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Assessment of Some Tropical Plants for Use in the Phytoremediation of Petroleum Contaminated Soil: Effects of Remediation on Soil Physical and Chemical Properties

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Authors' contributions

This work was carried out in collaboration between all authors. Author MANA designed the study. Author EEI did the data and statistical analysis. Authors JE and CO did the data collection and field work. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

Field experiment was conducted in the Teaching and Research Farm of Enugu State University of Science and Technology in 2015 cropping season to evaluate the effectiveness of phytoremediation as a tool for cleaning up soils contaminated with diesel (AGO). The experimental design was split-plot in a Randomized Complete Block Design (RCBD) with two soil amendments (petroleum contaminated soil and petroleum uncontaminated soil) for main plots and eight plants [Soy bean (*Glycine max*), cowpea (*Vigna unguiculata*), groundnut (*Arachis hypogaea*), African yam bean (*Sphenostylis stenocarpa*), vetiver grass (*Chrysopogon zizanioides*), maize (*Zea mays*), carpet grass (*Axonopus fissifolius*) and spear grass (*Heteropogon contortus*)] consisted sub plots. Soil samples were collected before the application of petroleum and at 90 days after planting. The

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influence of petroleum contamination on the physical properties of the soil at 90 days after planting revealed that the soils with petroleum amendment were higher in bulk density (1.49 g cm^{-3}) and lower in hydraulic conductivity (8.22 k cm^{-3} hr^{-1}) than the uncontaminated ones. Petroleum treated soil contained lower total porosity value (43.75%) and moisture content (9.80%) than the uncontaminated soil. Soils without petroleum amendment contained more levels of total nitrogen, exchangeable sodium, exchangeable magnesium, base saturation and available phosphorus than the contaminated soils. Petroleum treated soil contained more concentration of carbon, organic matter, exchangeable calcium and cation exchange capacity than the uncontaminated soil. Cultivation of soy beans is recommended on petroleum contaminated soils, since the analyses of soil samples taken at 90 days after planting, showed that the soy beans suppressed the bulk density and increased the available potassium, exchangeable calcium and exchangeable magnesium of the soil for optimum soil fertility replenishment for crop production.

Keywords: Phytoremediation; petroleum contaminated soil; tropical plants; soil physical and chemical properties.

1. INTRODUCTION

Contamination of soils by oil spills is a widespread environmental problem that often requires cleaning up of the contaminated sites. Phytoremediation is an alternative to more expensive remediation technologies, because it is a feasible, effective and non-intrusive technology that utilizes natural plant processes to enhance degradation and removal of oil contaminants from the environment [1].

Oil spills have degraded most agricultural lands in Nigeria especially the soils in the Niger delta region and have turned hitherto productive areas into wastelands. With increasing soil infertility due to the destruction of soil micro-organisms, and dwindling agricultural productivity, farmers have been forced to abandon their land, to seek non-existent alternative means of livelihood. Aquatic lives have also been destroyed with the pollution of traditional fishing grounds, exacerbating hunger and poverty in fishing communities. Many authors have reported a lower rate of germination in petroleum or its derivatives contaminated soil [2,3,4]. Germination, growth and pod production of *Glycine max* have been found to be inhibited by crude oil pollution [5]. Yellowing, dropping of leaves and complete shedding of leaves in areas of heavy pollution have been reported by [6].

The remediation of oil contaminated soils has been a major problem in oil producing countries and recently the use of plants to clean such soils has been on investigation [7,8]. According to [9], plants for phytoremediation should be appropriate for the climatic and soil conditions of the contaminated sites. Such plants should also have the ability to tolerate conditions of stress. Various plants have been identified for their potential to facilitate the phytoremediation of sites contaminated with petroleum hydrocarbon. In the majority of studies, grasses and legumes have been singled out for their potential in this regard [10]. Grasses have extensive, fibrous root systems, which favors a vast community of micro-organisms. They also exhibit an inherent genetic diversity which may give them a competitive advantage in becoming established under unfavorable soil condition [10]. In a survey of 15 oil-contaminated sites, [11] reported that leguminous plants were the dominant flora. Legumes are thought to have an advantage over non-leguminous plants in phytoremediation because of their ability to fix nitrogen, i.e., legumes do not have to compete with micro-organisms and other plants for limited supplies of available soil nitrogen at oil contaminated sites.

As a result of crude oil pollution, soil physical properties such as pore spaces might be clogged which reduces soil aeration, infiltration of water into the soil, decreased saturated hydraulic conductivity and increased bulk density of the soil which may affect plant growth. Crude oil which is denser than water may reduce and restrict permeability. Oil pollution of soil can also lead to build up of essential nutrients such as organic carbon, available phosphorus, exchangeable calcium and exchangeable magnesium and non-essential nutrients like lead, zinc, iron and copper in soil and the eventual translocation in plant tissues [12]. Although some heavy metals at low concentrations are essential micronutrients for plants, but at high concentrations they may cause metabolic disorders and growth inhibition for most of the plant species [13]. All these possibilities deserve empirical studies to establish their reality or otherwise. Generally, there is scanty literature information on the use of some tropical plant to clean up oil contaminated soils, Therefore, the main objective of this study was to examine the effects of crude oil contamination on soil physiochemical properties and to identify the plant best suited for phytoremediation of the soil.

2. MATERIALS AND METHODS

2.1 Description of the Experimental Site

The experiment was carried out in 2015 planting season at the Teaching and Research Farm of the Faculty of Agriculture and Natural Resources Management, Enugu State University of Science and Technology, Nigeria (06°52'N, 07°15'E and elevation 450 m above sea level). The area has an annual rainfall which ranges from 1700 – 2010 mm. The rainfall pattern is bimodal and is between April and October, and the dry season is between November and March. The soil's textural class is sandy loam with an isohyperthermic soil temperature regime [14] and is classified as Typic Paleudults of the order Utisol [15].

2.2 Experimental Design and Field Operations

Field trials were conducted using sixteen treatment combinations (Table 1) i.e. eight plants [Soy bean (*Glycine max*), cowpea (*Vigna unguiculata*), groundnut (*Arachis hypogaea*), African yam bean (*Sphenostylis stenocarpa*), vetiver grass (*Chrysopogon zizanioides*), maize (*Zea mays*), carpet grass (*Axonopus fissifolius*) and spear grass (*Heteropogon contortus*)] and two soil amendments (petroleum treated soil and petroleum untreated soil). The treatments were laid out in a split-plot in a randomized complete block design with three replications. The main plot comprised of the soil amendments and the sub-plots comprised of the eight plants.

A total land area of 209 m^2 was mapped out for the experiment. The site was slashed and cleared of existing grasses. The field was divided into 3 blocks measuring 19.5 m x 3 m (58.5 m^2) each and was demarcated by a one meter pathway. Each block was divided into two main plots measuring 3 m x 2 m (6 m^2) and was separated from each other by one meter alley between them. The two main plots were divided into eight sub-plots each, giving a total of 48 plots for the experiments.

Beds measuring 30 cm high were prepared manually with hand hoe. Two weeks before planting, 10 liters of diesel (AGO) obtained from Nigeria National Petroleum Co-operation Enugu Mega Station Emene was applied basally (pouring) per plot to the soil and thoroughly mixed with the soil at a tillage depth of 30 cm using a hand hoe. The seeds of soy bean, cowpea, African yam bean, groundnuts and maize were planted at two seeds per hole at 5 cm depth using a plant spacing of 50 cm by 50 cm (intra row and inter row spacing). A total of 24 plants were sown on each plot making a plant population of 567 plants. Grasses such as vetiver grass, spear grass and carpet grass established four weeks before planting, were transplanted to the experimental plots by uprooting, their roots and shoots trimmed to 5 cm high before planting. Lost stands were replaced weeding was carried out throughout the period of the experiment usually with the aid of hand hoe at three weeks intervals. A dose of NPK 15:15:15 fertilizer was applied basally by banding in plots at the rate of 50 kg ha^{-1} in two splits doses at planting and at 21 days after planting (DAP).

Table 1. Matrix of the treatment combinations

		Soils	
		S* (petroleum contaminated soil)	**S (petroleum uncontaminated soil)**
P (Plants)	P_1 (Soybean)	P_1 S*	P_1 S
	P_2 (Cowpea)	P_2 S*	P_2 S
	P_3 (Groundnut)	P_3 S*	P_3 S
	P_4 (African yam bean)	P_4 S*	P_4 S
	P_5 (Vetiver grass)	P_5 S*	P_5 S
	P_6 (Maize)	P_6 S*	P_6 S
	P_7 (Spear grass)	P_7 S*	P_7 S
	P_8 (Carpet grass)	P_8 S*	P_8 S

2.3 Soil Sample Collection

Soil samples were collected with steel auger from the top soil to a depth of 0 to 20 cm two weeks before the application of petroleum and at 90 days after planting. Three representative soil samples were randomly collected per plot and bulked to form a composite soil sample for each plot. A total of 48 composite soil samples were collected.

2.4 Soil Sample Analyses

Samples were air dried ground and passed through a sieve of 2 mm standard mesh size. The soil pH was determined with a pH meter using 1:2.5 soil to water ratio and 1: 2.5 soil to 0.1 N KCl (potassium chloride) suspension according to [16]. Organic carbon was determined using the Walkley and Black wet digestion method [17]. Soil organic matter content was obtained by multiplying the value of organic carbon by 1.724 (Van Bemmeler factor). Total nitrogen was determined by micro-kjeldahl procedure [16]. Available phosphorus was extracted with Bray II extractant as described by [18] and determined colorimeterically using ascorbic acid method [19]. Exchangeable potassium was extracted using 1 N ammonium acetate (NH_4OAC) solution and determined by the flame emission spectroscopy as outlined by [20]. Aluminum and hydrogen content (exchangeable acidity) were determined by titrimetric method after extraction with 1.0 N KCl [21]. The cation exchange capacity was determined by NH_4OAC displacement method [22]. Calcium and magnesium were determined by the complexiometeric titration method as described by [23]. Particle size distribution analysis was done by the hydrometer method [24] and the corresponding textural class determined from the United States Department of Agriculture Soil Textural Triangle. Base saturation was determined by the method outline by [16]. Dry bulk density was determined by the core method [25]. Total porosity values were derived from bulk density data. Hydraulic conductivity was determined by the method of [26].

2.5 Statistical Analysis

Data collected were subjected to analysis of variance (ANOVA) test for split plot in randomized complete block design as outlined by [27]. Significant means were separated using Fisher's least significant difference (F-LSD) at 5% probability level. Statistical analysis was executed using [28] statistical software.

3. RESULTS AND DISCUSSION

3.1 Initial Soil Properties before the Application of Petroleum

The results shown in the Table 2 indicates that the soil of the study area before the application of petroleum was acidic (pH 6.2 and 5.7 in water and potassium chloride respectively). The soil textural class was a sandy loam, which contained 8% clay, 14% silt, 35% fine sand and 43% coarse sand. The organic carbon, organic matter and total nitrogen contents were found to be 0.272%, 0.469% and 0.140% respectively. The exchangeable bases [sodium (Na), potassium (K), calcium (Ca), and magnesium (Mg)] were 0.661 mg kg^{-1}, 0.10 mg kg^{-1}, 4.40 mg kg^{-1} and 0.40 mg kg^{-1} respectively. The cation exchange capacity (CEC) of the soil was 14.40 mg kg^{-1}. The hydrogen content was found to be 0.80 mg kg^{-1} and available phosphorus (Bray 11) was found to be 6.53 mg kg^{-1}.

Table 2. Initial soil characteristics before the application of petroleum

Parameters	Level
Particle size distribution (%)	
Coarse sand	43
Fine sand	35
Clay	8
Silt	14
Textural class	sandy loam
pH (water)	6.2
pH (KCl)	5.7
Organic carbon (%)	0.272
Organic matter (%)	0.469
Total nitrogen (%)	0.140
Available phosphorus (mg kg^{-1})	6.53
Exchangeable bases (mg kg^{-1})	
Calcium	4.40
Magnesium	0.40
Potassium	0.10
Sodium	0.661
Exchangeable acidity (mg kg^{-1})	
Hydrogen	0.80
Cation exchangeable capacity (mg kg^{-1})	14.40

3.2 Effects of Petroleum on the Physical Properties of Soil

The results of the physical properties of the soil presented in Table 3 reveals that the petroleum treated soil had a significant (*P = .05*) effect on the bulk density of the soil at ninety days after planting. The bulk density of the contaminated soil was the highest (1.49 g cm^{-3}) in comparison with the petroleum uncontaminated soil which had a value of 1.46 g cm^{-3}. The least bulk density (1.42 g cm^{-3}) was observed in the petroleum contaminated soil with soy bean grown on it. Oil is thought to increase soil bulk density by reducing the frictional forces that interfaces between soil particles and with the slightest impact from rain drops and some other agents of denudation, the particles assume a more tightly packed structure [4]. Lower bulk density obtained in the uncontaminated soil is a positive productivity indicator as it helps in easing root penetration and encourages downward movement of water through the root channel [2]. Low bulk density could lower run off and erosion, while increasing aeration and internal drainage [29]. Total porosity was found to be lowest (43.75%) in petroleum contaminated soil and highest (44.98%) in the control treatment. The result revealed that total porosity tends to be reduced on the contaminated soil when compared to the control treatment. This could be as a result of blockage of pore spaces within the pollutants [4]. Furthermore, in Table 3, The petroleum contaminated soil had the lowest value of moisture content (7.37%) and hydraulic conductivity (8.22 k cm^{-3} hr^{-1}) while the uncontaminated soil significantly (*P = .05*) had the highest moisture content (9.80%) and hydraulic conductivity (11.07 k cm^{-3} hr^{-1}). According to [25] soils with high bulk density ranging from 1.6 – 1.7 gcm^{-3} show massive structures and less porosity which will hinder the movement of water down the profile. Furthermore, petroleum contaminated soils may have lost more water due to the hydrophobic properties of petroleum which impeded the adherence of water molecules to soil particles thereby increasing the free energy of soil water, with this, less energy was required for soil water loss by evaporation and percolation down the profile.

3.3 Effects of Petroleum on the Chemical Properties of Soil

Petroleum treated soil had significantly (*P = .05*) the highest organic matter content (0.79%) and the lowest was the control treatment (0.54%) (Table 4). This outcome is attributed to the addition of hydrocarbon to the soil by the petroleum [7]. The main effect of plants on the organic matter content showed that soils on which cowpea (0.86%) and soy beans (0.86%) were grown had significantly (*P = .05*) the highest organic matter content compared with the other plants. This is due to the fact that legumes have an advantage over non-leguminous plants in phytoremediation because of their ability to fix nitrogen; i.e., legumes do not have to compete with micro-organisms and other plants for limited supplies of available soil nitrogen [7,8]. The pH of the unamended soil was greater (6.55 in water and 5.38 in potassium chloride) and petroleum contaminated soil had the lowest pH value of 6.45 in water and 5.28 in potassium chloride respectively. This observation corroborated the findings of [12] who reported that petroleum waste sludge lowers the pH immediately around negatively charged soil surfaces. The carbon content level in Table 4 revealed that the petroleum treated soil contained more carbon (0.46%) than the untreated plot (0.31%). This outcome is attributed to the addition of hydrocarbon to the soil by the petroleum [7].

Control plot had the highest total nitrogen content (0.057%) in comparison with the petroleum treated soil which contained 0.055% total nitrogen (Table 5). Crude oil limits the bioavailability of nitrogen (a major plant growth element) in the soil [7]. According to [30] soil rhizosphere of soybean polluted with crude oil showed a decrease in nitrogen content. Oil spills kills or inhibit soil microbial activities and reduces microbes population [31].

The main effect of soy beans on total nitrogen content of the soil was also significantly (*P = .05*) greater (0.077%) than the other plants, while the lest total nitrogen content was observed in the plots with spear grass (0.042%). This is due to the fact that legumes harbor bacteria in their root nodules which are capable of fixing atmospheric nitrogen into the soil [32] More so, the cation exchange capacity (9.91 mg kg^{-1}) of petroleum contaminated soil was significantly (*P = .05*) the highest compared with the untreated plot which had a value of 8.72 C mol kg^{-1}. Also in Table 5 the available phosphorus of the unamended soil was found to be greater (1.52 mg kg^{-1}) than in the petroleum amended soil (1.51 mg kg^{-1}). This shows that petroleum limits bioavailability of phosphorus in the soil [7]. The base saturation of the soil was higher in the uncontaminated soil (30.61%) than in the petroleum contaminated soil (26.98%). This outcome is attributed to the addition of hydrocarbon to the soil by the petroleum [7].

Table 3. Effect of petroleum on soil physical properties at 90 days after planting

Plants	Soil											
	Bulk density (g cm^{-3})			Total porosity (%)			Moisture content (%)			Hydraulic conductivity (K cm^3hr^{-1})		
	*Soil	Soil	plant mean	*Soil	Soil	Plant mean	*Soil	Soil	Plant mean	*Soil	Soil	Plant mean
Soybean	1.42	1.46	1.44	46.61	44.91	45.76	7.84	9.47	8.65	5.01	8.60	6.80
Cowpea	1.55	1.43	1.49	46.04	41.51	43.78	7.70	9.83	8.76	7.16	11.22	9.19
Groundnut	1.45	1.53	1.49	45.48	42.27	43.87	7.01	8.46	7.73	8.12	10.75	9.43
African yam bean	1.48	1.45	1.46	44.34	45.28	44.81	7.59	11.79	9.69	9.65	13.85	11.75
Vetiver grass	1.48	1.45	1.46	44.15	45.47	44.81	5.77	9.05	7.41	11.94	10.75	11.34
Maize	1.49	1.49	1.49	43.97	43.96	43.96	9.00	9.17	9.08	8.60	13.37	10.98
Spear grass	1.47	1.49	1.48	44.72	43.96	44.34	6.79	10.32	8.55	6.92	13.13	10.03
Carpet grass	1.47	1.52	1.50	44.53	42.65	43.59	7.21	10.31	8.76	8.36	6.94	7.65
soil mean	1.49	1.46	1.47	43.75	44.98	44.36	7.37	9.80	8.58	8.22	11.07	9.65
F-LSD$_{(0.05)}$ for 2 soils (s)	0.01			0.10			1.00			2.14		
F-LSD$_{(0.05)}$ for 2 plants (p)	NS			NS			NS			2.61		
F-LSD$_{(0.05)}$ for 2 s × p	NS			NS			NS			NS		

*F-LSD (0.05) = Fishers' least significant difference at 0.05 probability level, NS = Non significant at 0.05 probability level, * = petroleum contaminated soil, DAP = days after planting*

Table 4. Effects of petroleum on soil pH, carbon and organic matter content at 90 days after planting

Plants	Soil											
	Soil pH (H_20)			Soil pH (KCl)			Carbon (%)			Organic matter (%)		
	*Soil	Soil	Plant mean	*Soil	Soil	Plant mean	*Soil	Soil	Plant mean	*Soil	Soil	Plant mean
Soybean	6.63	6.67	6.65	5.40	5.43	5.42	0.42	0.58	0.50	0.72	1.00	0.86
Cowpea	6.07	6.70	6.38	5.03	5.53	5.28	0.67	0.33	0.50	1.15	0.98	0.86
Groundnut	5.97	6.33	6.15	5.03	5.20	5.12	0.42	0.32	0.37	0.72	0.58	0.65
African yam bean	6.77	6.47	6.62	5.55	5.27	5.38	0.25	0.49	0.37	0.43	0.87	0.65
Vetiver grass	6.73	6.87	6.80	5.43	5.60	5.52	0.50	0.20	0.35	0.86	0.36	0.61
Maize	6.73	6.67	6.70	5.40	5.37	5.38	0.42	0.52	0.47	0.72	0.92	0.82
Spear grass	6.63	6.87	6.75	5.43	5.67	5.55	0.66	0.06	0.30	1.14	0.50	0.32
Carpet grass	6.07	5.88	5.95	5.03	5.00	5.02	0.32	0.29	0.32	0.57	0.51	0.54
soil mean	6.45	6.55	6.50	5.28	5.38	5.33	0.46	0.31	0.38	0.79	0.53	0.66
F-LSD$_{(0.05)}$ for 2 soils (s)	0.03			0.06			0.002			0.003		
F-LSD$_{(0.05)}$ for 2 plants (p)	0.08			0.08			0.002			0.003		
F-LSD$_{(0.05)}$ for 2 s × p	0.11			0.10			0.002			0.004		

*F-LSD $_{(0.05)}$ = Fishers' least significant difference at 0.05 probability level, NS = Non significant at 0.05 probability level, * = petroleum contaminated soil, DAP = days after planting*

Table 5. Effects of petroleum on total nitrogen, CEC, available phosphorus and base saturation at 90 days after planting

Plants	Soil											
	Total nitrogen (%)			CEC (mg kg^{-1})			Available phosphorus (mg kg^{-1})			Base saturation (%)		
	*Soil	Soil	Plant mean	*Soil	Soil	Plant mean	*Soil	Soil	Plant mean	*Soil	Soil	Plant mean
Soybean	0.057	0.097	0.077	8.87	8.47	8.67	0.93	0.94	0.94	41.72	33.73	37.73
Cowpea	0.070	0.056	0.063	14.33	7.73	11.03	1.86	1.87	1.87	16.61	31.01	23.81
Groundnut	0.042	0.070	0.056	10.00	9.73	9.87	1.87	0.92	1.40	24.77	26.61	25.69
African yam bean	0.056	0.056	0.056	8.40	9.60	9.00	0.91	0.93	0.92	28.65	25.24	26.94
Vetiver grass	0.067	0.067	0.043	8.53	7.27	7.90	1.86	1.87	1.87	27.60	37.64	32.63
Maize	0.029	0.059	0.044	8.33	8.33	8.33	1.87	1.89	1.88	27.35	25.61	26.48
Spear grass	0.070	0.014	0.042	10.73	8.47	9.60	1.85	0.93	1.39	21.45	33.00	27.23
Carpet grass	0.055	0.037	0.046	10.07	10.13	10.10	0.93	2.78	1.85	27.67	32.01	29.84
soil mean	0.055	0.057	0.056	9.91	8.72	9.31	1.51	1.52	1.51	26.98	30.61	28.79
F-$LSD_{(0.05)}$ for 2 soils (s)	NS			0.20			NS			2.65		
F-$LSD_{(0.05)}$ for 2 plants (p)	0.006			0.15			0.02			4.83		
F-$LSD_{(0.05)}$ for 2 s × p	0.008			0.22			0.02			6.50		

*F-LSD (0.05) = Fishers' least significant difference at 0.05 probability level, NS = Non significant at 0.05 probability level, * = petroleum contaminated soil, DAP = days after planting*

Table 6. Effects of petroleum on exchangeable bases (mg kg^{-1}) at 90 days after planting

Plants	Soil											
	Sodium (Na^+)			Potassium (K^+)			Calcium ($Ca^{2+)}$			Magnesium ($Mg^{2+)}$		
	*Soil	Soil	Plant mean	*Soil	Soil	Plant mean	*Soil	Soil	Plant mean	*Soil	Soil	Plant mean
Soybean	0.09	0.07	0.08	0.140	0.393	0.267	2.33	1.73	2.03	1.13	0.67	0.90
Cowpea	0.11	0.08	0.09	0.140	0.121	0.130	1.53	1.33	1.43	0.60	0.87	0.73
Groundnut	0.09	0.08	0.09	0.117	0.100	0.113	1.87	1.53	1.70	0.40	0.87	0.63
African yam bean	0.08	0.06	0.07	0.123	0.093	0.108	1.67	1.27	1.47	0.53	1.00	0.77
Vetiver grass	0.11	0.08	0.09	0.114	0.120	0.117	1.27	0.93	1.10	0.87	1.60	1.23
Maize	0.05	0.09	0.07	0.093	0.113	0.103	0.67	1.13	0.90	1.47	0.80	1.13
Spear grass	0.07	0.12	0.10	0.097	0.140	0.118	1.47	1.93	1.70	0.67	0.60	0.63
Carpet grass	0.08	0.33	0.20	0.107	0.123	0.115	1.73	1.60	1.67	0.87	1.20	1.03
soil mean	0.09	0.11	0.10	0.116	0.152	0.134	1.57	1.43	1.50	0.82	0.95	0.88
F-$LSD_{(0.05)}$ for 2 soils (s)	NS			NS			0.10			NS		
F-$LSD_{(0.05)}$ for 2 plants (p)	NS			NS			0.18			0.21		
F-$LSD_{(0.05)}$ for 2 s × p	NS			NS			0.25			0.29		

*F-LSD $_{(0.05)}$ = Fishers' least significant difference at 0.05 probability level, NS = Non significant at 0.05 probability level, * = petroleum contaminated soil, DAP = days after planting*

The data in Table 6 indicates that the exchangeable bases [Na^+ (0.11 mg kg^{-1}), K^+ (0.15 mg kg^{-1}) and Mg^{2+} (0.95 mg kg^{-1})] were significantly (*P* = *.05*) higher in the uncontaminated soil except calcium (1.57 mg kg^{-1}) which was higher in the petroleum treated plot [12] reported that petroleum waste sludge depletes the essential inorganic nutrients such as sodium, potassium and magnesium and other growth factors.

4. CONCLUSIONS

Soils treated with petroleum at 90 days after planting were higher in bulk density (1.49 g cm^{-3}) and lower in hydraulic conductivity (8.22 K cm^3 hr^{-1}) than the untreated soil. Petroleum treated soil contained lower total porosity value (43.75%) and moisture content (7.3%) than the uncontaminated soil. Impact of petroleum on the chemical properties of the soil at 90 days after planting revealed that the soils without petroleum amendment contained more levels of total nitrogen, exchangeable sodium, exchangeable magnesium, base saturation and available phosphorus than the contaminated soils. Petroleum treated soil contained more concentration of carbon, organic matter, exchangeable calcium and cation exchange capacity than the uncontaminated soil. Cultivation of soy beans is recommended on petroleum contaminated soils, since the analyses of soil samples taken at 90 days after planting, showed that the soy beans suppressed the bulk density and increased the available potassium, exchangeable calcium and exchangeable magnesium of the soil for optimum soil fertility replenishment for crop production.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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