Current Journal of Applied Science and Technology

40(17): 21-33, 2021; Article no.CJAST.71466
ISSN: 2457-1024
(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843, NLM ID: 101664541)

A Comparative Study on the use of Soil - Organic and Inorganic Biostimulants in the Remediation of Oily Waste

Ofonime U. M. John[1*], Senyene I. Umana[2], Christiana E. Asuquo[1] and Samuel I. Eduok[1]

[1]Department of Microbiology, University of Uyo, Akwa Ibom State, Nigeria.
[2]Department of Microbiology, Akwa Ibom State University, Ikot Akpaden, Akwa Ibom State, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CJAST/2021/v40i1731430
Editor(s):
(1) Dr. Chen Chin Chang, Hunan Women's University, China.
(2) Dr. Jakub Kostecki, University of Zielona Góra, Poland.
Reviewers:
(1) Milan Koszel, University of Life Sciences in Lublin, Poland.
(2) Abdel Fattah N. Abd Rabou, Islamic University of Gaza, Palestine.
Complete Peer review History: https://www.sdiarticle4.com/review-history/71466

Original Research Articles

Received 10 May 2021
Accepted 15 July 2021
Published 23 July 2021

ABSTRACT

Remediation of oily waste using soil-organic (goat dung, poultry dropping) and inorganic (NPK fertilizer) nutrients was assessed for twelve weeks using culture-dependent microbiological technique and chemical procedures. The results indicate increased counts of Hydrocarbon-utilizing bacteria, fungi and actinomycetes with remediation time for both nutrient types. Bacteria in the remediated waste were members of the genera *Bacillus, Pseudomonas, Acinetobacter, Alcaligenes and Serratia,* fungi: *Penicillium*, *Aspergillus* and *Cladosporium*, and actinomycetes: *Rhodococcus, Nocardia* and *Streptomyces* for all soil-nutrient amendment techniques. pH of the NPK fertilizer ranged between 6.7 ± 0.03 and 7.3±0.06 whereas the goat dung and poultry dropping amendments was 6.5± 0.02 and 7.1 ±0.05. Dehydrogenase activity increased for the biostimulant treatment cells with remediation time. Total Petroleum Hydrocarbon reduction was 99.3 and 99.6% in organic and 99.8% for inorganic amendments. Polycyclic Aromatic Hydrocarbons of the remediated waste for both techniques revealed values below detectable limits (< 0.01) at the end of remediation period. Remediation with soil-goat dung and soil-poultry dropping amendments compared favorably with

**Corresponding author: E-mail: ofonimejohn@uniuyo.edu.ng;*

soil-NPK fertilizer technique because microbial activities were enhanced to produce eco-friendly waste. The use of soil-organic amendments is therefore a low-cost alternative biostimulant for the management of oily waste in the petroleum industry.

Keywords: Eco-friendly; remediation; biostimulant; oily waste; microbial counts; enzyme activity.

1. INTRODUCTION

Crude oil exploration and production activities often generate waste that are discharged by accident or deliberately into the environment with ecological consequences of concern [1,2]. Crude oil polluted environments are usually restored through bioremediation that involves microbial degradation of the pollutants into innocuous substances and minimize associated ecosystem damage [3]. The process is mediated by microbial enzymatic activities to degrade contaminants and has been widely used to mitigate hydrocarbon pollution in the environment. The bioremediation of hydrocarbon contaminated Nigerian soils using organic nutrient amendments has been reported [4,5].With the advent of this promising technique for remediating hydrocarbon contaminated soils, there is need to employ the same technology in the management of oily wastes associated with crude oil exploration and production activities in Nigeria to ensure the disposal of eco-friendly wastes at reduced cost. Here, we evaluated the application and efficacy of soil-poultry dropping, soil- goat dung and soil- NPK fertilizer amendments to remediate oily wastes from crude oil exploration and production activities.

2. MATERIALS AND METHODS

2.1 Remediation Study

The remediation was done based on the principles of biostimulation**,** bioaugmentation and composting [6,7]**.** The soil – organic (soil-goat dung and soil- poultry dropping) and soil – inorganic (soil – NPK fertilizer) nutrient stimulants treatment and control were set up in triplicates using transparent sterile small sized buckets with perforated lids. 3kg of oily waste was mixed with 150 g of soil (5% of oily waste weight) from Unyenge coastal wetland, 300g of goat dung, poultry dropping (10% of oily waste weight), 150g of NPK fertilizer (50% of organic manure) and 15g of bulking agent (wood chips) (0.5% of oily waste weight). The control was also set up without the soil-organic or soil-inorganic stimulants. The different treatment cells were covered with net and perforated lids and incubated for twelve weeks at ambient temperature. The treatment and control cells were assessed immediately after set up and thereafter monitored weekly for changes in Total Viable Counts (TVC) of hydrocarbonoclastic organisms, Total Petroleum Hydrocarbon (TPH) reduction, PAH level and Dehydrogenase enzyme activity.

2.2 Isolation and Enumeration of Microorganisms

Ten-fold serial dilutions of oily waste samples were made by using Tween 80 as diluent [8]. The first ten-fold dilution was made using 10g of the oily waste sample in 90mLof diluent. The dilution was shaken and further serial ten-fold dilutions made up to 10^{-8}. The isolation and enumeration of hydrocarbon utilizing microorganisms were done by vapor-phase transfer method [9]. Aliquots (0.1mL) of appropriate dilutions (10^{-2} to 10^{-6}) of oily waste samples were inoculated onto mineral salt medium (MSM) using the surface spreading technique. The medium used for the isolation of oil-degrading bacteria was supplemented with 50μmL^{-1} nystatin to inhibit interfering yeast and mold and pH adjusted to 7.6. The medium for the enumeration of oil degrading mold was supplemented with 50 μml^{-1} of penicillin G and streptomycin to inhibit interfering bacteria and pH adjusted to 5.6 while that for the enumeration of oil-degrading actinomycetes was supplemented with cyclohexamide to prevent fungal growth and pH adjusted to 5.5 to arrest the growth of non-filamentous bacteria. Sterile filter papers (Whatman1) soaked with filter sterile crude oil (Nigerian light crude) were aseptically placed inside the lid of each Petri-dish and inverted over the inoculated plates. The filter papers supplied the hydrocarbon by vapor phase transfer to the inocula. Control plates were also prepared without crude oil and incubations made at 28 ± 2^{o}C for 5 to 7 days. Colony forming Units ($cfug^{-1}$) were enumerated and due number of hydrocarbon-utilizing bacteria, fungi and actinomycetes calculated by subtracting the number of colony forming units in control from those in test cultures.

The cultural characteristics of emerging colonies were observed after the incubation periods. Different colonies which appeared after the incubation periods were carefully sub-cultured on appropriate media originally used for their isolation. On further sub-culturing, the resulting pure cultures were preserved in the refrigerator for further use.

2.3 Characterization and Identification of Microbial Isolates

Characterization and identification of bacterial isolates and actinomycetes was based on the examination of cultural colonial morphology on plates, microscopy after staining techniques were applied and biochemical tests carried out. The bacteria and actinomycetes were characterized and identified by comparing to known taxa using Bergey's Manual of Determinative Bacteriology [10]. Characterization and identification of fungal isolates were based mainly on their cultural and microscopic morphology and with the presence or absence of special reproductive structures [11,12].

2.4 Physicochemical Analysis of Samples

Chemical characteristics of oily waste and organic manure samples were determined according to techniques described elsewhere [13,14]**.** pH was determined by electrometric method using the pH meter. Total nitrogen in the samples was determined by macrokjeldahl digestion and distillation method. Phosphorus was extracted from the samples by the Bray P-1 method and determined by Murphey Riley Method. The total organic carbon content of the samples was determined using the method of Walkley and Black. Heavy metals were determined by Atomic Adsorption Spectrophotometer after acid digestion. The Total Petroleum Hydrocarbon (TPH) content of the samples was assessed using Toluene extraction method [15]. Five gram of the oily waste sample was measured into a beaker and 10 mL of toluene (Analar grade) was added to it. After shaking vigorously for 5 min, it was allowed to stand for 20 min. After which, two layers were formed and the supernatant (toluene-residual oil extract) was put into fresh test tubes (cuvette). The hydrocarbon content (oil) extracted was determined spectrophotometrically at 420 nm using spectronic-20 Spectrophotometer. The absorbance reading was recorded after reading from a standard curve of the absorbance of different known concentrations of hydrocarbon extractant (toluene). Hydrocarbon concentrations were calculated by multiplying with the appropriate dilution factor and the results expressed as milligrams per kilogram (mg kg^{-1}).

Dehydrogenase activity of samples was determined by the Triphenyltetrazolium Chloride (TTC) method based on the estimation of TTC reduction rate to Triphenylformazan (TPF) in samples after incubation was employed to determine dehydrogenase activity of the treated waste [16]. Five grams of sample were weighed into test tubes and mixed with 5mL of Triphenyltetrazolium Chloride (TTC) solution. The tubes were sealed with rubber stoppers and incubated for 24h at 30^{o}C. The control containing only 5mL of Tris-HCl buffer (i.e.,Hydroxy-methyl-aminomethanein distilled water + HCl) without TTC was also prepared. After incubation, 40ml acetone was added to each tube and shaken thoroughly and further incubated at room temperature for 2 h in the dark, shaking the tubes at intervals. The suspension was then filtered and the optical density of the clear supernatant measured against the blank at 546nm (red color).

Polycyclic Aromatic Hydrocarbon (PAH) in samples were assessed according to the United States Environmental Protection Agency (US EPA) method 8270D, for semi volatile organic compounds by Gas Chromatography / Mass Spectrometry [17]

2.5 Statistical Analysis

The results were subjected to analysis of variance (ANOVA) and Kruskal Wallis test on log-transformed data using Statistical Package for the Social Science (SPSS version 20.0, IBM Corp, USA). Results are presented as mean ± standard deviation with levels of significance maintained at 95% for each test.

3. RESULTS

3.1 Microbial Counts during Remediation of Oily Waste

The microbial counts of hydrocarbon utilizing bacteria, fungi and actinomycetes during the remediation of oily waste are presented in Figure 1. There was increase in microbial counts with increase in remediation time. The Hydrocarbon Utilizing Bacteria (HUB) for the soil-organic treatments ranged between 2.5 ± 0.1× 10^{5} and 8.3 ± 0.4 × 10^{6} CFU/g while that of the soil-inorganic treatment ranged between 2.8 ± 0.0.3×

10^5 and 8.9 ± 0.01× 10^6CFU/g. Hydrocarbon Utilizing Fungi (HUF) for the soil-inorganic treatment revealed counts that ranged between 1.8 ± 0.01× 10^3 and 6.8 ± 0.01× 10^4CFU/g and the soil-organic treatments showed counts between 1.7± 0.2× 10^3CFU/g and 6.0 ± 0.01× 10^4CFU/g. Hydrocarbon Utilizing Actinomycetes in the Soil-organic treatments revealed counts of 2.2± 0.01× 10^2CFU/g to 6.7± 0.1× 10^3CFU/g while that of the soil-inorganic treatment was in the range of 2.4± 0.03× 10^2CFU/g and 7.4± 0.01× 10^3CFU/g. There was however, an insignificant increase in the control from 0-7weeks (1.1± 0.03× 10^3CFU/g to 5.9± 0.01× 10^3CFU/g and 1.4± 0.1× 10^2CFU/g to 4.1± 0.2× 10^2CFU/g) for the HUB and HUF respectively. There was a reduction from week eight to twelve in the HUB and HUF for both soil-organic and inorganic treatments. The HUA showed insignificant increase from 0- 6weeks (6.0± 0.1× 10CFU/g to 7.4± 0.05× 10CFU/g) and reduction from week seven to twelve (5.3± 0.02× 10CFU/g to 2.2± 0.03× 10CFU/g.

3.2 Microorganisms Associated with Remediated Waste

The microorganisms isolated from the remediated waste include species of the genera *Bacillus, Pseudomonas, Acinetobacter, Alcaligenes, Serratia, Penicillium*, *Aspergillus*, *Cladosporium*, *Rhodococcus*, *Nocardia* and *Streptomyces.*

3.3 Chemical/ Microbiological Characteristics of Organic Manure used for Remediation of Oily Waste

The organic manure includes poultry (chicken) dropping sand goat dung. Their chemical characteristics revealed pH range of 6.9 ±0.2 to 7.3 ±0.05, Total Carbon; 18.5 ± 0.06% to 25.6 ± 0.4%, Total Nitrogen; 1.1 ± 0.04% to 3.7 ± 0.1% and Available Phosphorus; 14.6 ± 0.1% to 23.4 ± 0.2%. Their microbiological characteristics indicate microbial counts of 5.4 ±0.05x $10^2$to 8.1± 0.03 x 10^2cfug^{-1} for HUB, 3.4 ± 0.05 x $10^2$to 5.7 ± 0.04 x 10^2cfug^{-1} for HUF and 2.2 ± 0.0 x $10^2$to 3.5 ± 0.01 x 10^2cfug^{-1} for HUA. The chemical/microbiological characteristic of organic manure used for bioremediation of oily waste is as presented on Table 1.

3.4 Physicochemical Characteristics of Oily Waste

The physical characteristics of the oily waste revealed it to be dark colored with clay texture. The chemical characteristics however indicate its pH as 5.5 ± 0.2, Total available Nitrogen of 0.02 ± 0.01%, Available Phosphorus of 0.16 ± 0.05mgkg^{-1} and Total Petroleum Hydrocarbon of 89, 900mgkg^{-1}. The heavy metals revealed Iron with highest value of 77.51 ± 0.07mgkg^{-1}and Cadmium with the least value of 0.7 ± 0.3mgkg^{-1}. The level of assessed Polycyclic aromatic hydrocarbon (PAH) associated with oily waste showed Naphthalene with highest PAH level of 65.24± 0.05mg L^{-1} and Benzo(a)pyrene with least PAH level of 3.52± 0.04mg L^{-1}. The physicochemical characteristics of oily waste are as presented on Tables 2 and 3.

3.5 Changes in Total Petroleum Hydrocarbon (TPH) during Oily Waste Remediation

Figure 2 shows percentage reduction in TPH during oily waste remediation. There was increase in the reduction rate of TPH with increase in remediation time in the amended treatments. The soil- goat dung, soil- poultry dropping and soil-NPK treatments showed 99.3%, 99.5% and 99.8% reduction in the TPH content of the remediated waste respectively.

3.6 Changes in pH during Oily Waste Remediation

The pH during the remediation of oily waste revealed decrease in pH with increase in remediation time in all the treatment cells. The changes in pH during the remediation of oily waste are as presented in Fig. 3.

3.7 Changes in Enzyme Activity during Oily Waste Remediation

The activity of Dehydrogenase during oily waste remediation is presented in Figure 4. Dehydrogenase activity increased with remediation time. The trend of Dehydrogenase activity was in the order: Soil-NPK > Soil-Poultry > Soil-Goat dung > Control.

3.8 Changes in PAH during Oily Waste Remediation

Figures 5 to 8 show changes in PAH of oily waste during remediation. There was remarkable decrease (< 0.01) in the levels of Naphthalene, Acenaphthalene, Anthracene and Benzo (a) pyrene with increase in remediation time in the soil – organic and inorganic nutrient treatments.

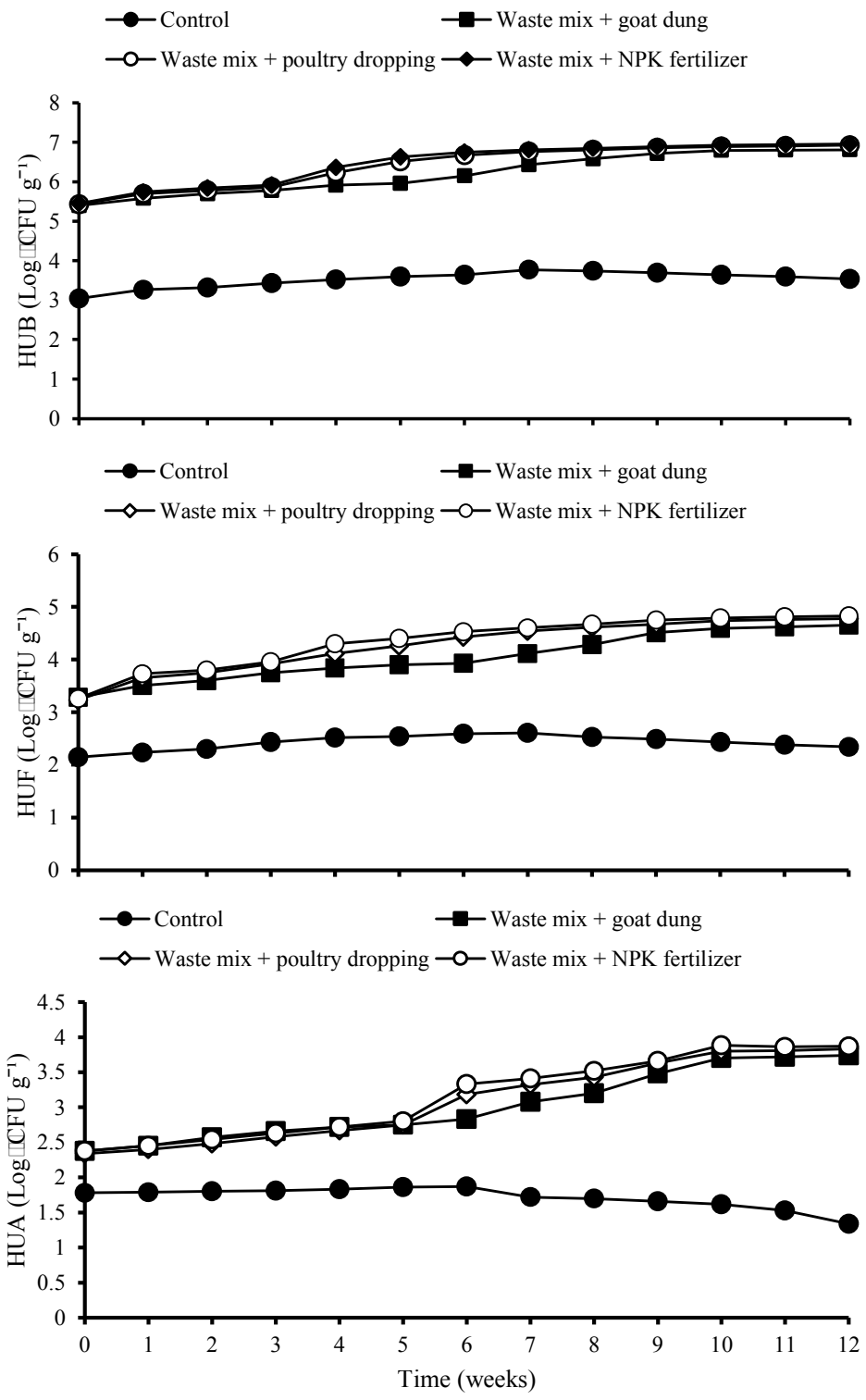

Fig. 1. Trend in microbial counts during remediation of oily waste using soil - organic and-inorganic stimulants

Table 1. Chemical/microbiological characteristic of organic manure used for bioremediation of oily waste

Organic Manure	pH	Total Nitrogen (%)	Available Phosphorus ($mgkg^{-1}$)	HUB ($x10^2cfug^{-1}$)	HUF ($x102cfug^{-1}$)	HUA ($x10^2cfug^{-1}$)	Hydrocarbonoclastic organisms associated with organic manure
Poultry (Chicken) droppings	7.3±0.05	3.7±0.1	23.4±0.2	8.1±0.03	5.7±0.04	2.2±0.0	*Pseudomonas, Micrococcus*, *Serratia*, *Flavobacterium, Penicillium*, *Aspergillus.*
Goat dung	7.3±0.04	3.5±0.3	14.6±0.1	6.3±0.02	3.4±0.05	2.8±0.03	*Acinetobacter*, *Serratia*, *Nocardia Penicillium*, *Aspergillus*

Table 2. Physicochemical Characteristics of Oily Waste

Physical Appearance	pH	TN (%)	AV. P (mg kg^{-1})	TPH (mg kg^{-1})	Heavy metals (mg kg^{-1})							
					Fe	Ni	V	Mn	Zn	Cu	Co	Cd
Dark coloured with Clay texture	5.5 ± 0.2	0.02 ± 0.01	0.16 ± 0.05	89.9 x 10^3(89,900 ± 0.01)	77.51 ± 0.07	31.02 ± 0.04	43.19 ± 0.3	15.12 ± 0.05	14.22 ± 0.2	18.05 ± 0.08	5.6 ± 0.5	0.7 ± 0.3

Key: TN – Total Nitrogen, Av.P – Available Phosphorus, TPH – Total Petroleum Hydrocarbon

Table 3. Levels of assessed Polycyclic Aromatic Hydrocarbon (PAH) associated with oily waste

Polycyclic Aromatic Hydrocarbon (PAH)	Level of PAH (mg L^{-1})
Naphthalene	65.24 ±0.05
Acenaphthene	3.95±0.07
Anthracene	28.42±0.5
Benzo (*a*) Pyrene	3.52±0.04

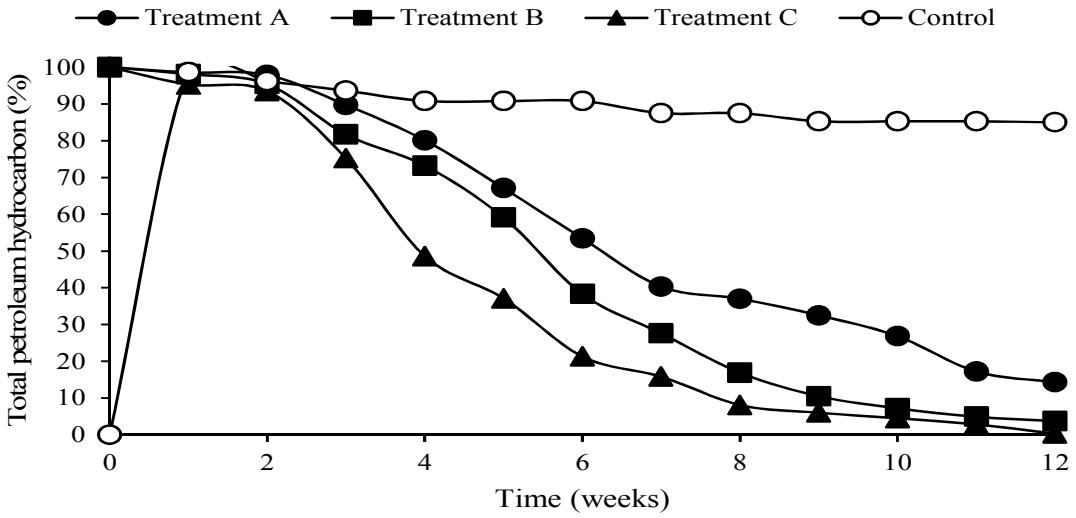

Fig. 2. Reduction in Total Petroleum Hydrocarbon of oily waste during remediation.
Key: A– Soil-Goat dung, B – Soil - Poultry dropping, C- Soil-NPK fertilizer

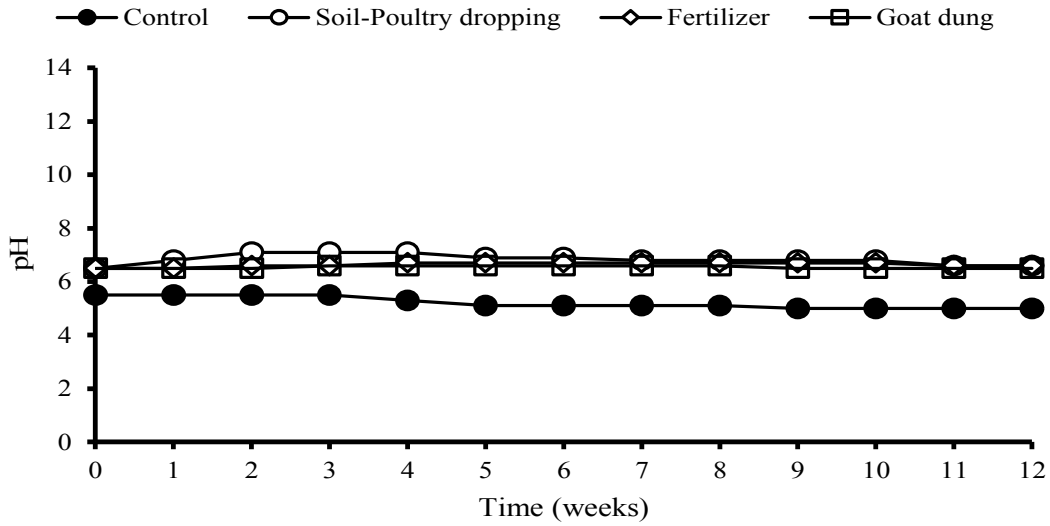

Fig. 3. pH during remediation of oily waste

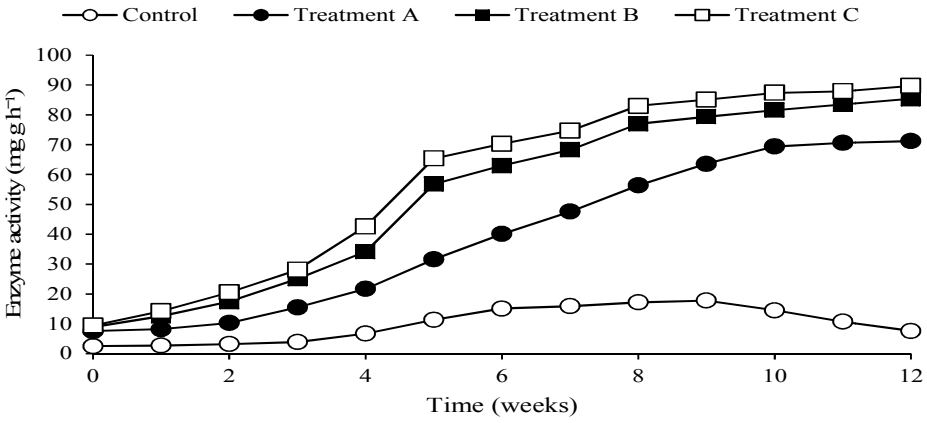

Fig. 4. Dehydrogenase activity during oily waste remediation
Key: A – Soil -Goat dung, B– Soil - Poultry dropping, C- Soil-NPK fertilizer

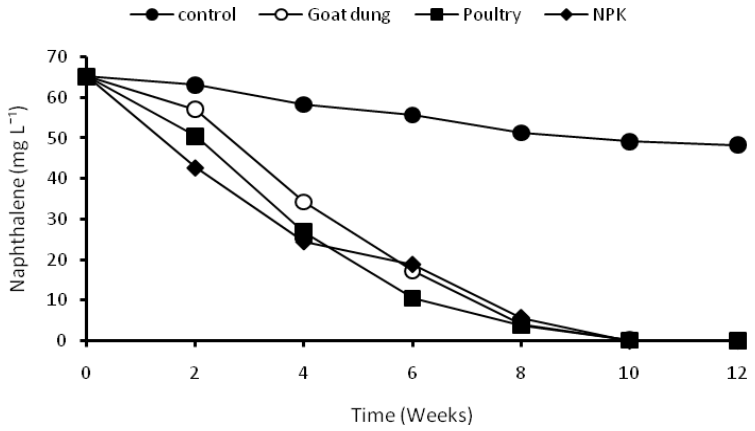

Fig. 5. Changes in Naphthalene level during oily waste remediation

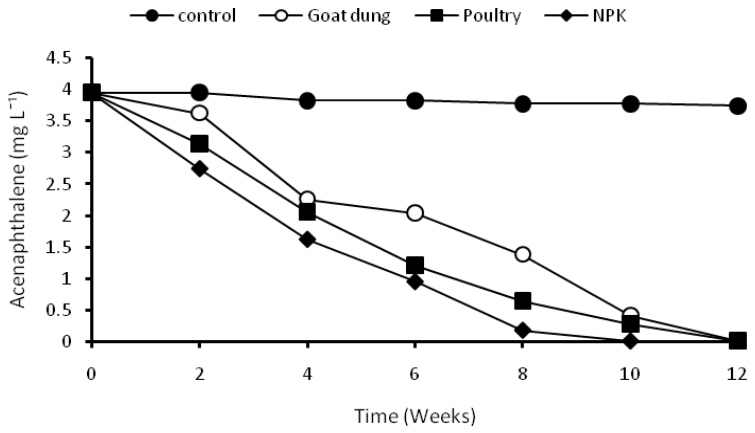

Fig. 6. Changes in Acenaphthalene level during oily waste remediation

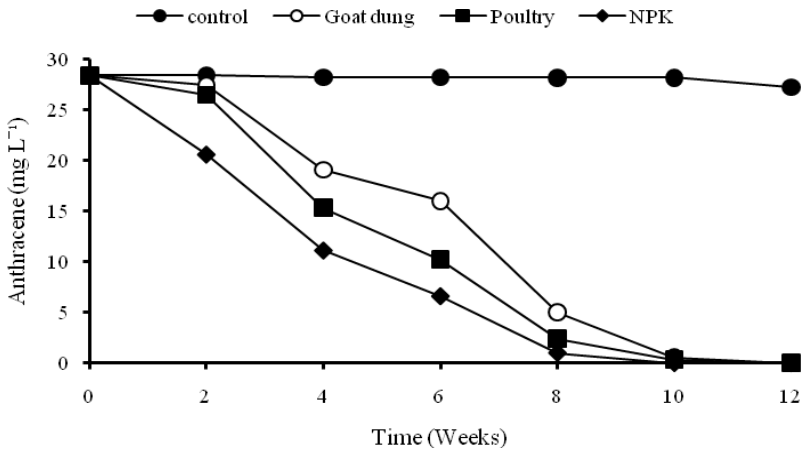

Fig. 7. Changes in Anthracenelevel during oily waste remediation

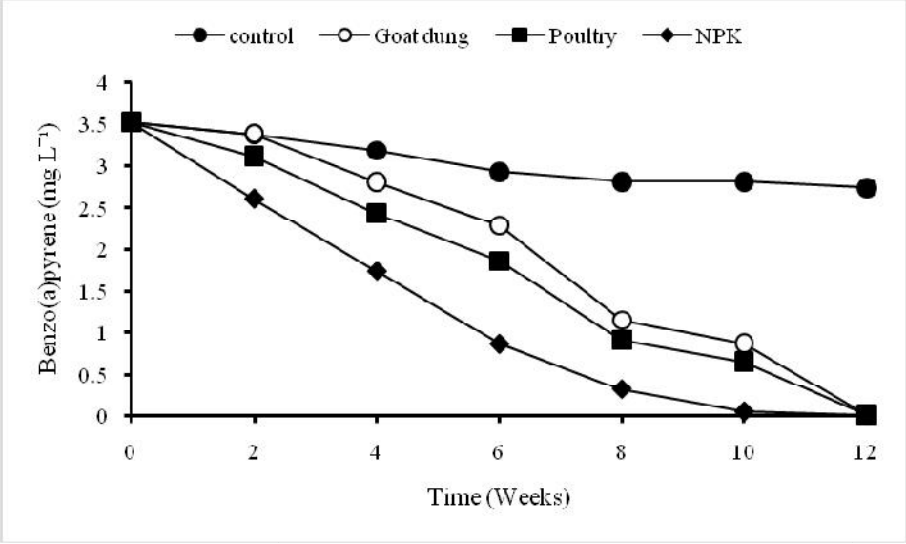

Fig. 8. Changes in Benzo (a) pyrene level during oily waste remediation

4. DISCUSSION

The cost of treating waste generated from industrial, exploration and production activities for safe disposal into the environment is often high, thus the environment becomes a sink for untreated waste disposal. The deleterious effects of crude oil exploration and production activities in Niger Delta, Nigeria are well documented [18]. The physicochemical result of the oily waste indicates high concentrations of known environmental pollutants (Table 2). This corroborates with the reports on the characteristics of waste from crude oil exploration and production activities [19]. The continuous discharge of waste with such constituents into the environment poses serious threat to water, soil organisms, plants and animals. The alteration of physical, chemical and microbiological characteristics of soils by waste from crude oil exploration and production activities has been reported [20,21].This include alterations in the soil total organic carbon, total nitrogen and pH. Low and high molecular weight PAHs were constituents of the oily waste (Table 2). PAHs are recognized as a heterogeneous group of persistent contaminants, because of the toxic, carcinogenic and mutagenic properties, and high recalcitrance to different types of degradation. PAHs are hydrophobic and readily

adsorbed onto particulate matter thus making them primary sink for such compounds. [22]. Though low molecular weight PAHs are biodegradable, high ring-number PAHs are difficult to biodegrade because the environmental fate of a PAH is dependent in part, on the number of aromatic rings and pattern of ring linkages. Generally, large size and angularity of a PAH molecule results in a concomitant increase in hydrophobicity and electrochemical stability [22].

The availability of nutrient such as Nitrogen and Phosphorus play vital roles in the biodegradation of hydrocarbons in any environment [23]. The physicochemical characteristics of the oily waste indicate low nitrogen and available phosphorus (Table 2). The concentration of Total petroleum hydrocarbon suggests high C:N and C:P ratio in the waste. Therefore, biodegradation of oily waste allowed to occur under natural condition wherever the waste is disposed will be slow. Studies have shown the use of organic and inorganic nutrient amendments to enhance hydrocarbon biodegradation activities. The examples include the use of cassava peels and poultry droppings [24], cow dung, poultry manure and pig manure [25], Brewer spent grain, banana skin and spent mushroom [4], cocoa pod husk and plantain peels [5] and commercial inorganic fertilizer [26]. The chemical and microbiological characteristics of the organic manure (Table 3) used for the remediation indicate support for biodegradation of hydrocarbons [3]. These contribute to raise the available nutrient level which is low in the oily waste to enhance biodegradation during remediation process. The microbiological characteristics of the organic manure indicated the association of hydrocarbonoclastic microbes with the organic manure (Table 3). These were members of the genera *Pseudomonas, Acinetobacter, Serratia, Micrococcus, Alcaligenes, Flavobacterium, Nocardia, Penicillium*, *Aspergillus* and *Mucor.* These microbes role in the biodegradation of hydrocarbons have been reported [3,27]. Though there are reports on the use of organic manure amendment for contaminated soils, the application in the remediation of oily waste is scarce. Here, organic manure (poultry droppings and goat dung) and inorganic fertilizer (NPK) in combination with non-E and P activities waste impacted coastal wetland soils was employed for the remediation of oily waste.

Generally, microbial counts of hydro-carbonoclastic microbes during oily waste remediation indicated increase in microbial population with remediation time for treatment cells. The trend of microbial density for hydrocarbonoclastic microbes during oily waste remediation was NPK fertilizer >poultry > goat dung amendment >control. The increase in microbial population is attributed to the addition of the organic manure/inorganic fertilizer that stimulated growth and proliferation of the microbes. The result corroborates with the reports on the use of organic amendments to enhance biodegradation activities [4,5]. The initial phase depicts little increase in microbial population attributed to the adaptation of the microbes to the oily waste, elaborate enzymes to breakdown and assimilate nutrient from the organic compounds. The rapid phase of growth suggests that the microbes had adapted to the oily waste mixture and produce appropriate enzymes/surfactants to degrade organic complex, reduce toxic effect and proliferate. Thereafter, there was marginal increase in microbial counts related to conditions such as competition for available nutrient because of depletion and accumulation of waste metabolites [21].

Microorganisms associated with remediated oily waste were bacteria of the genera *Bacillus, Pseudomonas, Acinetobacter, Alcaligenes* and *Serratia.* The Actinomycetes were members of the genera *Rhodococcus, Nocardia* and *Streptomyces,* whereas fungi of the genera *Penicillium, Aspergillus* and *Cladosprium*. These microbes have been implicated in hydrocarbon biodegradation by different reports [5,22]. The biodegradation potentials of these organisms is attributed to the presence of efficient hydrocarbon degradative enzyme systems and the presence of catabolic genes [3]. Members of the genera *Bacillus, Pseudomonas, Aspergillus, Penicillium* were the most prevalent bacteria and fungi associated with the remediated waste and were recovered in all the treatment cells. Species of *Rhodococcus* and *Nocardia* constitute the most prevalent actinomycete associated with the remediated oily waste and were considered more efficient metabolizers of hydrocarbon compared to other actinomycete associated with the remediated oily waste. The degraders of hydrocarbon among the bacteria, actinomycete and fungi in this study agree with the reports for microbes involved in hydrocarbon biodegradation from contaminated environments [4,5]. The coastal wetland soil which constitutes component of the different soil-organic / inorganic stimulants was the source of the hydrocarbon degraders

involved in the remediation process because it harbors diverse microbes [28].

Changes in pH during oily waste remediation indicate an increase in pH at the initial remediation period for the amended treatment cells. This could be attributed to the addition of organic manure to the oily waste. There was decrease in pH with increase in remediation time in all the treatment cells. This could be attributed to the production of acidic intermediates during the biodegradation of hydrocarbons [3]. The changes in Total petroleum hydrocarbon was observed to also occur in different phases; the initial reduction phase in the treatment cells depict a period of little biodegradation activities.This could be attributed to the influence of the toxicity of the oily waste which could inhibit the biodegradative ability of some microbes in the treatment cells. It could also have occurred due to the adaptation process of the microbes to the conditions prevalent in the treatment cells. The level of Total petroleum hydrocarbon reduction at the initial phase of reduction could also be attributed to the biodegradation of mostly low molecular hydrocarbon during this period [3,21]. The rapid increased reduction phase depicts a period of steady maximum biodegradation activities in the different treatment cells. This could be attributed to excellent adaptability of the microbes to the environment which in turn results in their population increase and production of efficient degradative enzyme systems involved in the biodegradation of low and high molecular weight hydrocarbons [29]. The reduction phase depicts a period when there were low biodegradation activities in the treatment cells probably this was when large molecular weight hydrocarbons were biodegraded and often proceed at a slow rate [23]. This results also agrees with other reports on the biodegradation of oil [4]

The enzyme activities in the different treatment cells during remediation of oily waste suggests increase in dehydrogenase activity (DH) with remediation time for all the treatment cell except control. The dehydrogenase activities in all the treatment cells correlated positively with the microbial counts. The results agree with other reports [30] for activities of dehydrogenase.

The levels of PAHs in the remediated oily waste was below detectable limit (i.e. < 0.01) in treatment cells amended with soil-poultry dropping, soil-goat dung and soil-NPK fertilizer (Figures 5 to 8). There was low reduction of PAH in the control at the end of twelve weeks remediation. Similar results of low biodegradative efficiency due to non-amendment with nutrient has been reported [4,30]. In contrast, oily waste amended with the soil-nutrient mix enhanced bioremediation activities, and produced non-hazardous waste with low concentration of PAHs. This result is consistent with other studies on the efficiency of organic manure such as cow dung and poultry droppings in the remediation of contaminated environments [22,30]

5. CONCLUSION

The oily waste contains chemical pollutants that can negatively impact the soils microbiological and physicochemical characteristics. The treatment of the oily waste using soil – poultry dropping and soil – goat dung as stimulants indicates high efficacy which compared favorably with soil - NPK fertilizer for remediation purposes. Most of the hydrocarbonoclastic microorganisms associated with the non-impacted soils of the coastal wetlands was a major tool in the bioconversion and biotransformation of the chemical pollutants contained in the oily waste during remediation process to produce eco-friendly waste. Therefore, use of the low cost biostimulants (soil - poultry or goat dung amendment for the remediation of oily waste from crude oil exploration and production activities before discharge into the environment could be a better alternative in the management of such waste in the Petroleum Industry. The remediation process mitigates environmental pollution with the potential to restore polluted wetlands and enhance agricultural productivity.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle4.com/review-history/71466