Effect of Plantain Peel Biochar on Physicochemical Properties of Soil Contaminated with Petroleum Hydrocarbon

Arimieari, L.W.[1*] and Ezeilo, F.E.[2]

[1, 2]*Department of Civil Engineering, Faculty of Engineering, Rivers State University, Port Harcourt, Nigeria.*
**Correspondence author*

***Abstract:* - This study modeled the effect of biochar on soil polluted with petroleum using plantain peel to prepare the biochar by method of local pyrolysis. The soil was collected from an agricultural farm land; it was polluted with petroleum product and mixed properly to achieve proper contamination. A total of five (5) microcosms was setup which included two (2) controls, one containing soil alone and the other containing soil and petroleum (polluted) while the other three (3) included polluted soil containing biochar. The microcosm containing polluted soil with biochar was kept moist by exposure to atmospheric condition for remediation process to take place. Each microcosm was taken to the laboratory after every two weeks for a total of six weeks. The samples were analyzed and results documented, the biochar material was also analyzed to determine its physicochemical properties. The results for T.N show that at the unpolluted stage the soil sample was 0.17, but at pollution level it moved to 2.36 while the biochar is 4.59. At remediation with plantain peel-biochar, T.N was 2.06 close to its natural level and increased at 42 days to 2.21. The analysis for pH shows that at the unpolluted stage the soil sample was neutral, but at pollution its pH level moved towards the Acidic to a pH of 6.0, the biochar itself was having a pH of 8.2. When applied to the polluted soil the pH level at 42 days increased to 8.0 which was close to its natural state. Hydrocarbon Utilizing Bacteria (HUB) was constantly increasing, this is because of its high content in the material. HUB is required so as to reduce the carbon content, bacterial necessary for self-remediation was reduced to the state of pollution, plantain - peel biochar when applied to the soil started restoring these bacterial. The results obtained when compared with the results of the controls proved that petroleum when in contact with the soil can reduce most of its physicochemical properties. Therefore, the use of plantain peel biochar to enhance petroleum biodegradation in the soil could be one of the severally sought bioremediation strategies of remediating natural environment contaminated with petroleum hydrocarbons.**

***Keywords*: Bioremediation, Plantain - Peel Biochar, Petroleum Hydrocarbon**

I. INTRODUCTION

Biochar is charcoal used as a soil amendment which is made from biomass via pyrolysis. Biochar addition to soil is currently being investigated as in situ technology to remediate polluted soil. In particular at sites polluted with a mixture of readily volatile petroleum hydrocarbon biodegradable and more persistent organic pollutants. Biomass-derived charred materials, so-called biochars, have attracted significant research interest due to their carbon storage and climate change mitigation potential [1]. Charred carbonaceous matter is more resilient to microbial degradation than other forms of organic matter, and adding biochars to soils may lastingly store CO_2 captured from the atmosphere in the terrestrial environment [2]. Biochar is recognised as offering a number of benefits for soil health. Many benefits are related to the extremely porous nature of biochar. This structure is found to be very effective at retaining both water and water-soluble nutrients. Biochar can enhance water quality, reduce soil emissions of greenhouse gases, reduce nutrient leaching, and reduce soil acidity. The various effects of biochar can be dependent on the properties of the biochar, as well as the amount applied, and there is still a lack of knowledge about the important mechanisms and properties. Biochar effect may depend on regional conditions including soil type, soil condition (depleted or healthy), temperature, and humidity.

Biochar is a desirable soil material in many locations due to its ability to attract and retain water. This is possible because of its porous structure and high surface area. As a result, nutrients, phosphorus, and agrochemicals are retained for the plants benefit. Plants therefore, are healthier and fertilizers leach less into surface or groundwater. Biochar is the pyrolysis product of biomass. As a soil amendment, biochar can greatly influence various soil properties and processes [3]. With the addition of biochar, the increase of the availability of soil organic matter, the water holding capacity, and the bioavailable nutrition elements can significantly improve the microbial activities and thereby the soil aggregate formation and stability [4]. Reference [5] has reported that the formation of complexes of biochar with minerals, as the result of interactions between oxidized carboxylic acid groups at the surface of biochar particles, should be responsible for the improved soil aggregate stability.

The ability of biochar to serve as a shelter for microbes is also exhibited by the appearance of microbial attachment to its surface [6], and therefore decreasing the rate of microbial leaching in soil [7]. The ability of biochar to serve as a shelter for microbes is also exhibited by the appearance of microbial attachment to its surface [6], and therefore decreasing the rate of microbial leaching in soil [7].

Another physicochemical parameter that influences microbial diversity and activity in the presence of biochar, is pH [8]. Studies have found that the diversity and abundance of bacteria in soils were greater at the neutral pH ranges (6.6–7.3) compared with acidic pH ranges (<6.5) [9], [10]. This effect is dependent on the pH of biochars which differs according to the feed stock, production temperature [6] and the extent of oxidation [11] which generates organic acids. The pH of biochar is commonly in the range from <4 to >12 [1], [12]. Furthermore, while fungi can survive under acidic pH, bacteria mainly survive at neutral or alkaline pH [13]. Therefore, the incorporation of biochar in soils may lead to variations in soil microbial population, by altering the bacteria to fungi ratio, in addition to the prevalence of different genera in the community [6]. One of the concerns regarding the use of biochar for soil remediation is its long-term impact on the persistence of biodegradable pollutants [14].

II. MATERIALS AND METHODS

1) Soil Collection and Experimental Design

Two different soils were collected from the soil surface of a field (0–1m) in Rivers State University, Port Harcourt, Nigeria, one having petroleum hydrocarbon and the soil without petroleum hydrocarbon. After air-drying, soil large macro aggregates were broken down and the soil samples sieved through a 4.75 mm (pore size) sieve and stored in a polythene bag and kept in the laboratory prior to use. The Bonny light crude oil (API, 31.2 and density, 0.8694 kg/l) was obtained from Nigerian National Petroleum Corporation, Port Harcourt, Nigeria. It was exposed to weather atmospheric condition from 9.00 a.m to 3.00 p.m for two weeks with occasional stirring after which it was stored for further use. Plantain peels used for the production of biochar were obtained from plantain roasters in Port Harcourt, Nigeria.

2) Characterization of Soil Sample

The soil sample was characterized for total nitrogen (N), total phosphorus, potassium, chloride ion, moisture content, Cr, Pb, Fe, Cd, HUB and pH according to standard methods. The pH was determined according to the modified method of [15]; total organic carbon was determined by the Walkley – Black chronic acid wet oxidation method and total nitrogen was determined by the semi-micro-Kjeldhal method [16]. Available phosphorus was determined by Brays No.1 method [17] and moisture content was determined by the dry weight method. The Hydrocarbon Utilizing Bacteria (HUB) populations was determined by the vapor phase transfer method [18].

3) Production and Characterization of Biochar

The plantain peels as the preceding material for biochar preparation was well washed with water several times, cut into small sizes, sun dried for two weeks and then oven dried at 110 °C for 3 h. The dried sample was used for black carbon (biochar) preparation. The plantain peel-biochar was prepared in a pyrolysis pot for thermal decomposition of the dried sample and after which it was cooled to room temperature. After cooling, the biochar was being passed through sieve and stored in a refrigerator before use.

4) Soil Phase Experimental Design and Soil Treatment

A total of five (5) microcosms of soil sample (2kg) was setup into 5 different plastic buckets with a volume of about 10L which included two (2) controls, one containing soil alone and the other containing soil and petroleum (polluted) while the other three (3) included polluted soil containing biochar. The microcosm containing polluted soil with biochar was kept moist by exposure to atmospheric condition for remediation process to take place. Each microcosm was taken to the laboratory after every two weeks for a total of six weeks.

5) Determination of Microbial (Hydrocarbon Utilizing Bacteria) Count

Quantification of the Hydrocarbon Utilizing Bacteria (HUB) present in the soil samples was determined at the beginning of the experiment (time zero) and after 14, 28 and 42 days of remediation time by the *pour plate* count technique. Soil samples (10 g) was transferred into sterilized Erlenmeyer conical flasks containing 90 ml of sterile 0.9% (m/v) NaCl solution and then shaken in a shaker for 15 min at 150 rpm. Samples (1 mL) were subjected to a serial 10-fold dilution procedure and cultivated in a nutrient agar medium. Three plates were inoculated for each dilution. The plates were incubated at 30 °C for 48 h and the number of colony forming units (CFU) was counted in each sample. The results were expressed as colony-forming units per gram of dry soil (CFU/g dry soil). All microbiological counts and experiments were carried out in triplicate.

III. RESULTS

1) Physicochemical Properties of Samples

The physicochemical properties considered in this analysis includes; Tennesseee (T.N), Hydrocarbon Utilizing Bacteria (HUB), Cadmium(Cd), Lead (Pd), Chromium (Cr), Phosphorus (P), Calcium (K) and Iron (Fe). The results for the physicochemical properties are shown in Tables 1 – 3.

Table 1 Physicochemical Analysis of Soil at 14 Days

Parameters	Plantain Peel-Biochar Control	Sample Control (Polluted)	Sample Control (Unpolluted)	Remediation with Plantain Peel-Biochar
pH	8.2	6.0	7.0	7.4
Cl^- (ppm)	200	20	20	30
$NaCl^-$ (ppm)	330	33	33	49.5
T.N (%)	4.59	2.36	0.17	2.06
P (mg/kg)	1.193	0.196	0.043	0.171
K (mg/kg)	3.935	1.42	1.03	1.263
Cr (mg/kg)	1.21029	12.35568	5.08710	11.15348
Fe (mg/kg)	1.23945	4.513840	3.10010	4.16963
Pb (mg/kg)	0.01051	9.58261	7.63599	8.69804
Cd (mg/kg)	0.01183	1.05496	0.31854	0.85621
HUB (cfu/ml)	7.18×10^2	5.1×10^4	6.8×10^2	7.42×10^5

The physicochemical properties of the soil, the material and the remediating stage (14 days) of the samples are shown in Table 1 above. The table considers how much the biochar material has affected the soil at a polluted stage. At 14 days the polluted soil sample with biochar has shown some reduction in amount of each property present

Table 2 Physicochemical Analysis of Soil at 28 Days

Parameters	Plantain Peel-Biochar Control	Sample Control (Polluted)	Sample Control (Unpolluted)	Remediation with Plantain Peel-Biochar
pH	8.2	6.0	7.0	7.8
Cl^- (ppm)	200	20	20	30
$NaCl^-$ (ppm)	330	33	33	49.5
T.N (%)	4.59	2.36	0.17	2.36
P (mg/kg)	1.193	0.196	0.043	0.418
K (mg/kg)	3.935	1.42	1.03	1.572
Cr (mg/kg)	1.21029	12.35568	5.08710	9.71193
Fe (mg/kg)	1.23945	4.513840	3.10010	3.87145
Pb (mg/kg)	0.01051	9.58261	7.63599	7.01731
Cd (mg/kg)	0.01183	1.05496	0.31854	0.61041
HUB (cfu/ml)	7.18×10^2	5.1×10^4	6.8×10^2	2.03×10^6

Table 2 presents a further reduction in the physicochemical properties of the material at 28 days remediation time, a careful consideration shows that at this stage the material has bonded strongly with the soil to reduce most of the carbon bond chain that held carbon to soil replacing them with its physicochemical properties.

Table 3 Physicochemical Analysis of Soil at 42 Days

Parameters	Plantain Peel-Biochar Control	Sample Control (Polluted)	Sample Control (Unpolluted)	Remediation with Plantain Peel-Biochar
pH	8.2	6.0	7.0	8.0
Cl^- (ppm)	200	20	20	140
$NaCl^-$ (ppm)	330	33	33	231
T.N (%)	4.59	2.36	0.17	2.21
P (mg/kg)	1.193	0.196	0.043	0.713
K (mg/kg)	3.935	1.42	1.03	2.318
Cr (mg/kg)	1.21029	12.35568	5.08710	5.12648
Fe (mg/kg)	1.23945	4.513840	3.10010	1.93362
Pb (mg/kg)	0.01051	9.58261	7.63599	4.19064
Cd (mg/kg)	0.01183	1.05496	0.31854	0.31153
HUB (cfu/ml)	7.18×10^2	5.1×10^4	6.8×10^2	9.46×10^6

The result after 42 days of remediation shows greatly a decrease in the physicochemical properties of the soil that was introduced into the soil during the petroleum pollution period. Except for HUB that was constantly increasing, this is because of its high content in the material. HUB is required so as to reduce the carbon content, bacterial necessary for self-remediation was reduced to the state of pollution, plantain - peel biochar when applied to the soil started restoring these bacterial.

2) Comparison of Physicochemical Properties of Sample with the Control

Table 4 Comparison of Physicochemical Properties of Sample with the Control

Parameters	Polluted Sample	Soil + Oil+Biochar (14 Days)	Soil + Oil+ Biochar (28 Days)	Soil + Oil+ Biochar (42 Days)
pH	6.0	7.4	7.8	8.0
Cl^- (ppm)	20	30	30	140
$NaCl^-$ (ppm)	33	49.5	49.5	231
T.N (%)	2.36	2.06	2.36	2.21
P (mg/kg)	0.196	0.171	0.418	0.713
K (mg/kg)	1.42	1.263	1.572	2.318
Cr (mg/kg)	12.35568	11.15348	9.71193	5.12648
Fe (mg/kg)	4.513840	4.16963	3.87145	1.93362
Pb (mg/kg)	9.58261	8.69804	7.01731	4.19064
Cd (mg/kg)	1.05496	0.85621	0.61041	0.31153
HUB (cfu/ml)	5.1×10^4	7.42×10^5	2.03×10^6	9.46×10^6

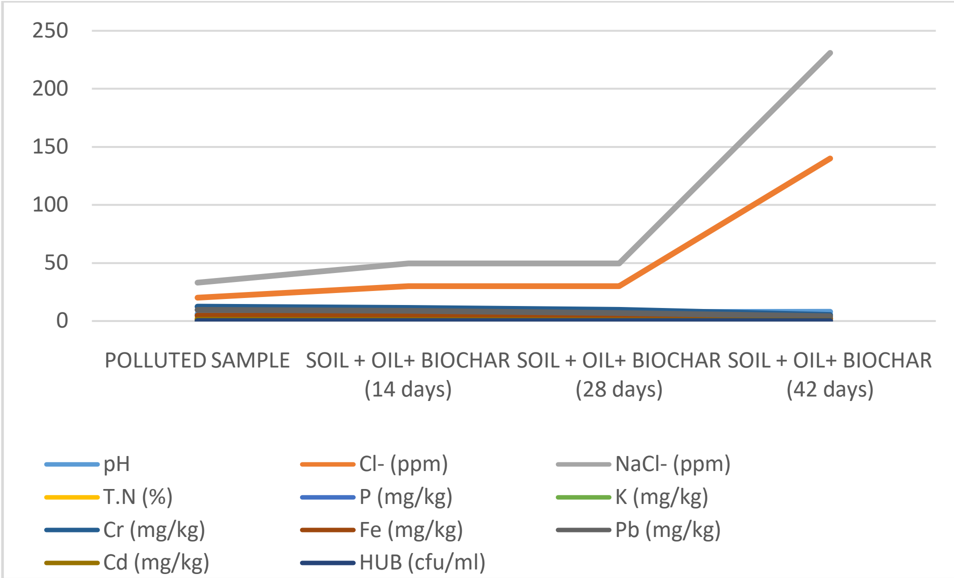

Fig. 1 Comparison of Physicochemical Properties of Sample with the Control

The properties considered is shown in figure 4, it is observed that during the two weeks of remediation the properties of under observation shows some percentage increase.

IV. CONCLUSION

Biochar which is a result of the pyrolysis of organic matter has been studied over the years with different approach and with different intentions; this study focuses on the use of biochar as an environmental remediating material. The material used was maize husk which is usually regarded as a waste product, it was obtained washed, cut into smaller sizes, dried and then pyrolyzed using local pyrolysis method. The soil was polluted using crude oil and then placed in a plastic bin as microcosm. A total of 5 microcosm were setup, two (polluted and unpolluted) served as control, while three (3) served as the remediation. The three remediation setup lasted for 42 (day), in which lab work was carried out every two weeks for three times, and at the end of each two weeks that particular setup was analysed in the lab and then discarded. . The analysis for pH shows that at the unpolluted stage the soil sample was neutral, but at pollution its pH level moved towards the Acidic to a pH of 6.0, the biochar itself was having a pH of 8.2. When applied to the polluted soil the pH level at 42 days increased to 8.0 which was close to its natural state.

The controls and the biochar material were also analyzed for both photochemical properties and other characteristics; they were compared with all the result to determine the rate of pollution reduction. All the analysis for the remediation proved that the biochar actually served its purpose as a remediation material for biodegradation.

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REFERENCES

[1]. Lehmann, J. (2007). Bio-energy in the black. *Front Ecol Environ* 5(7):381–387. doi:10.1890/1540-9295(2007)5[381:bitb]2.0.co;2.
[2]. Zimmerman, A.R., (2010). Abiotic and microbial oxidation of laboratory-produced black carbon (biochar). *Environ. Sci. Technol.* 44, 1295e1301.
[3]. Lehmann, J., Joseph, S. (2009). Biochar for environmental management: an introduction. In: Lehmann, J., Joseph, S. (eds.), Biochar for Environmental Management: Science and Technology, Earthscan, London, pp 1-12.
[4]. Downie, A., Crosky, A., Munroe, P. (2009). Physical properties of biochar. In: Lehmann, J., Joseph, S. (eds), Biochar for Environmental Management: Science and Technology, Earthscan, London. pp: 13-29.
[5]. Glaser, B., Lehmann, J., Zech, W. (2002). Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal - a review. *Biol. Fert. Soils.* 35, 219-230.
[6]. Thies, J.E, Rillig, M.C. (2009). Characteristics of biochar—biological properties. In: Lehmann JSJ (ed) Biochar for environmental management: science and technology. Earthscan, London.
[7]. Pietikäinen, J., Kiikkilä, O., Fritze, H. (2000). Charcoal as a habitat for microbes and its effect on the microbial community of the underlying humus. *Oikos* 89(2):231–242. doi:10.1034/j.1600-0706.2000. 890203. x.
[8]. Wardle, D.A (1998). Controls of temporal variability of the soil microbial biomass: a global-scale synthesis. *Soil Biol Biochem* 30(13):1627–1637.doi:10.1016/s0038-0717(97)00201-0.
[9]. Blagodatskaya, E. Kuzyakov, Y. (2008). Mechanisms of real and apparent priming effects and their dependence on soil microbial biomass and community structure: critical review. *Biol Fertil Soils* 45(2):115–131.
[10]. Wardle, D.A., Zackrisson, O., Nilsson, M.C. (1998). The charcoal effect in Boreal forests: mechanisms and ecological consequences. *Oecologia* 115(3):419–426. doi:10.1007/s004420050536.

[11]. Cheng, C.H., Lehmann, J., Thies, J.E, Burton, S.D., Engelhard, M.H. (2006). Oxidation of black carbon by biotic and abiotic processes. *Org Geochem* 37(11):1477–1488. doi:10.1016/j.orggeochem.2006.06.022.
[12]. Chan, K.Y, Xu, Z. (2009). Biochar: nutrient properties and their enhancement. Biochar for Environmental Management: Science and Technology Earthscan, London, pp 67–84.
[13]. Rousk, J., Bååth, E., Brookes, P.C., Lauber, C.L, Lozupone, C., Caporaso, J.G., Knight, R., Fierer, N. (2010). Soil bacterial and fungal communities across a pH gradient in an arable soil. *ISME J* 4(10):1340–1351.
[14]. Rhodes, A.H., Carlin, A., Semple, K.T., (2008). Impact of black carbon in the extraction and mineralization of phenanthrene in soil. *Environ. Sci. Technol.* 42, 740e745.
[15]. McLean, E.O (1982). Soil pH and lime requirement. Black C A (ed.): Methods in soil analysis: chemical and microbiological properties. Part II-American Society of Agronomy, Madison, Wisconsin, USA.
[16]. Bremner, J.M, Mulvaney, C.S. (1982). Total nitrogen determination. In: Page AL, Miller, R.H, Keeney, D.R (eds): Method of soil analysis, Am Soc Agron.
[17]. Olsen, S.R, Sommers, L.E. (1982). Determination of available phosphorus. In: Page AL, Miller, R.H, Keeney, D.R (eds): Methods of soil analysis, Am Soc Agron Madison.
[18]. Amanchukwu C.C., Obafemi A., Okpokwasili G.C. (1989). Hydrocarbon degradation and utilization by a palmwine yeast isolate. FEMS Microbiol. Lett. 57, 51–54.