Original Research Article

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

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) on the main plots and eight plants [Soya 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*)] on the sub plots. Soil samples were collected before the application of petroleum and at 90 days after planting. The 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 hydraulic conductivity (11.07 k cm^{-3}/hr) 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. Amending the soil with petroleum should be discouraged. At 90 days after planting the cultivation of soya bean is recommended as it helps in the suppression of the bulk density and hydraulic conductivity and causes an increase in 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 wide spread 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 (Marmiroli *et al*., 2003).

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 (Adam and Duncan, 2002; Vavrek and Campbell, 2002; Achuba, 2006).

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 leads 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 (Vwioko *et al*., 2006). 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 (Fernandes and Henriques, 1991). 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 particular study was to examine the effects of crude oil contamination on soil physical properties and chemical 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; mean elevation 450 m above sea level). The area has an annual rainfall of 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 loam with an isohyperthermic soil temperature regime (Ezeaku and Anikwe, 2006) and is classified as Typic Paleustult (Anikwe, *et al*., 1999).

2.2 Experimental Design and Field Operations

Field trials were conducted using sixteen treatment combinations i.e. eight plants [Soya 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 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 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, thus 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 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 soya 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 plant were sown on each plot making a plant population of 567 plants. Grasses like 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 all plots at the rate of 50 kg ha^{-1} in two splits dose at planting and at 21 days after planting (DAP)

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 day 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 Analysis

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 Page *et al*., (1982). Organic carbon was determined using the Walkley and Black wet digestion method (Bremner and Mulvaaney, 1982). 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 (Page *et al*., 1982). Available phosphorus was extracted with Bray II extractant as described by Bray and Kurtz, (1945) and determined colorimeterically using ascorbic acid method (Murphy and Riley 1962). Exchangeable potassium was extracted using 1 N ammonium acetate (NH_4OAC) solution and determined by the flame emission spectroscopy as outlined by Anderson and Ingram (1993). Aluminum and Hydrogen content (exchangeable acidity) were determined by titrimetric method after extraction with 1.0 N KCl (McLean, 1982). The cation exchange capacity was determined by NH_4OAC displacement method (Rhoades, 1982). Calcium and magnesium were determined by the complexiometeric titration method as described by Chapman (1982). Particle size distribution analysis was done by the hydrometer method (Gee and Bauder, 2002) 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 Page *et al*., (1982). Dry bulk density was determined by the core method (Grossman and Reinsch, 2002). Total porosity values derived from bulk density data. Hydraulic conductivity was determined by the method of Klute and Dirksen (1986).

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 Gomez and Gomez, 1984. Significant means were separated using Fishers least significant difference (F-LSD) at 5% probability level.

Statistical analysis was executed using GENSTAT Release 7.2DE Discovery Edition 3, 2007 statistical software

3. RESULTS AND DISCUSSION

3.1 Initial soil properties before the application of petroleum

The results shown in the Table 1 indicated 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 C mol kg^{-1}, 0.10 C mol kg^{-1}, 4.40 C mol kg^{-1} and 0.40 C mol kg^{-1} respectively. The cation exchange capacity (CEC) of the soil was 14.40 C mol kg^{-1}. The hydrogen content was found to be 0.80 C mol kg^{-1} and available phosphorus (Bray 11) was found to be 6.53 C mol kg^{-1}.

3.2 Effects of petroleum on the physical properties of soil

The results of the physical properties of the soil presented in Table 2 revealed that the petroleum treated soil had a non-significant ($p > 0.05$) 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 bulk density (1.50 g cm^{-3}) of the soil with carpet grass was the highest in comparison with the other plants. The bulk density (1.55 g cm^{-3}) of the petroleum treated soil with cowpea sown on it was greater than the other interaction effects. The least bulk density (1.42 g cm^{-3}) was observed in the petroleum contaminated soil with soybean grown on it. Oil is thought to increase soil bulk density by reducing the frictional forces at interfaces between soil particles and with the slightest impact from rain drops and some other agents of denudation, the particles assume a more tightly parked structure; this have been reported as crusting by some researchers (Rasiah *et. al.,* 1990; West *et. al.,* 1992 and Amadi *et. al.,* 1993). Lower bulk densities obtained in the uncontaminated soils is a positive productivity indicator as it helps in easing root penetration and encourages downward movement of water through the root channels (Mbah *et al.,* 2009). Low bulk density could lower run off and erosion, while increasing aeration and internal drainage (Johnson *et al.,* 1996). Total porosity was found to be lowest (43.75%) in petroleum contaminated soil and highest (44.98%) in the control treatment. The total porosity (46.61%) of the petroleum treated soil with soybean sown on it was greater than the other interaction effects. The least total porosity (41.51%) was observed in the petroleum uncontaminated soil with cowpea grown on it. Also, the total porosity (45.75%) of the soils with soy bean was the highest in comparison with the other plants. The result revealed that total porosity tends to be reduced on the contaminated soil when compared to the control soil, this could be as a result of blockage of pore spaces within the pollutants (Awobajo, 1981). The presence of diesel contaminate did not have significant influence on the bulk density and total porosity of the soil, when the control was compared with the contaminated soil, bulk density increased and total porosity reduced on the contaminated soil. This is worthy of note that oil pollution increase bulk density and reduce total porosity (Ayodeji *et al.,* 2009).

Furthermore, in Table 2, the moisture content (11.79%) of the petroleum untreated soil with African yam bean sown on it was greater than the other interaction effects. The least moisture content (5.77%) was observed in the petroleum contaminated soil with vetiver grass grown on it. The petroleum contaminated soil had the lowest value of moisture content (7.37%), while the uncontaminated soil significantly ($p < 0.05$) had the highest moisture content (9.80%). The moisture content (9.69%) of the soils with soil African yam bean was the highest in comparison with the other plants. Thus to increase the moisture content of the soil African yam bean should be planted. According to Grossman and Reinsch (2002) soils with high bulk density ranging from 1.6 – 1.7 gcm^3 shows 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 The hydraulic conductivity of the contaminated soil was significantly ($p < 0.05$) the highest (11.07 K cm^3/hr) in comparison with the petroleum unamended soil which had a value of 8.22 K cm^3/hr

3.3 Effects of petroleum on the chemical properties of soil

Table 3, indicated that petroleum treated soil significantly ($p < 0.05$) had the highest organic matter content (0.79%) and the lowest was the control treatment (0.54%). The main effect of plants on the organic matter content showed that soils on which cowpea (0.86%) and spear grass (0.86%) were grown had significantly ($p < 0.05$) the highest organic matter content compared with the other plants. soil with African yam bean (0.32%) grown on them had the lest organic matter content. 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. The vetivar grass (pH in water 6.87) and spear grass (pH in potassium chloride 5.67) grown in the soil without petroleum contamination had higher pH values than those from the contaminated soil. This observation corroborated the finds of Katsivela *et. al.,* (2005) who reported that petroleum waste sludge lowers the pH immediately around negatively charged soil surfaces. The carbon content level in Table 3 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.

In Table 4, the control plot had the highest total nitrogen content (0.057%) in comparison with the petroleum treated soil which contained 0.055% total nitrogen. The main effect of spear grass on total nitrogen content of the soil was also significantly ($p < 0.05$) greater (0.077%) than the other plants, while the lest total nitrogen content was observed in the plots with groundnut (0.042%). More so, the cation exchange capacity (9.91 me/100 g) of petroleum contaminated soil was significantly ($p < 0.05$) the highest compared with the untreated plot which had a value of 8.72 C mol kg^{-1}. Also in Table 4 the available phosphorus of the unamended soil was found to be greater (1.52 C mol kg^{-1}) than in the petroleum amended soil (1.51 C mol kg^{-1}). The base saturation of the soil was higher in the uncontaminated soil (30.61%) than in the petroleum contaminated soil (26.98%)

The data in Table 5 indicates that the exchangeable bases [Na^+ (0.11 C mol kg^{-1}), K^+ (0.15 C mol kg^{-1}) and Mg^{2+} (0.95 C mol kg^{-1})] were significantly ($p < 0.05$) higher in the uncontaminated soil except calcium (1.57 C mol kg^{-1}) which was higher in the petroleum treated plot. Katsivela *et. al.,* (2005) 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 hydraulic conductivity (11.07 K cm^3/hr) than the untreated soil. Petroleum treated soil contained lesser 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 contaminate soils. Petroleum treated soil contained more concentration of carbon, organic matter, exchangeable calcium and cation exchange capacity than the uncontaminated soil. Amending the soil with petroleum should be discouraged. At 90 days after planting the cultivation of soya bean is recommended as it helps in the suppression of the bulk density and hydraulic conductivity and causes an increase in the available potassium, exchangeable calcium and exchangeable magnesium of the soil for optimum soil fertility replenishment for crop production.

REFERENCES

Achuba, F. I. (2006). The effect of sublethal concentrations of crude oil on the growth and metabolism of Cowpea (Vigna unguiculata) seedlings. African J.

Adam, G. and Duncan, H. J. (2002): Influence of Diesel Fuel on Seed Germination. Environ.Pollut.

Anderson, J. M. and Ingram, J. S. I. (eds) (1993). Tropical Soil Biology and Fertility: A Handbook of Methods (2nd edition) CAB international 221pp.

Anderson, J. M. and Ingram, J.S.I. (eds) (1993). Tropical Soil Biology and Fertility: A Handbook of Methods (2nd edition) CAB international 221pp.

Anikwe, M. A.N. (2006). Soil quality assessment and monitoring: A review of current research efforts. *New Generation Publishers*, Enugu Nigeria. ISBN 9782900826. pp208;.

Bray, R. H. and Kurtz, L. T. (1945). Determination of Total, Organic and Available Forms of Phosphorus in Soils. Soil Science 91-96.

Bremner, J. M. and Mulvaaney, C. S.(1982). Total nitrogen. In: Page, A.L. (eds.). Methods of Soil Analysis, Part 2. Chemical and Microbial Properties, Second edition Agronomy Series no. 9 Madison, WI, USA, ASA, SSSA.

Chapman, H. D. (1982). Total Exchangeable bases. In. C.A. Black (ed.), methods of soil analysis, Part2. ASA, 9: 902-904 Madison, USA

Ezeaku, P. I. and Anikwe, M. A. (2006). A model for description of water and solute movement in soil-water restrictive horizons across two landscapes in south eastern Nigeria. *Soil science*, *171*(6), 492-500.

Fernandes, J. C. and Henriques, F. S. (1991). Biochemical, physiological and structural effects of excess copper in plants. *The Botanical Review*, 57: 246 -273.

Gee, G. W. and Bauder, D. (2002). Particle size analysis. In: Dane, J.H. and Topp, G.C. (eds.). Methods of Soil Analysis. Part 4, Physical methods. *Soil sci. soc. Am. 5:255-293.*

GENSTAT (2007). GENSTAT Release 7.2DE, Discovery Edition 3, Lawes Agricultural Trust, Rothamsted Experimental station.

Gomes, K. A and Gomes, A. A. (1984). Statistical producers for Agricultural Research. 2nd edition. John Wiley and Sons. Inc. New York, U S .A

Grossman, R. B. and Reinsch, T. G. (2002). Bulk density and extensibility: Core method. In: Dane, J.H, Topp, G.C. (Eds.).Methods of Soil Analysis, Part 4.Physical Methods. SSSA, Inc., Madison, WI, pp. 208-228.

Johnson, L.D., Marquaz, M. and Lamb. B. (1996). Inheritance of root traits in alfalfa, *Crop Science 36:* 1482 – 148.

Klute, A. and Dirkesen, C. (1986). Hydraulic conductivity and diffusivity: Laboratory methods. In Klute, A. (Ed.) Methods of soil analysis. Part 1. Physical and mineralogical methods, American Society of Agronomy Madison, Wisconsin, USA

Marmiroli, N. and McCutcheon, S. C. (2003). phytoremediation a successful technology. Phytoremediation. Transformation and Control of Contaminants. John Wiley, Hoboken.

McLean, E. O. (1982). Soil pH and lime requirements. In: Page, A.L. (eds.). Methods of Soil Analysis, Part 2. Chemical and Microbial Properties, Second edition Agronomy Series no. 9 Madison, WI, USA, ASA, SSSA.

Murphy, J. and Riley, J. P. (1962). A Modified Single Solution Method for determination of phosphate in natural waters. *Anal. Chem. Acta 27:31-36*

Page, J. R., Miller, R. H., Keeney, D. R., Baker, D. E., Roscoe Ellis, J. R. and Rhoades, J. D. (1982). Methods Soil Analysis 2. Chemical and Microbiology Properties (2^{nd} Edn.) Madison, Wisconsin, U.S.A, 1159 pp.

Rhoades, J. D. (1982). Cation exchange capacity. In; Page, A.L.., Miller, R.H. and Keeney, D.R. (eds.). Methods of soil analysis, Part 2: Chemical methods. Agronomy Monograph no. 9, American Society of Agronomy Madison, Wisconsin, USA.

Vavrek, M. C. and Campbell, W. J. (2002). Contribution of seed banks to freshwater wetland vegetation recovery. Louisiana Applied and Educational Oil Spill Research and Development Program, OSRADP.

Vwioko, D E., Anoliefo, G. O. and Fashemi, S. D. (2006). Metals concentration in plant tissues of Ricinus communis L. (Castor Oil) grown in soil contaminated with spent lubricating oil. *Journal of Applied Science and Environmental*

Table 1. 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 (**C mol kg^{-1}**)	6.53
Exchangeable bases (C mol kg^{-1})	
Calcium	4.40
Magnesium	0.40
Potassium	0.10
Sodium	0.661
Exchangeable Acidity (C mol kg^{-1})	
Hydrogen	0.80
Cation exchangeable capacity (**C mol kg^{-1}**)	14.40

Table 2. Effect of petroleum on soil physical properties at 90 days after planting

	Soil											
	Bulk density (g cm $^{-3}$)			Total porosity (%)			Moisture content (%)			Hydraulic conductivity (K cm ^{3}/hr)		
plants	***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	8.60	5.01	6.80
Cowpea	1.55	1.43	1.49	46.04	41.51	43.78	7.70	9.83	8.76	11.22	7.16	9.19
Groundnut	1.45	1.53	1.49	45.48	42.27	43.87	7.01	8.46	7.73	10.75	8.12	9.43
African yam bean	1.48	1.45	1.46	44.34	45.28	44.81	7.59	11.79	9.69	13.85	9.65	11.75
Vetivar grass	1.48	1.45	1.46	44.15	45.47	44.81	5.77	9.05	7.41	10.75	11.94	11.34
Maize	1.49	1.49	1.49	43.97	43.96	43.96	9.00	9.17	9.08	13.37	8.60	10.98
Spear grass	1.47	1.49	1.48	44.72	43.96	44.34	6.79	10.32	8.55	13.13	6.92	10.03
Carpet grass	1.47	1.52	1.50	44.53	42.65	43.59	7.21	10.31	8.76	6.94	8.36	7.65
soil mean	1.49	1.46	1.47	43.75	44.98	44.36	7.37	9.80	8.58	11.07	8.22	9.65
F-LSD $_{(0.05)}$ for 2 soils (s)	NS			NS			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 3. Effects of petroleum on soil pH, carbon and organic matter content at 90 days after planting

	Soil											
	soil pH (H_20)			soil pH (KCL)			Carbon (%)			Organic matter (%)		
plants	*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	0.33	0.37	0.72	0.57	0.65
Cowpea	6.07	6.70	6.38	5.03	5.53	5.28	0.67	0.33	0.50	1.15	0.57	0.86
Groundnut	5.97	6.33	6.15	5.03	5.20	5.12	0.42	0.33	0.37	0.72	0.57	0.65
African yam bean	6.77	6.47	6.62	5.55	5.27	5.38	0.25	0.13	0.19	0.43	0.22	0.32
Vetivar grass	6.73	6.87	6.80	5.43	5.60	5.52	0.50	0.21	0.35	0.86	0.36	0.61
Maize	6.73	6.67	6.70	5.40	5.37	5.38	0.42	0.54	0.48	0.72	0.93	0.82
Spear grass	6.63	6.87	6.75	5.43	5.67	5.55	0.66	0.33	0.50	1.14	0.57	0.86
Carpet grass	6.07	5.88	5.95	5.03	5.00	5.02	0.33	0.29	0.32	0.57	0.50	0.54
soil mean	6.45	6.55	6.50	5.28	5.38	5.33	0.46	0.31	0.38	0.79	0.54	0.66
$F\text{-}LSD_{(0.05)}$ for 2 soils (s)	0.03			0.06			0.002			0.003		
$F\text{-}LSD_{(0.05)}$ for 2 plants (p)	0.08			0.08			0.002			0.003		
$F\text{-}LSD_{(0.05)}$ for 2 s × p	0.11			0.10			0.002			0.004		

$F\text{-}LSD_{(0.05)}$ = 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 total nitrogen, CEC, available phosphorus and base saturation at 90 days after planting

	Soil											
	Total nitrogen (%)			CEC (C mol kg^{-1})			Available phosphorus (C mol kg^{-1})			Base saturation (%)		
plants	*soil	Soil	plant mean	*soil	soil	plant mean	*soil	soil	plant mean	*soil	soil	plant mean
Soybean	0.057	0.069	0.063	8.87	8.47	8.67	0.93	0.94	0.94	41.72	33.73	37.73
Cowpea	0.070	0.055	0.063	14.33	7.73	11.03	1.86	1.87	1.87	16.61	31.01	23.81
Groundnut	0.042	0.041	0.042	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
Vetivar grass	0.067	0.056	0.062	8.53	7.27	7.90	1.86	1.87	1.87	27.60	37.64	32.63
Maize	0.029	0.058	0.044	8.33	8.33	8.33	1.87	1.89	1.88	27.35	25.61	26.48
Spear grass	0.070	0.083	0.077	10.73	8.47	9.60	1.85	0.93	1.39	21.45	33.00	27.23
Carpet grass	0.055	0.043	0.049	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 5. Effects of petroleum on exchangeable bases (C mol kg^{-1}) at 90 days after planting

	Soil											
	sodium (Na^+)			Potassium (K^+)			Calcium (Ca^{2+})			Magnesium (Mg^{2+})		
plants	***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
Vetivar 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