

Bioremediation Potential of Compost and Biochar on Total Hydrocarbon and Heavy Metals Concentration in Crude Oil Contaminated Soil

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Abstract- Crude oil contamination of soils in the Niger Delta has led to severe loss of soil fertility, reduced crop productivity and groundwater pollution. This study evaluated the bioremediation potential of compost (CP) and biochar (BC) on total hydrocarbon and heavy metals concentration in crude oil contaminated soil. Hydrocarbons can easily find their way to the soil's ecosystem through a lot of sources. People living in oil-rich areas experience lots of oil pollution in their environment and this has been a major concern. The experiment was laid out in a Completely Randomized Design (CRD) with 9 treatments. The remediation materials compost and biochar were prepared on and offsite respectively. The soil was collected from Igbo-Etche following standard procedure. It was artificially contaminated with 200ml of Bonny light crude oil and allowed to stand for 10 days. The amendments were applied in two (2) rates namely: 40 tonnes/hectare and 100 tonnes/hectares for biochar while compost was 60 tonnes/hectare and 100 tonnes/hectare. The moisture content of soil was maintained at field capacity for 60 days. All samples were transferred into appropriately labeled polyethylene bags and taken to the laboratory for analysis. The soil samples were spread out individually to air dry. This was followed by crushing which was done using a cylindrical crusher and sieving was done using a 2mm mesh size sieve. The result showed Zinc content in the soil increased significantly from 0.10 mg/kg to 2.66 mg/kg upon contamination. After amendment, BC1+CP0 had the lowest as 1.45 mg/kg. Copper content in the soil increased from 1.27 mg/kg to 2.12 mg/kg. Treatment BC1+CP1 had 1.45 mg/kg as the least. There was a significant difference ($P < 0.05$) among treatment means. Iron content had significant difference ($P < 0.05$) among treatment means. The study concluded that organic amendments significantly reduced THC and the studied heavy metals (Zn, Cu and Fe). However, THC reduction was highest in BC2+CP0 as 87.66 mg/kg. For heavy metals, biochar alone gave the least available Zn, while biochar + compost

gave the least available Cu (BC1+CP1 – 1.58 mg/kg) and Fe (BC1+CP2 – 1.39 mg/kg) due to adsorption, complexation and pH increase. This confirms that organic amendments are effective for remediation of crude oil contaminated soils.

Keywords: Hydrocarbon, Amendment, Contamination, Biochar and Compost.

I. INTRODUCTION

Hydrocarbons can easily find their way to the soil's ecosystem through a lot of sources. Unlike other chemicals (notably pesticides) hydrocarbons were generally not applied to soils for a purpose and thus hydrocarbon contamination results almost entirely from accidents. The source that is probably most familiar to persons involved in the study of contaminated sites is leakage from underground storage tanks. This is particularly important at the site of former petrol stations and the hydrocarbons involved are generally in the gasoline range. Other major sources include spillage during refueling and lubrication (notably in places such as railway yards), the hydrocarbons here being within the diesel and heavy oil range. Places in which transfer and handling of crude oils takes place (such as tanker terminals and oil refineries) are also potential places of contamination, the oil being largely of the heavier hydrocarbon type. Shale oil retorting plants makes another source of hydrocarbon contamination as do coal gasworks sites, particularly those at which "benzole recovery" was exercised (Ross and Des 2003).

Heavy metals are released into the environment by both natural and anthropogenic sources. The main natural sources of metals in soil, water and air are chemical weathering of minerals. The existence of total petroleum hydrocarbons and heavy metals in soil and water has led to serious concerns about their influence on plant and animal life. Total petroleum hydrocarbons (TPH) are a term used to describe a large family of several hundred chemical compounds that originally come from crude oil. Crude oil is used to make petroleum products, which can contaminate the environment while heavy metals is used to describe more than a dozen elements that are metals or metalloids e.g. chromium, arsenic, cadmium, lead, mercury, manganese, copper etc. Heavy metals are natural constituents of the Earth's Crust; they are persistent and non-degradable in all parts of the environment (Hassan *et al.*, 2013). Crude oil alters soil physical, chemical and biological properties, leading to poor aeration, hydrophobicity, nutrient immobilization, increased acidity and death of soil microorganisms, resulting in total loss of soil fertility (Udo and Fayemi, 1975; Ayotamuno *et al.*, 2006). Conventional remediation methods such as excavation and incineration are expensive and not sustainable for agrarian communities. Bioremediation, which uses biological agents to degrade pollutants, is a cost-effective and eco-friendly alternative (Abioye *et al.*, 2012). Organic amendments such as compost and biochar have been reported to enhance bioremediation through two mechanisms: biostimulation (supplying nutrients and microorganisms) and bioaugmentation (improving soil conditions for degraders) (Akinbile *et al.*, 2017). Compost provides N, P, K and diverse hydrocarbon-degrading bacteria and fungi, while biochar, produced from pyrolysis of biomass, has high porosity, high CEC, high surface area and ability to adsorb hydrocarbons and improve soil pH and water holding capacity (Lehmann and Joseph, 2015). Despite several studies on either compost or biochar, limited information exists on their potential for Bonny Light crude oil contaminated soils.

The main objective of this research was to evaluate the bioremediation potential of compost and biochar on crude oil-contaminated soil.

II. LITERATURE REVIEW

Crude oil contamination of Agricultural Soils

The rapid growth in industrial, agricultural, and municipal activities, together with the unprecedented global population growth rate, has led to a high demand for petroleum production. Global demand for petroleum products is expected to reach 100.90 million barrels per day. Petroleum industrial activities, such as drilling, exploration, storage, transportation, processing, and refining, are major sources of petroleum hydrocarbon spillage, which leads to terrestrial oil pollution that generally contains hydrophobic compounds. The spillage of petroleum hydrocarbons (PHCs) into the environment is a critical hazard to ecosystems, and can pose serious human health and environmental problems (Mekonnen, 2024). The annual crude oil leakage into the environment is estimated to be 0.6 Mt. PHCs are fundamentally composed of carbon and hydrogen, and their pollution in the soil results in a disproportion of the C/N fraction at the spill site. This causes nitrogen deficit and hinders soil fertility and microbial activity. PHCs are fundamentally composed of carbon and hydrogen, and their pollution in the soil results in a disproportion of the C/N fraction at the spill site. This causes nitrogen deficit and hinders soil fertility and microbial activity. Moreover, immense quantities of biodegradable organic compounds in the top layer of the soil deplete oxygen reserves and decelerate the degree of oxygen diffusion into deeper layers. Therefore, the remediation of PHC-contaminated soils is presently a significant task, and it is vital to develop eco-friendly and effective approaches to uphold soil ecosystems (Mekonnen, 2024). The toxicity of crude oil depends largely on the chemical and physical properties of the particular type of crude oil and the quality of the contaminated water or soil. During migration, the released hydrocarbons penetrate soil capillaries that were previously filled with water or air and bind to soil particles or to minerals in the interstitial spaces of the soil. All these regions are ecologically damaged as both air and water are excluded from the soil microenvironment (Okafor, 2023).

PHC (petroleum hydrocarbons) is widely used to refer to the hydrogen and carbon-containing compounds

that originate from crude oil. TPH (total petroleum hydrocarbons) refers to the measurable amount of petroleum-based hydrocarbons in an environmental matrix. Thus, whilst PHC deals with an absolute and somewhat intangible quantity, TPH pertains to actual results obtained by sampling and analysis. As mentioned above, in its strictest sense, TPH pertains to a mixture and hence the results of simple TPH analysis are not of great help in terms of risk assessment (Ross and Des 2003).

Heavy metal concentration in crude oil contaminated soil

The issue of heavy metal pollution in soil has prompted the implementation of a wide variety of responses. In order to rid soil of heavy metals, scientists are considering utilizing biochar. In a study conducted by Meier *et al.*, (2017), it was revealed that inclusion of 5% biochar derived from chicken dung resulted in a reduction of Cu uptake by *Oenothera picensis* plants in Copper (Cu)-mine-polluted soil.

Heavy metals are released into the environment by both natural and anthropogenic sources. The main natural sources of metals in soil, water and air are chemical weathering of minerals. The existence of total petroleum hydrocarbons and heavy metals in soil and water has led to serious concerns about their influence on plant and animal life. Total petroleum hydrocarbons (TPH) are a term used to describe a large family of several hundred chemical compounds that originally come from crude oil. Crude oil is used to make petroleum products, which can contaminate the environment while heavy metals is used to describe more than a dozen elements that are metals or metalloids e.g. chromium, arsenic, cadmium, lead, mercury, manganese, copper etc. Heavy metals are natural constituents of the Earth's Crust; they are persistent and non-degradable in all parts of the environment (Hassan *et al.*, 2013).

Soil Amendments

Soil amendments are used in agriculture to support plant growth and development, specifically by adding organic and inorganic nutrients to the soil, and improving soil tilth, organic matter, and water holding capacity (Donna *et al.*, 2019).

Organic soil amendments are known to improve soil structure and increase soil OM content, thereby enhancing soil's ability to hold nutrients and moisture. This in turn contributes to improved plant growth and health. In addition, certain organic soil amendments, such as biochar, compost, and animal wastes, have been recognized as PTE immobilizing agents because of their abilities to restrain PTEs through different mechanisms (Ahmad *et al.*, 2017; Park *et al.*, 2011; Shaheen *et al.*, 2017).

Organic amendments

The addition of organic amendments such as compost or manure to soils has been shown to improve soil function by increasing water holding capacity, porosity, and surface area (Cogger, 2005; Zhang, 1994). Organic amendments can help to stabilize soil structure (Thomas *et al.*, 1996) and decrease soil bulk density (Db) (Curtis and Claassen, 2009), thereby providing an environment that will allow for the growth of healthy root systems.

Biochar

Biochar, a product formed by pyrolysis of organic waste, which is rich in carbon, has the aptitude to ameliorate climate change by sequestering carbon while also enhancing soil quality and crop yields. Two-edged implications of biochar on soil amendment are still being discussed yet; clarity on the long-term implications of biochar on soil health and the environment is not yet achieved. As a result, it is crucial to systematically uncover the pertinent information regarding biochar remediation, as this can serve as a roadmap for future research on using biochar to remediate contaminated soils in mining regions (Thanh-Binh, 2023).

Biochar can immobilize PTEs in contaminated soils while improving soil quality and can significantly reduce crop uptake of PTEs (O'Connor *et al.*, 2018c; Palansooriya *et al.*, 2019b). However, increased PTE mobilization in soil can also result after biochar application depending on the type of biochar, soil conditions, and PTE species (Igalavithana *et al.*, 2017b; Shaheen *et al.*, 2019c). Therefore, selecting a type of biochar suitable for remediating soils contaminated with multiple PTEs requires careful examination.

III. COMPOST

Incorporation of approximately 33% compost by volume into degraded soil has been proven to improve soil health and structure over time while avoiding the financial and environmental costs of importing soil mixes from elsewhere. Composting is a process of humifying and stabilizing organic waste, in which microbial and enzyme activities accelerate organic waste degradation, converting it into humic substances, mineral ions, CO₂, and H₂O through mesophilic, thermophilic, and maturation phases (Białobrzewski et al., 2015; Lu et al., 2014). However, additions of high volumes of compost could potentially increase the risk of nutrient loss through leaching and runoff (Heyman, *et al.*, 2019).

Composting is an ex situ technology designed to treat excavated soils impacted by a range of recalcitrant contaminants, including nitroaromatic and nitramine explosive compounds. The process involves mixing contaminated soil with bulking agents such as wood chips, straw, hay or alfalfa, and organic amendments such as cattle and/or chicken manure, or other vegetative wastes.

The selection of specific compost ingredients depends on the contaminants to be treated, the physical/chemical characteristics of the soil, and the availability of low-cost organic amendments. The goal is to achieve the desired bulk density, porosity, and organic amendments that can provide the proper

balance of carbon and nitrogen (C/N ratio) to promote biological activity in the compost. For most composting applications, it is necessary to provide amendments that will support mesophilic or thermophilic microbial activity (USEPA, 2002).

Composting is a biological remediation technology that exploits the activity of a diverse range of microorganisms to degrade target contaminants. The biological activity is enhanced through the addition of readily degradable amendments to provide a sufficient supply of nutrients.

IV. MATERIALS AND METHODS

The experiment was carried out at the high tunnel hoop house of the Teaching and Research Farm of the Rivers State University (R.S.U) in Port Harcourt.

The study area is located at longitude "N4° 48' 14.1" and latitude E60 58'34.8 and on the elevation of 15m above sea level. It is located in the humid forest zone of Southern Nigeria with the annual rainfall of above 2400mm usually in a monomodal distribution which lasts from March to November. There is usually a dry period from December to March with little or no rain. The wettest months are between July and October (Ikpe *et al.*, 2003).

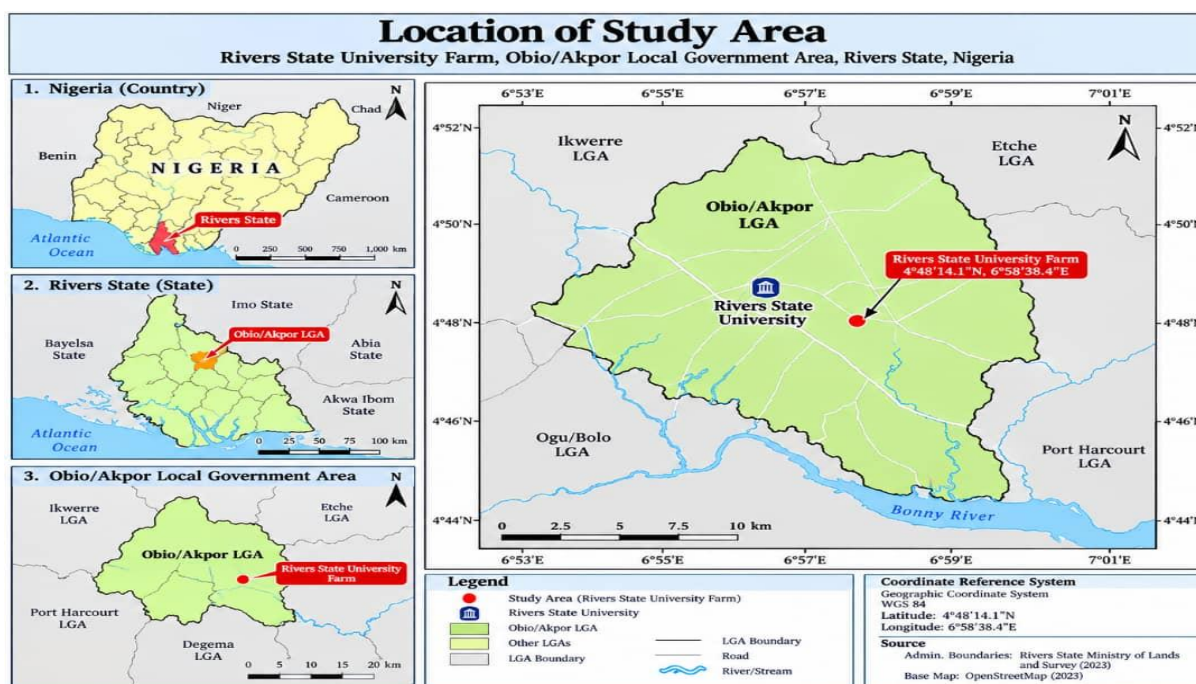


Fig 1: Map showing the study area

The experiment was a Complete Randomized Design (CRD) which consisted of nine (9) treatments. These treatments were replicated three (3) times. The treatments were:

Biochar (BC1) = 40ton/ha
 Biochar (BC2) = 100ton/ha
 Compost (CP1) = 60ton/ha
 Compost (CP2) = 100ton/ha
 BC1+CP1, BC1+CP2, BC2+CP1, BC2+CP2, and BC0 + CP0

Compost: This was prepared using saw dust, plantain peels, yam peels as well as spoilt parts of whole yam, egg shells, fruit peels such as orange, pineapple, watermelon and yard trimmings (grasses and ornamental plants) at the experimental site for 60 days. The constituents of this preparation was watered and turned thrice weekly with a shovel and rake.

The compost heap was started on a bare soil to allow beneficial organisms to colonize the composting materials. A layer of carbon-rich material such as saw dust, were first added. Another layer of nitrogen-rich material such as fruit and vegetable scraps was also

added. Finally a layer of soil was spread and the heap was watered. The above layers were repeated until the materials were exhausted. This was done following the procedure according to Kugbe *et al.*, 2021.

Biochar: This was achieved through the pyrolysis of wood. A cone-like shape was dug in the soil and the wood where introduced and heated. The biochar was cooled to room temperature and crushed with a stainless steel mill and passed through a 2mm mesh size sieve for routine analysis.

Soil sample collection

Top soil (plough layer) was gotten from a farm in Igbo-Etche, Etche Local Government Area of Rivers State. The standard sampling procedure was followed; a V shape to the plough layer was dug. This was done randomly and composited (bulked) to achieve a uniform sample. These bulked samples were bagged and weighed to 15kg each. The bagged soil samples were taken to the experimental site.

Contamination of soil sample

The soil samples were contaminated with 200ml of crude oil which represents 1.3% v/w contamination.

This was achieved firstly by spreading out the soil on paper which was placed on a flat leveled surface and a hole made in the middle. Secondly 200ml of crude oil was measured using a measuring cylinder, poured into the hole made and mixed thoroughly by hand as shown in plate 5. After mixing, the 15kg soil was put back in the bag and the process repeated for all the sample. The contaminated soils were kept at field capacity for 10days.

Soil amendment application: The contaminated soil samples were amended after 10 days contamination. The soil amendments which were biochar and compost already prepared were applied in two (2) rates. For the biochar, 300g being the first rate at 40tonnes/ha representing 20% v/w was applied as well as 750g at 100tonnes/ha representing 50% v/w which was the second biochar rate. These biochar rates were applied

singly and in combination with compost in a 1:1 ratio. The compost was applied singly at a rate of 60tonnes/ha (450g) representing 30% v/w and a second rate of 100tonnes/ha (750g) representing 50% v/w.

The contaminated soil samples were transferred to a large bowl where the amendments were applied and mixed thoroughly by hand then transferred back to the bag. This was repeated for all samples and arranged in three replicates. The moisture content of the soil was maintained at field capacity for 60 days of incubation which aligns with the work of Salu *et al.*, (2023) on the potential of biochar for hydrocarbon degradation of crude oil-contaminated soils. Cultural practices such as watering and weeding were carried out.



Plate 1: Compost pile

Laboratory Analysis

Heavy Metals Determination: Heavy metals (Fe, Cu, Zn) was analyzed using Atomic Adsorption Spectrometer (AAS) by GBC Avanta version 2.20 following standard procedure. **Digestion or extraction:** A nominal weight (0.5 g or 1.0 g) is accurately weighed to 0.1 mg accuracy and transferred to a digestion vessel (microwave digestion tube or beaker). A volume of concentrated acid (nitric) or a combination of nitric and hydrochloric acids is carefully added to the sample and digested. On completion of the prior step, the digestate is quantitatively transferred to a fixed volume (50 or 100

ml). A portion is filtered and introduced for analysis by inductively coupled plasma-optical emission spectrometry (ICP-OES) or atomic absorption spectroscopy (AAS) technique for the detection of the metal(loid)s.

Total Hydrocarbon Content: Residual oil in soil was extracted using the conventional soxhlet extraction method. About 15g of dry soil was placed in a cellulose thimble mixed with 2g anhydrous magnesium sulfate to remove the moisture. The thimble and its contents were extracted with dichloromethane for 16hours in a soxhlet apparatus.

The extraction efficiency of oil from soil was calculated using the formular

$$\text{Oil yield} = \frac{\text{wt of oil extracted}}{\text{wt of soil}} \times 100$$

Equation 1

The extract was condensed to 1ml in a rotary evaporator and fractionated by silica gel column chromatography to separate the different fractions of crude oil. The components of hydrocarbons in extracted oil were analyzed by GC-MS (Agilent 6890NGC) equipped with MS, GC column (DB-5MS 3 x 0.25mm and 0.25micron)

Statistical Analysis of Data

Data was summarized in an excel spread sheet and analyzed using SPSS Software. Significant means were analyzed using Analysis of Variance (ANOVA). Pearson's correlation was performed using SPSS.

V. RESULTS AND DISCUSSION

Chemical properties of soil organic amendments.

The results showed relatively high pH values of 7.41 and 8.2 for compost and biochar respectively. A C/N ratio of 12.02 for the compost was calculated. Organic Matter, Sodium and Magnesium levels were higher in biochar as compared to compost with values such as 30.38%, 286.15cmolkg⁻¹ and 15.1cmolkg⁻¹ respectively. In compost, calcium and potassium content were higher than in biochar with values such as 47cmolkg⁻¹ and 42.11cmolkg⁻¹ respectively.

The pH value (7.41) of compost as shown on Table 1 was in line with work of Khater (2012) who used herbal plant residues and obtained 7.6. He further stated that the pH falls in the optimum range for growing media. However, according to this work the feedstocks (saw dust and egg shells) may have contributed to the slightly alkaline pH. In general, pH value changes throughout the composting process due to changes in chemical composition as materials decompose. The composition of the compost can greatly determine its value. Consequently abundant orange peels, pineapple waste, watermelon etc can lower compost pH value thereby tending to acidity.

Conversely, when an adequate amount of saw dust as was done in this work is incorporated it tends to increase the pH. In contrast, a lower pH could be as a result of excess moisture as the system (compost pile) becomes anaerobic (oxygen-deprived). This was however not so according to this work as it was monitored and balanced with addition of saw dust.

The high content of Available Phosphorus with a value of 139mgkg⁻¹. This value was so as a result of the fruit peels and tuber waste used in the preparatory process. The grass clippings and flower trimmings contributed greatly to the Total nitrogen content of 0.467%.

The high sodium content in both compost and biochar is attributed to the concentration effect during decomposition and pyrolysis respectively. Worthy of note is that sodium is a non-volatile element.

Table 1: Chemical properties of soil organic amendments.

Parameters	Bioremediation Materials	
	Compost	Biochar
pH	7.41	8.2
Organic Matter (%)	10.98	30.38
Organic Carbon (%)	5.62	17.62
Nitrogen (%)	0.47	0.52
C/N	11.96	33.89
Available Phosphorus (mgkg ⁻¹)	139.36	118.47
Ca ²⁺ (cmolkg ⁻¹)	47	40.2
Mg ²⁺ (cmolkg ⁻¹)	10.53	15.1
Na ⁺ (cmolkg ⁻¹)	162.64	286.15
K ⁺ (cmolkg ⁻¹)	42.11	32.11

Heavy metals concentration in amended soil

The effect of amendment on heavy metal concentration is shown on Table 2.

ZINC (Zn): Treatment effects on Zn were statistically significant at $P < 0.05$. Contamination raised soil Zn from 0.10 mg/kg to 2.66 mg/kg. Following amendment, concentrations declined across treatments. The minimum value of 1.45 mg/kg was obtained in BC1+CP0.

COPPER (Cu): Significant variation ($P < 0.05$) existed among the treatments. Soil Cu rose from 1.27 mg/kg

to 2.12 mg/kg due to crude oil pollution. After biochar and compost application, the levels dropped. The least Cu content, 1.45 mg/kg, was observed in BC1+CP1.

IRON (Fe): The differences among treatment means were significant ($P < 0.05$). Iron concentration increased from 1.21 mg/kg to 1.92 mg/kg as a result of contamination. Amendment led to a reduction in Fe levels, with BC1+CP1 recording the lowest value of 1.55 mg/kg.

Table 2: Heavy metal concentration in amended soil

TREATMENTS	ZINC (mgkg ⁻¹)	COPPER (mgkg ⁻¹)	IRON (mgkg ⁻¹)
BC1+CP0	0.15 ^f	1.60 ^g	1.44 ^{hi}
BC2+CP0	0.18 ^{def}	1.68 ^{ef}	1.49 ^{gh}
CP1+BC0	0.21 ^d	1.80 ^d	1.55 ^{ef}
CP2+BC0	0.21 ^{cd}	1.82 ^d	1.53 ^{efg}
BC1+CP1	0.15 ^{ef}	1.55 ^g	1.44 ^{hi}
BC1+CP2	0.15 ^{ef}	1.58 ^g	1.39 ⁱ
BC2+CP1	0.18 ^{def}	1.66 ^f	1.48 ^{gh}
BC2+CP2	0.18 ^{def}	1.65 ^f	1.48 ^{gh}
BC0+CP0	2.66 ^a	2.12 ^a	1.92 ^a
WHO LIMITS	44.19	8.39	56.90

Means that do not share a letter on the same column are significantly differently (Tukey HSD at 95%)

Key: BC1+CP0= 300g Biochar only, BC2+CP0= 750g Biochar only, CP1+BC0= 450g Compost only, CP2+BC0= 750g Compost only, BC1+CP1= 300g Biochar + 450g Compost, BC1+CP2= 300g Biochar + 750g Compost, BC2+CP1= 750g Biochar + 450g Compost, BC2+CP2= 750g Biochar + 750g Compost, BC0+CP0= No Biochar + No Compost (Control).

Percentage Heavy Metal removed from soil after amendment

The percentage heavy metal removed from the soil is shown on Table 3.

ZINC (Zn): There was a 94.55% reduction in Zinc concentration after amendment with BC1+CP1. The least reduction was for CP2+BC0 as 92.11%.

COPPER (Cu): Copper recorded the highest % removal with BC1+CP1 as 26.89% and the least was with BC2+CP0 as 20.46%.

IRON (Fe): The highest percentage Fe content removed was recorded for BC1+CP2 as 27.58% while the least was recorded as 19.15% for CP1+BC0.

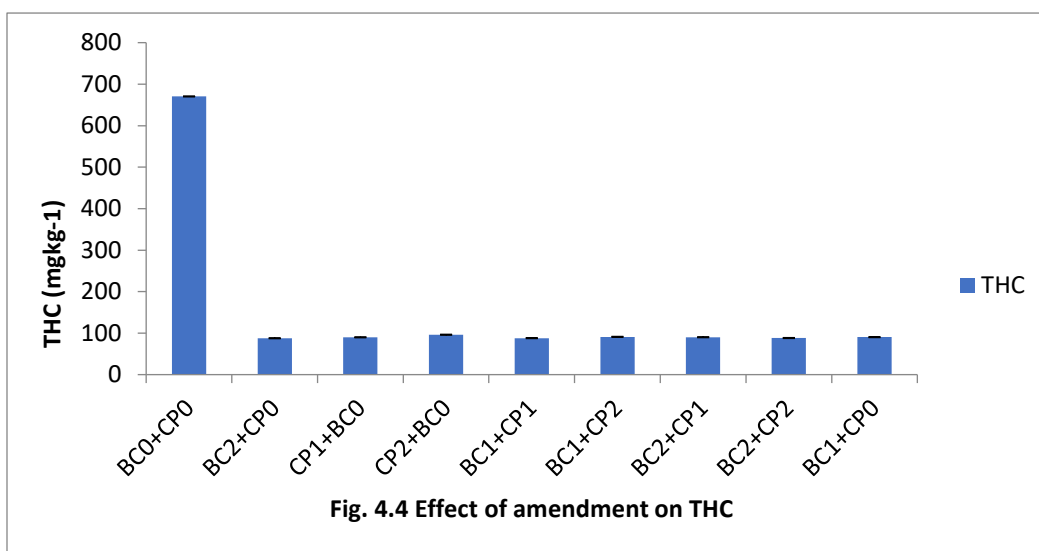
Table 3: The percentage heavy metal removed from the soil after amendment

TREATMENT S	%ZIN C	%COPPE R	%IRO N
BC1+CP0	94.55	24.57	25.08
BC2+CP0	93.39	20.46	22.32
CP1+BC0	92.30	14.98	19.15
CP2+BC0	92.11	13.94	20.34
BC1+CP1	94.25	26.89	25.23
BC1+CP2	94.40	25.33	27.58
BC2+CP1	93.24	21.60	22.84
BC2+CP2	93.31	22.02	23.05
BC0+CP0	0.00	0.00	0.00

Total hydrocarbon content

The effect of amendment on total hydrocarbon content is shown on Fig.1. There was a significant difference ($P < 0.05$) amongst the remediation materials. The result showed BC2+CP0 had the lowest mean value of 87.66mgkg⁻¹ as compared to the control BC0+ CP0 with the value of 670.40mgkg⁻¹.

The total hydrocarbon content showed that BC2+CP0 was statistically different from the control. Biochar function mostly with ability to uptake (sorption) other substances. This can be chemical or physical. Sorption is a major environmental process that has a major impact on pollutant biogeochemistry. In sorption, the surface properties of biochar, which includes surface functional groups (carboxyl, carbonyl, phenolic-OH, ester, aliphatic, aromatic, hydroxyl, amino, and azyl groups), surface charges, and free radicals, are important for the behaviour of the interface between biochar and organic and inorganic pollutants, as it provides important sites for sorption and catalytic degradation of pollutants (Chandola, and Rana, 2023). Conversely, another study by Dike et al. (2022) conclusively stated that biochar co-application generally resulted in higher hydrocarbon removal than sole biochar treatment.



Key: BC1+CP0= 300g Biochar only, BC2+CP0= 750g Biochar only, CP1+BC0= 450g Compost only, CP2+BC0= 750g Compost only, BC1+CP1= 300g Biochar + 450g Compost, BC1+CP2= 300g Biochar +

750g Compost, BC2+CP1= 750g Biochar + 450g Compost, BC2+CP2= 750g Biochar + 750g Compost, BC0+CP0= No Biochar + No Compost (Control).

Heavy metal concentration of amended

All heavy metal concentrations were within permissible level (lower limits). However, Iron was quite low as compared to other literatures such as Adiele, et al., 2015; Isaac et al., 2024 which reported values higher and reported abundance of soluble Iron. All amendments were shown to reduce the total hydrocarbon content. This means the amendments were effective in the remediation of the crude oil contaminated soil. However, the lowest value was for BC2+CP0 which had 750g of Biochar only. Worthy of note is that BC1+CP2 showed a more reduced THC value after planting. This agrees with a 2022 study by Obi-Iyeke, (2022) where it was stated that maize plant has phytoremediation properties.

Biochar's large surface area and cation exchange capacity, enables enhanced adsorption of both organic and inorganic contaminants to their surfaces, reducing pollutant mobility when amending contaminated soils. The combination of composts, manures and other amendments with biochars could be their most effective deployment to soils requiring stabilization by re-vegetation (Beesley, 2011).

Compost bioremediation has proven effective in degrading or altering many types of contaminants, such as chlorinated and non-chlorinated hydrocarbons, wood-preserving chemicals, solvents, heavy metals, pesticides, petroleum products, and explosives. In addition to reducing contaminant levels, compost advances this goal by facilitating plant growth. In this role, compost provides soil conditioning and also provides nutrients to a wide variety of vegetation (USEPA, 1997).

VI. CONCLUSION

The study concluded that organic amendments significantly reduced THC and the studied heavy metals (Zn, Cu and Fe). However, THC reduction was highest in BC2+CP0 as 87.66mgkg⁻¹. For heavy metals, biochar alone gave the least available Zn, while biochar + compost gave the least available Cu (BC1+CP1 – 1.58mgkg⁻¹) and Fe (BC1+CP2 – 1.39mgkg⁻¹) due to adsorption, complexation and pH increase. This confirms that organic amendments are

effective for remediation of crude oil contaminated soils.

This study recommends the use combined amendments: For remediation of crude oil polluted soils, the combined application of biochar and compost (BC1+CP2= 300g Biochar + 750g Compost) is recommended. It gave the best reduction in THC and immobilized Cu and Fe most effectively. Where Zn contamination is a concern, application of biochar alone (BC1+CP0 with a value 0.15mgkg⁻¹) is recommended because it had the highest immobilization capacity for Zn.

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