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COMPARATIVE ANALYSIS OF BIOREMEDIATION RATES OF WELL-DRAINED AND WATERLOGGED SOILS IN THE NIGER DELTA

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Abstract

Oil exploitation in the Niger Delta has resulted in widespread hydrocarbon pollution. Despite vast research on bioremediation using organic amendments for restoring hydrocarbon-contaminated land, the potential of decomposed cassava peels has attracted little attention in the literature. This study was therefore designed to examine the seasonal effect of decomposed cassava peels for bioremediation of hydrocarbon-polluted soils of different topographic surfaces in the Niger Delta area of Nigeria. The experimental research design was used. Well-drained and waterlogged sites were purposively selected for the study. Each site was divided into 18 plots, each measuring 2m by 2m and was contaminated with Bonny Light crude oil at three levels of 2.0,4.0 and 6.0% concentrations. The experiment was undertaken in both dry and wet seasons. The baseline soil without contamination served as a control. Decomposed cassava peels were introduced into the soil to a depth of 10cm seven days after contamination. Thirty-six soil samples were collected from 0-15cm and from 15-30cm depth. Soils in the experimental sites were analysed before and after contamination and after three months of bioremediation for Total Hydrocarbon Content (THC). The properties of polluted soils before and after remediation were compared using descriptive statistics and independent t-test at $p \leq 0.05$. Rates of bioremediation in the well-drained and waterlogged soils were analysed and compared. The THC in both well-drained and waterlogged sites before contamination was low. THC increased in both sites after contamination and decreased after remediation. The study revealed that there was a 51% reduction in THC in well-drained soils and 22% in waterlogged soils. The study also revealed that remediation was more effective in well-drained soil than in waterlogged soil but proceeded faster in the dry season than in the wet season. The study recommends that decomposed cassava peels for hydrocarbon remediation should be applied on well-drained soil in the dry season.

Keywords: Bioremediation of polluted soil, Decomposed cassava peels, Total hydrocarbon content, Well-drained, Waterlogged.

INTRODUCTION

The release of liquid petroleum hydrocarbon into the environment, especially the marine ecosystem, as a result of human activity constitutes a form of pollution. Oil spills, which often result from accidental or operational discharges of petroleum hydrocarbon into the environment, are a global issue. Crude oil and natural gas are the main sources of foreign exchange for the Nigerian economy; they contribute as much as 95% to Nigeria's annual expenditures (Owugah, 2001). Despite this contribution, the Niger Delta area, which is a major oil-producing area in Nigeria, has severe deterioration in the quality of its environment because of the activities associated with oil exploration. These activities have resulted in oil spill pollution with attendant environmental degradation (Nwangwu & Okoye, 1981; Baker, 1982). This has become a matter of great concern to the people of the Niger Delta area because their water bodies and terrestrial ecosystems have been affected by oil pollution. Farming, usage of water for domestic purposes and fishing are what the majority of the people in the Niger Delta do for a living. However, these have resulted in environmental pollution from petroleum exploration in the area due to contamination of farmlands, fisheries and water supplies for domestic use. It has been observed that most farmers in areas where oil is produced find it difficult to restore the fertility of contaminated farmlands because of inadequate knowledge of proper remediation methods (Okoh, 2006). This problem could be solved if adequate attention is given to baseline data to evaluate bioremediation application strategies in various communities using native microorganisms that are isolated (Ebuehi et al., 2005). The government shows little or no concern for the problem of oil pollution, and this has affected food safety because long-term pollution could lead to the release of pollutants into food and water that can cause harm.

The process of exploration, production, distribution and handling of crude oil petroleum has affected the biophysical environment of the Niger Delta wetland. Since it is practically impossible to totally eliminate the occurrence of oil spills in the oil and gas industry, the best management approach is to focus on reducing, to a minimum, the risk and impact of oil spill occurrence through bioremediation. Remediation of hydrocarbon-polluted soils is usually the only alternative available for the people of the Niger Delta area to reduce the damage to human well-being and the biophysical and socio-economic environment. Bioremediation is the use of microorganisms or living plants to reduce and detoxify pollution in the environment. It is used to remove pollutants from the environment and, therefore, restores the original natural environment. Bioremediation uses different options to clean up oil-polluted sites, and one such option is the utilization of wastes derived from agricultural products, which have proved to be efficient in controlling pollution (Daane et al., 2001). Due to the low cost of design and the ability to reduce pollutants to a low and reasonable level, researchers have started to adopt the application of organic wastes for effective bioremediation.

Cassava peels are generally regarded as waste that should be disposed of or allowed to rot or, in some instances, fed to livestock. Microorganisms usually colonize the cassava peels because of their chemical composition, while the waste peels are decomposed by the microorganisms' enzymatic activities. Adding decomposed cassava peel organic waste to the soil has been found to improve the soil and can reduce the hydrocarbon through biodegradation to a level that is safe for human health and the environment.

The Niger Delta environment has been greatly polluted by the oil industry in the area. Crude oil spillage has environmental impacts on both coastal and terrestrial environments. Oil spills can result in immediate and long-term deterioration of water bodies and soil, as well as the health of plants, animals, man, and natural resources because most hydrocarbon compounds are harmful and continuous in aquatic and soil environments. In the Niger Delta area of Nigeria, the people attach importance to the quality of the environment because their economy, well-being and development depend on it. Over 60 percent of the people in the area depend on the natural environment for their survival, (UNDP, 2006). They use the environment for agriculture, fishing and collection of forest products. However, pollution has destroyed the environment, which is their means of survival.

Several studies on bioremediation of hydrocarbon-contaminated soil have been carried out by scholars in different parts of Nigeria using different agro wastes on the same topographic surface. However, only a few or no studies on comparative analysis of bioremediation rates of well-drained and waterlogged soils have been conducted in the Niger Delta. This study fills the gap. Decomposed cassava peels as organic wastes are used in this study as a natural attenuation agent for petroleum-contaminated soil with the aim of bioremediation in well-drained and waterlogged soils to ascertain which season and under which soil environment bioremediation proceeds faster.

Experimental Design

The study used experimental research design. The experimental plots were located on two topographic surfaces in Rumuagholu and Rumuekini in the Niger Delta area of Nigeria. The experiment consisted of six treatment plots at each of the three levels of contamination with three replications. These gave a total of eighteen plots in a randomized complete block design.

The size of each plot was 2m by 2m. Eighteen sampling plots were located in Rumuogholu, representing well-drained soils because the area allows water to percolate through the soil structure at a moderate rate, and eighteen sampling plots were located in Rumuekini behind the University of Port Harcourt Teaching Hospital (UPTH), representing the waterlogged (swampy) area because the area does not allow water to drain through it easily. The experimental setup consisted of plots with three grades of pollution, which include 2%, 4%, and 6% of Bonny light crude oil. The soil samples before contamination served as control.

Soil Treatment

The experimental plots were contaminated by pouring crude oil (Bonny-light) on them. The sample plots were graded into three levels of contamination with six replicates. Each sampling plot of 2m by 2m size was contaminated with different grades of Bonny-light crude oil. The crude oil was measured in a watering can and spread on each plot. The objective of applying crude on the sampling plots was to simulate the conditions of the oil spill. The plots were left undisturbed for seven days to allow for infiltration and percolation of the contaminant into the soil. The cassava peels were exposed to heat from sunlight and moisture and allowed to decompose for three weeks. Seven days after crude oil contamination of each plot, remediation materials were carefully introduced into each polluted plot. 28kg weight of decomposed cassava peels was introduced on each polluted plot of 2m by 2m to a depth of 10cm. The method involves the treatment of contaminated plots by incorporating topsoil with the decomposed cassava peels.

Soil Sample

Soil samples were collected from well-drained and waterlogged sites in Rumuagholu and Rumuekini, respectively, using soil augers at depths of 0-15cm (topsoil) and (15-30cm) subsoil. The decomposed cassava peels were introduced into the soil and left for three months before soil sampling after remediation. Soil samples were collected and bulked together from each grade of 2%, 4% and 6% pollution plots.

Eighteen sampled plots were augured and bulked together from the soils (0- 15cm) topsoil and 15-30 (subsoil). In all, thirty-six soil samples were collected from both sites for analysis. The soil samples were put in polythene bags, labelled accordingly and immediately transferred to the laboratory for analysis. Soil samples for analysis were collected before contamination, after contamination and after remediation.

Laboratory Soil Analysis: Estimation of Total Hydrocarbon Content (THC)

One gram (l.0g) of soil samples was air-dried at room temperature for five days and put in a 500-volumetric flask. 200ml xylenes were added. The xylene/soil mixture was shaken vigorously for 10 minutes. The extra was filtered into a 400ml cylinder. THC in the xylene mixture was determined by a photometric method using a Fisher Electro photometer II at a wavelength of 435mm. THC was estimated from the calibration curve obtained by measuring the absorbance of 30.0ml of Bonny light crude oil with 50ml xylene solution. Results were subjected to statistical analysis using descriptive statistics and independent t-test at $p < 0.05$.

Results and Discussion

Seasonal variation in the rate of Bioremediation

The data in Tables 1.1 and 1.2 showed the total hydrocarbon content of top soils and subsoils after remediation in dry and wet seasons. It was observed that the values of total hydrocarbon content were lower after remediation in both surface and subsurface soils in the dry season when compared to the values obtained after remediation in the wet season. The mean values of THC were 341.67 mg/kg, 355 mg/kg and 503.33 mg/kg in surface soils and 267.50 mg/kg, 269.17 mg/kg and 322.5 mg/kg in subsurface soils in the well-drained site after remediation during the dry season while the mean values of total hydrocarbon content were 391.67 mg/kg, 490 mg/kg and 670mg/kg in surface soils and 271.67 mg/kg, 297.5 mg/kg and 362.5 mg/kg in subsurface soil in the same site in the wet season after remediation. A similar observation was made in the waterlogged site. While the mean values of total hydrocarbon content were 434.17mg/kg, 426.67 mg/kg and 543.33 mg/kg in surface soils and 224.17 mg/kg, 243.33 mg/kg and 390 mg/kg in subsurface soils in the dry season after remediation, the mean values were 463.33 mg/kg, 535 mg/kg and 742.5 mg/kg in surface soils and 275mg/kg, 294.83 mg/kg and 410.83 mg/kg in subsurface soils in the wet season after remediation. Generally, the mean values of total hydrocarbon content after remediation in the dry season were lower compared to the mean values after remediation in the wet season.

Table 1.1 Total hydrocarbon content (mg/kg) of top soils (0-15cm) of remediated soils during the dry and wet seasons

Polluted Level		**Well Drained Site**		**Water Logged Site**	
		THC after remediation in dry season	**THC after remediation in wet season**	**THC after remediation in dry season**	**THC after remediation in wet season**
Treatment replicates	2% 1	400	425	350	675
	2	305	300	525	360
	3	300	400	410	350
	4	325	450	400	560
	5	420	390	540	345
	6	300	385	380	490
	Range	300-420	300-450	350-540	345-675
	Mean	341.67	391.67	434.17	463.33
Treatment replicates	4% 1	300	540	300	750
	2	300	345	490	475
	3	420	585	350	490
	4	385	480	560	520
	5	415	470	520	445
	6	310	520	340	530
	Range	300-415	345-585	300-560	445-750
	Mean	355	490	426.67	535
Treatment replicates	6% 1	515	825	530	800
	2	510	960	420	870
	3	450	360	625	595
	4	540	450	565	670
	5	475	485	630	700
	6	530	940	490	820
	Range	450-540	360-960	490-630	595-870
	Mean	503.33	670	543.33	742.5

Source: Author's analysis, 2021

Table 1.2 Total hydrocarbon content (mg/kg) of subsoils (15-30cm) of remediated soils during the dry and wet seasons

Polluted Level		Well Drained Site		Water Logged Site	
		THC of remediation in dry season	**THC of remediation in wet season**	**THC of remediation in dry season**	**THC of remediation in wet season**
Treatment replicates	2% 1	250	260	180	500
	2	300	245	190	250
	3	240	300	200	220
	4	270	320	230	240
	5	260	195	245	210
	6	285	310	300	230
	Range	240-300	195-320	180-300	210-500
	Mean	267.50	271.67	224.17	275
Treatment replicates	4% 1	195	300	250	300
	2	230	240	175	310
	3	275	340	315	205
	4	280	290	200	374
	5	310	320	280	300
	6	325	265	240	280
	Range	195-325	240-340	175-315	250-374
	Mean	269.17	297.50	243.33	294.83
Treatment replicates	6% 1	350	435	190	430
	2	230	490	700	485
	3	270	360	345	390
	4	310	280	300	470
	5	380	330	425	395
	6	305	280	380	295
	Range	270-380	280-490	190-700	295-485
	Mean	322.5	362.5	390	410.83

Source: Author's Analysis, 2021

Percentage reduction in total hydrocarbon content (mg/kg) of soils after remediation during the dry and wet seasons

The percentage reductions in total hydrocarbon content in surface and subsurface soils during the dry and wet seasons were compared in Tables 1.3 and 1.4. The mean percentage reductions in THC in the well-drained site after remediation during the dry season were 56.16 mg/kg, 55.55 mg/kg and 42.27 mg/kg in surface soils and 56.32 mg/kg, 56.25 mg/kg and 56.48 mg/kg in subsurface soils while in the wet season, the mean percentage reductions were 20.40. mg/kg, 22.38, and 24.15 mg/kg in surface soils and mean percentage reduction was 16.40

mg/kg, 18.38 mg/kg and 24.15 mg/kg in surface soils and 16.57 mg/kg, 18.13 mg/kg and 17.02 mg/kg in subsurface soils after remediation in the 2%, 4% and 6% polluted plots respectively. In the waterlogged site, the mean percentage reductions in total hydrocarbon content after remediation during the dry season were 50.74 mg/kg, 43.72 mg/kg and 41.41 mg/kg in subsurface soils, while in the wet season, the mean percentage reduction was 40.46 mg/kg, 47.73 mg/kg and 44.84 mg/kg in subsurface soils after remediation in the 2%, 4% and 6% polluted plots as indicated in tables 1.3 and 1.4. In the waterlogged site, the mean percentage reductions in total hydrocarbon content after remediation during the wet season were 14.01mg/kg, 18.69 mg/kg and 20.30 mg/kg in surface soils, while the values were 30.96 mg/kg, 20.79 mg/kg 18.32 mg/kg in the subsurface soils in the 2%, 4% and 6% polluted plots as shown in tables 1.3 and 1.4 respectively. From Tables 1.3 and 1.4, the results revealed that the values of percentage reduction in THC after remediation in the dry season were higher compared to the values of percentage reduction obtained after remediation in the wet season. Statistical test of significance showed that percentage reductions in THC in the dry season were higher ($P < 0.05$) than in the wet season. The values were significantly different. This means that the rate of crude oil biodegradation was more rapid in the dry season than in the wet season.

The metabolism modes for biodegradation of hydrocarbon molecules include aerobic and anaerobic conditions. Aerobic condition results in a higher biodegradation rate (Suthersan, 1999). From the results of the analysis in Tables 1.1 and 1.2, it was evident that the bioremediation conducted during the dry season proceeded at a higher rate under aerobic conditions compared to the wet season. Hydrocarbons are readily degraded under aerobic conditions, where oxygen is transferred into the lower layers of soil by diffusion. This creates an ideal growing environment for the microbes together with the proper amount of water, pH, nutrients and the proper range of temperature to accelerate the natural bioremediation process. Some bacteria grow and reproduce only when oxygen is present. They use the oxygen for the process of aerobic biodegradation. While the hydrocarbon loses electrons and is oxidized, oxygen gains electrons and is reduced and this results in the formation of carbon dioxide and water (Nester et al., 2001).

Rainfall affects the amount of soil moisture. During the rainy season, the high amount of water reduces the oxygen in the soil and so decreases the biodegradation rate. The wet season phase of the study started in April and continued to July during which there was heavy rainfall. This resulted in a significant increase in the moisture content of the soil. Too much water in the soil leads to anaerobic conditions as the pore spaces within the soil are covered with water, causing a lack of oxygen. Decreased soil oxygen levels result in reduced biodegradation efficiency and rate (Johnson et al., 1999; Yang et al., 2009).

High moisture content may reduce microbial activities by the indirect hindrance to the movement of air, which would reduce oxygen supply to plants. The infusion of degradable hydrocarbons likely stimulates aerobic and anaerobic microbial metabolism. However, as oxygen becomes limiting, it reduces the environment and slows down the rate of bioremediation during the wet season. As crude oil infiltrates the soil, it physically displaces soil air and water. This can have a significant effect in promoting anaerobic conditions in soil (Iwegbue et al., 2007). Anaerobic respiration produces less energy for microorganisms (than aerobic respiration) and can slow down the rate of biodegradation.

Table 1.3 Percentage reduction in total hydrocarbon content (mg/kg) of top soils (0-15cm) after remediation during the dry and wet seasons

Polluted Level		**Well Drained Site**		**Water Logged Site**	
		% reduction in THC in dry season	**% reduction in THC in wet season**	**% reduction in THC in dry season**	**% reduction in THC in wet season**
Treatment replicates	2% 1	55.56	24.78	54.25	6.25
	2	55.80	21.67	44.74	25.00
	3	61.64	18.39	53.67	12.50
	4	51.85	17.65	52.94	13.85
	5	51.16	19.59	44.90	19.77
	6	61.04	20.32	53.94	6.67
	Mean	56.16	20.40	50.74	14.01
Treatment replicates	4% 1	62.50	23.18	42.04	10.67
	2	59.73	24.33	38.94	26.67
	3	53.33	20.33	50.00	08.33
	4	54.44	22.00	40.09	22.59
	5	56.77	19.07	39.48	25.97
	6	46.55	25.38	51.76	17.89
	Mean	55.55	22.38	43.72	18.69
Treatment replicates	6% 1	47.18	19.12	34.97	21.57
	2	37.80	25.29	46.15	19.82
	3	44.44	23.33	34.21	21.71
	4	41.94	29.49	42.93	20.24
	5	35.81	33.14	49.60	24.14
	6	46.46	14.55	40.61	14.14
	Mean	42.27	24.15	41.41	20.30

Source: Author’s Analysis, 2021

Table 1.4 Percentage reduction in total hydrocarbon content (mg/kg) of sub-soils (15-30cm) after remediation during the dry and wet seasons

Polluted Level		Well Drained Site		Water Logged Site	
		% reduction in THC in dry season	**% reduction in THC in wet season**	**% reduction in THC in dry season**	**% reduction in THC in wet season**
Treatment replicates	2% 1	58.33	16.30	40.00	3.85
	2	53.49	15.52	36.67	33.33
	3	58.62	16.67	42.03	26.67
	4	56.45	14.67	46.51	37.66
	5	55.93	25.00	36.36	43.24
	6	55.12	11.43	41.18	41.03
	Mean	56.32	16.57	40.46	30.96
Treatment replicates	4% 1	55.17	26.67	52.38	23.08
	2	60.68	20.00	51.39	22.50
	3	55.28	4.23	50.00	33.87
	4	58.21	19.44	47.37	10.95
	5	52.67	20.00	40.43	16.67
	6	55.48	18.46	44.83	17.65
	Mean	56.25	18.13	47.73	20.79
Treatment replicates	6% 1	58.33	5.43	50.00	15.69
	2	53.33	18.33	33.33	19.17
	3	57.14	20.00	48.89	15.22
	4	60.51	12.50	53.85	16.07
	5	52.50	19.51	39.29	19.39
	6	57.04	26.34	43.70	24.36
	Mean	56.48	17.02	44.84	18.32

Source: Author's Analysis, 2021

Comparison of rates of bioremediation in well-drained and waterlogged soils

Different soil types and their potential for contaminant degradation differ significantly. Particle size distribution parameters have an influence on bioremediation. Sand was observed to be the predominant soil fraction in the well-drained site and clay was slightly higher in waterlogged site than in the well-drained site. These soil characteristics have an influence on the remediation of hydrocarbon-contaminated soil. The data in Tables 1.3 and 1.4 indicated that the rate of remediation depended on the type of the soil as it was much higher in the well-drained site where the soil was sandy loam dominated by more sand particles than the waterlogged site where the soil was sandy clay dominated by more silt and clay particles.

There was a difference between the total hydrocarbon content in the well-drained and waterlogged sites after remediation in both dry and wet seasons. The mean values of total hydrocarbon content were lower in the well-drained site than in the waterlogged site. These differences can be explained by the loose structure of the soil particulates in the sandy soil of the well-drained site and the much higher stickiness and plasticity of clay in the waterlogged site. At the microscopic level, clay is composed of fine particles (< 0.002 mm in size) and adheres easily to one another (Kujawski et al., 2009). The biodegradation rates are affected by the fineness of the soil. Clay soil characterized by more fines exhibited a lower biodegradation rate, and the extent of bioremediation was lower than that of sandy soils with smaller fine fractions. The increased sorptive surface area of clay soil with larger fines affects the bioavailability of certain hydrocarbon contaminants. Contaminants can adsorb to soil particles, rendering some contaminants unavailable to microorganisms for biodegradation. Thus, in some circumstances, the bioavailability of contaminants depends not only on the nature of the contaminant but also on soil type. Hydrophobic contaminants, like petroleum hydrocarbons, have low solubility in water and tend to adsorb strongly in soil with high organic matter content. The fineness of the soil in the waterlogged site reduces the rate of remediation.

Soil texture determines the "water retention" capacity of soil and affects how well nutrients and water are retained in the soil. Fine textured soils like clays have low permeability, which prevents oxygen and nutrients from dispersing throughout the soil. It is also difficult to control moisture content in fine-textured soils because their smaller pores and high surface area allow it to retain water. Fine textured soils are slow to drain water-saturated conditions, thus preventing oxygen from reaching soil microbes throughout the contaminated area (USEPA, 2006). Gawel (2003) found that loamy soil remediates at a faster rate than heavy clay soil. In the well-drained upland area, the soil texture was loamy sand, with a little fraction of clay. Hence, remediation was faster because the soil was better drained with good pore spaces. The soil microorganisms require air and water, both of which are necessary for aerobic biodegradation to occur. Thus, the hydrocarbon concentration levels of the well-drained remediated soils were observed to be lower than those of poorly drained or waterlogged soils of the swamp area.

Porosity, bulk density and air permeability are other major physical characteristics of soil that may influence the bioremediation process. The permeability determines the rate of transfer of electron acceptors to the contaminated soil. Bulk density is used to measure compaction. The greater the bulk density, the less the pore space for water movement, root growth, penetration and seedling germination. It reflects the ability of the soil to function for structural support, water and solute movement and soil aeration.

Conclusion

The study revealed that cassava peels (agro waste) significantly improved the rate of petroleum hydrocarbon degradation in polluted soil. The results also showed that hydrocarbon-degrading bacteria were present in the soil and also in the cassava peels used for remediation. The cassava peels supplied both nutrients and hydrocarbon-degrading bacteria to the contaminated environment and, therefore, can enhance the biodegradation of crude oil in polluted soil. The study also showed that crude oil pollution encouraged the rapid development of some hydrocarbon-degrading microbes that utilized crude oil as a source of food, thereby breaking down the hydrocarbon chain. The study discovered that though bioremediation is an economical technique for polluted soils, its efficacy depends on the nature of the soil and the season in which it is conducted. The study revealed that bioremediation is more efficacious in well-drained soils than in waterlogged or swampy soils, and it proceeds at a higher rate in the dry season than in the wet season.

Therefore, in some parts of the Niger Delta region of Nigeria, where the soils are poorly drained, the application of bioremediation technique may be limited, especially when it has to do with recalcitrant hydrocarbon compounds. However, the study has shown that bioremediation using decomposed cassava peels as a remediation material can be applied to deal with hydrocarbon on well-drained soils and during the dry season in the Niger Delta area and other parts of the world with similar problems of hydrocarbon pollution.

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