IKR Publishers

IKR Journal of Agriculture and Biosciences (IKRJAB)
Journal homepage: https://ikrpublishers.com/ikrjab/
Volume-2, Issue-1 (January-February) 2026

OPEN ACCESS
ISSN: 3107-5509 (Online)

Remediation of Crude Oil Contaminated Soil: Assessment of Poultry Manure and Sawdust

Juliet Akudo Mbabie[1*], Abimbola Y. Sangodoyin[2] & Francis Olawale Abulude[3]

[1]Chemistry Advance Research Center, Sheda Science and Technology Complex, FCT-Abuja, Nigeria
[2]Department of Agricultural and Environmental Engineering, Faculty of Technology, University of Ibadan, Oyo State, Nigeria
[3]Environmental and Sustainable Research Group, Science and Education Development Institute, Akure, Ondo State, Nigeria

DOI:*10.5281/zenodo.18496796*

ARTICLE INFO

Article history:
Received : 14-01-2026
Accepted : 25-01-2026
Available online : 05-02-2026

Citation: Mbabie, J. A., Sangodoyin, A. Y., & Abulude, F. O. (2026). Remediation of Crude Oil Contaminated Soil: Assessment of Poultry Manure and Sawdust. *IKR Journal of Agriculture and Biosciences (IKRJAB)*, 2(1), 34-43.

ABSTRACT **Original Research Article**

Soil acidification, nutrient depletion, and hydrocarbon levels are all impacted by petroleum contamination, which is known to alter physico-chemical properties. Low-cost and sustainable remediation methods are necessary to restore soil functionality, especially in regions affected by oil contamination. Over the course of a 56-day incubation period, this study investigated the effectiveness of applying sawdust and poultry manure at different rates to clean up petroleum-contaminated soil. Regular measurements were made of soil nitrogen, pH, phosphorus, and total petroleum hydrocarbon (TPH). The effects of therapy, time, and their interaction on the collected data were evaluated using two-way analysis of variance (ANOVA). At each sampling interval, a one-way ANOVA with post-hoc mean separation ($p < 0.05$) was used, and Pearson correlation was used to detect temporal trends. The results show that petroleum contamination significantly reduced soil nutritional status and raised TPH levels while lowering soil pH. Organic amendments improved all soil properties ($p < 0.05$), with poultry manure-treated soils continuously out-performing sawdust-treated soils. TPH levels and remediation time showed significant negative connections (r=-0.95 to -0.97, $p < 0.01$), whereas nitrogen, phosphorus, and pH showed strong positive relationships with time (r=0.095 to 0.99, $p < 0.01$). Significant treatment*time interactions showed that remedial effectiveness gradually increased over time. In conclusion, manure-base remediation is a very effective and cost-effective way to reduce petroleum hydrocarbons while simultaneously restoring soil fertility and chemical equilibrium. Organic additions aid in the sustainable management of petroleum-contaminated soils, according to statistical data.

Keywords: Remediation, Soil Acidification, Treatments, Phosphorus, Total Petroleum Hydrocarbon, Organic Amendments.

**Corresponding author: Juliet Akudo Mbabie*
Chemistry Advance Research Center, Sheda Science and Technology Complex, FCT-Abuja, Nigeria

Introduction

Decontaminating the soil is referred to as "soil remediation" (Soil Erosion, 2019). It is designed to treat contaminated soil by removing and converting pollutants into less harmful chemicals. Soil pollutants include petroleum and fuel residues, heavy metals, cyanide, pesticides, creosote, and semi-volatiles. Among the several methods of soil remediation are thermal remediation, air sparging, encapsulation, and bioremediation. It is essential to choose the best soil remediation option for each situation (Soil Erosion, 2019).

In Nigeria, oil spills have become more common with increase in petroleum extraction, refining, transportation and trade. Crude oil characteristics have very important bearing on the impact it may have when spilled into the environment. The first impact on the soil is to destroy the thin layer of fertile top soils, which provides nutrients to plants (Hauane et al., 2022). Whenever there is oil spill most microorganisms in the soil are killed. The surviving ones becomes inactive and requires a condition that will reactivate them and where possible new biodegradable microorganisms are introduced in order to digest oil in the soil. Crude oil spills introduce a lot of hydrocarbons to the soil, which increases the quantity of organic carbon content. Too much of carbon in the soil is injurious to plant growth (Odukoya et al., 2019) and organic matter content derivable from crude oil spill is not readily available to plant (Hauane et al., 2022). The soil which is very important for the survival of life when contaminated or polluted by petroleum hydrocarbons poses serious effects and danger to the environment worldwide and hence attracts the attention of the public. One major way which petroleum hydrocarbons enter into the environment is by the activities of man, which is not properly checked, managed or controlled (Kanwal et al., 2022).

Crude oil pollution adversely affects the soil ecosystem through adsorption to soil particles, provision of an excess carbon that might be unavailable for microbial use and induction of a limitation in soil nitrogen and phosphorus (Ekeoma and Anukwa, 2020). This causes a delay in the natural rehabilitation of crude oil polluted soils and various treatments have been used in bioremediation strategies to hasten the process. These include surfactants, alternate carbon substrates and organic and inorganic nitrogen and phosphorus. The effectiveness of these treatments has however been conflicting (Lindstrom and Braddock, 2002). This might be related to the heterogeneity of soils and crude oil samples as well as possible interactions between the soil amendments and the natural soil constituents. The effectiveness of each treatment in any soil therefore needs to be evaluated on a case specific basis.

Poultry manure has over time been used to improve soil fertility (Farhan, 2022). Its efficacy in promoting plant growth in crude oil polluted Nigerian soils has also been reported (Amadi and Bari, 1992; Ogboghodo et al., 2004). Similarly, sawdust being a component of plant's vegetation derived from sawing wood has been found to possess some chemical and biological characteristics capable of amending polluted soils (Offor and Akonye, 2006).

Use of poultry manure and sawdust in remediation is an efficient strategy due to its low cost, high efficiency and eco-friendly nature. Based on this background, this study attempts to investigate the impact of addition of poultry manure and sawdust respectively in the remediation of crude oil polluted soils with a view to minimizing the potential adverse effects on the environment.

Materials and Methods

Study Area

This research work was carried out at the Department of Agricultural and Environmental Engineering, Faculty of Technology, University of Ibadan, Oyo State. University of Ibadan lies between latitude $7^{0}25^{1}$ – $7^{0}31^{1}$North of the equator and longitude $3^{0}51^{1}$ – $3^{0}56^{1}$ East of the Greenwich meridian.

Experimental Method

Four plots of land area 480cm by 240cm were used for this experiment. A preliminary survey was carried out before the four locations were chosen at a slope of 5% and distance of 4m apart behind the wooden block in the Agricultural and Environmental Engineering Department. The plots were located in an open place where it was exposed to almost the same atmospheric conditions like sunlight, rainfall, wind etc.

The first plot was measured using a meter rule and divided into eight sub-plots A_1, A_2, A_3, B_1, B_2, B_3, C and D each of dimensions 240cm long and 60cm wide. The other 3 plots (a replicate of the first) were also divided into eight sub-plots A_1, A_2, A_3, B_1, B_2, B_3, C and D each of dimension 240cm long and 60cm wide. The sub-plots were demarcated with metal sheets which served as buffers. The metal sheets were of dimensions 240cm long and 35cm wide. They were installed at depths 200mm below the ground surface and 150mm above the ground surface. The aim of this was to minimize interactions between the sub-plots.

Soil Pollution/Treatments

Twenty-eight 5 litres of bonny light crude oil having an American Petroleum Institute (API) gravity of 34 was used for this experiment. 5litres of Bonny light crude oil was poured on each of the sub-plots A_1, A_2, A_3, B_1, B_2, B_3 and C in each of the plots. The soil was densely polluted to the extent that most of the pore spaces were filled with oil. The objective was to simulate conditions of a major spill. Thereafter, poultry manure was used to treat sub-plots A_1, A_2 and A_3 at a rate of 10kg, 20kg and 30kg per sub plot respectively. Also, sub-plots B_1, B_2, B_3 were treated with sawdust at a rate of 10kg, 20kg and 30kg per sub plot respectively. Sub-plot C was the control plot, it was polluted but not treated. Sub- plot D in all the plots were not polluted and as well received no treatment. These sub-plots were left undisturbed (in open air and exposed to the rains and sunlight) for five days before the first samples were collected for analysis.

The Bonny light crude oil used for the experiment was gotten from the Nigerian Agip Oil Company (NAOC) Ebeocha base Port Harcourt. The poultry manure and sawdust were sourced from the poultry farm of the department of Veterinary Medicine University of Ibadan and Wood mill Iso-kpako in Bodija market, Ibadan.

Sample Collection

Soil samples were collected randomly at five points in each of the sub-plots using a 12cm hand-dug soil auger at a depth between 0 - 12cm. The soil samples were put in polyethylene bags and taken to the soil chemistry laboratory for analysis. In order to determine the effects of pollution and that of treatment with poultry manure and sawdust, soil samples were analyzed before pollution, after pollution and as the treatment progresses. After the first samples were collected, other samples were collected at an interval of two weeks for the two-month remediation period.

Laboratory Analysis

The soil samples collected were air dried and sieved in preparation for laboratory analysis. Particle size distribution of the soil and chemical composition of the poultry manure and sawdust used for the experiment was determined. Soil samples were analysed for total petroleum hydrocarbon using gravimetric method, Nitrogen was determined by the kjeldahl method, Phosphorus was determined using Bray-1 solution, and Soil pH in water was measured using a glass electrode pH meter. Each analysis was replicated thrice, and the collected data were subjected to a two - way Analysis of Variance (ANOVA) with post-hoc tests.

Results and Discussion

Particle Size Distribution

The results of the analysis of the particle size distribution of the soil samples prior to pollution and treatment are shown in Table 1.

Table 1: Particle size distribution and textural classification of the soils

Soil Description	Particle sizes (%)			Textural Class
	Sand	Silt	Clay	
Plot 1	73.2	18.0	8.8	Loamy sand
Plot 2	85.2	8.0	6.8	Loamy sand

The results of the particle size distribution from the study site showed that Plot 1 contains 73.2% sand, 18.0% silt and 8.8% clay. Plot 2 also contains 85.2% sand, 8.0% silt and 6.8%g clay. These results imply that the soils belong to the same textural class of loamy sand. However, the trend of reduction in the proportion of silt and clay in Plot 2 compared to Plot 1 may be attributed to soil erosion due to cultivation. In Chen et al. (2020) it was reported that the major components of the soil particles that is more vulnerable to agents of erosion are silt and clay due to their particle sizes. Moreover, soil erodibility increases with particle size decrease.

Table 2: Chemical Composition of the Poultry manure and Sawdust (g/kg)

	Sawdust	Poultry Manure
Nitrogen	3.12	5.18
Phosphorus	1.58	1.84
Potassium	1.12	2.54

The chemical composition of the two amendments shows that the poultry manure used for this experiment contains 5.18g/kg nitrogen, 1.84g/kg phosphorus and 2.54g/kg potassium while sawdust contains 3.12g/kg nitrogen, 1.58g/kg phosphorus and 1.12g/kg potassium.

Table 3: Overall effects of treatment type (S), remediation, duration (T), and their interaction S*T) on nitrogen, TPH, phosphorus, and soil pH

Group	Nitrogen (%)	Total Petroleum Hydrocarbon (g/kg)	Phosphorus (mg /g)	Soil pH
Treatments (S)				
A1(10)	0.52 ± 0.17^{c}	5.12 ± 4.23^{e}	57.33 ± 9.07^{d}	5.80 ± 0.46^{d}
A2(20)	0.53 ± 0.18^{b}	4.90 ± 4.16^{f}	57.91 ± 9.27^{c}	5.88 ± 0.45^{c}
A3(30)	0.53 ± 0.18^{b}	4.88 ± 4.22^{f}	59.34 ± 9.81^{b}	5.94 ± 0.48^{b}
B1(10)	0.50 ± 0.16^{e}	5.67 ± 3.90^{b}	52.20 ± 5.05^{g}	5.58 ± 0.35^{g}
B2(20)	0.51 ± 0.16^{d}	5.63 ± 3.97^{c}	52.72 ± 5.11^{f}	5.66 ± 0.34^{f}
B3(30)	0.52 ± 0.17^{c}	5.52 ± 3.95^{d}	53.24 ± 5.39^{e}	5.73 ± 0.34^{e}
C	0.36 ± 0.01^{f}	11.02 ± 0.66^{a}	47.76 ± 1.58^{h}	5.38 ± 0.16^{h}
D	0.81 ± 0.00^{a}	BDL	59.68 ± 0.08^{a}	6.83 ± 0.06^{a}
Period after treatment pollution (Days) (T)				
5	0.41 ± 0.16^{e}	10.24 ± 3.93^{a}	47.73 ± 4.58^{e}	5.39 ± 0.55^{e}
14	0.42 ± 0.15^{d}	7.24 ± 3.10^{b}	49.74 ± 3.93^{d}	5.65 ± 0.50^{d}
28	0.48 ± 0.13^{c}	4.40 ± 2.96^{c}	55.96 ± 4.70^{c}	5.85 ± 0.42^{c}
42	0.66 ± 0.12^{b}	2.94 ± 2.82^{d}	59.87 ± 5.83^{b}	6.07 ± 0.37^{b}
56	0.70 ± 0.13^{a}	1.89 ± 3.38^{e}	61.81 ± 6.60^{a}	6.27 ± 0.35^{a}
Interaction				
S*T	**	**	**	**

Mean (± Standard deviation) of each group of data on the same column with different superscripts are significantly different ($P < 0.05$);
**Interaction is significant ($p < 0.01$);
A1 = Polluted + 10kg Manure; A2 = Polluted + 20kg Manure; A3= Polluted + 30kg Manure; B1 = Polluted + 10kg Sawdust; B2 = Polluted + 20kg Sawdust; B3 = Polluted + 30kg Sawdust; C = Polluted + No treatment; D = Unpolluted.

Table 3 displays the overall impacts of treatment type (S), remediation, duration (T), and their interaction (S*T) on nitrogen, TPH, phosphorus, and soil pH. An acidic pH, high TPH levels, and low nitrogen and phosphorus levels are signs of poor soil quality brought on by petroleum contamination (treatment C). The table displays a few features of these organic additives. Polluted + 10 kg, polluted + 20 kg, polluted + 30 kg of poultry manure, also Polluted + 10 kg, polluted + 20 kg, polluted + 30 kg of poultry of sawdust. The pH levels employed in the study were sawdust, polluted + No treatment, and D = Unpolluted highly acidic and moderately acidic. Although total nitrogen and TPH were usually low, phosphorus concentrations were generally high, even at periods 5–56. Crude oil contamination inevitably alters the chemical, physical, and biological properties of soil, which lowers its fertility, according to studies (Etuk et al., 2013; Osu, 2017; Muhammad et al., 2019; Osu et al., 2021). However, under some natural and therapeutic circumstances, these alterations can be undone. In line with the raised pH in the amendment samples, Obasi et al. (2013) discovered that adding agricultural wastes to motor oil-polluted soils raises the soil's pH.

However, all soil parameters were significantly improved by amended treatments (A and B) as compared to the untreated polluted soil. Poultry manure-amended soils (A1–A3) consistently showed stronger restoration than sawdust-amended soils (B1–B3) at higher treatment rates. By preserving the highest nutrient levels and almost neutral pH, the unpolluted control (D) illustrated the worsening effects of petroleum contamination on soil health. Soils polluted by oil must be thoroughly cleaned up. In this study, two-way ANOVA, mean, and standard deviation were used to test the effects of treatments (S), time after pollution (T), and their interaction (S*T) on nitrogen, TPH, phosphorus, and soil pH (Table 3) using mean separation statistically significant differences among treatments and sampling times ($P < 0.05$). The significant S*T interaction ($p < 0.01$) showed that the treatment effects changed over time. This study shows that the idea is supported and that using organic amendments increased remediation's efficacy.

Table 4: Mean Separation for Nitrogen (%) of the Eight Treatments

Period after treatment pollution (Days)	A1(10)	A2(20)	A3(30)	B1(10)	B2(20)	B3(30)	C	D
5	0.35^{tu}	0.35^{tu}	0.35^{u}	0.35^{tu}	0.35^{tu}	0.35^{tu}	0.35^{tu}	0.81^{a}
14	0.36^{pq}	0.37^{p}	0.37^{o}	0.36^{rs}	0.36^{qr}	0.36^{qr}	0.35^{st}	0.81^{a}
28	0.45^{lm}	0.45^{kl}	0.46^{k}	0.44^{n}	0.45^{m}	0.45^{m}	0.36^{rs}	0.81^{a}
42	0.69^{hi}	0.69^{gh}	0.69^{gh}	0.68^{j}	0.69^{ij}	0.69^{hij}	0.36^{qr}	0.81^{a}
56	0.76^{d}	0.77^{c}	0.78^{b}	0.69^{gh}	0.72^{f}	0.73^{e}	0.38^{o}	0.81^{a}

Mean with different superscripts are significantly different ($P < 0.05$)

Table 4's nitrogen (%) mean separations varied from 0.35 to 0.78%, with treatment B1 having the lowest concentration. The study's findings for sawdust and poultry manure were different from those of Coo et al. (2022). The treated soil has more nitrogen and phosphate than the contaminated soil. This can be as a result of the amendment materials' high phosphate and nitrogenous chemical content. Similar results were found by Obasi et al. (2013) and Adams et al. (2014), who investigated organic manure. This outcome is also consistent with the findings of Osazee et al. (2019), who found that adding organic nutrients increased the content of phosphorus, potassium, and nitrogen, indicating a favorable impact on nutrient concentration.

Nitrogen concentration gradually increased over time in all modified treatments, particularly in soils treated with manure. By day 56, the nitrogen levels in A3 (30 kg of manure) were almost identical to those of the unpolluted control, whereas the sawdust treatments had somewhat improved. Untreated contaminated soil demonstrated minimal nitrogen recovery, according to the study. There are notable variations in the modifications' different nutrient-release capabilities throughout the treatments. While sawdust's high carbon-to-nitrogen ratio probably led to some nitrogen immobilization after decomposition, manure provided easily mineralized nitrogen. These results imply that poultry manure-amended remediation is appropriate for post-spill agricultural reuse since it not only detoxifies soil but also recovers its agronomic value. The comparison of nitrogen content between treatments throughout the same time period that controlled temporal variability is displayed in Table 4. Each sampling period and mean at $P < 0.05$ were subjected to a two-way ANOVA. Different amendment kinds and rates resulted in different nitrogen recovery. Poultry manure treatments are better than sawdust and untreated soils in this regard.

Table 5: Mean Separation for Total Petroleum Hydrocarbon (g/kg) of the Eight Treatments

Period after treatment pollution (Days)	A1(10)	A2(20)	A3(30)	B1(10)	B2(20)	B3(30)	C	D
5	11.80^{a}	11.60^{a}	11.80^{a}	11.60^{a}	11.75^{a}	11.70^{a}	11.70^{a}	0.00^{q}
14	7.60^{g}	7.20^{h}	7.00^{h}	8.30^{e}	8.24^{e}	8.02^{f}	11.60^{a}	0.00^{q}
28	3.85^{k}	3.46^{l}	3.42^{l}	4.62^{ij}	4.43^{ij}	4.22^{j}	11.22^{b}	0.00^{q}
42	2.06^{n}	1.98^{n}	1.94^{n}	2.53^{m}	2.51^{m}	2.48^{m}	10.00^{d}	0.00^{q}
56	0.31^{p}	0.29^{p}	0.26^{p}	1.29^{o}	1.23^{o}	1.18^{o}	10.60^{c}	0.00^{q}

Mean with different superscripts are significantly different ($P < 0.05$)

Table 5 demonstrates the significant and time-dependent decrease in TPH concentrations in the treated soils, with poultry manure treatments attaining the quickest and most thorough degradation. On day 56, residual hydrocarbons were still present in sawdust treatments, whereas TPH levels in A1 treatments were almost nonexistent. On the other hand, TPH concentrations exceeding 10 g/kg were not significantly reduced in the untreated contaminated soil. The findings showed that such organic amendments improved hydrocarbon microbial breakdown, with manure supplying the nutrients and microbial consortia required for efficient biodegradation. The significant decrease in TPH is highlighted by the efficacy of organic remediation techniques for petroleum-contaminated soils. This directly relates to areas that produce oil, where there is an urgent demand for inexpensive and ecologically friendly remediation techniques. Similar outcomes were noted in hydrocarbon-contaminated soils treated with an organic soap solution (Eboibi et al., 2018). Because of their high nitrogen content, Akpokodje and Uguru (2019) found that compost manure and organic soap could break down hydrocarbons in crude oil-contaminated soil by 75% in ten weeks. The findings published by Aneke et al. (2025) were significantly higher than those found here for grass trimmings, sawdust, and chicken droppings. Additionally, TPH levels among treatments were compared using two-way ANOVA. in Table 4, followed by post-hoc mean separation ($P < 0.05$). The superscripts indicate statistically significant variations in the intervals following pollution treatments. This demonstrates that TPH was much higher in improved soils than in untreated contaminated soil. The data show that the TPH reductions were treatment-driven and eliminate any doubt about natural attenuation.

Table 6: Mean Separation for Phosphorus (mg/g) of the Eight Treatments

Period after treatment pollution (Days)	A1(10)	A2(20)	A3(30)	B1(10)	B2(20)	B3(30)	C	D
5	46.03^{t}	46.03^{t}	46.03^{t}	46.03^{t}	46.03^{t}	46.03^{t}	46.03^{t}	59.65^{gh}
14	48.63^{pq}	49.15^{p}	50.28^{o}	47.38^{s}	48.03^{r}	48.40^{qr}	46.50^{t}	59.60^{gh}
28	58.35^{j}	59.50^{gh}	62.58^{f}	52.40^{n}	53.60^{m}	54.20^{l}	47.35^{s}	59.70^{gh}
42	65.18^{e}	65.65^{e}	67.40^{d}	56.80^{k}	57.20^{k}	58.35^{j}	48.65^{pq}	59.70^{gh}
56	68.48^{c}	69.20^{b}	70.40^{a}	58.40^{j}	58.75^{ij}	59.20^{hi}	50.28^{o}	59.75^{gh}

Mean with different superscripts are significantly different ($P < 0.05$)

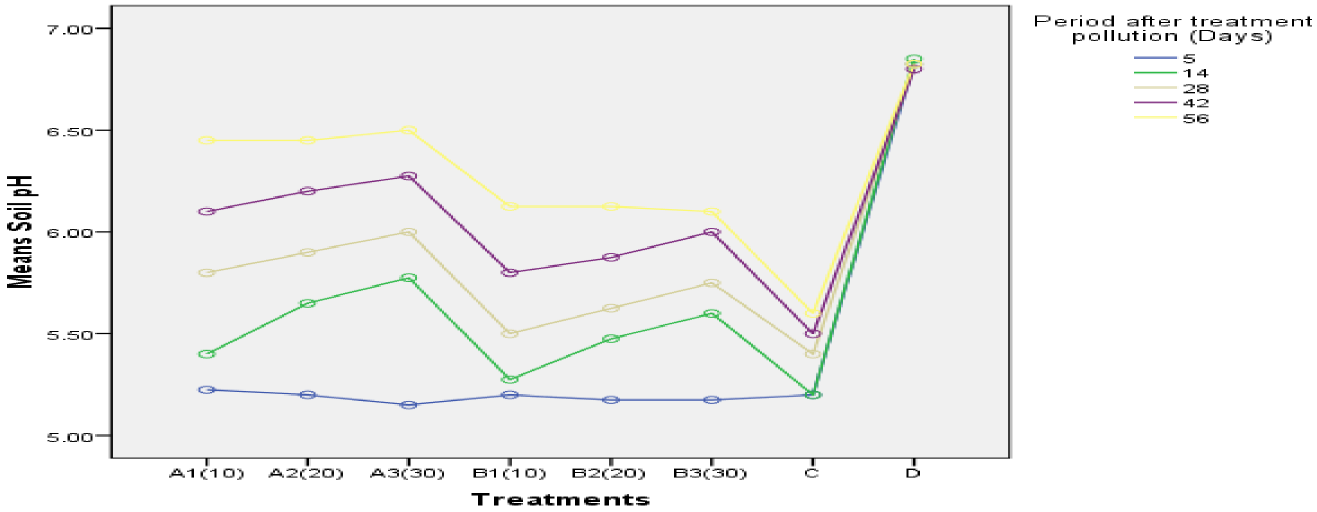
Table 6 shows that phosphorus levels in modified soils, particularly in manure treatments, rose noticeably over time. Higher application rates were found to increase phosphorus recovery in the research, with A3 eventually surpassing the unpolluted control. While the untreated contaminated soil continued to be phosphorus-deficient, sawdust treatments demonstrated slower and less noticeable improvements. This pattern illustrates how phosphorus availability is restricted by petroleum contamination, but organic additions can counteract this effect by increasing microbial activity and organic matter mineralization. It should be noted that microbial metabolism and plant growth depend on phosphorus. By restoring soil nitrogen cycle, bioremediation can lessen the requirement for synthetic fertilizers following cleanup. This might be explained by the fact that sawdust and poultry manure have different nutritional compositions. Due to its high nutrient content, poultry manure contains more organic nutrients that promote increased degradation (Hanson-Akpan et al., 2023). The statistically significant treatment groups at $P < 0.05$ are indicated by the subscripts in Table 6. Manure amendments improved nutrient restoration beyond baseline variability, as evidenced by the uneven phosphorus recovery across treatments, supporting the dual role of remediation in contaminant removal and fertility restoration.

Table 7: Mean Separation for Soil pH of the Eight Treatments

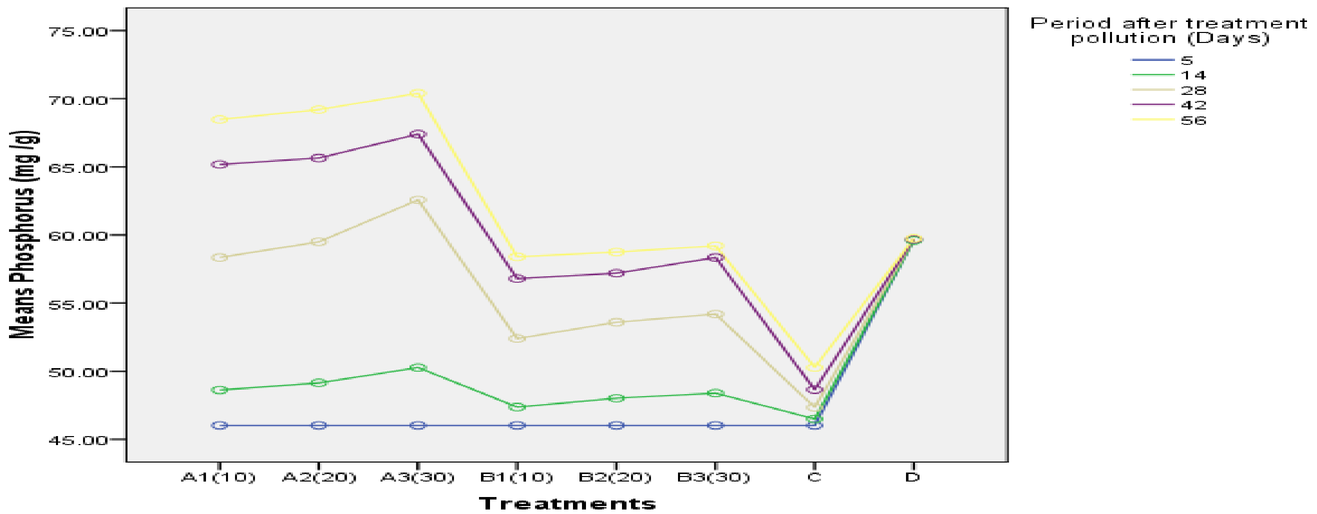
Period after treatment pollution (Days)	A1(10)	A2(20)	A3(30)	B1(10)	B2(20)	B3(30)	C	D
5	5.23^{no}	5.20^{no}	5.15^{o}	5.20^{no}	5.18^{no}	5.18^{no}	5.20^{no}	6.83^{a}
14	5.40^{lmn}	5.65^{ijk}	5.78^{ghij}	5.28^{mno}	5.48^{klm}	5.60^{jkl}	5.20^{no}	6.85^{a}
28	5.80^{ghij}	5.90^{efgh}	6.00^{defg}	5.50^{klm}	5.63^{jkl}	5.75^{hij}	5.40^{lmn}	6.83^{a}
42	6.10^{cdef}	6.20^{cd}	6.28^{bc}	5.80^{ghij}	5.88^{fghi}	6.00^{defg}	5.50^{klm}	6.80^{a}
56	6.45^{b}	6.45^{b}	6.50^{b}	6.13^{cde}	6.13^{cde}	6.10^{cdef}	5.60^{jkl}	6.83^{a}

Mean with different superscripts are significantly different ($P < 0.05$)

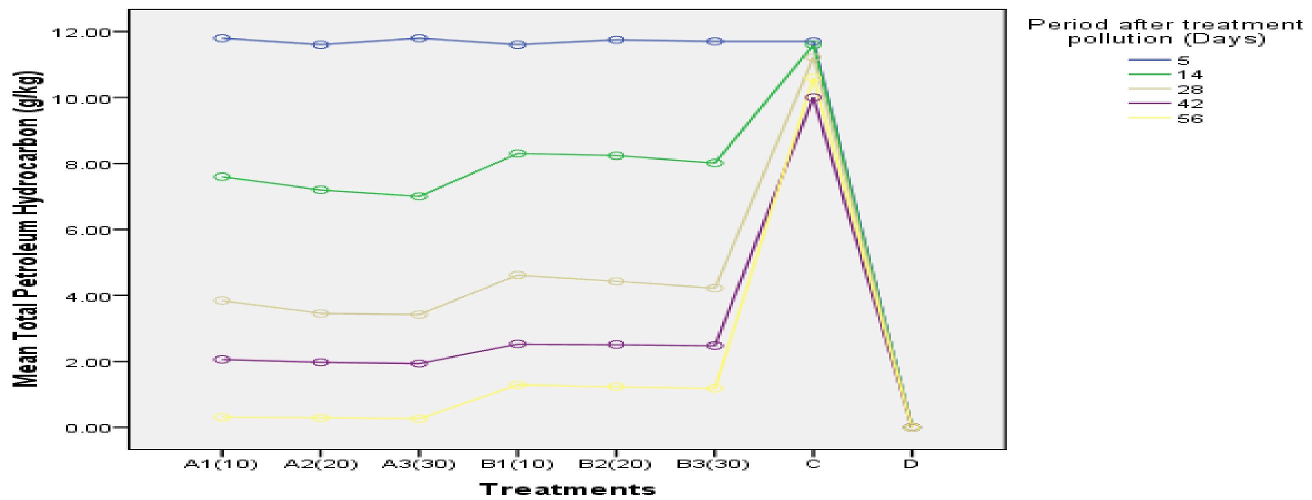
In amended treatments, the pH of the soil gradually rose from acidic to almost neutral values. Compared to sawdust treatments, poultry manure treatments exhibit a higher buffering capability. While the unpolluted control maintained a steady, almost neutral pH, the untreated polluted soil remained acidic during the research period. The breakdown of organic debris, decreased hydrocarbon toxicity, and the release of basic cations from amendments are all responsible for the pH increase. For microbial activity and nutrient availability, pH adjustment is essential. The findings of this study suggest that organic additions enhance long-term soil resilience by concurrently detoxifying hydrocarbons and improving soil chemical stability. The soil pH data at $p < 0.05$ for each measurement interval are shown in Table 7. The findings demonstrate that there were notable and treatment-dependent improvements in soil pH. The pH changes have a significant impact on the environment and the organic amendments' ability to act as buffers.



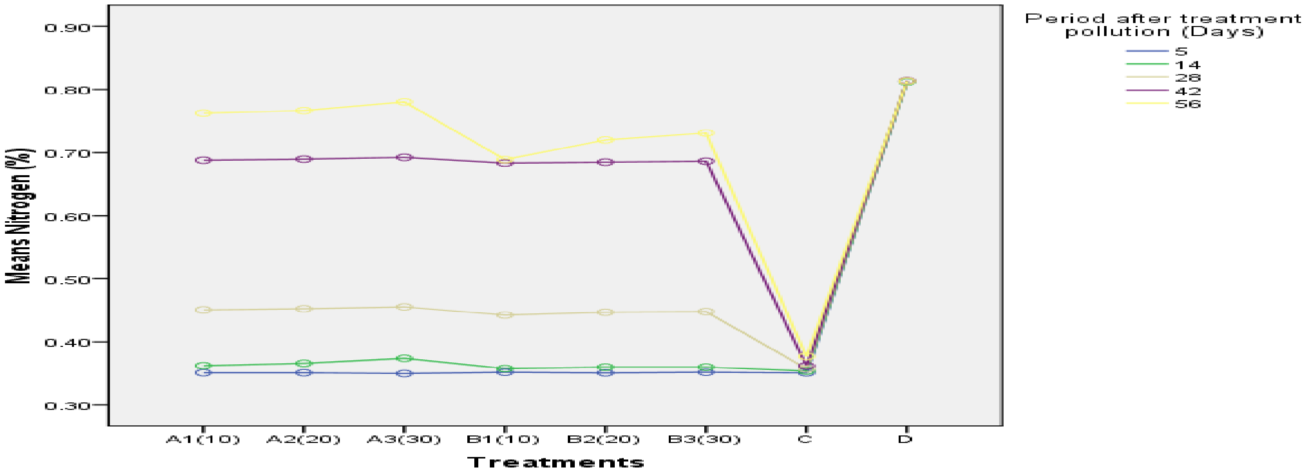
(a)



(b)



(c)



(d)

Figure 1 (a-d): ANOVA and correlation analyses depicting the plots of means across time for nitrogen, TPH, phosphorus, and pH.

The descriptive diagrams of Tables 1–7 (ANOVA and correlation analyses) that show the charting of means over time for nitrogen, TPH, phosphorus, and pH are shown in Figures 1 (a–d). The direction, amplitude, and consistency of treatment effects are all supported by statistical evidence. Overall, poultry manure-based bioremediation outperformed sawdust in speeding up hydrocarbon breakdown and replenishing soil fertility, demonstrating its applicability as an affordable and environmentally friendly remediation method.

Table 8: The Concentration of Nitrogen (%) in the Treatments at Different Pollution Time

Treatment	Period after treatment pollution (Days)					r
	5	14	28	42	56	
A1(10)	0.3512 ± 0.0005[c]	0.362 ± 0.0003[d]	0.4508 ± 0.0005[d]	0.6880 ± 0.0007[d]	0.7625 ± 0.0003[d]	0.969**
A2(20)	0.3512 ± 0.0003[c]	0.366 ± 0.0009[c]	0.4525 ± 0.0003[c]	0.6898 ± 0.0003[c]	0.7665 ± 0.0007[c]	0.970**
A3(30)	0.3500 ± 0.0000[d]	0.374 ± 0.0000[b]	0.4555 ± 0.0005[b]	0.6925 ± 0.0005[b]	0.7803 ± 0.0003[b]	0.973**
B1(10)	0.3520 ± 0.0000[b]	0.358 ± 0.0003[f]	0.4425 ± 0.0003[g]	0.6835 ± 0.0003[g]	0.6890 ± 0.0000[g]	0.948**
B2(20)	0.3510 ± 0.0000[c]	0.360 ± 0.0000[e]	0.4470 ± 0.0000[f]	0.6850 ± 0.0000[f]	0.7200 ± 0.0000[f]	0.960**
B3(30)	0.3520 ± 0.0000[b]	0.360 ± 0.0000[e]	0.4480 ± 0.0000[e]	0.6865 ± 0.0003[e]	0.7310 ± 0.0010[e]	0.962**
C	0.3510 ± 0.0000[c]	0.354 ± 0.0000[g]	0.3575 ± 0.0003[h]	0.3620 ± 0.0000[h]	0.3770 ± 0.0006[h]	0.942**
D	0.8125 ± 0.0003[a]	0.812 ± 0.0000[a]	0.8130 ± 0.0000[a]	0.8135 ± 0.0005[a]	0.8130 ± 0.0000[a]	0.536*

Means (± Standard errors) on the same column (each time) with different superscripts are significantly different ($p < 0.05$)
r: Correlation coefficient of each treatment with the exposure period (in days) after treatment pollution
**Correlation is significant at 1% level
* Correlation is significant at 5% level

Table 9: The Concentration of Total Petroleum Hydrocarbon (g/kg) in the Treatments at Different Pollution Time

Treatment	Period after treatment pollution (Days)					r
	5	14	28	42	56	
A1(10)	11.8000 ± 0.0000[a]	7.6000 ± 0.0817[d]	3.8450 ± 0.0096[e]	2.0605 ± 0.0344[d]	0.3100 ± 0.0058[e]	-0.963**
A2(20)	11.6000 ± 0.0000[c]	7.2000 ± 0.0000[e]	3.4550 ± 0.0050[f]	1.9750 ± 0.0050[e]	0.2875 ± 0.0111[f]	-0.954**
A3(30)	11.8000 ± 0.0000[a]	7.0000 ± 0.0000[f]	3.4200 ± 0.0000[g]	1.9350 ± 0.0050[f]	0.2625 ± 0.0085[g]	-0.948**
B1(10)	11.6000 ± 0.0000[c]	8.3000 ± 0.0000[b]	4.6200 ± 0.0000[b]	2.5275 ± 0.0025[b]	1.2850 ± 0.0050[b]	-0.970**
B2(20)	11.7500 ± 0.0289[ab]	8.2350 ± 0.0050[b]	4.4250 ± 0.0050[c]	2.5100 ± 0.0000[bc]	1.2300 ± 0.0000[c]	-0.965**
B3(30)	11.7000 ± 0.0577[b]	8.0150 ± 0.0050[c]	4.2200 ± 0.0000[d]	2.4775 ± 0.0025[c]	1.1800 ± 0.0000[d]	-0.961**
C	11.7000 ± 0.0577[b]	11.6000 ± 0.0000[a]	11.2200 ± 0.0000[a]	10.0000 ± 0.0000[a]	10.6000 ± 0.0000[a]	-0.841**
D	0.0015 ± 0.0009[d]	0.0015 ± 0.0009[g]	0.0010 ± 0.0006[h]	0.0015 ± 0.0009[g]	0.0015 ± 0.0009[h]	0.004

Means (± Standard errors) on the same column (each time) with different superscripts are significantly different ($p < 0.05$)
r: Correlation coefficient of each treatment with the exposure period (in days) after treatment pollution
**Correlation is significant at 1% level
* Correlation is significant at 5% level

Table10: The Concentration of Phosphorus (mg /g) in the Treatments at Different Pollution Time

Treatment	Period after treatment pollution (Days)					r
	5	14	28	42	56	
A1(10)	46.025 ± 0.075[b]	48.625 ± 0.048[d]	58.350 ± 0.065[d]	65.175 ± 0.025[c]	68.475 ± 0.025[c]	0.987**
A2(20)	46.025 ± 0.075[b]	49.150 ± 0.029[c]	59.500 ± 0.041[c]	65.650 ± 0.050[b]	69.200 ± 0.000[b]	0.985**
A3(30)	46.025 ± 0.075[b]	50.275 ± 0.025[b]	62.575 ± 0.132[a]	67.400 ± 0.071[a]	70.400 ± 0.041[a]	0.970**
B1(10)	46.025 ± 0.075[b]	47.375 ± 0.025[g]	52.400 ± 0.000[g]	56.800 ± 0.000[g]	58.400 ± 0.000[g]	0.987**
B2(20)	46.025 ± 0.075[b]	48.025 ± 0.025[f]	53.600 ± 0.071[f]	57.200 ± 0.000[f]	58.750 ± 0.050[f]	0.982**
B3(30)	46.025 ± 0.075[b]	48.400 ± 0.000[e]	54.200 ± 0.000[e]	58.350 ± 0.029[e]	59.200 ± 0.000[e]	0.975**
C	46.025 ± 0.075[b]	46.500 ± 0.041[h]	47.350 ± 0.050[h]	48.650 ± 0.065[h]	50.275 ± 0.025[h]	0.986**
D	59.650 ± 0.029[a]	59.600 ± 0.000[a]	59.700 ± 0.000[b]	59.700 ± 0.057[d]	59.750 ± 0.029[d]	0.587**

Means (± Standard errors) on the same column (each time) with different superscripts are significantly different ($p < 0.05$)
r: Correlation coefficient of each treatment with the exposure period (in days) after treatment pollution
**Correlation is significant at 1% level
* Correlation is significant at 5% level

Table 11: The Concentration of Soil pH in the Treatments at Different Pollution Time

Treatment	Period after treatment pollution					r
	5	14	28	42	56	
A1(10)	5.225 ± 0.025[b]	5.400 ± 0.000[e]	5.800 ± 0.000[d]	6.100 ± 0.000[d]	6.450 ± 0.050[b]	0.994**
A2(20)	5.200 ± 0.000[bc]	5.650 ± 0.029[c]	5.900 ± 0.000[c]	6.200 ± 0.000[c]	6.450 ± 0.029[b]	0.979**
A3(30)	5.150 ± 0.029[c]	5.775 ± 0.025[b]	6.000 ± 0.000[b]	6.275 ± 0.025[b]	6.500 ± 0.000[b]	0.950**
B1(10)	5.200 ± 0.000[bc]	5.275 ± 0.025[f]	5.500 ± 0.000[g]	5.800 ± 0.000[g]	6.125 ± 0.025[c]	0.987**
B2(20)	5.175 ± 0.025[bc]	5.475 ± 0.025[d]	5.625 ± 0.025[f]	5.875 ± 0.025[f]	6.125 ± 0.025[c]	0.981**
B3(30)	5.175 ± 0.025[bc]	5.600 ± 0.000[c]	5.750 ± 0.029[e]	6.000 ± 0.000[e]	6.100 ± 0.000[c]	0.949**
C	5.200 ± 0.000[cb]	5.200 ± 0.000[g]	5.400 ± 0.000[h]	5.500 ± 0.000[h]	5.600 ± 0.000[d]	0.983**
D	6.825 ± 0.025[a]	6.850 ± 0.029[a]	6.825 ± 0.025[a]	6.800 ± 0.057[a]	6.825 ± 0.025[a]	-0.122

Means (± Standard errors) on the same column (each time) with different superscripts are significantly different ($p < 0.05$)
r: Correlation coefficient of each treatment with the exposure period (in days) after treatment pollution
**Correlation is significant at 1% level
*Correlation is significant at 5% level

Strong positive relationships between remediation time and nitrogen content in treated soils are shown in Table 8 (r=0.95-0.97, $p < 0.01$). This demonstrates that soil nitrogen recovered sustainably while remediation went on. While the unpolluted control stayed the same, the untreated contaminated soil only slightly improved. The significance of time-dependent biological processes in nutrient recovery is determined by the strong relationship seen in the data. Additionally, organic additions have the benefit of restoring soil fertility in addition to eliminating pollutants. These findings demonstrate the association between nitrogen level and remediation time for each therapy using a combination of mean ± standard error and Pearson correlation analysis (r). The dependability and strength of temporal patterns are indicated by $p < 0.05$ and $p < 0.01$. Strong positive correlations (r=0.95-0.97) demonstrated the relationship between time and nitrogen recovery in treated soils.

Time and TPH content in improved soils showed strong negative relationships (r=-0.95 to -0.97, $p < 0.01$) (Table 9). This demonstrates that hydrocarbons continue to degrade during the cleanup process. The drop in the untreated polluted soil was significantly weaker, suggesting that natural attenuation is insufficient on its own. Sawdust-treated soils retained more residual hydrocarbons at 56 days, although TPH levels in manure-treated soils were close to background levels. To verify any association between THP levels and time, Table 9 employed Pearson correlation coefficients. This is confirmed by a strong negative, which also demonstrates the TPH's temporal fall. The hydrocarbon degradation in modified soils is depicted in the statistics. The reduced efficacy of natural attenuation is demonstrated by the weaker correlations in untreated contaminated soil.

Phosphorus concentration is shown as mean ± standard error in Table 10. ANOVA was used to assess treatment differences at each sample period, and Pearson correlation analysis was used to determine the association between phosphorus concentration and time after treatment. The unpolluted control showed a lesser association (r=0.587), indicating fixed phosphorus levels rather than time-dependent recovery, but the modified soils showed very high positive correlations (r=0.970-0.987, $p < 0.01$). Phosphorus recovery followed by a treatment-driven temporal pattern rather than random fluctuation is confirmed by the combination of ANOVA and correlation data.

The pH of the oil-contaminated soil was 5.15–6.52 (acidic), as shown in Table 11. Muhammad et al. (2019) found that the presence of TPH has the capacity to release hydrogen ions. The findings of (Obasi et al., 2013) that the addition of agricultural wastes to motor oil-polluted soils raises the soil pH are supported by the fact that the soil pH increased in the amendment samples. Because the amendment materials were alkaline, this pH value was attained. Soil pH temporal trends (Table 11) demonstrated a strong association (r = 0.949-0.994, $p < 0.01$), indicating a considerable rise in soil pH over time after amendment application. At lower pH levels, the untreated contaminated soil also showed a positive correlation, indicating limited natural recovery. The unpolluted control, on the other hand, demonstrated no significant correlation with time (r = -0.122), indicating a chemically stable state. The findings show that adding organic amendments improves pH recovery.

Conclusion

Organic amendments improve the rehabilitation of petroleum-contaminated soils, according to statistical evidence in this study. Nitrogen, phosphorus, and soil pH all significantly improved when organic amendments were applied, and TPH levels significantly decreased. Soil recovery was both amendment-specific and time-dependent, as confirmed by a two-way ANOVA that displayed the effects of treatment, remediation time, and their interactions across all assessed parameters. Strong, predictable temporal trends in nutrient recovery and hydrocarbon degradation were confirmed by Pearson correlation analysis, and the one-way ANOVA with post-hoc mean separation further showed distinct and enduring differences across treatments. Poultry manure consistently showed better remediation effectiveness than sawdust among the evaluated amendments, especially at higher application rates, according to the study. Poultry manure amendments successfully promote microbial degradation processes while recovering soil chemical functioning, as evidenced by the substantial negative correlations between TPH levels and time as well as the positive correlations for nutrients and pH recovery. Lastly, poultry manure-based remediation is an environmentally sound, economical, and sustainable method of cleaning up petroleum-polluted soils.

References

1. Adams, G. O., Tawari-Fufeyin, P., Ehinomen, I. (2014). Bioremediation of Spent Oil Contaminated Soils Using Poultry Litter. *Research Journal in Engineering and Applied Sciences*, *3*(2), 124-130.
2. Akpokodje, O. I. and Uguru, H. (2019). Bioremediation of Hydrocarbon Contaminated Soil: Assessment of Compost Manure and Organic Soap. *Transactions on Machine Learning and Artificial Intelligence*, *7*(5), 13-23. http://dx.doi.org/10.14738/tmlai.75.7013.
3. Amadi, A. and Bari, Y. U. (1992). Use of Poultry Manure for Amendment of Oil Polluted Soils in Relation to Growth of (*Zea mays* L). *Environment International*, *18*(5), 521-527.
4. Aneke, J. C., Ewoh, N. A., Iloputaife, J. E. (2025). Bioremediation of Crude Oil Polluted Soil Using Sawdust, Poultry Droppings, and Grass Trimmings through Optimization of Biostimulant Levels Using Box-Behnken Statistical Design. *Environment and Ecology Research*, *13*(6), 931 - 937. DOI: 10.13189/eer.2025.130614.
5. Chen, L., Cai, G., Gu, J., Tan, Y., Chen, C. and Yin, Z. (2020). Effects of clay on internal erosion of Clay-Sand-Gravel Mixture. *Advances in Civil Engineering*, 1-18. doi:10.1155/2020/8869289.
6. Coo, A. E., Oviasogie, F. E., Ikhajiagbe, B. (2022). Microbial effects of manure from poultry droppings and pig dung in diesel-contaminated soil. *Journal of Biotechnology, Computational Biology and Bionanotechnology*, *103*(4), 385–396.
7. Eboibi, O., Akpokodje, O. I., and Uguru, H. (2018). Bioremediation of soil contaminated with cassava effluent using organic soap solution. Journal of Environmental Science, Toxicology and Food Technology, *12*, 50-57.
8. Ekeoma, M. O. and Anukwa, F. (2020). Potential of Pineapple peel (*Ananas comosus*) and Coconut (*Cocos nucifera*) husk char in crude oil polluted soil. *International Journal of Environment Agriculture and Biotechnology*, *3*, 582-593.
9. Etuk, E. A., Ogboi, K. C., Nwadinigwe, C. A. (2013). Bioremediation of Hydrocarbon polluted soil in the lowland forest ecosystem in the Niger Delta through enhanced natural attenuation process (ENAP). *Int. J. of Appl. Sci. and Tech*, *3*(8), 128 – 137.
10. Farhan, S. (2022). The Significance and Use of Poultry Manure as a Fertilizer. "Poultry Management Guide, *Poultry Research Guide*" 2022. Available: thepoultryguide.com. (March 20, 2025).
11. Hauane, S. C., Christopher, T. B., Franklin, G., and Leila, T.M. (2022). Effects of oil contamination on plant growth and development. *Environmental Science Pollution Research International*, *29*, 43501 – 43515.
12. Kanwal, M., Ullah, H., Gulzar, A., Sadiq, T., Ullah, M., Safraz, M., Aslam, M. W., Khan, N. N., Batol, T., Masqsood, S., and Nawaz, A. (2022). Biodegradation of Petroleum Hydrocarbons and The Factors Effecting Rate of Biodegradation. *Am J Biomed Sci & Res*, *16*(1), 713-714.
13. Lindstrom, J. and J. Braddock. (2002). Biodegradation of Petroleum Hydrocarbon at Low Temperature in the Presence of the Dispersant. Corexit 9500- *Marine Pollution Bulletin*, *44*, 739-747.
14. Muhammad, R. G., Machido, D. A., Ado, S. A., Atta. H. I., Bello I. A. (2019). A Comparism of the Effect of Some Organic Wastes on the Rate of Bioremediation of Soil Contaminated with Spent Engine Oil Using Gas Chromatography/Mass Spectrophotometer. *Journal of Agriculture & Agricultural Technology*, *19*(1), 36-52.

15. Obasi, N. A., Eberechukwu, E., Anyanwu, D. I., Okorie, U. C. (2013). Effects of organic manures on the physicochemical properties of crude oil polluted soils. *African Journal of Biochemistry Research, 7*(6), 67-75.
16. Odukoya, J., Ronnie, L., and Ruben, S. (2019). Understanding the Impact of Crude oil and its Induced abiotic stresses on Agrifood Production: A Review. *Journal of Horticulture, 5*(2), 1-13.
17. Offor, U. S. and Akonye. L. A. (2006). Amendment of Crude Oil Contaminated Soil with Sawdust and Chromolena Leaves for Optimum Plant Protection. *African Journal of Biotechnology, 5*(9), 770-774.
18. Ogboghodo, I., Erebor, E. B., Osemwota, I. O. and Isitekhale, H. H. (2004). Effects of Application of Poultry Manure on Crude Oil Polluted Soils on Maize Growth and Soil Properties. *Environmental Monitoring and Assessment*, *96*, 153-161.
19. Osazee, E., Adebola, M. O., Falusi, O. A., Abioye, O. P. (2019). Influenced of Organic Waste On Physicochemical Properties of Spent Engine Oil Contaminated Soil Supplemented with Fungi Isolated from Mechanic Workshops in Minna, Nigeria. *Mediterranean Publication and Research International Journal of Medical, Biological and Pharmaceutical Sciences*, *9*(9), 77-87.
20. Osu, S. R., Udosen, I. R., Udofia, G. E. (2021). Remediation of Crude Oil Contaminated Soil, Using Organic Supplement: Effects on Growth and Heavy Metal Uptake in Cassava (Manihot esculenta Crantz). *J. Appl. Sci. Environ. Manage*, *25*(1), 5-14. DOI: https://dx.doi.org/10.4314/jasem.v25i1.1
21. Osu, S. R. (2017). Amelioration of crude oil impacted soil using cassava (Manihot esculenta Crantz) with oil palm bunch ash and dried poultry litters as supplements. PhD thesis, Department of Botany and Ecological studies University of Uyo. Nigeria. P.216.
22. SoilErosion.com (2019*). Introduction to soil erosion.* What is soil remediation? Introduction to Soil Remediation - SoilErosion.com (accessed 5th January 2026).