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Co-composting of Non-aqueous Drilling Fluid Contaminated Cuttings from Ologbo Active Oilfield with Organic Manure.

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Abstract

Drill cuttings (from Ologbo active oil field) contaminated with non-aqueous drilling fluid was co-composted with poultry manure and plant waste for eighteen weeks. A homogenized non-aqueous based fluid contaminated cutting was mixed with wood chips in a ratio of 1:1 and then mixed with soil, poultry and plant waste manure in ratio of 4:2:1. Results of total heterotrophic bacterial counts showed steady increase in counts from week 0 to week 12 in all treatments. The highest bacterial count of 8.8 x 10^7 ± 0.2 cfu/g was observed in macrocosm containing drill cuttings, soil and poultry manure at week 12. The highest fungal count of 6.5 x 10^4 ±0.2 cfu/g occurred in macrocosm containing drill cuttings, soil and poultry manure at week 12. The mixed community population of the compost system was observed to compose of ten (10) bacterial genera and five (5) fungal genera. The highest recorded pH was 8.15. Steady decreases were observed in electrical conductivity of the compost systems. Macrocosms containing poultry manure and plant waste had the highest percentage reduction of oil and grease and total petroleum hydrocarbon (99.57% and 99.92% respectively). Based on the findings from this study it is recommended that oil exploration and production companies should adopt compost technology with organic manure such as poultry and plant waste manure, as a waste management policy in order to reduce the high cost, energy and pollution associated with other conventional treatment options.

Keywords: drill-cuttings, non-aqueous based fluid, bacteria, fungi, TPH.

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Introduction

Drill cuttings have been found to pose a big problem to well-engineers and indeed oil prospecting companies, especially drill cutting derived using non-aqueous based fluids. This is so because the oil loading of the drilling mud makes the drill cutting unacceptable to the environment considering standards contained in the environmental guidelines and standards for the petroleum industries in Nigeria (DPR, 2002) and other standards in the world (Mairs *et al*., 1999). Drilling for crude-oil generates huge amounts of drill cuttings, which are mixtures of rocks and particulates released from geologic formations in the drill hole during drilling operation (Ayotamuno *et al*., 2009). Drilling fluids and their additives have been observed to greatly influence the biology and chemistry of the resulting drill cuttings. (Okparanma *et al*., 2009, Imarhiagbe and Atuanya, 2013).The two primary types of drilling fluids are water based fluids, which consists of water mixed with bentonite clay and additives and non-aqueous based fluids, which comprise all non-water and non-dispersible based fluids and they include Oil Based fluids, Low Toxicity Mineral Based fluids, Enhanced Mineral Oil Based fluids and Synthetic Based fluids (Mairs *et al*., 1999). The world today is moving toward sustainable means of combating pollution rather than the method which involves the addition of chemicals (e.g. detergent) to the environment (Isikhuemhen *et al.,* 2003). Odokuma and Akpanah (2008), had earlier stated that the management of drilling fluids and cuttings in Nigeria, sometimes involves discharge into fills and from where they over flow into nearby farms and rivers. Small amounts are re-injected into special cutting re-injection (CRI) wells while lesser amounts are treated in thermal desorption units (TDU). Over the years, scientists have relied on bacteria for the purpose of biodegrading hydrocarbon-contaminated environment (Allen-Christopher *et al.,* 1999). According to

Atagana (2008), the use of composting in bioremediation has received little attention (Potter *et al.,* 1999), despite its application in the treatment of soils contaminated with organic compounds for many years. It is known that soil is composed of a heterogeneous community of bacteria and other microorganisms. This study therefore aims at examining the effect of co-composting with poultry and plant waste manure, as a means of biotreatment of drill cuttings from Ologbo oil field wells that are contaminated with non-aqueous base fluid.

Materials and Methods

Sources and collection of Samples: The drill cutting samples were collected in sterile clean plastic containers during drilling process of the onshore wells at Ologbo community in Edo state. They were transported to the laboratory in ice-cooled containers where they were immediately analyzed. The geographic position system (GPS) of the well was E: 350017.978 m, N: 229469.956 m.

Co-Composting of drill cuttings impaired with non-aqueous based fluid using poultry manure and plant waste manures. The method employed was adapted from Atagana, (2008), McCosh and Getliff (2004) and Ayotamuno *et al.* (2009). The experiment was carried out on four treatment sets. A homogenized non-aqueous based fluid contaminated cuttings was mixed with wood chips in a ratio of 1:1 and then mixed with soil, poultry and plant waste manure in ratio of 4:2:1 (drill cuttings + wood chips + soil + compost manure). The experiments were set up in triplicates. The control was contaminated cuttings without compost manures. The experiments were incubated for duration of 18 weeks.

Isolation and enumeration of microorganisms: Heterotrophic bacteria and fungi were enumerated using the standard plate count technique (Cheesbrough, 2000). Appropriate dilutions of samples were plated out in duplicates on nutrient agar and potato dextrose agar (incorporated with 2 µg/l of chloramphenicol) for bacteria and fungi respectively. A set of nutrient agar plates were incubated at 30^0C for 48 hours (aerobic bacteria) while the other sets were incubated with the aid of an anaerobic jar with an oxygen removing system (oxoid gas pack), to create an anaerobic system. The plates for fungal isolation were incubated at room temperature for 5-7 days. The means of duplicate colony counts were calculated and used to compute the colony forming unit per gram (cfu/g).

Enumeration of drilling muds utilizing microorganisms: Drilling mud utilizing microorganisms were isolated and counted using mineral salt medium according to Okpokwasili and Okorie (1988). The minerals salt medium had in litre, $MgS0_4.7H_20$, 0.42 g/l, KCl, 0.30 g/l, KH_2PO_4, 0.8 g/l, K_2HPO_2, 1.3 g/l, $NaNO_3$, 0.42 g/l, pH 7.4 and Agar 15 g/l. The plates were incubated at 29 ^{o}C for 6 days after which the growth of drilling mud degraders were observed and counted. For fungal plates, 2 µg/l of chloramphenicol was incorporated to inhibit the bacterial growth. The various isolates were further characterized and identified (Buchanan and Gibbons, 1974, Barnett and Hunter, 1975).

Preparation of Plant waste Manure

The plant waste manure was prepared with reference to method of Atuanya (1991). The manure contained elephant grass (*Andrepogon sp*), plantain leave (*Musa sp*) and lettuce, (40: 30: 30) 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 plant waste manure was applied to drill cuttings impaired with non-aqueous based fluid.

pH, Electrical conductivity (µS/cm): The samples were prepared by homogenizing 25 g of the sample in 25 ml of water. The contents of the beaker were then thoroughly stirred and left to stand for at least 6 hours, with occasional stirring. Following standardization with pH distilled 7 and 4 buffers, the pH of the homogenate was determined in duplicate using a single electrode pH meter (Jen-way Patterson Scientific, London). Also from the above homogenate, the electrical conductivity was determined using a single electrode conductivity meter (Jen-way Pattern Scientific, London).

Oil and grease (mg/kg): Five grams (5 g) of the drill cuttings sample was weighed into a 150 ml glass bottle for extraction. Twenty milliliters (20 ml) of tetrachloromethane was added into the bottle containing the weighed sample and extraction was done in a water bath for 3 hrs. The content in the bottle was allowed to settle and thereafter was filtered into a clean bottle and 5 g of anhydrous sodium sulphate was added. Absorbance was read at 420 nm to determine the concentration of oil and grease. Value in mg/kg was calculated as below:

Oil and grease (mg/kg) = Instrumental Reading. X Vol. X 10^3 / Wt. of sample X 10^4

Total petroleum hydrocarbon (TPH): Ten grams (10 g) of drill cuttings was weighed into a solvent rinsed beaker and 50ml of 50:50 mixtures of acetone and dichloromethane (DCM) was added. The samples were spiked with 1ml of a surrogate mixture (orthoterphenyl-OTP) and placed in a sonicator for about 15min at about 20^0C. Ten grams (10 g) of anhydrous sodium sulphate was added to the samples and allowed to stand until a clear extract developed and it was then decanted. The extracted samples were transferred into a teflon lined screwed-cap vial, labeled, corked and transferred to the gas chromatography (GC) for the TPH analysis.

Statistical analysis: The data obtained were subjected to descriptive statistical analysis such as mean and standard deviation (Ogbeibu, 2005).

Results

The total heterotrophic bacterial and fungal count (cfu/g) of compost biotreatment of drill cuttings contaminated with non-aqueous based fluid showed steady increase in counts from week 0 to week 12 respectively in all treatments, and thereafter started decreasing till the end of experiment (table 1A). The highest bacterial count of $8.8 \times 10^7 \pm 0.2$ cfu/g was observed in macrocosm containing drill cuttings, soil and poultry manure at week 12. Table 1B showed the highest fungal count of $6.5 \times 10^4 \pm 0.2$ cfu/g which occurred in macrocosm containing drill cuttings, soil and poultry manure at week 12. The total non-aqueous based fluid utilizing bacterial counts (cfu/g) of the composting experiment revealed relative high counts and steady increase from week 0 to 12, and thereafter decreased till week 18 of the experiment (Table 1C). The initial C: N ratios for cuttings + soil + poultry manure and cuttings + soil + plant waste manure were 11: 1 and 9: 1, these ratios gradually reduced to 4: 1 by week 18 respectively(Table 2).Table 3 shows the biodiversity changes of the microbial population. The mixed community population of the compost system was observed to compose of ten (10) bacterial genera and five (5) fungal genera.

There was steady increase in pH within the first 10 weeks, reaching 8.10 and 8.15 for compost mixed with poultry manure and plant waste respectively(Fig 1A). Steady decreases were observed in electrical conductivity of the compost systems (Fig 1B). Generally, there were obvious decreases in percentage reduction of oil and grease and total petroleum hydrocarbon (Fig 2A & B) as the experiment progressed. Macrocosms containing poultry manure and plant waste had the highest percentage reduction of 99.57% respectively and cuttings only (control) had the least percentage reduction of 92.49% (Fig 2A). Macrocosm containing cuttings, soil and poultry manure had the highest percentage reduction of total petroleum hydrocarbon (TPH) of 99.92% (Fig 2B).

Table 1A: Total Heterotrophic Bacterial Counts (Cfu/G) Of Compost Bio-treatment Of Drill Cuttings Impaired With Non Aqueous Drilling Fluid.

	WK 0	WK 2	WK 4	WK 6	WK 8	WK 10	WK 12	WK 14	WK 16	WK 18
Cuttings only	$0.5x10^5$ ±0.25	$1.8x10^5$ ±0.35	$0.6x10^6$ ±0.25	$0.8x10^6$ ±0.15	$1.4x10^6$ ±0.25	$2.5x10^6$ ±0.27	$3.2x10^6$ ±0.2	$3.7x10^6$ ±0.3	$1.7x10^6$ ±0.2	$1.5x10^6$ ±0.2
Cuttings+Soil	$9.1x10^5$ ±0.4	$1.5x10^6$ ±0.6	$2.0x10^6$ ±0.5	$2.9x10^6$ ±0.2	$3.5x10^6$ ±0.6	$4.3x10^7$ ±0.41	$4.2x10^7$ ±0.22	$5.9x10^6$ ±0.4	$6.3x10^6$ ±0.5	$2.0x10^6$ ±0.5
Cuttings+Soil+Poultry manure	$1.5x10^5$ ±0.31	$2.5x10^6$ ±0.2	$3.4x10^6$ ±1.0	$4.7x10^6$ ±1.12	$2.01x10^7$ ±0.2	$7.2x10^7$ ±0.33	$8.8x10^7$ ±0.2	$1.01x10^6$ ±0.5	$1.2x10^6$ ±1.2	$1.1x10^6$ ±0.5
Cuttings+Soil+Plant waste manure	$1.88x10^5$ ±0.4	$1.9x10^6$ ±1.12	$3.0x10^6$ ±0.4	$3.9x10^6$ ±0.1	$1.25x10^7$ ±0.5	$5.7x10^7$ ±0.4	$7.5x10^7$ ±1.12	$7.4x10^6$ ±0.21	$7.0x10^6$ ±1.25	$6.0x10^6$ ±0.31

Over all mean values ± Standard deviation

Table 1B: Total Heterotrophic Fungal Counts (CFU/G) Of Compost Bio-treatment Of Drill Cuttings Impaired With Non Aqueous Drilling Fluid

	WK 0	WK 2	WK 4	WK 6	WK 8	WK 10	WK 12	WK 14	WK 16	WK 18
Cuttings only	$0.2x10^4$ ±0.02	$0.4x10^4$ ±1.5	$1.0x10^4$ ±0.25	$1.1x10^4$ ±0.6	$1.8x10^4$ ±0.12	$2.1x10^4$ ±1.5	$2.4x10^4$ ±0.5	$2.1x10^4$ ±0.01	$1.5x10^3$ ±0.2	$1.2x10^3$ ±0.1
Cuttings+Soil	$0.5x10^4$ ±0.01	$1.3x10^4$ ±1.0	$1.9x10^4$ ±0.3	$2.5x10^4$ ±0.1	$3.0x10^4$ ±0.12	$2.8x10^4$ ±0.04	$4.2x10^4$ ±0.01	$1.0x10^4$ ±0.02	$5.7x10^3$ ±0.05	$3.1x10^3$ ±0.2
Cuttings+Soil+Poultry manure	$2.3x10^4$ ±0.02	$3.1x10^4$ ±1.1	$3.7x10^4$ ±0.2	$4.4x10^4$ ±0.1	$5.5x10^4$ ±1.0	$6.0x10^4$ ±0.3	$6.5x10^4$ ±0.2	$5.1x10^4$ ±0.04	$2.0x10^4$ ±0.01	$3.2x10^3$ ±0.7
Cuttings+Soil+Plant waste manure	$1.5x10^4$ ±0.02	$2.8x10^4$ ±0.5	$3.5x10^4$ ±0.7	$4.1x10^4$ ±1.0	$4.9x10^4$ ±0.1	$5.8x10^4$ ±0.2	$5.9x10^4$ ±0.1	$2.9x10^4$ ±0.05	$1.2x10^4$ ±0.01	$2.7x10^3$ ±0.01

Over all mean values ± Standard deviation

TABLE 1C: Total utilizing bacterial counts (cfu/g) of compost bio-treatment of drill cuttings impaired with non aqueous drilling fluid.

	WK 0	WK 2	WK 4	WK 6	WK 8	WK 10	WK 12	WK 14	WK 16	WK 18
Cuttings only	$0.6x10^4$ ±0.05	$1.2x10^4$ ±1.0	$0.7x10^5$ ±2.1	$1.3x10^5$ ±0.34	$1.8x10^5$ ±1.35	$1.8x10^5$ ±2.0	$2.1x10^4$ ±0.75	$2.1x10^4$ ±2.0	$2.8x10^4$ ±0.4	$3.0x10^3$ ±0.15
Cuttings+Soil	$1.1x10^4$ ±0.2	$3.7x10^4$ ±1.0	$4.9x10^5$ ±0.02	$5.7x10^5$ ±0.7	$6.8x10^5$ ±0.52	$7.9x10^5$ ±0.3	$7.1x10^5$ ±0.15	$6.1x10^5$ ±0.22	$5.2x10^5$ ±0.1	$3.8x10^3$ ±0.24
Cuttings+Soil+Poultry manure	$5.1x10^4$ ±0.05	$6.9x10^4$ ±0.8	$8.2x10^5$ ±0.72	$1.07x10^6$ ±0.61	$1.15x10^6$ ±0.21	$1.47x10^6$ ±0.35	$1.20x10^6$ ±0.7	$2.8x10^5$ ±1.1	$4.0x10^4$ ±0.5	$2.1x10^3$ ±0.8
Cuttings+Soil+Plant waste manure	$1.7x10^4$ ±0.2	$6.2x10^4$ ±0.1	$2.7x10^5$ ±0.55	$4.1x10^5$ ±0.27	$7.5x10^5$ ±1.5	$8.5x10^5$ ±0.51	$9.1x10^5$ ±0.18	$8.8x10^5$ ±0.72	$6.5x10^4$ ±0.8	$2.0x10^3$ ±0.30

Over all mean values ± Standard deviation

Table 2: Changes in C:N Ratios of Compost Bio-Treatment of Drill Cuttings Impaired With Non Aqueous Drilling Fluid

	WK 0	WK 4	WK 8	WK 12	WK 16	WK 18
Cuttings only	15:1	19:1	39:1	37:1	32:1	22:1
Cuttings+Soil	12:1	19:1	29:1	25:1	21:1	18:1
Cuttings+Soil+Poultry manure	11:1	17:1	32:1	16:1	6:1	4:1
Cuttings+Soil+Plant waste manure	9:1	17:1	25:1	15:1	6:1	4:1

Over all mean values

TABLE 3: Microbial changes of the compost system as enumerated using culture technique

	Cuttings only	Cuttings+Soil	Cuttings+Soil+Poultry manure	Cuttings+Soil+Plant waste manure
WK 0-4	*Enterobacter aerogenes, Micrococcus sp, Bacillus sp,Aspergillus spp, Penicillium spp*	*Pseudomonas aeruginosa, Micrococcus sp, Bacillus sp, Enterobacter aerogenes, Aspergillus spp, Penicillium s*	*Bacillus* sp *, Bacillus* sp*, Pseudomonas spp, Serratia sp, Penicillium spp ,Aspergillus spp, Rhizopus sp*	*Staphylococcus sp, E. aerogenes, Bacillus spp Micrococcus sp, Penicillium spp, Aspergillus spp.*
WK 5-8	*Enterobacter aerogenes, Micrococcus spp, Bacillus sp , Aspergillus spp, Penicillium spp*	*Pseudomonas aeruginosa, Micrococcus sp, Bacillus sp, Enterobacter aerogenes, Aspergillus spp, Penicillium sp, Rhizopus sp.*	*Klebsiella sp,Serratia sp,Bacillus sp, Micrococcus sp, Pseudomonas spp, Penicillium spp,Aspergillus spp, Rhizopus sp,Fusarium sp.*	*Pseudomonas sp, Staphylococcus sp, Citrobacter sp,E, aerogenes, Bacillus spp Micrococcus sp, Penicillium spp, Aspergillus spp.*
WK 9-12	*Enterobacter aerogenes, Micrococcus spp, Bacillus sp, Aspergillus spp, Penicillium spp*	*Pseudomonas aeruginosa ,Citrobacter sp Micrococcus sp, Bacillus sp, Enterobacter aerogenes, Aspergillus spp, Penicillium sp, Fusarium sp, Rhizopus sp*	*Klebsiella sp,Serratia sp,Bacillus sp, Bacillus sp,Micrococcus sp, Pseudomonas spp,Nocardia sp, Penicillium spp,Aspergillus spp, Rhizopus sp,Fusarium sp.*	*Pseudomonas sp, Staphylococcus sp, Citrobacter sp,E, aerogenes, Bacillus spp Micrococcus sp, Penicillium spp, Aspergillus spp.*
WK 13-16	*Bacillus spp,Pseudomonas sp,Nocardia sp, Aspergillus spp, Penicillium spp*	*Pseudomonas aeruginosa ,Citrobacter sp Micrococcus sp, Bacillus sp, Enterobacter aerogenes, Aspergillus spp, Penicillium sp, Rhizopus sp*	*Klebsiella sp,Bacillus sp,Micrococcus sp, Arthrobacter sp, Pseudomonas spp,Nocardia sp, Penicillium spp,Aspergillus spp, Rhizopus spMucor sp.*	*Pseudomonas sp, Staphylococcus sp, Citrobacter sp,E, aerogenes, Bacillus spp Micrococcus sp, Penicillium spp, Aspergillus spp.*
WK 17-18	*Bacillus spp,Pseudomonas sp,Nocardia sp, Aspergillus spp, Penicillium spp*	*Pseudomonas aeruginosa, Citrobacter sp. Micrococcus sp, Bacillus sp, Enterobacter aerogenes, Nocardia sp, Aspergillus spp, Penicillium sp, Fusarium sp, Rhizopus sp*	*Klebsiella sp,Bacillus sp,Micrococcus sp, Arthrobacter sp, Pseudomonas spp,Nocardia sp, Penicillium spp,Aspergillus spp, Rhizopus sp,Fusarium sp.Mucor sp.*	*Pseudomonas sp, Staphylococcus sp, Citrobacter sp,E, aerogenes, Bacillus spp Micrococcus sp,Nocardia sp, Penicillium spp, Aspergillus spp.*

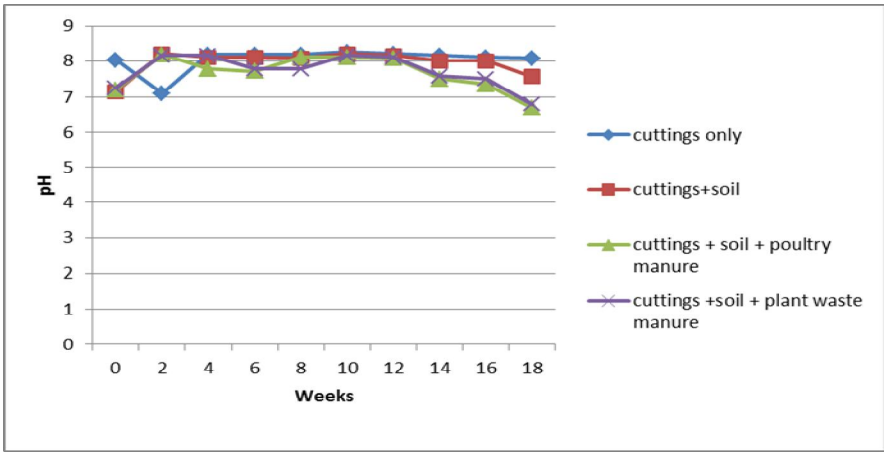

Figure 1A: Changes in pH of compost biotreatment of drill cuttings contaminated with non-aqueous based fluid.

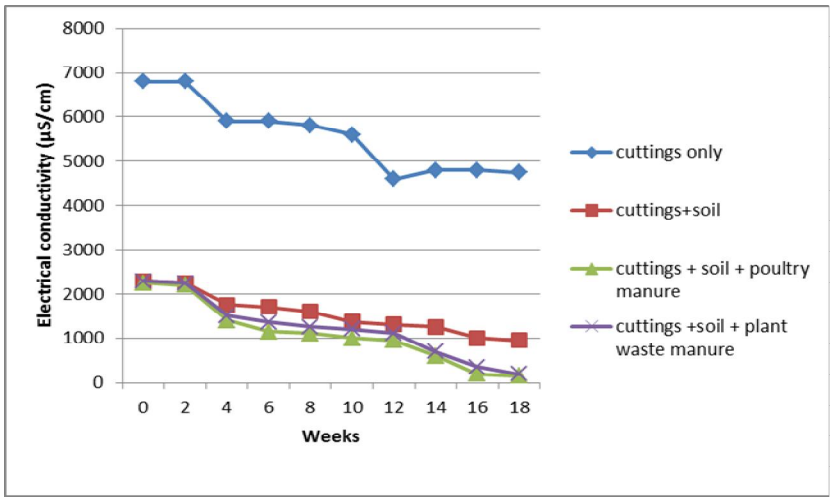

Figure 1B: Changes in Electrical conductivity (µS/cm) of compost biotreatment of drill cuttings contaminated with non-aqueous based fluid.

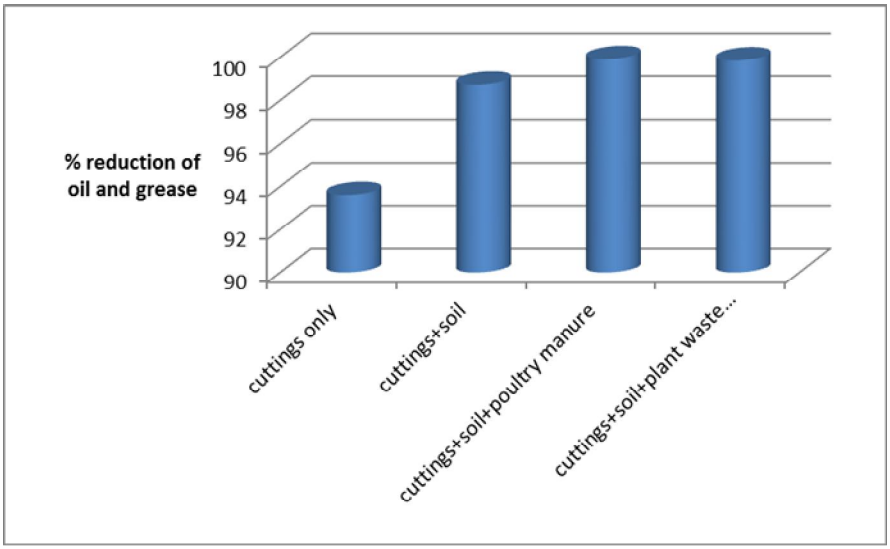

Fig 2A: Percentage Reduction of oil and grease concentration of compost biotreatment of drill cuttings contaminated with non-aqueous based fluid.

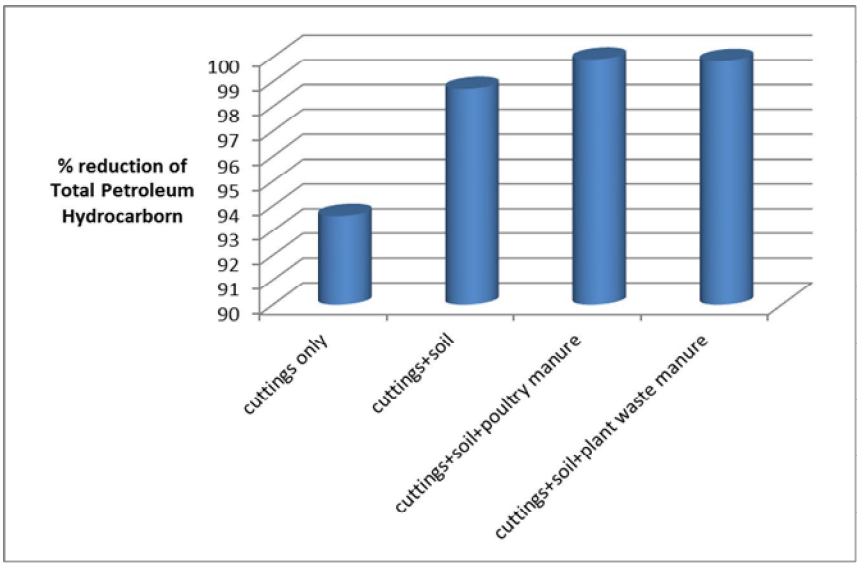

Fig 2B: Percentage Reduction of Total Petroleum Hydrocarbon concentration of compost biotreatment of drill cuttings contaminated with non-aqueous based fluid.

Discussion

The counts of total heterotrophic bacteria, total fungi and total utilizing bacteria were observed to be generally high within the period of study. The total microbial counts (cfu/g) were observed to reach their maximum peaks with in the 10 - 12 weeks before they started decreasing (Table 1 A-C). These observations can be attributed to the fact that utilization of the contaminant commences from the moment the micro-organisms get in contact with the contaminant(s). However, as the period of exposure progresses, higher utilization rates are possible until a maximum peak is reached at that point energies are diverted to proliferation causing an increase in cell number (Prescott *et al*., 2005). This increase cannot however exceed the carrying capacity of the immediate environment, thus, the accumulation of toxic by-products during decomposition will eventually result in the decline of microbial population, as observed in the various treatment sets. The maximum counts of utilizing bacterial count (cfu/g) in this study was at tenth (10^{th}) week, while the maximum counts of heterotrophic bacteria counts (cfu/g) was about twelfth (12^{th}) week. This observation lends credence to the findings of Bartha and Atlas (1987) that the break down products of contaminating hydrocarbon by utilizing microorganisms constitutes a substrate for the heterotrophic micro-organisms, as these hydrocarbons in their unmetabolized state cannot be utilized by the heterotrophic micro flora.

Changes in the types of microorganisms during the experimental period showed a gradual population decline after week 12, which was the peak population density. This can be attributed to the considerable drop in the concentration of the non-aqueous based fluid as biodegradation progressed. The community structure of the compost showed a successive decline in gram-negative bacterial population toward the end of the experiment (i.e. from week 12) and a relative dominance and increase of gram positive-bacteria and fungi. This may be due to the inability of the gram-negative bacteria to withstand adverse environmental condition, which result from changes in composition accomplishing biodegradation e.g. pH, nutrient reduction, synthesis of toxic end product (Prescott *et al*., 2005, Atagana 2008). The dominant bacterial isolates at week 0 – 4 were *Enterobacter aerogenes, Micrococcus* sp.*, Bacillus* sp.*, Bacillus* sp.*, Pseudomonas aeruginosa, Bacillus* sp.*, Serratia marcescens, Klebsiella* sp.*, Staphylococcus epidermidis,* and *Staphylococcus* sp. While the dominant fungal isolates were *Aspergillus* spp., *Penicillium* sp. and *Rhizopus* sp. At the end of the composting period, (week 14-18), the bacterial isolates were *Bacillus* spp., *Micrococcus* sp.*, Nocardia* sp.*, Pseudomonas* sp. and *Arthrobacter* sp. The fungal isolates were *Penicillium spp., Aspergillus* spp. and *Fusarium* sp. Rapid growth and high counts observed in the compost was expected since poultry

manures and plant wastes were known to be rich in nitrogen, phosphorus and other mineral nutrients (Atagana 2008). In the presence of these nutrient sources (organic and/ or inorganic forms) micro-organisms proliferation and organic contaminants degradation is always enhanced. Therefore, population increase was due to the readily available nutrients in the compost. The C: N ratios observed in this work were considerably adequate for composting organic materials. Statistical analysis showed significant differences ($P < 0.05$) for counts of total heterotrophic bacteria, total fungi and total utilizing bacteria among the various treatment sets of the composting system.

The increases in pH at the early stage of the composting could be from high metabolic activities of the micro-organisms which possibly resulted in the production of acidic intermediate metabolites in the compost system leading to decreases in the pH (Atagana, 2008). The pH ranges observed in these experiments are well within the recommended range for composting organic materials (Marin *et al.,* 2006). The decreases in pH can be attributed to the subsequent release of intermediate and final products that probably had lowering effects on the pH of the treatment sets. A definite uniform pattern was observed in electrical conductivity and oil and grease for all treatments, with electrical conductivity values decreasing with a decrease in the oil and grease level of the treatments. This progressive decrease in electrical conductivity could be as a result of loss of free ions which follows the utilization of the drill mud attached on the cuttings. The reduction in ionic strength of the environment partly explains the observed negative correlation between electrical conductivity and microbial load. Thus, as the electrical conductivity (ionic strength) reduced more micro-organisms are proliferating.

The effects of the rapid increases in the microbial activity within the first 12 weeks manifested in the high decreases in the concentrations of oil and grease and the total petroleum hydrocarbons. Comparisons with standard limits from the Department of Petroleum Resources (DPR), all the tested components were removed below the remediation target (10 mg/kg for oil and grease and TPH). Generally, the percentage reductions of the monitored components (oil and grease and total petroleum hydrocarbon) were high in all macrocosms. In this study, the high percentage reduction recorded in macrocosm containing drill cuttings only (control) indicates that the non-aqueous based fluid used in this experiment can readily biodegrade through natural attenuation. However, percentage reductions were observed to be highest in macrocosms containing drill cuttings, soil and amendments (poultry manure and plant waste manure). A similar investigation by Ayotamuno *et al.*, (2009) was carried out to determine the potentials of composting as bioremediation technology for the removal of polycyclic aromatic hydrocarbon (PAH) from oil-field drill cuttings. There was no significant difference ($P > 0.05$) for total petroleum hydrocarbon and oil and grease among the treatment sets. Based on the findings from study, oil exploration and production companies should adopt compost technology with organic manure such as poultry and plant waste manure, as a waste management policy in order to reduce the high cost, energy and pollution associated with other conventional treatment options.

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