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Phytoremediation of Petroleum Products Contaminated Soil

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Authors' contributions

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

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ABSTRACT

This study investigated the impact of petroleum products on the physiochemical properties, heavy metals and THC of soil samples; and their possible phytoremediation. Perforated plastic buckets were filled with 10 kg of sieved virgin topsoil. A mixture of 2 L of spent engine oil, 2 L of kerosene, 2 L of petrol and 2 L of diesel was gradually poured into each bucket and allowed to drain through the soil, once a day for five days, and there after left to stabilize for a period of 21 days. Fluted pumpkin (*Telforia Occidentalis*) and Okra (*Abelmoschus esculentus*, Cv. *Kirikou*) seeds were planted in buckets and closely monitored for 14 weeks. Soil analysis of the virgin topsoil, contaminated soil and remediated soil was done using standard methods. Tests results showed that the petroleum products significantly ($p \leq 0.05$) altered the physicochemical properties, heavy metals and THC of the soil. From the results, the soil porosity decreased from 35% to 14%; specific gravity decreased from 2.34 to 1.35; the soil pH decreased from 7.05 to 5.34; the THC increased from 0,923 mg/kg to 964.35 mg/kg; copper level increased from 4.892 mg/kg to 7.729 mg/kg; the lead content increased from <0.0001 mg/kg to 1.128 mg/kg; while the iron content increased from 1251.2 mg/kg to 1587.9 mg/kg after the contamination. After the 14 weeks

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phytoremediation period, *Telfairia occidentalis* was able to degrade the THC in the soil from 964.35 mg/kg to 82.67 mg/kg; while *Abelmoschus esculentus* degraded the THC in the soil from 964.35 mg/kg to 104 mg/kg. Therefore, due to the harmful effects of the petroleum products on agricultural soils, laws banning their indiscriminate disposal of should be enforced.

Keywords: Abelmoschus esculentus; Telfairia occidentalis; contaminated soils; phytoremediation; THC.

1. INTRODUCTION

Since Nigeria commenced crude oil exploration in commercial quantity, its exploitation has grown tremendously replacing agriculture, which was Nigeria's main source of revenue [1]. Crude oil exploration has had a lot negative impact on the environment, if not well managed. It has led to the land, air and water pollution through gas flaring, oil spills, indiscriminate disposal of petroleum products etc. The people living in the Niger Delta region of Nigeria (the oil exploration hub of Nigeria), are badly affected by oil exploration activities. Their fishing waters and farming lands have become polluted leading to poor catch and crop yield [1].

Petroleum contamination in the environment causes serious problems. This is because petroleum hydrocarbons compounds are toxic to all forms of life, and have adverse effect on the soil's physical and chemical properties. Petroleum is a complex mixture of a wide variety of low and high molecular weight hydrocarbons. The mixture contains saturated alkanes, alkynes, alkenes, napthenes, highly toxic polycyclic aromatic hydrocarbons, and some heavy metals [2,3]. Peng et al. [4] reported that the population of living microorganisms was highly dependent on the concentration of petroleum contaminants in the soil, as uncontaminated soils favoured high bacteria population more than petroleum contaminated soil. Reduced dry mass accumulation of *Gambaya albida* and *Dacryodes edulis* plants caused by spent oil contamination had been reported [5,6] where they noted that hydrocarbons from oil contaminated soils accumulate in the chloroplast of plant leaves.

Phytoremediation uses plants and their associated microorganisms to restore soil and water bodies contaminated with hydrocarbons and other heavy metals. Phytoremediation is more environmentally friendly than most conventional clean-up methods used in the remediation of contaminated soil [7,8]. The main mechanisms of phytoremediation include the following: the direct uptake of contaminants and their subsequent metabolism in plant tissues, transpiration of volatile organic hydrocarbons through the stems and leaves, discharge of exudates that stimulate microbial activity, and the enhancement of mineralization at the root–soil interface [9,10].

Phytoremediation of contaminated soils using some plants have been studied. Al-Baldawi *et al*. [10] reported that the average total petroleum hydrocarbon (TPH) concentration detected in *Scirpus grossus* ranged between 19.86 to 91.36 mg/kg in the roots, and 16.14 to 223.56 mg/ kg in the leaves. Schnoor [11] reported that phyto-remediation is more effective with vigorously growing plants, and have the ability to accumulate large concentration of contaminants in body parts (roots, stems and leaves). The ability of given crop to degrade crude oil content in contaminated soil can help to restore polluted soils back for agricultural use [12]. Akpokoje et al. [8] demonstrated that Arachis *hypogaea* L, *Amaranthus hybridus* and *Celosia argentea* planted on soil contaminated with mixture of petroleum products were able to degrade the Total Hydrocarbon Content (THC) of the contaminated soil by about 80%. Water hyacinth (*Eichhornia crassipes*) significantly remediates petroleum hydrocarbon levels in the contaminated soil [13]. According to [14], spent lubricating oil adversely affected soil aeration, soil bulk density and soil water holding capacity. In their report, they stated that the bulk density increased from 1.38 kg/m^3 to 3.80 kg/m^3, while the water holding capacity decreased from 59 ml to 8 ml [14]. In a study conducted by [15], they reported that fluted pumpkin degraded the Total Petroleum Hydrocarbon (TPH) in a diesel oil contaminated soil from 82.5 mg/kg to 5.8 mg/kg within the 18 week experimental period [15].

Although, reference [15] and other researchers had studied the phytoremediation of diesel contaminated soil using fluted pumpkin (*Telfairia occidentalis),* there is no literature on the phytoremediation of agricultural soil contaminated with mixture of petroleum products using okra and fluted pumpkin plants. It is therefore important to study the ability of okra plant (*Abelmoschus esculentus*, cv. *Kirikou*) and fluted pumpkin (*Telfairia occidentalis)* in mitigating the effect of some physicochemical (specific gravity, porosity, bulk density and electrical conductivity) impact and THC of soil polluted with a mixture of petroleum products. Therefore, the objective of this study was to evaluate the role and influence of the Pumpkin (*Telforia Occidentalis*) and Okra (*Abelmoschus esculentus*, Cv. *Kirikou*) within the context of the phytoremediation of petroleum products contaminated soil.

2. MATERIALS AND METHODS

2.1 Materials

Soil sample: The top soil was collected within 6cm depth from a virgin plot at the Delta State Polytechnic research station.

Petroleum products: The spent motor engine oil was purchased from a mechanic workshop located along Ozoro – Kwale road, Delta State, Nigeria; while the petrol, diesel and kerosene were purchased from a filling station located at Ozoro, Delta State, Nigeria.

Plants of interest: The Pumpkin (*Telforia Occidentalis*) and Okra (*Abelmoschus esculentus*, Cv. *Kirikou*) seeds were obtained from the Department of Agricultural and Bio-environmental Engineering Technology, Delta State Polytechnic, Ozoro, Nigeria.

2.2 Methods

Soil sample preparation: The dug topsoil was air dried in the laboratory at ambient temperature (23±4°C) for two weeks. After which, it was sieved with 2 mm stainless steel sieve to remove stones and plants roots from it. Plastic buckets were filled with 10 kg of the sieved soil before the contamination with petroleum products. Mixture of petroleum products (2 L of spent engine oil, 2 L of kerosene, 2 L of petrol and 2 L of diesel) was gradually poured into each bucket and allowed to drain through the soil. This procedure was repeated daily for five days, before the contaminated soil in the buckets was left to stabilize for three weeks.

Soil analysis: Soil analysis was carried out on the uncontaminated, the contaminated (after stabilization period), and the remediated soil samples. The soil bulk density, porosity, specific gravity, pH and Total Hydrocarbon Content (THC) in the soil sample was determined using the standard method recommended by [10,16, 17]. The heavy metals (copper, Iron and Lead) were determined using an atomic absorption spectrophotometer, in accordance with standard methods [18,19].

2.3 Phytoremediation Setup

All the buckets filled with contaminated soil were arranged under a shady environment to minimize excessive evapotranspiration and the effects of heavy downpour, during the experimental period. They were arranged in the manner shown in Table 1, for easily data collections.

Table 1. Phytoremediation set up

Row	Plant
Row 1	*Abelmoschus esculentus*, *Okra*
Row 2	*Telforia Occidentalis, Fluted pumpkin*

Ten seeds (of each plant) were sown into each of the buckets. Three weeks after germination, the seedlings were thinned down to five seedlings per bucket. Before planting, 200 g compost manure (made from green leaves, cattle dungs and poultry droppings) mixed with 100 g of loamy soil was placed on top of all the buckets, to encourage early establishment of the seedlings, as recommended by [8]. All the buckets were moderately watered when necessary to keep the soils moist. Weeding was done by handpicking throughout the experimental period, while systemic pesticide was applied when necessary. Disease symptoms were not observed; therefore, fungicide was not used during the experimental period.

At the end of the experimental period, random soil samples were taken (0-20 cm depth) from the buckets and coded. This depth (0-20 cm depth) is considered the rhizosphere region of the plants. Rhizosphere region is the region of the soil closest to the plant's root which is under the direct influence of the root system [20]. All the soil samples collected were air-dried and sieved with a 2 mm sieve before the soil analysis.

2.4 Statistical Analysis

The statistical analysis of data obtained from this study was done by using the Statistical Product and Service Solutions (SPSS) version 20.0 (Chicago, USA). The means were separated using the Duncan method at 95% confidence level ($p \leq 0.05$). All the tests were carried out in triplicates to minimize experimental errors.

3. RESULTS AND DISCUSSION

3.1 Impact of the Petroleum Products on the Soil

The results of the soil analysis presented in Tables 2 and 3 showed that the petroleum products had significant effects on the physicochemical properties and heavy metals level of agricultural soil. As shown in Tables 2, the soil bulk density, and total hydrocarbon content increased significantly ($p \leq 0.05$) after the petroleum products contamination. The soil porosity, pH, and specific gravity decreased significantly ($p \leq 0.05$) after the contamination (Table 2). From the results, the soil porosity decreased from 35% to 14% (about 60% decrease), specific gravity decreased from 2.34 to 1.35 (about 50% decrease), while the soil pH decreased from 7.05 to 5.34, making the soil more acidic in nature after the contamination. It can be seen from the results that the petroleum products increased the bulk density of the soil samples. This could be attributed to the blockage of soil pores by the pollutant. This result is similar to the previous studies of [14,21] on spent lubricating oil contaminated soil. In addition, [22] reported increase in the acidity and decrease in porosity of soils polluted with crude oil. Furthermore, [23] stated that High hydrocarbon content of soils may affect the physicochemical properties of the soil which may in turn affect the agricultural potentials and productivities of such soils.

As seen in the results, the THC of the soil drastically increased from 0,923 mg/kg to 964.35 mg/kg, after the commination. In terms of heavy metals, the contaminated soil had significantly higher values than control soils ($p \leq 0.05$) with respect to total Cu, Fe and Pb. The copper level in the soil increased from 4.892 mg/kg to 7.729 mg/kg; the lead content increased from <0.0001 mg/kg to 1.128 mg/kg; while the iron content increased from 1251.2 mg/kg to 1587.9 mg/kg (Table 3). Similar result trend was reported by [22], where the copper content of soil sample increased from 16 mg/kg to 45.88 mg/kg; and the iron content increased from 314 mg/kg to 432.88 mg/kg after crude oil contamination. Ekundayo [24] reported that a marked change in properties occurs in soils polluted with petroleum hydrocarbons; affecting the physical, chemical and microbiological properties of the soil.

3.2 Phytoremediation Potential of the Plants

THC degradation in the soil: The results of the study presented in Fig. 1, showed that the two plants were able to significantly ($p \leq 0.05$) degrade the THC in the soil. From the results, it can be seen that the phytoremediation potential of *Telfairia occidentalis* was higher than *Abelmoschus esculentus*, after the 14 week experimental period. *Telfairia occidentalis* was able to degrade the THC in the soil from 964.35 mg/kg to 82.67 mg/kg; while *Abelmoschus esculentus* degraded the THC in the soil from 964.35 mg/kg to 104 mg/kg. In similar result, *Telfairia occidentalis* degraded the TPH is a diesel contaminated soil by about 86.53%, after 18 week experimental period [15]. Furthermore, the TPH concentrations of sandy soil decreased progressively from 18.8 to 11.4 mg/kg after phytoremediation using *Scirpus grossus* grass for 72 days [10]. The higher phytoremediation potential of fluted pumpkin over okra may be attributed to its extensive root network systems, higher foliage and better root biomass.

Heavy metals content: The results of the degradation of the heavy metals by the plants are presented in Figs. 2, 3 and 4. From the results, it can be seen that the two plants significantly degrade the heavy metals content in the soil. It was observed that *Telfairia occidentalis* had higher remediation potential as it was able to bring the copper content in the contaminated soil from 7.73 mg/kg to 5.26 mg/kg; while *Abelmoschus esculentus* degraded the copper content in the contaminated soil from 7.73 mg/kg to 5.97 mg/kg within the 14 week experimental period (Fig. 2). In terms of the iron remediation in the soil, it was observed that the two plants were able to remediate the iron content in the contaminated soil. As shown in Fig. 3, the *Telfairia occidentalis* was able to degrade the iron content in the contaminated soil from 1586.67 mg/kg to 1370.67 mg/kg, showing higher remediation potential against the *Abelmoschus esculentus*. In the results, *Abelmoschus esculentus* brought the concentration of iron in the contaminated soil from 1586.67 mg/kg to 1447.67 mg/kg.

The results of analysis of the soil samples showed that there was significant ($p \leq 0.05$) improvement in the lead content of the contaminated soil after the experimental period. Results of the study presented in Fig. 4, showed that *Telfairia occidentalis* had higher tendency of degrading the lead content in the soil. *Telfairia occidentalis* degraded the lead content from in the contaminated soil from 1.1277 mg/kg to 0.163 mg/kg; while *Abelmoschus esculentus* brought the content of lead in the contaminated soil down from 1.1277 mg/kg to 0.4897 mg/kg. Some heavy metals at low doses are essential micronutrients for plants, but in higher doses they may cause metabolic disorders and growth inhibition for most of the plants species. Palmroth et al. [25] reported that root exudates from plants help to degrade toxic organic chemicals and act as substrates for bacteria in the soil, which improves the plants phytoremediation potential. Atlas and Bartha [26] suggested that it is the interaction between plants and micro-organisms which is the primary mechanisms responsible for petrochemical degradation in phytoremediation efforts.

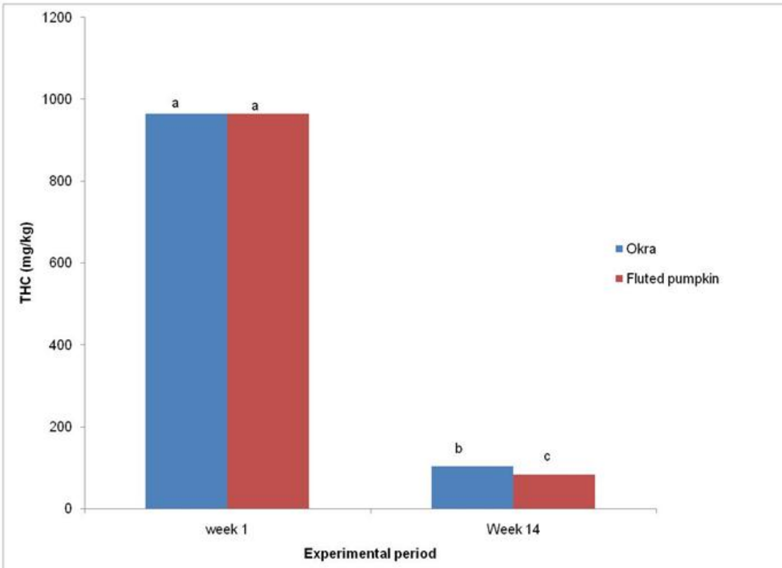

Fig. 1. Effect of phytoremediation crops on the THC of contaminated soil
Different letters on columns represent statistical differences (p ≤ 0.05) using Duncan's multiple range test

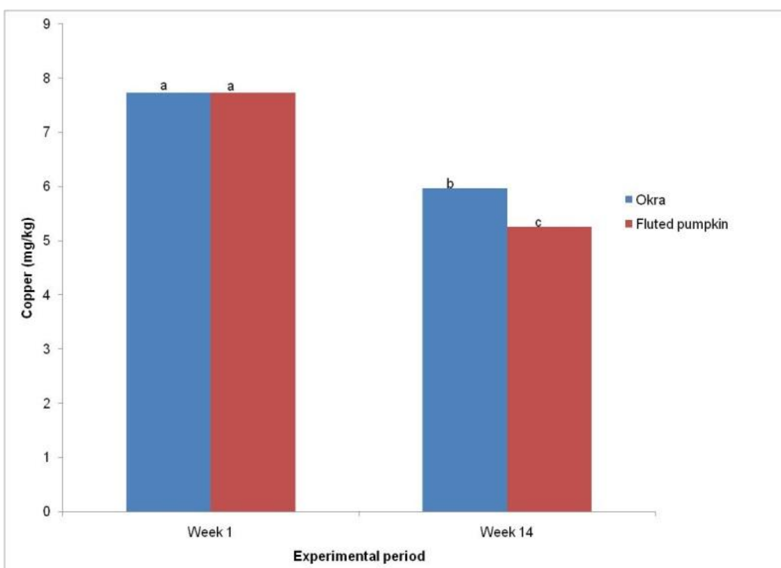

Fig. 2. Effect of phytoremediation crops on the Copper content of contaminated soil
Different letters on columns represent statistical differences (p ≤ 0.05) using Duncan's multiple range test

Table 2. Result of the impact of petroleum products on the physicochemical properties of soil

Parameters	Level	
	Before contamination	**After contamination**
Soil pH (H_20)	7.05^a	5.34^b
Soil porosity (%)	35^a	14^b
Soil bulk density (kg/m^3)	2510^a	3120^b
Specific gravity	2.34^a	1.35^b
THC		
Soil sample (mg/kg)	0.923^a	964.35^b

Rows with the same common letter superscript are not significantly different at (p ≤0.05)

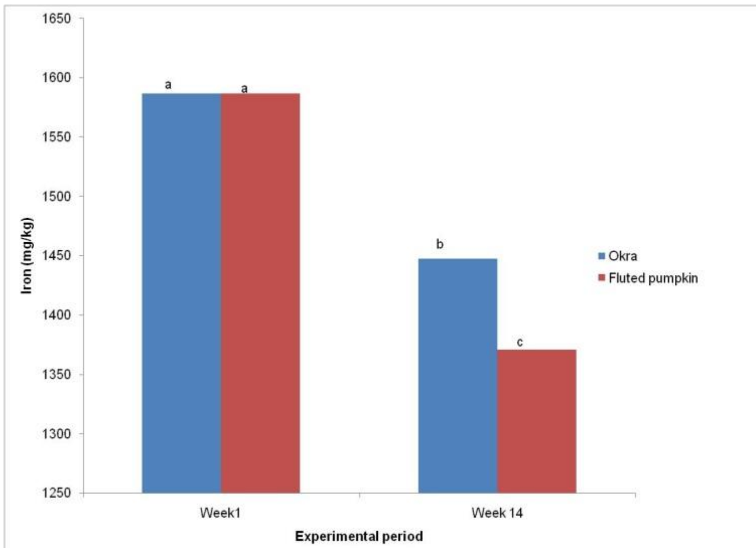

Fig. 3. Effect of phytoremediation crops on the Iron content of contaminated soil
Different letters on columns represent statistical differences (p ≤0.05) using Duncan's multiple range test

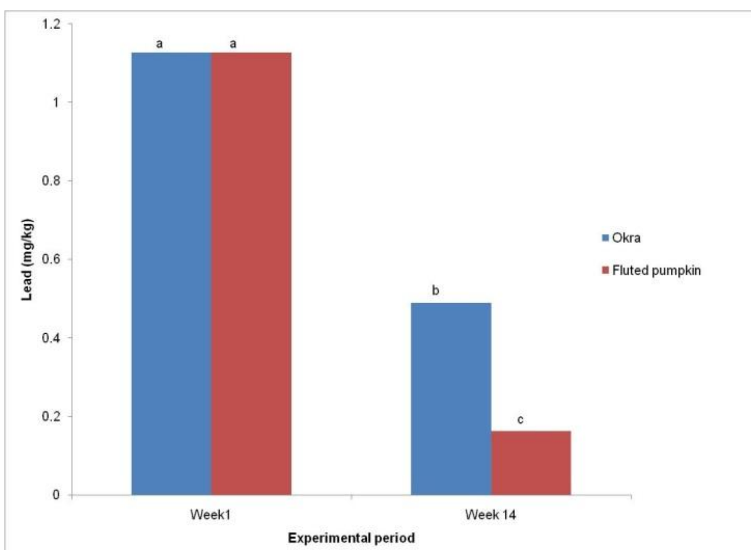

Fig. 4. Effect of phytoremediation crops on the lead content of contaminated soil
Different letters on columns represent statistical differences (p ≤ 0.05) using Duncan's multiple range test

Table 3. Result of the impact of petroleum products on the soil heavy metals

Parameters	Level	
	Before contamination	After contamination
Lead (mg/kg)	< 0.001[a]	1.128[b]
Copper (mg/kg)	4.892[a]	7.729[b]
Iron (mg/kg)	1251.2[a]	1587.9[b]

4. CONCLUSION

The present study investigated the effect of petroleum products on the physiochemical, THC and heavy metals content of agricultural soil, and its possible remediation using two vegetable crops. Results of the soil analysis showed that the petroleum products had significant (p ≤0.05) adverse effects on the physicochemical properties, heavy metals and THC of the agricultural soil. Phytoremediation of the contaminated soil was carried out using fluted pumpkin (*Telfairia occidentalis)* and okra (*Abelmoschus esculentus)* within 14 week experimental period. Results obtained from the study showed that both vegetable crops had good phytoremediation potential, as they improved the soil conditions within the experimental period. Results obtained from the study showed that both crops had a good phytoremediation potential. However, fluted pumpkin (*Telfairia occidentalis)* had a higher potential than the okra (*Abelmoschus esculentus*). After the 14 week experimental period, *Telfairia occidentalis* was able to degrade the THC in the soil from 964.35 mg/kg to 82.67 mg/kg; while *Abelmoschus esculentus* degraded the THC in the soil from 964.35 mg/kg to 104 mg/kg. From the study results, laws banning indiscriminate disposal of petroleum products should be enforced; and more plants should be research on to determine their phytoremediation potential.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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