The recorded ECEC values were observed to decrease from 5.44 cmol(+)/kg in treatment A (pure sludge) to 3.24 cmol(+)/kg in treatment D (2:1 water/Sludge ratio) at 0 - 5cm depth. The decrease was consistent in 5 - 10cm depth from 7.56 - 3.96 cmol(+)/kg, and 6.15 - 4.34 cmol(+)/kg at 10 - 20cm depth. The highest values were recorded in treatment A, meaning that the pure sludge had the highest nutrients. This suggests improved soil fertility due to sludge application.

Total Hydrocarbon Content (THC)

THC values recorded were very high at 0 - 5cm depth with all the dilutions **and much lower down the profiles.** This means hydrocarbons were mainly concentrated at the surface. While sludge improved fertility, high THC levels may pose environmental risks and should be monitored.

Table 4: Summary of Physicochemical Properties of Sludge/Soil Treatments

		Depth (cm)	A	B	C	D	E
pH		5	6.30	6.10	5.20	4.90	5.70
1:2.5		10	5.30	5.30	5.00	5.20	5.00
		20	5.70	5.30	5.70	5.40	5.20
EC		5	287	223	189	185	205
µs/cm		10	310	210	170	136	190
		20	660	160	160	80	60
AP		5	141.89	133.83	123.56	100.07	96.31
mg/kg		10	61.00	56.72	46.50	42.11	30.72
		20	91.08	89.77	86.45	79.87	79.89
	TN	5	0.16	0.13	0.08	0.02	0.09
		10	0.04	0.05	0.06	0.08	0.06
		20	0.06	0.07	0.06	0.08	0.06
	OC	5	3.87	2.77	3.08	2.34	1.03
		10	1.38	1.00	0.96	1.07	0.99
		20	1.21	1.14	1.21	1.16	1.10
	OM	5	6.64	4.78	5.31	4.03	1.78
%		10	2.38	1.81	1.66	1.84	1.71
		20	2.09	1.78	1.83	1.93	1.90
	MC	5	27.40	21.02	19.00	20.40	18.30
		10	24.22	15.64	14.94	14.22	22.70
		20	11.73	14.20	14.25	12.99	1.01
	WHC	5	16.30	13.95	12.75	9.19	37.53
		10	32.13	32.10	32.07	27.03	31.11
		20	39.83	37.10	36.35	29.29	35.55
	TEA	5	0.84	0.84	1.40	0.64	0.84
		10	0.70	1.22	0.74	0.64	0.85
		20	0.54	0.62	0.70	1.02	0.98
Cmol(+)/kg	ECEC	5	5.44	4.29	3.88	3.24	3.21
		10	7.56	6.51	4.82	3.96	5.77
		20	6.15	4.99	4.38	4.35	4.30
THC		5	18118.96	7668.30	7479,43	3153.98	77.44
		10	1154.43	29.74	65.19	10.87	13.38
		20	24.37	13.63	34.63	9.48	44.07

Source: Authors' Analysis (2025).

4.2. Discussion

Looking at the values recorded after soil treatments and the control; it is observed that Palm oil fruit sludge (POFS) significantly influenced the physicochemical properties of the soil.

The pH as a useful indicator of other soil parameters is very prominent here. The observed values have a limited variation (4.90–6.30) as expected in an agricultural soil which according to (Isirimah, 2000) should be neutral or on the acid side of neutrality, that is slightly less than 7. This indicates that POFS application did not cause harmful acidification and remains suitable for plant growth (Food and Agriculture Organization, 2022).

EC was highest in the 100% sludge treatment at the topmost layer, suggesting increased soluble salts due to nutrient enrichment. High concentrations of soluble salts in the root zone alter soil osmotic potential and ion balance, creating stress that limits plant water absorption and disrupts essential metabolic functions, particularly when salts are not leached through effective drainage (Science Publishing Group, 2026). It is possible that it is the high concentration of soluble salts in the POFS contaminated soils that weed off plants (FAO, 2003). This buttresses the fact that plants that are less tolerant to salts will not survive in this POFS heavily polluted soils. Reports of (Isirimah, 2000) showed that EC values of 4 µs/cm which correspond to osmotic pressure of 3.5 atmosphere in the soil solution at field capacity is generally accepted as the limit above which the yield of most sensitive crops starts to be affected. Also, excessive salt accumulation may require monitoring to avoid salinity stress. However, the problem seemed to be less prominent in treatments with higher dilutions as the 2:1 water/sludge ratio after 9 weeks had the best growth.

At every sampled depth, the value of available phosphorous was observed to decrease as the dilution increased. This confirms that POFS enriched the topsoil with essential nutrients. The concentration of phosphorus at the surface is consistent with its low mobility in soil. This is in line with the study of (Brandy,1996) which reported that plant growth, vigor, longevity, and appearance are dependent on soil available phosphorous. However, going by the standard rating of (Landon, 1991), the available phosphorous values recorded were too high for tropical soils and will likely affect plants negatively. Though, this is not the only determining factor for plant survival and growth.

The average percentage TN was less than 0.1%. The standard rating of (Landon, 1991), shows that TN of less than 0.1% is very low for tropical soils. As such, the TN in these soils cannot sustain plant life. Enhanced nitrogen and phosphorus levels directly support vegetative growth, root development, and crop productivity.

Organic matter (OM) content is subject to organic carbon (OC). OM is commonly assumed to contain about 58% carbon, which is the basis of the Van Bemmelen conversion factor (1.724) used to estimate OM from soil OC (MDPI, 2023). OC and (OM) were highest in the 100% sludge treatment. The overall mineral values of the sludge treatment on soil are poor. Increased organic matter improves soil structure, aggregation, microbial activity, and nutrient retention capacity. Soil fertility can be seen from the angle of amount of nutrients in available forms to the plants. Is it critical, just sufficient or excess? The report of (Rajagapolan and Sivalingam, 1975) which showed that the soil micro-organisms inability to convert sludge into available minerals for plant could be attributed to the imbalance in Nitrogen: phosphorous: potassium (N:P: K) ratios.

Laboratory analyzed values were high for MC and WHC. Klute,1965 reported that the assessment of water content to represent a simple way of controlling concentration and water if present above certain level encourages the excessive growth of micro-organisms. These organisms help to balance the soil minerals (Rajagapolan and Sivalingam, 1975). According to (Olson and Summer, 1994), most of the nutrients in oil polluted soils are tied up in the cells and tissues of microbes that use these nutrients for growth and development. A possible condition may have developed where the population of the organisms was so high that they utilized the soil nutrients to sustain themselves in growth and development, thereby the plants are starved to death. Improved water retention is essential in tropical environments where irregular rainfall can limit plant performance.

The THC of the sludge treated soils were very high compared to the control. Hydrocarbons of low boiling points which are soluble in water and readily volatile permeate plant tissues, preventing the effective translocation of essential mineral elements between the root and the shoot systems leading to wilting of leaves (Landon, 1991). However, THC values are found to decrease with depth and time. This indicates that if well diluted with water, and allowed to decay well over time, POFS can seep and mix well in soil to bring out acceptable qualities for plant growth.

5.0. CONCLUSION AND RECOMMENDATIONS

This study so far has established that the highest dilution of POFS had the least polluting effect compared to more concentrated dilutions and the pure sludge. It is seen that the dilution helps the waste to seep and be absorbed faster by soil thereby significantly enhancing the key soil physicochemical properties associated with plant growth and reducing the problem of accumulation. Different sludge applications improved available phosphorus, total nitrogen, organic matter content, effective cation exchange capacity, moisture content, and water holding capacity, particularly at the surface layer (0–5 cm) at the first week.

In other to valorize PFOS for soil quality and plant growth in the tropical soil, especially in Nigeria, it is advisable to dilute POFS with water on 2:1 water/Sludge ratio (50% water + 25% sludge). Although pure sludge treatments recorded the highest fertility indices, with high EC and THC highlighted, the need to prevent salinity and contamination risks arises. Diluted treatments appear to provide a more sustainable balance between soil fertility and environmental safety. Therefore, sustainable valorization of POFS offers a promising strategy for improving soil productivity in tropical agroecosystems. Future studies should integrate plant growth performance, valorization of appropriate percentage diluted sludge as irrigation water.

Conflict of Interest

The authors declare that no conflict of interest exist in this manuscript.

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