Phytodegradation Potential Of Tiger Nut (*Cyperus Esculentus*) In Remediating Petroleum Hydrocarbon Contaminated Soi

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Abstract. Conventional (Physical and chemical) treatment methods for remediating petroleum hydrocarbon-contaminated soils present some limitations. Phytodegradation is an effective treatment in terms of efficacy, cost-effectiveness, environmental friendliness in long-term use, and simplicity of administration. This research aimed to study the effectiveness of Tiger Nut (*Cyperus Esculentus*) in the remediation of soil contaminated by Total petroleum hydrocarbon (TPH). The result revealed irregular variations in the level of the physiochemical properties of the soil before, during and after the experiment. The result also revealed that all the planted seeds in the different concentrations or treatments of the TPH (including control) germinated with the exception (50% germination) in the soil treated with 25 g and 35 g of the TPH. Generally, there is a decrease in the plant's height, and the mass or concentration of the TPH increases relatively. The highest plant heights are observed in the control on the 80th day. Also, there is an increase in the height of all the plants every 10 days. There is a decrease in the values of TPH for all samples considered after the phytodegradation. The relative potential or efficiency (parentage reduction) of the grasses remediating the TPH-contaminated soils with the different concentrations of the Petroleum Hydrocarbon is in the order 5g> 15g> 25g>35g. The phytodegradation of the TPH-contaminated soil using tiger nut is higher when amended (with an average of 35% percentage reduction) with the cow dung than the unamended (with an average of 4% percentage reduction). It is therefore concluded that the Tiger Nut (with an overall 20% percentage reduction) has a low potential for the degradation of TPH-contaminated soil.

Keywords: Phytodegradation; Tiger Nut; Petroleum Hydrocarbon; Soil.

INTRODUCTION

There has been an increasing concern regarding the accumulation of toxic contaminants in the environment and their impact on public health and the natural environment [1]. Soil contamination has become a global phenomenon. Chemicals and contaminants have contaminated soil in many parts of the world due to industrial and agricultural activities and unregulated waste disposal. In Europe alone, 2.5 million sites were identified as potentially contaminated, with an estimated 342000 sites contaminated [2]. A large proportion of chemical-contaminated soil is attributed to the environmental release of petroleum products, particularly crude oil [3]. Global intensification of oil and gas activities comprising exploration, drilling, production, onshore storage and transportation of petroleum has increased the risk of spillage and leakage of crude oil into the environment [4]. Crude oil is a complex mixture of hydrocarbon and organic compounds, some of which, such as benzene and polyaromatic hydrocarbons, are known to pose environmental and health hazards [5]. Soil contaminated by crude oil could render it unsafe for habitation and agricultural activities due to potential human exposure to the harmful compounds of crude oil and bio-accumulation of the compounds in agricultural products [6]. Conventional methods of remediating soil contaminated by crude oil involve excavation of the soil followed by subsequent chemical or physical treatments

[7]. Chemical treatment utilises strong oxidants, which alter soil properties and are often pH-dependent. Physical treatment applies heat, which converts crude oil-related contaminants into simpler compounds, but the compounds could still be harmful [8]. Gaseous compounds from heat treatment may require further treatment before environmental release. In addition to the effect on soil properties, health, and the environment, in-situ soil excavation is also costly and labour-intensive [7]. Besides, in-situ treatment of soil using techniques such as in-situ extraction, soil vapour extraction, air sparging and stabilisation can be employed. However, these methods require extensive site characterisation to be effective, are complicated and could be costly [8].

Phytoremediation provides a cost-effective alternative to soil remediation by expediting the removal of contaminants from the soil via physiological processes of plant and microbial activities at plant roots [9]. The use of local plant species in phytoremediation is preferred as local plant species adapt well to local climate and soil conditions, thus having a higher probability of success in growing and propagating on contaminated soil [10]. Some plants can render harmless, extract or stabilise a contaminant in soil, thus making it unavailable for other organisms and reducing environmental hazards in phytoremediation [9]. Phytoremediation involves using plants to clean up accumulated Petroleum hydrocarbon in the soil [4], as reported in numerous studies [11]. These include grasses, vegetables, legumes, cultivated crops ornamentals and some woody plants [12]. Current phytoremediation techniques require that plants live in the zone of contamination. Consequently, plant viability is a critical issue in successfully applying phytoremediation. If the contaminant in its present concentration is not phytotoxic, cultivating plants can be a valuable tool in soil remediation [13]. The mechanisms and efficiency of this technology, called phytoremediation, depend on the contaminant, bioavailability and soil properties [9]. The mechanism believed to be responsible for most of the degradation of petroleum hydrocarbons in vegetated soil is the stimulation of growth and activity of degrading microorganisms in the rhizosphere [14]. There are several approaches to selecting candidate plants for phytoremediation of soils contaminated with organic pollutants. These approaches have been based on the occurrence of plants under specific climatic conditions [15], their resistance to pollutant phytotoxicity [16], the presence of phenolic compounds in the plant root exudates [17], or their capability to reduce the pollutant concentration in soil.

Most studies on the phytoremediation of petroleum hydrocarbon-contaminated soils have employed grasses, vegetables, legumes, cultivated crops, ornamentals and some woody plants [12]. Grasses are particularly suitable for phytoremediation since they offer an increased rhizosphere zone because of their multiple ramified root systems. This increases microbial activity and growth around the root zone [18]. Researchers like [13] have concluded that grasses and legumes are the best candidates for phytoremediation or rhizoremediation because of their root systems. Bioremediation is generally considered a promising technology for the tropics because climatic conditions favour microbial growth and activity [13]. Grasses like *Panicum maximum* and *Brachiara brizantha* could degrade 55 and 63% of the oil and grease present in the contaminated soils in the tropics. Screening plant species for their ability to grow and establish in contaminated soil is one of the first steps in selecting species for phytoremediation in the tropics, followed by evaluating their influence on the degradation of petroleum hydrocarbons in soil [13]. However, little is known about tropical species that could help clean up oil contamination. A successful phytoremediation requires the plants not only to survive the contamination but also to grow and thrive. More importantly, the reclaimed site should have sufficient diversity and composition similar to the plant species before the contamination in a given location to maintain the ecological functions, such as erosion control, water conservation, and wildlife habitat. Plant species with good seed germination do not always tolerate drill cuttings or crude oil at seedling or mature stages. Furthermore, different species may have varying ability to reduce hydrocarbons in soil.

Phytodegradation is the uptake, metabolising, and degradation of contaminants within the plant or the degradation of contaminants in the soil, sediments, sludges, groundwater, or surface water by enzymes produced and released by the plant. Phytodegradation is not dependent on microorganisms associated with the rhizosphere. Contaminants subject to phytodegradation include organic compounds such as munitions, chlorinated solvents, herbicides, insecticides, and inorganic nutrients. Phytodegradation is also known as phytotransformation and is a contami-

nant destruction process. For phytodegradation to occur within the plant, the plant must be able to take up the compound. Uptake of contaminants requires that they have a moderate log kow, and laboratory experiments at the University of Washington indicated that short-chain halogenated aliphatic compounds could be taken up by plants [19]. Plants can metabolise a variety of organic compounds, including TCE (Newman *et al.,* 1997), trinitrotoluene (TNT) and the herbicide atrazine). Partial metabolism by wheat and soybean plant cell cultures was found for a variety of compounds, including 2,4-dichlorophenoxyacetic acid (2,4-D); 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), 4-chloroaniline; 3,4- dichloroaniline; PCP; diethylhexylphthalate (DEHP); perylene; benzo(a)pyrene; hexachlorobenzene; DDT; and PCBs. In phytodegradation applications, transforming a contaminant within the plant to a more toxic form, with subsequent release to the atmosphere through transpiration, is undesirable. The formation and release of vinyl chloride resulting from the uptake and phytodegradation of TCE has been a concern. However, although low TCE metabolites have been found in plant tissue [19], vinyl chloride has not been reported.

Plant-produced enzymes that metabolise contaminants may be released into the rhizosphere, where they can remain active in contaminant transformation. Plant-formed enzymes have been discovered in plant sediments and soils. These enzymes include dehalogenase, nitroreductase, peroxidase, laccase, and nitrilase [20]. These enzymes are associated with transformations of chlorinated compounds, munitions, phenols, the oxidative step in munitions, and herbicides, respectively. In one week, the dissolved TNT concentrations in flooded soil decreased from 128 ppm to 10 ppm in the presence of the aquatic plant parrot feather (Myriophyllum aquaticum), which produces a nitroreductase enzyme that can partially degrade TNT [20]. The nitroreductase enzyme has also been identified in various algae, aquatic plants, and trees [20]. Hybrid poplar trees metabolised TNT to 4-amino-2,6-dinitrotoluene (4-ADNT), 2-amino-4,6-dinitrotoluene (2-ADNT), and other unidentified compounds in laboratory hydroponic and soil experiments.

Tiger nut Grass (*Cyperus esculentus*) is a crop of the sedge family widespread worldwide [21]. It is found in most Eastern Hemisphere, including Southern Europe, Africa and Madagascar, the Middle East and the Indian subcontinent [22]. *C. esculentus* is cultivated for its edible tubers, earth almonds or tiger nuts, as a snack food and for preparing *horchata de chufa*, a sweet, milk-like beverage. Tiger nut *(Cyperus esculentus)* was one of the oldest cultivated plants in prehistoric and Ancient Egypt, where it was an important food. Roots of wild chufa have been found at Wadi Kubbaniya, north of Aswan, dating to around 16,000 BC [23]. Dry tubers also appear later in tombs of the Predynastic period, around 3000 BC. During that time, *C. esculentus* tubers were consumed as food, either boiled in beer, roasted or as sweets made of ground tubers with honey [24]. They were also used in various ways as medicine (Defelice, 2002). The modern name for tiger nuts in Egypt is *Hab el Aziz in Arabic, meaning grains of Al-Aziz,* named after the Fatimid ruler who was reputedly fond of it (Hab' el Aziz).

This study aims to determine the grass's potential (*Cyperus Esculentus*) in remediating petroleum hydrocarbon-contaminated soil.

METHODS

Sample Collection. Soil samples were collected as composite topsoil samples at 0–20 cm depth from the University of Maiduguri football pitch. The samples were air-dried and sieved to remove debris. Petroleum hydrocarbon (crude oil) was obtained (purchased) from Kaduna refinery, Kaduna state. Seeds of the Tiger Nut (*Cyperus Esculentus*) grass plants were purchased from Monday market in Maiduguri, Borno state. Samples collected were labelled with unique identification numbers.

Laboratory Experimental Design. Four groups of experimental pots were prepared. Each group had four sets of replicate experimental pots for statistical analysis. A control experimental pot was also being prepared. An experimental pot in each group contained 2.5 kg of soil, contaminated (mixed) with 5, 15, 25 and 35 g/Kg of the crude oil obtained. Another set of experiments amended with a constant 75.0 g of cow dung was prepared. This is to catalyse the growth and efficiency of the grass plants. All the mixing was done with a small quantity of water, and we were allowed to stand for seventy-two hours before sowing/planting the grasses. An equal number of viable seeds of the grasses were seeded into the pots, including the control. Experiments were exposed to natural daylight and temperature. The pots were watered sufficiently to maintain

constant moisture and minimise leachate generation. Polyvinyl chloride (PVC) pans were placed under each pot to collect leachate in case of spillage. Collected leached water was included in the next watering to avoid petroleum hydrocarbon loss. Plant growth was monitored every 10 days from the date of planting. This research was conducted for approximately twelve weeks, during which soil and plant samples were taken to the laboratory for further analytical procedures.

Sample Preparation and Analysis. At the end of the experiment, fresh weights of the shoots and roots of the plants were taken by cutting at the base, and the length of the plants was determined. The roots were carefully separated from the soil and rinsed. The partitioned plant parts (shoots and roots) were then oven-dried at 65°C to a constant weight, and dry matter yield was determined [25].

After removing the plants, the Phytochemical properties of the soil were determined before, during, and after the experiments. 5 g of soil sample from each experimental pot, including the control, were acidified with Hydrochloric acid (HCl) to pH2 and dehydrated with Magnesium sulphate ($MgSO_4$). Soxhlet extraction with dichloromethane (DCM) was done for about eight hours. The extract obtained was passed through a filter paper (Whatman No.4) with approximately 1 g Sodium sulphate (Na_2SO_4). The solvent was then evaporated, and the constant weight of the dry extract was determined. The total petroleum hydrocarbon (TPH) percentage was then calculated based on the soil dry weight [13]. The degradation of TPH was obtained by subtracting the TPH values of different treatments (after) from the initial (before) TPH values.

Data Handling. Analysis of variance (ANOVA) using SPSS version 20.0 was used to assess whether the TPH concentration varied significantly between treatments. A significant level less than 0.05 ($p<0.05$) was used throughout the experiment.

RESULTS AND DISCUSSION

Physiochemical parameters for non-contaminated soil Samples. Table 1 summarises the results of Physicochemical parameters for non-contaminated soil Samples. The levels of the Physiochemical parameters decrease with the increase in the soil depth from 0-15 cm to 15-30 cm except for O.C, O.M, C: N, clay and silt.

The result revealed that at a depth of 0-15 cm and 15-30 cm, the levels of pH are 6.96±0.02 and 4.10±0.05 respectively, and the less acidic nature of the soil is generally within the range for soil in the region, the values of pH are in line with that of [26]. A very low Electric Conductivity was observed in the experimental soil (0.24±0.02 and 0.05±0.02); EC does not directly affect plant growth but can be used to indicate the amount of nutrients available for uptake by plants and the salinity levels of soils, which can impede growth and microbial activity. Also, a low calcium concentration Ca^{2+} (9.35±0.34 and 6.5±0.12) was observed in the soil sample, which is lower than the value (9.92) observed by [26].

In a similar study [26], the level of CEC (13.84) obtained is within the range of the present study, which are 18.29±0.06 and 9.67±0.02 for 0-15 cm and 15-30 cm, respectively, CEC measures the ability of soil to allow for mobility of electron within the soils. The concentration of Magnesium (13.24±0.24 and 3.40±0.02) and potassium (6.52±0.00 and 0.20±0.0) obtained in the present study are higher than that obtained by [26], which is 1.25 and 1.96 respectively. Also, the concentration (0.94) of sodium obtained by [26] is higher than that obtained in the present study, which is 0.15±0.04 and 0.07±0.03. ECEC are 23.29±0.82 and 9.97±0.04. Base sat. are 98.10±0.56 and 96.99±0.45, E.A ($cmol^{(+)}/kg$) are 0.61±0.08 and 0.3±0.01.

The level of nitrogen observed in the present (0.77±0.01 and 0.25±0.01) is higher than that obtained by [26], which is (0.27). The levels of Organic Carbon observed in the present study are 0.25±0.04 and 1.0±0.00 (%).

Similarly, authors [27] obtained 0.85 %, which aligns with the present study of 0.34 and 1.78 %. C: N (%) are 2.57±0.33 and 4.15±0.04. The concentration (mg/kg) of phosphorus obtained in this study, which are 16.10±0.29 and 15.40±0.03, are in line with the value (15.64) obtained by [26].

The percentage of clay obtained in the present study is 17.3±0.06 and 19.8±0.02, which are very low compared with that of [26], which is (61.9%.). An appreciable amount of silt was observed in both samples (17.4±0.02 and 25.04±0.00), which is higher than that obtained by [26], which is 14.47% silt improves the soil, resulting in better plant growth. The taxonomic classification of the soil are Sandy-loam and Sandy-loam, respectively.

Table 1 – Physiochemical parameters for non-contaminated soil Samples

Depth (cm)	pH	EC	cmol(+)/kg soil							%					mg/kg soil	%			Textural
	01:02.5	dsm^{-1}	E.A	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	CEC	ECEC	Base sat.	N	O.C	O.M	C:N	P	Clay	sand	silt	class
0-15	6.96 ±0.02	0.24 ±0.02	0.61 ±0.08	9.35 ±0.34	13.24 ±0.24	6.52 ±0.00	0.15 ±0.04	18.29 ±0.06	23.29 ±0.82	98.10 ±0.56	0.77 ±0.01	0.25 ±0.04	0.31 ±0.02	2.57 ±0.33	16.10 ±0.29	17.30 ±0.06	65.30 ±0.23	17.40 ±0.02	Sandy loam
15-30	4.10 ±0.05	0.05 ±0.00	0.30 ±0.01	6.50 ±0.12	3.40 ±0.02	0.20 ±0.01	0.07 ±0.03	9.67 ±0.02	9.97 ±0.40	96.99 ±0.45	0.25 0.01	1.00 ±0.00	1.78 ±0.02	4.15 ±0.04	15.40 ±0.03	19.80 ±0.02	55.30 ±0.18	25.04 ±0.00	Sandy loam

Notes: EC=Electrical Connectivity; CEC=Cation Exchange Capacity; E. A= Exchangeable Acidity; ECEC= Effective Cation Exchange Capacity; O.M= Organic Matter; O.C= Organic Content

Plants growth parameters. Figure 1 shows the result of the Seed Germination of the *axonopus fissifolius*.

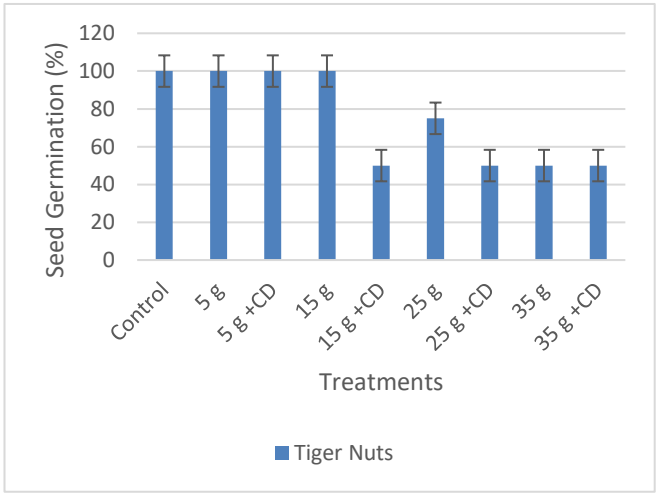

Figure 1 – Seed germination percentage under different concentrations of total petroleum hydrocarbon (TPH)

Notes: CD= Cow Dung

The result revealed that all the planted seeds in the different concentrations or treatments of the TPH (including control) germinated except tiger nut treated with 15 g with cow dung, 25 g, 25 g with cow dung, 35 g and 35 g with cow dung which germinated with 50%, 75%,50%, 50% and 50% respectively. In such a situation, it is eminent that plant germination, and consequently growth, is interfered with. Moreover, aerated and nutrient-rich soils present the potential factors for seed germination and plant growth [26].

Figure 2 shows the result of the height of the Tiger nut (*Cyperus esculentus)* every ten days for eighty days.

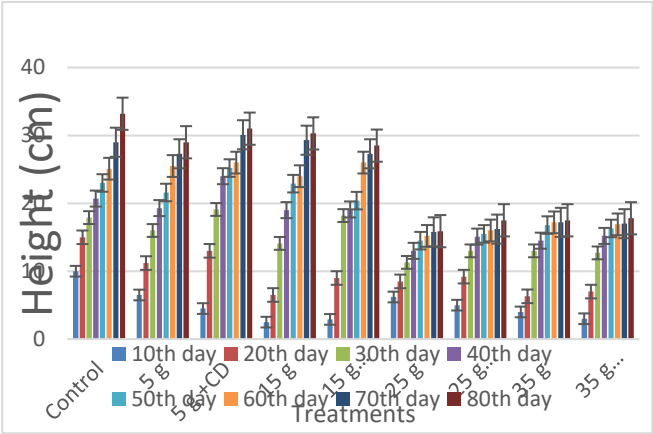

Figure 2 – Tiger Nut Height

Notes: CD= Cow Dung

The result revealed an increase in the plants' height every ten days for all the plants in each treatment. Generally, there is a decrease in the plant's height, and the mass or concentration of the TPH increases relatively. The highest plant heights are observed in the control on the 80th day, followed by the soil treated with 5g of TPH and Cow dung, while the lowest heights are observed in the pots treated with 25g of TPH on the 10th day. At about the 50th day, 25g and 35g started withering, while by the 60th day, 25g and 35g with cow dung started withering, and all died before the 80th day, respectively. It was observed that there was a reduction in the height and root length of plants in contaminated samples as compared to the control sample, which corresponds to the findings made by [25]. Contamination of petroleum in soil has adverse effects on plant morphology and anatomy. Reduction in plant height is a typical response caused by petroleum hydrocarbon contamination [28]. This result of the present study is in line with the above.

The results of the present study are also in line with that [26]. According to [26], four months after planting, all the plant species displayed a

significant decrease in plant height compared to the control. The plant height response varied with the presence of different concentrations of TPH. The plants in the control treatment grew taller than in the hydrocarbon-contaminated soil at 25, 50, and 75 g/kg, implying that TPH had an adverse effect. As earlier indicated, plant nutrients, air and water tremendously reduce with increased in concentration of TPH in the soil. Deficiency in these conditions results in stunted plant growth. Similar results were reported in separate studies [29], which observed that excessive hydrocarbons in a plant environment affect oxygen and nutrient transfer as they cover the roots and pores. It leads to asphyxiation of subsurface roots, especially in fine-textured (clay) or shallow soils with impervious subsoils. The small fibrous roots are deprived of oxygen, leading to their death. In totality, this impairs the root system, making it unable to supply the necessary water to replace that transpired by the leaves. This causes a water shortage, leading to withering and/or death of plants. Besides height, all plant species in the control treatment exhibited the greatest mean values for destructive pot plant biomass [26].

Physiochemical parameters for contaminated soil Samples. Tables 2 to 16 show the results of the levels of the Physiochemical parameters for the contaminated soil samples for Tiger Nut (*Cyperus Esculentus*) before, during and after the experiment with the different concentrations of the petroleum hydrocarbon.

Table 2 – Levels of pH values for contaminated soil sample

Tiger nut	5g			15g			25g			35g		
	Before	During	After	Before	During	After	Before	During	After	Before	During	After
Unamended	6.67a ±0.12	6.84a ±0.06	5.90a ±0.04	6.97a ±0.02	5.11a ±0.09	5.05a ±0.07	6.95a ±0.03	5.32a ±0.02	5.26a ±0.03	6.88a ±0.02	5.71a ±0.02	5.19a ±0.04
Amended	6.91a ±0.01	6.14b ±0.01	7.12b ±0.02	6.88a ±0.02	5.75b ±0.02	7.06b ±0.00	6.94a ±0.01	3.63b ±0.04	6.99b ±0.16	6.95a ±0.02	5.10b ±0.01	6.95b ±0.03
Control	6.96a ±0.02	6.68a ±0.19	5.22a ±0.22	6.96a ±0.02	6.68c ±0.19	5.22a ±0.22	6.96a ±0.02	6.68c ±0.19	5.22a ±0.22	6.96a ±0.02	6.68c ±0.19	5.22a ±0.22

Notes: N= 4 replicates. Within the columns, means with different alphabet are statistically different ($p<0.05$)

Table 3 – Concentration of EC(Dsm^{-1}) values for contaminated soil sample

Tiger nut	5g			15g			25g			35g		
	Before	During	After	Before	During	After	Before	During	After	Before	During	After
Unamended	0.02a ±0.00	0.06a ±0.01	0.13a ±0.01	0.06aa ±0.00	0.04a ±0.08	0.10a ±0.02	0.70a ±0.01	0.05a ±0.02	0.10a ±0.02	0.07a ±0.01	0.05a ±0.00	0.13a ±0.01
Amended	0.03a ±0.01	0.06a ±0.01	0.14a ±0.00	0.03b ±0.01	0.07a ±0.02	0.13a ±0.01	0.02a ±0.00	0.08a ±0.00	0.13a ±0.00	0.01a ±0.00	0.08a ±0.00	0.14a ±0.00
Control	0.24a ±0.02	0.21b ±0.02	0.13a ±0.02	0.24a ±0.02	0.21b ±0.02	0.13a ±0.02	0.24b ±0.02	0.21b ±0.02	0.13a ±0.02	0.24b ±0.02	0.21b ±0.02	0.13a ±0.02

Notes: N= 4 replicates. Within the columns, means with different alphabet are statistically different ($p<0.05$)

Table 4 – Concentration of EA values for polluted soil sample

Tiger nut	5g			15g			25g			35g		
	Before	During	After	Before	During	After	Before	During	After	Before	During	After
Unamended	0.50a ±0.08	3.45a ±0.20	0.47a ±0.12	0.80a ±0.08	2.67a ±0.12	0.52a ±0.95	0.92a ±0.09	3.17a ±0.09	0.47a ±0.95	0.97a ±0.09	3.55a ±0.10	0.42a ±0.05
Amended	0.47a ±0.09	2.70b ±0.47	0.22b ±0.09	0.22b ±0.09	2.12b ±0.12	0.15b ±0.57	0.42b ±0.50	3.37a ±0.05	0.45a ±0.05	0.30b ±0.81	2.62b ±0.15	0.47a ±0.95
Control	0.61a ±0.08	1.92b ±0.42	0.46a ±0.05	0.61a ±0.08	1.92b ±0.42	0.46a ±0.05	0.61c ±0.08	1.92b ±0.42	0.46a ±0.05	0.61c ±0.08	1.92c ±0.42	0.46a ±0.05

Notes: N= 4 replicates. Within the columns, means with different alphabet are statistically different ($p<0.05$)

Table 5 – Concentration of Calcium in the soil sample

Tiger nut	5g			15g			25g			35g		
	Before	During	After	Before	During	After	Before	During	After	Before	During	After
Unamended	2.20a ±0.16	6.87a ±0.15	8.87a ±0.15	2.70a ±0.08	5.20a ±0.17	8.30a ±0.25	2.92a ±0.15	5.60a ±0.18	11.02a ±0.26	5.47a ±0.15	9.37a ±0.12	9.12a ±0.18
Amended	2.25a ±0.09	7.15a ±0.10	8.97a ±0.05	2.87a ±0.15	8.07b ±0.15	9.65a ±0.90	2.27b ±0.15	7.12b ±0.09	13.17b ±0.30	2.05b ±0.19	7.12b ±0.15	7.87b ±0.22
Control	9.35b ±0.34	3.15b ±0.31	14.29b ±0.21	9.35b ±0.34	3.15c ±0.31	14.29b ±0.21	9.35c ±0.34	3.15c ±0.31	14.29c ±0.21	9.35c ±0.34	3.15c ±0.31	14.29c ±0.21

Notes: N= 4 replicates. Within the columns, means with different alphabet are statistically different (p<0.05)

Table 6 – Concentration of Magnesium in the soil sample

Tiger nut	5g			15g			25g			35g		
	Before	During	After	Before	During	After	Before	During	After	Before	During	After
Unamended	3.55a ±0.05	3.22a ±0.12	5.30a ±0.18	3.17a ±0.12	7.62a ±0.05	5.20a ±0.14	5.40a ±0.18	0.40a ±0.21	3.27a ±0.15	1.47a ±0.09	5.52a ±0.05	4.50a ±0.08
Amended	8.32b ±0.09	4.22b ±0.12	8.55b ±0.26	7.27b ±0.09	2.04b ±0.10	3.20b ±0.14	6.45b ±0.05	6.62b ±0.17	4.47b ±0.18	5.02b ±0.12	2.60b ±0.08	8.12b ±0.15
Control	13.24c ±0.24	3.57a ±0.38	4.63c ±0.43	13.24c ±0.24	3.57c ±0.38	4.63c ±0.43	13.24c ±0.24	3.57c ±0.38	4.63b ±0.43	13.24c ±0.24	3.57c ±0.38	4.63c ±0.43

Notes: N= 4 replicates. Within the columns, means with different alphabet are statistically different (p<0.05)

Table 7 – Concentration of Potassium in the soil sample

Tiger nut	5g			15g			25g			35g		
	Before	During	After	Before	During	After	Before	During	After	Before	During	After
Unamended	3.15a ±0.05	0.63a ±0.01	0.15a ±0.00	3.08a ±0.00	0.75a ±0.01	0.23ab ±0.00	3.30a ±0.11	0.72a ±0.00	0.14a ±0.00	3.47a ±0.00	0.72a ±0.01	0.21a ±0.01
Amended	6.52b ±0.00	0.66a ±0.00	0.21b ±0.00	5.38b ±0.00	2.26a ±3.15	0.26a ±0.01	5.39b ±0.00	0.70a ±0.01	0.25b ±0.01	6.32b ±0.17	0.70a ±0.00	0.21a ±0.01
Control	0.14c ±0.00	0.59a ±0.07	0.21b ±0.02	0.14c ±0.00	0.59a ±0.07	0.21b ±0.02	0.14c ±0.00	0.59b ±0.07	0.21b ±0.02	0.14c ±0.00	0.59b ±0.07	0.21a ±0.02

Notes: N= 4 replicates. Within the columns, means with different alphabet are statistically different (p<0.05)

Table 8 – Concentration of Sodium in the soil sample

Tiger nut	5g			15g			25g			35g		
	Before	During	After	Before	During	After	Before	During	After	Before	During	After
Unamended	0.20a ±0.00	1.65a ±0.05	0.85a ±0.00	0.10a ±0.01	3.47a ±0.01	0.81a ±0.02	0.15a ±0.00	1.73a ±0.00	0.76a ±0.01	0.22a ±0.00	0.62a ±0.01	0.75a ±0.01
Amended	0.79b ±0.00	1.73a ±0.00	0.71b ±0.17	0.38b ±0.03	3.49a ±0.02	0.75b ±0.01	0.46b ±0.01	1.61b ±0.01	0.67b ±0.02	0.72b ±0.02	1.59b ±0.01	0.70a ±0.02
Control	0.15a ±0.04	0.56b ±0.02	0.70b ±0.020	0.15a ±0.04	0.56b ±0.02	0.70b ±0.020	0.15a ±0.04	0.56c ±0.02	0.70b ±0.020	0.15a ±0.04	0.56a ±0.02	0.70a ±0.020

Notes: N= 4 replicates. Within the columns, means with different alphabet are statistically different (p<0.05)

Table 9 – Concentration of CEC in the soil sample

Tiger nut	5g			15g			25g			35g		
	Before	During	After	Before	During	After	Before	During	After	Before	During	After
Unamended	9.14a ±0.09	12.58a ±0.11	15.4a ±0.10	9.10a ±0.14	17.00a ±0.01	14.21a ±0.31	11.68a ±0.22	8.26a ±0.29	15.46a ±0.07	10.79a ±0.09	16.29a ±0.11	14.48a ±0.42
Amended	18.29b ±0.06	13.15b ±0.65	18.63b ±0.10	15.37b ±0.59	14.40b ±0.14	15.86b ±0.64	14.36b ±0.33	15.88b ±0.17	18.92b ±0.12	13.98b ±0.37	11.95b ±0.06	16.73b ±0.35
Control	23.00c ±0.23	7.62a ±0.07	19.33c ±0.25	23.00c ±0.23	7.62c ±0.07	19.33c ±0.25	23.00c ±0.23	7.62c ±0.07	19.33b ±0.25	23.00c ±0.23	7.62c ±0.07	19.33c ±0.25

Notes: N= 4 replicates. Within the columns, means with different alphabet are statistically different (p<0.05)

Table 10 – Concentration of ECEC in the soil sample

Tiger nut	5g			15g			25g			35g		
	Before	During	After	Before	During	After	Before	During	After	Before	During	After
Unamended	9.92a ±0.18	16.08a ±0.43	15.98a ±0.14	9.95a ±0.30	19.57a ±0.43	15.24a ±0.45	13.00a ±0.15	11.86a ±0.21	15.98a ±0.14	11.97a ±0.14	19.94a ±0.05	15.15a ±0.15
Amended	19.05b ±0.31	16.80a ±0.26	18.99b ±0.23	16.66b ±0.34	16.88b ±0.19	16.66b ±0.35	15.01b ±0.21	19.73b ±0.23	19.20b ±0.05	14.86b ±0.10	14.80b ±0.14	17.22b ±0.16
Control	23.29c ±0.82	10.66c ±0.56	18.96c ±0.44	23.29b ±0.82	10.66c ±0.56	18.96c ±0.44	23.29c ±0.82	10.66c ±0.56	18.96b ±0.44	23.29c ±0.82	10.66c ±0.56	18.96c ±0.44

Notes: N= 4 replicates. Within the columns, means with different alphabet are statistically different (p<0.05)

Table 11 – Levels of Base Saturation in the soil sample

Tiger nut	5g			15g			25g			35g		
	Before	During	After	Before	During	After	Before	During	After	Before	During	After
Unamended	94.75a ±0.12	78.64a ±0.31	96.03ab ±0.21	91.43a ±0.82	85.79a ±0.24	95.90a ±0.39	91.66a ±0.67	72.35a ±0.47	96.85a ±0.47	90.77a ±0.38	81.70a ±0.32	97.03a ±0.35
Amended	97.57b ±0.31	82.33b ±0.46	97.84a ±0.48	98.34b ±0.27	86.07a ±0.20	98.45b ±0.38	97.10b ±0.30	82.70b ±0.23	97.45a ±0.40	97.01b ±0.89	81.30a ±0.28	97.88a ±0.40
Control	98.10b ±0.56	77.69a ±2.37	96.65b ±1.51	98.10b ±0.56	77.69b ±2.37	96.65a ±1.51	98.10b ±0.56	77.69b ±2.37	96.65a ±1.51	98.10b ±0.56	77.69b ±2.37	96.65a ±1.51

Notes: N= 4 replicates. Within the columns, means with different alphabet are statistically different (p<0.05)

Table 12 – Concentration of Nitrogen in the soil sample

Tiger nut	5g			15g			25g			35g		
	Before	During	After	Before	During	After	Before	During	After	Before	During	After
Unamended	0.16a ±0.04	0.21a ±0.01	0.22a ±0.00	0.07a ±0.01	8.26a ±15.82	0.26a ±0.00	0.14a ±0.03	0.29a ±0.02	0.28a ±0.00	0.13a ±0.00	0.41a ±0.01	0.21a ±0.00
Amended	0.13a ±0.00	0.25a ±0.01	0.22a ±0.00	0.13b ±0.02	0.34a ±0.02	0.27a ±0.02	0.71b ±0.00	0.38b ±0.00	0.30a ±0.01	0.26b ±0.03	0.32b ±0.01	0.31b ±0.00
Control	0.77b ±0.01	0.51b ±0.07	0.28a ±0.07	0.77a ±0.01	0.51a ±0.07	0.28a ±0.07	0.77c ±0.01	0.51c ±0.07	0.28a ±0.07	0.77a ±0.01	0.51c ±0.07	0.28ab ±0.07

Notes: N= 4 replicates. Within the columns, means with different alphabet are statistically different (p<0.05)

Table 13 – Concentration of Organic Carbon in the soil sample

Tiger nut	5g			15g			25g			35g		
	Before	During	After	Before	During	After	Before	During	After	Before	During	After
Unamended	0.35a ±0.00	0.83a ±0.04	0.74a ±0.03	0.20a ±0.08	1.53a ±0.04	1.03a ±0.06	0.34a ±0.03	1.12a ±0.04	1.07a ±0.09	0.55a ±0.03	1.55a ±0.03	0.96a ±0.01
Amended	0.47b ±0.00	1.01a ±0.08	0.71ab ±0.01	0.40b ±0.01	1.37a ±0.20	0.98a ±0.02	0.51b ±0.03	1.55b ±0.04	1.07a ±0.08	0.98b ±0.02	1.32a ±0.02	0.97a ±0.09
Control	0.25c ±0.04	2.18b ±0.34	0.67b ±0.02	0.25a ±0.04	2.18b ±0.34	0.67b ±0.02	0.25c ±0.04	2.18c ±0.34	0.67b ±0.02	0.25c ±0.04	2.18b ±0.34	0.67b ±0.02

Notes: N= 4 replicates. Within the columns, means with different alphabet are statistically different (p<0.05)

Table 14 – Concentration of Organic Matter in the polluted soil sample

Tiger nut	5g			15g			25g			35g		
	Before	During	After	Before	During	After	Before	During	After	Before	During	After
Unamended	0.58a ±0.05	1.51a ±0.01	1.36a ±0.03	0.38a ±0.03	2.68a ±0.05	1.72a ±0.07	0.59a ±0.02	1.98a ±0.06	1.65a ±0.05	1.03a ±0.08	2.59a ±0.06	1.69a ±0.02
Amended	0.81b ±0.01	1.81a ±0.01	1.30ab ±0.02	0.70b ±0.02	2.14a ±0.18	1.69a ±0.02	0.87b ±0.04	2.80b ±0.05	2.14b ±0.23	1.78b ±0.15	2.14a ±0.11	1.88b ±0.02
Control	0.31c ±0.02	3.55b ±0.77	1.16b ±0.05	0.31a ±0.02	3.55b ±0.77	1.16b ±0.05	0.31c ±0.02	3.55c ±0.77	1.16c ±0.05	0.31c ±0.02	3.55b ±0.77	1.16c ±0.05

Notes: N= 4 replicates. Within the columns, means with different alphabet are statistically different (p<0.05)

Table 15 Concentration of C:N in the soil sample

Tiger nut	5g			15g			25g			35g		
	Before	During	After	Before	During	After	Before	During	After	Before	During	After
Unamended	3.19a ±0.01	4.19ab ±0.05	3.50a ±0.07	2.84a ±0.04	4.09ab ±0.04	3.65a ±0.04	2.87a ±0.08	4.06a ±0.05	3.47a ±0.03	3.76a ±0.05	3.68a ±0.07	4.29a ±0.14
Amended	3.30a ±0.03	3.89a ±0.07	3.49a ±0.03	3.06ab ±0.08	3.85a ±0.04	3.91a ±0.06	2.85a ±0.05	3.94a ±0.11	3.96b ±0.05	3.56a ±0.06	3.97ab ±0.10	3.11b ±0.23
Control	2.57b ±0.33	4.60b ±0.08	3.25a ±0.17	2.57b ±0.33	4.60b ±0.08	3.25b ±0.17	2.57a ±0.33	4.60a ±0.08	3.25a ±0.17	2.57b ±0.33	4.60b ±0.08	3.25b ±0.17

Notes: N= 4 replicates. Within the columns, means with different alphabet are statistically different ($p<0.05$)

Table 16 – Concentration of Phosphorus in the oil sample

Tiger nut	5g			15g			25g			35g		
	Before	During	After	Before	During	After	Before	During	After	Before	During	After
Unamended	18.94a ±0.11	3.12a ±0.07	10.25a ±0.35	19.19a ±0.40	3.79a ±0.05	7.76a ±0.32	17.88a ±0.09	4.80a ±0.63	12.02a ±0.68	16.87a ±0.22	1.73a ±0.06	14.54a ±0.61
Amended	22.35b ±0.23	1.77b ±0.02	16.07b ±0.71	21.6b ±0.40	4.88a ±0.04	9.61b ±.0.55	19.35b ±0.17	12.81b ±0.42	9.12b ±0.78	15.91a ±1.00	3.77b ±0.08	12.16a ±0.76
Control	16.10c ±0.29	1.52b ±0.38	8.62c ±0.44	16.10c ±0.29	1.52b ±0.38	8.62ab ±0.44	16.10c ±0.29	1.52c ±0.38	8.62b ±0.44	16.10a ±0.29	1.52a ±0.38	8.62b ±0.44

Notes: N= 4 replicates. Within the columns, means with different alphabet are statistically different ($p<0.05$)

The result revealed irregular variation in the levels of Physiochemical parameters before, during and after the experiment. Generally, amended soils have the highest physiochemical parameter values compared to the corresponding unamended soil. In a similar work carried out by [30], for all results, there is a reduction in the pH value as time progresses. The result showed that the soil becomes more acidic for all sample mixtures as time progresses, which aligns with the present study. The results show that as the concentration of petroleum hydrocarbon increases, the value of organic carbon also increases for amended and unamended soil samples. Generally, it can be seen that the addition of cow dung shows a significant increase in the value of the organic matter. This is also in line with the present study.

Concentration of TPH in the contaminated soil sample. Table 17 shows the results of the concentration of TPH value in the contaminated soil sample for Tiger nut (*Cyperus esculentus*) before and after the experiment with the different concentrations of the Petroleum Hydrocarbon, respectively**.**

Table 17 – Concentration of TPH values for polluted soil sample

Tiger nut	5g			15g			25g			35g		
	Before	After	%	Before	After	%	Before	After	%	Before	After	%
Unamended	0.62a ±0.00	0.58a ±0.01	6	0.62a ±0.01	0.59a ±0.01	4	0.70ab ±0.08	0.68a ±0.06	3	0.81a ±0.04	0.79a ±0.01	2
Amended	0.66b ±0.03	0.12b ±0.01	82	0.78b ±0.00	0.43b ±0.02	45	0.64b ±0.00	0.60b ±0.00	6	0.65b ±0.01	0.62b ±0.02	5

Notes: N= 4 replicates. Within the columns, means with different alphabet are statistically different ($p<0.05$)

There is a decrease in the values of TPH for all samples considered after the phytoremediation. The result revealed that the highest value of TPH (0.81±0.04) was observed in an unamended Tiger nut pot treated with 35g TPH before the experiment with the least parentage reduction of 2%. In comparison, the lowest value of TPH (0.12±0.01) was observed in the amended Tiger nut pot treated with 5g TPH with the highest parentage reduction of 82%. There is a statistical difference between the mean values of TPH in the experiment.

The relative potential or efficiency (parentage reduction) of the grasses remediating the TPH-contaminated soils with the different concentrations of the Petroleum Hydrocarbon is in the or-

der 5g> 15g> 25g>35g. Generally, the phytodegradation of the TPH-contaminated soil using tiger nuts is higher when amended with cow dung than when unamended.

Authors [31] carried out Phytoremediation of Petroleum Hydrocarbons Using Jatropha curcas in Soils Contaminated with Spent Engine Oil (SEO). From the results, soil pH, Total Nitrogen, Potassium and %sand significantly decreased (P ≤0.05) by 3%, 68%, 7% and 3% respectively while organic carbon (O.C), organic matter (O.M), available phosphate,, exchangeable bases (EB), Cation Exchange Capacity (CEC), %Silt and % clay significantly (P ≤0.05) increased by 200%, 200%, 2%, 2%, 1%, 9% and 6% respectively after contamination with spent engine oil. This agrees with the findings [32]. On the contrary, authors [28] documented that SEO did not affect the soil's pH. Still, Organic Carbon and Total Nitrogen in the contaminated soils increased compared to the control, while phosphate decreased due to contamination with spent engine oil. These factors (type and oil dosage) may have attributed to the significant increase in the properties of soil samples used in this study [31].

In a similar work by [33], TPH concentration decreased the values of TPH for all samples considered. The decrease for sample B was very minute compared to sample D when cow dung was not added, and a similar result was also noticed for C and E. The addition of cow dung reduced the concentration of the TPH in the soil for both 75 g and 150 g crude oil contaminations. In their assertion, [34] state that adding cow dung manure improves calcium, Magnesium, phosphorus, potassium, and nitrogenous contents, which are vital for plant species' better growth. The percentage degradation of TPH in soils amended with poultry droppings was higher (52%) than in non-amended soils (45%). This might be because poultry droppings are biostimulants that contain appreciable amounts of hydrocarbon utilisers readily available to degrade, eliminate or transform TPH and allow the plants to grow. This is similar to the findings of [35], with reports that 68% and 12% TPH degradation were recorded in soil samples amended with poultry droppings and non-amended soils, respectively, using the Hibiscus cannabinus L. plant. Authors [27] reported 89.6% and 96.6% in soils contaminated with 2.5% and 1% oil, respectively, after amendments with Banana skin (BS) and brewery-spent grain (BSG) for about 180 days. Authors [36] also opined that applying soil amendment appears to be a valuable option for the phytoremediation of Petroleum Hydrocarbons contaminated soil because it enables great vegetative coverage and increases the rate of Petroleum Hydrocarbons removal in soil. This suggests that organic amendments enhanced the phytoremediation potential of Jatropha curcas. The results showed that all vegetated pots had higher crude oil removal than the control. Epipremmum aureum demonstrated the highest ability of crude oil removal, with 50.4% of crude oil removed, followed by Imperata cylindrica (39.5%), Pteris vittata (36%) and Mucuna bractea (30.9%). This finding rhymes with the observations made in numerous studies in which it is reported that grasses (Poaceae) and legumes (Leguminosae) are effective in the cleanup of contaminants from the environment [11, 13]. More light on the suitability of legumes and plant species is shed by [11, 13], who conclude that grasses and legumes are the best candidates for the phytoremediation process owing to their multiple and larger root surface area. Further, they espouse that legumes can fix atmospheric nitrogen by potentially replenishing what is lost from the soil during oil spills.

Similar observations have been reported regarding using plant- and animal-derived organic waste in the bioremediation of soil contaminated with petroleum hydrocarbons. Authors [33] used organic manure made up of rice straw and pig dung to bio-stimulate the degradation of oily sludge. They obtained a TPH reduction of 58.2% in a remediation period of 360 days, while [29] their investigation on the kinetic model and half-life study of Bonny light crude oil amended with crop residue and animal-derived organic manure confirms that the use of crop residue and animal-derived organic manure improved the rate of biodegradation of hydrocarbon in a crude oil contaminated soil.

Phytoremediation is an innovative technology that uses plants to remove and/or degrade environmental contaminants such as heavy metals and organic compounds. This technology is environmentally friendly and potentially cost-effective [36]. In this study, an assessment of remediation was done to observe the remediation potential of crude oil-contaminated soil using *Cyperus esculentus,* where the grass demonstrated its ability to absorb crude oil contamination from the soil.

CONCLUSIONS

In this study, the technology for phytodegradation is simple, effective, inexpensive and environmentally friendly. This study shows that the Tiger Nut seeds could germinate partially and grow in the different concentrations of TPH in the soil. The relative potential or efficiency (parentage reduction) of the grasses remediating the TPH-contaminated soils with the different concentrations of the Petroleum Hydrocarbon is in the order 5g> 15g> 25g>35g. The phytodegradation of the TPH-contaminated soil using tiger nut is higher when amended (with an average of 35% percentage reduction) with the cow dung than the unamended (with an average of 4% percentage reduction). It is therefore concluded that the Tiger Nut (with an overall 20% percentage reduction) has a low potential for the degradation of TPH-contaminated soil.

Replanting Tiger Nut with organic manure (cow dung) can be done after 80 days to improve the cleanup activity of the plant samples since the plant samples died on the 80th day.

Other local plants should be investigated for tolerance with different crude oil concentrations to increase phytoremediation.

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