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Comparative Evaluation of Total Hydrocarbon Content (THC) in Crude Oil-Polluted Soil After Bone Char, Palm Bunch, and NPK Biodegradation Treatment.

EKENE NWUDE[1], AFAM A. NWUDE[2], IPEGHAN J. OTARAKU[3]
[1,3]*Department of Environmental Engineering, University of Port Harcourt, Nigeria*
[2]*Department of Petroleum Engineering, Madonna University, Nigeria*

Abstract- ***This study comparatively evaluated the efficacy of two organic amendments: bone char and spent palm bunch (SPB), against conventional NPK (20:10:10) fertilizer and natural attenuation in reducing total hydrocarbon content (THC) in crude oil-polluted soil over a 10-week incubation period, across application rates ranging from 0.5 to 14.0 kg. After contamination with THC from an initial concentration of 38 mg/kg in unpolluted soil to 23,560 mg/kg, soil acidification and a decrease in nitrogen and phosphorus availability were detected. All amendments produced statistically significant THC reductions relative to the unamended control ($p < 0.05$). Bone char achieved the fastest degradation kinetics, with a first-order rate constant of 0.021 day^{-1}, a half-life of 33.01 days, and biostimulation efficiency of 79.37% at 6.5 kg application, outperforming both NPK (half-life ≈ 57.76 days) and SPB (half-life ≈ 99.02 days). The highest degradation efficiency was observed at intermediate application rates, which did not increase linearly with the dosage, indicating an optimal nutrient threshold. Total THC degradation was below 25% in all treatments within the study period. These results identify bone char as a highly effective, low-cost alternative to inorganic fertilization for accelerating hydrocarbon bioremediation in tropical, petroleum-impacted soils, with implications for scalable, field-level restoration practice.***

Keywords: Total Hydrocarbon Content, Crude Oil-Polluted Soil, Bioremediation, Bone Char, Spent Palm-Bunch, Inorganic Fertilizer.

I. INTRODUCTION

Degradation of petroleum hydrocarbons in the soil is a complex process that depends on the nature and on the amount of the hydrocarbons present. One of the important factors that limit degradation of oil pollutants in the environment is their limited availability to microorganisms, Adebusoye, et al (2007). Petroleum hydrocarbon compounds bind to soil components, and they are difficult to be removed or degrade. Hydrocarbons differ in their susceptibility to microbial attack. The susceptibility of hydrocarbons to microbial degradation can be generally ranked as follows: linear alkanes, branched alkanes, small aromatics cyclic alkanes. Some compounds, such as the high molecular weight polycyclic aromatic hydrocarbons (PAHs), may not be degraded at all. The recognition of biodegraded petroleum-derived aromatic hydrocarbons in marine sediments was reported by Jones et al (2017).

Soil contamination by petroleum and its products changes more or less all soil properties, including its physical, physicochemical and chemical properties Pathak et al. (2010). The extent of such changes depends on the soil type, the soil's initial condition, and the type and concentration of contaminant. According to Wang et al., (2013) result of contamination and the petroleum film coating of soil particles, the color of the soil profile changes to grey and dark brown. It can further, lead to a considerable loss of water conductivity and capacity. Thus, petroleum and its products mainly cause negative changes in all soil properties, from the soil layer morphology to hemic acid chemistry, Elinskiy, V.I.; Akmedov (2020).

II. MATERIALS AND METHODS

Experimental Materials

- Uncontaminated Soil: Surface soil (0–30 cm depth) was collected from selected uncontaminated locations within the University of Port Harcourt.
- Bonny Light Crude Oil: Bonny Light crude oil obtained from a petroleum production facility in

Rivers State was used as the contaminant. The crude oil was uniformly applied to all experimental cells to simulate hydrocarbon pollution.

- Bone Char: Bone char produced from calcined animal bones served as one of the organic nutrient amendments. Bone char supplied phosphorus, calcium and trace minerals capable of stimulating microbial degradation of petroleum hydrocarbons, Ikiogha et al (2019).
- Spent Palm Bunch (SPB): Spent palm bunch obtained from a palm oil processing mill was air-dried, shredded and sieved before application. The material served as an organic fertilizer by supplying organic carbon, nitrogen and micronutrients while improving soil aeration and moisture retention.
- NPK Fertilizer (20:10:10): Commercial NPK (20:10:10) fertilizer served as the inorganic nutrient amendment, Venosa et al., (2003).
- Distilled Water for moisture adjustment of the experimental soils.

Apparatus

The following equipment were used during sample preparation, and treatment application:

- Electronic weighing balance (LT 502)
- 0.30 mm laboratory sieve
- Jenway 6305 UV–Visible Spectrophotometer: used for determining Total Hydrocarbon Content (THC) following solvent extraction procedures.
- Gallenkamp Prime Oven: used for oven-drying soil samples prior to moisture determination and laboratory analyses.
- pH Meter: used for measuring soil pH throughout the remediation period.
- Volumetric Flasks: used for preparing analytical solutions and calibration standards.
- Measuring Cylinders: used for measuring solvents and distilled water during laboratory procedures.
- Funnels: used during filtration and sample transfer.
- Sample Bottles: used for preserving soil samples before laboratory analyses.
- Buckets: used for soil mixing, homogenization and amendment preparation.
- Spatulas: used for handling soil and reagent samples.
- Syringes: used for accurate measurement of extraction solvents where required.
- Masking Tape and Permanent Markers: used for labeling samples and experimental plots.

III. METHODS

The design enabled the comparison of the remediation efficiencies of two organic nutrient amendments (bone char and spent palm bunch), inorganic fertilizer (NPK 20:10:10), and natural attenuation (control) on hydrocarbon-polluted soil under identical environmental conditions.

Sampling Station (Field Preparation, Contamination, and Measurement).

The sampling field was divided into sectors or quadrants and a total of 40 replicates cells each with a dimension of 1.5metres x 1.5metres and a depth of 30cm (contaminated soil depth) Venosa et al., (2003). The cells were separated from each other with a 10cm gap. (Ayotamuno and Kogbara, 2006; Daka et al. 2007) used similar designs. To avoid cross contamination or chemical and biological changes in samples, clean PVC bags were used for collection of the contaminated soil taken to the laboratory. Figure 1 shows the different cells created from the experimental design.

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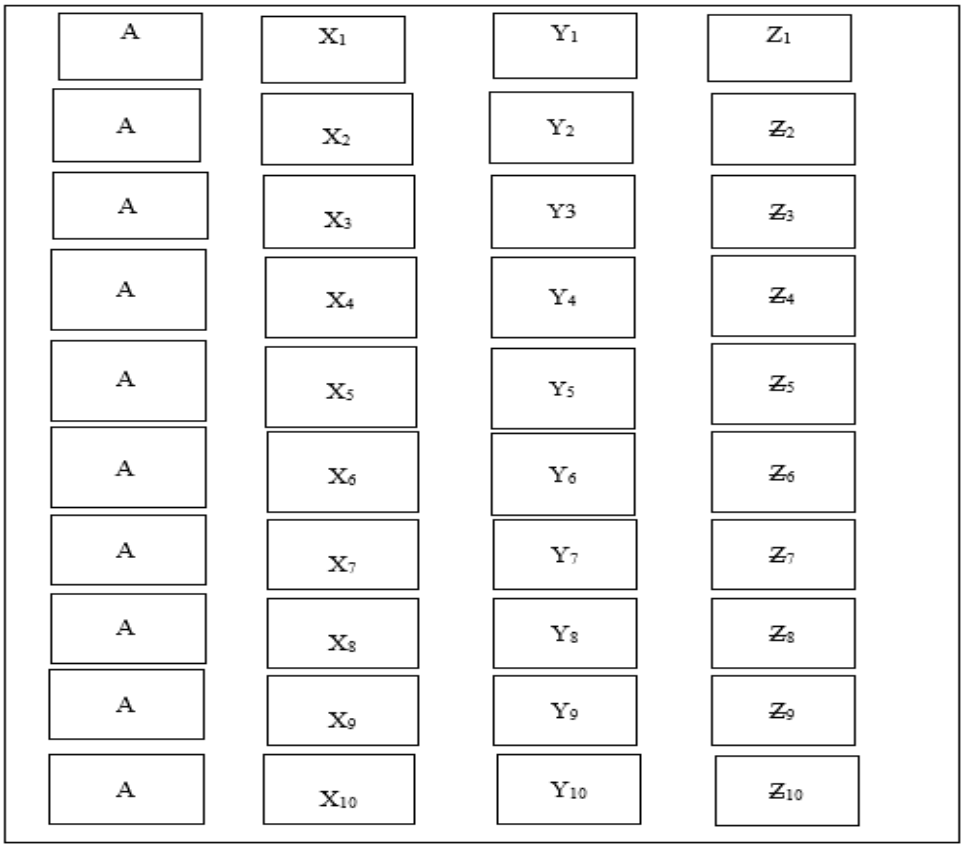

Figure 1: Differentiated Cells: Control Cells (Natural Attenuation) and Cells with Different Concentrations of NPK, Palm Bunch and Bone char

IV. RESULTS

Result of Physiochemical Properties of Unpolluted and Polluted Soil

The polluted and Unpolluted soil samples were analyzed of their physiochemical properties their results are presented in Table 4.1 below and confirms that the sandy loam soil sample was heavily contaminated by hydrocarbon crude oil, judging from the values of critical parameters such as moisture content, Organic matter (%), TOC (%) and THC.

Table 1: The Physico-chemical analysis of Unpolluted Soil and Polluted Soil

S/No	Parameter	Unpolluted Soil	Polluted Soil
1.	Ph	6.45	5.30
2.	Electrical Conductivity (μS/cm)	101	290
3.	Moisture Content (%)	21.8	14.2
4.	Total Nitrogen (%)	0.015	0.008
5.	Extractable Phosphorus (mg)	18.5	10.2
6.	Organic Matter (%)	1.05	3.97
7.	Total Organic Carbon (%)	0.60	2.35
8.	Total Hydrocarbon Content (mg/kg)	38	23,560

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Result of Physiochemical Analysis of Bone Char, Palm Bunch, and NPK

The results of the physiochemical analysis of bone char, palm bunch, and N.P.K, applied in this study are in Table 2. The parameter analyzed include; pH (1:2.5 in water), Electrical conductivity (dS/m), Total Potassium (%), Total Calcium (%), Ash content (%), O Conductivity.

The physiochemical analysis was gotten for the bone char, palm bunch, and N.P.K, stating the pH (1:2.5 in water), Electric conductivity (dS/m), Total Potassium (%), Total Calcium %, Ash content %, Organic matter (%), Total Nitrogen (%), Total Phosphorus (%), Moisture content (%), and Cation Exchange (CEC).

Table 2: The Physiochemical Analysis of bone char, Palm Bunch and N.P.K

S/No	Parameter	N.P.K	Palm Bunch	Bone Char
1.	pH (1 : 2.5; in water)	6.2	9.4	8.7
2.	Electrical Conductivity	5.4	3.8	1.12
3.	Moisture Content (%)	1.9	3.1	2.4
4.	Ash Content (%)	92.3	82.7	68.5
5.	Organic Carbon (%)	0.2	7.4	14.2
6.	Total Nitrogen (%)	15.1	0.22	0.18
7.	Total Phosphorus (P2O5, %)	14.8	4.6	29.4
8.	Total Potassium (%)	15.2	18.2	0.5
9.	Total Calcium (%)	0.9	6.7	35.6
10.	Cation Exchange Capacity (CEC) cmol/kg	1.3	8.6	17.4
11.	Organic Matter (%)	0.7	13.4	24.5

Results of Bioremediation of Polluted Soils

The analysis of bioremediation of crude oil polluted soil was observed for a total period of 10 weeks. The physiochemical parameters and THC of the soil was determined for the organic (Bone char, Palm Bunch) and inorganic (N.P.K 20:10:10) fertilizers respectively. The results were tabulated and plotted in Figures 2 to 11, which shows remediation process been done. These graphical representations from Figure 2 to 11, gives various insights to the degradation process of Total Hydrocarbon Content (THC).

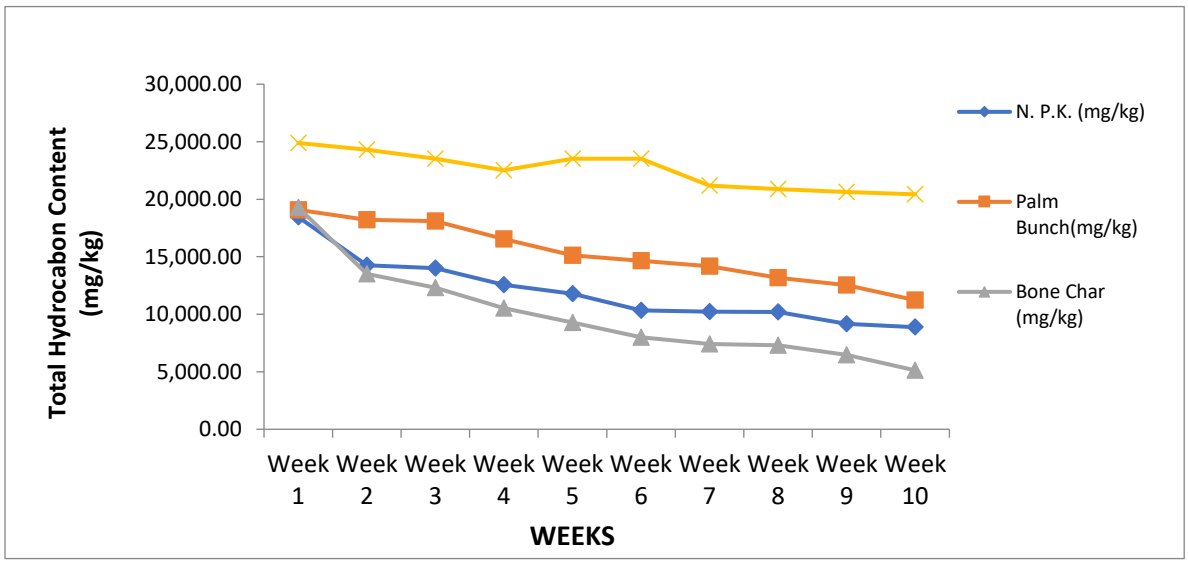

Figure 2: Remediation of THC with 0.5 kg of Different Sample Concentration

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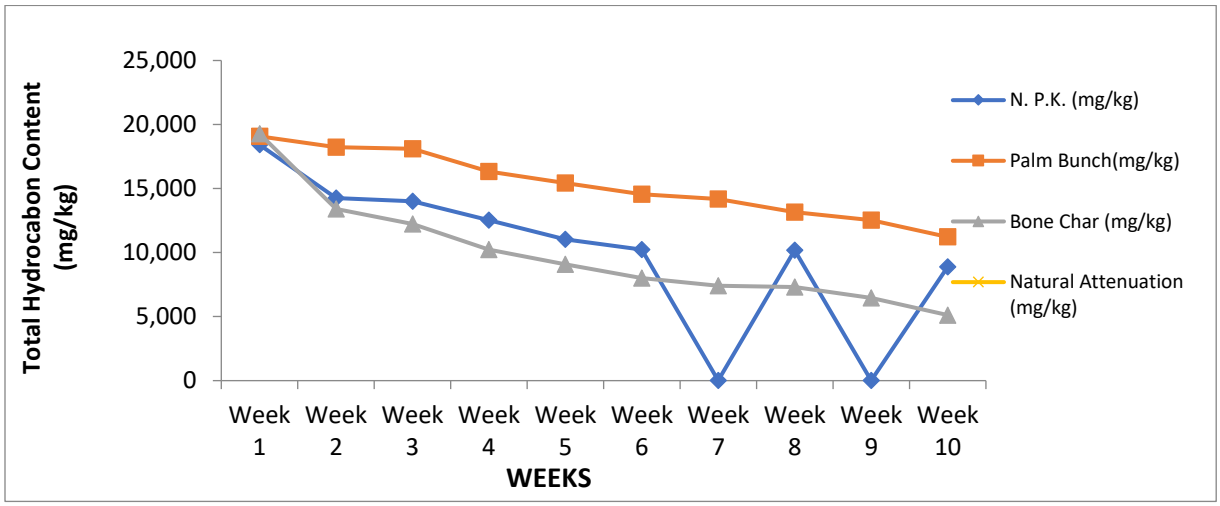

Figure 3: Remediation of THC with 2.0KG of Different Sample Concentration

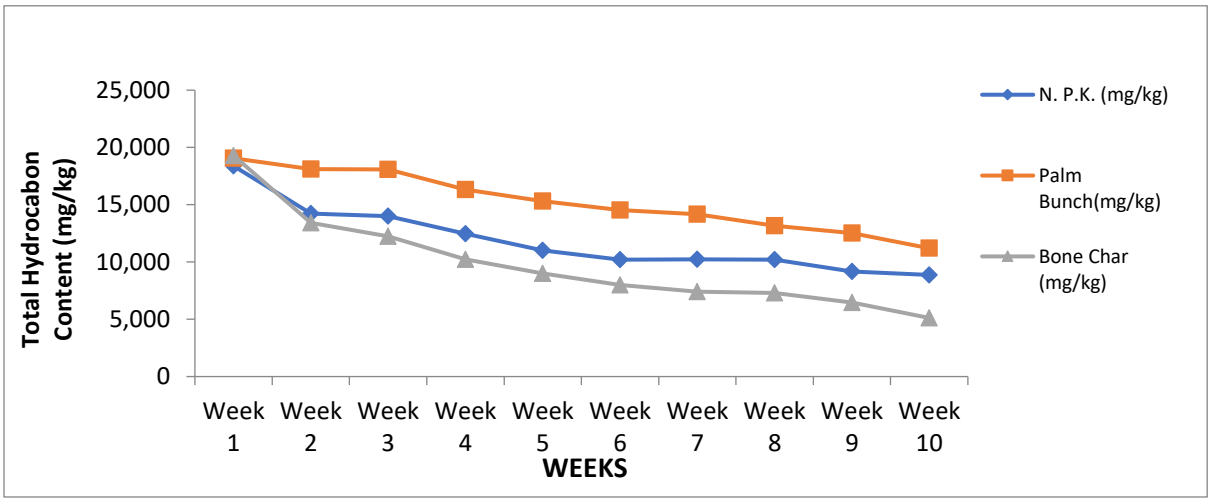

Figure 4: Remediation of THC with 3.5 kg of different Sample Concentration

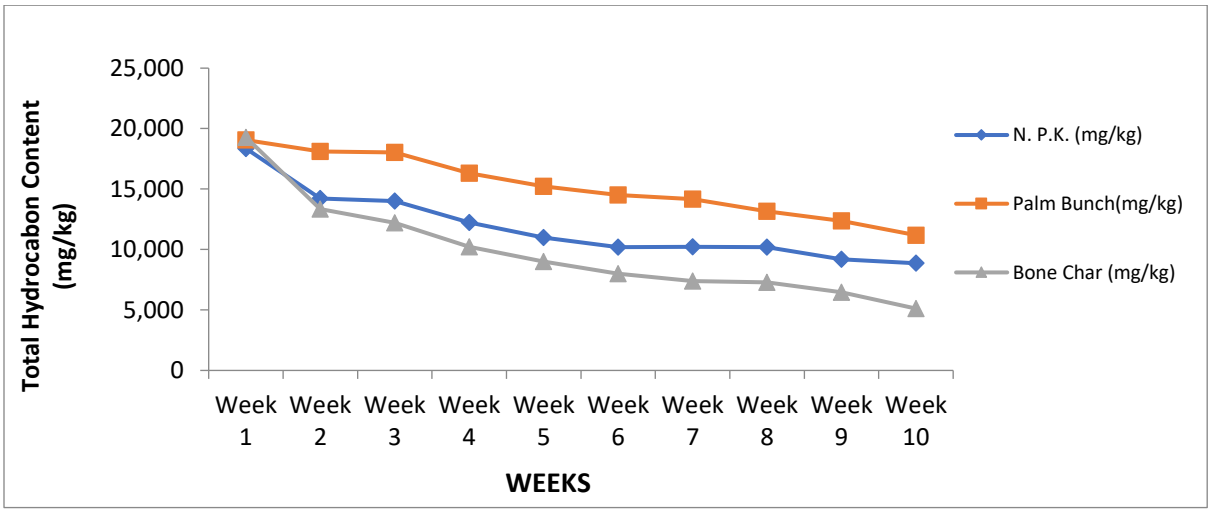

Figure 5: Remediation of Hydrocarbon Content at 5.0 kg Concentration

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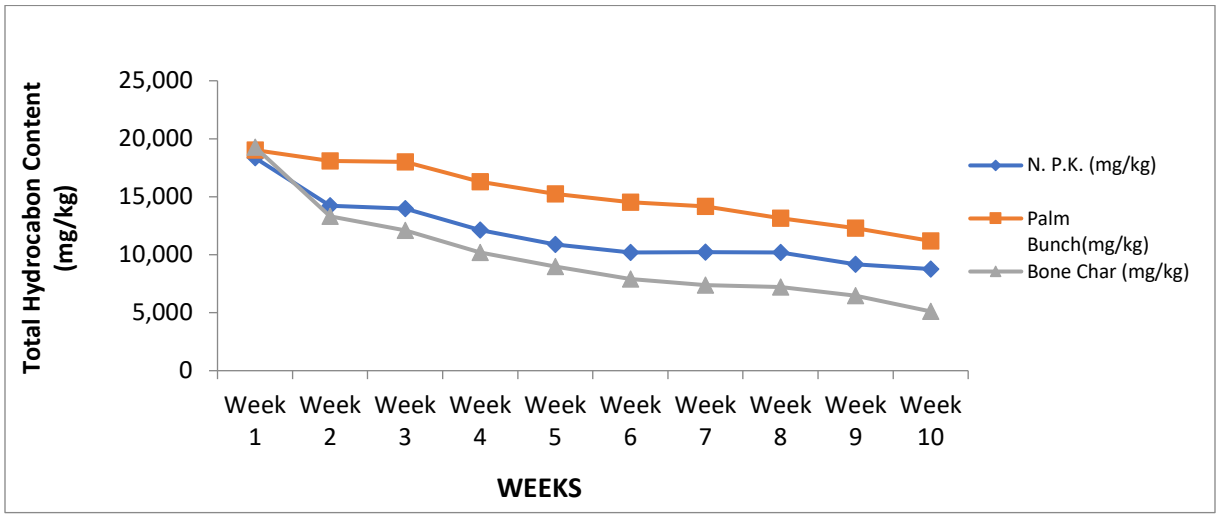

Figure 6: Remediation of THC with 6.5 kg of Different Sample Concentration

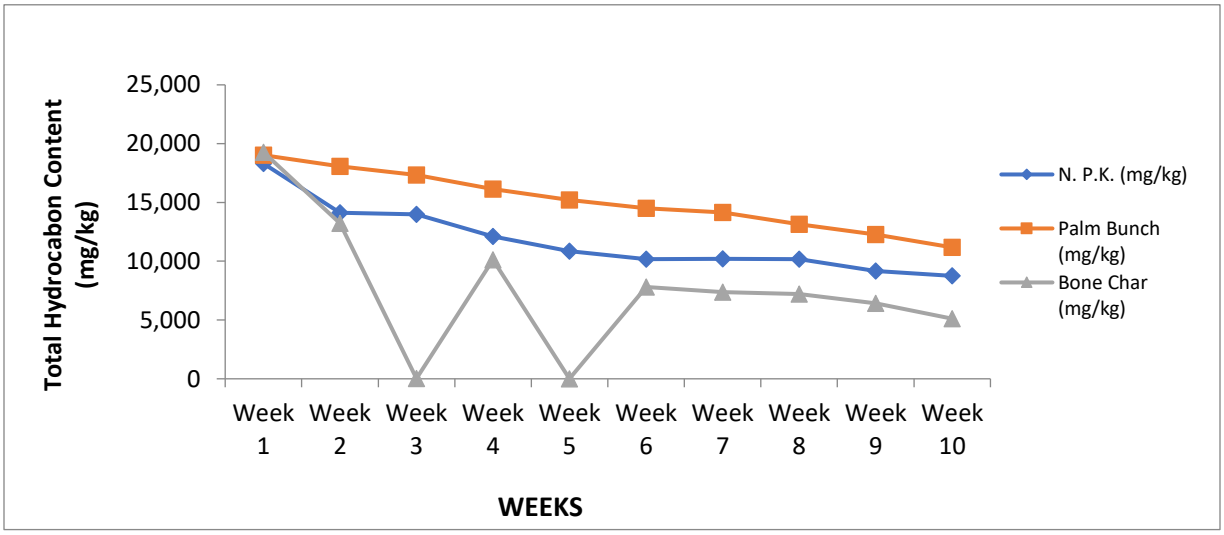

Figure 7: Remediation of THC with 8kg of Different Sample Concentration

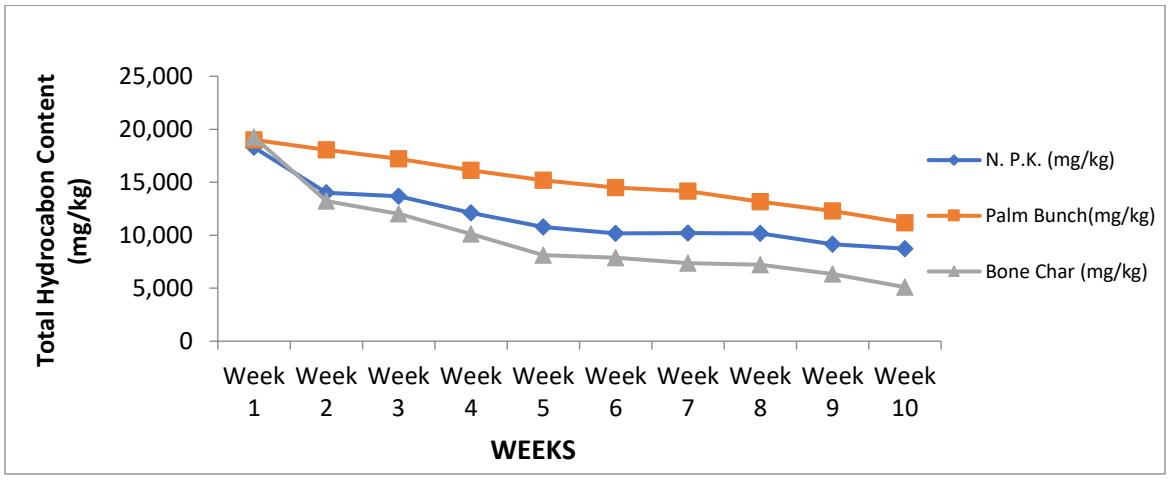

Figure 8: Remediation of THC with 9.5 kg Different Sample Concentration

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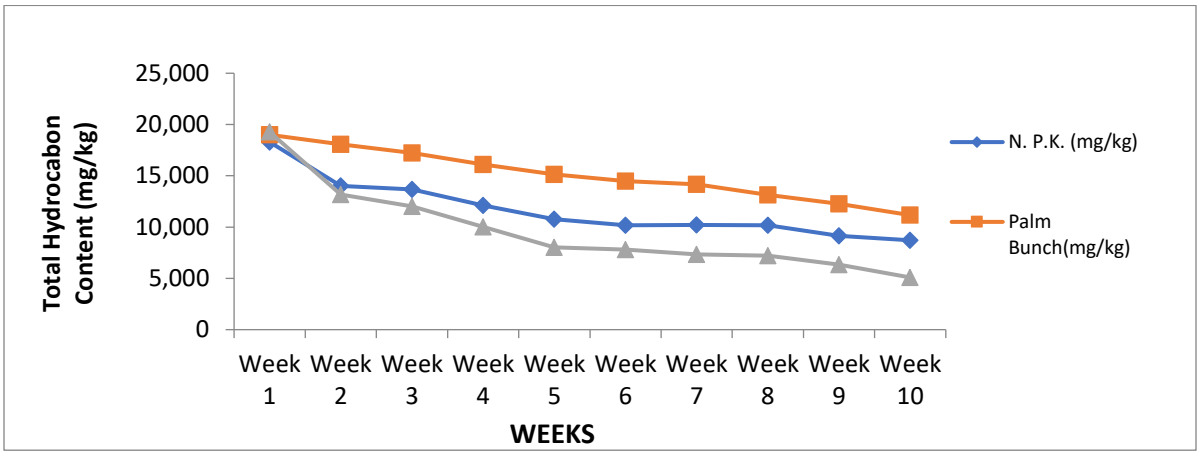

Figure 9: Remediation of THC with 11kg of Different Sample Concentration

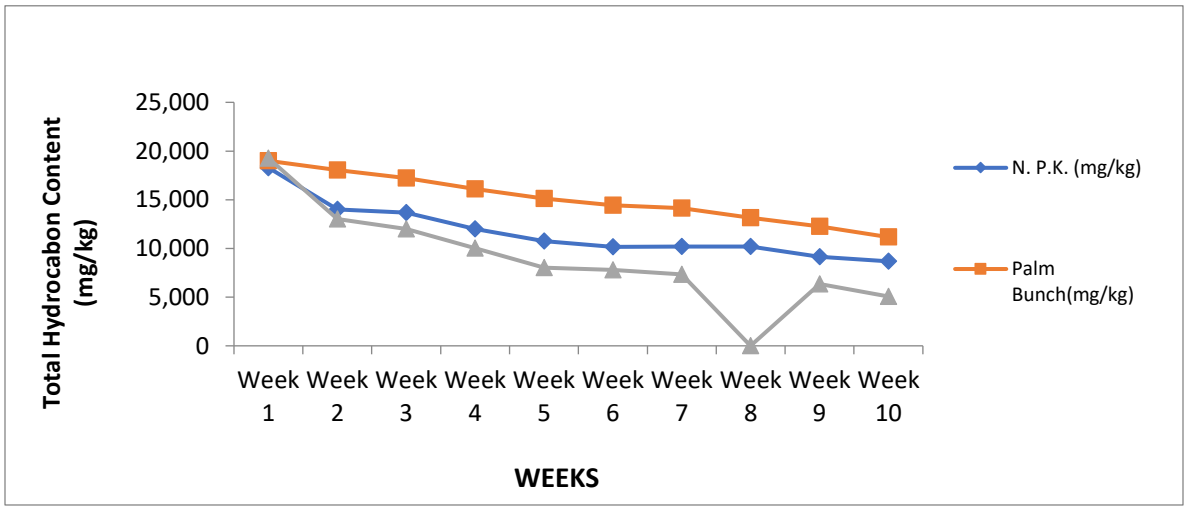

Figure 10: Remediation of THC with 12.5 kg of Different Samples Concentration

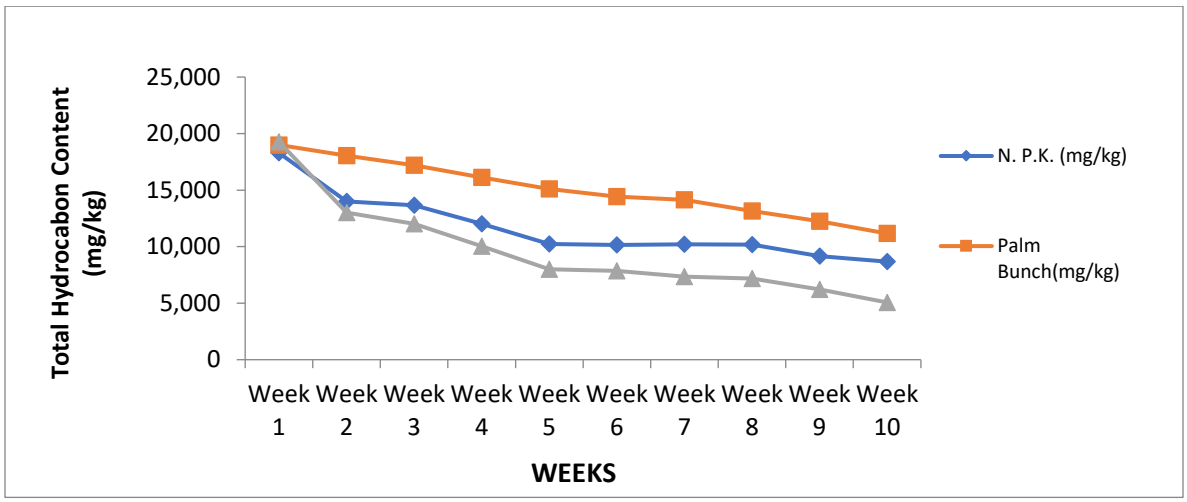

Figure 11: Remediation of THC of 14.0 kg of Different Sample Concentration

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Analysis of Total Hydrocarbon (THC) in Soil Using Statistical Hypothesis Test

The results from 10 weeks biodegradation of THC contaminated soil was analyzed using the t-test analysis by comparing results obtained from treatments with that of control sites. The following conditional statements were considered;

i. If P> 0.05 we should accept null hypothesis (H_o); of no appreciable effect on remediation process and reject alternative hypothesis (H_i); of an appreciable effect on remediation.

ii. If P<0.0 reject null hypothesis 〖(H〗 _o); of no appreciable effect on remediation process and we accept alternative hypothesis (H_i); of a significant effect on remediation process. .

The T-test were ran with remediation results from Table 4.3 using Excel data sheet. Table 4.5 shows the various P-Value and their remarks. Details is shown in Appendix.

From the data gathered, the table shows the various P-value and remarks of the samples;

Table 4: Statistical Hypothesis Test Table for Total Hydrocarbon (THC) in Crude Oil Contaminated Soil against Control Soil

Samples	Amendments (kg)	P-Value	Remarks
1	Natural Attenuation	-	-
2	N.P.K (0.5kg)	0.00006	Significant Difference
3	N.P.K (2.0kg)	0.000015	Significant Difference
4	N.P.K (3.5kg)	0.000025	Significant Difference
5	N.P.K (5.0kg)	0.000011	Significant Difference
6	N.P.K (6.5kg)	0.000009	Significant Difference
]7	N.P.K (8.0kg)	0,00001	Significant Difference
8	N.P.K (9.5kg)	0.000003	Significant Difference
9	N.P.K (11kg)	0.00003	Significant Difference
10	N.P.K (12.5kg)	0.000004	Significant difference
11	N.P.K (13.5kg)	0.000003	Significant Difference
12	Palm Bunch (0.5kg)	0.00005	Significant Difference
13	Palm Bunch (2kg)	0.00005	Significant Difference
14	Palm Bunch (3.5kg)	0.00004	Significant Difference
15	Palm Bunch (5kg)	0.0000398	Significant Difference

16	Palm Bunch (6.5kg)	0.00004	Significant Difference
17	Palm Bunch (8kg)	0.00004	Significant Difference
18	Palm Bunch (9.5kg)	0.00004	Significant Difference
19	Palm Bunch (11kg)	0.00004	Significant Difference
20	Palm Bunch 12.5kg	0.00004	Significant Difference
21	Palm Bunch 13.5kg	0.00004	Significant Difference
22	Bone Char (5.0kg)	0.00000578	Significant Difference
23	Bone Char (2kg)	0.0000005	Significant Difference
24	Bone Char (3.5kg)	0.00000529	Significant Difference
25	Bone Char (5.0kg)	0.0000398	Significant Difference
26	Bone Char (6.5kg)	0.00001	Significant Difference
27	Bone Char (8.0kg)	0.00000231	Significant Difference
28	Bone Char (9.5kg)	0.0000003	Significant Difference
29	Bone Char (11.0kg)	0.0000003	Significant Difference
30	Bone Char (12.5kg)	0.00000041	Significant Difference
31	Bone Char (14.0kg)	0.0000003	Significant Difference

From the t-test results shown in Table 4.5 significant level ($P<0.05$) was observed for treatment using various optimization rates of amendments in Samples 2 through 31, ascompared to natural attenuation serving as control (Sample 1). Thus, there was appreciable difference in entire samples. Therefore, alternative hypothesis (H_i) was accepted which indicates appreciable reduction of Total Hydrocarbon (THC) in crude oil contaminated soil for entire samples.

4.1.10 Percentage Degradation (% D) of Total Hydrocarbon Content (THC)

The percentage degradation for the various sample blocks are shown in the Table 4.6 and the periodical disaggregation from (3 to 4weeks), and (9 to 10 weeks) are represented in Figure 4.23. From Figure 4.23 it can be deducted that: Bone char showed highest %D from early period of 3 – 4 weeks, at 8kg concentration was 16.5% degradation, and during 9 to 10 weeks was 19.8% degradation. Palm Bunch %D within 3 – 4 weeks at 3.5kg was 9.8% and 9 – 10 weeks, approximately 10.5% of Total Hydrocarbon Content (THC). NPK Treated sample, at 3 – 4 weeks was 13.4% but dropped at 9 – 10 weeks to 4.5% degradation of THC. Natural attenuation was low at 3 – 4 weeks with %D of 4.3% and dropped lower to 0.95% at 9 – 10 weeks. Thus, in all samples the percentage degradation was below 25%, however impact of bioremediation was greatly significant.

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Table 5: (% D) of Total Hydrocarbon Content (THC)

S/n	Sample (kg)	%D, Week 3 – 4	%D, Week 4 – 5	%D, Week 5 – 6	%D, Week 6 – 7	%D, Week 7 – 8	%D Week 8 – 9	%D (Week 9 – 10)
1	Natural Attenuation	4.3%	0.5%	2.4%	1.85%	1.42%	1.20%	0.97%
2	N.P.K (0.5kg)	10.3%	6.3%	12.3%	0.96%	0.32%	9.98%	3.27%
3	N.P.K (2.0kg)	10.6%	9.3%	7.3%	0.10%	0.25%	10.01%	3.25%
4	N.P.K (3.5kg)	10.6%	11.7%	7.3%	-0.10%	0.28%	9.99%	3.32%
5	N.P.K (5.0kg)	12.5%	10.2%	7.3%	-0.23%	0.29%	9.96%	3.42%
6	N.P.K (6.5kg)	13.3%	10.2%	6.4%	-0.22%	0.27%	10.05%	4.38%
7	N.P.K (8.0kg)	13.4%	10.3%	6.6%	-0.47%	0.29%	10.03%	4.45%
8	N.P.K (9.5kg)	11.5%	10.9%	5.8%	-0.54%	0.31%	10.12%	4.59%
9	N.P.K (11.0kg)	11.4%	11.0%	5.5%	-0.49%	0.30%	10.07%	4.84%
10	N.P.K (12.5kg)	12.0%	10.5%	5.5%	-0.47%	0.28%	10.10%	5.18%
11	N.P.K (13.5kg)	12.2%	14.9%	6.5%	-0.49%	0.32%	10.10%	5.18%
12	Palm Bunch (0.5kg)	8.7%	8.5%	3.1%	3.23%	7.14%	4.84%	10.38%
13	Palm Bunch (2.0kg)	9.6%	-5.1%	5.6%	2.60%	7.16%	4.82%	10.41%
14	Palm Bunch (3.5kg)	9.5%	6.2%	5.3%	2.49%	7.16%	4.90%	10.48%
15	Palm Bunch (5.0kg)	9.5%	6.7%	4.7%	2.46%	7.13%	5.98%	9.54%
16	Palm Bunch (6.5kg)	9.6%	6.5%	4.8%	2.37%	7.15%	6.51%	9.02%
17	Palm Bunch (8.0kg)	7.0%	5.5%	4.7%	2.34%	7.11%	6.65%	8.96%
18	Palm Bunch (9.5kg)	6.5%	4.2%	4.5%	2.29%	6.90%	6.82%	9.00%
19	Palm Bunch (11.0kg)	6.5%	-5.1%	5.2%	2.20%	7.14%	6.74%	8.95%
20	Palm Bunch 12.5kg	6.5%	5.2%	4.9%	2.15%	7.05%	6.82%	8.90%
21	Palm Bunch 13.5kg	6.6%	5.3%	5.3%	1.98%	6.98%	6.96%	8.77%
22	Bone Char (0.5kg)	14.5%	11.9%	13.6%	7.24%	1.57%	11.41%	20.84%
23	Bone Char (2.0kg)	16.2%	11.4%	12.0%	7.21%	1.61%	11.44%	20.87%
24	Bone Char (3.5kg)	16.4%	11.9%	11.4%	7.17%	1.52%	11.51%	20.84%
25	Bone Char (5.0kg)	16.4%	11.9%	11.3%	7.51%	1.50%	11.21%	20.82%
26	Bone Char (6.5kg)	15.7%	11.7%	12.2%	6.59%	2.19%	10.57%	20.84%

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27	Bone Char (8.0kg)	16.2%	19.7%	3.8%	5.69%	2.12%	10.95%	20.46%
28	Bone Char (9.5kg)	16.0%	19.8%	13.5%	6.55%	2.12%	11.98%	19.59%
29	Bone Char (11.0kg)	16.5%	20.2%	2.4%	6.08%	1.70%	11.99%	19.76%
30	Bone Char (12.5kg)	16.0%	20.2%	2.4%	6.07%	1.82%	11.89%	20.33%
31	Bone Char (13.5kg)	16.0%	20.3%	1.7%	6.76%	2.33%	13.42%	18.63%

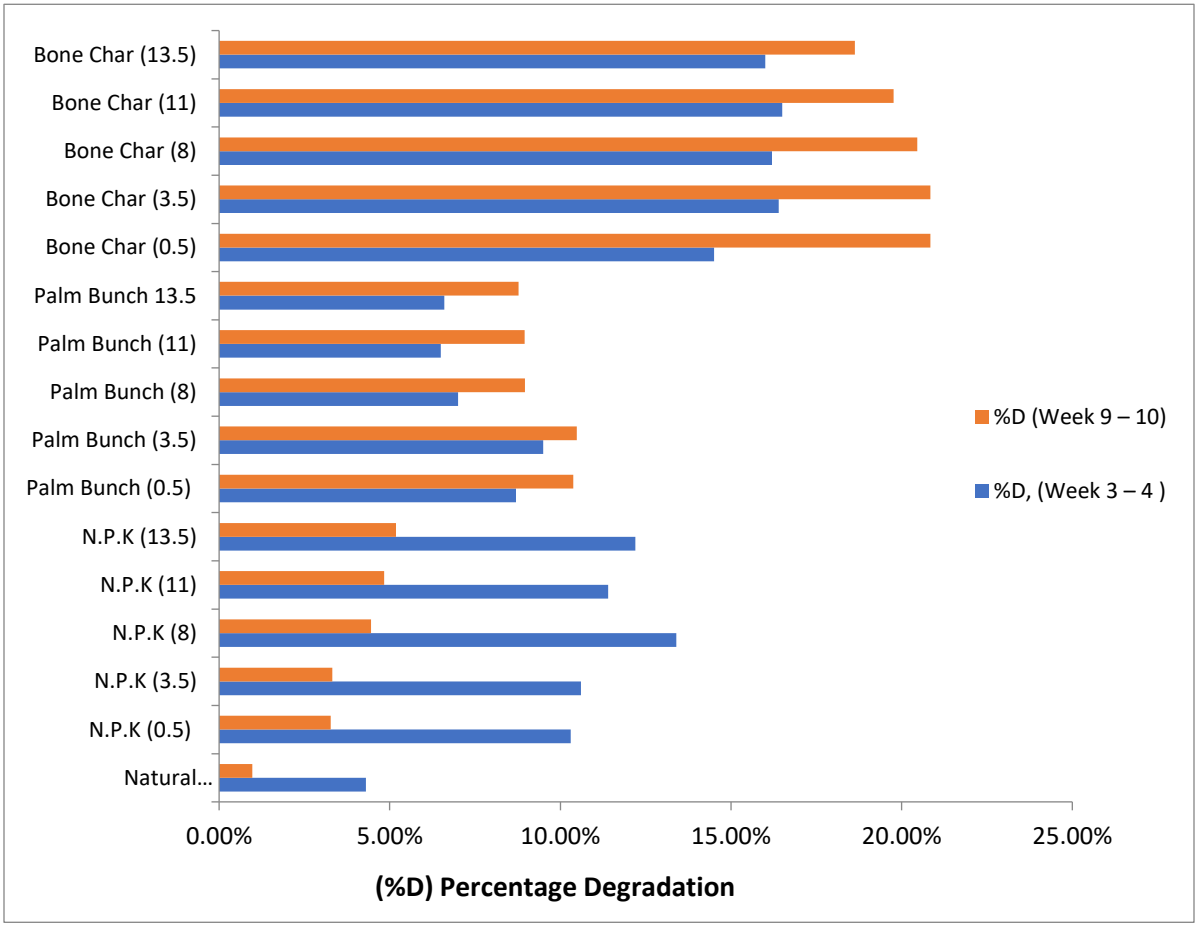

Figure 12: A Bar Chart Showing %D of Samples Treatment with NPK, Palm Bunch, Bone Char, Natural Attenuation for Week 3-4, and Week 9-10.

First Order Degradative Process of Total Hydrocarbon Content (THC)

The 'first order kinetics' was applied in the study of the kinetics of Total Hydrocarbon Content (THC) degradation, which proposes that rate of change of substrate is directly proportional to substrate concentration. High degradation rate is denoted by High K value. The first order kinetics model was used in finding degradation level of total hydrocarbon carbon (THC) content in polluted soil. The following result from Figure 13 to was gotten for the Total Hydrocarbon (THC) for a period of eight (10) weeks for various amendments proportions.

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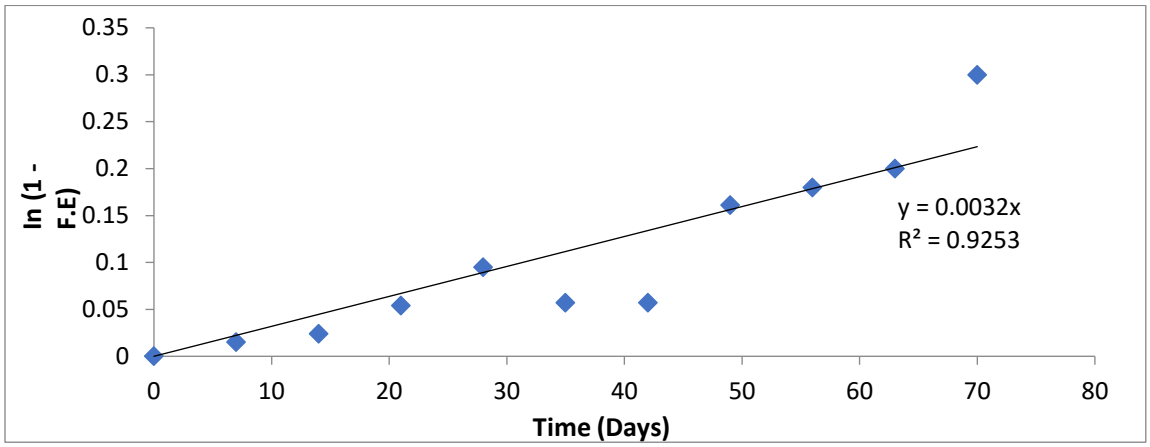

Figure 13: First Order Kinetics pattern of THC reduction for Natural Attenuation

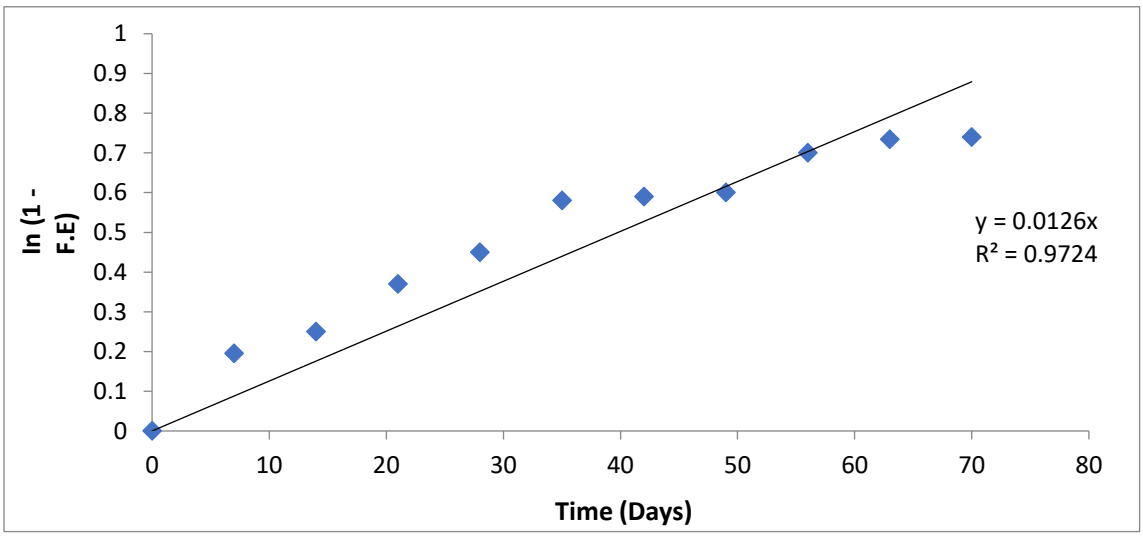

Figure 14: First Order Kinetics pattern of THC reduction for NPK (0.5kg)

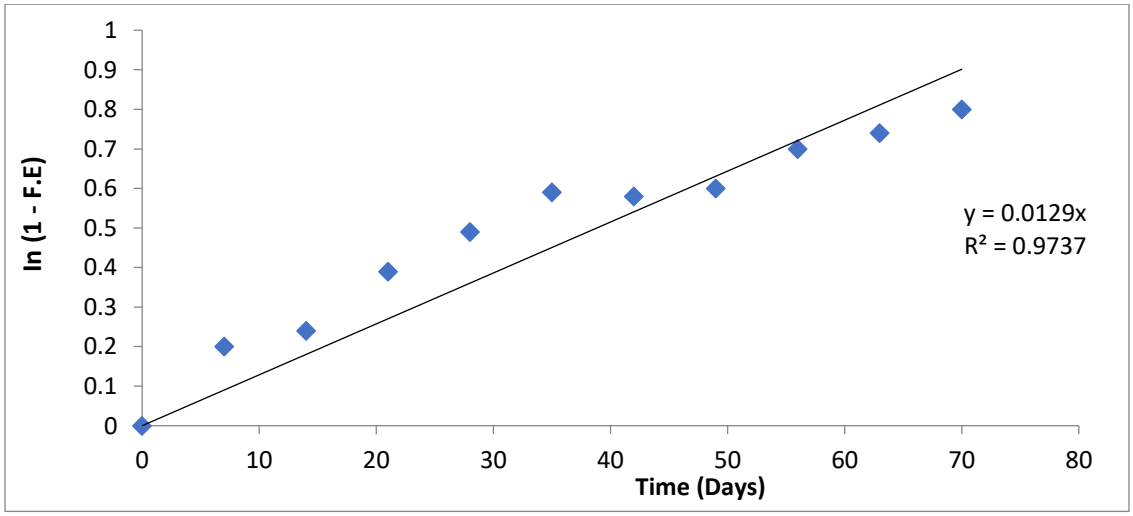

Figure 15: First Order Kinetics pattern of THC reduction for NPK (6.5kg)

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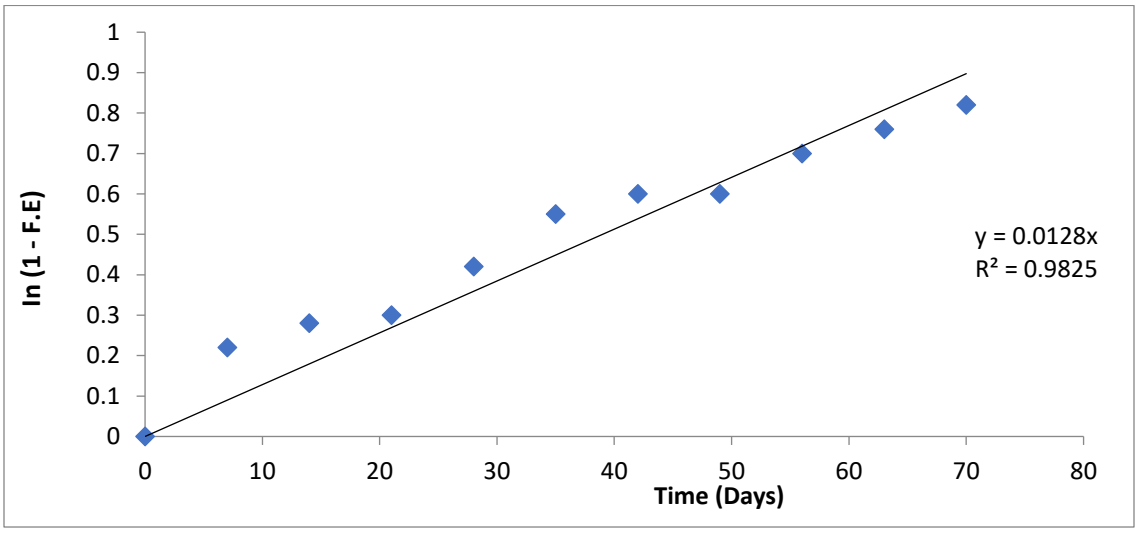

Figure 16: First Order Kinetics pattern of THC reduction for NPK (13.5kg)

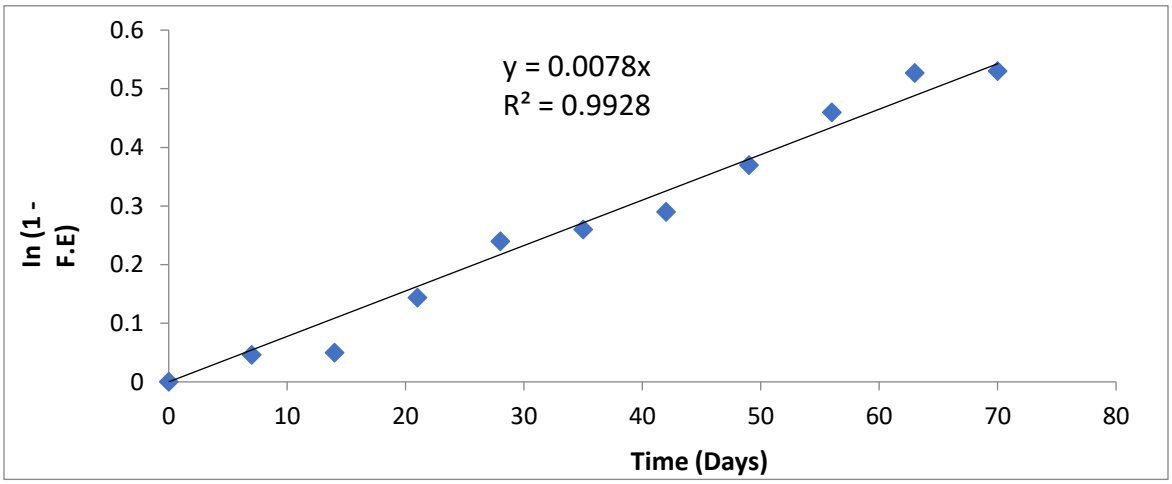

Figure 17: First Order Kinetics pattern of THC reduction for Palm Bunch(0.5Kg)

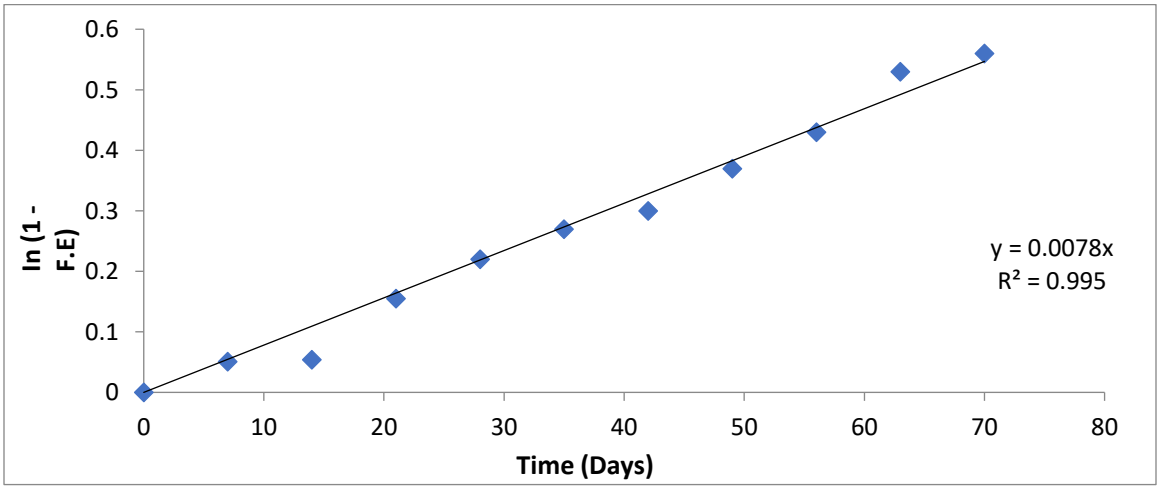

Figure 18: First Order Kinetics pattern of THC reduction for Palm Bunch(6.5Kg)

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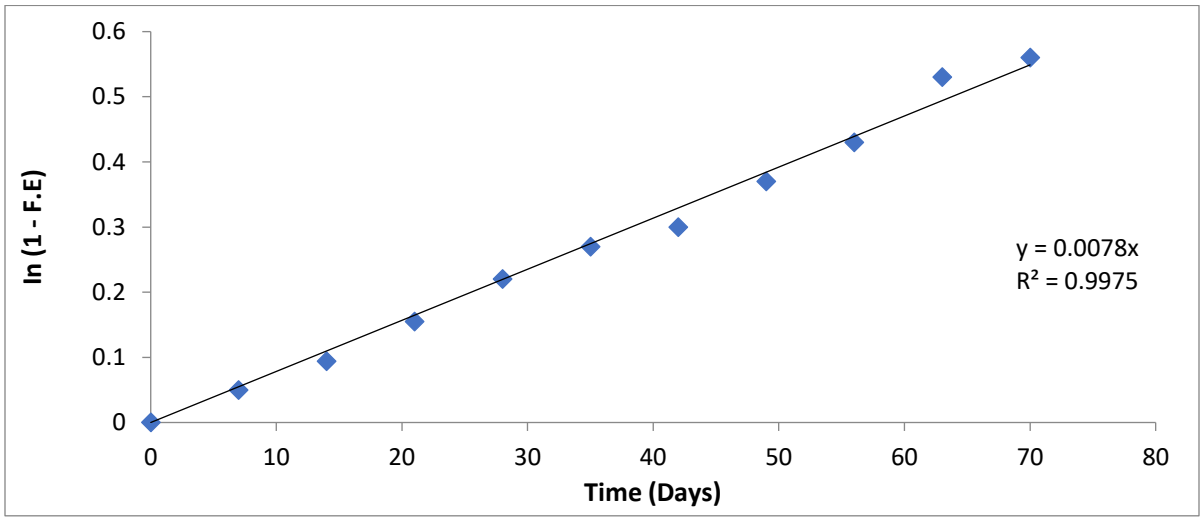

Figure 19: First Order Kinetics pattern of THC reduction for Palm Bunch (14.0Kg)

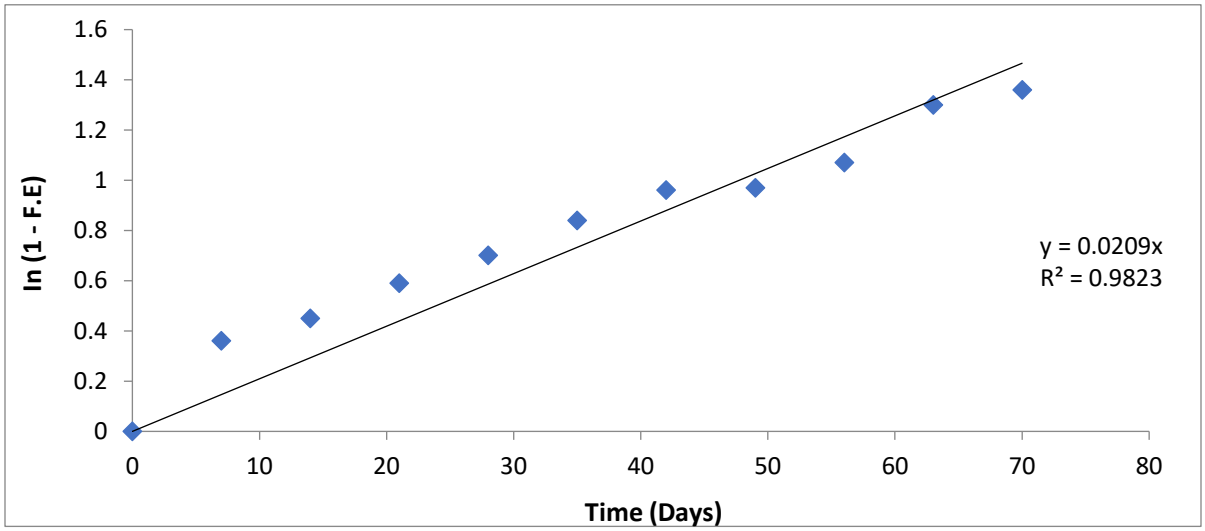

Figure 20: First Order Kinetics pattern of THC reduction for Bone Char (0.5Kg)

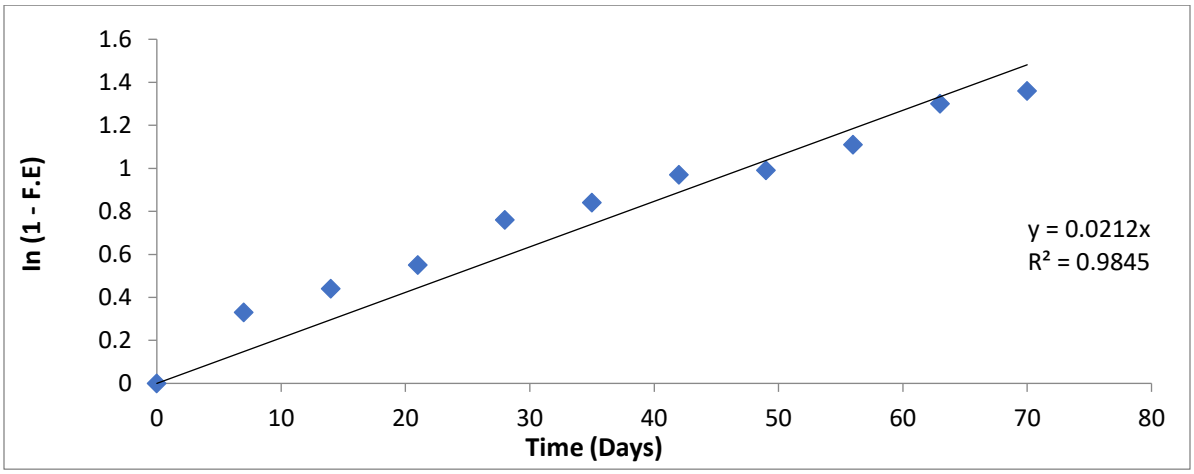

Figure 21: First Order Kinetics pattern of THC reduction for Bone Char (6.5Kg)

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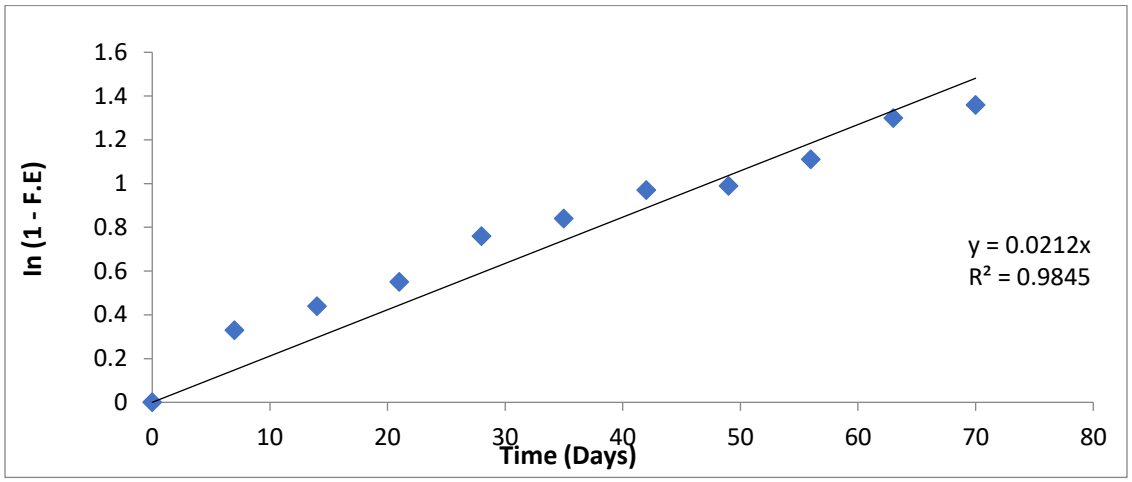

Figure 22: First Order Kinetics pattern of THC reduction for Bone Char (14.0Kg)

Table 6: Total Hydrocarbon (THC) First Order Decay Equation, Bio-Degradation Rate Constant, Half Life, Percentage Degradation, Biostimulation Efficiency and Correlation of Determination of Various Samples.

Samples	Treatments (Kg)	Kinetics Equation	% Degradation	B.E (%)	K (day^{-1})	Half Life	R^2
1	Natural Attenuation	y = 0.0003x	4.3	-	0.0022	315.06	0.9929
2	NPK (0.5)	y = 0.012x	10.6	58.25	0.0120	57.76	0.9901
3	NPK (6.5)	y = 0.012x	11.4	67.67	0.0120	57.76	0.9968
4	NPK (13.5)	y = 0.012x	12.2	64.75	0.0120	57.76	0.9658
5	Palm Bunch (0.5)	y = 0.007x	10.7	50.57	0.0070	99.02	0.9742
6	Palm Bunch (6.5)	y = 0.007x	10.15	55.20	0.0070	99.02	0.9933
7	Palm Bunch (13.5)	y = 0.007x	8.77	50.97	0.0070	99.03	0.9625
8	Bone Char (0.5)	y = 0.02x	20.84	79.33	0.0200	34.66	0.9120
9	Bone Char (6.5)	y = 0.021x	19.76	79.37	0.0210	33.01	0.9250
10	Bone Char (13.5)	y = 0.018x	18.63	76.92	0.0180	38.51	0.8820

K = Bio-Degradation Rate Constant
B.E (%) = Biostimulation Efficiency
% D = Percentage Degradation
R^2 = Correlation of Determination

Data Analysis for First Order Degradative Process of THC in the Samples

Table 6 shows a positive correlation between THC degradation in petroleum-contaminated sludge and time, as indicated by the coefficient of determination (R squared)). There are different rate constants for the samples and it is noted that smaller the rate constant the bigger the half-life. The table 7 shows the different rate constant and half-life for each treatment cells.

Table 7: First order degradative process Total Hydrocarbon Content (THC) degradation positions of the various samples.

Samples	Treatments (kg)	Rate Constant	Half Life	B.E (%)	Position
9	Bone Char (6.5)	79.37	33.01	0.0210	1st
8	Bone Char (0.5)	79.33	34.66	0.0200	2nd
10	Bone Char (13.5)	76.92	38.51	0.0180	3rd
3	NPK (6.5)	67.67	57.76	0.0120	4th
4	NPK (13.5)	64.75	57.76	0.0120	5th
2	NPK (0.5)	58.25	57.76	0.0120	6th
6	Palm Bunch (6.5)	55.20	99.02	0.0070	7th
7	Palm Bunch (13.5)	50.97	99.02	0.0070	8th
5	Palm Bunch (0.5)	50.57	99.03	0.0070	9th
1	Natural Attenuation	-	315.06	0.0022	10th

The descending order for remediation of THC degradation is given as: Sample 9> sample 8> sample 10> sample 3 > sample 4> sample 2 > sample 6 > sample 7 > sample 5 > and sample1

V. CONCLUSION

This comparative study demonstrates that bone char, spent palm bunch, and NPK fertilizer all significantly enhanced degradation of total hydrocarbon content (THC) in Bonny Light crude oil-polluted soil relative to natural attenuation ($p < 0.05$ across all treatments) over the 10-week remediation period. Bone char was the most effective amendment, achieving the highest biodegradation rate constant (0.021 day^{-1}), shortest half-life (33.01 days), and greatest biostimulation efficiency (79.37%), attributable to its superior phosphorus, calcium, and cation-exchange capacity. NPK fertilizer produced intermediate results, while spent palm bunch, despite high organic carbon content, degraded THC most slowly among the active amendments. Degradation did not scale linearly with dosage: intermediate application rates (~6.5 kg) consistently outperformed both lower and higher concentrations, indicating an optimal nutrient threshold beyond which additional input offers no further benefit. As overall percentage degradation remained below 25% within the study window, biostimulation should be regarded as an effective accelerant rather than a complete remediation solution. These findings support bone char as a low-cost, regionally available alternative to inorganic fertilization for hydrocarbon bioremediation in Niger Delta tropical, oil-impacted soils, warranting field-scale and microbial-mechanistic validation.

Future work should prioritize field-scale validation under variable climatic and hydrological conditions, microbial community profiling to elucidate the taxa and enzymatic pathways driving bone char's superior performance, and economic life-cycle comparisons to support scale-up of bone char-based remediation as a practical, sustainable option for petroleum-impacted soils in resource-constrained settings.

REFERENCES

[1] S. A. Adebusoye, M. O. Ilori, O. O. Amund, O. D. Teniola, and S. O. Olatope, "Microbial Degradation of Petroleum Hydrocarbons in a Polluted Tropical Stream," *The Journal of American Science*, vol. 2, no. 3, 2007.

[2] M. J. Ayotamuno, R. B. Kogbara, and J. C. Agunwamba, "Bioremediation of Petroleum Hydrocarbon Polluted Agricultural Soil at Various Levels of Soil Tillage in Port Harcourt,

Nigeria," *Nigerian Journal of Technology*, vol. 25, pp. 44–55, 2025.

[3] E. R. Daka, M. Moslen, C. A. Ekeh, and I. K. E. Ekweozor, "Sediment Quality Status of Two Creeks in the Upper Bonny Estuary, Niger Delta, in Relation to Urban/Industrial Activities," *Bulletin of Environmental Contamination and Toxicology*, vol. 78, pp. 515–521, 2007, doi: 10.1007/s00128-007-9151-5. Springer

[4] I. Elinskiy, R. M. Akhmedov, and Y. A. Ivanova, "The problem of environmental pollution in oil production: Topical issue," *Vestnik of Moscow University of the Ministry of Internal Affairs of Russia*, no. 7, pp. 118–122, 2020, doi: 10.24411/2073-0454-2020-10397. Crossref

[5] D. B. Ikiogha, I. J. Otaraku, O. L. Y. Momoh, and M. O. Welcome, "Comparative Effects of Bone Char and NPK Agricultural Fertilizers on Hydrocarbon Utilizing Bacteria and Fungi in Crude Oil Polluted Soil," *American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)*, vol. 55, pp. 35–49, 2019.

[6] D. Jones, D. Health, M. Hagley, M. Jones, S. Petch, R. Milne, R. Croxford, and K. Lee, "A field Demonstration of the efficacy of Bioremediation to treat oiled shorelines following the sea Empress incident," *Environmental Technology*, vol. 20, p. 862, 1999.

[7] H. Pathak, A. Vashishtha, P. K. Jain, A. Nagmani, D. P. Jaroli, and P. Jain, "Physico-chemical properties of Petroleum contaminated soil collected from coastal areas of Mumbai," *Asian Journal of Experimental Sciences*, vol. 24, no. 1, pp. 175–178, 2010.

[8] D. V. Venosa, "Bioremediation in Oil spill response," 2012. Accessed: Jul. 27, 2013.

[9] A. D. Venosa and X. Zhu, "Biodegradation of crude oil contaminating marine shorelines and freshwater wetlands," *Spill Science & Technology Bulletin*, vol. 8, no. 2, pp. 163–178, 2003, doi: 10.1016/S1353-2561(03)00019-7. ScienceDirect

[10] Y. Wang, J. Feng, Q. Lin, X. Lyu, X. Wang, and G. Wang, "Effects of Crude Oil Contamination on Soil Physical and Chemical Properties in Monaoge Wetland of China," *Chinese Geographical Science*, vol. 23, no. 6, pp. 708–715, 2013.