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Research Article

Effect of Crude Oil Contaminated Soil on the Growth, Development and Nutritional Composition of Maize (*Zea mays L.*,)

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ABSTRACT

Petroleum hydrocarbon contamination remains a major environmental challenge because of the release of toxic by-products that affect soil quality and plant growth. This study assessed the effect of crude oil on the growth, development, and nutritional composition of maize (Zea mays L.) with a view to evaluating its toxicity. Soil samples were collected, characterized using FTIR, and contaminated with crude oil at varying v/w levels. Maize seeds were planted in pots and monitored for 12 weeks. Two groups were established: an uncontaminated control (20 replicates) and contaminated soils (20 replicates). Key growth parameters, including germination rate, plant height, chlorophyll content, and yield, were monitored, alongside macronutrient and micronutrient composition. Results showed that contaminated soils caused a significant reduction in nutrient availability and uptake compared to controls. During the germination phase (weeks 1–3), there was no significant difference ($p>0.05$) in plant height, girth, leaf area, and stem diameter. However, as the plants advanced into the vegetative phase, a significant decline ($p<0.05$) in these parameters was observed in the contaminated group. FTIR analysis further revealed distinct changes in functional groups and hydrocarbon compound presence in contaminated soils, confirming crude oil's interference with soil chemistry. Overall, the findings indicate that crude oil pollution hampers maize growth, development, and nutritional quality, largely through nutrient depletion and structural alterations in the soil. The study underscores the need for effective remediation strategies to restore soil fertility and sustain agricultural productivity in crude oil-polluted environments.

Keywords: Contamination; Hydrocarbon; Nutritional composition; Oil pollution; *Zea mays*

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INTRODUCTION

Oil pollution in the environment has become a significant concern for residents in areas rich in crude oil (Ohanmu *et al*, 2018). Severe crude oil pollution can lead to destruction of marsh vegetation (Pezeshki *et al*., 2015).

Pollution is defined as the persistent appearance of radioactive elements, toxic compounds, salts, chemicals, or disease causing-gents which have an adverse effect on the environment, this in turn impacts the quality of human life, reduce plant productivity, threatens the survivals of animals and disrupts microbial populations. The contamination of both terrestrial and aquatic environments by crude oil is known as crude oil pollution, with an estimated 80% of such pollution resulting from oil spills (Ohanmu *et al.,* 2018).

Crude oil is a complex mixture of hydrocarbons primarily made of aliphatic, alicyclic and aromatic hydrocarbons. It also contains trace amounts of other chemical compounds like nitrogen, oxygen or sulphur, as well as elements such as iron, nickel, copper and palladium (James, 1999). The composition of crude oil varies, with differing proportions of each type of hydrocarbon

depending on its origin. The types of petroleum hydrocarbon present determine the distribution of hydrocarbons in different types of crude oil (Norman, 2001). The chemical and physical characteristics of permeability are subject to variation depending on its origin (Norman, 2001). The paraffins are the most sought-after components in crude oil, primarily used for fuel production. They constitute approximately 15% to 60% of crude oil. Generally, the shorter the paraffin chains, the lighter the quality of the crude oil. Napthenes have a higher density viscosity than equivalent paraffins, and they constitute 30% to 60% of crude oil. Aromatics make up 3% to 30% of crude oil and are considered undesirable because their combustion produces soot. Aliphatics, generally unwanted in crude oil, are valued for their stickiness, making them ideal for road construction (Ante, 2009). The presence of these hydrocarbons from crude oil in soil leads to the accumulation of heavy metals and other hydrocarbon compounds, which decrease soil fertility, increase toxicity to plants, and ultimately reduce crop yield (Ekpo *et al*., 2012).

In Nigeria, crude oil exploration is the backbone of the economy, accounting for approximately 90% of the country's foreign exchange earnings (Amadi *et al*., 2000). Oil plays a crucial role in shaping the global economic and political landscape. The Petroleum industry has brought economic prosperity to Nigeria, but it has also led to environmental and socio - economic challenges (Ekpo *et al.*, 2012). Crude oil which is abundantly located in the Niger Delta region of Nigeria is spilled on soil due to pipeline destruction (Ewetola, 2013) and is usually transported in large quantities for refining and the production of its by-products. The transportation methods used include oceanic tankers and overland pipelines. However, these methods can sometimes result in environmental pollution through accidental oil spills and operational discharge, causing significant amounts of crude oil to be lost into both land and water bodies. The discharge of crude oil onto land alters the physicochemical properties of the soil, leading to harmful effects on plant germination and growth (Ekpo *et al.*, 2012), additionally, the accumulation of essential elements (such as carbon, Phosphorus, Calcium, Magnesium) and non-essential elements (Maganese, lead, Zinc, Iron, Cobalt and Copper) in the soil which can then be translocated into plant tissues (Vwioko *et al*., 2006).

Crude oil exploration leads to environmental pollution, affecting rivers and streams. Exposure to crude oil poses a significant threat to both aquatic and terrestrial species, creating potential hazards to their health and survival (Shore & Douben, 2001). While some heavy metals are essential micronutrients for plants at low concentrations, high concentrations lead to metabolic disorders and negatively affect plant health (Fernandes & Henriques, 1991). Ingesting food contaminated with petroleum hydrocarbon (PHC) can lead to liver enlargement, growth suppression and histological changes in tissues (Onwurah & Eze, 2000). During the oxidation of petroleum hydrocarbons, carbon-containing compounds are typically converted into free radicals or activated metabolites in the cell. These activated metabolites react with cellular components, such as membrane lipids leading to the production of lipid peroxidation products, which can damage the membrane (Odo *et al*., 2012). Crude oil being a toxic substance, its accumulation in the body can induce harmful symptoms that may, in some cases, lead to death (Heintz *et al*., 1999).

MATERIALS AND METHODS

Chemicals / Reagents

All the chemicals and reagents used were of analytical grade and obtained from Merck, Germany; May and Baker Ltd, England; Riedel-De-Haen Hannover, Randox kit, Germany and Hopkins and Williams Essex, England.

Maize Seed

Maize (*Zea mays*) seed was purchased from Dutsin-Ma Central Market, Katsina State and was authenticated by a botanist (voucher number HERB/FUDMA/PSB/00018) in the Department of Plant Science and Biotechnology, Federal University Dutsin-Ma, Nigeria.

Crude Oil

Crude oil was obtained from the Ebedei terminal well 8 of Platform Petroleum Limited Company, Delta State. A class A oil, light and volatile.

Study Area

Dutsin-Ma is located in the northern part of Nigeria, Katsina State (Northwest) region. Dutsin-Ma has latitude of $12^{0}27'16.13''N$ and a longitude of $7^{0}29'51.55''E$. Dutsin-Ma, Nigeria coordinates are near the Niger border: 101.6 kilometers SSE of Madarounfa, Maradi, Niger.

Soil Preparation

Sandy loam soil was collected and weighed from the school yard of the Department of Agricultural Sciences of Federal University Dutsin-Ma Katsina State. Forty (40) plant pots of the 8 kg category were used. Other materials used include crude oil, a cylinder and a beaker for measurements.

Soil Treatment

The experiment involves 2 different groups consisting of forty (40) planting pots. Twenty (20) planting pots in each group containing Loam soil. The control group (A) is the control and contains absolutely no amount of

crude oil. It was left under normal conditions of temperature, sunlight and water. Group B: a test group that contains (20) different planting pots, but with the soil treated with 80 ml of crude oil before planting. The Soil was allowed to stay 7days before planting.

Data Collection Procedure

Plant Height: Plant heights were measured weekly starting from two weeks after planting. The plants were randomly tagged in each experiment until their heights were measured from ground level to tip of the terminal, bud, using a meter rule. The data that was obtained from the measurement were computed and the height of plant for each treatment was determined and recorded.

Leaf Area: Leaf length and leaf area index was taken every week after planting with a meter rule.

Plant Girth: Stem circumference was taken every week after planting, and this was done using a thread and meter rule.

Stem Diameter: Stem circumference was taken every week after planting, and this was done using a Vernier Callipers.

Germination rate: The germination rate was calculated for each group a week after planting.

$$\text{Germination rate} = \frac{\text{Number of germinated seeds}}{\text{total number of seeds planted}} \times 100$$

Soil Analysis before Planting

Soil Electrical Conductivity Measurement

Procedures:

About 20 g of air-dried soil was weighed into a 250ml capacity polyethylene bottle. 100 mL of deionized/distilled water (1:5, w/v) was added to the container, covered with bottle caps and placed horizontally on the reciprocating shaker and shaken at 180 oscillations for 60 minutes/min after shaking, it was taken out from the shaker and allowed to stand for 30 minutes. The conductivity cell was immersed in the supernatant without disturbing the sediment. The measured value was determined in a stable state. The electrode was rinsed thoroughly with deionized/distilled water and blot up excess water. EC was reported as (dS m-1) at 25°C (USDA-ARS 2007).

Hydraulic Conductivity Measurements

Procedure: Soil samples (17 cm height) were placed in a permeameter, saturated from the bottom up with water. Four samples with similar characteristics were tested. Hydraulic conductivity (K) was calculated using the formula: $K = 2.3\ L\ (\lg H_o / (H_o - h_i)) / t_i$ Where L is sample height, H_o is the Kamenski tube's free surface, h_i is the tank's free water surface, and t_i is time (Kamenski, 1994).

Soil Cation Exchange Capacity (CEC)

Procedure: 25.0 g soil was mixed with 125 mL 1 M NH_4OAc, shaken, and left overnight. Soil was filtered through a 5.5 cm Buchner funnel, washed with 25 mL NH_4OAc (4x), then leached with 25 mL 1 M KCl (8x). Leachate was diluted to 250 mL with KCl, and NH_4-N concentration was determined by distillation, correcting for blank contamination (EPA, 2011). **Calculations**: CEC (cmolc/kg) = (NH_4-N_extract - NH_4-N_blank) / 14 (if NH_4-N in mg N/L) CEC (cmolc/kg) = (NH_4-N_extract - NH_4-N_blank) / 18 (if NH_4-N in mg NH_4/L)

Soil Nitrogen Determination

Procedure: 20 mL H_3BO_3 was placed in an Erlenmeyer flask under a condenser. A distillation unit with 20 mL water and 20 mL NaOH distilled ~100 mL condensate at ≤25 mL/min, keeping distillate <22°C. The distillate was titrated with 0.01 M H_2SO_4 after adding indicator. Blank distillations (3x) ensured H_2SO_4 use was 0.05–0.30 mL, adjusting H_3BO_3 pH if needed (EPA, 2011).

Soil Phosphorus Determination

Procedure: 5 g dried soil, blanks, and quality control materials (QCMs) were shaken with 100 mL extracting solution and 0.5 g phosphate-free charcoal for 30 min. Filtered extracts (3 mL) were mixed with 3 mL reagent, vortexed, and left for 1 hour to develop blue color (EPA, 2011).

Soil Calcium Determination

Procedure: A standard calcium solution was titrated with EDTA after adding Eriochrome Black T indicator. Multiple titrations determined average EDTA volume, used to calculate calcium concentration (EPA, 2011).

Soil Potassium Determination

Procedure: Air-dried, sieved soil was shaken with 1N NH_4OAc (pH 7) for 30 min, filtered, and analyzed via flame photometry. Potassium emission at 768 nm was compared to a calibration curve to calculate concentration (EPA, 2011).

Soil Magnesium Determination

Procedure: A standard magnesium solution was titrated with EDTA using Eriochrome Black T or Calcein indicator. Average EDTA volume from multiple titrations was used to calculate magnesium concentration (EPA, 2011).

Soil Micronutrients (Mn, Zn, Cu, Fe)

Procedure: 5 g air-dried, sieved soil was mixed with 20 mL extracting solution (0.05N HCl + 0.025N H_2SO_4), stirred for 20 min, filtered, and diluted to 50 mL. A blank was prepared with acid only (EPA, 2011).

Soil pH

Procedure: 10 g sieved soil was mixed with 25 mL distilled water, stirred, and left for 30 min. pH was measured after calibrating the meter with buffers (4, 7, 9). Repeated with 0.01M $CaCl_2$ and 1N KCl (Hendershot, 1993).

Soil Water Holding Capacity (WHC)

Procedure: Sieved soil was weighed (W_2), flooded in a perforated container, drained overnight, and reweighed (W_3). WHC was calculated as %WHC = [(W_3 - W_2) / (W_2 - W_1)] × 100, where W_1 is the empty container weight (Bouyoucos, 1951).

Organic Matter Content

Procedure: 1 g soil was mixed with 5 mL 1N $K_2Cr_2O_7$ and 10 mL H_2SO_4, swirled, and left for 30 min. 10 mL H_3PO_4 and 1 mL diphenylamine indicator were added, then titrated with 0.5N ferrous ammonium sulphate until color changed. **Calculations**: %Organic Carbon (OC) = [(Blank titre – Actual titre) × 0.003 × m × 1.33 × 100] / W %Organic Matter (OM) = %OC × 1.724 (Bouyoucos, 1951).

Soil Texture

Procedure: 50 g sieved soil was mixed with 100 mL Calgon, shaken, and decanted into a 1L cylinder with water. Hydrometer readings were taken at 40 s, 2 h, 8 h, and 24 h. Sand was sieved, dried, and weighed. **Calculations**: C = R – R_L + (0.36 × T) %Clay = [(Corrected 2h reading – Blank) × 100] / W %Silt = [(Corrected 40s reading – Blank) × 100 / W] – %Clay %Sand = 100 – (%Clay + %Silt) (Bouyoucos, 1951).

Fourier Transform Infrared Spectroscopy (FTIR)

Procedure: Soil was placed in a sample holder, and a background measurement was taken. Infrared radiation (4000–400 cm^{-1}) passed through the sample, producing a spectrum. Software analyzed peaks to identify chemical bonds and composition by comparing them to a database (NIST, 1995).

RESULTS

Micronutrient

In the Fe, Mn, Cu, Zn, the contaminated group decrease significantly (P<0.05) compared to the control group (Table 1).

Macronutrient

In the Ca, Mg, N and P shows a significant difference (P<0.05) however, in K there was no significant difference (Table 2).

Soil Texture

In the contaminated group, Silt and sand shows a significant increase (P<0.05) compared to control group, however clay significantly decreased (P<0.05) compared to the control group (Table 3).

Electrical Conductivity

In the electrical conductivity, the control group shows a significant increase (p<0.05) compared to the contaminated group (Figure 1).

Soil Salinity

There was significant increase in the contaminated group (p<0.05) compared to the control group (figure 2)

Cation Exchange Capacity

Soil Cation 1 Exchange Capacity (CEC) shows that contaminated group caused a significant decrease (p<0.05) in cation exchange capacity as compared to the control group (Figure 3).

Hydraulic Conductivity

There was significant decrease in the contaminated group as compared to the control group (Figure 4).

Table 1: Effects of Crude Oil Contamination on Soil Micronutrients

Groups	Fe(ppm)	Mn(ppm)	Cu(ppm)	Zn(ppm)
Control	12.07±0.001^b	0.54±0.0004^b	0.059±0.0005^b	0.443±0.0006^b
Crude oil	3.73±0.001^a	0.12±0.0128^a	0.029±0.0006^a	0.059±0.0005^a

Mean±SEM values with different superscript(s) alphabet within a Column, differ significantly at (P<0.05).

Table 2: Effects of Crude Oil on Soil Macronutrients

Groups	Ca(ppm)	Mg(ppm)	N(kg/100)	K(ppm)	P(ppm)
Control	0.95±0.006^a	10.112±0.0001^a	1.88±0.001^b	1.86±0.009^b	0.182±0.001^a
Crude oil	0.73±0.006^b	0.012±0.0001^b	1.33±0.001^a	1.62±0.009^b	0.164±0.005^b

Within Column, mean±SEM with different superscript(s) differ significantly at (P<0.05).

Table 3: Effects of Crude Oil Contaminated Soil on Soil Texture

Groups	Silt (%)	Clay (%)	Sand (%)
Control	6.10±0.006^a	3.60±0.006^b	88.80±0.005^a
Crude oil	7.60±0.006^b	3.40±0.006^a	90.40±0.005^b

Within Column, mean±SEM with different superscript(s) differ significantly at (P<0.05).

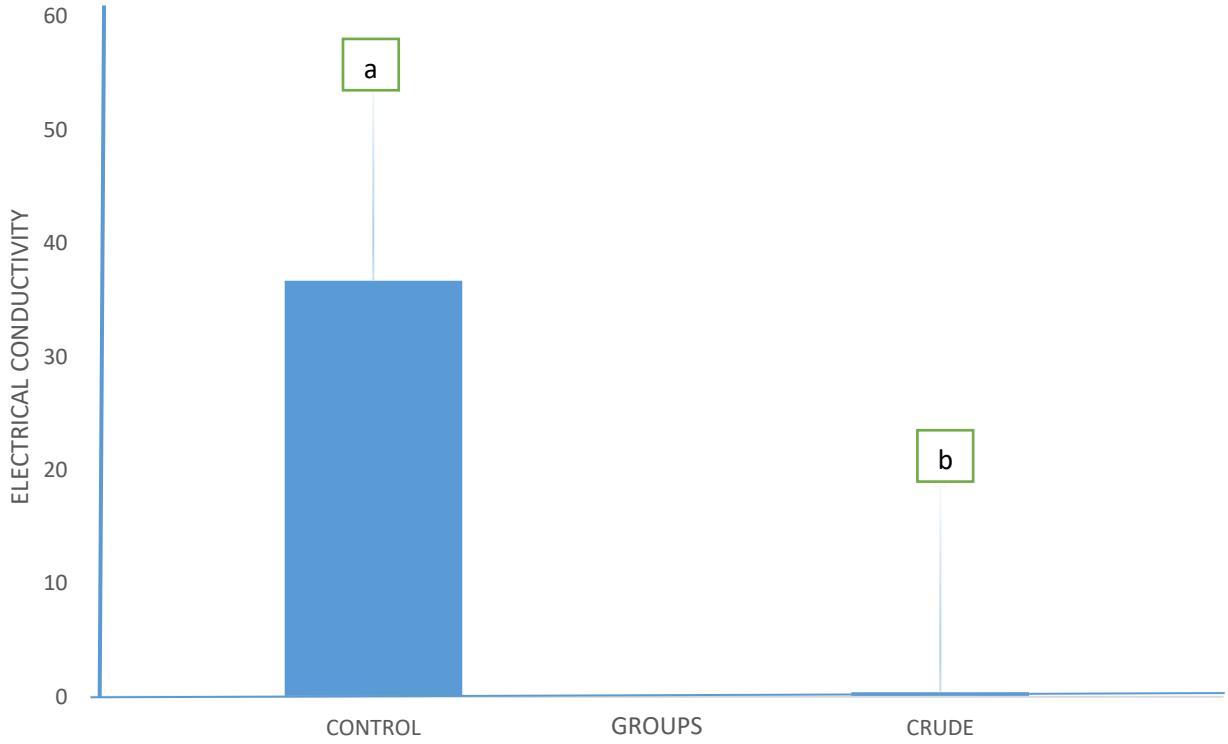

Figure 1. Effect of Crude oil on Electrical Conductivity in contaminated soil
Results are expressed as mean±SD (n=4). P<0.05 (Control vs Contaminated group)

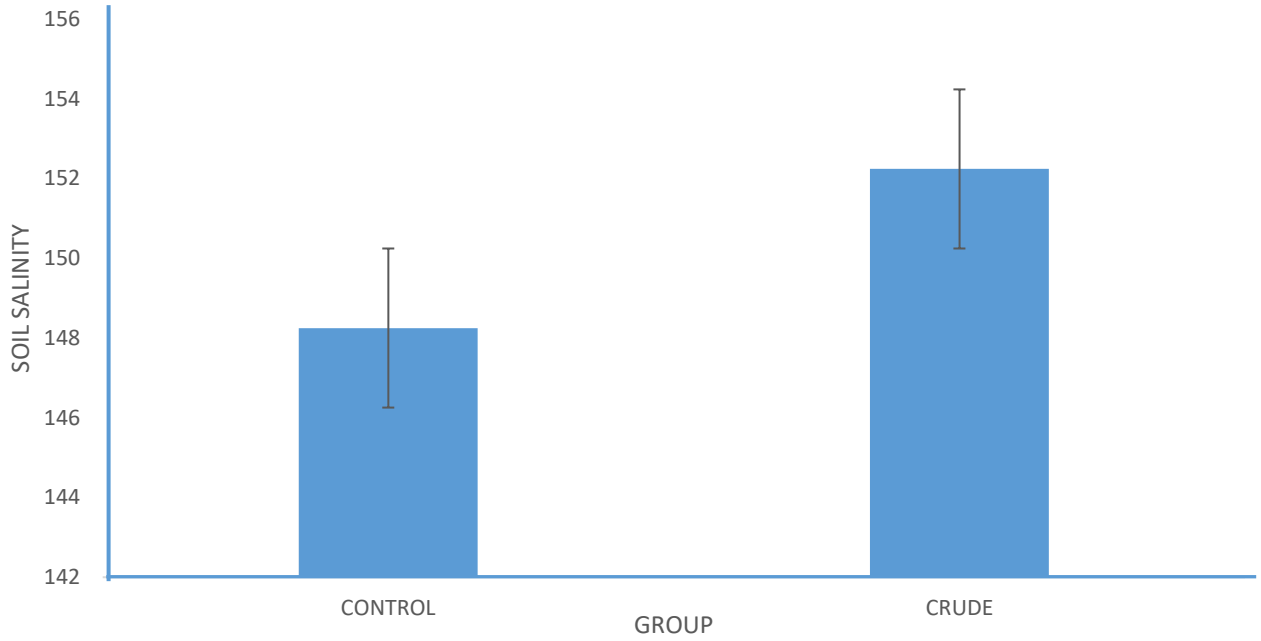

Figure 2. Effect of Crude oil on Soil Salinity in contaminated soil
Results are expressed as mean±SD (n=4). P<0.05 (Control vs Contaminated group)

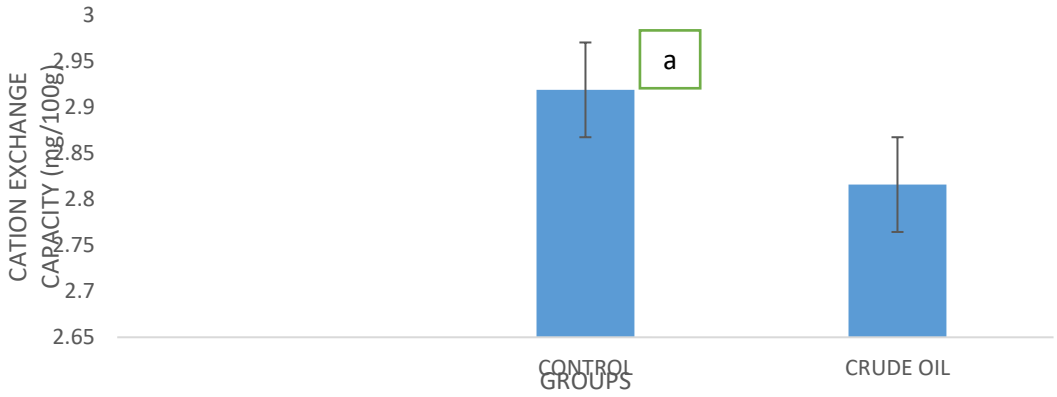

Figure 3. Effect of Crude oil on Cation Exchange Capacity in contaminated soil
Results are expressed as mean±SD (n=4). P<0.05 (Control vs Contaminated group).

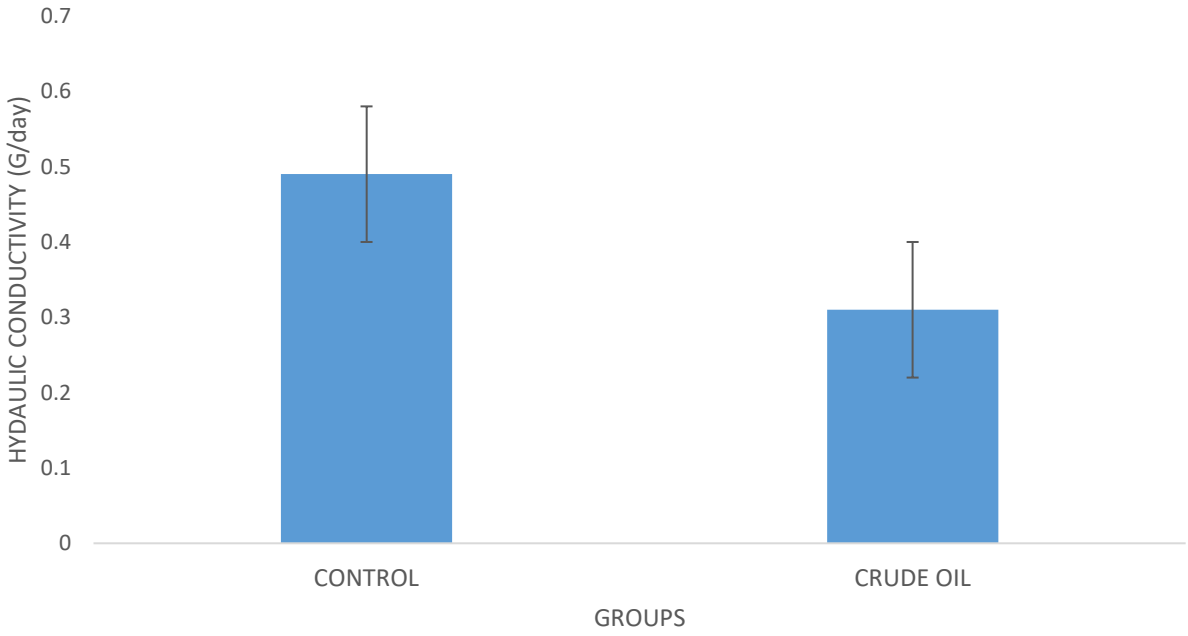

Figure 4. Effect of Crude oil on Hydraulic Conductivity in contaminated soil
Results are expressed as mean±SD (n=4). P<0.05 (Control vs Contaminated groups).

Organic Matter Content

There was significant decrease ($p>0.05$) in the contaminated group as compared to the control group (Figure 5).

Soil pH

The contaminated group caused a significant decrease ($p<0.005$) in soil pH as compared to the control group (Figure 6).

Water Holding Capacity

In the contaminated group there was a significant decrease ($p<0.05$) in soil water holding capacity (WHC) as compared to the control group (Figure 7).

Effects of Crude Oil on Plant Growth and Development Parameters

Plant Height: There was no significant change ($p>0.05$) in the contaminated group in week 1-3 of germination phase but as the plant grew into vegetative phase, there was significant decrease ($p<0.05$) compared to the control group (table 4).

Plant Girth: The contaminated group showed no significant change ($p>0.05$) in the 1-3 weeks of germination phase but as the plant grew into vegetative phase there was significant decrease ($p<0.05$) compared to the control group (Table 4).

Leaf Area: In the contaminated group, there was no significant change ($p> 0.05$) in the 1, 2 and 3 weeks of germination phase. However, as the plant grew into vegetative phase, there was significant decrease ($p<0.05$) compared to the control group (Table 4).

Stem Diameter: There was no significant change ($p>0.05$) in the contaminated group in the 1-3 weeks of germination phase but there was significant decrease ($p<0.05$) as the plant grew into vegetative phase compared to the control group (Table 4).

Seed Germination Rate

Seeds germination rate shows that contaminated group caused a significant decrease ($p<0.05$) compared to the control group (Figure 8).

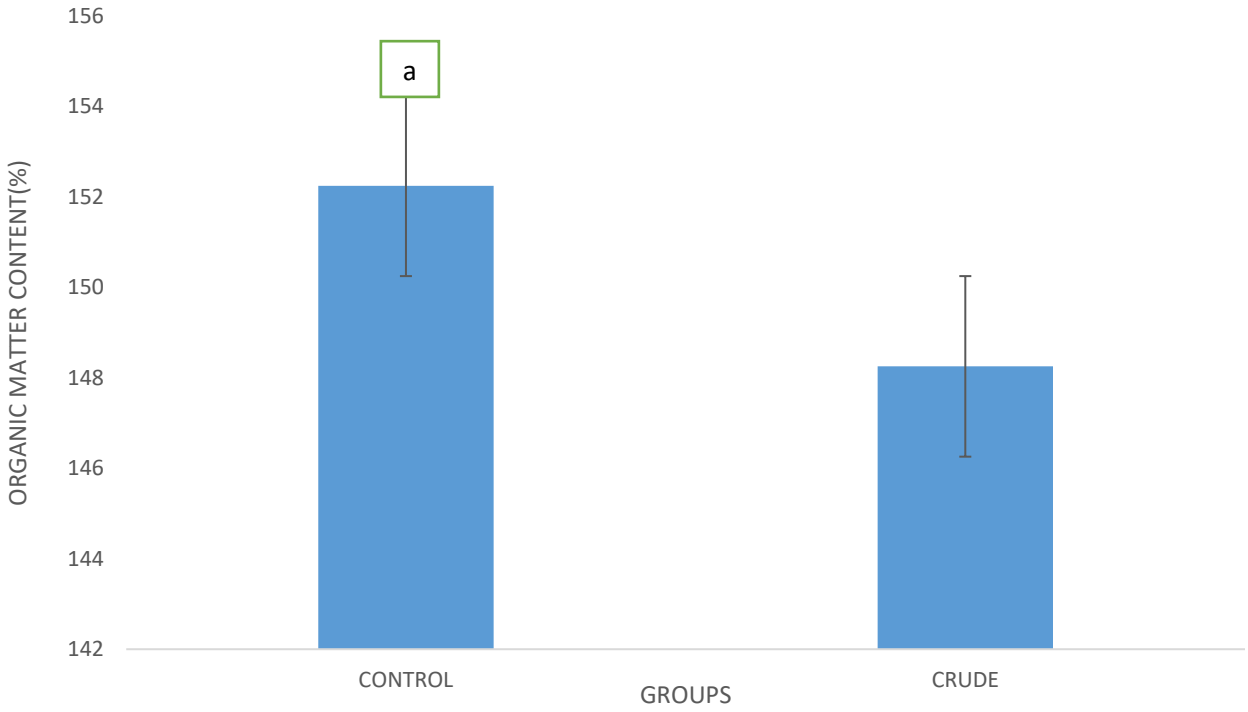

Figure 5. Effect of Crude oil on Organic Matter Content in contaminated soil

Results are expressed as mean±SD (n=4). P<0.05 (Control vs Contaminated group).

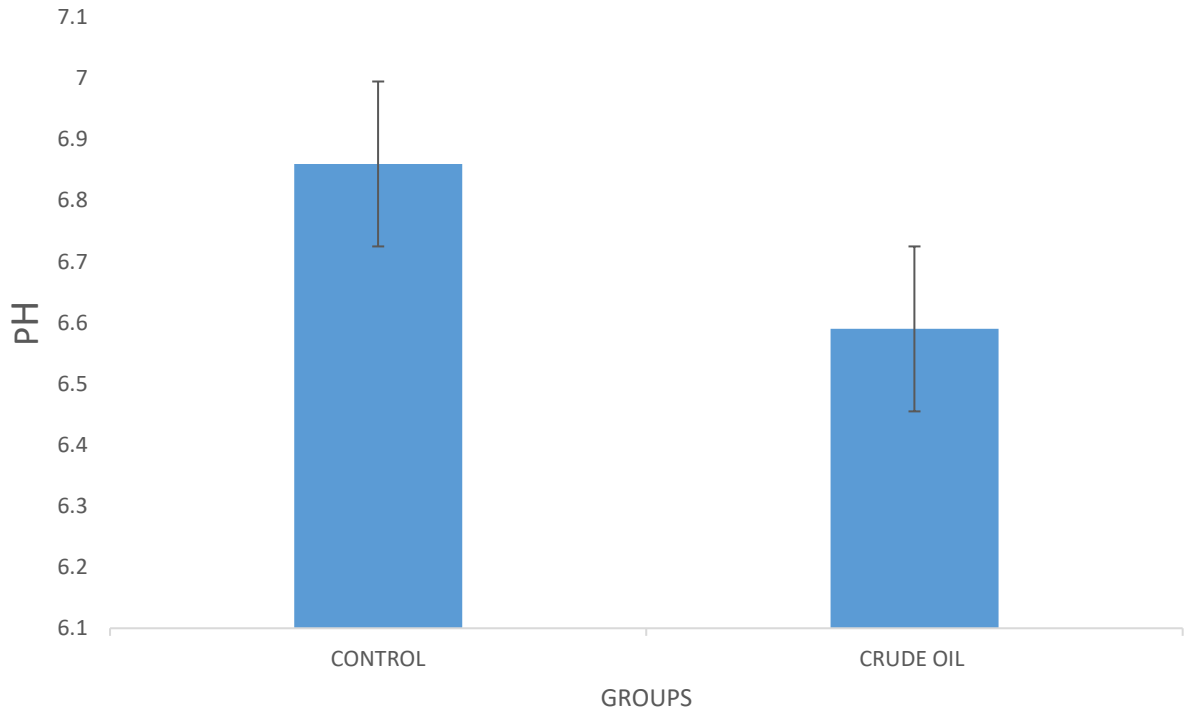

Figure 6: Crude oil on Soil pH in contaminated soil. Results are expressed as mean±SD (n=4). P<0.05 (Control vs Contaminated group).

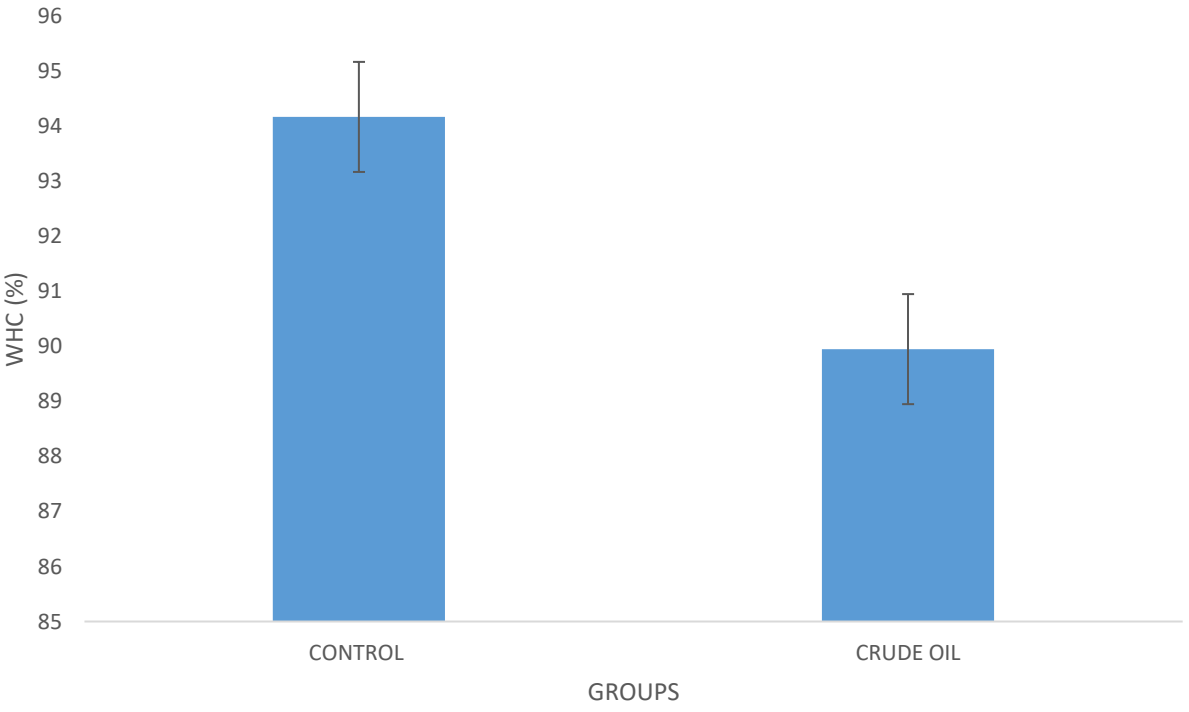

Figure 7. Effect of Crude oil on Water Holding Capacity in contaminated soil
Results are expressed as mean±SD (n=4). P<0.05 (Control vs Contaminated group).

Table 4. Effects of Crude Oil Contaminated Soil on Plant Parameters

GROUP	WEEKS	PH (m)	PG (m)	LA (m^2)	SD (cm)
CONTROL	1	0.13±0.050^a	0.01±0.004^a	0.002±0.006^a	1.10±0.05^b
	2	0.39±0.006^b	0.01±0.002^a	0.06±0.006^b	1.15±0.03^b
	3	0.40±0.006^a	0.04±0.003^b	0.02±0.001^b	1.30±0.03^b
	4	0.45±0.006^b	0.04±0.001^b	0.02±0.001^b	1.38±0.006^b
	5	0.55±0.006^b	0.04±0.003^b	0.019±0.001^b	1.52±0.006^b
	6	0.58±0.006^b	0.04±0.003^a	0.023±0.001^b	1.55±0.006^b
	7	0.065±0.005^b	0.04±0.03^b	0.03±0.001^b	1.08±0.340^a
	8	1.20±0.006^b	0.04±0.003^b	0.03±0.006^b	1.60±0.006^b
	9	1.23±0.006^b	0.05±0.003^b	0.03±0.001^b	1.43±0.006^b
	10	1.56±0.006^b	0.05±0.003^b	0.02±0.006^b	1.22±0.006^b
	11	1.60±0.006^b	0.33±0.017^b	0.02±0.006^b	1.20±0.006^b
	12	1.45±0.006^b	0.30±0.012^b	0.03±0.001^b	0.68±0.295^a
CRUDE OIL	1	0.13±0.050^a	0.01±0.001^a	0.003±0.006^a	0.75±0.03^a
	2	0.36±0.006^b	0.02±0.003^a	0.01±0.001^a	0.85±0.03^a
	3	0.40±0.006^a	0.02±0.001^a	0.01±0.001^a	1.10±0.03^b
	4	0.39±0.006^a	0.03±0.003^a	0.01±0.001^a	1.16±0.009^b
	5	0.46±0.006^b	0.03±0.001^a	0.014±0.001^b	1.33±0.006^b
	6	0.55±0.006^b	0.04±0.003^a	0.012±0.001^a	1.36±0.006^b
	7	0.058±0.005^b	0.04±0.03^a	0.02±0.001^a	1.26±0.006^a
	8	0.72±0.006^b	0.04±0.003^a	0.02±0.006^a	1.41±0.006^b
	9	1.08±0.006^b	0.04±0.003^a	0.02±0.001^b	1.12±0.006^b
	10	1.25±0.006^a	0.03±0.001^a	0.01±0.006^a	1.11±0.006^a
	11	1.30±0.006^a	0.03±0.003^a	0.01±0.006^b	1.00±0.006^b
	12	1.35±0.006^a	0.03±0.001^a	0.01±0.001^b	1.10±0.006^a

Within column, mean±SEM(n=3) with different superscript(s) differ significantly at (P<0.05). Where PH=Plant height, PG=Plant girth, LA=Leaf area, SD=Stem diameter, wks.= Number of weeks

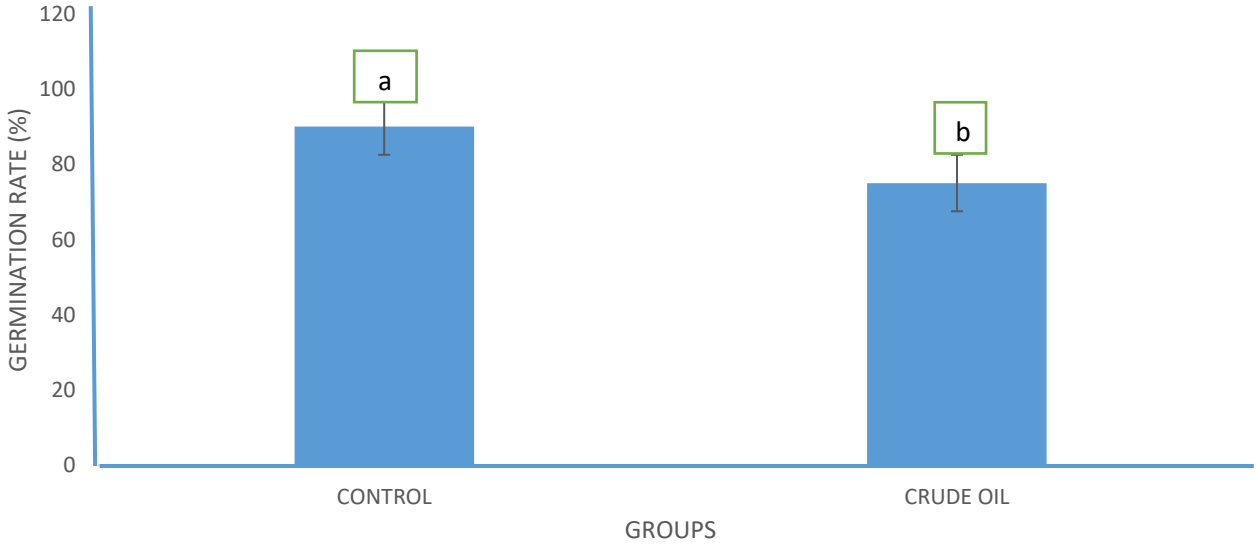

Figure 8. Crude oil on Germination Rate in contaminated soil
Results are expressed as mean±SD (n=4). P<0.05 (Control vs Contaminated group).

FTIR Characterization on Some Important Soil Chemical Composition

In the contaminated group (B) there was a change in the functional group, bonds and the presence of hydrocarbon compounds as compared to the control group (table 5).

Proximate Analysis

In the analysis, it showed that there were variations in the proximate analysis parameters between the different groups. The contaminated group showed significant decrease (P<0.05) across the column as compared to the control group (Table 6).

Table 5: FTIR Characterization on Soil Contaminated with Crude Oil and Cadmium

Groups	Peak Number	Bond	Functional Group Assigned	Wavenumbers (cm^{-1})
A	1	C-N	Amine	1314.84162
	2	C=O	Carboxylic acid, Aldehyde, Ketone	1640.02865
	3	C≡N Stretch	Nitrile	2109.67322
B	1	C-F	Metal-Hydrogen bonding	1423.84305
	2	C=O	Carbonyl	1640.02865
	3	C≡C	Alkyne	2117.12789
	4	O-H Stretch	Phenol, Alcohol	3294.96665

Where A=Control, B=Crude oil only

Table 6: Nutritional Composition of Maize Grown on Soil Contaminated with Crude Oil

Groups	Moisture (%)	Ash (%)	Oil (%)	CF (%)	CP (%)	NFE (%)
Control	7.23±0.005^{b}	1.24±0.03^{b}	2.10±0.05^{b}	6.04±0.05^{b}	10.15±0.002^{b}	76.22±0.005^{b}
Crude oil	7.20±0.006^{a}	1.18±0.01^{a}	1.99±0.01^{a}	5.17±0.04^{a}	8.55±0.05^{a}	75.56±0.06^{a}

Within column, mean±SEM(n=3) with different superscript(s) differ significantly at (P<0.05). Where CF= Crude Fiber, CP= Crude protein, NFE= Nitrogen Free Extract

DISCUSSION

Oil contamination can alter the physical and chemical properties of soil, often leading to higher daily maximum surface temperatures in hydrocarbon-contaminated soils compared to uncontaminated areas (Wang *et al*., 2013).

In thesefindings, crude oil pollution negatively impacted growth parameters of *Zea mays* L. plants. Udo & Fayemi (1975) reported similar findings on dose-dependent adverse effects of crude oil pollution on germination of *Ricinus communis* and maize. These effects may be likely due to disruptions in water and nutrient uptake caused by the presence of oil in soil, as well as the depletion of soil nitrogen and phosphorus levels (Baran *et al.,* 2020). The inhibition of plant growth could also be attributed to the toxic compounds present in petroleum hydrocarbons (Tang *et al* 2011).

This study is like that of Ekundayo *et al.* (2001), who observed that plant height, root number, root length and grain yield were negatively impacted by soil crude oil contamination. This adverse effect is primarily due to oil creating an environment devoid of air in soil by coating soil particles and preventing air diffusion in soil holes, which also disrupt soil microbial growth (Ossai *et al*., 2020). This result also agrees with the findings of Odiyi *et al*. (2020), which confirmed that the height of plant was higher in ideal plant condition when compared to the crude oil contaminated plant.

A similar trend was reported by Etukudoh & Chukwumati (2016) who observed that plants heights were greater in unpolluted soil compared to polluted soil. This finding aligns with earlier research by Ikhajiagbe & Anoliefo (2011), which highlighted a significant reduction of plant growth due to oil pollution. The decrease in plant height may be attributed to unfavorable soil conditions, such as reduced aeration caused by a decrease in the air-filled pore spaces (Atuanya, 1987), adverse effects on soil microorganisms (Benka-Coker & Ekundayo, 1995), the presence of toxic oil components (Siddiqui and Adams, 2002), diminished biochemical activities, accumulation of heavy metals (Agbogidi & Egbuchua, 2010) and disruption in the soil-water-plant interrelationship (Agbogidi, 2011).

This result agrees with the findings of Kekere *et al.* (2011) which showed that crude oil pollution adversely impacted various plant parameters, including leaf number, total leaf area, plant height, stem girth, total biomass and crop yield in *Vigna unguiculata*. Similarly, Aniefiok *et al*, (2023) observed a significant reduction in leaf number in air potato plants grown in crude oil-polluted soil compared to the control, with the reduction increasing as crude oil concentration intensified. Since leaf are critical for photosynthesis, any reduction in leaf length and area leads to decreased surface area for photosynthetic activities, ultimately diminishing the plant's ability to produce energy. Moreso, a decline in leaf chlorophyll content in plants grown on crude oil-contaminated soil could further impair photosynthesis. This decrease in leaf number may result from several factors, including blockage of conducting tissues which restrict the movement of water and nutrients, thereby limiting plant's ability to produce new leaves. Kekere *et al*., (2011) also reported

that oil pollution impairs the value of the membrane, drastically alter enzymes system (particularly membrane-bound enzymes), and affects the metabolic processes of the plant.

Reports from various research indicated that stem girth measurement tended to decrease in polluted soil. This study aligns with the trend and supports the findings of Okonokhua *et al*., (2007). They observed a decrease in maize stem girth as pollutant concentrations increase. In a study by Mule *et al*. (2016) it was observed that exposure to crude oil reduces the girth of *Brassica juncea* plants due to inhibition of cell division and expansion by crude oil.

The silt, clay and sand proportions showed no significant difference (P>0.05) between the treated and control soils. These findings suggest that crude oil in the soil notably impacts on soil properties such as nitrogen content, phosphorus, carbon and heavy metals. This aligns with earlier findings of Agbogidi and Egbuchua (2010), who observed that oil contamination in soil adversely affects its biological, chemical and physical characteristics, depending on factors such as the amount of oil, soil type and other variables.

Soil pH, a key factor affecting the availability of nutrients for plant uptake (Okonokhua *et al*., 2007) was found to decrease in the crude oil-contaminated group. This aligns with the findings of Devatha *et al*. (2019), who reported a significant reduction in soil pH due to crude oil contamination, indicating that higher crude oil concentration leads to increased soil acidity. This acidic nature arises from hydrocarbons in the crude oil reacting with soil salts and minerals, converting alkaline minerals to acidic forms. This agrees with the findings of Pereira *et al*. (2019), soil pH increase initially following petroleum contamination, but then decrease overtime. A study by Xu *et al* (2019) found that petroleum hydrocarbons decrease the soil pH.

There is a significant reduction of hydraulic conductivity in the contaminated soil as compared to the uncontaminated soil, this study is in line with the study by Devatha *et al*, 2019 who revealed that crude oil contamination brings about reduction in the pore size of the soil which on the other hand affects hydraulic conductivity, which is due to the oil coating which surrounds the soil particles, it reduces the availability of water to the plant roots because of the gradient development between the soil particles and pore spaces. Sometimes, pore spaces in the soil may be occupied by oil instead of water particles. This can hinder the flow of moisture from the soil to plant roots and, in some cases, even because of a reverse flow. As a result, the soil's conductivity is significantly reduced.

Available phosphorus presented the declining trend with augmenting oil contamination (Wang *et al*. 2009). Available phosphorus is an important macronutrient for plant and soil microorganisms; the reduction could be because of unevenness in the distribution of nutrients due to the high levels of carbon concentration.

Hydrocarbon contamination can also increase the total organic carbon content of the soil as reported by Ekundayo & Obuekwe, (2000). Additionally, it can alter soil pH values and other soil chemical properties in soil composition (Wang *et al*., 2009).

The amount of available phosphorus was greatly reduced by crude oil contamination and the amount of nitrogen also decreases, which is in line with the findings of Aniefiok *et al*. (2013), who reported that the amount of available phosphorus was greatly reduced by crude oil contamination, increased total hydrocarbon content, and decreased the availability of total nitrogen in the soil sample due to crude oil contamination.

The FTIR analysis detects changes in the functional group indicating alteration in maize chemical composition and changes in chemical structure which also align with findings of Radenovic *et al.* (2018). Shifts in hydroxyl group indicate changes in water content or chemical structure.

The findings indicate that crude oil contamination decreases the carbohydrate, protein, fat and moisture content of the maize seeds. This aligns with earlier findings of Agbogidi *et al.* (2006) this may be due to disrupted metabolic pathways, soil water relation, nutrient imbalance or oxidative stress.

CONCLUSION

This study reveals that crude oil-polluted soil negatively impacts the growth and yield of maize and results to change in chemical composition due to physiological and biochemical activities.

Conflicts of Interest

The authors declare no conflict of interest.

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