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Co-Compost Biotreatment of Drilling Muds Contaminated Sites

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Abstract

The widespread use of drilling muds has raised concern regarding their impacts on human and environmental health hence the compost biotreatment of oil and water based drilling muds used by petroleum industries in Nigeria was studied. Standard analytical and microbiological procedures were adopted in this study. The results of the compost biotreatment of the oil based mud showed that the amendment with poultry manure recorded the highest Total Petroleum Hydrocarbon degradation of 99.77% while the macrocosm with soil only recorded the lowest (57.13%). For the water based mud, the Total Petroleum Hydrocarbon degradation of the entire macrocosm was uniform giving a percentage degradation of 98.31%. Treatment with oil based mud + vegetable compost + soil recorded the highest oil and grease reduction from 246.1mg/l in week 1 to 94.1mg/kg after 11 weeks. Treatment with oil based mud + NPK only recorded the lowest oil and grease reduction from 245.5mg/kg in week 1 to 143.8mg/kg in week 11. Macrocosm with water based mud + vegetable compost + soil also recorded the highest oil and grease reduction from 142.7mg/l in week 1 to 30.1mg/kg in week 11, while treatment with water based mud + soil recorded the lowest oil and grease reduction from 143.6mg/l in week 1 to 92.4mg/kg in week 11.

1. Introduction

After the completion of drilling borehole section, spent drilling mud as a used up fluid together with drilled cuttings becomes a drilling waste that is highly detrimental to the environment. The amount of drilling waste produced by a given drilling process varies because it depends on the well depth, the kind of drilled formation, and on the mud and water management regime. Field data show that drilling a length of one meter of borehole produces 0.6 cubic meters of waste, and 60–80% of this waste constitutes spent drilling muds [1]. The rest is a solid waste such as cuttings laden with mud and hydrated mud cakes removed from borehole walls during pipe trips [1]. The discharge of these potentially toxic chemicals into the environment may cause adverse impacts on aquatic biological systems. The degree of effect depends on the type, dosage, and exposure duration of chemicals [2]. The primary sources of drilling fluid released into the marine environment are accidental spillage, standing of tankers, and drill-cutting processes. About 3–4 million milligram of oil is disposed of in the sea through human activities and tanker accidents [3]. These fluids are chemically toxic or physically harmful to marine's flora and fauna [4]. Various studies indicated that the growth of flora and fauna was affected by the toxic heavy-metals contamination in the environment [5, 6]. Studies had shown that oily drill cutting discharges affected 750 m^2 of area from a disposal site at Congo, West Africa [4]; and the formation of intertidal mud-flats owing to oil spillages [7]. These discharges also have an adverse impact on aquatic organisms and wildlife present near the shoreline [8]. They can have both short- and long-term adverse impacts. The short-term impacts are on the water column organisms such as fish and long-term impacts are generally restricted to the benthic organisms near the discharge point [9].

Research by [10] on the effects of drilling fluid exposure to oil and gas workers indicates that Derrick men, mud engineers, roughnecks, deep sea divers, laboratory supervisors and motor men are mostly and directly affected. Their findings revealed that, the major health hazard such as dermatitis, body irritation, neurological effects etc., associated with drilling fluids exposure is mainly through inhalation, skin contact and oral exposure. In the Nigerian oil industry both water-based and oil- based mud systems are employed in oil drilling operations [11]. Oil-based mud systems are especially used during directional drilling for oil and gas [12].

Spent drilling muds and oily cuttings management techniques include chemical stabilization, controlled land filling, biological treatment, etc. These technologies are expensive and can lead to incomplete decomposition of contaminants. Biological treatment is one of the most cost-effective, ecologically sound, and sustainable alternatives. The process of biotreatment, defined as the use of microorganisms to detoxify or remove pollutants owing to their diverse metabolic capabilities is an evolving method for the removal and degradation of many environmental pollutants including the products of petroleum industry [13]. In addition, the technology is believed to be noninvasive and relatively cost-effective [14]. Biotreatment by natural populations of microorganisms represents one of the primary mechanisms by which petroleum and other hydrocarbon pollutants can be removed from the environment [15] and is cheaper than other remediation technologies [16]. The success of bioremediation depends on one's ability to establish and maintain conditions that favor enhanced oil biodegradation rates in the contaminated environment [17]. Enhanced biodegradation through composting systems have shown great promise in the treatment of the drilling wastes associated with oil based mud drilling, and are now moving to become a mainstream option [16].

The process of composting reduces organic matter into carbon dioxide, water, heat, and humus [18]. The composting process is also, by definition, a 'self-heating' process, whereby the decomposition process releases energy in the form of heat. These compost temperatures follow a predictable pattern as the process evolves with spikes and drops impacted by aeration events and internal conditions.

Composting systems have demonstrated effective remediation of biodegradable organic compounds, including but not limited to petroleum and non-petroleum hydrocarbons, explosives (Trinitrotoluene, Royal demolition explosive, High melting explosive), ammonium picrate (yellow-D) and organic pesticides [19]. Wood fibre (e.g. post peelings, bark, wood residuals) has demonstrated suitability as the primary stabilization and bulking agent within a compost media. Structural parameters, microbial quality, carbon type, macro and micro-nutrient levels, oxygen availability, moisture content, and trace elements must be balanced with the remedial method to optimize degradation rates. The very nature of composting technology allows for near optimal aerobic biodegradation activity. This study was designed to investigate the possible application of poultry manure and vegetable compost amendments as a means of managing drilling mud contaminated sites.

2. Methodology

2.1 Co - Composting of drilling mud using poultry manure and vegetable compost amendments

The method employed for this test was adopted from (16, 20, 21, 22). The experiment was carried out in eight treatment sets. These includes drill mud (1500g) + poultry manure(20g) + Sawdust (500g), drill mud (1500g) + vegetable compost (20g) + sawdust (500g), drill mud (1500g) + Soil (250g) + poultry manure (20g) + sawdust (250g), drill mud (1500g) + Soil (250g) + vegetable compost (20g) + sawdust (250g), drill mud (1500g) + Soil (250g) + sawdust (250g), drill mud(1500g) + NPK (20g) + sawdust (500g), drill mud (1500g) + Soil (250g) + sawdust (250g) + NPK (20g). The un-amended drill mud (2000g) served as the control.

The duration of the experiment was eleven weeks. Total viable counts, pH, conductivity, oil and grease, were monitored interval to confirm degradation. The changes in TPH degradation was monitored using gas chromatography (Buck Scientific model 910) at week one and week eleven. The soil used in this experiment was collected from the University of Benin, Benin-City premises while the inorganic fertilizer NPK (15:15:15) was obtained from the Edo State Ministry of Agriculture and Natural Resources Benin-City.

2.2 Preparation of vegetable compost manure

The vegetable compost manure was prepared with reference to the method of [16]. The manure contained elephant grass (*Andrepogon* sp.), plantain leaves (*Musa* sp.) and lettuce at 33.3% each to give a total of 100% by weight. After the leaves were weighed out, they were mixed up together and placed in a plastic container with lid. The leaves were moistened adequately, rewetted and turned regularly and left to form compost for a period of 30 days. The vegetable compost manure was applied to the drill mud.

2.3 Isolation and enumeration of culturable bacterial counts

Ten grams of each drill mud treatments and untreated drill muds were aseptically weighed and homogenized with 90ml of sterilized 0.1% peptone water to produce a stock homogenate. The homogenate was serially diluted up to 10^6 and plated aseptically using the pour plate method as described by [23]. Plating was conducted in duplicates and nutrient agar (NA) was utilized as the general purpose medium for the recovery of discrete heterotrophic bacterial colonies at 30^{o}C for 48 hours. The mean colony counts were determined as colony forming units per gram (cfu/g).

2.4 Purification and identification of microbial isolates

Bacterial purification was done by sub-culturing the various unique bacterial isolates onto nutrient agar plates and slants respectively under aseptic conditions using the streaking procedure as described by [23]. The freshly purified were then subjected to Gram staining. After interpreting the results of the Gram staining, further phenotypic profiling of the bacterial cultures was conducted by subjecting the purified bacterial cultures to an assortment of relevant biochemical tests which included; catalase and coagulase production, spore staining, oxidase test and methyl red test respectively. The results of these tests were compiled and compared with reference tables as described by [24].

2.5 Determination of pH

pH was determined using Hanna multi probe meter. The meter was calibrated using pH 4.0, 7.0 and 10.0 buffer solution. Sample pH was measured by inserting the probe in the sample and taking the corresponding readings on the digital meter. For the compost, 20g of air-dry sample was weighed into 50ml beaker and 20ml of distilled water added. It was stirred and allowed to stand for 30 minutes before the pH values were obtained using the meter.

2.6 Electrical Conductivity
Electrical conductivity was determined using Hanna multi probe meter. The meter was calibrated using any calibration standards (84, 1413, 12880 and 80000µS/cm). Sample for EC was measured by inserting the probe in the sample and taking the corresponding readings on the digital meter.

2.7 Oil and grease
Solid-Liquid phase and Liquid-Liquid phase solvent extraction was carried out using n-Hexane which is then read at 350nm whilst comparing/quantifying using a standard calibration curve prepared from crude oil stock.

2.8 Determination of total petroleum hydrocarbon in the compost
Total petroleum hydrocarbon was determined from the compost using a modified standard protocol of determining hydrocarbon content in soil according to international standard organization (ISO/DIS 16703 GC Method). TPH concentration in the compost was monitored using GC (Gas Chromatography Philip UNICAM Series Model 304 New York), performed on a varian 3500 gas chromatography equipped with varian 8200 auto sample, Flame ionization detector (FID) and split less injector valve. The capillary column used was as Alltech EC -5 (30 X 0.25MM with 0.25um film thickness) with helium as a carrier gas flowing at a rate of 2ml/min in a constant flow mode.

3. Results and Discussion

The results of the compost biotreatment of the two types of drilling muds are presented in Figures 1 to 8 and Tables 1 and 2.
The pH values of the compost treatment are presented in Figures 1 and 2. In all the treatments, the pH showed a steady decrease from week 1 to week 11. The steady decrease in pH is likely due to acid production as a result of microbial activity. The treatment with soil and vegetable compost recorded the lowest pH of 5.78 and 5.62 for oil based mud and water based mud respectively. These treatments incidentally recorded the highest total viable counts after 11 weeks. The treatment with NPK recorded the highest pH values of 6.46 and 6.41 for oil based mud and water based mud respectively after 11 weeks and also recorded the lowest total viable counts.
The electrical conductivity (EC) values of the compost treatments are presented in figures 3 and 4. Electrical conductivity reflects the level of salinity of the compost. The conductivity values in all the treatments showed a steady increase from the first week to the eleventh week. Treatment with soil + NPK recorded the highest conductivity values for both types of mud. The conductivity values were 1573 µs/cm and 1233 µs/cm for oil based mud and water based mud respectively. For the oil based mud the treatment with poultry manure recorded the lowest EC value of 1375 µs/cm while for the water based mud treatment with soil recorded the lowest EC value of 1140 µs/cm. Electrical conductivity has an inverse relationship with pH such that as the pH values are decreasing, the EC values are increasing. The increase in the EC values can also be attributed to the release of mineral salts such as phosphate and ammonium ions through the decomposition of organic substances.
The total viable count of the compost treatments are presented in Figures 5 and 6. The treatment with soil + vegetable compost recorded the highest total viable counts for both types of mud. The total viable counts were 27.9×10^4 cfu/g and 30.4×10^4 cfu/g for oil based mud and water based mud respectively. The treatments with only NPK recorded the lowest count for the two types of mud. The treatment with only NPK recorded 87.0×10^3 cfu/g and 97.0×10^3 cfu/g respectively for the oil based mud and the water based mud. The un-amended treatment recorded 49.0×10^3 cfu/g and 71.0×10^3 cfu/g for the oil based mud and water based mud respectively.

Microbial activity, quantity, and biomass are parameters that are used to explain the dynamics of composting process. Due to the complexity of substrates and intermediate products, microbial diversity and the succession of populations is therefore a prerequisite to ensure complete biodegradation. The high total viable counts in the soil + vegetable compost could mean that this treatment contains more available nutrients for the microorganisms. The bacterial isolates from the different treatments with oil and water based muds are listed in Tables 1 and 2.

The oil and grease degradation values are presented in Figures 7 and 8. There was a steady reduction in the oil and grease values from the first to the eleventh week. The treatment with vegetable compost + soil recorded the highest oil and grease reduction for both types of mud. For the oil based mud, the treatment with the vegetable compost + soil recorded the highest oil and grease reduction from 246.1mg/kg in week 1 to 94.1mg/kg in week 11 while the treatment with only NPK recorded the lowest oil and grease reduction from 245.5mg/kg in week 1 to 143.8mg/kg in week 11. For the water based mud the treatment with vegetable compost + soil recorded the highest reduction from 142.7mg/kg in week 1 to 30.1mg/kg in week 11 while treatment with only soil recorded the lowest reduction from 143.6mg/kg in week 1 to 92.4mg/kg in week 11.The higher reduction of the oil and grease by the vegetable compost + soil treatment is very likely due to the higher microbial activity recorded in the treatment.

The total petroleum hydrocarbon (TPH) degradation by the compost treatments are presented in Tables 1 and 2. For the oil based mud, the total petroleum hydrocarbon content of the macrocosm was 8.175 mg/kg. The amendment with poultry manure recorded the highest TPH degradation of 99.77% followed by NPK + soil amendment (98.10%), soil + poultry manure (97.31%), soil + vegetable compost (84.37%), amendment with only vegetable compost (77.69%), and amendment with only NPK (75.31%), amendment with only soil (57.13%). The un-amended mud (control) recorded zero TPH degradation. For the water based mud, the total petroleum hydrocarbon content of the macrocosm was 0.059 mg/kg. The TPH degradation of the entire macrocosm was uniform giving a percentage degradation of 98.31%. The un-amended mud (control) also recorded zero TPH degradation. The total petroleum hydrocarbon content of the macrocosm was low (0.059 mg/kg). This could be attributed to the known fact that water based muds contain lower TPH than the oil based mud since their base fluid is water and not oil. The high TPH degradation is also a confirmation of the work of [16 and 22] that water based muds are more easily degraded than the oil based muds.

The use of composting as a bioremediation technology has been given very little attention [22, 25]. The application of bioremediation techniques to polycyclic aromatic hydrocarbons (PAH) is based on the findings that adding fertilizer [26, 27, 28] or adding degrading bacteria [29, 30, 31] to contaminated soils stimulated the microbial degradation of the PAH. It could be very possible that the poultry manure is highly enriched with hydrocarbon utilizing bacteria hence the high TPH degradation that was recorded. Biostimulation has been reported to enhance the growth of indigenous microorganisms by addition of nutrients (NPK). This could be attributed to the observed high percentage TPH degradation by the NPK + soil treatment. According to [18] large quantities of carbon tend to result in rapid depletion of the available pools of major inorganic nutrients such as N and P. Hence the soil treated with NPK recording a very high amount of nutrient that resulted in the corresponding TPH degradation. This is despite recording lower total viable bacterial count. The lower TPH degradation recorded for the vegetable compost despite recording a higher total bacterial viable count could be attributed to the observation by [32] that compost is made up of over 90% by weight of carbon and oxygen and some amount of hydrogen and nitrogen and sulphur but the nutrients are released slowly in relation to NPK. The oil based mud amended with only soil recorded the lowest TPH degradation of 57.13%. This observation is in line with the observation that hydrocarbon degraders are ubiquitous in nature [33, 34]. It also implies that low concentration of the petroleum hydrocarbon contaminated soils could be bioremediated by natural attenuation since the C: N ratio threshold is not exceeded. The unammended drill muds recorded steady but mild decrease in pH and oil and grease. It also recorded a gradual but mild increase in the total viable counts. This could be a confirmation that the drill mud itself has some hydrocarbon degrading microorganisms.

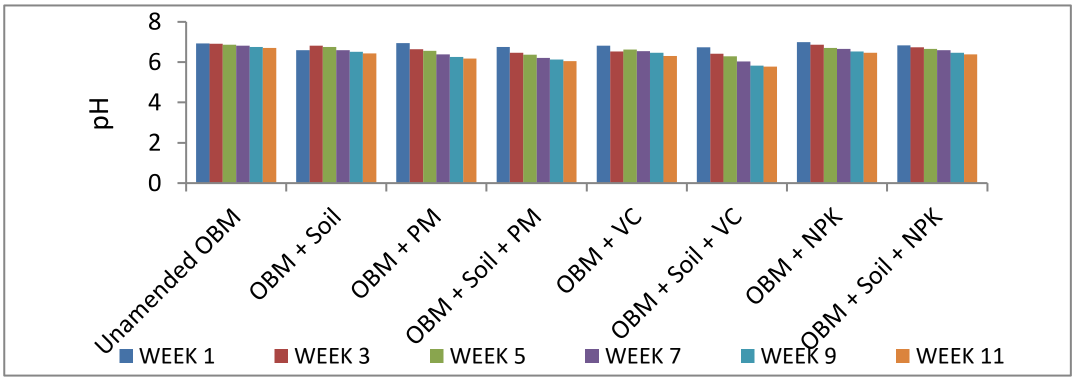

Figure 1: pH values of compost biotreatment of oil based mud
Key: OBM = Oil Based Mud, PM = Poultry Manure, VC = Vegetable Compost, NPK = Inorganic Fertilizer

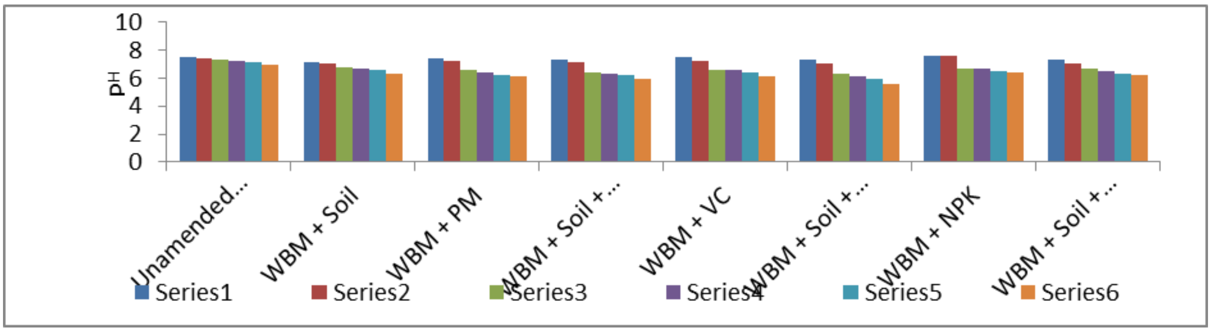

Figure 2: pH values of compost biotreatment of water based mud
Key: WBM = Water Based Mud, PM = Poultry Manure, VC = Vegetable Compost, NPK = Inorganic Fertilizer

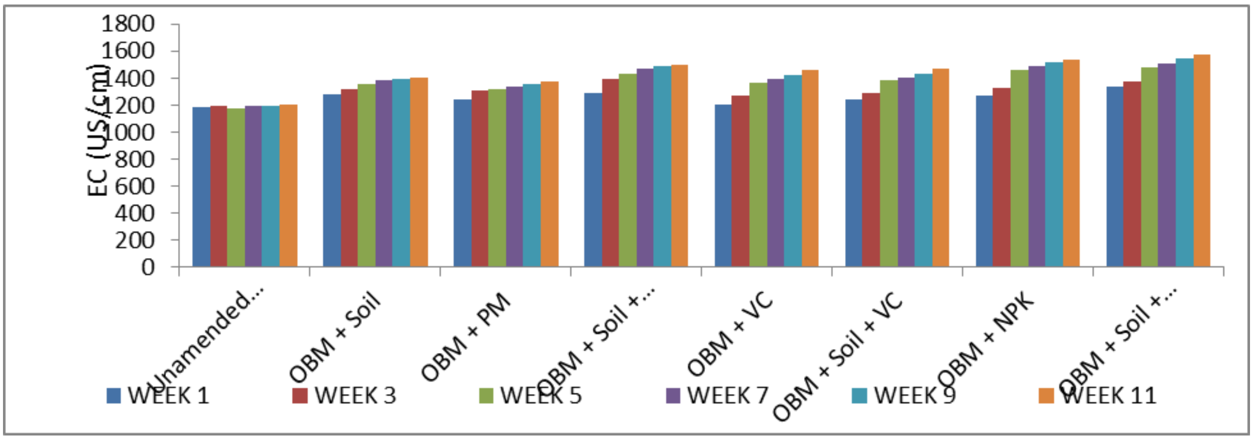

Figure 3: Electrical conductivity values of compost biotreatment of oil based mud
Key: OBM = Oil Based Mud, PM = Poultry Manure, VC = Vegetable Compost, NPK = Inorganic Fertilizer

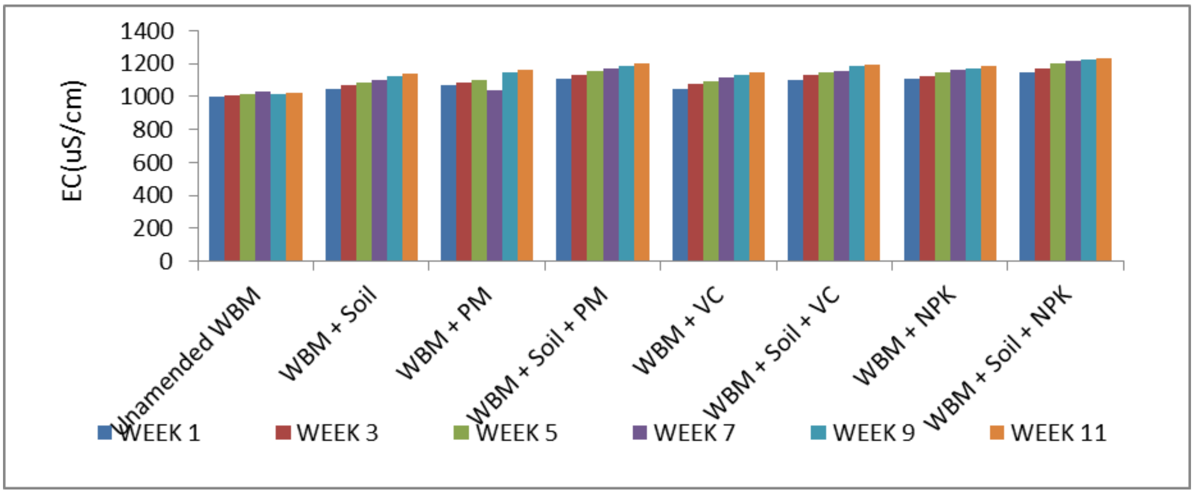

Figure 4: Electrical conductivity values of compost biotreatment of water based mud
Key: WBM = Water Based Mud, PM = Poultry Manure, VC = Vegetable Compost, NPK = Inorganic Fertilizer

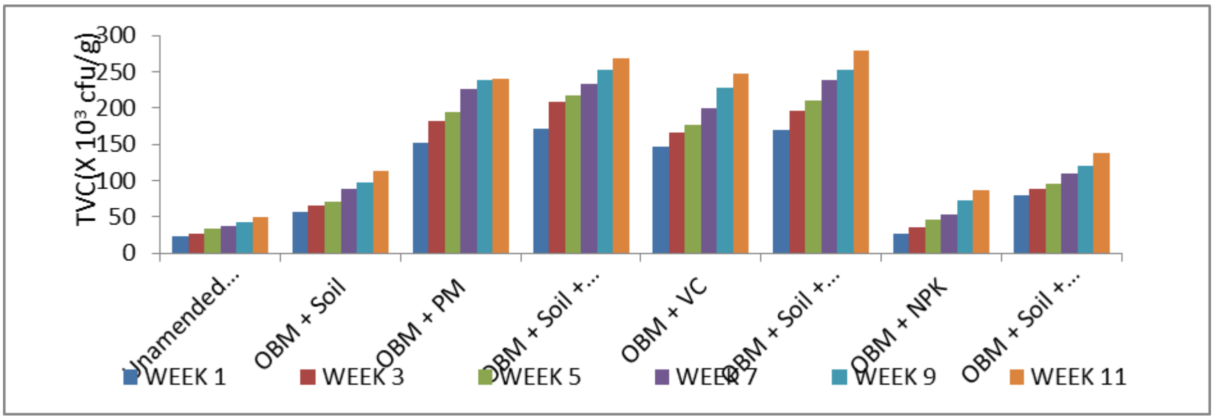

Figure 5: Total viable count values of compost biotreatment of oil based mud
Key: OBM = Oil Based Mud, PM = Poultry Manure, VC = Vegetable Compost, NPK = Inorganic Fertilize

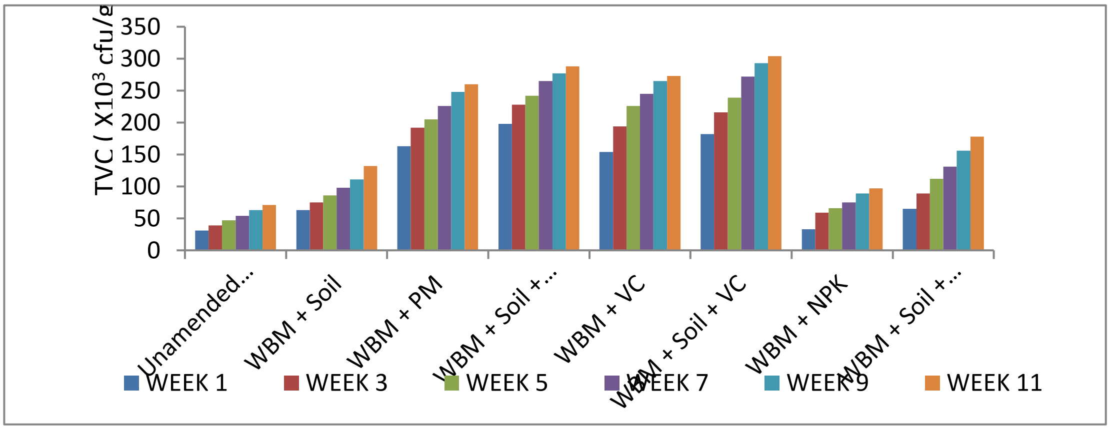

Figure 6: Total viable count values of compost biotreatment of water based mud
Key: WBM = Water Based Mud, PM = Poultry Manure, VC = Vegetable Compost, NPK = Inorganic Fertilizer

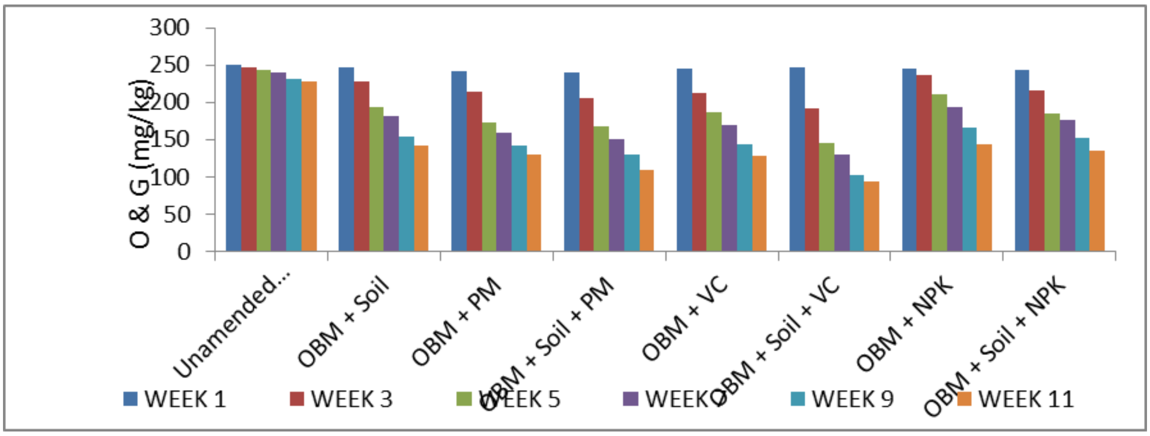

Figure 7: Oil and grease values of compost biotreatment of oil based mud
Key: OBM = Oil Based Mud, PM = Poultry Manure, VC = Vegetable Compost, NPK = Inorganic Fertilize

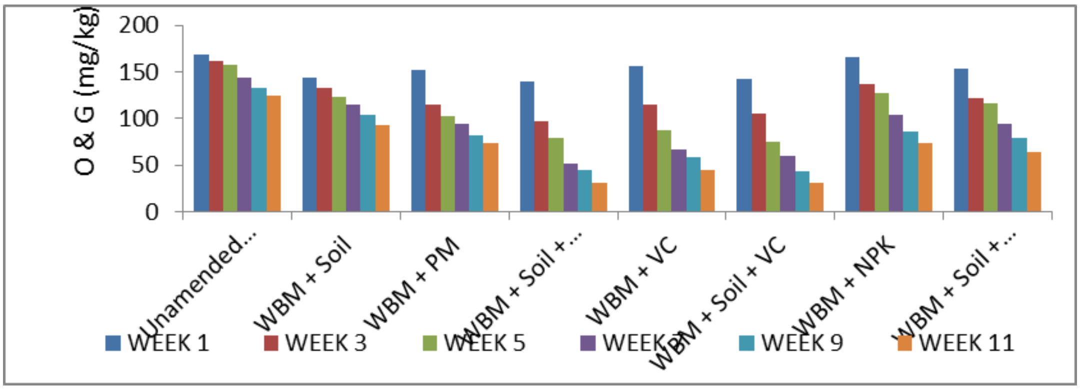

Figure 8: Oil and grease values of compost biotreatment of water based mud
Key: WBM = Water Based Mud, PM = Poultry Manure, VC = Vegetable Compost, NPK = Inorganic Fertilizer

Table 1: Bacterial isolates from the compost treatments with oil based mud

Treatments/Microcosms	Bacterial isolates
Unamended OBM	*Bacillus* sp., *Providencia* sp., *Micrococcus* sp.
OBM + Soil	*Bacillus* sp., *Micrococcus* sp., *Serratia* sp. and *Flavobacterium* sp.
OBM + PM	*Bacillus* sp., *Klebsiella* sp., *Enterobacter* sp., *Staphylococcus* sp. and *Citrobacter* sp.
OBM + Soil + PM	*Bacillus* sp., *Micrococcus* sp., *Serratia* sp., *Flavobacterium* sp., *Enterobacter* sp., *Citrobacter* sp. and *Providencia* sp.
OBM + VC	*Bacillus* sp., *Flavobacterium* sp., *Enterobacter* sp., *Micrococcus* sp.
OBM + Soil + VC	*Bacillus* sp., *Micrococcus* sp., *Enterobacter* sp., *Serratia* sp., *Micrococcus* sp. and *Flavobacterium* sp.
OBM + NPK	*Micrococcus* sp. and *Enterobacter* sp.,
OBM + Soil + NPK	*Micrococcus* sp., *Bacillus* sp., *Enterobacter* sp., *Serratia* sp. and *Flavobacterium* sp.,

Key: **Un-amended OBM** = Un-amended Oil based mud, **OBM + Soil** = Oil based mud + Soil, **OBM + PM** = Oil based mud + Poultry Manure, **OBM + Soil + PM** = Oil based mud + Soil + Poultry manure, **OBM + VC** = Oil based mud + Vegetable compost, **OBM + Soil + VC** = Oil based mud + Soil + Vegetable compost, **OBM + NPK** = Oil based mud + Inorganic fertilizer, **OBM + Soil + NPK** = Oil based mud + Soil + Inorganic fertilizer.

Table 2: Bacterial isolates from the compost treatments with water based mud

Treatments/Microcosms	Bacterial isolates
Unamended WBM	*Proteus* sp., *Bacillus* sp., *Providencia* sp., *Micrococcus* sp.
WBM + Soil	*Acinetobacter* sp., *Bacillus* sp., *Micrococcus* sp., *Serratia* sp. and *Flavobacterium* sp.
WBM + PM	*Micrococcus* sp., *Bacillus* sp., *Klebsiella* sp., *Enterobacter* sp., *Providencia* sp.and *Ciitrobacter* sp.
WBM + Soil + PM	*Acinetobacter* sp., *Bacillus sp., Micrococcus* sp., *Serratia* sp. and *Flavobacterium* sp.
WBM + VC	*Klebsiella* sp., *Bacillus* sp., *Flavobacterium* sp., *Enterobacter* sp. and *Micrococcus* sp.
WBM + Soil + VC	*Serratia* sp., *Bacillus* sp., *Micrococcus* sp., *Enterobacter* sp., *Serratia* sp., *Micrococcus* sp. and *Flavobacterium* sp.
WBM + NPK	*Enterobacter* sp., *Acinetobacter* sp., *Bacillus* sp. and *Providencia* sp.,
WBM + Soil + NPK	*Acinetobacter sp., Micrococcus* sp., *Bacillus* sp., *Enterobacter* sp., *Providencia* sp.,*Serratia* sp. and *Flavobacterium* sp.,

Key: **Un-amended OBM** = Un-amended Oil based mud, **OBM + Soil** = Oil based mud + Soil, **OBM + PM** = Oil based mud + Poultry Manure, **OBM + Soil + PM** = Oil based mud + Soil + Poultry manure, **OBM + VC** = Oil based mud + Vegetable compost, **OBM + Soil + VC** = Oil based mud + Soil + Vegetable compost, **OBM + NPK** = Oil based mud + Inorganic fertilizer, **OBM + Soil + NPK** = Oil based mud + Soil + Inorganic fertilizer.

Table 3: Concentration (mg/kg) and percentage reduction of total petroleum hydrocarbon in compost biotreatment of oil based mud

TREATMENTS	WEEK 1	WEEK 11	% TPH Reduction
Unamended OBM	8.175	8.175	0.00
OBM + Soil	8.175	3.505	57.13
OBM + PM	8.175	0.220	97.31
OBM + Soil + PM	8.175	0.019	99.77
OBM + VC	8.175	1.824	77.69
OBM + Soil + VC	8.175	1.278	84.37
OBM + NPK	8.175	2.018	75.31
OBM + Soil + NPK	8.175	0.155	98.10

Key: **Un-amended OBM** = Un-amended Oil based mud, **OBM + Soil** = Oil based mud + Soil, **OBM + PM** = Oil based mud + Poultry Manure, **OBM + Soil + PM** = Oil based mud + Soil + Poultry manure, **OBM + VC** = Oil based mud + Vegetable compost, **OBM + Soil + VC** = Oil based mud + Soil + Vegetable compost, **OBM + NPK** = Oil based mud + Inorganic fertilizer, **OBM + Soil + NPK** = Oil based mud + Soil + Inorganic fertilizer, all values are in mean

Table 4: Concentration (mg/kg) and percentage reduction of total petroleum hydrocarbon in compost biotreatment of water based mud

TREATMENTS	WEEK 1	WEEK 11	% TPH Reduction
Unamended WBM	0.059	0.059	0.00
WBM + Soil	0.059	0.001	98.31
WBM + PM	0.059	0.001	98.31
WBM + Soil + PM	0.059	0.001	98.31
WBM + VC	0.059	0.001	98.31
WBM + Soil + VC	0.059	0.001	98.31
WBM + NPK	0.059	0.001	98.31
WBM + Soil + NPK	0.059	0.001	98.31

Key: **Un-amended WBM** = Un-amended Water based mud, **WBM + Soil** = Water based mud + Soil, **WBM + PM** = Water based mud + Poultry Manure, **WBM + Soil + PM** = Water based mud + Soil + Poultry manure, **WBM + VC** = Water based mud + Vegetable compost, **WBM + Soil + VC** = Water based mud + Soil + Vegetable compost, **WBM + NPK** = Water based mud + Inorganic fertilizer, **WBM + Soil + NPK** = Water based mud + Soil + Inorganic fertilizer, all values are in mean.

4. Conclusion

In conclusion, the results of this research have further proven compost biotreatment technology to be a very useful tool in the remediation of drill mud contaminated sites and as such regulating agencies in the oil sector should encourage its adoption and usage by the concerned industries.

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