International Journal of Plant & Soil Science

17(1): 1-13, 2017; Article no.IJPSS.32948
ISSN: 2320-7035

Studying the Physico-edaphic and Hydraulic Conductivity of Phytoremediated Spent Oil Polluted Habitat

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Authors' contributions

This work was carried out in collaboration between both authors. Authors NLEW and AEN designed the study. Author NLEW performed the statistical analysis, wrote the protocol and the first draft of the manuscript. Author AEN managed the analyses of the study and literature searches. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2017/32948
Editor(s):
(1) Lakesh K. Sharma, Extension and Sustainable Agriculture, University of Maine, Cooperative Extension, Maine, USA.
Reviewers:
(1) Augustine Uche Abel, Federal University Lafia, Nigeria.
(2) Arezoo Dadrasnia, University of Malaya, Malaysia.
Complete Peer review History: http://www.sciencedomain.org/review-history/19719

Original Research Article

Received 24th March 2017
Accepted 25th April 2017
Published 27th June 2017

ABSTRACT

Several studies have recorded effect of spent lubricant oil pollution on soil properties. This study aims at evaluating the ecology of waste oil pollution and the impact of phytoremediation on soil hydraulic conductivity vis-à-vis some edaphic properties using three leguminous plants; with the objectives of performing field and laboratory study of such contamination and impact of phytoremediation on such properties as soil texture and structure, particle density, bulk density, porosity, organic matter content and total hydrocarbon content and hydraulic conductivity. Using classical and conventional methods to assess the performance of these plant species, result showed a trajectory influence across pollution levels on the soil edaphic properties culminating to decrease in hydraulic conductivity. With the impact of phytoapplication *P. pterocarpum* had greater particle size (87.73%) of sand, particle density of 2.61 g/cm^3 with significant difference (*P=0.05*) than *C. retusa* and *L. leucocephala* treated soils. A significantly (*P=0.05*) lower bulk density (0.83 g/cm^3), increased porosity (68%) and reduced organic matter content (2.65%) were recorded in

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P. pterocarpum treated soil. Total hydrocarbon reduction (1.8 mg/g) content and its equivalent potency of greater removal and reduction (0.43 mg/g), high efficiency of 55% and 34.40 bioaccumulation quotient and a lower crusting hazard (24.63%) of sealing with increased hydraulic conductivity (5.73 ml/s) were recorded in *P. pterocarpum* treated soil. By the foregoing potency *P. pterocarpum* could be suggested as a good biological measure in integrated environmental remediation programmes.

Keywords: Organic matter; bulk density; soil texture; soil structure; particle density.

1. INTRODUCTION

The use of natural gas and motor oil has been on the increase due to industrialization that has resulted in increased consumption of petroleum products resulting in increased contamination of sites with petroleum and petroleum by-products [1]. According to Sulaiman et al. [2], petroleum and its products are of specific concern in pollution studies because of their structural complexity, slow biodegradability, biomagnification potential and the serious health hazards associated with their release into the environment.

Waste oil also known as spent engine oil is one of the most common forms and sources of pollution by petroleum hydrocarbon and its derivatives on environmental media, especially on soil terrestrial habitat. Spent engine oil, is commonly obtained from the activities and services of auto mechanics, generator repairers, and allied artisans with workshops on the road sides and open places [3]. It is dark brown to black in colour and a complex mixture of mono and multi-grade crankcase oils from petrol, diesel engines, gear oils and transmission fluids with significant levels of hydrocarbons, low to high molecular weight (C_{15} – C_{21}) compounds, lubricants, additives and decomposition products, heavy metals and other properties present in all petroleum products. The indiscriminate disposal of this oil into gutters, water drains, and open vacant plots of land in both farms and industrial built up areas is a common experience especially in developing nations like Nigeria and with its attendance pollution incidence in the environment it has been shown to be more widespread and harmful than crude oil pollution to the soil environment [4,5].

Over several decades, the changes of soil properties resulting from organic and inorganic sources of contamination have been a subject of interest for many researchers. The saturation of soil by fluids characterized by physico-chemical properties that differ from water has been found to have a deteriorating effect on its mechanical and filtration parameters, plasticity, swelling and other properties [6,7,8]. Eze et al. [9], had earlier observed marked changes occurrence in the physico-chemical and microbiological properties of soils contaminated with lubricant oil. Several other studies have also recorded effect of spent lubricant oil contamination on soil properties [10,11,12,13].

In general, increase in oil contamination of soil reduces the permeability, strength and Atterberg limits [8]. The aim of this study is to evaluate the impact of phytoremediation techniques using three legume plants on waste oil-contaminated soils, it is necessary to quantify the modifications in some of these physical properties, since they are the most important factors affecting hydraulic conductivity. The objectives of this study is to perform field and laboratory testing program to study the ecology of motor oil contamination together with the effect of phytoremediation on soils; hydraulic conductivity. The studied properties include soil texture and structure, particle density, bulk density, porosity, organic matter content and total hydrocarbon content.

2. MATERIALS AND METHODS

The study was carried out in two phases involving: field work and laboratory analyses.

2.1 Field Work

2.1.1 Sources of materials

Adopting the Stewarte et al. [14] and Song et al. [15] approach, replicates of top loam soil (20 kg) were collected in bulk within the standardized 0-15 cm soil layer from a fallowed garden land of the Faculty of Agriculture, University of Calabar, Cross River State, Nigeria. The seeds of *Peltophorum pterocarpum* (DC.) Heyne were obtained from one of the green belt formations of

the University of Port Harcourt, Rivers State, Nigeria. The seeds of *Leucaena leucocephala* (Lam) De Wit. and *Crotolaria retusa* Linn were obtained from the wild in a dump site in Port Harcourt and authenticated. The waste oil used was obtained from mechanic workshop in Port Harcourt. All chemical reagents, used in this study were of analytical grade, purchased from Welly International Company Nigeria (Scientific/Hospital and Chemical supplier) located in Port Harcourt.

2.1.2 Experimental design and pollution of the study site with waste oil

The "*nested design*" of Akindele [16] was adopted in this study using a double split plot design in which the nested analysis of variance (PROC. ANOVA) procedures [17] was carried out on the physico-edaphic parameter vis-à-vis the hydraulic conductivity of waste oil polluted sites. In such design three (3) different species of plants were involved in the remediation of 3 different simulated doses or levels of waste oil polluted site that were in replicates of five. The pollutant was applied using a measuring cylinder. The pollution was done in four levels in mill and concentration (V/W %) doses of 0%, 75 (0.4%), 150 (0.8%) and 300 (1.5%) per 1,809 cm^2 surface area. In each level of pollution, 3 phyto-treatments were performed and replicated five times. Differences in post-pollution soil, post-phytoapplication species performance and soil were tested using the parameter replicates by treatment interaction and treatment by levels interaction as the error terms.

2.1.3 Post-pollution habitat reclamation treatment using the phytometers

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 the Fabaceae plant family (*P. pterocarpum, L. leucocephala and C retusa*). Healthy 14 days old seedlings of the three species were planted into the control and polluted soils in the microplots. 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 relation to comparative analysis of the root biota and organic content of the species.

2.2 Baseline Analyses

The baseline analyses of pollutant and pre-pollution soil was carried out. Post-pollution and post-phytoapplication recuperation of the polluted soil under the seedling was assessed by means of comparative analysis of the biotic and physico-edaphic parameters of the polluted soil using classical methods;

2.2.1 Pollutant characterization

The waste oil used for the study was characterized for the following properties: specific gravity ASTM-D 1298-67, [18], pH API-RP 45, [19], kinematic viscosity ASTM-D 445-75, [20], base water sediment ASTM-D 96-73, [20], Electrical conductivity, Oil & Grease / Total hydrocarbon content API-RP- 45, [19], Organic Carbon & Matter [21], nitrate APHA-419D, [22], Sulphate ASTM-D-516, [20], Chloride ASTM-D-512, [20], Phosphate ASTM-D-482-74, [20], Sodium ASTM-D-4191, [20], Potassium ASTM-D - 4192, [20], Calcium ASTM-D-511, [20], Magnesium ASTM-D-511, [20] and Iron (ASTM-D-1068, [20] and Zinc ASTM-D-3557, [20]. The ASTM, API and APHA procedures were adopted and result given in Table 1.

2.2.2 Soil structure

Particle size analysis for soil structure adapted the Black [23] and Bouyocous [24] methods and textural analysis for various combination of sand, silt and clay was extrapolated using the Textural triangle model [25].

2.2.3 Bulk density

Bulk density was determined by the core method of Black and Hartge [26] using a core sample with a volume of 205 cm^3 and designated formula.

2.2.4 Particle density

The Gradwell [27] as modified in Black [23] was adopted for particle density analyses using the Pycnometer gravity bottle of 50 cm^3 capacity and designated formula.

2.2.5 Porosity

Porosity by percentage determination of total pore spaces was extrapolation from bulk and particle density analyses using the formula designate:

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

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

2.2.6 Hydraulic conductivity

Hydraulic conductivity by Darcy's law of constant head permeameter technique of Klute and Dirkson, [28] was adopted in which the volume of water (ml) passing in time (t) seconds was measured using designated formula.

2.2.7 Crusting hazard

The Crusting hazard of hydrocarbon Risk of sealing (R) was estimated using the Vander

Watt and Claassen's [29] method as:

$$\%R = \frac{\% \text{ Organic matter x } 100}{(\% \text{ Clay} + \% \text{ Silt})} \quad (2)$$

2.2.8 Total hydrocarbon

Total hydrocarbon (THC) content was analysed using the American Petroleum Institute (API-RP-45) [19] method, through which the content was estimated by reference to a calibration curve using toluene as standard.

2.2.9 Organic matter

Organic matter (OM) content was extrapolated from Organic Carbon following Walkley and Black [30] method as modified in Nelson and Somners [21], 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.

2.2.10 Root-length formation

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.

2.3 Phytoremediation Potency of the Plant Species

The potential of these species for remediation activities was assessed using classical indices among others which include: soil hydrocarbon removal index, species efficiency index, and bioaccumulation quotient index.

The amount of hydrocarbon removed or loss from the soil per plant was estimated using the Raghuvanshi et al. [31] method as in the formular:

$$QH = \frac{Ci - Ce}{M} \quad (3)$$

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. [32] using the equation:

$$E = \frac{(Ci - Ce)}{Ci} \times 100 \quad (4)$$

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 by the formula designate:

BQ = (Concentration of accumulated pollutant in plant/ Concentration of remaining accumulated pollutant in species treated soil) (5)

2.4 Data Analysis

The remediation performance was estimated using the Statistical Analysis System (SAS) PROC. NLIN procedure [17]. Data were then analysed as a double-split plot design with 5 replicates using the Analysis of Variance (PROC ANOVA) procedures [17]. Where significant differences 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.

3. RESULTS AND DISCUSSION

The physico-chemical properties of the waste oil are presented in Table 1. The result as observed in the structural and textural condition of the soil habitat (Table 2) in the pre-pollution, post-pollution and post-phytoapplication phases of ecological study has recorded variation in percentage structural composition of sand, silt and clay content of the soil and by the textural triangle analysis was a sandy loam. There was increase in the sandy component across various levels of the waste oil post-pollution soil though with non-significant difference (*P=0.05*) and exemplified by the negative correction (r = - 0.42, *P=0.05*) between THC and sand component (Table 3). However, there was decrease in the grain size of the silt and clay components with silt across pollution level non-significantly (*P=0.05*) different and clay significantly lower at medium (0.8%) and High (1.5%) levels than pre-pollution soil. This was presented in a positive correlation (r = 0.23, *P=0.05*) between the THC and Silt and (r = 0.30, *P=0.05*) with clay component of the soil.

Table 1. Physicochemical properties of the waste oil used for pollution of the soil

S/N	Parameters	Results
1	Specific gravity (g/cm^3)	0.89
2	pH	4.03
3	Kinematics viscosity (Cst)	4.90
4	Base water sediment (%)	0.56
5	Electrical conductivity (µsCm^{-1})	0.90
6	Oil & Grease (mg/l)	9.76
7	Total hydrocarbon content (mg/l)	0.41
8	Organic carbon (%)	19.80
9	Organic matter (%)	35.00
	Anions	
10	Nitrate (mg/l)	0.05
11	Sulphate (mg/l)	0.04
12	Chloride (mg/l)	13.60
13	Phosphate (mg/l)	0.70
	Cations	
14	Sodium (%)	0.89
15	Potassium (%)	0.31
16	Calcium (%)	0.28
17	Magnesium (%)	0.33
	Metal	
18	Iron (mg/l)	0.10
19	Zinc (mg/l)	0.18

The increase in grain size of sand could probably be due to the base sediment component of the waste oil, which subsequently enhances the sandy loam texture of the waste oil soil. Similar assertion by Essien and John [33] has shown enhancement of particles size. The reduction in silt and clay size was due to the fact that the spent oil had considerable effect on the structure of the soil. The solvent and hydrophobic component of waste oil enhanced deaggregation by dissolving gums and waxes that naturally help cement soil aggregate together thereby causing distortion in soil structure as interpreted in the positive correction (r = 0.23; *P=0.05*) between the THC and silt and (r = 0.30, *P=0.05*) clay particles.

This corroborates the assertion that soil physical properties could be impacted and degraded by spent oil due to complete breakdown of structure and dispersion of soil particles [34]. Though the post polluted sandy component was non-significantly higher than pre-polluted soil, it was significantly lower than the species controlled soil in percentage grain or particle size. The impact of phytoapplication on the post-polluted soil, has recorded increase the in the % particle size of sand with *P. pterocarpum* treated soil having a greater percentage of sand with significant difference (*P=0.05*) than *C. retusa* and *L. leucocephala* treated polluted soil.

The decrease in % silt size of post polluted soil was also restored to the status of controlled soil with *L. leucocephala* having greater % silt significantly different (*P=0.05*) at medium and high pollution remediation levels than *P. pterocarpum* and *C. retusa* treated soil in the order *Ll>PP>Cr*, while the polluted clay particle size was not significantly restored by phytoapplication though with *L. leucocephala* treated soil having greater clay percentage (5.8%) than *P. pterocarpum* (5.7%) and *C. retusa* (5%) clay of treated soil in the order *Ll>Pp>Cr*. The impact of the plant species treatment on the polluted soils could also be a reflection of the assertion that leguminous plant helps in improving the aggregate sizes of degraded soils, due to enhanced positive changes in the physico-chemical conditions [35,36,37].

The post-polluted soil had significant reduction in particle density than pre-polluted and species controlled soils, but was significantly restored by phytoapplication with *P. pterocarpum* soil recording a greater PD of 2.61 g/cm^3 than *L. leucocephala* and *C. retusa* treated pollutions soils. The decrease in particle density as a result of pollution corroborates the assertion that oil usually cause smothering of soil particles [38]. This could be represented in a positive correlation (r = 0.23; *P=0.05*) between THC and Silt, and (r = 0.30; *P=0.05*) with clay and also reaffirmed by negative correlation (r = - 0.40; *P=0.05*) between PD and Clay.

Table 2. The influence of waste oil pollution and post-phytoapplication remediation process on the hydraulic conductivity vis-à-vis some physico-edaphic parameters in tropical Niger Delta soil

Parameter	Pre pollution	Post-pollution soil			Post – phytoapplication / pollution levels												Mean	*LSD (p<0.05)*
					P. pterocarpum soil				*L. leucocephala soil*				*C. retusa soil*					
		75 mil	150 ml	300 ml	*Pp.* contro	75 mil	150 ml	300 ml	*Ll.* contro	75 mil	150 ml	300 ml	*Cr.* contro	75 mil	150 ml	300 ml		
% Sand	79.20 ±2.49^{h}	82.40 ±2.19^{efg}	80.40 ±3.36^{gh}	82.00 ±1.73^{fgh}	88.00 ±0.71^{abc}	87.80 ±1.48^{abc}	88.60 ±2.30^{ab}	89.60 ±0.55^{a}	85.80 ±1.10^{bcd}	88.00 ±0.00^{abc}	85.20 ±1.92^{cde}	81.20 ±2.39^{gh}	88.20 ±0.84^{abc}	85.00 ±0.71^{cdef}	84.60 ±5.55^{def}	89.00 ±0.00^{ab}	85.31	2.85
% Silt	7.60 ±2.97^{cdef}	6.60 ±2.07^{ef}	8.20 ±2.49^{bcdef}	6.80 ±1.48^{def}	6.20 ±2.86^{f}	8.20 ±0.84^{bcdef}	6.00 ±0.71^{f}	6.40 ±0.89ef	10.00 ±0.71^{abc}	8.00 ±0.71^{bcdef}	10.40 ±0.89^{ab}	11.00 ±1.58^{a}	8.00 ±1.23^{bcdef}	9.00 ±0.00^{abcde}	9.40 ±3.36^{abcd}	8.20 ±0.84^{bcdef}	8.13	2.26
% Clay	13.20 ±0.84^{a}	11.80 ±0.45^{ab}	11.40 ±0.89^{b}	11.40 ±0.89^{b}	5.80 ±2.17^{def}	4.00 ±0.71^{fg}	5.80 ±1.48^{def}	2.80 ±0.45^{g}	4.60 ±1.82^{efg}	4.00 ±0.71^{fg}	5.20 ±1.30^{def}	8.20 ±0.84^{c}	4.60 ±1.82^{efg}	6.40 ±0.89^{de}	6.60 ±2.30^{cd}	5.00 ±0.71^{def}	6.93	1.66
PD (g/cm^{3})	2.61 ±0.03^{bc}	2.49 ±0.03^{fg}	2.49 ±0.03^{fg}	2.48 ±0.10^{g}	2.62 ±0.02^{ab}	2.66 ±0.04^{a}	2.58 ±0.02^{bcd}	2.59 ±0.01^{bcd}	2.62 ±0.06^{ab}	2.59 ±0.00^{bc}	2.57 ±0.02^{cde}	2.54 ±0.00^{de}	2.61 ±0.01^{bc}	2.60 ±0.01^{bc}	2.56 ±0.02^{cde}	2.53 ±0.00^{ef}	2.57	0.04
BD (g/cm^{3})	1.10 ±0.07^{b}	1.20 ±0.07^{abc}	1.20 ±0.07^{abc}	1.23 ±0.13^{ab}	1.09 ±0.03^{abcd}	0.64 ±0.49^{e}	0.81 ±0.45de	1.05 ±0.05^{abcd}	1.18 ±0.05^{abc}	0.86 ±0.43^{cde}	1.11 ±0.01^{abcd}	1.12 ±0.02^{abcd}	1.25 ±0.04^{ab}	0.82 ±0.46^{de}	1.04 ±0.06^{bcd}	1.12 ±0.01^{abcd}	1.07	0.30
Porosity (%)	46.36^{ab}	51.81^{abcd}	51.81^{abcd}	50.40^{abcd}	58.40^{ab}	75.94^{e}	68.61^{e}	59.46^{abcde}	54.96^{abcd}	66.80^{cde}	56.81^{abcd}	55.91^{abcd}	52.11^{abcd}	68.46^{de}	59.38^{bcd}	55.73^{abcd}	58.34	10
HC (ml/s)	18.61 ±5.97^{c}	3.74 ±1.80^{d}	2.98 ±1.26^{d}	4.79 ±6.81^{d}	37.22 ±11.93^{a}	7.48 ±3.60^{d}	5.77 ±2.42^{d}	3.93 ±1.40^{d}	28.48 ±9.03^{b}	5.42 ±2.81^{d}	4.33 ±1.81^{d}	2.62 ±0.76^{d}	33.50 ±10.73^{ab}	6.73 ±3.24^{d}	5.19 ±2.18^{d}	3.14 ±0.92^{d}	10.87	6.53
THC (mg / g)	0.00 ±0.00^{g}	3.26 ±0.08^{b}	4.08 ±0.45^{a}	4.56 ±0.25^{a}	0.00 ±0.00^{g}	1.50 ±0.21^{def}	1.75 ±0.16^{de}	2.15 ±0.22^{cd}	0.00 ±0.00^{g}	1.09 ±0.47^{ef}	2.52 ±0.68^{c}	3.18 ±1.54^{b}	0.00 ±0.00^{g}	1.66 ±0.12^{def}	1.72 ±0.14^{de}	2.66 ±0.22^{bc}	2.17	0.61
% OM	1.46 ±0.21^{h}	2.40 ±0.34^{defg}	3.40 ±0.65^{ab}	3.64 ±0.31^{a}	2.08 ±0.29^{efgh}	2.37 ±0.43^{defg}	2.58 ±0.35^{cde}	3.00 ±0.63^{abcd}	1.73 ±0.91^{fgh}	2.49 ±0.61^{def}	2.61 ±0.81^{bcde}	3.74 ±0.57^{a}	1.64 ±0.39^{gh}	2.41 ±0.49^{defg}	2.72 ±0.48^{bcde}	3.32 ±0.86^{abc}	2.60	0.72

*Note: Pp = Peltophorum pterocarpium. Ll = Leucaena leucocephala. Cr = Crotolaria retusa .75 ml (0.4%vw) = low pollution, 150 ml (0.8%vw) = medium pollution, 300 (1.5%vw) = high pollution. * Means of five replicates and with the same superscript letter are not significantly different, using the Duncan's New Multiple Range Test (DNMRT)*

The significant (*P=0.05*) performance of *P. pterocarpum* treatment of pollution soil in the order *Pp>LI>Cr*, could be interpreted as a positive correlation (r = 0.25; *P=0.05*) between PD and sand and (r = 0.15; *P=0.05*) between PD and silt and reaffirmed by the negative correlation (r = - 0.42; *P=0.05*) between THC and sand, and (r = - 0.24; *P=0.05*) THC and PD. This is supported by the Udom et al. [35] and Udom and Nuja [37] assertion.

There was inverse relationship between the bulk density and porosity as affected by the waste (spent) oil pollution. Increase in Bulk density and 51.34% reduction in porosity across the post-polluted soil was recorded though non-significantly (*P=0.05*) higher than pre-polluted and species controlled soils. This can be represented in the positive correlation (r = 0.06; *P=0.05*) between THC and BD of polluted soil. The inverse relationship of the soil bulk density and porosity as attributed to the waste oil filling the pore spaces and with the hydrophobic portion causing more compaction and adhesion among soil aggregates could be contributed by viscosity and base water sediment of the waste oil (Table 1). Similar increase in bulk density and reduced porosity as attributed to compaction resulting from spent oil contaminated soil has been observed by Kayode et al. [39]; Nwite et al. [40] and Nwite and Alu [41].

The impact of phytoapplication had recorded significant reduction in bulk density and increased porosity with *P. pterocarpum* treated soil having grater performance in the order *Pp<Cr<LI* in bulk density and a higher porosity in the order *Pp>Cr>LI.* The decrease in bulk density and increased porosity could be attributed to enhanced root development (Table 4). This should have caused increase in pore spaces with greater particle density, as been expressed in a negative correlation (r = - 0.42; *P=0.05*) between THC and sand, and (r = - 0.24; *P=0.05*) in THC and PD, and exemplified in the positive correlation (r = 0.4.; *P=0.05*) between root formation and THC of the waste oil polluted soil. This could be reaffirmed by the fact that plant root in vegetated soil is known to create pore spaces, decrease bulk density and increase hydraulic conductivity of hydrocarbon polluted soil [42].

The results show organic matter (OM) of the post-polluted soil to have significantly (*P=0.05*) increased (Table 2) across pollution level relative to pre-pollution and controlled species treated soils. This increase was attributed to exogenous source of carbon content in the oil been added to the *in-situ* carbon of the soil been exemplified in the positive correlation (r = 0.40; *P=0.05*) with THC (Table 3). Similarly it has been observed that the release of organic carbon to soil due to hydrocarbon degradation possibly led to organic matter accumulation, because organic carbon is a major component of organic matter [39,43,44]. The impact of phytoapplication had revealed reduction in OM content across species treatment soil levels; which could be attributed to the assertions by Ayotamuno et al. [45] and Njoku et al. [42] in a course of nutrient absorption during plant growth and also in course of hydrocarbon mineralization [46,47].

This could lead to lesser OM accumulation in the species treated than non species polluted soil. *Peltophorum pterocarpum* treated soil had much lesser OM content of 2.65% though non-significantly different (*P=0.05*) from *L. leucocephala* and *C. retusa* treated soils in the order *Pp<LI<Cl* vis-à-vis the aerial accumulation of the species in the order *Pp>Cr>LI* (Table 4). The enhanced performance of *P. pterocarpum* could be the contribution of a greater root development and represented in the positive correlation (r = 0.31; *P=0.05*) between the plant root and OM (Table 3). However, the remediated soils had greater OM than pre-polluted and species controlled soils as in a similar assertion by Njoku et al. [42]. Also organic matter with its colloidal nature has the ability to bind with sorbed hydrocarbon molecules thereby increasing its values.

The total hydrocarbon (THC) content of waste oil polluted soil was significantly higher than those of the pre-pollution and species controlled soils. The THC concentration of soils under macrophytic treatment were significantly lower than post-polluted soils which indicated that phytoremediation can enhance oil attenuation in which *P. pterocarpum* among the species had a greater performance in hydrocarbon reduction in the order *Pp<Cl<LI* vis-à-vis increased bioaccumulation in the order *Pp>Cl>LI*. The *P. pterocarpum* treated oil polluted soil had a greater removal and reduction of 0.43 mg/g in THC content of the soil in relation to its high efficiency (55%) (Table 5) and 34.40 bioaccumulation quotient (Table 6). This corroborate Merki et al. [48], Wang et al. [49], Wang et al. [36], Udom and Nuga [37] who have earlier reported a similar higher degradation and removal of petroleum hydrocarbon in vegetated

soils than non vegetated bulk soil. The performance of *P. pterocarpum* could be attributed to its extensive root system, which could be represented in a positive correlation (r = 0.40; *P=0.05*) between the plant root and THC content of the soil and also in the activities of the detoxifying enzyme of the plant [50]. The root system of plant species are capable of penetration into impermeable soil, thus it become desirable for phytoremediation to have plants that grows with dense ramified fibrous root system deep down [51].

The lower performance of *L. leucocephala* and *C. retusa* in THC reduction could be attributed to poor root growth as factor responsible for hydrocarbon degradation, possibly due to clayey textured soil and high organic matter content earlier recorded. This might have caused increase in the colloidal property of the soil and with the high negative charges of clay greater compaction and dense will have strong adsorption with the hydrocarbon molecules. This can be exemplified in a positive correlation (r = 0.30, *P=0.05*) between THC and Clay and (r = 0.40; *P=0.05*) with OM. Thus making it difficult for plant root growth, penetration and desorption of these hydrocarbon molecules as earlier affirmed by Njoku et al. [42].

The lower reduction of THC in *L. leucocephala* and *C. retusa* treated does not imply lack of remediation though may not reduce concentration of contaminant, as earlier noted by Siciliano and Germida [52] but can reduce toxicity of such contaminants. This reduction as noted by Pivets [53] is such also a mechanism of phytoremediation hence it is also a technique of rendering harmful materials harmless under the synergy of plant and microbes. Also such lower performance could be due to short duration of the phytoremediation period considering the shrub by life form and growth habit of the plant species which could suggest a longer period of phytoremediation as earlier affirmed by Wang et al. [36].

Table 3. Pearson correlation coefficient amongst parameters of phytoremediation waste oil polluted soil

Parameter	Sand	Silt	Clay	PD	BD	HC	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			
HC	- 0.17*	- 0.15^{NS}	- 0.08*	0.38*	0.15	1.00		
THC	- 0.42^{NS}	0.23^{NS}	0.30*	- 0.24*	0.06*	- 0.43*	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*

Table 4. Post phytoapplication performance of remediation species on the waste oil 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	109.40±2.30^{a}	62.88±0.27^{b}	36.00±1.12^{c}	69.38	2.05
	Medium	81.18±6.00^{a}	55.00±24.00^{b}	32.00±0.82^{c}	55.93	19.40
	High	36.58±0.81^{a}	30.20±3.90^{b}	23.00±1.12^{c}	29.76	3.29
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	62.26±1.90^{a}	60.38±0.39^{a}	60.47±1.49^{a}	61.04	1.95
	Medium	61.55±2.10^{a}	58.03±3.91^{a}	59.29±1.91^{a}	59.62	3.84
	High	57.04±0.64^{a}	57.06±2.59^{a}	58.73±5.34^{a}	57.61	4.75
Plant TOM	Control	**4.51±0.53^{a}**	**1.94±0.75^{b}**	**2.51±0.73^{b}**	**2.99**	**0.93**
	Low	3.86±0.52^{a}	3.62±0.57^{a}	2.35±0.78^{b}	3.28	0.87
	Medium	3.06±0.20^{a}	2.89±0.76^{a}	2.97±1.20^{a}	2.97	1.14
	High	1.85±0.75^{b}	1.75±0.41^{b}	2.97±0.26^{a}	2.19	0.71

*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)*

Table 5. Hydrocarbon removal and efficiency of species in the waste 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. pterocarpum	1.50	1.75	2.15	**1.80**	0.35	0.47	0.48	**0.43**	54.00	57.11	52.85	**55.00**
L. leucocephala	1.09	2.52	3.18	**2.26**	0.43	0.31	0.28	**0.34**	66.56	38.24	30.26	**45.02**
C. retusa	1.66	1.72	2.66	**2.01**	0.32	0.47	0.38	**0.39**	49.08	57.84	41.67	**49.53**

Initial concentration of THC in the polluted soil (Ci) = 3.97 mg/g

Table 6. The phytoremediation potency of the species in the waste oil polluted soil

Potency	**Pre-pollution**	**Post-pollution soil**				**Post – phytoapplication / pollution levels**											
						P. pterocarpum soil				***L. leucocephala soil***				***C. retusa soil***			
		75 mil	**150 ml**	**300 ml**	**Mean**	**75 mil**	**150 ml**	**300 ml**	**Mean**	**75 mil**	**150 ml**	**300 ml**	**Mean**	**75 mil**	**150 ml**	**300 ml**	**Mean**
Bioaccumulation Quotient (BQ)	--	--	--	--	--	41.51	35.17	26.53	**34.40**	55.40	23.03	17.94	**32.12**	36.43	34.47	22.08	**30.99**
Crusting hazard risk of sealing (R %)	7.02	13.04	17.35	20.00	**17.00**	19.43	21.86	32.61	**24.63**	20.75	16.73	19.48	**19.00**	15.65	17.00	25.15	**19.30**

Such impact of hydrocarbon waste (spent) oil also led to significant decrease in saturated hydraulic conductivity (HC). The decrease in HC due to the pollution was attributed to the influence of THC of the pollutant on the edaphic (texture, structure, particle density, bulk density, porosity and organic matter), properties, as represented in the positive correlation (r = 0.23; *P=0.05*) between THC and silt, (r = 0.30; *P=0.05*) with clay, (r = 0.23; *P=0.05*) with BD and (r = 0.40; *P=0.05*) with OM. This led to compaction due to the observed clogging of pore spaces, distortion, blockage of water by air in the pore spaces while the crust hazard of sealing (Table 5) due to oil deposit on the top soil layer (hydrophobic layer) prevent water penetration. This could be amplified in the negative correlation (r = - 0.15; *P=0.05*) between HC and silt, (r = - 0.08; *P=0.05*) with Clay, (r = - 0.47; *P=0.05*) with OM, and (r = - 0.43; *P=0.05*) with THC. This corroborates the assertion by Agbogidi and Enujeke [54], Ezeaku and Egbemba [44], Nwite and Alu [41] and Udom and Nuja [37].

Clay soil texture type and organic matter are known for their influence on contaminant bioavailability in a phytoremediation process [42]. Such implication also applies in this present research. The clay was capable of binding hydrocarbon molecules more than sand and silt as could be represented in the positive correlation (r = 0.30; *P=0.05*) between THC and clay, negative correlation (r = - 0.42; *P=0.05*) between THC and sand and negative correlation (r = - 0.77; *P=0.05*) between clay and sand and (r = - 0.15; *P=0.05*) with silt. This resulted to the lower bioavailability of the pollutant in the clay rich soil for remediation. The organic matter content also improved the binding process in the soil, leading to strong adsorption and low bioavailability, as exemplified in the positive correlation (r = 0.19; *P=0.05*) between organic matter and clay and (r = 0.40; *P=0.05*) between organic matter and THC content. Such binding reduces water drainage and improves water retention ability of soil and bulk density.

Reduced hydraulic conductivity implies how soil water transmission and less water would be available for plants roots physiological processes. The impact of phytoapplication showed an enhanced hydraulic conductivity trend across the various levels of the polluted soil toward the non pollution status with *P. pterocarpum* among other species treated soil recording a higher conductivity in the order *Pp>Cr>LI*, though non-significantly different (*P=0.05*) (Table 2). This could suggest a longer period of phytoremediation duration as earlier affirmed by Wang et al. [36]. The greater performance of *P. pterocarpum* in enhancing hydraulic conductivity could be attributed to its potency in improving the soil porosity, texture, structure, particle density and reduction in bulk density, organic matter and THC content as reported in this research and the influence of botanical explants (enzyme) in the rhizosphere soil [50].

Hence HC is soil structure and texture dependant and with *P. pterocarpum* soil having a greater sandy structure, it was characterized by more porosity, improved PD as represented in the positive correlation (r = 0.17; *P=0.05*) between HC and sand, (r = 0.38; *P=0.05*) PD and (r = 0.15; *P=0.05*) BD in the remediated soil, reduced BD, lesser clay and silt, lesser OM and THC content as represented in the negative correlation (r = - 0.15; *P=0.05*) between HC and Silt, (r = - 0.18; *P=0.05*) Clay, (r = - 0.47; *P=0.05*) OM, and (r = - 0.43, *P=0.05*) THC of the remediated soil and enhanced root formation could be reasons for enhanced hydraulic conductivity. This reaffirms the assertion by Horn et al. [55] who observed a higher HC in a highly porous, fractured or aggregated and lower in tightly compacted dense soil. Excess binding of soil particles together due to clay and organic matter reduces root penetration and inhibit the absorption of materials. This possibly causes lesser HC in *L. leucocephala* and *C. retusa* treated soils.

4. CONCLUSION

From the research it could be deduced that the application of waste oil has deleterious effect on the physico-edaphic properties of the soil. The application of waste increased the grain size of sand component of soil, increased bulk density, organic matter, and total hydrocarbon content. Inversely the waste oil also reduced the clay and silt component, porosity, and hydraulic conductivity. It can also be inferred from the findings of this research that the result of phytoremediation by *P. pterocarpum* shows the potential of simultaneously restoring and remediating the hydrocarbon waste oil polluted soil. However, results also imply that longer time is required for an effective improvement of physico-edaphic characteristics of the polluted soil, thus contribute to the degradation of the waste oil soil.

ACKNOWLEDGEMENTS

The authors thank colleagues and laboratory staffs that helped with fieldwork and laboratory analyses during the study. Our appreciation also goes to the blessed memory of the Late Prof. Dave Nosa Omakaro for his supervision and contributions. The authors also wish to appreciate Barrister Ezebunwo Nyesom Wike for his financial support.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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