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Original Research Article

Bioremediation of Crude-Oil-Contaminated Soil Using Oil Palm Frond (Leaf)

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Abstract

Crude oil spillage is a major problem in Nigeria as it basically affects soils, plants grown on the soil, and the environment at large. The need to remediate crude-oil-contaminated soil to its original state is of utmost importance. The potential of oil palm frond (leaf) to remediate crude-oil-contaminated soil was investigated in this study. The soil samples were analyzed before and after contamination, during bioremediation process and after the treatment process by determining the pH, moisture content and total organic carbon (TOC) parameters of the soil sample each week for a period of four (4) weeks. The results obtained showed that the pH of the soil sample before and after contamination were pH 8.0 and pH 6.0 respectively, while during the bioremediation process with the oil palm frond (leaf) sample applied on the contaminated soil samples and at the end of the treatment process, the pH of the samples was pH 6.2, pH 6.3, pH 8.0, pH 7.0 respectively. The moisture content result obtained showed that the soil sample before and after contamination were 16.2% and 11.2% respectively, during the bioremediation process and at the end of the treatment process the moisture content were 7.5%, 1.4%, 7.4%, and 9.4% respectively. While the TOC result obtained for the soil sample before and after contamination were 2.55% and 1.22% respectively while during the bioremediation process the results were 1.22%, 1.22%, 1.29%, 1.36% respectively. This demonstrated the ability of oil palm frond (leaf) to reduce contaminants in the soil and consequently remediate the crude oil contaminated soil to an extent.

Keywords: Crude oil, Bioremediation, palm leaf.

1. INTRODUCTION

Bioremediation broadly refers to any process wherein a biological system (typically bacteria, microalgae, fungi and plants) living or dead is used for removing environmental pollutants from air, water, soil, flare gases, industrial effluents, etc. in natural or artificial settings (Wikipedia, 2022). The natural ability of organisms to adsorb, accumulate, and degrade common and emerging pollutants has attracted the use of biological resources in the treatment of contaminated environment. In comparism to conventional physiochemical treatment methods which suffer serious drawbacks, bioremediation is sustainable, eco-friendly, cheap, and scalable. Most bioremediation is inadvertent involving native organisms. Research on bioremediation is heavily focused on stimulating the process by inoculation of a polluted site with organisms or supplying nutrients to promote the growth. In principle, bioremediation could prove less expensive and more sustainable than other remediation alternatives (Wikipedia, 2022). The primary aims of any remediation are reduction of actual or potential environmental threat and reduction of potential risks so that unacceptable risks are reduced to acceptable levels (Atlas, 1995). Consequently, the need for remediation will depend on the degree of actual or potential environmental threat or the level of risk (Ukoli, 2003).

Crude-oil-contaminated soils are soils that have been contaminated by petroleum hydrocarbon. Soils contaminated by petroleum hydrocarbons can affect soil health by harming soil microorganisms, reducing their number and activity. Reducing microbes numbers or activity also affects plants (Soil Science Society of America, 2022). Petroleum liquid in its natural state is referred to as crude oil (Ukoli, 2003). Crude oil is mainly either black or green but it can be light yellow (Onifade *et al.*, 2007). Crude oil varies considerably in density and is described as heavy, average or light. Petroleum products remain the principal source of energy; however, despite its importance and large amounts of usage on land, petroleum products have posed global environmental pollution (Amund, 2000; Phlohl *et al.*, 2002; Chikere & Chijioke-Osuji, 2006). In the Niger Delta region of Nigeria, terrestrial and aquatic systems are the main recipients of crude oil spillage, sometimes resulting in large scale contamination of these environments. Crude oil contamination in the Niger Delta region is gaining more prominence as a result of increased upstream and downstream activities of the petroleum industry, hence increased deleterious effect on the ecology of this area (UN Report, 2001).

Oil palm leaf popularly known as "oil palm fronds" are one of the biomass residues originating from oil palm plantation (Razak *et al.*, 2021). Oil palm known as Elaeis guineensis is a species of palm also sometimes called African oil palm or macaw fat, it is the principal source of palm oil (Wikepedia, 2022; Dune, 2022). Oil palm includes the palm species native to Africa, South and Central America (plant village: CABI Crop Protection Compendium, 2013). Oil palm leaves are members of the Arecaceae or palmae family and grow on flowering evergreen shrubs, trees and woody vines known as lianas.

2. MATERIALS AND METHODS

In order to achieve the set objectives, an experimental approach (conducted at the Department of Petroleum Engineering Laboratory, Rivers State University, Port Harcourt) was employed in the process of bioremediating crude-oil-contaminated soil samples using oil palm frond (leaves).

2.1 Materials

The following materials, reagents and equipment were used for the experiment. The **materials** used were (1) Oil palm frond (leaf) (2) Loamy soil, and (3) Crude Oil.

Reagents

The following reagents were used: potassium dichromate, ferrous ammonium sulfate (FAS), ferroin indicator, distilled water, sulphuric acid (H_2SO4).

Apparatus

Electronic weighing balance, reactor bucket, sieve, knife, filter paper, rubber cans, retort stand, empty crucible (moisture can), digital oven, manual weighing balance, burette, measuring cylinder, beaker, petri-dish, spatula, and litmus paper.

2.2 Methods

2.2.1 Collection of Samples

The loamy soil sample was dug from a small farm site at Rumuodani, Port Harcourt, the crude oil sample was gotten from Sigmund pump station (Shell outlet) at Abonnema Wharf, Port Harcourt, while oil palm frond sample was cut from a tall palm tree in a residential area at Odani, Elelenwo, Port Harcourt, Rivers State.

2.2.2 Preparation, Sieving and Weighing of the Soil and Leaf Sample

The oil palm frond (leaves) sample was plugged out from the stalk to separate it for easier grinding. The leaves were washed with distilled water in other to get rid of dirts and impurities, then air dried to remove some amount of moisture in it. Then, they were cut in small pieces and grinded using a grinder. After grinding the oil palm leaf (frond) sample, the weight of the crushed sample was obtained using an electronic weighing balance and later sieved according to particle sizes.

The total weight of the loamy soil was obtained by placing a cut-open nylon on the weighing balance, the soil sample was poured on the nylon and a counter weight was placed at the other side of the weighing balance to counter balance the weight of the soil sample. The weight obtained in grams was added to the weight of the counter balance to get the total weight of the soil sample, which was 5,370g.

The total weight of the oil palm leaf sample was obtained using the same procedure for obtaining the weight of the soil sample and the total weight of the oil palm leaf sample obtained using the weighing balance was 1,360g.

2.2.3 Bioremediation Process

2,000g of soil was measured into two (2) treatment cells (containers) respectively, labelled sample A and sample B. 1,370g of soil was measured into another treatment cell and labelled sample X, which was used as the control sample. 50ml of crude oil was measured in a measuring cylinder and poured into sample A and sample B respectively. The samples mixed thoroughly to ensure the crude oil mixes with the soil properly. After mixing, it was set aside to allow it infiltrate properly for three days. The pH, moisture content and total organic carbon of sample X was then tested and the results were recorded. After three days, 200g of oil palm leaf was added into sample B and mixed thoroughly for the treatment process and was set aside. The pH, moisture content and total organic carbon of sample A was then tested and the results recorded. After one week of applying the leaf sample in sample B, the pH, moisture content and total organic carbon of sample B was tested and the obtained result recorded. The same procedure was carried out after each week of treatment process for a total of four weeks to determine the effectiveness of the oil palm leaf (frond) in remediating the crude oil contaminated soil. The soil sample divided into three treatment cells were categorized thus:

i. The first cell was labelled sample A, containing crude oil contaminated soil sample with no treatment added in it.

ii. The second cell was labelled sample B, containing crude oil contaminated soil sample with 200g of oil palm leaf (frond) added in it + 0.2 litres of water.
iii. The third cell was labelled sample X, containing uncontaminated soil sample (also called control sample) with no treatment applied on it.

2.2.4 Sample Characterization

In the characterization of the soil sample, the pH, moisture content and Total Organic Carbon (TOC) were determined according to standard methods.

(i) pH Determination

Amongst the many methods for determining pH in a soil, litmus paper test was favoured. The experimental procedure was carried out by measuring 5g of soil sample into a rubber can. 20ml of distilled water was measured and poured into the rubber can and stirred thoroughly to mix for 10 minutes. After which a filter paper was placed in a funnel-like rubber can on top a cut open rubber can and the mixed sample was poured onto the filter paper to get the filtrate. A litmus paper was then slightly dipped into the filtrate and was placed on a white experiment bench for a clear observation of colour change. The colour change of the litmus paper was observed and the result recorded. This procedure was repeated for each soil sample and the respective pH result were recorded.

The United States Department of Agriculture Natural Resources Conservation Service classification of soil pH is displayed in Table 1.

Table 1: US Department of Agriculture Natural Resources Conservation Service classification of soil pH

Denomination	pH Range
Ultra acidic	<3.5
Extremely acidic	3.5 – 4.4
Very strongly acidic	4.5 – 5.0
Strongly acidic	5.1 – 5.5
Moderately acidic	5.6 – 6.0
Slightly acidic	6.1 – 6.5
Neutral	6.6 – 7.3
Slightly alkaline	7.4 – 7.8
Moderately alkaline	7.9 – 8.4
Strongly alkaline	8.5 – 9.0
Very strongly alkaline	>9.0

0 to 6 = acidic, 7 = neutral, and 8 and above alkalinity

Source: Wikepedia, 2022.

(ii) Moisture Content Determination

The moisture content of the soil sample was determined by oven drying method. The experimental procedure involved turning on the electronic weighing balance and setting the reading to 0.00 to avoid additional weight being recorded before weighing the soil sample. A well labelled empty moisture can (crucible) was weighed on an electronic weighing balance and the weight recorded. 5g of soil sample was poured into the empty moisture can and weighed, the weight was also recorded. The moisture can was then placed in the oven at 105^{0}C and left to dry for 24 hours. After 24 hours, the moisture can was brought out of the oven carefully with a hand towel and was weighed in an electronic weighing balance. The new weight was recorded. The soil was kept aside to be used for the Total Organic Carbon (TOC) experiment. This procedure was repeated for each soil sample and the respective weights were recorded.

(iii) Total Organic Carbon Determination

The determination of soil organic carbon was done based on the Walkley-Black chronic acid wet oxidation method. The experimental procedure involved reducing the moisture content of the soil samples to the barest minimum. 2g of the dried soil sample used for moisture content experiment was grinded finely and poured into a well labelled beaker. 10ml of potassium dichromate was poured into the beaker, the beaker was swirled to disperse the soil in the solution. Another 20ml of concentrated H_2SO_4 was added into the solution directing the steam into the suspension immediately the beaker was swirled until the soil and the reagents were mixed and set aside to cool in a fume chamber. A burette was clamped firmly on a retort stand and 50ml of ferrous ammonium sulphate (FAS) was measured in the burette set for titration. A blank sample (distilled water precisely) was test run by titrating with $FeSO_4$ (FAS) in other standardize the $FeSO_4$ and confirm if it is effective. The titrate values were recorded. After the solution in the labelled beaker has been cooled for 20 minutes, it was diluted up to 200ml with delonized water and stirred. 20ml of the solution was measured in a measuring cylinder and poured in another beaker. 2 – 3 drops of ferroin indicator were added to the beaker and swirled then titrated with ferrous Ammonium Sulphate (FAS). As the end point is approached, the solution takes on a greenish colour and then changes to a dark green colour at this point, the ferrous ammonium sulphate was added drop by drop until the colour changed sharply from blue-green to reddish grey. The titration was stopped and the values were recorded. This procedure was repeated for each soil sample and the respective values were recorded.

3. RESULTS, ANALYSIS AND DISCUSSION

The following results were obtained before and after the bioremediation treatment of the contaminated soil with 200g of oil palm leaf (frond) sample. The pH, moisture content and TOC are illustrated in the table of results (Tables 2-4).

3.1 pH Determination

Table 2 shows the pH result of the uncontaminated soil sample and the contaminated soil sample before treatment while Table 3 shows the pH result of the contaminated soil sample during treatment and after treatment with the application of the oil palm leaf sample.

Table 2: pH Result before bioremediation

Sample	Week	pH
X (uncontaminated soil)	1	8.0
A (contaminated soil)	1	6.0

Table 3: pH Result during bioremediation

Sample	Week	pH
B (contaminated soil + 200g of oil palm leaf sample)	1	6.2
B	2	6.3
B	3	6.5
B	4	7.0
B	5	7.1

From the experimental results, the pH obtained from the uncontaminated soil sample showed that the soil was moderately alkaline but when contaminated with crude oil, the soil became moderately acidic. During the bioremediation treatment process with the oil palm leaf (OPL) sample, the pH of the contaminated soil gradually increased to neutral towards the end of the treatment process as seen in Table 3 and Figure 1.

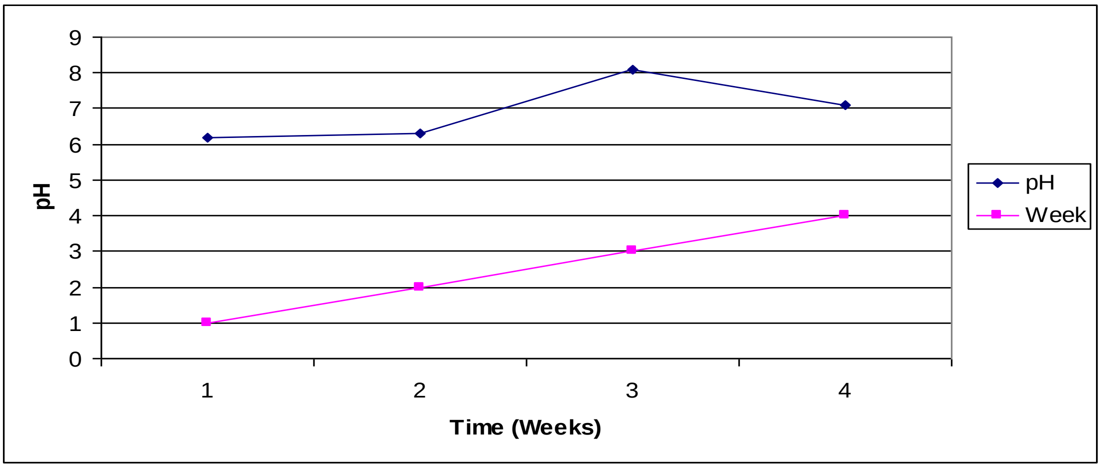

Figure 1: pH Result Graph

Soil pH is a measure of the acidity or basicity (alkalinity) of a soil and is a key parameter that can be used to make informative analysis both qualitatively and quantitatively regarding soil characteristics. In soils, it is measured in a slurry of soil mixed with water and normally falls between 3 and 10, with 7 being neutral. Acidic soils have a pH below 7 and alkaline soils have a pH above 7. Ultra-acidic soils (pH < 3.5) and very strongly alkaline soils (pH > 9) are rare. The pH of a natural soil depends on the mineral composition of the parent material of the soil, and the weathering reactions undergone by that parent material. In warm, humid environments, soil acidification occurs overtime as the product of weathering are leached by water moving laterally or downwards through the soil. The optimum pH range for most plants is between 5.5 and 7.5, however, many plants have adapted to thrive at pH values outside this range (Wikepedia, 2022). The United States Department of Agriculture Natural Resources Conservation Service classification of soil pH is displayed in Table 1

3.2 Moisture Content Determination

Table 4 shows the result of the moisture content of the uncontaminated and contaminated soil sample before treatment and the result during treatment and after treatment with the application of the oil palm leaf sample.

Table 4: Moisture Content Result

Sample	Week	Weight of Moist Soil Sample (g)	Weight of Empty can (g)	Weight of can + Moist Soil Sample (g)	Weight of can + dry soil sample (g)	Weight of dry soil sample (g)	Moisture Content (%)
X (uncontaminated soil)	1	5.02	21.18	26.20	25.50	4.32	16.2
A (contaminated soil)	1	5.04	22.76	27.80	27.29	4.53	11.2
B (contaminated soil + 200g of Oil Palm Leaf)	1	5.01	20.95	25.96	25.61	4.66	7.5
B	2	5.05	21.35	26.40	26.33	4.98	1.4
B	3	5.05	21.30	26.35	26.00	4.70	7.4
B	4	5.00	21.00	26.00	25.57	4.53	9.4

The moisture content of the contaminated soil sample reduced and during the treatment process with the OPL sample, there was a gradual reduction in the moisture content of the soil in the 2nd week which later increased gradually at the 3rd and 4th week as shown in Figure 2. This cause is due to weather condition effect since moisture content is an in-situ property which gets affected by present condition.

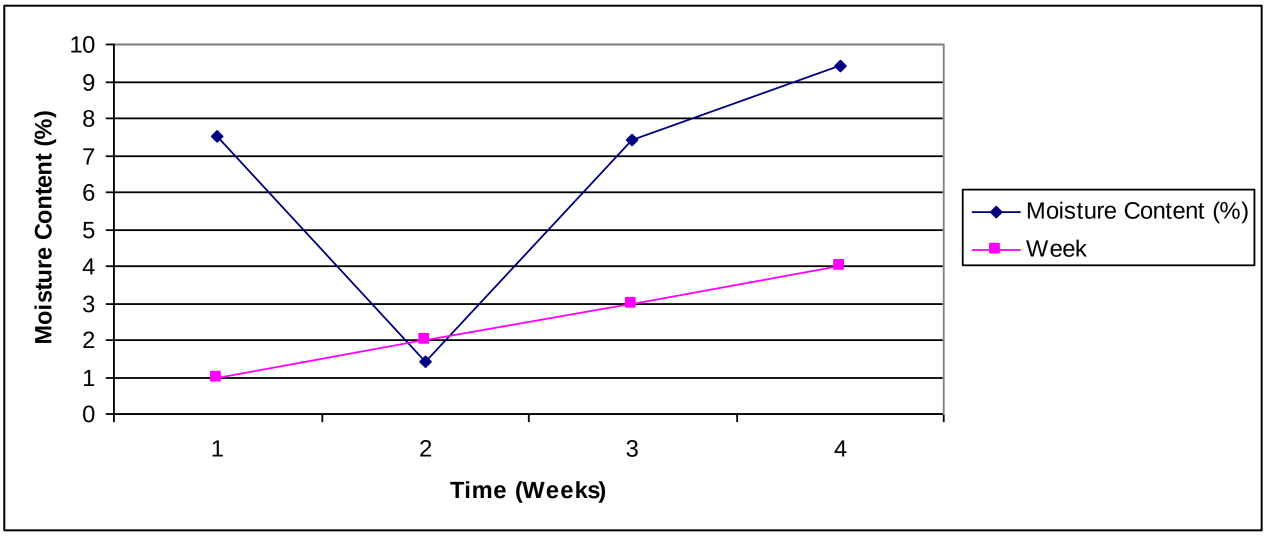

Figure 2: Moisture Content Result Graph

Soil moisture refers to the entire quality of water in the soil's pores. If there is a shortage or overabundance of water, plants may die. The moisture content of soil depends on such factors as weather, type of land, and plants. The parameter is vital in monitoring farming activities, predicting natural disasters, managing water supply, etc. Soil moisture affects: content of air, salinity and number of toxic substances; soil structure and thickness; temperature and heat capacity of the ground. This parameter prevents weathering and determines the field's readiness for agricultural processing. The optimal range of soil moisture content for crops depends on the specific plant species, but the range for most crops is between 20-60%. Soil Moisture Thresholds for Specific Ground Textures is presented in Figure 3. The desired moisture content depends on the Field Capacity (FC) and the Permanent Wilting Point (PWP). FC means how much water the soil can hold after the excess drains off. It displays the balance of water and air in the ground's pores. There would not be enough oxygen if the moisture percentage is too high. PWP reflects the temperature threshold below which plants begin to wither and die because they do not receive enough water. Both depend on the type of soil. It is thus critical to conduct an appropriate analysis that specify the optimal soil moisture range. Also, an important indicator is Total Available Water (TAW), that is, how much of it plants can get. Above FC, crops can take it only for 1 – 3 days; below PWP, crops cannot absorb the needed water any more (EOS Data Analytics, Inc, 2022). The section below shows the list of standard moisture content of soil for some of its different types.

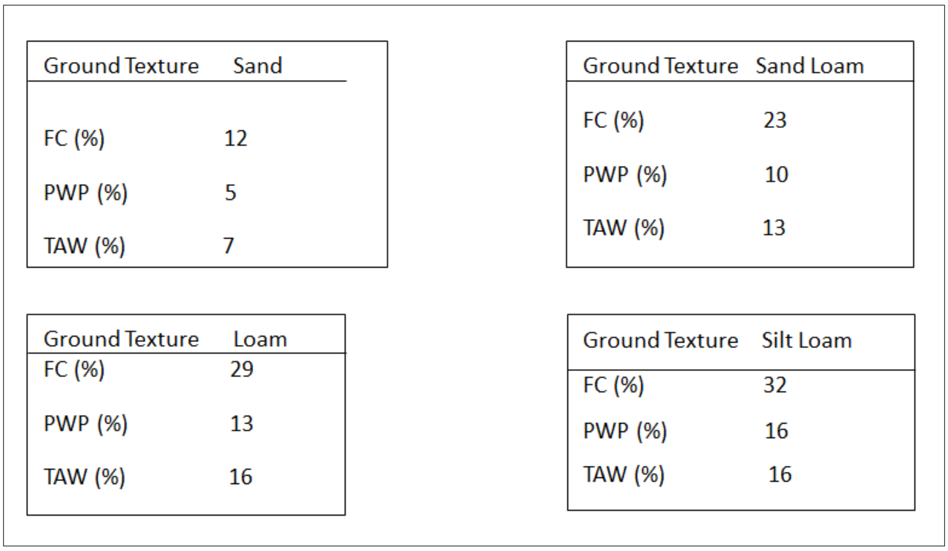

Figure 3: Soil Moisture Thresholds for Specific Ground Textures (EOS Data Analytics, Inc. 2022)

Total Organic Carbon (TOC) Determination

Table 5 shows the value result for the total organic carbon in the uncontaminated and the contaminated soil sample and the gradual increase during the treatment process and after the treatment period with the application of the oil palm leaf sample.

Table 5: Total Organic Carbon Result

Sample	**Week 1 (%)**	**Week 2 (%)**	**Week 3 (%)**	**Week 4 (%)**
Blank	0.4	0.4	0.4	0.4
X (uncontaminated soil)	2.55	2.55	2.56	2.5
A (contaminated soil)	1.22	1.22	1.28	1.35
B (contaminated soil + 200g of oil palm leaf)	1.22	1.22	1.29	1.36

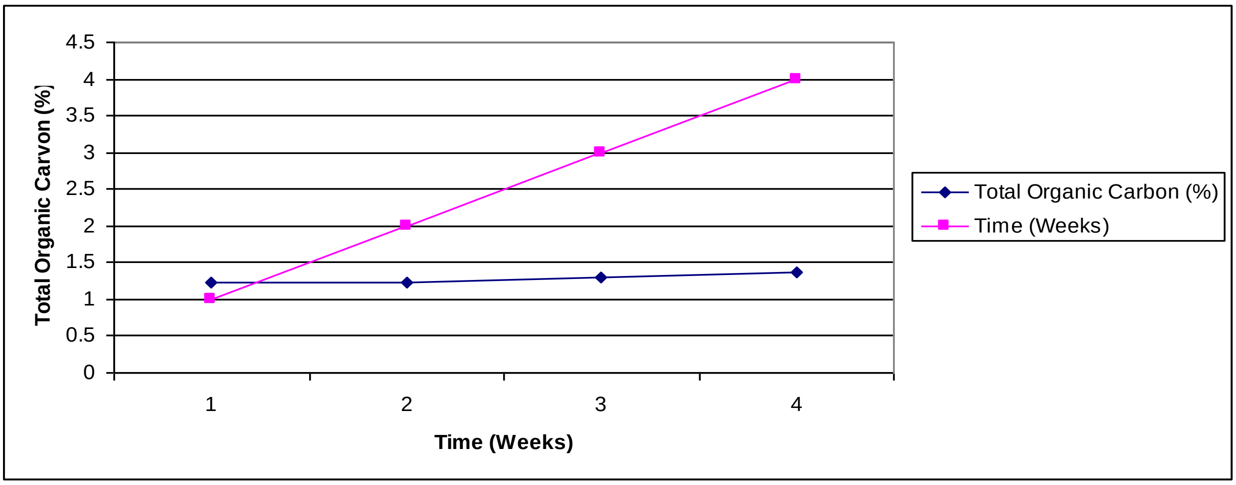

Figure 4: Total Organic Carbon (TOC) Result

The total organic carbon in the contaminated soil reduced compared to the uncontaminated soil and during the treatment process with the application of the OPL sample, there was a gradual increase in the TOC of the treated soil till the end of the treatment process as shown in Figure 4. This suggest that if given a longer period of time for treatment, more effective result will be observed as the experimental procedure for this result lasted for only four (4) weeks. However, the use of oil palm leaf can be employed as a new material in the bioremediation of crude oil contaminated soil if further investigations are carried out on its total effectiveness.

Total Organic Carbon (TOC) is the amount of carbon found in an organic compound. TOC may also refer to the amount of organic carbon in soil, or in a geological formation, particularly the source rock for a petroleum play; 20% is a rough minimum (Wikepedia, 2022). Estimates of total organic carbon (TOC expressed as C) are used to assess the amount of organic matter in soils. The method measures the amount of carbon in plant and animal remains, including soil humus but not charcoal or coal. Levels are commonly highest in surface soils but wide variations from almost zero to above 15% are possible. Presence of CL will produce a positive interference in saline soils (>0.590CL); the bias resulting from the presence of Cl can be corrected if required.

5. CONCLUSION

Soils contaminated by crude oil are economically useless and dangerous to the health of organisms living in and around them. Such soils need to be remediated in other to redeem it to it's original state which can be useful for agricultural purposes. Bioremediation is considered as a safe and sustainable technology which can be simultaneously used with other physical and chemical treatment method for complete management of diverse group to of environmental pollutants. Hence, there is need for more research in this area. More efforts need to be made to generate a synergistic interaction between the environmental impact on the behaviour of environmental contaminants and performance of the most suitable bioremediation technique and other relevant technique that can sustain the effective and successful operation and monitoring of a bioremediation process. This study investigates the use of oil palm frond (leaf) in the remediation of crude oil contaminated soil. The results show that oil palm frond (leaf) is effective in reducing the pH of crude oil contaminated soil and it also stabilizes the moisture content and total organic carbon of the soil making it a considerable material for use in the remediation of crude oil contaminated soil. This research work further illustrates the potential of oil palm frond (leaf) in minimizing environmental pollution which will reduce economical cost in the treatment of crude oil contaminated soil via bioremediation method.

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