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RESEARCH ARTICLE

THE ECOLOGICAL RESTORATION OF SOIL-WATER INFILTRATION RATE BY PHYTOREMEDIATION TREATMENT OF CRUDE OIL POLLUTED TROPICAL NIGER DELTA SOIL

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ABSTRACT

Several contributions on the ecological interaction between hydrocarbon and soil habitat-water relationship in different parts of Niger Delta have been revealed. Based on demonstrated remediation potential of plants species, this study was aimed evaluating the suitability of three species (*Peltophorum pterocarpum* (DC.) Heyne, *Leucaena leucocephala* (Lam) De wit. and *Crotolaria retusa* Linn.) of the Fabaceae family for the restoration of infiltration rate of crude oil impacted Niger Delta soil habitat. Standard field and laboratory methods of data collection and analyses were adopted. Result showed varying increase in water repellency with increased time across pollution levels. It has also evaluated the trajectories of water movement in the phytoapplication restoration based on species biological performance and infiltration time rate of the species treated sandy loam soil. *Peltophorum pterocarpum* among the species recorded greater performance due to its restoration potential of the infiltration dynamics of the post-polluted soil. This was attributed to its ability in the improvement of the soil porosity, texture, structure, particle density (PD), and reduces bulk density (BD), organic matter (OM), highest hydrocarbon removal efficiency (low THC content), enhanced accumulation quotient and root formation. It can thus be proposed as part of a bioremediation integradation in environmental restoration programme.

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INTRODUCTION

The issue of hydrocarbon crude oil pollution on environmental media of Niger Delta has called for global attention and concern hence the region has become a common hot spot as a hub of hydrocarbon exploration and exploitation in Nigeria (UNEP, 2011; Ite *et al*., 2013; Sam *et al*., 2015). When pollution occurs in an environment both biotic and abiotic factors and processes are affected, such impact result to changes in the physico-chemical (pH, nutrient status etc.) and biological factors of such environment. In frequent cases the soil habitat is the most impacted with its characterized features and processes degraded and / or lost. (Kadafa, 2012; Anejionu *et al*., 2015; Duke, 2016; Obinaju and Martin, 2016). Several contributions to the understanding of ecological impact of human disturbances among all forms of land use practices such as hydrocarbon exploration and it interaction with soil habitat-water relationship in light of increase in soil bulk density, organic matter, and texture and decreased soil porosity, structure, permeability and water holding capacity have been documented in different parts of Niger Delta environment (Bisong, 2001; Amusan and Anderson 2005; Edwin-Wosu, 2005; Kigne 2006; Essien and John, 2010; Uzoije and Agunwamba, 2011; Agbor, *et al*., 2015). They highlighted the potential for interactions among hydrocarbon pollution, plant species and abiotic edaphic factors vis-à-vis infiltration process of a soil habitat. Infiltration is the process of water, crossing soil surface and entering the soil profile. Every given soil averagely has a potential for water absorption at a given maximum rate (infiltration capacity); expressed as depth of water per unit time (in/hr or mm/hr). Therefore, infiltration rate is the actual amount of water crossing the soil surface per unit time at any point in time (in/hr or mm/hr). Several implicating variation of biotic and abiotic factors are known to engender alteration in the infiltration rate of a typical tropical soil environment among which include land use ecology and availability of vegetation cover (Bisong, 2001; Wood and Finger 2006), changes in soil structure, texture and organic matter content (Amusan and Anderson 2005). In a similar view studies have recorded some distortion effect of crude oil hydrocarbon pollution on soil habitat edaphic properties involving increase in soil texture, Bulk density (BD) and organic matter (OM) content and decrease in soil structure,

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particle density (PD), porosity, with a concomitant decreasing effect on soil infiltration process (Carter *et al*., 2006; Brassington *et al*., 2007; Ewetola, (2013); Anna *et al*., 2015; Jiang *et al*., 2016; Edwin-Wosu and Nkang, 2017b). The use of remediation alternatives involving soil additives to improve infiltration rate and moisture retention capacity of soil has earlier been documented by Schwab *et al*. (1995). Also various conventional methods involving the use of microbial seeding and physico-chemical processes such as enhanced bioremediation, fixation / stabilization and incineration / thermal treatment have been engaged in some remediation processes in parts of the Niger Delta environment (Philip and Augustine, 2014). However, the various approaches were characterized by several limitations in terms of cost implication availability, usage and sophistication. In recent times biological techniques like phytoremediation are been evaluated as alternative options for the decontamination of environmental media of their pollutants. Phytoremediation is a green revolution composed of various processes involving phytosequestration, phytostabilisation, phytoextraction, rhizofiltration, phytodegradation, rhizodegradation, phytovolatilization using organic degrading and inorganic accumulating, dissipating and immobilizing plants to remove pollutant. (Bruce, 2001; Pamila, 2016; Shanon, 2017). It is a promising technology from the decade of 1990, and excellent strategy since it pre- and post-emergence in the 90's for the treatment of various contaminants of organic and inorganic nature (Lee and Charles, 2004; Ferrera-Cerrato *et al*., 2007; Gherhardt *et al.*,2009; Peng *et al.,* 2009; Tripathi *et al*.,2015). This could be exemplified by several report of efficacy and potency of plant or consortium of plant species in various phytoremediation processes.

A hyperaccumulation of nickel, cadmium and zinc in different parts of *Alyssum heldreichii* and shoot portion of *Thlaspi caeruleciens* for Zn (Brooks, 1998b), *Brassica juncea* for lead, chromium, cadmium, Ni, Zn, Cu (Kumar *et al*., 1995; Blaylock *et al*., 1999) are documented in phytoextraction process. *Agrostis tenius* and *Festuca rubra* are known for Cu, Pd, and Zn phytostabilization (Smith and Bradshaw, 1979). Sunflower (*Helianthus annus*) has been used in rhizofiltration process of Uranium contaminated ground and process water (Dushenkov *et al*., 1997). Hybrid poplar (*Populus deltoides*), salt marsh – *Spartina alternifolia* and *S. patens* has demonstrated the rhizodegradation potential of atrazines BTX and oil contaminant (Jordahl *et al*., 1997; Lin and Mendelssohn, 1998). Hybrid poplar has also demonstrated the phytodegradation potential of TNT to 4-amino-2, 6-dinitrotoluene (4-ADNT), 2-amino-4, 6-dnitrotoluene (2-ADNT) (Thompson *et al*., 1996), atrazine (Burken and Schnoor, 1997) and *Salix nigra, Liriodendron tulipifera, Taxodium distichum, Betula nigra, Quercus falcate* and *Q. viginiana* have recorded potential for bentazon herbicide (Conger and Portier, 1997). *Nicotiana tabacum* and *Arabidopsis thaliana* have volatilized mercury from ground water (Meager *et al*., 2000). Indian mustard and canola (*Brassica napus*) has volatilized selenium while Hybrid poplar has recorded 98 to 99% loss of 50ppm TCE contaminated ground water (Newman *et al*., 1999). Infiltration studies have shown that vegetation is one of the most paramount parameter affecting soil surface entry of water and it infiltration rate into the soil (Bharati *et al*., 2002; Lee and Charles, 2004; Wood and Finger 2006; Eze *et al*., 2011; Shameem and Irfana, 2011). Similarly the introduction of leguminous crops to improve soil characteristics due to it nitrogen fixing and enzyme remediation potential has also been documented (Schwab *et al.,* 1995; Edwin-Wosu and Nkang, 2015; 2016). Based on foregoing demonstrated remediation potential of leguminous plants species (Edwin-Wosu and Nkang, 2015; 2016; 2017a, b), this study therefore seeks to evaluate and reaffirm the suitability of three species (*Peltophorum pterocarpum*, *Leucaena leucocephala* and *Crotolaria retusa*) of the Fabaceae family for restoration of infiltration rate predicated on some edaphic properties (soil texture, structure, particle density, bulk density, porosity and organic matter content) of a tropical Niger Delta soil habitat in presence of hydrocarbon crude oil pollution.

MATERIALS AND METHODS

Field Sampling

Replicates of top sandy loam soil (20 kg) at 21% moisture content were collected in bulk within the standardized 0-15cm soil layer (Stewarte *et al*., 1974 and Song *et al.*, 1990) from a fallowed garden land in part of Niger Delta, Nigeria. A double split plot "*nested design*" (Fig. 1) (Akindele, 1996) was adopted and with the SAS (2002) soft ware, analysis of variance (PROC. ANOVA) procedures was carried out on the data acquired from the study. The pristine soil under pollution was in four levels of concentration (V/W %) doses of 0 %, 75 (0.4 %), 150 (0.8 %) and 300 (1.5 %) per 1,809 cm^2 surface area and in replicates of five per level. Habitat reclamation treatment commenced 7 days after the pollution of the habitats. Each of the three different levels of polluted replicates and the control replicates were subjected to post-pollution habitat reclamation using three species of observed 14 days healthy seedlings of *P. pterocarpum,* (Pp); *L. leucocephala* (Ll) and *C retusa* (Cr) among the Fabaceae plant family. The pre- and post-pollution and post-phytoapplication growth performance of these seedlings were monitored for a period of ten (10) months and used as a measure of their level of tolerance in the polluted environment in light of comparative analysis of the root biota and organic content of the species.

Laboratory Analyses

Soil texture determination in light of particle size analysis adopted the Black (1965) and Bouyocous (1962) hydrometer method in which 51g air dried sample was weighed into a 500ml dispersing cup filled with distilled water in excess of 5cm above the sample. Fifty (50ml) (5% sodium hexametaphosphate) calgon dispersant was added and allowed for 15 minutes, then shaken for 10 minutes and with aliquot transferred to a graduated cylinder, followed by hydrometer insertion into the aliquot made up to 1000ml mark with distilled water. The hydrometer was removed and with the cylinder inverted several times and kept for stability at about 30 seconds. This was followed by the hydrometer slowly and carefully placed in the aliquot suspension and reading at exactly 40 seconds for percent sand and then after 2hours for percent clay as well as the temperature reading of the suspension taken. The hydrometer reading was corrected by adding 0.3 for every ^{O}C (or 0.2 for Fahrenheit) above the calibration temperature ($20^{O}C$) or by subtracting 0.3 for every ^{O}C below the calibration temperature ($20^{O}C$). Also 2.0 was subtracted from every hydrometer reading to compensate for the added dispersing agent. Using the designated formular below:

$$\% \text{ (silt + clay)} = [H_1 + 0.3 (T_1\text{-}T) – 2.0] \times 100/50 \quad \ldots\ldots\ldots\ldots (1)$$

% clay = [H_2 + 0.2 (T_2-T) – 2.0] x 100/50
% sand = 100 - % (silt + clay)
% silt = % (silt + clay) - % clay

Where
H_1 and H_2 = hydrometer readings,
T_1 and T_2 = temperature (^{O}C) at 40sec. and 2hours respectively.
T^{o}C = Calibration temperature
50 in the denominator for 51g sample used and 100 as % factor expression

The textural name analysis for various components (sand, silt and clay) of the soil was extrapolated using the Textural triangle model (Harry and Nyle, 1962). Bulk density analysis was by the core method of Black and Hartge (1986) using a core sample with a volume of 205cm^3 in which a metal cylinder core driven into the soil at the study location was removed from the land and with the soil content was dried in an oven. By its procedure: Core cutter was weighed using a weighing balance; followed by insertion into soil to be filled completely without compression; then extruded, cleaned and trimmed on both surfaces with a small spatula. The core + soil were weighed again and oven dried and allowed to cool and then dried and value extrapolated using designated formula.

$$\text{Bulk density (g/cm}^3\text{)} = \text{Soil mass } \frac{\text{(Dry wt – Core wt)}}{\text{Soil volume}} \quad \text{…. (2)}$$

$$\text{Where volume (cm3)} = \frac{\pi dh}{2} \equiv \pi r^2 l$$

π = 3.14

The Gradwell (1955) as modified in ASTM (1958) was adopted for particle density analyses using the Pycnometer gravity bottle of 50cm^3 capacity after been weighed (Wa) then with 10g air dried soil added, and filled with distilled water one-half full, gently boiled for several minutes to remove entrapped air with gentle swirling of the content to prevent loss of soil by foaming, then cooled to room temperature, during which an equivalent 10g soil oven dried at 105^{o}C was determined. The cooled pycnometer at room temperature was filled to brim with boiled, cooled, distilled water, stoppered, carefully erected, thoroughly dried and cleaned with dry cloth and then weighed (Wsw). Again the pycnometer was also emptied of its content and dried, then filled with the boiled, cooled distilled water at room temperature, stoppered, dried and weighed (Ww). It was emptied of water, dried and then weighed again with oven dried soil (Ws). The density of water was extrapolated from Ww – Wa as mass of water and volume as 50cm^3 (pycnometer capacity) with designated formula:

$$\text{d} = \frac{\text{mass}}{\text{Volume}} \equiv \text{d w} \quad \text{……. (3)}$$

Thus particle density could be extrapolated using formula:

$$D_p = \frac{dw\ (Ws - Wa)}{(Ws - Wa) - (Wsw - Ww)}$$

Where Wa = weight of pycnometer filled with air.
Wsw = weight of pycnometer filled with air-dried soil and water.
Ws = weight of pycnometer plus soil sample corrected to oven dry condition.
Ww = weight of pycnometer filled with water.
dw = density of water in grams per cubic centimeter.

Porosity by percentage determination of total pore spaces was extrapolation from bulk and particle density analyses using designated formula.

$$\% \text{ Ø} = (1 - \frac{\text{BD}}{\text{PD}}) \times 100 \quad \text{……..…… (4)}$$

Where Ø = porosity
BD = bulk density
PD = particle density

By the method of Bouwere (1986) the comparative assessment of the water infiltration rate was carried out in three phases at the control and polluted micro plots in pre-pollution, post-pollution and post-phytoapplication periods, using a double ring glass infiltrometer (1.17 mm inside ring and 3mm outer ring diameter), 54.5 cm height and a stop watch. The exercise was carried out for five consecutive periods at 2 months interval within ten months of post-phytoapplication ecological study. At each of the replicate plot (Fig. 1) the infiltrometer was carefully driven (to achieve minimum or no disturbance to the soil) vertically down at a depth of 5cm into the soil and 50 ml (60 cm^3) tap water poured into it. Observing the duration of each test run for water movement, the time taken for the water to infiltrate into the soil in relation to repellency was recorded with the infiltration values calculated by reading the change in water level (cm) over time (min) from the stop watch recorder. The Crusting hazard of hydrocarbon Risk of sealing (R) was estimated using the Vander

Watt and Claassen's (1990) method as:

$$\%R = \% \frac{\text{Organic matter x 100}}{\text{(\% Clay + \% Silt)}} \quad \text{……..…… (5)}$$

Total hydrocarbon (THC) content was analysed using the American Petroleum Institute (API-RP-45) (2005) method, through which a representative gram (1g) of a homogenized air dried soil was mixed in 10ml chloroform and decanted into an Anhydrous Sodium Sulphate ($NaSO_4$) receptacle for proper dehydration. The absorbance of the resultant clear solution was read spectrophotometrically at 420 nm using chloroform as blank. The THC content was calculated by reference to a calibration curve using toluene as standard. Organic matter (OM) content was extrapolated from Organic Carbon following Walkley and Black (1934) method as modified in Nelson and Somners (1982), in which a complete oxidation of aqueous potassium dichromate ($K_2Cr_2O_7$) mixed with sulphuric acid (H_2SO_4) and the residual $K_2Cr_2O_7$ (in oxidation) titrated against ferrous sulphate solution was carried out and converted to OM by multiplying the organic carbon values by 1.724 with designated formula. The Root-length (cm) and level of formation of the remediation species was determined by means of meter rule placed at the base of the primary (tap) roots from where reading took place to the apex (tip) and data recorded in cm. The potential of the plant species for remediation was assessed using classical indices involving; soil hydrocarbon removal index, species efficiency index, and bioaccumulation quotient index. The amount of hydrocarbon loss from the soil per plant was estimated using the Raghuvanshi *et al*. (2004) method as in the formular:

$$QH = \frac{Ci - Ce}{M} \quad \text{……. (6)}$$

Where QH is the amount of hydrocarbon removed from the soil (mg/g). *Ci* is the initial concentration of hydrocarbon in the soil (mg/g), *Ce* is equilibrium concentration of hydrocarbon in the soil (mg/g) and *M* is the number of plants. The efficiency of hydrocarbon removal per plant from the soil was estimated as adopted by Badmus *et al*. (2007) using the equation:

$$E = \frac{(Ci - Ce)}{Ci} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where E is the efficiency of species for hydrocarbon removal from the soil (%). *Ci* is the initial concentration of hydrocarbon in the soil (mg/g), *Ce* is equilibrium concentration of hydrocarbon in the soil (mg/g).

The bioaccumulation quotient expresses the possibility of contaminant being significantly accumulated in plant parts, and imminent risk of health hazard. It was expressed according to Ezeaku and Egbemba, (2014) by the formula designate:

$$BQ = \frac{\text{Concentration of accumulated pollutant in plant}}{\text{Concentration of remaining accumulated pollutant in species treated soil.}}$$

were observed, means were separated according to the procedures of the Duncan's New Multiple Range Test (DNMRT) using least significant difference (LSD) tests at 5% probability level. Pearson correlation was applied to determine the relationship between the parameters of the pre- and post-polluted and post-phytoremediated soil of species performance.

RESULTS

The result of the phytoapplication performance of the remediation species are presented in Tables 1 to 5 in quantitative terms. The root length formation within remediation species had reduction in an increasing pollution trend except in *C. retusa*, however with significant difference ($p<0.05$) in *L. leucocephala* at high concentration level. Among the species *P.pterocarpum* had the highest root length with significant difference ($p<0.05$) at low and medium pollution concentration level. Total hydrocarbon (THC) content recorded similar decrease within all species at increasing pollution trend with significant difference ($p<0.05$) at medium concentration level in *L. leucocephala* and *C. retusa*. Among species *P.pterocarpum* had a higher content with significant difference ($p<0.05$) at medium pollution levels.

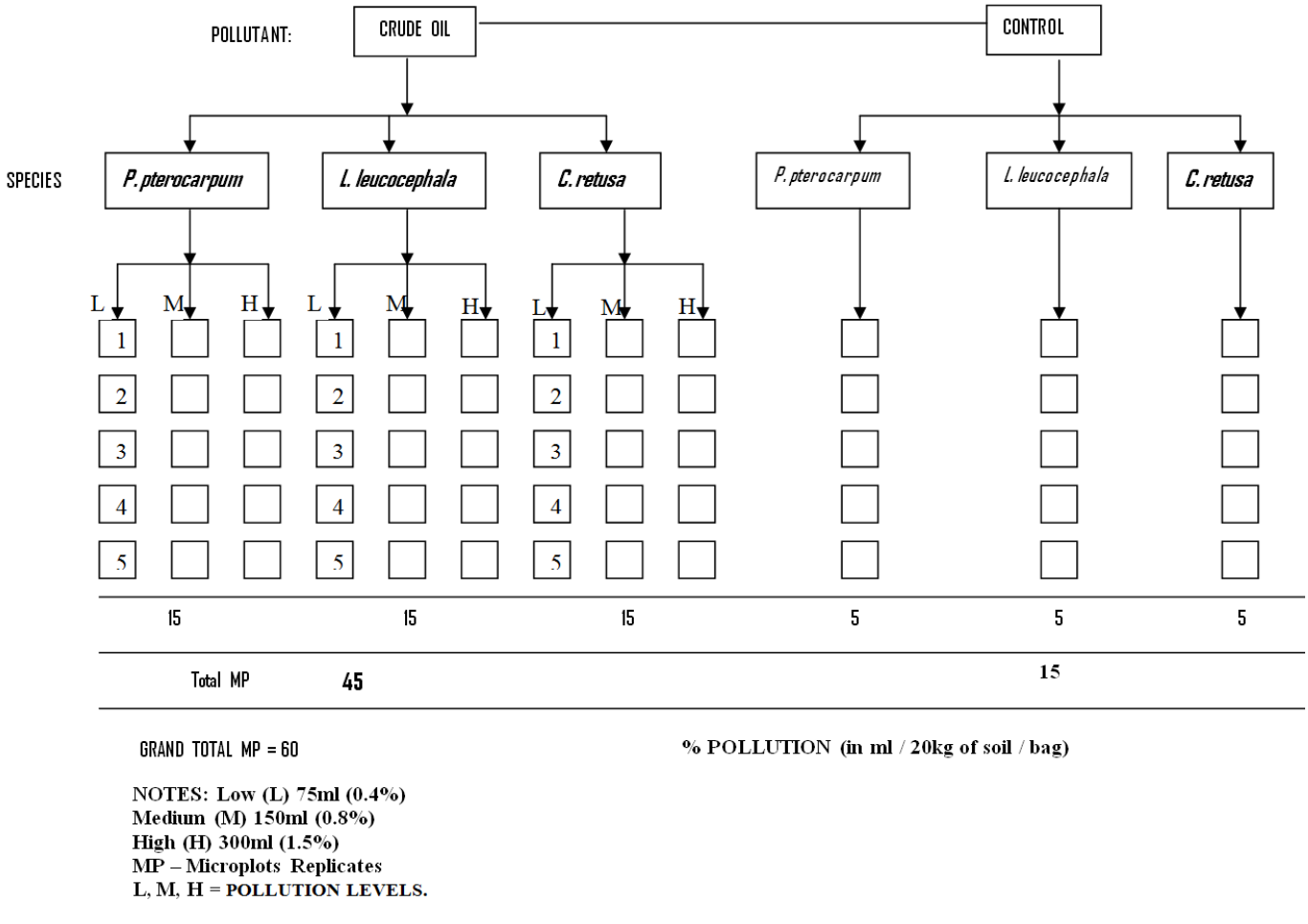

Fig. 1. Phytoremediation experimental design layout

Analyses of Experimental Data

The remediation performance was estimated using the Statistical Analysis System (SAS) PROC. NLIN procedure (2002). Data were then analysed as a double-split plot design with 5 replicates using the Analysis of Variance (PROC ANOVA) procedures (2002). Where significant differences

A non-significant difference ($p<0.05$) trend of organic matter (OM) decline across pollution levels was recorded but higher than control with significant difference ($p<0.05$) within species for *L. leucocephala* and *C. retusa*. Among species a non-significant increasing trend of OM in *P. pterocarpum* was recorded across pollution levels. By the structural observation of the pristine soil at sampling plot it was recorded as a

granular with small, spheroidal pedelogical unit within the depth of sample collection while the textural triangle analyses

pollution levels, was significantly ($p<0.05$) higher than in the pristine pre-polluted and controlled species treated soils.

Table 1. Post phytoapplication performance of remediation species on the polluted soil.

Plant species indices	Treatment level	Species			Mean	LSD (p<0.05)
		Peltophorum pterocarpum	*Leucaena leucocephala*	*Crotolaria retusa*		
Plant root (cm)	Control	73.20±10.04[a]	69.26±19.81[a]	34.90±2.97[b]	59.12	17.83
	Low	61.26±1.36[a]	49.95±8.79[b]	36.23±2.68[c]	49.15	7.39
	Medium	55.00±1.12[a]	34.80 ± 3.77[b]	34.00±4.51[c]	41.23	4.76
	High	33.77±4.84[a]	30.20 ± 3.96[a]	33.10±1.65[a]	31.74	5.59
Plant THC (mg/g)	Control	0.00±0.00[b]	0.00 ± 0.00[b]	0.00±0.00[b]	0.00	0.00
	Low	61.90±0.79[a]	61.67 ± 0.48[a]	60.45±1.94[a]	61.34	1.50
	Medium	60.68±1.65[a]	53.48 ± 0.48[c]	59.63±0.89[b]	57.73	1.54
	High	54.19±1.31[a]	52.95 ± 2.83[a]	55.89±5.03[a]	54.34	4.71
Plant TOM	Control	4.51±0.53[a]	1.94 ± 0.75[b]	2.51±0.73[b]	2.99	0.93
	Low	3.47±1.21[a]	3.14 ± 0.63[a]	3.44±0.93[a]	3.35	1.31
	Medium	3.32±0.31[a]	3.12 ± 0.16[a]	3.13±0.48[a]	3.19	0.47
	High	2.58±0.56[a]	2.60 ± 0.43[a]	2.14±0.17[a]	2.44	0.58

Note: Pp = *Peltophorum pterocarpium*. Ll = *Leucaena leucocephala*. Cr = *Crotolaria retusa* * Means of five replicates and with the same superscript letter are not significantly different, using the Duncan's New Multiple Range Test (DNMRT).

recorded a sandy loam soil habitat with percentage structural composition of sand, silt and clay (Table 1) at the various phases of remediation protocol. There was non-significant difference ($p<0.05$) in sandy component, a significant ($p<0.05$) increase in the silt and a non-significant ($p<0.05$) increase of clay component in post-pollution soil. The influence of phytoapplication has recorded increasing trend of restoration across pre- and post-pollution soils. In post-phytoapplication the species treated soil has indicated greater sandy component than in post-pollution soil across all level of *P.pterocarpum* treatment with significant difference ($p<0.05$) among the species. While *L. leucocephala* treated soil has recorded a significantly ($p<0.05$) higher silty component at medium treatment across species treated levels among the species, *C. retusa* had decrease in clay content across species treatment levels, significantly different ($p<0.05$) from post-pollution among the species. The reduction in particle density (PD) across post-pollution levels than pre-pollution was recorded with significant difference ($p<0.05$) at medium and high pollution levels. In post-phytoapplication *P.pterocarpum* among species treated soils had increased PD across treatment level with significant difference ($p<0.05$) at low and medium levels. There was increase in bulk density (BD) with non-significant difference ($p<0.05$) across post-polluted soil in relation to decreased BD in pre-polluted soil. In the phytoapplication species treatment levels *P.pterocarpum* soil among other species had a significant decrease in BD at low and medium treatment levels. A reduction in porosity across post-pollution levels than pre-pollution with non-significant difference ($p<0.05$) was recorded. Among the species treated soil in post- phytoapplication a significant ($p<0.05$) increase in porosity was recorded in low and medium levels of *P. pterocarpum* treated soil, which also had a significantly reduced THC and OM following a significant increase across post-pollution soil levels. Based on the remediation potency of post-phytoapplication *P. pterocarpum* had the highest (13.31) bioaccumulation quotient and a medium degree of percentage (13%) risk of hydrocarbon sealing (crusting hazard) of soil pores. This was followed by *L. leucocephala* with BQ value of 13.03 and least crusting hazard of 11.81% while *C. retusa* recorded the least BQ value of 10 and highest crusting hazard of 17.52%. The efficiency of hydrocarbon removal from species treated soils per plant has recorded 45% reduction in the *P. pterocarpum* treated soil, *L. leucocephala* soil had 43% reduction and *C.retusa* soil recorded 42% removal of crude oil hydrocarbon pollutant. The infiltration time rate across post-

In post-phytoapplication treatment a significant reduction of infiltration time rate was recorded in *P.pterocarpum* soil among the species treated soils.

DISCUSSION

This study has evaluated the trajectories of water movement and restoration potential of three leguminous plant species in light of their biological performance and infiltration time rate predicated on the physico-edaphic properties of the crude oil polluted sandy loam textured soil. Infiltration characteristics are closely related to several factors such as slope of landscape, soil texture and structure, vegetation cover, management systems, antecedent water content and soil organic matter and may be good indicator of changes in soil physical and biological properties (Radke and Berry 1993). However, report of the study has shown varying increase in water repellency across increased pollution levels. The various levels of pollution induced changes in the edaphic physico-chemical properties of the polluted soil. Such effect made the affected habitat become strongly hydrophobic with the formation of crusting hazard (an index for assessing the degree of soil modification by the hydrocarbon sealing of soil pores) over the soil surface (Table 3). This corroborates Edwin-Wosu, (2005); Edwin-Wosu and Nkang, (2017b) who in their study have recorded increase in potential crusting hazard risk of sealing by crude oil pollution with a concomitant decrease in saturated hydraulic conductivity and porosity and increased bulk density. The pre-polluted soil had increased infiltration rate within a short time compared to post-pollution soil which had a decreased infiltration rate at increased time period due to crude oil pollution influence on the soil physico-edaphic properties involving texture, structure, particle density (PD), bulk density (BD), porosity and organic matter (OM) content. The relationship between crude oil hydrocarbon and soil properties as indicated in Table 4 is exemplified in a weak positive correlation (r = 0.23; $P<0.05$) between THC and silt and (r = 0.30; $P<0.05$) with clay; and negative correlation (r = -0.42; $P<0.05$) with sand, (r = -0.24; $P<0.05$) with PD and negative correlation (r = -0.40; $P<0.05$) between PD and clay for texture, structure and particle density of the polluted soil. Similarly is a positive correlation (r = 0.06; $P<0.05$) between THC and BD and (r = 0.40; $P<0.05$) THC and OM. This could imply the militating influence of crude oil pollution on infiltration rate as exemplified in the positive correlation (r = 0.52; $P<0.05$) between THC and infiltration, positive correlation (r = 0.09; $P<0.05$) between infiltration and

Table 2. The influence of crude oil pollution and post-phytoapplication remediation process on some edaphic parameters of tropical Niger Delta soil

Parameter	Pre pollution	Post-pollution soil			Species controlled soil			Post – phytoapplication / pollution levels									Mean	*LSD (p<0.05)*
								P. pterocarpum soil			*L. leucocephala soil*			*C. retusa soil*				
		75mil	150ml	300ml	*Pp.* contro	*Ll.* contro	*Cr.* contro	75mil	150ml	300ml	75ml	150ml	300ml	75ml	150ml	300ml		
Sand	79.20 ± 2.49^{d}	78.00 ± 0.00^{d}	79.00 ± 0.00^{d}	78.00 ± 1.87^{d}	88.00 ± 0.71^{a}	85.80 ± 1.10^{bc}	88.20 ± 0.84^{a}	85.80 ± 0.45^{bc}	87.00 ± 0.00^{ab}	87.60 ± 2.19^{ab}	84.20 ± 1.92^{c}	78.80 ± 0.45^{d}	83.80 ± 3.77^{c}	84.80 ± 1.09^{c}	85.80 ± 1.10^{bc}	87.40 ± 0.89^{ab}	83.84	1.91
Silt	7.60 ± 2.97^{def}	8.80 ± 1.48^{bcde}	10.40 ± 0.89^{bc}	10.20 ± 1.30^{bc}	6.20 ± 2.86^{f}	10.00 ± 0.71^{bcd}	8.00 ± 1.23^{cdef}	11.00 ± 0.00^{b}	8.00 ± 0.71^{cdef}	9.00 ± 0.00^{bcde}	8.00 ± 2.13^{cdef}	16.60 ± 1.14^{a}	9.60 ± 2.19^{bcd}	8.40 ± 2.30^{cdef}	7.00 ± 1.87^{ef}	8.20 ± 0.84^{cdef}	9.19	2.13
Clay	13.20 ± 0.84^{a}	13.20 ± 1.48^{a}	10.80 ± 0.84^{b}	12.00 ± 1.00^{ab}	5.80 ± 2.17^{defgh}	4.60 ± 1.82^{gfh}	4.60 ± 1.82^{gfh}	4.80 ± 1.10^{efgh}	6.40 ± 2.49^{d}	4.00 ± 0.71^{h}	8.80 ± 0.45^{c}	5.00 ± 1.41^{efgh}	6.80 ± 1.48^{de}	7.40 ± 2.70^{cd}	6.60 ± 1.82^{def}	4.40 ± 1.52^{gh}	7.40	1.90
PD	2.61 ± 0.23^{bc}	2.58 ± 0.01^{c}	2.52 ± 0.34^{d}	2.52 ± 0.08^{d}	2.62 ± 0.02^{bc}	2.62 ± 0.06^{bc}	2.61 ± 0.01^{bc}	2.68 ± 0.02^{a}	2.63 ± 0.03^{b}	2.60 ± 0.01^{bc}	2.64 ± 0.01^{b}	2.64 ± 0.01^{b}	2.62 ± 0.03^{b}	2.61 ± 0.02^{bc}	2.61 ± 0.03^{bc}	2.61 ± 0.01^{bc}	2.61	0.04
BD	1.10 ± 0.01^{b}	1.14 ± 0.11^{b}	1.18 ± 0.08^{ab}	1.20 ± 0.00^{ab}	1.09 ± 0.03^{b}	1.18 ± 0.05^{ab}	1.25 ± 0.04^{ab}	0.81 ± 0.45^{c}	0.65 ± 0.50^{c}	1.11 ± 0.01^{b}	1.12 ± 0.02^{b}	1.13 ± 0.01^{b}	1.15 ± 0.00^{b}	1.10 ± 0.00^{b}	1.12 ± 0.04^{b}	1.12 ± 0.00^{b}	1.11	0.22
Porosity (%)	57.85^{b}	55.81^{b}	53.18^{ab}	52.38^{ab}	58.40^{b}	54.96^{ab}	52.11^{ab}	69.78^{c}	75.29^{c}	57.31^{b}	57.58^{b}	57.20^{b}	56.11^{b}	57.85^{b}	57.09^{b}	57.09^{b}	58.12	7.00
THC	0.00 ± 0.00^{g}	7.32 ± 1.28^{c}	8.72 ± 2.06^{b}	10.33 ± 1.85^{a}	0.00 ± 0.00^{g}	0.00 ± 0.00^{g}	0.00 ± 0.00^{g}	3.17 ± 0.28^{ef}	4.85 ± 0.85^{d}	6.86 ± 0.35^{c}	2.87 ± 0.51^{f}	4.96 ± 0.36^{d}	7.78 ± 0.48^{bc}	3.62 ± 1.04^{ef}	4.28 ± 0.61^{de}	7.80 ± 0.20^{bc}	4.53	1.07
OM	1.46 ± 0.21^{gh}	2.78 ± 0.46^{bc}	3.02 ± 0.73^{b}	3.81 ± 0.17^{a}	2.08 ± 0.29^{defg}	1.73 ± 0.91^{fgh}	1.64 ± 0.39^{fgh}	1.25 ± 0.43^{h}	2.10 ± 0.38^{efg}	2.25 ± 0.13^{cdef}	1.85 ± 0.6^{8efgh}	2.01 ± 0.23^{efg}	2.48 ± 0.38^{bcde}	1.93 ± 0.44^{efg}	2.68 ± 0.69^{bcd}	2.75 ± 0.43^{bc}	2.24	0.57
IFILT	5.00 ± 1.00^{b}	12.00 ± 2.00^{a}	12.02 ± 1.00^{a}	12.10 ± 1.20^{a}	1.10 ± 1.00^{b}	1.43 ± 0.01^{b}	1.60 ± 0.10^{b}	1.30 ± 0.02^{b}	1.91 ± 0.02^{b}	5.18 ± 2.00^{b}	3.00 ± 0.10^{b}	6.34 ± 1.20^{ab}	7.83 ± 2.00^{ab}	2.10 ± 0.01^{b}	4.00 ± 0.10^{b}	6.03 ± 2.00^{ab}	5.10	5.67

Note: Pp = *Peltophorum pterocarpum*. Ll = *Leucaena leucocephala*. Cr = *Crotolaria retusa* .75ml (0.4%vw) = low pollution, 150ml (0.8%vw) = medium pollution, 300 (1.5%vw) = high pollution. PD = Particle density, BD = Bulk density, THC = Total Hydrocarbon, OM = Organic matter, INFILT = Infiltration. * Means of five replicates and with the same superscript letter are not significantly different, using the Duncan's New Multiple Range Test (DNMRT).

Table 3. The phytoremediation potency of the species in the crude oil polluted soil.

Potency	Pre-pollution	Post-pollution soil				Post – phytoapplication / pollution levels											
						P. pterocarpum / Soil				*L. leucocephala/ Soil*				*C. retusa / Soil*			
		75mil	150ml	300ml	Mean	75mil	150ml	300ml	Mean	75ml	150ml	300ml	Mean	75ml	150ml	300ml	Mean
Bioaccumulation Quotient (BQ)	--	--	--	--	--	19.53	12.51	7.90	13.31	21.49	10.78	6.81	13.03	10.70	13.93	7.17	10.60
Crusting hazard risk of sealing (R %)	7.02	12.64	14.25	17.16	14.68	7.91	14.58	17.31	13.00	11.01	9.31	15.12	11.81	12.22	19.71	21.83	17.52

silt; (r = 0.50; *P<0.05*) with clay, and (r = 0.21; *P<0.05*) with BD and negative correlation (r = -0.05; *P<0.05*) between infiltration and sand, (r = -0.50; *P<0.05*) with PD. Similar studies by Marinescu *et al*., (2001); Essien and John (2010); Ewetola, (2013); Jerzy *et al*. (2015); Uzoije and Ogunwamba (2011) and Edwin-Wosu and Nkang, (2017b) have documented the diverse impact of crude oil hydrocarbon pollution on soil physicochemical properties in light of changes in soil edaphic properties associated with increase in bulk density, organic matter, and increased soil texture due to increase in silt particle sizes, decrease in clay and sand associated with increase hydrophobic waxy texture adsorbed to the particle surfaces and decrease in porosity and particle density.

The impact of post-phytoapplication in the remediation process has contributed to the restoration of post-pollution crude oil impacted soil in light of enhanced soil structure and texture, improved particle density, reduced bulk density, increased porosity, reduced organic matter, reduced THC, enhanced root formation and improved infiltration rate. The restoration of soil structure due to enhanced sandy component in the post-phytoapplication with greater percentage in *P. pterocarpum* treated soil in the order *Pp>Cr>Ll,* suggest that phytoremediation enhances the attenuation of sandy loam soil as exemplified in the negative correlation (r = -0.42; *P<0.05*) between THC and sand particle size. This corroborates earlier studies by Wang *et al.* (2013); Udom and Nuga (2015) and Edwin-Wosu and Nkang, (2017b)

Table 4. Pearson correlation coefficient amongst parameters of phytoremediation crude oil polluted soil.

Parameter	Sand	Silt	Clay	PD	BD	INF.	THC	OM
Sand	1.00							
Silt	- 0.47^{NS}	1.00						
Clay	- 0.77^{NS}	- 0.15^{NS}	1.00					
PD	0.25*	0.15*	- 0.40^{NS}	1.00				
BD	- 0.20^{NS}	- 0.07^{NS}	0.30*	- 0.22^{NS}	1.00			
INF.	- 0.50*	0.09^{NS}	- 0.50*	0.50*	0.21	1.00		
THC	- 0.42^{NS}	0.23^{NS}	0.30*	- 0.24*	0.06*	0.52*	1.00	
OM	- 0.15^{NS}	- 0.04^{NS}	0.19*	- 0.62^{NS}	- 0.04^{NS}	- 0.47*	0.40*	1.00
	Root	OM	THC					
Root	1.00							
OM	0.31*	1.00						
THC	0.40*	0.36	1.00					

*p<0.05, significantly different; NS: non-significantly different. PD = Particle density, BD = Bulk density, THC = Total Hydrocarbon, OM = Organic matter, INFILT = Infiltration

Table 5. Hydrocarbon removal and efficiency of species in the crude oil polluted soil.

	THC (mg/g) content (mean) remaining in species treated soils (*Ce*) per plant.				Amount of hydrocarbon removed from species treated soil (q) (mg/g) per plant.				Efficiency of removal of hydrocarbon from species treated soil per plant (E %)			
Species	Low	Medium	High	Mean	Low	Medium	High	Mean	Low	Medium	High	Mean
P. pterocarpium	3.17	4.85	6.86	4.96	0.83	0.77	0.69	0.76	57	44.38	33.59	45
L. leucocephala	2.87	4.96	7.78	5.20	0.89	0.75	0.51	0.72	61	43.12	24.69	43
C. retusa	3.62	4.28	7.80	5.23	0.74	0.89	0.51	0.71	50.55	50.92	24.49	42

Initial concentration of THC in the polluted soil (Ci) = 8.79mg/g

who have reported a higher phytodegradation and removal of petroleum hydrocarbon, high efficiency and bioaccumulation quotient in vegetated polluted soils than in non-vegetated polluted soils in light of a hydraulic conductivity assessment of crude oil polluted soil in the Niger Delta, Nigeria and a crude oil contaminated Momoge wetland in China. Soil texture does influence phytoremediation due to binding potential of clay component which lowers bioavailability of molecules and contaminant than in silt and sandy soil. This was represented in a positive correlation (r = 0.30; *P<0.05*) between THC and clay and supported by earlier assertion by Izinyon and Seghosime, (2013) and Edwin-Wosu and Nkang, (2017b) who have noticed a greater binding potential in clay than in silt and sandy component of crude and waste oil contaminated soil in which there was a strong adsorption and low bioavailability. Such binding reduces water drainage and conductivity but improves water retention ability of the soil clay and bulk density. The decreased particle density due to pollution also gained restoration by the phyto-treatment of the soil as represented in a positive correlation (r = 0.25; *P<0.05*) between PD and sand; and (r = 0.15; *P<0.05*) with silt, and with *P. pterocarpum* soil having a higher particle density in the order *Pp> Ll >Cr*. The increased bulk density and reduced porosity in post – pollution as expressed in the aforementioned positive correlation with pollution impact had a restoration impact of the post-phytoapplication treatment. This consequentially caused a reversal of the increased bulk density and reduced porosity. This trend is represented in the order *Pp<Cr<Ll* with *P. pterocarpum* treated soil having a significantly lowest bulk density (g/cm^3) and high porosity in the order *Pp>Cr>Ll,* (Table 2). This could be exemplified in a negative correlation (r = - 0.42; *P<0.05*) between THC and sand; (r = - 0.24; *P<0.05*) with PD and positive correlation (r = 0.40; *P<0.05*) between root formation and THC of the crude oil polluted soil. The impact and implication of phytoapplication has caused reduction in OM among species treated soils with *P. pterocarpum* soil non-significantly recording a lesser OM content than *L. leucocephala* and *C. retusa* treated soils in the order *Pp< Ll < Cr* but with above ground accumulation in the order *Pp>Ll>Cr*. This performance of *P. pterocarpum* could be attributed to its activity of mineralization and nutrient absorption which could be represented in the positive correlation (r = 0.31; *P<0.05*) between plant root and OM (Table 4). Similarly, the increase in THC content of the post-polluted soil condition was reversed by the phytoapplication with reduction in THC among the species treated soils in the order *Pp<Cr<Ll* as exemplified in a positive correlation (r = 0.40; *P<0.05*) between plant root and THC and increase in bioaccumulation of above ground content in the order *Pp>Cr>Ll*. The reduction in THC content of *P. pterocarpum* treated soil is amplified in its high efficiency removal and bioaccumulation quotient (Table 3 and 5). Also according to earlier studies by Wang *et al*. (2010; 2013), Udom and Nuga (2015) and Edwin-Wosu and Nkang (2017b) it has been reported that higher degradation and hydrocarbon removal is faster and rapid in vegetated soils than non vegetated soils. Thus considers phytoremediation as a means of enhancing oil attenuation by the plant taking in molecular hydrocarbons. The efficiency of *P. pterocarpum* in hydrocarbon removal could also be the effect of phytodegradation process among the mechanism of phytoremediation. Other sources of efficacy could be the ability of the species for enhanced rhizospheric microbial activity due to its extensive rooting system (Edwin-Wosu, 2012) and the activities of *Peroxidase* (POD) and *Polyphenoloxidase* (PPO) detoxifying enzymes of the plant (Edwin-Wosu and Nkang, 2015). The soil infiltration rate of the different phases of ecological study has indicated variation in the time (t –minute) for water passing through the surface of pre-polluted soil to be significantly (*P<0.05*) lower than the post-polluted soil, which was significantly (*P<0.05*) higher across the various levels of phyto-application treated soil. The pre-polluted soil with lesser time (in minutes) of increased infiltration rate tend to increase in time with decreased infiltration rate across post-pollution which had influence on edaphic properties involving decrease in soil texture, structure, PD, porosity and increase in BD, and OM content. This could imply the impact of crusting hazard of crude oil risk of sealing on the soil surface (Table 3). The clay soil texture and organic matter do affect phytoremediation process; hence such components of soil induce binding effect, strong adsorption, increase bulk density and low or no contaminant bioavailability in the soil for plant uptake. Consequently, such effect reduces

infiltration rate following reduction in water movement, increase in water retention ability of soil and bulk density. The increase in bulk density across pollution levels with simultaneous compaction and formation of crust layer at soil surface could imply the reason for reduction in root formation of *L. leucocephala* and *C. retusa* (Table 1). However, the restoration of infiltration rate by phytoapplication among species treated soil as indicated with the greater performance of *P. pterocarpum* has shown improvement among the edaphic properties. Though a significantly ($P<0.05$) decreased time rate of infiltration process, but non-significantly different from the pre-polluted pristine soil. This is attributed to its ability to improve the soil porosity, texture, structure, PD, and reduce BD, OM, and THC content as earlier observed in this research and the enhanced enzymes in the soil rhizosphere (Edwin-Wosu and Nkang, 2015). Though a greater performance was recorded in the *P. pterocarpum* treated soil, yet with a greater crusting hazard than the *L. leucocephala* treated soil. This could corroborate the assertion that Soil texture **(s**oil particle size distribution) particularly clay, does affects soil crusting. A high clay content generally favours aggregation and reduces the rate of crust formation, although clay mineralogy can modify this generalization while medium-textured soils (<20% clay) are usually very susceptible to crusting (Collinet and Valentin, 1984). Also organic matter content is well known as one of the most important aggregate-stabilizing agents in soil. The effects of organic matter on aggregate stability have been widely studied on various soil types. When soils are intensively cultivated, the susceptibility to crusting is increased (Marcello, 2007). This can be related to the progressive decrease of organic matter content in *P. pterocarpum* treated soil in light of its bioaccumulation quotient, hydrocarbon removal efficiency and organic carbon mineralization higher than other biotest plant species.

The enhancing performance of phytoapplication in the restoration of the aforementioned edaphic properties with simultaneous restoration of infiltration at a decreased time rate of water movement is an indication that growing plants have profound potential and impacts on the physical and chemical properties of soil. Root formation and elongation are characteristics of a growing plant. Studies have indicated among the grasses, sedges and legumes some species with great potentials to facilitate the remediation of hydrocarbon polluted habitat through their extensive and fibrous root systems (Aprill and Sims, 1990; Ifante *et al*., 2010). The presence of vegetation and growth of plants extensive rooting system penetrates soil pores, impermeable soil layer, disrupts aggregates, create channels to air and water penetration, enhances soil structure, texture, surface area and enhance biodegradation of entrapped hydrophobic contaminants (Bharati *et al*., 2002; Abdel *et al*., 2015). The bases for root system and development of the selected leguminous test plants is a reflection of their fast growing, deep reaching widely extended roots that create an extended rhizosphere (Edwin-Wosu and Nkang, 2017b). Obviously, it might be desirable for phytoremediation to have plants that grow dense, highly ramified fibrous root system very deep down. Beside, it has been shown that the species had root length reduction across pollution levels as indicated in a positive correlation (r = 0.40; $P<0.05$) between THC and plant root than in controlled soil. Within species root length reduction was significantly different ($P<0.05$) in *L. leucocephala* and *C. retusa*. This could also be affirmed by the increase in bulk density across pollution levels resulting to compaction and formation crust layer on soil surface as exemplified in a positive correlation (r = 0.23; $P<0.05$) between THC and silt; (r = 0.30; $P<0.05$) with clay; (r = 0.06; $P\leq0.05$) with BD; and (r = 0.40; $P<0.05$) with OM. This could suggest the reason for the reduction in root formation of *L. leucocephala* and *C. retusa* (Table 1). This corroborates Edwin-Wosu and Nkang, (2017b) following earlier observation by Essien and John (2010) that an oil polluted soil with harsh, infertile and less permeability could be a constraint by slowing down root elongation and growth with a pollution depression of 45.67 to 90%, while *P. pterocarpum* had a higher root length formation with significant difference ($P<0.05$) across low and medium pollution remediated soil levels (Table 1) in the order *Pp>Ll>Cr*.

Conclusion

Infiltration characteristics are closely related to soil edaphic parameters and may be a good indicator of changes in soil physical and biological properties. From the study it has been shown based on the species potency and efficiency level of hydrocarbon removal that these legumes are suspected hydrocarbon tolerant species with potential demonstration for growth and survival in crude oil polluted soil. *P. pterocarpum* among the species has shown comparative advantage across pollution levels in light of its potential to restore the infiltration dynamics of the post-polluted soil. Such potential is predicated also on its ability to improve on the underpinning edaphic factors (soil structure, texture, particle density, bulk density, porosity, and organic matter) that regulate water movement process such as infiltration in a crude oil polluted soil habitat. *P. pterocarpum* also had the highest hydrocarbon removal efficiency, enhanced accumulation quotient and root formation. It can thus be proposed as part of a bioremediation implementation in environmental restoration programme.

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REFERENCES

Abdel-Ghany TM, Mohamed, AA, Moustafa EN, Abdel-Rahman MS. 2015. Rhizosphere Microorganisms as Inducers for Phytoremediation a Review. *International Journal of Bioinformatics and Biomedical Engineering*, 1(1):7-15. http://www.aiscience.org/journal/ijbbe

Agbor RB, Ekpo IA, Kalu SE, Bassey IU, Okoi EP, Ude EO. 2015. Growth pattern of two crop species on bioremediated hydrocarbon polluted soils. Scientific Research and Essays 10 (2): 58 – 63.

Akindele SO. 1996. Basic Experimental Design in Agricultural Research, Akure, Federal University of Technology Akure (FUTA) Press. Pp 77 – 84.

Amusan B, Ball E, Anderson G. 2005. Changes in characteristics of a degraded soil under fallow in south western Nigeria. *Journal of Agricultural Engineering,* 4: 12-17.

Anejionu OCD, Ahiarammunnah PN, Nri-ezedi CJ. 2015. Hydrocarbon pollution in the Niger Delta: geographies of impacts and appraisal of lapses in extant legal frame- work. Res. Policy 45:65–77.

Anna KI, Ewa B, Jaroslaw L, Agnieszka K, Piotr W. 2015. Influence of Oil Contamination on Physical and Biological Properties of Forest Soil After Chainsaw Use. Water Air Soil Pollution 226: 2 - 9. DOI 10.1007/s11270-015-2649-2

API. 2005. Recommended practice of oil field water analysis. American Petroleum Institute (API-RP-45).

Aprill W, Sims RC. 1990. Evaluation of use of prairie grasses for stimulating polycyclic aromatic hydrocarbon treatment in soil. Chemosphere 20 (1-2):253-265.

ASTM. 1958. Procedure for testing soils. American Soil Testing and Materials. Philadephia.

Badmus MAO, Audu TOK, Anyata BU. 2007. Removal of lead ion from industrial waste water by activated carbon prepared from periwinkle shells. *Turkish Journal of Engineering and Environmental Science*, pp. 251 –263.

Bharati L, Lee KH, Isenhart TM, Schultz RC. 2002. Soil-water infiltration under crops, pasture, and established riparian buffer in Midwestern USA,

Bisong FE. 2001. Natural resource use and conservation for sustainable rural development, BAAJ Publisher, pp. 69-80.

Black CA. 1965. Methods of soil analysis, part 1. ASA Inc. Publisher, Madison, Wisconsin, USA. Agronomy 9: 383 – 390,

Blake GR, Hartge KH. 1986. Bulk density. In: Klute A. (Ed.) Method of Soil Analysis, part 1. Agronomy 9. ASA, Madison. WI., P. 363 – 373.

Blaylock MJ, Elless MP, Huang JW, Dushenkov SM. 1999. Phytoremediation of lead-contaminated soil at a New Jersey brownfield site. Remediation 9(3):93 -101.

Bouwere H. 1986. Intake rate: cylinder infiltrometer. In: Klute A. (ed.), Methods of Soil Analysis. Part 1. ASA and SSSA, Madison, WI, pp. 825–844.

Bouyoucos GH. 1962. Hydrometer method improved for making particle size analysis of soil. Soil Science Agronomy Journal 53: 464 – 465.

Brassington KJ, Hough RL, Paton GI, Semple KT, Risdon GC, Crossley J, Hay I, Askari K, Pollard SJT. 2007. Weathered hydrocarbon wastes: a risk management primer. Critical Review in Environmental Science and Technology, 37: 199 – 232.

Brooks RR. 1998b. Phytochemistry of hyperaccumulators. In: Brooks RR (ed.) Plant that hyperaccumulate heavy metals. CAB International, New York, NY, pp. 15 – 53.

Burken JG, Schnoor JL. 1997. Uptake and metabolism of atrazine by poplar trees. Environmental Science Technology, 31: 1399 – 1406.

Carter P, Cole H, Burton J. 2006. Bioremediation: successes and shortfalls. Interspill Conference.

Collinet J, Valentin C. 1984. Evaluation of factors influencing water erosion in West Africa using rainfall simulation. In: *Challenges in Africa Hydrology and Water Resources.* IAHS Publication. 144:451- 461.

Conger RM, Portier R. 1997. Phytoremediation experimentation with the herbicide bentazon. Remediation. 7(2): 19-37.

Duke NC. 2016. Oil spill impacts on mangrove: recommendations for operational planning and action based on a global review. MPB, 109: 700 – 715.

Dushenkov SD, Vasudev Y, Kapulinik D, Gleba D, Fleisher D, Ting KC, Ensley B. 1997. Removal of uranium from water using terrestrial plants. *Environmental Science Technology,* 31(12):3468 – 3474.

Edwin-Wosu NL, Nkang A. 2016. Evaluation of phytoremediation potential of *Peltophorum pterocarpum* (DC.) Heyne *Leucaena leucocephala* (Lam.) De Wit. and *Crotolaria retusa* Linn for waste oil contaminated soils. *Journal Applied Science Environmental Management*, 20 (3): 669-678.

Edwin-Wosu NL, Nkang AE. 2017. Studying the Physico-edaphic and Hydraulic conductivity of Phytoremediated Spent Oil Polluted Habitat. *International Journal of Plant and Soil Science*, 17(1): 1-13,

Edwin-Wosu NL, Nkang AE. 2017b. The Influence of Phytoremediation Potential on Water-Habitat Relationship of Crude Oil Polluted Tropical Niger Delta Soil: Hydraulic Conductivity Assessment. *Nigerian Journal of Botany,* 30(1):61-80.

Edwin-Wosu NL, Nkang Ani E. 2015. Evaluation of Enzyme Expression in a Macrophytic Treated Crude Oil Soil Habitat: Implication for Enhanced Phytoremediation Potential Using Transgenic Botanicals. Insight Ecology, 4 (1): 13-23. doi: 10.5567/ECOLOGY-IK.2015.13.23

Edwin-Wosu NL. 2005. Phytoremediation Innovative Technology (series 1): Ashort term comparative analyses of remediation potential of macrophytic agro-forestry species in a water-habitat relationship of a crude oil polluted terrestrial habitat. *Global Journal of Environmental Sciences*, 4(2):135 – 138.

Edwin-Wosu NL. 2012. Phytoremediation potential of some macrophytes on crude / waste oil polluted soils in the rainforest environment [PhD Thesis]. University of Calabar, Cross River State. 263pp.

Essien OE, John IA. 2010. Impact of Crude-Oil Spillage Pollution and Chemical Remediation on Agricultural Soil Properties and Crop Growth. *Jour. Appl. Sci. Environ. Manage.,* 14 (4) 147 - 154

Ewetola EA. 2013. Effect of Crude Oil Pollution on some Soil Physical Properties. *Journal of Agriculture and Veterinary Science,* 6 (3):14-17

Eze BE, Devalsam IE, Oko C. 2011. Evaluation of the Infiltration Capacity of Soils in Akpabuyo Local Government Area of Cross River, Nigeria. *Journal of Geography and Geology,* 3(1):189 – 199.

Ezeaku PI, Egbemba BO. 2014. Yield of maize (*Manoma* spp.) affected by automobile oil waste and compost manure. *African Journal of Biotechnology*, 13(11):1250 – 1256.

Ferrera-Cerrato R, Alarcon A, Mendonza-Lopez MR, Sangabriel W, Trejo-Aguillar D, Cruz-Sanchez S, Lopez-Ortis C, DelgadilloMartinez J. 2007. Fitorremediación deum Suelo Contaminado conCombustóleo Utilizando *Phaseoluscoccineus* y Fertilización Orgánica eInorgánica. Agrociencia 41(8):817-826.

Gerhardt KE, Huang X, Glick BR, Greenberg BM. 2009. Phytoremediation and rhizodegradation of organic soil contaminants: Potential and Challenges. *Plant Science,* 176(1):20-30.

Gradwell MW. 1955. The determination of specific gravities of soil as influenced by clay-mineral composition. N.Z.J. Science Technology, 37B: 283 – 289.

Harry OB, Nyle CB. 1962. The nature of soil properties. http:/www.bnl.gov./erd/preconic/fact sheet/phytoextraction. Pdf. Accessed on March 10, 2010.

Infante C, Morales F, Ehrman EU, Hernandez-Valencia I, Leon N. 2010. Hydrocarbon bioremediation and phytoremediation in tropical soils: Venezuelan study case. In: Grazyna, P. (Edit), Trends in Bioremediation and Phytoremediation. Pp. 429 – 451.

Ite AE, Ibok UJ, Ite MU, Petters SW. 2013. Petroleum exploration and production: past and present environmental issues in the Nigeria's Niger Delta. *American Journal of Environmental Protection*, 1: 78-90.

Izinyon OC, Seghosime A. 2013. Assessment of Sweet Potato (*Ipomoea batatas*) For Phytoremediation of Motor Oil Contaminated Soil phytoremediation Of Motor Oil Contaminated Soil. *Nigerian Journal of Technology,* 32 (3): 371 – 378

Jerzy T, David JW, Marek SZ. 2015. Can hydrocarbon contamination influence clay soil grain size composition? *Applied Clay Science,* 109 -110: 49-54.

Jiang Y, Brassington KJ, Prpich G, Paton GI, Semple KT, Pollard SJT, Coulon F. 2016. Insight into the biodegradation of weathered hydrocarbon in contaminated soils by bioaubumentation and nutriet stimulation. Chemosphere 161: 300 – 307. http://dx.doi.org/10.1016/j.

Jordahl JL, Foster L, Schnoor JL, Alvarez PJJ. 1997. Effect of hybrid poplar trees on microbial populations important to hazardous waste bioremediation. Environmental Toxicology Chemistry 16(6):1318 -1321.

Kadafa AA. 2012. Oil exploration and spillage in the Niger Delat of Nigeria. Civ. Environ. Res., 2: 38 – 51.

Kigne JW. 2006. Salinization in irrigated Agriculture in Pakistan: Mistaken Predictions. Water Policy 8:325-338.

Kumar PB, Nanda A, Dushenkov V, Motto H, Raskin I. 1995. Phytoextraction: the use of plants to remove heavy metals from soils. *Environmental Science Technology,* 29(5):1232 – 1238.

Lee AN, Charles MR. 2004. Phytodegradation of organic compounds. Current Opinion in Biotechnology 15:225–230

Lin Q, Mendelssohn IA. 1998. The combined effects of phytoremediation and biostimulation in enhancing habitat restoration and oil degradation of petroleum contaminated wetlands. *Ecological Engineering,* 10(3):263 – 274.

Marcello P. 2007. Soil surface sealing and crusting. The Abdusalam International Centre for Theoritical Physics. College of Soil Physics, pp.25.

Marinescu M, Toti M, Tanase V, Plopeanu G, Calciu I, Marinescu M. 2001. The effects of crude oil pollution on physical and chemical characteristics of soil. *Research Journal of Agricultural Science,* 43(3), 125-129.

Meagher RB, Rugh CL, Kandasamy MK, Gragson G, Wang NJ. 2000. Engineered Phytoremediation of Mercury Pollution in Soil and Water Using Bacteria Genes. In: Terry N, Banuelos G (Eds.). Phytoremediation of Contaminated Soil and Water. Lewis Publishers, Boca Raton, FL. Pp. 201 – 219.

Nelson DW, Sommer LE. 1982. Total carbon, organic carbon and organic matter. In: Page, A.C. (Ed.). Methods of Soil Analysis Part 2, 2nd ed. Agron. Monogr. 9. ASA and SSSA. Madison, WI; pp.539-379.

Newman LA, Wang X, Muiznieks IA, Ekuan G, Ruszaj M, Cortellucci R, Domroes D, Karscig G, Newman T, Crampton RS, Hashmonay RA, Yost MG, Heilman PE, Duffy J, Gordon MP, Strand SE. 1999. Remediation of trichloroethylene in an artificial aquifer with trees: A controlled field study. *Environmental Science Technology,* 33(13):2257 – 2265.

Obinaju BE, Martin FL. 2016. ATR-FTIR spectroscopy reveals polycyclic aromatic hydro- carbon contamination despite relatively pristine site characteristics: results of a field study in the Niger Delta. Environ. Int. 89–90:93–101.

Pamila D, Sivalingam A, Thirumarimurugan M. 2016. Green revolution- phytoremediation of heavy metals from industrial effluent by water hyacinth. Engineering. & Technology in India 7 (1):56 – 64.

Peng S, Zhou Q, Cai Z, Zhang Z. 2009. Phytoremediation of petroleumcontaminated soils by *Mirabilis jalapa* L., in a greenhouse pilot experiment. *J.Hazard Mat.,* 168(2):1490-1496.

Philip DS, Augustine I. 2014. Integrated Remediation Techniques in Handling Complex Crude Oil Impacted Site at Ejama Ebubu – Niger Delta, Nigeria. Presented at the 21st International Petroleum Environmental Conference in Houston, TX - October 14-16, The Shell Petroleum Development Company Nigeria Ltd. Port Harcourt, Nigeria.

Radke JK, Berry EC. 1993. Infiltration as a tool for detecting soil changes due to cropping, tillage, and grazing livestock. *American Journal of Alternative Agriculture,* 8: 164–174.

Raghuvanshi SP, Singh R, Kaushik CP. 2004. Kinetic studies of Methylene blue dye bio – adsorption on Baggase. *Applied Ecology and Environmental Research,* 2 (2): 35-43.

Sam K, Prpich G, Coulon F. 2015. Environmental and societal management of contaminated land in Nigeria: the need for policy and guidance changes. 4th International Contaminated Site Remediation Conference: Program and Proceedings. Melbourne, Australia, pp. 427 – 428.

SAS 2002. Institute Inc. SAS for Windows Release 9.1, Canny, United State America, Statistical Analysis Systems Institute Incorporated,

Schwab A, Fangmeir D, Elliot I, Frerert K. Soils and Water Conservation Engineering. New York, John Wiley & Sons Inc. (Chapter 12) 1995; 15-35.

Shameem SA, Irfana NK. 2011. Comparative assessment of edaphic features and phytodiversity in lower Dachigam National Park, Kashmir Himalaya, India. *African Journal of Environmental Science and Technology,* 5(11):972-984

Shanon T. 2017. Phytoremediation: cleaning the soil with flowers? www. Documents/Phytoremediation%20%20 Cleaning%20The%20Soil%20With%20Flowers. htm (Retrieved: 28 – 08 – 2017).

Smith RAH, Bradshaw AD. 1979. The use of metal tolerant plant populations for the reclamation of metalliferous wastes. *Journal of Applied Ecology,* 16:595 – 612.

Song HG, Wang X, Bartha R. 1990. Bioremediation potential of terrestrial fuel spills. *Applied and Environmental Microbiology,* 56(3): 652 – 656.

Stewarte A, Grimshaw HM, John AP. 1974. Chemical Analysis of Ecological Materials. Oxford. Blackwell Scientific Publications.

Thompson PL, Ramer LA, Schnoor JL. 1998. Uptake and transformation of TNT by hybrid poplar trees. *Environmental Science Technology,* 32:975 – 980.

Tripathi V, Fraceto LF, Abhilash, 2015. Sustainable clean-up technologies for soils contaminated with multiple pollutants: Plant-microbe-pollutant and climate nexus. *Ecol Eng.,* 82:330-335.

Udom BE, Nuga BO. 2015. Biodegradation of Petroleum Hydrocarbons in a Tropical Ultisol Using Legume Plants and Organic Manure. *Journal of Agricultural Science,* 7(4): 174 – 182.

UNEP. 2011. Environmental Assessment of Ogoniland. UNEP, Switzerland.

Uzoije AP, Agunwamba JC. 2011. Physiochemical Properties of Soil in Relation to Varying Rates of Crude Oil Pollution. *Journal of Environmental Science and Technology,* 4: 313-323.

Vander-Watt HVH, Claasens AS. 1990. Effect of surface treatment on soil crusting and infiltration. *Soil Technol.,* 3: 241-251.

Walkley A, Black CA. 1934. An examination of the Degtgareff method for determining soil organic matter and proposed modification of the chronic Acid titration method. *Soil Science,* 37:29-38.

Wang XY, Feng J, Zhao JM. 2010. Effects of crude oil residuals on soil chemical properties in oil sites, Momoge Wetland, China. *Environmental Monitoring and Assessment,* 161(1): 271–280. doi: 10.1007/s10661-008-0744-1

Wang Y, Feng J, Lin Q, Lyu X, Wang X, Wang G. 2013. Effects of Crude Oil Contamination on Soil Physical and Chemical Properties in Momoge Wetland of China. *Chinese Geographical Science,* 23(6): 708 –715. doi: 10.1007/ s11769-013-0641-6

Wood M, Finger L. 2006. Influenced of irrigation method on water use and production period partners in Northern Victoria. *Australian Journal of Experimental Agriculture,* 46: 1604-1614. doi:10.1071/EA05197, http://dx.doi.org/10. 1071/EA05197

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