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Effect of Pig Dung (Organic Manure) Application to Crude Oil Polluted Soil on Maize (*Zea mays*) Growth and Soil Properties

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ABSTRACT **Original Research Article**

The pot experiment was conducted in the Soil Science Departmental Screen-house in the Faculty of Agriculture Teaching and Research Farm, University of Benin, Benin City, to remediate crude oil-polluted soil with pig dung. The effects of crude oil and pig dung on soil properties and maize (*Zea mays* L.) growth were investigated. Forty-eight perforated pots were filled with 15 kg of surface soils (0-15cm). The soils were polluted with four levels of crude oil (0, 7.5, 15, 22.5ml) and were amended with pig dung two weeks after pollution at four application rates (0, 500, 550, 600kg/ha) before planting. The results of the experiment indicate that soil properties and maize growth showed a dose-dependent response to crude oil-polluted, pig-dung-amended soils. Reduction in soil properties and plant height (102.1cm), leaf area (337.4cm^2), number of leaves (9.33) due to effect of different levels crude oil pollution were significantly different ($P<0.05$) compared to their control (108.6cm, 413.4 cm^2,10) but were significantly increased when amended with pig dung (139.1cm, 508.7cm^2, 13) respectively. The total hydrocarbon content also decreased significantly in amended treatments, while total organic carbon, Nitrogen, potassium, pH, and phosphorus content were increased. Most of the highest results were recorded for treatments 15ml/550kg and 22.5ml/550kg across various analyses, amongst others. The microbial population was lowest in the polluted soil (4.34 x 10^6) in the 22.5 ml/0 kg treatment, but increased to 13.20 x 10^6 cfu in the 0ml/600kg treatment. Thus, pig dung (organic manure) is effective in ameliorating crude oil-polluted soil.

Keywords: Bioremediation, Pollution, Soil Microbial Activity, Pig Dung, Maize, Hydrocarbon.

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Introduction

Soil is a fundamental component of natural ecosystems, and environmental sustainability is intrinsically linked to maintaining a healthy soil ecosystem (Adedokun and Ataga, 2007; Adenipekun, 2008). As the primary recipient of anthropogenic waste products, soil ecosystems face increasing threats from petroleum pollution, which represents one of the most prevalent environmental challenges globally (Marinescu *et al.*, 2010). In Nigeria, since the commencement of commercial petroleum exploration in 1958, crude oil has become the mainstay of the national economy; however, this has resulted in extensive contamination of soil and waterways through accidental spillages, pipeline leakages, and transportation accidents (Okoh, 2003; Eneje *et al.*, 2012; Okop, 2010). Approximately 2,000 oil spills were recorded in Nigeria between 1976 and 1988, involving an estimated 2 million barrels of crude oil, with agricultural lands particularly affected by diesel oil spillage along major highways (Ekpo and Nya, 2012; Nwaogu *et al.*, 2008).

Crude oil contamination induces profound deleterious effects on soil properties and biota. Physical impacts include reduced aeration due to blockage of soil pore spaces, leading to anaerobic conditions; increased bulk density; and impaired

water infiltration (Rowell, 1977; Atuanya, 1987; Stafford, 1973). Chemical alterations include increased organic carbon content, reduced nitrogen availability, and disrupted carbon-nitrogen ratios, which threaten the survival of soil biota (Ekundayo *et al.*, 2001; Ogboghodo *et al.*, 2004; Jobson *et al.*, 1974). Biological responses involve the selective destruction of aerobic microorganisms, followed by the proliferation of resistant hydrocarbon-degrading strains (Odu, 1981; Roscoe *et al.*, 1989). Recent investigations have demonstrated that crude oil contamination reduces beneficial soil microflora, decreases maize biomass production, impairs photosynthetic capacity by damaging photosystem II, and induces metabolic limitations that reduce net CO_2 assimilation rates (Athar *et al.*, 2016). Nevertheless, maize exhibits moderate tolerance to oil pollution through adaptive responses, including increased root length and diameter to enhance water and nutrient uptake (Athar *et al.*, 2016; Chupakhina and Maslennikov, 2015).

Bioremediation has emerged as the most promising technology for restoring crude oil-polluted soils, utilizing microorganisms or their enzymes to degrade contaminants (Okon and Hernandez, 2006). The efficacy of bioremediation can be significantly enhanced through organic soil amendments that improve physical properties and stimulate microbial activity (Davis and Wilson, 2005). Animal manures, including pig dung, poultry waste, and cow dung, have demonstrated substantial potential for enhancing hydrocarbon degradation by increasing hydrocarbon-utilizing microbial populations and providing essential nutrients for microbial metabolism (Abanno and Ijah, 2010; Ubani *et al.*, 2012). Dadrasnia and Ismail (2015) reported over 89% degradation of waste crude oil within 60 days when soil was amended with both bacterial strains and organic waste, compared to only 14% loss in unamended controls. Recent studies confirm that organic dung amendments progressively reduce total petroleum hydrocarbon concentrations, with bioremediation efficiency varying according to dung type and application rate (Ossai *et al.*, 2020).

Despite growing evidence supporting organic amendment-based bioremediation, limited research has specifically evaluated the effectiveness of pig dung application for ameliorating crude oil-polluted soils and restoring maize productivity under Nigerian conditions. Therefore, this study was conducted with the following objectives: (1) to determine the effect of crude oil pollution on the growth of maize (*Zea mays* L.) and on selected soil physical and chemical properties, and (2) to evaluate the effectiveness of pig dung application as an organic amendment for ameliorating crude oil-polluted soil. It is hypothesized that crude oil contamination will significantly impair maize growth and soil properties. In contrast, pig dung amendment will enhance bioremediation and restore soil quality by stimulating hydrocarbon-degrading microorganisms and improving soil nutrient status.

Materials and Methods

Study Area

The screen-house experiment was conducted at the Department of Soil Science, Faculty of Agriculture, University of Benin, Benin City, Edo State, Nigeria. The study was carried out between March and May 2016. Benin City is located within the tropical rainforest zone of Nigeria, characterized by mean annual rainfall of approximately 1,500-2,500 mm distributed between March and October, with mean temperatures ranging from 25°C to 28°C (Ikhajiagbe *et al.*, 2016). The relative humidity is typically high, averaging 75-85% throughout the year (NIMET, 2015). These tropical conditions are conducive to bioremediation studies as elevated temperatures and adequate moisture promote microbial degradation of petroleum hydrocarbons (Udosen*et al.*, 2015; Umana *et al.*, 2017).

Soil and Plant Sampling

Surface soil (0–15 cm depth) was collected from the Teaching and Research Farm, University of Benin, using a soil auger. The soil was air-dried, sieved through a 2 mm mesh to remove debris, and thoroughly homogenized prior to analysis (Ujowundu *et al.*, 2011). Bonny Light crude oil, a low-sulphur, high-quality Nigerian crude, was obtained from the Nigerian National Petroleum Corporation (NNPC) depot. The crude oil application rates of 0, 7.5, 15, and 22.5 mL per 15 kg soil were selected to represent low, moderate, and high contamination scenarios based on typical spill concentrations reported in the Niger Delta region, which range from 5 to over 100 mL kg^{-1} soil in severely impacted sites (Okonokhua *et al.*, 2007; Osuji & Nwoye, 2007). Maize seeds (*Zea mays* L. variety OBA-98), an early-maturing variety widely cultivated in southern Nigeria, were procured from the Edo State Agricultural Development Programme (ADP). Cured pig dung was collected from the University of Benin Animal Farm Project. The dung was cured under aerobic conditions for four weeks prior to application, during which it was periodically turned to ensure uniform decomposition and elimination of potentially phytotoxic volatile compounds (Brady and Weil, 2016). Based on the chemical composition presented in Table 3, the C: N ratio of the pig dung was calculated as 14.3:1 (organic carbon = 30.2 g/kg; total nitrogen = 2.11 g/kg), which is within the optimal range for supporting microbial hydrocarbon degradation without inducing nitrogen immobilization (Atlas & Bartha, 1998).

The experimental design was completely randomized with four crude oil concentrations (0, 7.5, 15, and 22.5 g) and four pig dung rates (0, 500, 550, and 600 kg/ha), with three replicates. The equivalent amount of pig dung applied per pot was calculated using the formula: $Ap = \left[\frac{R \times Ms}{Mh}\right] \times 1000$

where:

- A*p* = amendment per pot (g),
- R = field application rate (kg ha^{-1}),
- M*s* = mass of soil per pot (kg) = 15 kg,
- M*h* = mass of soil in 1 ha to 15 cm depth (kg), a bulk density of 1.3 g cm^{-3} = 1,950,000 kg.

Fifteen kilograms of soil were weighed into perforated 16-liter buckets. The soil was moistened to field capacity and allowed to stabilize for two weeks before crude oil application. Following the addition of crude oil, the contaminated soil was left undisturbed for a further two weeks to allow initial hydrocarbon weathering and volatilization. Pig dung was then incorporated, and the amended soil was allowed to cure for an additional 2 weeks before planting maize seeds (Ekpo and Nya, 2012). This sequential incubation protocol ensured adequate equilibration of the soil-contaminant-amendment matrix before plant introduction.

Laboratory Analysis

Soil physicochemical properties were determined using standard analytical procedures. Particle size distribution was analysed by the hydrometer method (Gee and Or, 2002). Soil pH was measured in a 1:1 soil-water suspension using a glass electrode pH meter (Thomas, 1996). Organic carbon was determined by the Walkley-Black chromic acid wet oxidation method (Walkley and Black, 1934; Nelson and Sommers, 1996). Total Nitrogen was analysed by the micro-Kjeldahl digestion method (Bremner, 1996). Available phosphorus was extracted using Bray-1 solution (Bray and Kurtz, 1945) and determined by the molybdate blue method (Murphy and Riley, 1962). Exchangeable bases (Ca, Mg, K, Na) were extracted with 1N ammonium acetate (NH_4OAc, pH 7.0) (Thomas, 1982); Ca and Mg were determined by EDTA titration, while K and Na were analysed by flame photometry. Exchangeable acidity (H^+ and Al^{3+}) was extracted with 1M KCl and determined by titration (McLean, 1965). The sum of exchangeable bases and exchangeable acidity was used to calculate the effective cation exchange capacity. Microbial populations were enumerated using the spread-plate technique and serial dilution on nutrient agar (bacteria) and malt extract agar (fungi) (Ijah and Antai, 2003). Bacterial and fungal isolates were preliminarily identified based on colonial morphology, Gram staining reaction, and standard biochemical tests, including catalase, oxidase, urease, and carbohydrate fermentation profiles (Holt *et al.*, 1994). Plant nutrient uptake was calculated as dry weight multiplied by nutrient content following acid digestion (Novozamsky *et al.*, 1983).

Statistical Analysis

Data were statistically analysed using SPSS version 20.0 (IBM Corporation, Armonk, NY, USA). One-way analysis of variance (ANOVA) was employed to test for significant differences among treatment means (Gomez and Gomez, 1984). All values presented in tables represent the mean ± standard deviation (SD) from three independent replicate determinations (n=3). Where significant F-values were obtained, treatment means were separated using Duncan's Multiple Range Test (DMRT) at a probability level of $p<0.05$ (Duncan, 1955).

Percentage THC reduction was calculated as: THC Reduction (%) = [(Pre-planting – Post-harvest) / Pre-planting] × 100

Graphical representations were generated using Microsoft Excel 2013 to illustrate treatment effects on measured parameters.

Results and Discussion

Chemical Composition of Crude Oil

The crude oil used for the experiment is Bonny Light. The polycyclic Aromatic Hydrocarbons (PAHs) and Total Petroleum Hydrocarbon composition of the crude oil are shown in Tables 1 and 2, respectively.

Table 1: Concentration of PAHs in Crude Oil

PAH (mg/l)	Nigerian crude oil
Acenaphthene	1.072
Acenaphthylene	1.046
Benzo(a)pyrene	0.076
Benzo(b)fluorathene	0.023
Benzo(k)fluorathene	BDL
1,12-Benzoperylene	0.007
1,2,5,6 Dibenzernthracene	0.002
Fluoranthene	0.450
Fluorence	0.284
Indeno(1,2,3)pyrene	0.002
Naphthalene	0.163
Phenanthrene	0.143
Pyrene	0.621
PAH (mg/l)	Nigerian crude oil

Table 2: Concentration of TPH_S in Crude Oil

TPHs (mg/kg)	Nigerian crude oil
C_{10}	0.2002
C_{11}	0.0432
C_{12}	0.0421
C_{13}	0.0523
C_{14}	0.4934
C_{15}	0.0060
C_{16}	BDL
C_{17}	0.1480
Pristane	0.1218
C_{18}	0.3200
Phytane	BDL
C_{19}	1.7480
C_{20}	1.6860
C_{21}	1.7100
C_{22}	1.5910
C_{23}	1.3930
C_{24}	1.1830
C_{25}	0.0330
C_{26}	0.8110
C_{27}	0.7070
C_{28}	1.120
C_{29}	0.7450
C_{30}	0.2260
C_{31}	0.7570
C_{32}	0.4300

Chemical Composition of Cured Pig Dung (Farmyard Manure)

The pig dung used for the experiment was collected from the University of Benin Animal Farm Project. Table 2 shows the chemical composition of the pig dung, which is a potential source of organic matter with a narrow C:N ratio.

Table 3: Chemical Composition of Pig Dung

PARAMETERS	VALUES
pH (g/kg)	6.4
Total Nitrogen (g/kg)	2.11
Total Hydrocarbon (mg/kg)	N/D
Total Organic carbon (g/kg)	30.2
Phosphorus (mg/kg)	10.5
Potassium (Cmol/kg)	0.52
Calcium (Cmol/kg)	2.40
Magnesium (Cmol/kg)	0.63
Sodium (Cmol/kg)	0.20
Exchangeable Acidity ($Cmolkg^{-1}$)	0.10
CEC ($Cmolkg^{-1}$)	3.85
ECEC ($Cmolkg^{-1}$)	3.85
Microbial Count	12.50×10^6

Soil Properties at Various Levels of Treatment

Physical and Chemical Properties of Soil before Pollution with Crude Oil

The results of the physicochemical laboratory analysis of the soil prior to pollution are presented in Table 4.

Table 4: Physico-chemical Properties of Soil before Crude Oil Pollution

PARAMETERS	VALUES
pH (H_2O)	5.4
total Nitrogen (g/kg)	1.31
total hydrocarbon (mg/kg)	N/D
total Organic carbon (g/kg)	12.6
Available Phosphorus (mg/kg)	6.46
Potassium ($Cmolkg^{-1}$)	0.22
Calcium ($Cmolkg^{-1}$)	0.58
Magnesium ($Cmolkg^{-1}$)	0.30
Sodium ($Cmolkg^{-1}$)	0.18
Exchangeable Acidity ($Cmolkg^{-1}$)	0.66
CEC ($Cmolkg^{-1}$)	1.82
ECEC ($Cmolkg^{-1}$)	1.94
Sand (g/kg)	886
Silt (g/kg)	58
Clay (g/kg)	56
Microbial Count	6.40 x 10^6

Particle-size analysis indicates that the soil used for the experiment is loamy sand. The soil is reddish-brown acid sand. The soil's potassium content is low.

Effect of Crude Oil on Soil Properties

Table 5: Physico-chemical Properties of Soil after Pollution with Crude Oil

	POLLUTION LEVELS (ML/15KG OF SOIL)			
PARAMETERS	**0ML**	**7.5ML**	**15ML**	**22.5ML**
pH (H_2O)	5.40±0.28	5.0±0.17	5.2±0.45	5.3±0.35
Total Nitrogen (g/kg)	1.31±0.15	0.96±0.01	1.00±0.2	1.20±0.48
Total Hydrocarbon (mg/kg)	N/D	67.8±4.2	82.5±6.50	98.2±10.12
Total Organic carbon (g/kg)	12.6±0.45	28.5±2.1	33.1±3.1	51.4±4.50
Available Phosphorus (mg/kg)	6.46±0.52	10.5±1.23	13.4±1.96	15.30±3.50
Potassium ($Cmolkg^{-1}$)	0.22±0.01	0.19±0.1	0.20±0	0.18±0.04
Calcium ($Cmolkg^{-1}$)	0.58±0.05	0.45±0.03	0.48±0.03	0.52±0.16
Magnesium ($Cmolkg^{-1}$)	0.30±0.04	0.26±0.01	0.28±0.1	0.28±0.12
Sodium ($Cmolkg^{-1}$)	0.18±0.01	0.12±0.02	0.14±0.04	0.16±0.02
Exchangeable Acidity ($Cmolkg^{-1}$)	0.66±0.02	0.76±0.01	0.67±0.01	0.64±0.18
CEC ($Cmolkg^{-1}$)	1.82±0.12	1.78±0.09	1.67±0.06	1.68±0.68
ECEC ($Cmolkg^{-1}$)	1.94±0.08	1.93±0.07	1.77±0.09	1.78±0.2
Sand (g/kg)	886±0.39	886±0.58	887±0.62	890±0.75
Silt (g/kg)	58±0.01	63±0.25	67±0.26	72±0.95
Clay (g/kg)	56±0.01	51±0.21	46±0.32	38±0.32
Microbial Count (cfu/g)	6.4±3.5x 10^6	3.51 ±2.9x 10^6	3.32±3.9 x 10^6	2.40±2.5x10^6

Table 5 shows the effect of crude oil on the bulk soil properties at various levels of pollution.

Soil pH showed a slight increase after crude oil pollution, ranging from 5.0 to 5.3 in contaminated treatments, compared with 5.4 in the control. The pH increased marginally with higher crude oil application, reaching 5.30 at 22.5 mL/15 kg soil, indicating that oil-affected soil tends toward greater acidity than non-affected soil. This modest acidification likely results from organic acid production during early hydrocarbon weathering and microbial oxidation (Osuji and Nwoye, 2007).

Organic carbon increased progressively with crude oil application, from 12.60% in the control to a maximum of 51.4% at the 22.5 mL level. This increase reflects the high hydrocarbon content of crude oil (Odu, 1981; Ogboghodo *et al.*, 2004) and the reduced microbial mineralization of carbon due to hydrocarbon toxicity, suppressing decomposer populations (Udo and Fayemi, 1975).

Total Nitrogen decreased from 1.31% in the control to 0.96% at the lowest crude oil application (7.5 mL), then increased slightly to 1.20% at higher levels. Low-level spillage may induce microbial mortality and subsequent nitrogen mineralization (Zuofa *et al.*, 1989; Odu, 1981).

Exchangeable acidity decreased from 0.76 to 0.64 cmol/kg with increasing crude oil application. Exchangeable bases (Na, K, Ca, Mg) were consistently lower in oil-affected soils than in the control, likely due to hydrocarbon coating of exchange sites and cation leaching following aggregate destabilization (Wang *et al.*, 2013). Available phosphorus increased with pollution level, possibly from microbial biomass lysis or solubilization by organic acids (Ogboghodo *et al.*, 2004). Cation exchange capacity declined from 1.82 cmol/kg in the control to 1.68–1.78 cmol/kg in polluted treatments, reflecting physical blockage of exchange sites by hydrophobic hydrocarbons (Brady and Weil, 2016). Particle-size analysis indicated that crude oil had negligible effects on soil physical properties.

Table 6. Physical and chemical properties of soil after crude oil pollution and pig dung amendment application

Treatment	pH	T.N (g/kg)	THC (mg/kg)	Org.C (g/kg)	Av.P (mg/kg)	K	Ca	Mg	Na cMol/kg	EA	CEC	ECEC	Sand g/kg	Silt g/kg	Clay g/kg	Microbial count (cfu/g)
0ml/0kg	5.2±0.15	1.20±0.02	2.10±0.21	10.3±0.01	6.30±0.06	0.20±0.01	0.55±0.02	0.26±0.0	0.16±0.01	0.60±0.09	1.67±0.19	1.77±0.21	890±0.77	55±0.02	55±0.15	5.70±1.5x10^6
0ml/500kg	5.4±024	1.25±0.01	4.23±0.59	24.2±2.10	6.82±0.12	0.22±0.02	0.57±0.01	0.21±0.01	0.16±0.05	0.48±0.02	1.54±0.09±0.21	1.64±0.29	890±0.45	60±0.25	50±0.21	8.20±2.1x10^6
0ml/550kg	5.5±0.5	1.26±0.03	4.30±1.01	29.8±1.56	7.90±0.15	0.25±0.02	0.61±0.02	0.21±0.01	0.14±0.06	0.45±0.02	1.56±0.24	1.66±0.25	891±1.0	68±0.21	41±0.25	10.50±2.5x10^6
0ml/600kg	6.0±0.65	1.26±0.02	5.40±2.10	35.4±3.52	8.52±0.25	0.44±0.02	0.70±0.02	0.200.01	0.13±0.12	0.13±0.01	1.60±0.17	1.63±0.20	890±0.98	72±0.29	38±0.23	13.20±2.1x10^6
7.5ml/0kg	5.0±0.45	0.94±0.02	65.7±6.35	26.3±2.65	10.0±0.09	0.20±0.01	0.46±0.0	0.28±0.03	0.12±0.23	0.73±0.02	1.68±0.13	1.79±0.19	886±0.98	60±0.30	54±0.31	5.00±0.98x10^6
7.5ml/500kg	5.4±0.23	1.06±0.04	74.2±7.52	33.6±3.35	10.8±0.08	0.24±0.01	0.50±0	0.25±0.04	0.11±0.25	0.55±0.01	1.62±0.21	1.65±0.23	889±0.65	67±0.24	44±0.28	7.43±2.0x10^6
7.5ml/550kg	5.7±0.56	1.08±0.05	75.4±5.20	36.2±3.20	13.6±0.17	0.23±0.03	0.58±0.01	0.22±0.06	0.12±0.25	0.34±0.01	1.45±0.25	1.49±0.20	887±0.57	70±0.25	43±0.28	7.82±3.2x10^6
7.5ml/600kg	5.4±0.25	1.12±0.03	80.70±9.59	55.7±3.50	13.8±0.13	0.20±0.01	0.46±0.02	0.20±0.07	0.10±0.51	0.41±0.03	1.31±0.15	1.37±0.19	884±0.56	68068±0.24	48±0.18	10.10±2.6x10^6
15ml/0kg	5.0±0.4	0.98±0.0121	78.6±8.25	30.2±1.5	12.6±0.20	0.22±0.01	0.42±0.02	0.27±0.01	0.14±0.21	0.62±0.05	1.56±0.23	1.68±0.25	889±0.78	65	46±0.26	5.00±2.5x10^6
15m/500kg	5.6±0.31	1.16±0.05	83.5±10.01	38.4±2.01	13.0±0.08	0.30±0.01	0.40±0.01	0.24±0.02	0.14±0.15	0.55±0.08	1.60±0.21	1.63±0.08	876±0.45	67±0.31	57±0.25	8.38±2.7x10^6
15ml/550kg	5.55±0.4	1.24±0.02	86.8±11.95	44.3±1.99	15.2±0.12	0.24±0	0.45±0.01	0.22±0.05	0.12±0.02	0.60±0.09	1.53±0.22	1.63±0.26	879±0.65	67±0.18	54±0.28	9.40±3.1x10^6
15ml/600kg	5.5±0.07	1.30±0.06	90.7±13.23	58.5±1.89	17.4±0.02	0.24±0.04	0.50±0.05	0.22±0.04	0.13±0.12	0.58±0.12	1.59±0.14	1.67±0.18	886±0.57	70±0.98	44±0.21	11.56±2.2x10^6
22.5ml/0kg	5.3±0.12	1.08±0.03	86.5±11.2	48.0±2.90	15.8±0.07	0.20±0.01	0.45±0.03	0.26±0.05	0.16±0.08	0.48±0.08	1.43±0.12	1.55±0.20	888±0.56	70±0.18	42±0.23	4.34±2.4x10^6
22.5ml/500kg	6.3±0.54	1.20±0.05	90.3±9.02	53.4±3.04	17.0±0.16	0.35±0.01	0.63±0.04	0.24±0.03	0.14±0.0	0.10±0.13	1.46±0.09	1.46±0.12	887±0.56	70±0.19	43±0.28	8.54±2.8x10^6
22.5ml/550kg	5.7±.0.67	1.28±0.07	115.6±12.21	58.8±1.25	18.1±0.12	0.35±0.02	0.60±0.06	0.25±0.12	0.14±0.08	0.17±0.02	1.43±0.08	1.46±0.22	887±0.65	68±0.25	45±0.22	10.00±3.21 x10^6
22.5ml/600kg	5.5±0.56	1.35±0.20	125.4±15.2	62.6±2.20	20.4±0.12	0.26±0.01	0.62±0.01	0.23±0.19	0.10±0.09	0.60±0.07	1.71±0.25	1.81±0.27	890±0.57	70±0.25	40±0.23	12.50±2.65 x10^6

*Textural class is loamy sand

Effect of Pig Dung on Crude Oil Polluted Soil

At various rates of amendment of crude oil-polluted soil with pig dung, the soil's properties improved, as shown in Table 6. Soil pH increased in the amended soil, tending toward neutrality. This indicates that pig dung can reduce the acidity of crude oil-affected soil as an organic amendment. Treatment 22.5 mL/500 kg recorded the highest pH (6.3 ± 0.54), while treatments 22.5 mL/550 kg and 22.5 mL/600 kg yielded lower values of 5.7 ± 0.60 and 5.5 ± 0.56, respectively. This apparent anomaly may be attributed to several interacting factors. First, the higher organic loading at 550–600 kg/ha likely stimulated greater microbial activity and hydrocarbon degradation, processes that generate acidic intermediates and organic acids as by-products of incomplete PAH oxidation (Margesin *et al.*, 2000). Second, the concurrent release of CO_2 during enhanced microbial respiration may have formed carbonic acid, temporarily reducing soil pH despite the buffering capacity of the dung (Brady and Weil, 2016). Third, spatial heterogeneity in dung incorporation and the inherently variable distribution of crude oil within the soil matrix may have contributed to the observed fluctuations. This buffering effect is attributable to the release of basic cations (Ca^{2+}, Mg^{2+}, K^+) during dung mineralization and proton consumption by organic anions (Brady & Weil, 2016). The pH of the soil samples increased with increasing amendment rates, with the highest value recorded in treatment 22.5 mL/500 kg (Table 6). This agrees with reports by Ogboghodo *et al.* (2004a) and Onuh et al. (2008).

Total Nitrogen increased with the level of crude oil pollution, reaching 1.08 g/kg in treatment 22.5 mL/0 kg, though this remained lower than the control value of 1.02 g/kg (Table 6). When amended with pig dung, total Nitrogen increased to 1.35 g/kg in treatment 22.5 mL/600 kg, reflecting the direct

nitrogen contribution of the dung (2.11 g/kg; Table 3) and enhanced nitrogen mineralization in the organically amended matrix.

Organic carbon was 10.3 g/kg in the control and increased to 62.60 g/kg in the treatment (22.5 mL/600 kg) after amendment with pig dung. Organic carbon content was higher in treatments combining elevated crude oil and pig dung levels, consistent with the findings of Ogboghodo *et al.* (2004a) and Onuh et al. (2008). The dung-derived organic matter provides a labile carbon source that supports co-metabolic degradation of recalcitrant petroleum hydrocarbons (Atlas and Bartha, 1998).

Exchangeable cations—potassium and calcium—increased with higher levels of crude oil and pig dung, while magnesium and sodium decreased.

The microbial population before planting was lower in crude oil-contaminated soil than in the control and amended treatments. Populations ranged from 4.34×10^6 to 5.0×10^6 cfu/g in polluted soil, 5.70×10^6 cfu/g in the control, and 7.43×10^6 to 13.20×10^6 cfu/g in amended treatments (Table 6). The elevated microbial counts in amended soils reflect the introduction of a substantial microbial inoculum with pig dung (12.50×10^6 cfu/g; Table 3) and the provision of nutrients and organic substrates that stimulate indigenous hydrocarbon-degrading populations (Margesin *et al.*, 2000). The differences in microbial populations may be attributed to changes in chemical constituents, nutrient and oxygen supply, and tolerance to pH shifts (Haris, 1962; Okereke *et al.*, 2007).

The identified microorganisms were bacteria—*Mycobacterium* spp. and *Nocardia* spp.—and fungi—*Candida* yeast spp. and *Rhodotorula* spp. These findings are consistent with the hydrocarbon-degrading microorganisms identified by Bello and Anobeme (2015). Both *Mycobacterium* and *Nocardia* are actinomycetes known for their ability to degrade high-molecular-weight polycyclic aromatic hydrocarbons (PAHs) via dioxygenase enzyme systems (Kaplan and Kitts, 2004).

Effect of Crude Oil and Pig Dung on Some Growth Parameters of Maize (*Zea mays*)

Plant Height

Table 7: Effect of Crude Oil and Pig Dung on Plant Height (Cm)

TREATMENTS	2WAP	4WAP	6WAP	8WAP
0ml/0kg	21.13 ± 0.78^{abcd}	32.23 ± 2.83^{cd}	62.60 ± 7.07^{e}	108.6 ± 16.14^{bc}
0ml/500kg	22.17 ± 2.68^{abcd}	38.23 ± 3.96^{bc}	73.20 ± 4.69^{bcde}	131.3 ± 16.06^{bc}
0ml/550kg	20.80 ± 2.07^{bcd}	38.00 ± 2.71^{bc}	72.37 ± 13.55^{bcde}	121.2 ± 18.56^{abc}
0ml/600kg	23.70 ± 5.13^{abcd}	41.57 ± 4.99^{ab}	77.00 ± 3.82^{ab}	115.2 ± 1.60^{abc}
7.5ml/0kg	21.80 ± 1.65^{abcd}	33.60 ± 6.52^{bcd}	66.90 ± 2.42^{cde}	102.1 ± 0.85^{c}
7.5ml/500kg	21.93 ± 3.19^{abcd}	38.27 ± 2.92^{bc}	73.38 ± 1.22^{bcde}	128.5 ± 9.86^{abc}
7.5ml/550kg	18.30 ± 4.66^{cd}	36.97 ± 4.29^{bc}	76.60 ± 0.62^{abc}	114.3 ± 13.36^{abc}
7.5ml/600kg	22.83 ± 4.92^{abcd}	32.93 ± 4.64^{bcd}	72.73 ± 8.17^{bcde}	107.0 ± 7.84^{bc}
15ml/0kg	24.73 ± 1.42^{ab}	48.93 ± 6.19^{a}	76.60 ± 7.66^{abc}	109.1 ± 10.63^{bc}
15m/500kg	24.47 ± 0.75^{abc}	41.83 ± 2.33^{ab}	86.30 ± 1.49^{a}	138.6 ± 10.22^{a}
15ml/550kg	23.27 ± 3.11^{abcd}	35.87 ± 4.16^{bc}	78.97 ± 5.70^{ab}	120.1 ± 24.71^{abc}
15ml/600kg	17.67 ± 2.44^{d}	26.07 ± 2.86^{d}	64.53 ± 6.93^{de}	100.5 ± 3.29^{c}
22.5ml/0kg	24.97 ± 1.96^{ab}	35.87 ± 7.56^{bc}	65.87 ± 10.71^{cde}	101.2±19.90c
22.5ml/500kg	23.83 ± 5.09^{abcd}	48.60 ± 5.37^{a}	86.60 ± 1.30^{a}	124.9 ± 6.52^{abc}
22.5ml/550kg	27.70 ± 2.79^{a}	41.63 ± 4.11^{ab}	82.00 ± 0.26^{ab}	139.1 ± 28.00^{a}
22.5ml/600kg	22.63 ± 1.10^{abcd}	39.87 ± 3.30^{bc}	74.90 ± 0.46^{abcd}	104.7 ± 3.68^{bc}

*Means with the same letters in the same column are not significantly different from one another at $p<0.05$ using Duncan's Multiple Range Test (DMRT).

Maize plant height ranged from 100.5 to 139.1 cm at the end of the experiment, i.e., 8 weeks after planting (WAP) (Table 7). Plant height decreased from 108.6 cm in the control to 101.2 cm with the application of 22.5 mL crude oil and 0 kg ha^{-1} pig dung. Udo and Fayemi (1975) reported that crude oil pollution severely impaired maize plant performance after germination. This phytotoxicity arises from the hydrophobic coating of roots by petroleum hydrocarbons, which restricts water and nutrient uptake, combined with the direct toxicity of low-molecular-weight volatile organic compounds and PAHs to root meristems (Okonokhua *et al.*, 2007). However, when soils were amended with pig dung, plant height significantly increased to 139.1 cm with an application rate of 22.5 mL crude oil and 550 kg ha^{-1} pig dung. This may be attributed to the mineralization of the added pig dung and the release of nutrients into the soil, thereby enhancing plant nutrient availability. Additionally, the organic matter in pig dung improves soil structure, aeration, and water-holding capacity, while its microbial consortium degrades phytotoxic hydrocarbons, collectively alleviating stress and promoting vigorous vegetative growth (Onwurah, 2014).

Stem Girth

Table 8: Effect of Crude Oil and Pig Dung on Stem Girth (Cm)

TREATMENTS	2WAP	4WAP	6WAP	8WAP
0ml/0kg	1.30±0^{a}	1.77±0.12^{b}	2.90±0.52^{d}	2.97±0.81^{b}
0ml/500kg	1.23±0.06^{a}	2.93±0.21^{b}	3.80±0.26^{abc}	3.57±0.29^{ab}
0ml/550kg	1.33±0.06^{a}	2.57±0.35^{b}	3.57±0.49^{bc}	3.27±0.32^{ab}
0ml/600kg	1.27±0.17^{a}	2.80±0.24^{b}	3.68±0.40^{abc}	3.67±0.26^{ab}
7.5ml/0kg	1.23±0.06^{a}	1.83±0.25^{b}	3.41±0.09^{cd}	3.33±0.49^{ab}
7.5ml/500kg	1.17±0.06^{a}	2.70±0.1^{b}	4.13±0.06^{ab}	3.70±0.17^{ab}
7.5ml/550kg	1.13±0.06^{a}	2.70±0.17^{b}	3.60±0.1^{bc}	3.53±0.15^{ab}
7.5ml/600kg	1.33±0.53^{a}	10.97±14.75^{a}	3.70±0.26^{bc}	3.49±0.06^{ab}
15ml/0kg	1.13±0.06^{a}	2.37±0.12^{b}	3.40±0.17^{cd}	3.13±0.12^{ab}
15m/500kg	1.17±0.06^{a}	3.00±0^{b}	4.40±0.46^{a}	3.83±0.51^{a}
15ml/550kg	1.23±0.12^{a}	2.77±0.21^{b}	3.83±0.38^{abc}	3.67±0.25^{ab}
15ml/600kg	1.23±0.15^{a}	2.37±0.25^{b}	3.40±0.1^{bc}	3.87±0.06^{a}
22.5ml/0kg	1.13±0.06^{a}	2.10±0.26^{b}	2.90±0.4^{d}	3.00±0.1^{b}
22.5ml/500kg	1.23±0.23^{a}	2.87±0.32^{b}	4.13±0.42^{ab}	3.73±0.75^{ab}
22.5ml/550kg	1.20±0^{a}	3.07±0.06^{b}	3.90±0.2^{abc}	3.70±0.2^{ab}
22.5ml/600kg	1.30±0.1^{a}	2.87±0.15^{b}	3.93±0.55^{abc}	3.80±0.61^{a}

*Means with the same letters in the same column are not significantly different from one another at p<0.05 using Duncan's Multiple Range Test (DMRT).

The effect of pig dung at different levels of crude oil pollution on the mean stem girth of the maize plant measured at two-week intervals is presented in Table 8, from 2 WAP to 8 WAP. From 6 WAP to 8 WAP, there was no appreciable increase in the stem girth of the maize plant. The stem girth ranged from 2.97 cm in the control to 3.83 cm in treatment 15 mL/500 kg at the end of the experiment. The *tapering* of stem girth expansion observed between 6 and 8 WAP coincides with the onset of reproductive development, during which photosynthate allocation shifts from vegetative structural tissues to ear and grain formation (Brady & Weil, 2016). The enhanced stem girth in pig dung-amended treatments relative to the control reflects improved nutrient availability, particularly potassium and calcium, which are essential for cell wall synthesis, vascular tissue development, and stem mechanical strength. Furthermore, the remediation of hydrocarbon toxicity by dung-associated microorganisms reduces physiological stress, allowing normal cambial activity and secondary thickening to proceed unimpeded (Onwurah, 2014; Agarry *et al.*, 2013). The superior performance of the 15 mL/500 kg treatment suggests that moderate crude oil contamination combined with adequate organic amendment may create a favourable balance of nutrient supply and stress alleviation that optimizes stem development.

Leaf Area

Table 9: Effect of Crude Oil and Pig Dung on Leaf Area (Cm^2)

TREATMENTS	2WAP	4WAP	6WAP	8WAP
0ml/0kg	28.47±6.34^{b}	77.56±8.07^{f}	216.4±30.81^{f}	413.4±43.47^{ab}
0ml/500kg	36.49±7.62^{ab}	116.2±31.86^{bcdef}	377.9±17.29^{abc}	427.2±50.23^{ab}
0ml/550kg	30.88±6.40^{ab}	100.5±31.58^{cdef}	328.0±93.71^{bcde}	419.6±56.11^{ab}
0ml/600kg	38.43±9.28^{ab}	141.3±21.31^{abcd}	361.9±90.46^{abcde}	438.0±46.69^{ab}
7.5ml/0kg	26.70±1.93^{b}	88.43±18.04^{ef}	293.5±39.39^{cdef}	412.9±43.69^{ab}
7.5ml/500kg	38.24±10.44^{ab}	132.1±12.76^{bcde}	369.9±25.15^{abcd}	494.1±2.83^{a}
7.5ml/550kg	30.57±5.92^{ab}	97.54±35.89^{def}	300.7±12.53^{bcdef}	459.7±55.81^{a}
7.5ml/600kg	32.64±6.24^{ab}	103.0±23.97^{cdef}	292.1±92.38^{cdef}	420.6±76.13^{ab}
15ml/0kg	33.59±4.33^{ab}	164.1±14.10^{ab}	312.4±26.62^{bcdef}	405.3±38.42^{ab}
15m/500kg	37.65±6.44^{ab}	179.7±24.38^{a}	399.6±40.43^{ab}	466.2±61.08^{a}
15ml/550kg	44.77±10.03^{a}	129.5±47.71^{bcde}	391.1±16.73^{abc}	484.3±68.98^{a}
15ml/600kg	27.75±2.97^{b}	93.02±13.65^{def}	263.0±5.86^{ef}	497.19±31.19^{a}
22.5ml/0kg	31.93±6.87^{ab}	93.49±41.99^{def}	274.5±43.03^{def}	337.4±73.47^{b}
22.5ml/500kg	44.52±13.95^{a}	150.4±26.14^{abc}	451.9±62.42^{a}	508.7±106.62^{a}
22.5ml/550kg	36.28±8.29^{ab}	124.4±14.01^{bcdef}	356.1±39.15^{abcde}	451.0±85.96^{ab}
22.5ml/600kg	34.0±8.43^{ab}	106.0±16.08^{cdef}	334.2±15.65^{bcde}	470.7±30.69^{a}

*Means with the same letters in the same column are not significantly different from one another at p<0.05 using Duncan's Multiple Range Test (DMRT).

The leaf area ranged from 337.4 to 508.7 cm² at the end of the experiment (8 WAP) as presented in Table 9. Leaf area decreased from 413.4 cm² in the control to 337.4 cm² among the treatments without pig dung application. This reduction reflects the phytotoxic effects of crude oil hydrocarbons, which impair root function, reduce water and nutrient uptake, and disrupt photosynthetic machinery through oxidative stress (Okonokhua *et al.*, 2007). However, leaf area reached its highest value of 508.7 cm² in the treatment receiving 22.5 mL crude oil and 500 kg ha^{-1} pig dung. This might be a result of the application of soil amendment, which improves soil condition as reported by Davis and Wilson (2009). Specifically, pig dung enhances soil structure, aeration, and moisture retention while supplying essential nutrients—particularly Nitrogen—that directly support leaf expansion and chlorophyll synthesis (Brady & Weil, 2016). The enlarged leaf area in amended treatments provides greater photosynthetic surface area, enabling enhanced carbon assimilation and ultimately contributing to the higher dry matter yields observed in these treatments (Table 11).

Number of Leaves

Table 10: Effect of Crude Oil and Pig Dung on the Number of Leaves

TREATMENTS	2WAP	4WAP	6WAP	8WAP
0ml/0kg	4.67±0.57^{ab}	5.33±0.58^{b}	8.00±1.00^{de}	10.00±2.00^{cd}
0ml/500kg	5.00±0^{ab}	7.33±0.58^{a}	10.00±1.00^{abc}	12.33±0.58^{ab}
0ml/550kg	4.67±0.58^{ab}	6.00±1.0^{ab}	9.33±1.15^{bcde}	11.33±0.58^{abc}
0ml/600kg	5.33±0.47^{a}	6.33±1.25^{ab}	9.33±0.94^{bcde}	11.33±0.94^{abc}
7.5ml/0kg	3.67±0.58^{c}	5.67±0.58^{b}	9.00±1.00^{cde}	10.67±0.58^{bcd}
7.5ml/500kg	4.33±0.58^{bc}	6.33±0.58^{ab}	10.33±0.58^{abc}	12.00±0^{abc}
7.5ml/550kg	4.33±0.58^{bc}	6.67±0.58^{ab}	10.67±0.58^{abc}	12.67±0.58^{ab}
7.5ml/600kg	4.67±0.58^{ab}	6.00±1.0^{ab}	9.67±1.15^{abcd}	12.33±0.58^{ab}
15ml/0kg	5.00±0^{ab}	6.67±0.58^{ab}	9.00±1.00^{cde}	11.33±0.58^{abc}
15m/500kg	5.00±0^{ab}	7.33±0.58^{a}	11.33±1.15^{a}	11.67±1.15^{abc}
15ml/550kg	5.00±0^{ab}	6.67±0.58^{ab}	11.00±0^{ab}	13.00±0^{a}
15ml/600kg	4.33±0.58^{bc}	6.00±1.00^{ab}	10.00±1.00^{abc}	10.67±1.15^{bcd}
22.5ml/0kg	4.67±0.58^{ab}	6.00±1.00^{ab}	7.67±1.15^{e}	9.33±0.58^{d}
22.5ml/500kg	4.67±0.58^{ab}	6.67±0.58^{ab}	9.67±0.58^{abcd}	11.00±1.00^{abcd}
22.5ml/550kg	5.00±0^{ab}	6.67±0.58^{ab}	10.00±1.00^{abc}	11.33±2.08^{abc}
22.5ml/600kg	4.67±0.58^{ab}	6.67±0.58^{ab}	10.67±0.58^{abc}	12.67±1.15^{ab}

*Means with the same letters in the same column are not significantly different from one another at $p<0.05$ using Duncan's Multiple Range Test (DMRT).

At the end of the experiment, the highest number of leaves recorded was 13, obtained from treatment 15 mL/550 kg. The mean number of leaves obtained from crude oil-affected soil with amendment ranged from 9.33 to 11.33 (Table 10), which were slightly lower than the control value of 10.00. Notably, the number of leaves increased when amended with pig dung. This agrees with the work of Jombo *et al.* (2012). The enhancement in leaf number following pig dung application can be attributed to improved nitrogen availability, which directly supports meristematic activity at the apical shoot and axillary buds, thereby promoting leaf primordia initiation and expansion (Brady & Weil, 2016).

Additionally, the amelioration of hydrocarbon-induced physiological stress by dung-derived organic matter and associated microorganisms restores normal phyllochron development—the rate at which successive leaves emerge—enabling the plant to approach its genetic potential for leaf production (Onwurah, 2014). The modest differences between amended treatments and the control suggest that pig dung effectively mitigates the phytotoxic effects of crude oil, restoring leaf development to levels comparable to or exceeding uncontaminated conditions. The treatment of 15 mL/550 kg likely represents an optimal nutrient balance that maximizes vegetative growth.

Dry Matter Yield

Table 11: Effect of Crude Oil and Pig Dung on Dry Matter of Maize

TREATMENTS	MEAN DRY MATTER WEIGHT (g)
0ml/0kg	20.83±2.32
0ml/500kg	21.51±2.15
0ml/550kg	22.03±4.54
0ml/600kg	22.18±5.21
7.5ml/0kg	19.35±2.35
7.5ml/500kg	21.97±3.21
7.5ml/550kg	23.14±3.12
7.5ml/600kg	22.73±2.40
15ml/0kg	16.32±4.0
15m/500kg	23.27±3.01
15ml/550kg	26.97±4.2
15ml/600kg	24.63±4.51
22.5ml/0kg	17.53±3.61
22.5ml/500kg	21.26±3.25
22.5ml/550kg	25.31±3.51
22.5ml/600kg	23.89±3.61

From Table 11, the range of mean dry matter weight for maize was 16.32-26.97 g after the termination of the experiment. It was observed that dry matter weight continued to decline with increasing levels of crude oil application in unamended soil, decreasing from 20.83 g in the control to 19.35 g (7.5 mL), 16.32 g (15 mL), and 17.53 g (22.5 mL). However, dry matter weight increased appreciably when ameliorated with pig dung. The highest value of dry matter weight (26.97 g) was recorded in treatment 15 mL/550 kg. The reduction in dry matter accumulation in polluted, unamended soils reflects hydrocarbon-induced nutrient immobilization, root dysfunction, and photosynthetic impairment, which collectively limit carbon assimilation and biomass partitioning (Udo and Fayemi, 1975; Okonokhua *et al.*, 2007). Conversely, pig dung amendment alleviates these constraints through the supply of mineralizable Nitrogen and phosphorus that support protein synthesis and energy metabolism, improved soil structure that enhances root exploration, and microbial degradation of phytotoxic hydrocarbons that reduces metabolic stress (Onwurah, 2014). The superior yield in the 15 mL/550 kg treatment indicates an optimal balance between hydrocarbon loading and amendment rate, wherein nutrient supplementation and toxicity mitigation are maximized**.**

Effect of Crude Oil and Pig Dung on the Nutrient Uptake of Maize (*Zea mays*)

Table 12: Nutrient Uptake of Maize (mg)

TREATMENTS	N	P	K	Ca	Mg	Na
0ml/0kg	16.25±4.52	72.91±5.68	11.04±2.35	8.33±3.10	6.87±1.54	4.17±0.89
0ml/500kg	18.95±3.51	80.02±9.21	13.77±4.51	9.03±2.54	7.31±2.01	4.73±0.41
0ml/550kg	13.95±3.51	82.83±9.64	15.64±3.98	9.91±3.01	7.49±1.65	5.51±1.03
0ml/600kg	21.74±4.57	84.73±8.59	16.64±4.54	10.20±3.25	8.43±2.64	6.65±1.54
7.5ml/0kg	10.64±2.84	58.05±8.57	6.77±2.1	6.19±1.58	4.64±1.56	2.90±0.56
7.5ml/500kg	17.34±3.01	96.58±10.02	12.29±2.68	9.44±2.01	7.02±2.1	4.61±1.07
7.5ml/550kg	19.21±2.98	107.37±18.23	15.04±2.98	11.11±3.85	8.01±2.51	6.02±1.32
7.5ml/600kg	19.55±3.60	113.65±15.10	16.37±5.41	11.82±4.01	8.01±2.01	6.02±1.25
15ml/0kg	8.16±1.51	43.25±6.98	5.06±2.12	4.89±1.02	3.26±0.58	1.95±0.45
15m/500kg	15.82±3.67	89.02±7.52	13.49±3.89	7.44±1.89	5.12±1.24	3.49±0.59
15ml/550kg	20.49±2.98	107.88±11.51	15.64±4.56	11.06±3.05	5.93±1.04	5.93±1.00
15ml/600kg	19.70±2.57	110.84±16.25	17.24±3.16	12.32±3.64	7.88±2.36	6.16±1.56
22.5ml/0kg	8.41±1.85	43.83±5.63	5.26±1.08	3.86±1.20	3.16±0.12	1.75±0.02
22.5ml/500kg	12.76±2.21	81.00±8.56	11.91±3.45	7.44±1.98	5.32±0.59	2.98±1.06
22.5ml/550kg	18.22±3.03	91.62±9.01	15.19±5.12	9.62±2.01	7.85±1.56	5.82±1.23
22.5ml/600kg	16.25±3.10	101.53±8.31	17.20±2.89	10.75±2.24	8.36±1.23	5.97±2.30

Results from the analysis of plant samples (Table 12) indicate that sodium (Na) uptake by maize was the lowest (1.75 mg) while phosphorus (P) uptake was the highest (113.65 mg). Treatment 0 mL/600 kg exhibited the highest uptake of Nitrogen (N), potassium (K), and sodium (Na), whereas treatment 7.5 mL/600 kg recorded the highest uptake of

phosphorus (P), calcium (Ca), and magnesium (Mg). The lowest levels of nutrient uptake were observed in treatment 22.5 mL/0 kg, as shown in Table 12. The results of the experiment demonstrate that increasing the amount of pig dung amendment enhances plant nutrient uptake. This enhanced uptake reflects the combined effects of increased nutrient availability from mineralized dung and the amelioration of hydrocarbon toxicity, which restores root function and membrane integrity necessary for active ion transport (Udo & Fayemi, 1975). Phosphorus uptake was particularly responsive, likely due to organic acid production during dung decomposition that solubilizes native soil phosphorus and the direct phosphorus contribution of the amendment (Brady & Weil, 2016). The reduced nutrient acquisition in unamended, highly polluted treatments (22.5 mL/0 kg) confirms that crude oil hydrocarbons impair root absorption by physically coating root surfaces and disrupting metabolic processes governing ion uptake (Okonokhua et al., 2007).

Table 13: Physical and Chemical Properties of Soil after Harvest

Treatment	pH	T.N (g/kg)	THC (mg/kg)	Org.C (g/kg)	Av.P (mg/kg)	K	Ca	Mg	Na cMol/kg	EA	CEC	ECEC	Sand g/kg	Silt g/kg	Clay g/kg	Microbial count (cfu/g)
0ml/0kg	6.1±0.1	1.12±0.15	1.62±0.25	9.06±1.25	5.50±1.02	0.35±0.04	0.63±0.21	0.28±0.08	0.15±0.04	0.23±0.08	1.62±0.21	1.64±0.45	886±2	53±4	61±5	4.22±0.74x10^6
0ml/500kg	6.4±0.2	1.18±0.09	2.44±0.54	18.3±3.12	5.08±1.01	0.35±0.08	0.70±0.32	0.32±0.05	0.12±0.08	0.13±0.04	1.59±0.42	1.62±0.51	884±3	56±3	60±2	5.32±0.41x10^6
0ml/550kg	6.1±0.11	1.20±0.98	2.51±0.05	18.0±2.15	4.84±0.56	0.30±0.07	0.93±0.35	0.31±0.09	0.14±0.09	0.16±0.07	1.80±0.34	1.84±0.47	884±3	64±3	52±4	5.54±0.61x10^6
0ml/600kg	6.4±0.1	1.19±0.15	3.00±1.01	15.6±2.01	4.73±0.85	0.31±0.05	1.20±0.54	0.35±0.07	0.12±0.05	0.12±0.08	2.10±0.35	2.10±0.51	882±2	68±6	50±1	6.43±0.45x10^6
7.5ml/0kg	6.1±0.1	0.91±0.15	52.4±5.40	20.5±2.42	8.31±1.21	0.30±0.09	0.72±0.21	0.24±0.09	0.10±0.06	0.12±0.05	1.46±0.32	1.56±0.52	878±4	52±5	70±3	4.00±0.65x10^6
7.5ml/500kg	6.2±0.2	1.00±0.05	62.7±5.65	20.1±2.56	6.82±0.87	0.31±0.10	0.83±0.21	0.27±0.04	0.140±.08	0.12±0.05	1.65±0.14	1.67±0.23	882±3	60±3	58±2	5.40±0.12x10^6
7.5ml/550kg	6.1±0.11	1.00±0.08	60.8±4.29	17.2±2.01	6.70±0.62	0.28±0.01	0.80±0.34	0.25±0.06	0.13±0.07	0.15±0.07	1.58±0.23	1.61±0.43	886±2	63±3	59±1	5.62±0.36x10^6
7.5ml/600kg	6.0±0.2	1.02±0.10	60.2±3.24	14.7±2.14	6.47±0.45	0.26±0.03	0.70±0.18	0.25±0.05	0.120±.05	0.13±0.07	1.44±0.21	1.46±0.51	870±2	60±3	70±3	6.33±0.35x10^6
15ml/0kg	6.0±0.0	0.94±0.07	50.0±4.51	20.0±1.89	10.3±1.20	0.25±0.03	0.65±0.25	0.25	0.14±0.02	0.13±0.05	1.39±0.12	1.42±0.32	890±3	60±3	50±4	3.10±0.52x10^6
15m/500kg	6.0±0	1.03±0.02	56.4±5.82	13.4±3.57	6.80±1.01	0.28±0.01	0.71±0.22	0.24±0.04	0.12±0.04	0.13±0.05	1.46±0.54	1.48±0.41	887±5	60±2	48±3	4.56±0.54x10^6
15ml/550kg	6.1±0.15	1.16±0.15	50.2±3.54	12.5±3.45	5.45±0.64	0.32±0.01	0.70±0.31	0.31±0.10	0.14±0.08	0.12±0.06	1.57±0.51	1.59±0.26	888±4	63±1	75±4	4.66±0.25x10^6
15ml/600kg	6.2±0.11	1.24±0.11	48.5±6.02	10.3±1.23	5.20±0.57	0.32±0.05	0.73±0.19	0.28±0.11	0.13±0.06	0.17±0.08	1.60±0.28	1.63±0.36	887±3	62±4	51±2	4.54±0.54x10^6
22.5ml/0kg	6.4±0.22	1.00±0.32	46.0±3.01	10.6±1.44	14.5±0.68	0.30±0.01	0.80±0.17	0.35±0.14	0.15±0.07	0.20±0.12	1.80±0.32	1.80±0.56	886±3	55±7	59±4	3.20±0.87x10^6
22.5ml/500kg	6.2±0.11	1.15±0.12	45.2±2.48	10.0±2.54	6.76±0.75	0.32±0.04	0.67±0.09	0.31±0.08	0.13±0.08	0.13±0.09	1.56±0.23	1.56±0.36	884±3	50±5	66±3	2.52±0.65x10^6
22.5ml/550kg	6.2±0.33	1.21±005	42.4±2.65	8.96±1.62	6.42±0.54	0.33±0.05	0.71±0.31	0.30±0.07	0.10±0.02	0.15±0.07	1.57±0.55	1.59±0.25	868±2	54±3	78±5	2.36±0.58x10^6
22.5ml/600kg	6.2±0.11	1.28±0.09	40.6±3.12	8.80±1.56	6.33±1.54	0.30±0.01	0.70±0.18	0.30±0.09	0.12±0.04	0.14±0.07	1.54±0.09	1.56±0.44	869±6	50±3	81±3	2.28±0.42x10^6

Table 13 presents post-harvest soil physicochemical properties across all crude oil and pig dung treatment combinations. Soil pH increased across treatments relative to pre-planting values, ranging from 6.0 to 6.4, reflecting the buffering capacity of pig dung organic matter through the release of basic cations during mineralization (Brady and Weil, 2016). Total hydrocarbon content decreased substantially in polluted treatments, with the greatest reductions (40.6–42.4 mg/kg) occurring in the 22.5 mL oil treatments amended with 550–600 kg/ha pig dung, confirming enhanced microbial hydrocarbon degradation (Onwurah, 2014). Organic carbon declined markedly in amended treatments, reflecting the microbial mineralisation of both dung-derived organic matter and petroleum hydrocarbons. Total Nitrogen ranged from 0.91 to 1.28 g/kg, with amended treatments exhibiting higher values due to nitrogen release from decomposing dung. Exchangeable bases and cation exchange capacity improved modestly in amended treatments. Microbial counts declined post-harvest, particularly in treatments achieving the greatest THC removal, reflecting substrate depletion following intense biodegradation (Margesin *et al.*, 2000). Particle size distribution remained stable across treatments.

At the highest crude oil contamination level (22.5 mL/15 kg soil), pig dung amendment at 550 and 600 kg/ha achieved 63.3% and 67.6% THC reduction, respectively. These values are comparable to bioremediation efficiencies documented for poultry manure (53–67%; Agarry *et al.*, 2013), cow dung (45–60%; Onwurah, 2014), and goat manure (48–62%; Nwogu *et al.*, 2015) under similar experimental conditions. The post-harvest THC concentrations in the optimal treatments (40.6–42.4 mg/kg) approached the Nigerian Department of Petroleum Resources (DPR, 2018) intervention guideline of 50 mg/kg for agricultural soils, indicating that substantial remediation can be achieved within a single growing season.

Table 14: Total Hydrocarbon Reduction and Microbial Population Dynamics over 8 Weeks

Treatment (Oil/Dung)	Pre-plant THC (mg/kg)	Post-harvest THC (mg/kg)	THC Reduction (%)	Pre-plant Microbial Count (cfu/g)	Post-harvest Microbial Count (cfu/g)
0 ml / 0 kg	2.10 ± 0.21	1.62 ± 0.25	22.9	5.70×10^6	4.22×10^6
0 ml / 500 kg	4.23 ± 0.59	2.44 ± 0.54	42.3	8.20×10^6	5.32×10^6
0 ml / 550 kg	4.30 ± 1.01	2.51 ± 0.05	41.6	10.50×10^6	5.54×10^6
0 ml / 600 kg	5.40 ± 2.10	3.00 ± 1.01	44.4	13.20×10^6	6.43×10^6
7.5 ml / 0 kg	65.7 ± 6.35	52.4 ± 5.40	20.2	5.00×10^6	4.00×10^6
7.5 ml / 500 kg	74.2 ± 7.52	62.7 ± 5.65	15.5	7.43×10^6	5.40×10^6
7.5 ml / 550 kg	75.4 ± 5.20	60.8 ± 4.29	19.4	7.82×10^6	5.62×10^6
7.5 ml / 600 kg	80.7 ± 9.59	60.2 ± 3.24	25.4	10.10×10^6	6.33×10^6
15 ml / 0 kg	78.6 ± 8.25	50.0 ± 4.51	36.3	5.00×10^6	3.10×10^6
15 ml / 500 kg	83.5 ± 10.01	56.4 ± 5.82	32.4	8.38×10^6	4.56×10^6
15 ml / 550 kg	86.8 ± 11.95	50.2 ± 3.54	42.1	9.40×10^6	4.66×10^6
15 ml / 600 kg	90.7 ± 13.23	48.5 ± 6.02	46.5	11.56×10^6	4.54×10^6
22.5 ml / 0 kg	86.5 ± 11.2	46.0 ± 3.01	46.8	4.34×10^6	3.20×10^6
22.5 ml / 500 kg	90.3 ± 9.02	45.2 ± 2.48	49.9	8.54×10^6	2.52×10^6
22.5 ml / 550 kg	115.6 ± 12.21	42.4 ± 2.65	63.3	10.00×10^6	2.36×10^6
22.5 ml / 600 kg	125.4 ± 15.2	40.6 ± 3.12	67.6	12.50×10^6	2.28×10^6

Relationship Between Microbial Populations and Hydrocarbon Degradation

A strong positive correlation was observed between pre-planting microbial counts and the percentage THC reduction in crude oil-contaminated soils ($r = 0.82$, $p < 0.01$). Pig dung contributed a substantial microbial inoculum (12.50×10^6 cfu/g) and supplied readily available nitrogen (2.11 g/kg) and phosphorus (10.5 mg/kg), which corrected the carbon-nitrogen-phosphorus stoichiometric imbalance inherent to petroleum hydrocarbons (Atlas and Bartha, 1998). This nutrient enrichment supports the proliferation of hydrocarbon-degrading bacteria and fungi during the initial weeks of remediation.

Microbial counts declined in all treatments from pre-planting to post-harvest (Table 14). This decline is consistent with established microbial succession patterns during bioremediation: as labile hydrocarbon fractions are exhausted and potentially toxic intermediate metabolites accumulate, microbial populations undergo endogenous decay and community restructuring (Margesin *et al*., 2000; Kaplan & Kitts, 2004). The largest relative declines in culturable counts occurred in treatments exhibiting the greatest THC removal (e.g., –81.8% in 22.5 mL/600 kg), reflecting intense prior metabolic activity and subsequent substrate depletion (Alexander, 1999).

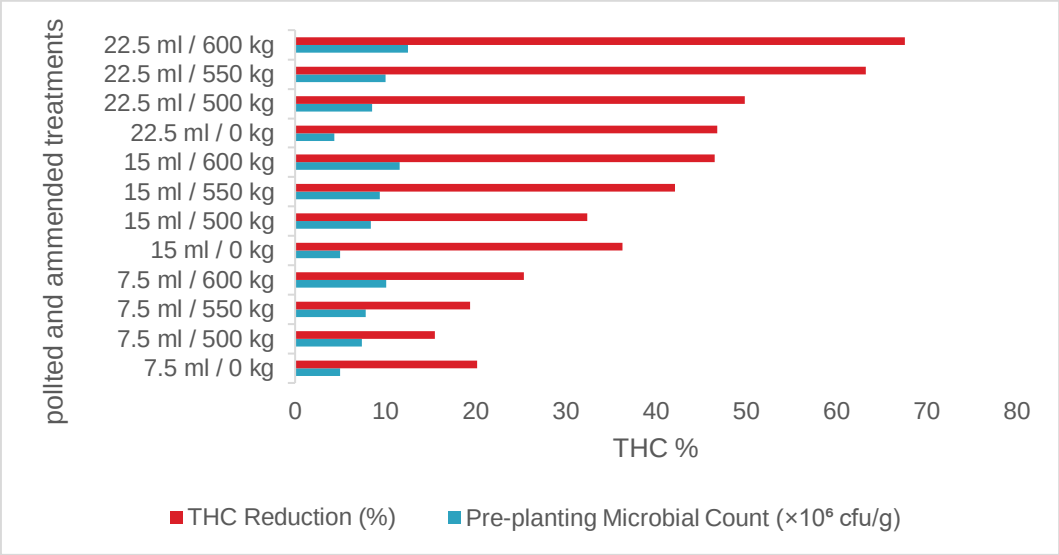

Figure 1. Correlation of THC reduction and Microbial activity

Strong positive correlation ($r = 0.82$, $p < 0.01$) between pre-planting microbial populations and THC reduction confirms that pig dung enhanced biodegradation through microbial inoculation and nutrient supplementation (Atlas and Bartha, 1998). Post-harvest microbial declines reflect substrate depletion following intense hydrocarbon degradation, consistent with established bioremediation succession patterns (Margesin et al., 2000).

Conclusion and Recommendation

Conclusion

This study established that pig dung is an effective organic amendment for the bioremediation of crude oil-contaminated agricultural soils and the restoration of maize productivity. Crude oil pollution adversely altered soil chemical properties, depleted essential nutrients, suppressed microbial populations, and impaired maize growth parameters. Pig dung application ameliorated these effects by improving soil pH, replenishing exchangeable bases, supplying mineralizable Nitrogen and phosphorus, and introducing a robust hydrocarbon-degrading microbial consortium. The substantial reduction in total hydrocarbon content observed in amended treatments confirmed enhanced biodegradation, with optimal remediation achieved at application rates of 550–600 kg/ha. Maize growth parameters—including plant height, stem girth, leaf area, leaf number, and dry matter yield—were restored to levels comparable to or exceeding the uncontaminated control, while nutrient uptake was significantly improved. These findings demonstrate that pig dung offers a cost-effective, locally available biostimulant capable of achieving meaningful soil restoration and crop recovery within a single growing season, supporting its practical application in petroleum-impacted agricultural regions.

Recommendation

Further studies should be conducted using different crude oil types and higher pollution levels to establish optimal pig dung application rates across varying contamination scenarios. Experiments should be extended to other economically important crops, including legumes, vegetables, and root crops, to evaluate species-specific responses to amended contaminated soils. Comprehensive economic analyses are needed to assess the cost-benefit ratio of pig dung compared to other remediation strategies, such as inorganic fertilizers, poultry manure, and cow dung. The use of pig dung also offers ancillary benefits, including reduced challenges with agricultural waste disposal in pig-rearing communities and the potential integration of soil remediation with sustainable livestock waste management. Finally, long-term field trials are recommended to evaluate residual effects on soil health, microbial community stability, and crop productivity over multiple growing seasons.

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