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Assessment of the potential of *Pterocarpus osun* Craib to remediate crude oil-contaminated soil in the Niger Delta

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ABSTRACT

Crude oil pollution affects biodiversity by inhibiting seed germination and plant growth, among other physiological and metabolic obstructions. Some leguminous tree plants have a high tolerance for hydrocarbon pollutants and could prove valuable in the remediation of polluted land. This study aimed to assess the potential of *Pterocarpus osun* to remediate crude oil-tainted soil in the Niger Delta. The germination and growth rates were determined following standard procedures conducted under a controlled environment. Soil pH, organic matter, fertilizer (nitrogen, phosphorous, potassium), and exchangeable bases (magnesium, sodium and calcium) were determined following standard protocol. The percentage germination and coefficient of velocity (COV) for the plant treated with 0 ml crude oil spiked soil extract was 28% (22); for 25 ml treatment it was 23% (17); for 50 ml treatment it was 21% (17); for 75 ml it was 17% (13) and for 100 ml of crude oil it was 15% (9). Mean heights corresponding to 0 ml, 25 ml, 50 ml, 75 ml and 100 ml crude oil-polluted soil treatment were 1.75 cm, 2.50±1.78 cm, 2.75±1.80 cm, 1.95±1.68 cm and 1.65±2.50 cm in that order, at 2 weeks after planting (2 WAP), which later increased to 58.50 cm, 38.60 cm, 28.70 cm, 21.50 cm and 20.10cm correspondingly at 16 WAP. The mean girth increased from 0.12 mm to 0.34 mm, 0.12 mm to 0.31 mm, 0.11 mm to 0.27 mm, 0.11mm to 0.24 mm, and 0.10 mm to 0.21 mm girth respectively, between 2 WAP and 16 WAP. The number of nodules was 8, 5, 6, 2 and 0 while the number of leaves was 10.00, 8.00, 6.00, 5.00 and 5.00 correspondingly in increasing order of crude oil concentration. The monitored soil physicochemical characteristics decreased inversely to the concentration of crude oil in the soil. The percentage growth

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suppression was 34.00% for 25 ml crude oil-spiked soil treatment, 50.90% for 50ml crude oil-spiked soil treatment, 63.20% for 75 ml crude oil-spiked soil treatment and 65.60% for crude oil-spiked soil treatment. The relative growth (RGR) for the plants at 0 ml, 25 ml, 50 ml, 75 ml and 100 ml crude oil-spiked soil treatment was 0.25, 0.20, 0.17, 0.17 and 0.18 in that order. The results point to the high tolerance of *P. osun* and its suitability for use in the remediation of crude oil-tainted soils in the Niger Delta.

***Keywords*:** Leguminous tree plant, *Pterocarpus osun*, soil pollution, remediation

1. INTRODUCTION

Crude oil is a resource majorly abundant in the Niger Delta region (comprising all the states in the South-South and some states in the Southeast and Southwest). The oil-bearing states in this region are Ondo, Alkwa-Ibom, Bayelsa, Edo, Delta, Imo, Cross Rivers and Rivers State. In recent times, crude oil has been discovered in other states in the northeastern and southeastern part of the country, though marginal in amount compared to reserves in the Niger Delta. Ondo State is the most prominent oil-producing state in Southwest Nigeria, whereas all the states in the South-South have massive crude oil reserves.

The Niger Delta region is a typical tropical rainforest, located in the Atlantic coastal area, south of Nigeria and is the second largest delta in the world with a coastline of about 450km [1], the largest wetland in Africa occupying about 20,000 sq/km [2-4], and the largest mangrove swamp in Africa, spanning about 11,134 sq/km [2], is today at the brink of severe biodiversity eradication owing to oil and gas exploration [5]. An estimated 25% of the total Nigerian population inhabits the Niger Delta region [6, 7]. Reports had it that approximately 30 million people are living in the Niger Delta region. This shows a fast-growing population in the area with more than 23% of Nigeria's total population dwelling in the region [1, 6, 7]. By implication, a quarter of the Nigerian population is likely to the impacted directly or indirectly by oil and gas exploration in the Niger Delta where oil pollution occasioned by oil spills is very likely, especially with the surge in artisanal crude oil refining in the region [8]

Typically, oil spills occur during the exploration, production, refining, transportation, distribution, and marketing of petroleum products. The presence of crude oil in the environment has caused several adverse impacts on the environment [9]. Onwuna *et al*. [10] and Aigberua *et al*. [11] reported that crude oil could impact the biophysiochemical environment which could lead to alteration in microbial, animal and plant populations, and imbalance of the ecosystem. Crude oil pollution is considered a very grave environmental concern as it could lead to habitat alteration, indirectly leading to the loss of food resources and death. The volatile fraction of the crude oil tends to aerosolise which may hurt humans that reside close to the neighbourhood. Crude oil also tends to contaminate drinking water sources of humans.

Due to the adversative impacts of crude oil on the soil and human health, environmentalists are clamouring for cleanup. To this effect, several methods of remediation are available depending on the environmental matrix and physical constituents of the crude oil. Some of the commonly available options include the use of surfactants, dispersants, microbes and plants. Each of these methods has varying determinant factors. The utility of plants to extricate toxicants from environmental matrices has been widely encouraged, as reports support their suitability for ecosystem restoration [12-17].

Typically, phytoremediation of crude oil sometimes requires amendment of the soil and symbiont rhizosphere microbes for the extrication, degradation and detoxification of contaminants depending on the environmental matrix. Plants in contaminated soil can be monitored and harvested and assessed for the level of contaminant in it.

The agricultural sufficiency of the Niger Delta region is under threat and so is the environmental health. As such, the region is attracting a lot of attention for ecosystem management. The use of plants as a means of remediating crude oil pollution in this region has been discussed in several literature. This study aimed to assess the suitability of *Pterocarpus osun* a leguminous plant, in the remediation of crude oil-tainted soil in the Niger Delta.

2. MATERIALS AND METHODS

2. 1. Experimental Site

This study was carried out in the greenhouse of the Niger Delta University, Nigeria.

2. 2. Sample Collection

Soil (clay-loamy) used in this study was collected at a depth of 0 – 10 cm (topsoil) from the Research and Experimental Farm of the Niger Delta University (NDU), Nigeria. Crude oil was secured from the Shell Petroleum Development Company Flow Station at Oporoma. The plant (*Pterocarpus osun*) was sourced from the National Centre for Genetic and Biotechnology (NAGRAB), Ibadan, Nigeria.

2. 3. Germination test

Five medium-sized plant bags (2000 cm^3) were each filled with 3000 g of clay-loamy soil and stacked inside the greenhouse. Each bag was spiked with either 25 ml, 50 ml, 75 ml or 100 ml of crude oil, and the uncontaminated treatment (0 ml) served as the control. From each bag, 200 g of soil was measured and dissolved in 1000 ml of distilled water and left for 72 hours. Aqueous extracts of the soil samples were obtained by filtration into 500 ml conical flasks, which were then labelled accordingly.

Viable *P. osun* seeds selected by floating method [18], were used in the germination test, carried out in Petri dishes as described by Kayode and Oyedeji [19], ten seeds per petri dish (in five replicates). The seeds were wetted diurnal using filtrates of the different treatments at 0700 for 10 days and the germination counts were made daily. The percentage germination was ascertained 10 days after sowing using the formula:

$$\text{Germination test Percentage (Gt \%)} = \frac{\text{Number of seedlings that emerged/dish}}{\text{Total number of seeds sown}} \times 100$$

2. 4. Growth response test

The growth response test was conducted in the greenhouse with 10 planting bags for each treatment, seeded with 3 viable seeds. Watering was done for two weeks at an intermission of 72 hours at 0700 prior. Two weeks after planting (2WAP) the number of germinated plants per bag was thinned to allow one per bag. Growth parameters (plant height and girth) were carried out every two weeks until the 16^{th} week. The seedling height girth was determined with the aid of a meter rule and girth with the aid of Vanier Calliper. The number of leaves and nodules was counted at 16 WAP. The relative growth rate (RGR) and percentage growth suppression (% GS) were estimated from mean heights [20].

2. 5. Analysis of the physical properties of the soil samples

The physicochemical analysis of soil samples was conducted at the Central Research Laboratory, Federal University of Technology, Akure, Nigeria. Soil organic matter, soil pH and bulk density were determined according to [21], moisture content according to [22], soil water capillarity, volume of air in soil and porosity content according to [23], soil nitrogen, calcium and magnesium content according to [24], and available phosphorous content according to [25].

3. RESULTS

3. 1. Germination rate

Figure 1 shows the germination rate of *P. osun* grown with crude oil-spiked soil water extracts. At 0 ml crude oil-contamination treatment, the percentage germination and coefficient of velocity (COV) for the plant was 28% (22), which is the highest. However, for 25 ml crude oil-contamination treatment, the percentage of germination and COV was 23% (17); for 50 ml treatment it was 21% (17 COV); for 75 ml it was 17% (13) and for 100 ml of crude oil it was 15% (9).

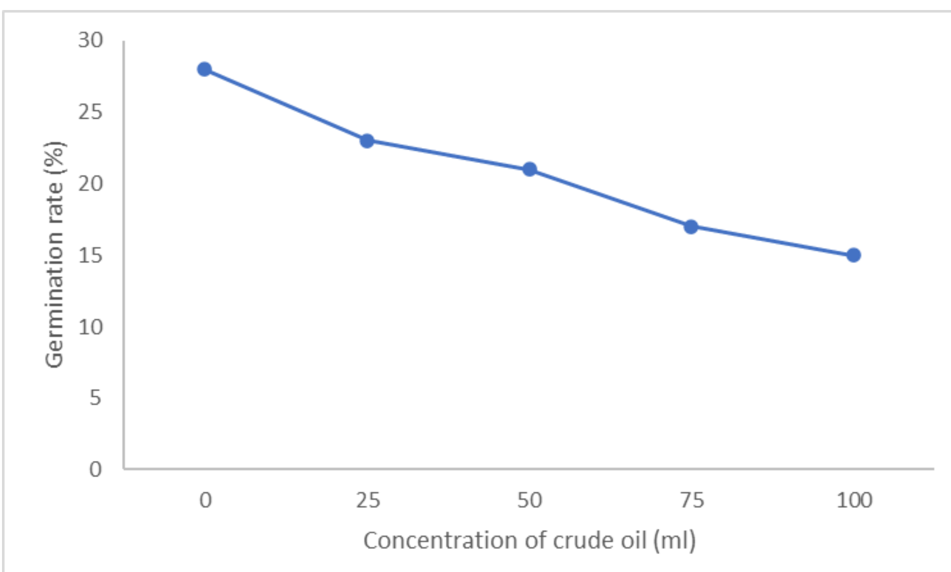

Figure 1. Germination rate of *P. macrophylla* in crude oil-polluted soil water extracts

3. 2. Growth response

Table 1 shows the mean heights of *P. osun* grown with crude oil-spiked soil. Mean heights corresponding to 25 ml, 50 ml, 75 ml and 100 ml crude oil-polluted soil treatment were 2.50±1.78 cm, 2.75±1.80 cm, 1.95±1.68 cm and 1.65±2.50 cm in that order, at 2 weeks after planting (2 WAP). The heights increased to 38.60±2.03cm, 28.70±2.07 cm, 21.50±2.03 cm and 20.10±2.20 cm in increasing order of crude oil concentration at 16 WAP.

This gives percentage growth suppression (% GS) of 34.00% for 25 ml crude oil-spiked soil treatment, 50.90% for 50 ml crude oil-spiked soil treatment, 63.20% for 75 ml crude oil-spiked soil treatment and 65.60% crude oil-spiked soil treatment. For the uncontaminated soil treatment (0 ml), the height was 1.75±1.50 cm 2 WAP and 58.50±2.10 cm 16 WAP. The relative growth (RGR) for the plants at 0 ml, 25 ml, 50 ml, 75 ml and 100 ml crude oil-spiked soil treatment was 0.25, 0.20, 0.17, 0.17 and 0.18 in that order.

Table 1. Mean heights of *P. osun* grown with crude oil-spiked soil water extracts

Time (WAP)	Plant height (cm)/Crude oil concentration (ml)				
	0	25	50	75	100
2	1.75±1.50	2.50±1.78	2.75±1.80	1.95±1.68	1.65±2.50
4	7.80±2.54	6.85±1.85	6.50±1.65	5.85±2.00	3.85±2.80
6	15.70±3.05	14.70±2.02	12.80±1.50	13.50±1.80	6.20±1.75
8	21.60±1.85	16.50±1.68	14.10±1.95	12.70±2.15	10.80±2.20
10	30.50±2.25	25.60±1.72	13.80±1.75	11.60±1.74	12.30±2.40
12	34.50±2.08	27.20±1.56	15.20±1.60	13.10±2.01	16.50±2.10
14	43.20±1.89	35.40±1.82	21.50±1.75	15.40±1.82	18.50±2.80
16	58.50±2.10	38.60±2.03	28.70±2.07	21.50±2.03	20.10±2.20
∑X±SD	213.55±17.26	167.35±14.46	115.35±14.07	95.60±15.23	89.90±18.75
$\Delta H = H_F - H_I$	56.75±0.60	36.10±0.25	25.95±0.27	19.55±0.35	18.45±0.30
RGR	0.25	0.20	0.17	0.17	0.18
GS	0.00	0.340	0.509	0.632	0.656
%GS	0.00	34.00	50.90	63.20	65.60

- RGR = Relative growth rate; GS = growth suppression
- H_I = Initial Height
- H_F = Final Height
- ΔH = Change in height
- $\overline{X}$ = Mean
- (±) = Standard deviation

The mean girth of *P. osun* 2 WAP was highest in the 0 ml and 25 ml crude oil treatments (0.12 mm), and lowest in the 100 ml treatment (0.10 mm). At 16 WAP, the mean girth was highest at 0 ml crude oil treatment (0.37 mm) and least at 100 ml treatment (0.21±0.04 mm, (Table 2).

Table 2. Mean girths of *P. osun* grown in crude oil-polluted soil

Experimental Time (WAP)	Plant girth (mm)/Crude oil concentration (ml)				
	0	25	50	75	100
2	0.12±0.01	0.12±0.02	0.11±0.03	0.11±0.02	0.10±0.03
4	0.13±0.03	0.11±0.04	0.12±0.01	0.12±0.03	0.11±0.02
6	0.15±0.02	0.14±0.03	0.13±0.02	0.12±0.01	0.12±0.04
8	0.17±0.04	0.15±0.04	0.14±0.03	0.13±0.02	0.13±0.05
10	0.23±0.05	0.18±0.03	0.16±0.04	0.14±0.05	0.13±0.04
12	0.25±0.04	0.21±0.01	0.19±0.05	0.17±0.04	0.15±0.01
14	0.27±0.06	0.23±0.04	0.21±0.06	0.19±0.03	0.17±0.06
16	0.34±0.02	0.31±0.05	0.27±0.04	0.24±0.01	0.21±0.05
$\Delta G= G_F-G_I$	0.22±0.01	0.19±0.03	0.16±0.01	0.13±0.01	0.11±0.02
$\sum X \pm SD$	1.66±0.27	1.45±0.26	1.33±0.28	1.22±1.43	1.12±0.30

Table 3 shows the mean number of leaves and nodules of *P. osun* grown with crude oil-spiked soil aqueous extracts. The utmost number of leaves counted was 10 which was for uncontaminated soil treatment (0 ml) and the least was 5, in 100 ml crude oil-spiked soil treatment. The highest number of nodules was 8, in uncontaminated soil treatment (0 ml) and no nodule was detected in 100 ml crude oil-spiked soil treatment.

Table 3. Mean number of leaves and nodules of *P. macrophylla* grown in crude oil-polluted soil.

Crude oil concentration (ml)								SD
Parameter	0	25	50	75	100	Mean	Variance	
Leaf	10.00	8.00	6.00	5.00	5.00	6.80	4.70	2.17
Nodule	8.00	5.00	6.00	2.00	0.00	5.25	6.25	2.50

3. 3. Physicochemical parameters

The physiochemical characteristics of crude oil-spiked soil and control are presented in Table 4. The pH of crude oil-spiked soil treatments ranged from 4.87 (at 0 ml) and 4.56 (at 100 ml). However, the control soil pH ranged between 5.68 – 4.81.

The organic matter concentration in crude oil-spiked soil treatments ranged from 1.30%-1.53%, and 1.57%-1.87% in the uncontaminated soil.

Nitrogen concentration in crude oil-spiked soil treatments ranged from 0.21%-0.34%, and 0.36%-0.52% in the uncontaminated soil. Phosphorus concentration in crude oil-spiked soil treatments ranged from 5.81 mg/kg-6.45 mg/kg, and 6.87 mg/kg-8.50 mg/kg in the uncontaminated soil. Potassium concentration in crude oil-spiked soil treatments ranged from 2.28 mg/kg-2.87 mg/kg, and 3.50 mg/kg-3.80 mg/kg in the uncontaminated soil. Sodium concentration in crude oil-spiked soil treatments ranged from 1.65 mg/kg-2.20 mg/kg, and from 2.05 mg/kg-3.87 mg/kg in the uncontaminated soil.

Calcium concentration in crude oil-spiked soil treatments ranged from 13.80 mg/kg-15.80 mg/kg, and from 20.50 mg/kg-23.50 mg/kg in the uncontaminated soil. Magnesium concentration in crude oil-spiked soil treatments ranged from 1.35 mg/kg-2.08 mg/kg, and 2.00 mg/kg-2.58 mg/kg in the uncontaminated soil.

Table 4. Physiochemical characteristics of crude oil-contaminated soil

Parameters	Groups	Crude oil concentration (ml)				
		0	25	50	75	100
pH	Contaminated	4.87	5.17	5.01	4.90	4.56
	Control	5.68	5.73	5.66	5.60	4.81
Organic matter, %	Contaminated	1.53	1.45	1.37	1.30	1.30
	Control	1.87	1.78	1.68	1.62	1.57
% N	Contaminated	0.34	0.30	0.26	0.21	0.21
	Control	0.52	0.48	0.48	0.36	0.41
P, mg/kg	Contaminated	6.45	6.20	6.07	6.01	5.81
	Control	8.50	8.29	7.85	7.80	6.87
K, mg/kg	Contaminated	2.85	2.87	2.65	2.40	2.28
	Control	3.80	3.74	3.63	3.58	3.50
Na, mg/kg	Contaminated	2.20	2.05	1.92	1.85	1.65
	Control	3.87	2.40	2.25	2.05	2.05

Ca, mg/kg	Contaminated	15.80	15.20	14.70	13.80	13.80
	Control	23.50	21.40	20.85	20.50	20.50
Mg, mg/kg	Contaminated	2.08	2.03	2.01	1.85	1.35
	Control	2.58	2.40	2.35	2.30	2.00

Table 5 shows the effect of the physical properties of crude oil-spiked soil. Soil moisture content ranged from 18.2% (100 ml treatment) - 72% (0 ml treatment); bulk density ranged from 5.80 (100 ml treatment) - 7.70 g/cm^3 (0 ml treatment); soil porosity ranged from 32.8 ml (100 ml treatment) - 86.4 ml (0 ml treatment); soil air ranged from 30.50% (50 ml treatment) - 72.50 % (0 ml treatment); and water holding capacity ranged from 13.7 ml (100 ml treatment) - 58.4 ml (0 ml treatment).

Table 5. Physical properties of unpolluted and crude oil-polluted soil

Crude oil (ml)	Moisture content (%)	Bulk Density (g/cm^3)	Soil porosity (ml)	Soil air (%)	Water Holding capacity (ml)
0	72	5.8	86.4	72.5	58.4
25	44.5	6.4	81.5	38.6	50
50	40	6.4	60.4	30.5	34.5
75	28.5	6.8	48.3	40.4	24.1
100	18.2	7.7	32.8	43.6	13.7

4. DISCUSSION

Crude oil pollution can have severe consequences on the environment, affecting various organisms including plants. The germination stage of a plant's life cycle is crucial for its establishment and growth. *P. osun* in crude oil-polluted soil showed a decrease in germination potentials with the increase in crude oil contamination. Increased concentration of crude oil leads to higher toxicity levels, which might hinder seedling development.

This finding agrees with the studies by Kayode *et al.* [26] and Oyedeji and Oyedeji [17] in which crude oil presence was shown to inhibit both seed germination and seedling growth. Hydrocarbons are genotoxic and can adversely affect the DNA integrity of plant species, potentially leading to reduced growth and survival rates [27].

Crude oil hindering the establishment and growth of important plant species spells dooms for biodiversity richness. However, with a good germination rate exhibited by *P. osun*, it can withstand the stress of crude oil pollution in the event of a spill and regenerate itself. The growth response of *P. osun* in the presence of crude oil was evident as a decrease in plant girth, height, number of leaves and number of nodules with the increase in the concentration of crude oil increase, such that as the concentration of the crude oil increased, the percentage growth suppression increased and the growth rate decreased. This is in congruence with the works of Anoliefo and Okoloko [28] and Oyedeji and Oyedeji [17] where it was reported that crude oil pollution significantly reduces plant height, girth, and the number of leaves, in addition to inhibition of nodulation, a critical symbiotic process between legumes and nitrogen-fixing bacteria.

The study posited that suppression of plant growth in the presence of crude oil in contaminated soil is an indication of metabolic hindrances. Osuagwu *et al*. [29] established that crude oil causes a reduction in chlorophyll pigments, further corroborating the negative impact on plant growth and overall development.

The growth of *P. osun* was suppressed by all crude oil concentrations tested. Agbogidi *et al*. [30] and Osubor and Anoliefo [31] reported that hydrocarbon inhibits photosynthesis, reduces nutrient uptake, and interferes with water balance, collectively resulting in stunted growth and decreased biomass accumulation. The mechanisms underlying growth suppression in the presence of crude oil also include disruption of nutrient uptake, oxidative stress, and impairment of root system development and functionality [12, 27].

The physiochemical characteristics of crude oil-spiked soil generally decreased with an increase in crude oil concentration. Besides, crude oil tends to reduce the physiochemical properties of the soil relative to the control. In the present study, crude oil increased the soil pH at low concentrations and reduced available nutrients. Wang *et al*. [32] similarly reported that crude oil pollution increased soil and reduced available phosphorus. Oyedeji and Oyedeji [17] reported that crude oil contamination often leads to a decrease in soil pH, primarily due to the release of organic acids during crude oil degradation.

The study also reported that crude oil pollution also causes a decline in organic matter content, alters soil cation exchange capacity, and reduces the availability of essential nutrients such as nitrogen, phosphorus, and potassium. Crude oil can hinder the transformation of organic nitrogen into plant-available forms and decrease phosphorus availability [32]. Typically, nitrogen-fixing plants such as *P. osun* provide root exudates which can be degraded to increase soil minerals [34].

In addition, these exudates prompt or boost microbial populations which can enhance the utilisation of organic contaminants and increase soil organic matter.

The exchangeable cations monitored in decreasing order of their concentration in the soil are Ca>K>Na>Mg, with the highest concentrations detected in uncontaminated treatment. Soil particles carry plant nutrients which exist within the rhizosphere as ions. However, the ability of plants to take up nutrients from the soil in the presence of crude is limited partly by availability, as important nutrients are often sequestered by crude oil [32, 33].

It was observed in the present study that the presence of crude oil in soil affects the physical properties of such soil at all concentrations. As the concentration of the crude oil increased, the soil bulk density, moisture content, soil air, water holding capacity and porosity reduced in the crude oil-polluted soil.

Ayodeji and Kayode [16] reported that crude oil pollution can significantly alter the physical properties of soil, influencing essential parameters that affect soil structure, water retention, and gas exchange. Crude oil in soil could block pore spaces within the soil and so impinge on soil aeration, porosity and water availability which may have adversative upshots on plant growth and productivity [26, 35].

5. CONCLUSION

Crude oil's impact on soil was manifested by decreases in soil physicochemical characteristics like nitrogen, phosphorous, calcium, sodium, magnesium, potassium, organic matter, bulk density, soil porosity, water holding capacity, air and moisture content, with an increase in crude oil concentration. *P. osun* showed it could tolerate crude oil as evidenced by its germination rate, height, girth, leaf number and nodulation. decreased as the concentration of the crude decreased. Therefore, *P. osun* is a good candidate plant species for the phytoremediation of crude oil contaminated soil in the Niger Delta.

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