

Remediation of Polycyclic Aromatic Hydrocarbon (Pah) and Total Petroleum Hydrocarbon (Tph) With *Megathyrsus Maximus*: A Field Study

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Abstract

The study explored the field phytoremediation of hydrocarbon contaminated soils with selected native grasses. Greenhouse experiment for the selection and screening of four (4) native plants that was undertaken as pilot studies for the remediation of diesel contaminated soils. "The plant *Megathyrsus maximus* (Guinea grass) amended with poultry manure has proven a positive potential for use in the phytoremediation of diesel contaminated soils. The field studies was performed on an experimental/simulated site within the campus vicinity. Four different subplots were designed as the experimental plots for both contaminated soils and uncontaminated soils. All subplots were tilled and homogenized for experimental determination. Laboratory physiochemical tests on both the contaminated and uncontaminated soil samples were carried out to obtain the physical and chemical parameters of the soil samples. Gas Chromatograph-Mass Spectrometer (GC-MS) analysis was used to identify and quantify the volatile organic compounds (VOCs) present in the contaminated and uncontaminated soil samples. The laboratory tests revealed some microstructural changes within the soil structure due to hydrocarbon contamination. The liquid limit value for the uncontaminated subplot soil is 30.3% relative to 33.4% for the contaminated subplot soils, while the plastic limit value for the uncontaminated subplot soil is 15.2% relative to 18.4% for the contaminated subplot soils. There is a 10% increase in the moisture content of the contaminated subplot soil relative to the uncontaminated subplot. Phytoremediation parameters such as the soil pH, Electrical Conductivity (EC), CEC and Exchangeable bases all showed improved field remediation parameters after 16 weeks of the field study, indicating positive remediation activity. The Polycyclic Aromatic Hydrocarbon (PAH) and Total Petroleum Hydrocarbon (TPH) contaminants from the hydrocarbon contamination were degraded from the soil. PAH values were reduced to 3.77% in the contaminated subplot (contaminated soil with 20% diesel and 10% poultry manure), while TPH values were reduced to 20.45%. The plant *Megathyrsus maximus* (Guinea grass) revealed positive contaminant uptake with contribution from the roots, stems and leaves. 33% and 17% uptake of the TPH contaminants was obtained through the stem and leaves. Also, results showed 52% and 40% uptake of the PAH contaminants was obtained through the stem and leaves. *Megathyrsus maximus* (Guinea grass) recorded improved biomass development with enhanced bioremediation by the application of poultry manure.

1.0 INTRODUCTION

Civil Engineering construction practices of EXCAVATING contaminated soils to pave way for the intended construction of infrastructural projects, serves only the ease of doing business but creates another geoenvironmental problem due to indiscriminate DUMPING of these contaminated soils. Contaminants are indiscriminately transferred back to the environment. This necessitates the need to degrade and remediate these excavated contaminated soils. The prevalence of localized oil spills within Nigeria has been a recurring decimal due to poor handling and accidental discharge of petroleum hydrocarbon products. The negative effect of such spills has resulted into the acidification of the scarce available soils which invariably affect the inherent geotechnical properties of the soils due to the release of PAHs directly from such spills into the environment. This results to adverse effect on the soil engineering

potential, ground water quality as well as the ecology. Also obtainable within these hydrocarbon contaminants are the total petroleum hydrocarbon (TPH). "PAHs are adjudged to be capable of inducing mutagenic and non-mutagenic, carcinogenic risks, as well as pose other non-carcinogenic threats to human health". (Ghosh and Mukherji, 2023). At the occurrence of oil spill in the soil, the volatile hydrocarbons begin to volatilize and the aromatic hydrocarbons (nonvolatile) such as benzene, toluene, xylene, naphthalene, biphenyls, dimethyl-phenanthrene, methyl-crisine, methyl-pirene, benzanthracene and benzopyrene are contained in the soil which are deposited in an asphaltic form resulting to constituents of Total petroleum Hydrocarbon (TPH) and Polycyclic Aromatic Hydrocarbon (PAH). These contaminants tend to aggravate toxicological degradation of the ecosystem. Such contamination infiltrates vertically into the soil. The denser hydrocarbons, such as fuel oil, penetrate more slowly resulting to shallow contamination from PAH, while the lighter ones, such as benzene, show a rapid movement in the soil profile making the soil a semi-natural reservoir for PAHs. Due to the hydrophobicity of the PAH, the soil structure is modified (through ruptures of the aggregates), with the reduction in the exchange of gases within the atmosphere and increasing the content of organic carbon (through oxidation processes) thereby reducing the cation exchange capacity (by loss of bases). This results in an acidification of the soil as postulated by Chan-Quijano, *et.al* (2020). Restoration of the soil engineering potential free from such contaminants can be achieved through physical and chemical remediation methods; however, these methods are destructive and have residual effect on the environment and ecology making them less sustainable. Onsite source removal of the contaminants is challenging owing to the fact that site conditions are unpredictable. Also, it's adjudged that the methods/level of clean up required is usually a composite mix of various remediation techniques. Phytoremediation uses plants such as the grass families and associated soil microbes to reduce the concentrations or toxic effects of contaminants such as TPH, BTEX, and PAHs in the environment through its various mechanisms. However, such plants are selected based upon the regional climate, root depth, and the nature of the contaminants. Pilot studies (i.e. Greenhouse Experiment for the selection and screening of four (4) native plants) undertaken earlier has revealed that the plant *Megathyrsus maximus* (Guinea grass) amended with poultry manure has proven a positive potential for use in the phytoremediation of diesel contaminated soils. (Abdul-Basit 2024). Complementing the effectiveness of the pilot studies, this study presents a 120days field phytoremediation experiment for the remediation of PAH and TPH contaminants within an experimental/simulated site.

2.0 MATERIALS AND METHODS

2.1 MATERIALS

2.1.1 Experimental Split Plot Design

The field experiment was performed on an experimental/simulated site (plot, 8.7m²) within the campus vicinity. The plot matrix is represented in Plate I. The various plot soil was tilled and made even to an approximate depth of 0.3m. Four different subplots were designed at the experimental plots. Subplot A

(2.1m x 0.6m) = contaminated soil (20% diesel and 10% poultry manure), Subplot B (1.0m x 0.6m) = contaminated soil (20% diesel), Subplot C (1.0m x 0.6m) = uncontaminated soil with 10% poultry manure and lastly, Subplot D (2.1m x 0.6m) = uncontaminated soil. Also, replicates of Subplots A & B (1.2m x 0.6m) were tilled and homogenized for experimental determination.

2.1.2 Soil Contamination:

Contaminated sub plots A & B were contaminated by the volume of the soil through the addition of 20% diesel, mixed thoroughly and spread-out evenly. 10% organic manure (i.e. poultry manure) by the volume of the soil was added for the required soil amendment. "The contamination to soil ratio was done with respect to the results obtained from the pilot greenhouse pot studies". (Abdul-Basit 2024). *Megathyrsus maximus* seeds were planted immediately and monitored for the field investigation. The uncontaminated soil within sub plot C, was amended with 10% organic manure (i.e. poultry manure) by the volume of the soil to observe the effect of poultry manure on *Megathyrsus maximus*. Sub-plot D represent the clean soil with planted *Megathyrsus maximus* seeds, to serve as a control plot. The field experiment lasted for a duration of 120 days.

Plate I: Field experimental plot design for phytoremediation of hydrocarbon contaminated soil with the plant *Megathyrsus maximus* amended with poultry manure

2.1.3 Soil and plant sampling

Phytoremediation can be best suited for tropical countries where plant growth occurs all year round. Moreso, the field experiment site is characterized by a sub-tropical savannah climate. The planting was done during the rainfall season (i.e. June – September) with an average temperature of 30°C, and average rainfall 1029mm. *Megathyrsus maximus* seeds were planted in the subplots by evenly spreading the seeds throughout the sub-plots. Vegetation cover was provided to aid the germination of the seeds and also prevent wind action as shown in Plate II below.

Plate II: Vegetation cover with the plant *Megathyrsus maximus* amended with poultry manure

At the expiration of the planting duration (i.e. 120days), the sample plants were uprooted out carefully and the root materials were collected. The laboratory examination involved obtaining soil samples from the subplots at various stages of the planting duration for characterization of the contaminated and uncontaminated field soil samples. The examination was done to ascertain the TPH and PAH within the field experiment soil. Furthermore, laboratory analysis for the determination of field phytoremediation parameters was undertaken to determine phytoremediation efficiency for all soil and plant material.

2.2 METHODS

2.2.1 Extraction of Plant material/Soil samples

The extraction of plant material to ascertain TPH and PAH within the soil and plant samples was achieved in accordance to ASTM D1796–22 protocols.

2.2.2 Total Petroleum Hydrocarbons (TPHs) and Polycyclic Aromatic Hydrocarbons (PAHs).

The plant/soil extract was used to ascertain both the Total Petroleum Hydrocarbons (TPHs) and Polycyclic Aromatic Hydrocarbons (PAHs) through the gas chromatograph-mass spectrometer (GC-MS) technique; all the test was carried out in accordance with ASTM D6420-18 protocols.

Contaminant uptake = $\frac{\text{contaminant in the plant (mg)}}{\text{contaminant in the soil initially(mg)}} \times 100\% \dots\dots\dots (1)$

2.2.3 Soil pH

The soil pH determination was carried out in accordance with ASTM D4972-19

2.2.4 Electrical conductivity

The bench top digital electrical conductivity meter was calibrated using the 1000uS/cm conductivity standard in accordance with ASTM WK75979 standards.

2.2.5 Soil Organic Carbon

A wet-oxidation technique for determining organic carbon in soil, plant material, and aqueous plant extracts was used in accordance to ASTM D 2974

2.2.6 Exchangeable Bases (cations)

The exchangeable cations (Ca⁺⁺, Mg⁺⁺, K⁺, Na⁺) in soil was determined through the soil filtered extract with the Atomic Absorption Spectroscopy (AAS) all in accordance with ASTM D7503-18.

3.0 RESULTS AND DISCUSSION

3.1Plot soils (Uncontaminated soil (sub-plot D) and Contaminated Soils sub-plot B & A)

Results of the greenhouse pilot studies indicated that with 20% diesel contamination relative to the soil volume, the soil’s inherent properties have microstructural transformation which results in poor moisture-holding capacity, low permeability and nutrient deficiencies. (Abdul-Basit 2024). Soil composition and soil quality is an important factor in determining successful germination, growth and health of plants. Heavily contaminated soils have a tendency towards poor physical conditioning which is unsuitable for vigorous growth of vegetation and rhizosphere bacteria. Results for the physico-chemical characteristics of the uncontaminated and contaminated field experiment soils as presented in Table 1 below, have shown that the index and physico-chemical properties of the uncontaminated soil (i.e. Subplot D) contain 0.96% sand, 98.0% silt and 1.04% clay. However, with 20% diesel contamination relative to the soil volume, the contaminated soil became hydrophobic resulting to 28% increase in

moisture content, likewise the contaminated soils grains also contain, 0.94% sand, 95.35% silt and 0.365% clay as presented in Table 1 with the grain size distribution of the control (i.e. uncontaminated soil) and test samples (i.e. contaminated soil) are also presented in Fig. 1.

Table 1
Physico-chemical characteristics of the uncontaminated and contaminated.

Parameter	Uncontaminated Soil	Contaminated Soil	Contaminated Soil
	Subplot D	Subplot B	Subplot A
Natural Moisture Content (%)	9.2	12.0	10.0
Specific Gravity	2.56	2.63	2.59
Liquid Limit (%)	30.34	33.54	32.54
Plastic Limit (%)	15.22	18.44	18.44
Plasticity Index	18.22	19.11	19.11
pH	6.9	5.9	5.7
Sand (%)	0.96	0.94	0.84
Silt (%)	98.0	95.35	96.45
Clay (%)	1.04	0.365	0.265
Soil Organic Carbon (g.kg-1)	7.3	8.78	8.98
CEC (C.mol. kg ⁻¹)	8.9	11.05	10.75
Electrical Conductivity (dS.m ⁻¹)	1.52	0.04	0.04
Avail. Potassium(k)(cmol.kg-1)	1.59	1.36	1.36
Extractable Sodium Na (cmol.kg-1)	1.35	1.07	1.07
Extractable Calcium Ca (cmol.kg-1)	4.5	5.4	5.4
Extractable Magnesium Mg (cmol.kg-1)	1.89	1.92	1.92

The experimental plots from soil particle size analysis contained 0.96% sand, 98.0% silt and 1.04% clay. The contaminated soil with diesel hydrocarbon in sub-plots A showed an increase of 10% in moisture content relative to the uncontaminated sample in subplot D. This phenomenon was also reported in the greenhouse experiment undertaken earlier (Abdulbasit, 2024). The 10% increase in moisture content in sub plot A showed a relative decrease in moisture content relative to sub plot B (i.e. 28%), this could be as a result of the 10% application of poultry manure. However, the increases in the moisture content could probably be due to the hydrophobic nature of the diesel contaminated soil which can adsorb small

amounts of moisture in the soil; ultimately increasing the amount of moisture content in the soil. The hydrocarbon contamination led to an increase in Atterberg's limits, as well as an increase in the specific gravity, between soil particles. Mohammadi *et al.* (2020) also reported similar phenomenon.

3.2 pH of Field Experiment

The variation of the pH values to ascertain the phytoremediation parameter for the uncontaminated soil in sub plot D presents a near neutral pH of 6.9 value. This trend was also observed in the uncontaminated subplot C. Meanwhile, the pH of the diesel contaminated soil in subplot B was acidic in the value of 5.9. Moreover, the observed pH trends for sub plot A presents a pH value of 5.7 as shown in Fig. 2. The variational trend for the uncontaminated sub plot D & C presents a near neutral pH of 6.9–7.0 throughout the duration of the experiment. This result was due to lack of diesel contamination. The pH value for subplot B (20% diesel contaminated soil) maintained an acidic range of 5.5–5.9 resulting to the mortality of *Megathyrsus maximus* seed after planting. This could be as a result of the toxicity of soil due to the diesel contamination. Similar trends were reported from the pilot studies undertaken earlier by (Abdulbasit, 2024). Aziz, *et al.* (2020) explained that the acidic nature of the soil could be due to the hydrocarbons in the diesel oil, in which the carbon content may react with the soil salts and minerals and change the alkaline minerals to be acidic in nature which can hamper the seed survivability.

Furthermore, the plant *Megathyrsus maximus* survived within subplot A (20% diesel contaminated soil and 10% poultry manure). The pH values of the sub-plot A with the plant *Megathyrsus maximus* attained an optimum level of 7.25 at the end of 120 days duration. This is presented in Fig. 3.

This indicates a marked improvement from the pH of 5.9 for the contaminated soil in sub plot B (20% diesel contaminated soil). Attaining a near neutral pH at 10% Poultry manure treatment with the plant *Megathyrsus maximus* after 120 days field experiment is an indication of positive phytoremediation process. This also buttresses the pH value of 7.1 obtained from the greenhouse experimentation undertaken as a pilot study in determining the potential of *Megathyrsus maximus* for use in the phytoremediation of diesel hydrocarbon contaminants. (Abdulbasit, 2024). "The attainment of a near neutral alkaline pH value of 7.5–10 was reported to be effective for hydrocarbon degradation" (Kebede *et al.* (2021).

3.3 Phytoremediation Parameters of the Experimental Plot

3.3.1 Poultry Manure

The plantlet that germinated within the subplot B exhibited chlorosis resulting to its death at 20% diesel contamination. This may be likely due to the interference of diesel compounds with mineral uptake. However, with 10% poultry amendment within subplot A, the plant survived within the toxic environment. This is an indication of the bioremediation potential of poultry manure through the growth of autochthonous microorganisms that stimulate hydrocarbon degrading bacteria in the soil. Osu *et al.* (2022) reported that this serves as a good technique for battling petroleum contamination in the natural environment. Also, results obtained from the pilot studies indicated that 10% treatment with poultry

manure assisted in the plant growth; higher treatment percentages resulted in toxicity of the soil and subsequent plant mortality (Abdulbasit, 2024). The addition of 10% poultry manure to the uncontaminated soil in subplot C proved the effectiveness of poultry manure in the plant growth and development. A healthy Biomass development with plant height of about 160cm was obtained after the planting duration as shown in plate III. This is as a result of the availability of essential macronutrients in the plant roots and shoots for the plant to thrive provided by the poultry manure at the expiration of the designated duration period (i.e. 120 days).

Plate III: *Megathyrsus maximus* growth development in subplot C

Furthermore, Table 2 presents field experimental phytoremediation parameters for sub-plot A (contaminated soil with 20% diesel and 10% poultry manure organic content) at the expiration of 120 days. Generally, there was improvement in all measured essential parameters needed for the plant *Megathyrsus maximus* to degrade and uptake the contaminants.

Table 2
Physico-chemical characteristics of sub-plot A after 16weeks

Phytoremediation Parameter	Sub-plot A (Cont. Soil with <i>Megathyrus maximus</i> + 10% Poultry Manure) at 0 weeks	Sub-plot A (Cont. Soil with <i>Megathyrus maximus</i> + 10% Poultry Manure) at 16 weeks	<i>Megathyrus maximus</i> Roots & Stem after 16 weeks	<i>Megathyrus maximus</i> Leaves after 16 weeks
pH	5.9	7.1	7.2	7.1
Oxidation reduction potential (mV)	73.9	60.1	40.1	35.2
Soil Organic Carbon (g.kg ⁻¹)	8.98	7.48	7.8	8.1
CEC (cmol(+)/kg).	10.75	15.39	NA	NA
Electrical Conductivity (dS.m – 1)	0.04	0.32	0.25	0.28
Avail. Potassium (k)(^{cmol} .kg-1)	1.36	1.79	3.41	2.28
Extractable Sodium Na (cmol.kg-1)	1.07	1.74	1.55	0.45
Extractable Calcium Ca (cmol.kg-1)	5.4	6.2	4.25	2.0
Extractable Magnesium Mg (cmol.kg-1)	1.92	1.67	1.06	0.63

3.3.2 pH Determination for Plant roots, stems and leaves:

The variation of the pH parameter for the subplot A (contaminated soil with 20% diesel and 10% poultry manure organic content) determined for the plant roots and stems as well as leaves showed marked improvement in remediation activity. The measured pH values range between 7.1–7.2 for the plant *Megathyrus maximus* roots, stem and leaves. This is a positive development when compared to 5.9 pH value for the contaminated soil in subplot A at 0 weeks as shown in Table 2. Furthermore, obtaining a neutral and optimal pH value of 7.1 within the plant roots, stems and leaves as presented in plate IV below is an indication of the potential of *Megathyrus maximus* roots, stem and leaves to resist toxic environment and possible uptake of contaminants. Results obtained are relative with results obtained in the greenhouse experiment undertaken as pilot studies. An alkaline pH of 7.5–10 was reported to be effective for hydrocarbon degradation as reported by Kebede *et al.* (2021).

3.3.3 Oxidation reduction potential (Redox potential)

A positive redox potential of + 60.1 was obtained within the subplot A after the duration of the field experiment. Also, redox potential of + 35 and above was recorded within *Megathyrsus maximus* roots and stem at the end of the field experiment as shown in Table 2. “This indicates an aerobic environment where oxygen is readily available, and it will in turn be favorable for microbial degradation of the hydrocarbon contaminants within the rhizosphere”. Singha and Pandey (2021). The favorable aerobic environment where oxygen is readily available for the plant will aid in the release of substrates/exudates from the *Megathyrsus maximus* roots and stems. The exudates will serve as a food source to the hydrocarbon degrading bacteria. Such processes assist the plant in the uptake of the contaminants thereby remediating the contaminated soil.

3.3.4 Soil Organic Carbon

The variation of the soil organic carbon within subplot A (contaminated soil with 20% diesel and 10% poultry manure organic content) revealed a reduction in the soil organic carbon from 8.98 at 0 weeks to 7.48 after 16 weeks, such reduction could be characterized by the activity of hydrocarbon degrading bacteria present in the poultry manure that served as a catalyst for the biodegradation of the hydrocarbon contaminants. Contributions from organic carbon in the phytoremediation of hydrocarbon contaminated soil served as a stimulant or food for the hydrocarbon degrading bacteria in the soil, this in turn assist the plant in the uptake of the contaminants. Such contribution had previously been reported by Osu *et al.* (2022). They postulated that poultry manure addition to hydrocarbon contaminated soils proves a good technique/mechanism for field remediation of hydrocarbon contamination in the natural environment.

3.3.5 Cation Exchange Capacity (CEC)

Furthermore, according to Piccoli *et.al* (2024), CEC value improvement could result to or can be responsible for the higher inherent fertility of the soil and also the fluidity of needed cations for nutrient availability. The variation of the determined CEC values as presented in Table 2 resulted in an improvement as the CEC values ranged from 10.75 cmol/kg at 0 weeks to 15.39 cmol/kg after 16 weeks within subplot A (contaminated soil with 20% diesel and 10% poultry manure organic content). Improved CEC values serve as a catalyst to enzymes secreted by plants that aid in degradation of hydrocarbon contaminants. Kumari, *et al.* (2021) also reported that some enzymes are also secreted by plants that also aid in degradation of organic toxicants. Although, some mortality of the planted seeds was observed after planting during the field experimentation, the field phytoremediation potential of *Megathyrsus maximus* amended with 10% poultry manure showed a positive potential with bioremediation assistance from poultry manure.

3.3.6 Electrical Conductivity

The variation of the electrical conductivity within subplot A (contaminated soil with 20% diesel and 10% poultry manure organic content) resulted in improved electrical conductivity values from 0.04 at 0 weeks to 0.32 after 16 weeks within subplot A. Improved EC led to the fluidity of cations responsible for nutrient availability and could be related to improved phytoremediation parameter as shown in Table 2. Enhanced EC values could aid the secretion of root exudates by the plant *Megathyrsus maximus* and as such encourage higher microbial activity in the rhizospheric region. Mahala, *et al.* (2020), reported that root exudates contain sugars (carbohydrates), proteins (amino acids), and pigments (flavonoids), which act as source of carbon and nitrogen to microbes and provide nutrients for enhancing microbial activities that help in degradation of contaminants.

3.3.7 Exchangeable bases parameters

The variation for the exchangeable base parameters (Extractable sodium, calcium, magnesium as well as available potassium) within subplot A (contaminated soil with 20% diesel and 10% poultry manure organic content) showed an increase in the accumulation of the exchangeable base parameters. The available potassium increased by 33% while extractable sodium increased by 63%. Also, extractable calcium increased by 15% after 16 weeks. However, a decrease of 18.5% was observed for the available magnesium after the experiment duration. Moreover, the increase in concentration of exchangeable bases could have led to ionic stability thereby providing sufficient nutrients. Improved ionic stability in the contaminated soil ensures nutrient availability and possible uptake in plants and thus leading to the survival of the plant (i.e. *Megathyrsus maximus*). This is a positive phytoremediation potential. Generally, as reported by Rajabi and Sharifipour (2019), hydrocarbon contamination negatively affects the soil moisture due to the hydrophobic coating of oil around the soil particles. This was also in agreement with the results from the greenhouse experiment.

3.4 Plant Growth Rate

The variation in the growth rate in Subplot C (i.e. uncontaminated soil with 10% poultry manure) and Subplot D (i.e. uncontaminated soil) showed a steady growth index. Nearly all the seeds sown (about 75%) germinated producing plantlets that grew till the end of the experiment (i.e. after 16 weeks). This is an indication of seeds viability as presented in plate V.

Plate V: Pictorial representation of *Megathyrsus maximus* (Guinea grass) growth development in phytoremediation

Furthermore, a negative growth index was observed within Subplot B (i.e. contaminated soil with 20% diesel), the toxicity of the environment within subplot B led to least germination and eventual death of the seeds planted as shown in plate VII. However, the variation of growth rate within subplot A (contaminated soil with 20% diesel and 10% poultry manure organic content), revealed a steady growth index with the plant attaining a height of about 110 cm at the end of 16 weeks as shown in Fig. 4.

The growth rate of *Megathyrsus maximus* could probably be due to the resistance of the plant to the toxicity of hydrocarbon contamination as well as the supply of needed nutrients from poultry manure. No

statistical difference was observed among the plant growth rate (ANOVA, $P < 0.05$). Steady growth rate was recorded from the leaves and shoots of the plants at the end of 16 weeks. This growth index is an indication of remediation characteristics of the plant, with similar growth indices obtained in the greenhouse pot experiment.

3.5 Identification and quantifying the Volatile Organic Compounds (VOCs) within the contaminated soils/results from GC-MS analysis

3.5.1 Sub-Plot B

The variation of the contaminants within the diesel hydrocarbon contaminated soil (subplot B) is presented in chromatograms obtained from the GC-MS analysis and presented in Fig. 5. The chromatographs revealed contamination levels after 2 weeks of contamination as a mixture of saturated hydrocarbons (40–60%, primarily paraffins) and aromatic hydrocarbons (20–40%, including naphthalenes and alkylbenzenes), and all obtained within a retention time of less than 24 mins. Such contamination levels are genotoxic to plant and can cause carcinogenic, teratogenic, and mutagenic effects in humans and animals. (Moubasher et.al 2015).

However, after 16 weeks of contamination, analysis from the control subplot B (Contaminated soil with diesel hydrocarbon) showed that the contaminative effect of TPH in the control plot reduced to 25.25% from the peak of 38.5% as shown in the Fig. 6.

A drop in PAH concentration from peak value of 42.5% to around 32% was also obtained after 120 days, as shown in Fig. 7.

Such phenomena could be a consequence of evaporative activities and soil chemical interactions. Nemati *et al.* (2024), reported a likelihood activity for evaporation activities and changes within soil/chemical interactions during hydrocarbon contamination. This could probably be due to physicochemical processes such as evaporation and photochemical oxidation, thereby altering the composition of the hydrocarbon oil. Yang *et al.* (2024) had previously reported that the depletion of soil hydrocarbon constituents could be related to leaching activity through the mobilization and transportation of oil compounds to lower soil layers. Such a process can be induced by irrigation water or rainfall. Nemati *et al.* (2024), also reported that 'resistant plants can degrade petroleum hydrocarbons and separate them from the soil environment; other factors such as pollutant behavior and concentration, plant handling, oxygen, nutrients, moisture, soil acidity and alkalinity, and other field conditions, can also affect their efficiency'.

3.5.2 Sub-Plot A

The variation of the contaminants within the diesel hydrocarbon contaminated soil and amended with poultry manure (subplot A) is presented in chromatograms obtained from the GC-MS analysis and

presented in Fig. 8. From the chromatograms presented in Fig. 8, there is a reduction of the contaminants within a retention time of less than 24 mins. A reduction to about 8% in aromatic contamination (i.e. PAH) from 36% obtained at peak values was recorded in Fig. 8.

This could be attributed to the degradation of the contaminants by the plant rhizosphere and subsequent bioremediation contributions from poultry manure.

3.6 Determination of PAH/TPH

3.6.1 Polycyclic Aromatic Hydrocarbon (PAH)

The variation of contaminants PAH (inclusive of BTEX compounds) of the remediated soil with *Megathyrsus maximus* treated with 10% poultry manure showed that peak PAH contaminant percentage of 47.25 mg/kg was obtained at the 2nd week of planting as presented in Fig. 7. However, there was a marked reduction of almost 96% (i.e. 3.77mg/kg) of the PAH contaminant after 16 weeks of planting for the field experiment as shown in Fig. 9.

The marked reduction of the PAH contaminant for the field experiment could probably be attributed to the less fluidity of the PAH in the contaminated hydrocarbon soils occasioned by bacteria degradation from the organic manure, with further contaminant uptake and rhizo degradation. Microorganisms in the rhizosphere degraded PAH through releasing extracellular enzymes as growth substrates and carbon sources in the soil that led to contaminant uptake in their metabolic pathways. Ansari, *et al.* (2023) reported such phenomenon. Verâne *et al.* (2020) also reported significant reduction of PAH through phytoremediation process. The GC-MS result obtained after 16 weeks showed that traces of PAH (i.e. Benzene, 1-ethyl-2-methyl, Benzene, 1, 2, 4-trimethyl) were still present in the remediated soil. This indicates an incomplete or phytoremediation process in progress within the subplot A. To achieve a total clean-up, another round of planting can help in remediating the soil.

3.6.2 Total Petroleum Hydrocarbon (TPH)

The variation of TPH contaminants for the remediated soil with *Megathyrsus maximus* treated with 10% poultry manure showed that the peak TPH contaminant percentage of 40.25 mg/kg was obtained at the 4th week of planting as presented in Fig. 10.

However, there was a marked reduction of almost 50% (i.e. 20.48mg/kg) of the TPH contaminant after 16 weeks of planting for the field experiment. The marked reduction could have been due to the biodegradation of the contaminants from poultry manure and rhizosphere degradation from *Megathyrsus maximus* resulting to the remediation of the soil in subplot A. The GC-MS result in this study showed an enhanced degradation of diesel hydrocarbon thereby resulting in less acidification of the contaminated soil through the reduction of carbon compounds. Similar trends in carbon reduction from the remediation of diesel contamination were reported by other researchers (Tyabo *et al.*, 2019) with few differences. A good correlation was found between “diesel contamination” and “TPHs removal for the enhancement of the soil geotechnical properties”. Portelinha *et al.* (2020); reported that high

concentration of diesel contamination could result to an inhibitive effect on plant growth and negatively affect the geotechnical soil properties. Elsaigh and Oluremi (2022), reported that the residual by-products from the degradation activity like oils and other chemical compounds similarly negatively impacted the soil.

3.6.3 Contaminant Uptake by Roots, Stem & Leaves

The variation of the percentage contaminant uptake by the roots stem and leaves of the plant *Megathyrsus maximus* is presented in Table 3. The percentage uptake of about 33% and 17% of the TPH contaminants was obtained through the stem and leaves. Also, results showed 52% and 40% uptake of the PAH contaminants was obtained through the stem and leaves

Table 3
The variation of the percentage contaminant uptake by the roots stem and leaves

Contaminant(mg/kg)	Mass of contaminant(mg)		Contaminant uptake (%)		
	Contaminant in the soil initially	Contaminant in plant			
			Roots	Leaves	Roots
T P H	40.25	13.09	7.02	32.52	17.45
P A H	47.25	24.56	18.89	51.99	39.98

The plant *Megathyrsus maximus* has shown the ability to uptake some of the soil hydrocarbon contaminants and it could be effective not only in absorbing various elements but also in transferring these elements from the roots to the leaves and stems. This phenomenon was also reported in the greenhouse experiment undertaken earlier (Abdulbasit, 2024). Phytoremediation parameters in the determination of the degradation/removal percentage are an indication of phytoremediation efficiency. Several researchers reported from their studies the various phytoremediation removal efficiency as a phytoremediation parameter. Nemati *et al.* (2025), reported that the plant *Lolium perenne* could attain a removal efficiency of 45.6%, while *Iris dichotoma* degraded approximately 30.79% of the TPHs present in a hydrocarbon contaminated soil.

3.7 Plant Biomass

The variation of the plant biomass within the subplots C, D and A is presented in Fig. 11. There was a marked development in the growth, shoot, and biomass production of *Megathyrsus maximus* within subplots C, D and A. Growth rate of 120g ,80g, and 75g were obtained for fresh biomass in subplots C, D and A,respectively as shown in Fig. 11.

The dry biomass of 65g was recorded within subplot C, 50g within subplot D and also 38g within subplot A. Relatively, fresh biomass of 80g for the subplot A is less than that of 130g for the subplot C, such variation in the biomass development within subplot A irrespective of the toxicity could be attributed to

the role of poultry manure in ensuring the availability of nutrient pool in the hydrocarbon uncontaminated soils. However, within subplot C (uncontaminated soil with 10% poultry manure), better biomass production (i.e. 160g) was obtained resulting in increased growth, shoot and leaves. Moreso, the plant within subplot D (uncontaminated soil) recorded fresh biomass growth of up to 90g indicating seed viability. Plate VI presents a pictorial representation of the field growth within the subplots D, C and A with their relative biomass production.

Plate VI Subplot D, C and A growth development and biomass production.

Several researchers have reported the efficacy of organic manure as potential soil amendment in phytoremediation. Obasi *et al.* (2021), reported that for effective phytoremediation of oil-contaminated soil, there should be the incorporation of organic manure as amendments. Also, Barati, *et al.* (2022) reported improvements in mean roots, shoots and height of plants amended with poultry manure on the phytoremediation of petroleum contaminated soils.

4.0 CONCLUSION

The field experiment to examine the phytoremediation potential of *Megathyrsus maximus* (Guinea grass) amended with poultry manure, in remediating petroleum hydrocarbon contaminated soils revealed the following:

1. The measured field remediation parameters such as pH, Electrical Conductivity (EC), CEC and Exchangeable bases showed improved field parameters thereby remediating the soil.
2. TPH and PAH contaminants from the hydrocarbon contamination were degraded from the soil with the help of the plant and poultry manure. PAH values were reduced to 3.77% in subplot A (contaminated soil with 20% diesel and 10% poultry manure), while TPH values were reduced to 20.45%.
3. The plant *Megathyrsus maximus* (Guinea grass) revealed positive contaminant uptake with contribution from the roots, stems and leaves. 33% and 17% uptake of the TPH contaminants was obtained through the stem and leaves. Also, results showed 52% and 40% uptake of the PAH contaminants was obtained through the stem and leaves
4. 10% addition of organic manure amendment with poultry droppings aided the bioremediation potential. However, the contamination levels had a profound effect on the level of clean up.
5. The reduction in the contamination levels and the improvement of the soil index properties renders the soil fit for engineering use.

Declarations

(i) ACKNOWLEDGEMENTS

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nominating me for the sponsorship.

(ii) FUNDING DECLARATION

The authors declare that they have no known financial interests or specific funding in the preparation of the manuscript that could have appeared to influence the work reported in this paper.

(iii) DATA AVAILABILITY STATEMENT

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

(iv) DECLARATION OF COMPETING INTERESTS

The authors declare that they have no known competing interests or personal relationships that could have appeared to influence the work reported in this paper.

(v) AUTHORS CONTRIBUTIONS

- Abdul-Basit S.A is the main Author, and who drafted the manuscript culled from my PhD thesis
- Eberemu A.O. is main supervisor and analysed the data.
- Ijimdiya T.S is a team member of the supervisory team
- Ochepo J. is also a team member of the supervisory team
- Osinubi K.J is also a team member of the supervisory team.

All authors approve the manuscript of submission.

(vi) ETHICS APPROVAL

The authors declare that this study does not involve animals.

(vii) CONSENT TO PARTICIPATE

Informed consent to participate is not required, as the study is in accordance with ethical guidelines

(viii) CONSENT TO PUBLISH

The author confirms that:

1. The work described has not been published before.
2. The work is not under consideration for publication elsewhere.

3. Its publication has been approved by all co-authors
4. The copyright for publication is transferred is the manuscript is accepted for publication.

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Plates

Plates 1 to 6 are available in the Supplementary Files section

Figures

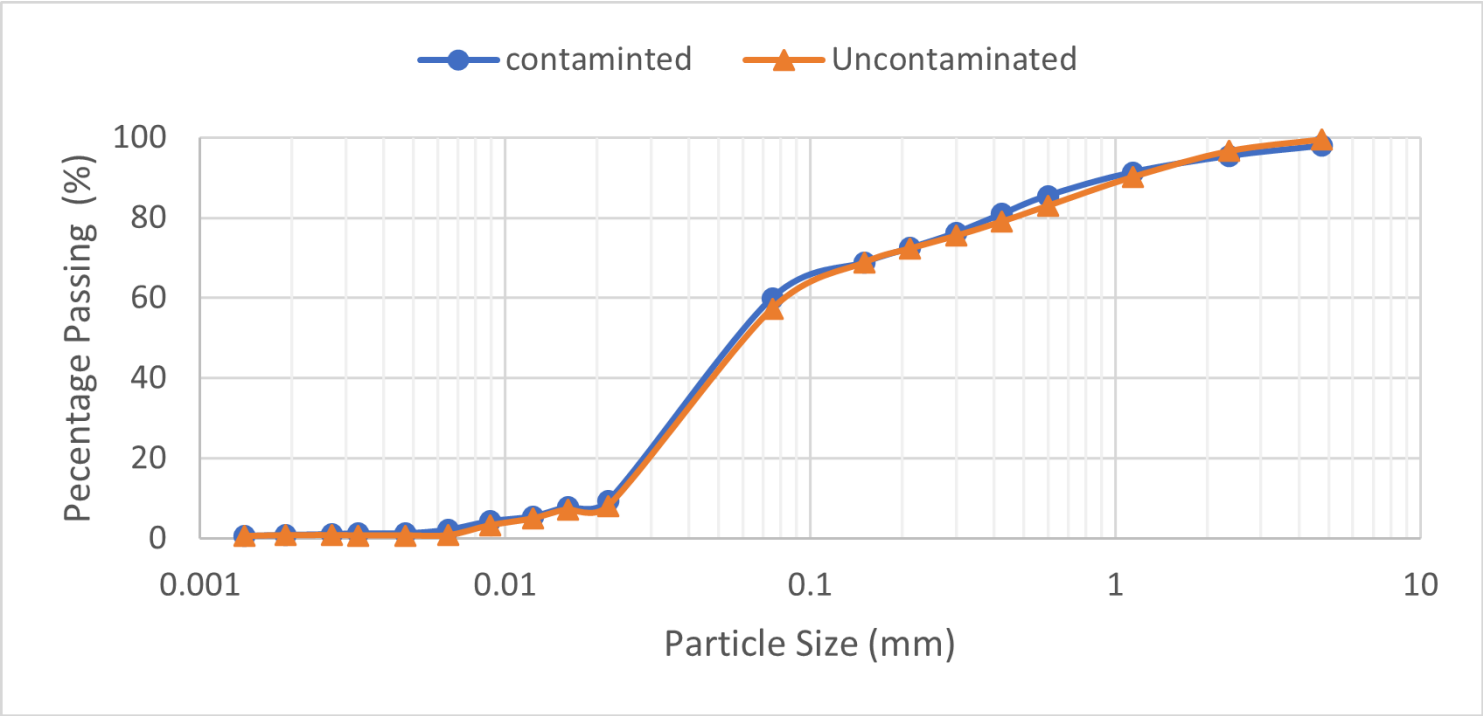


Figure 1

Particle size distribution for uncontaminated and contaminated soil samples

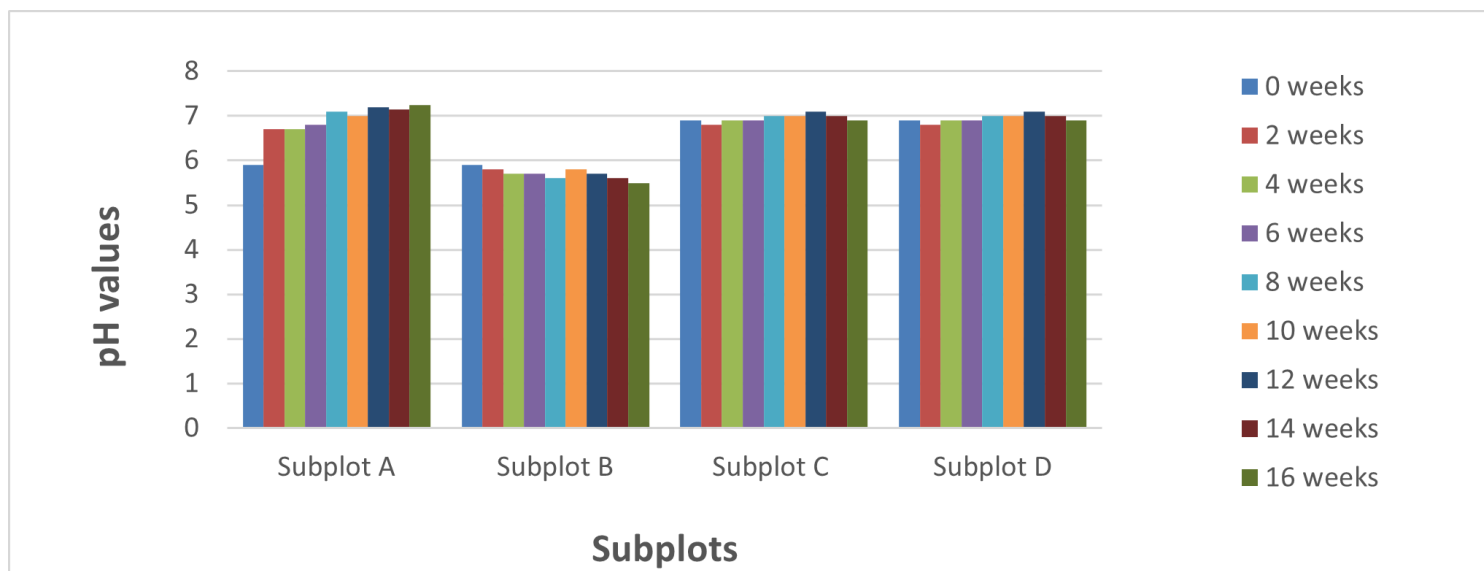


Figure 2

pH variation for uncontaminated and contaminated soil samples

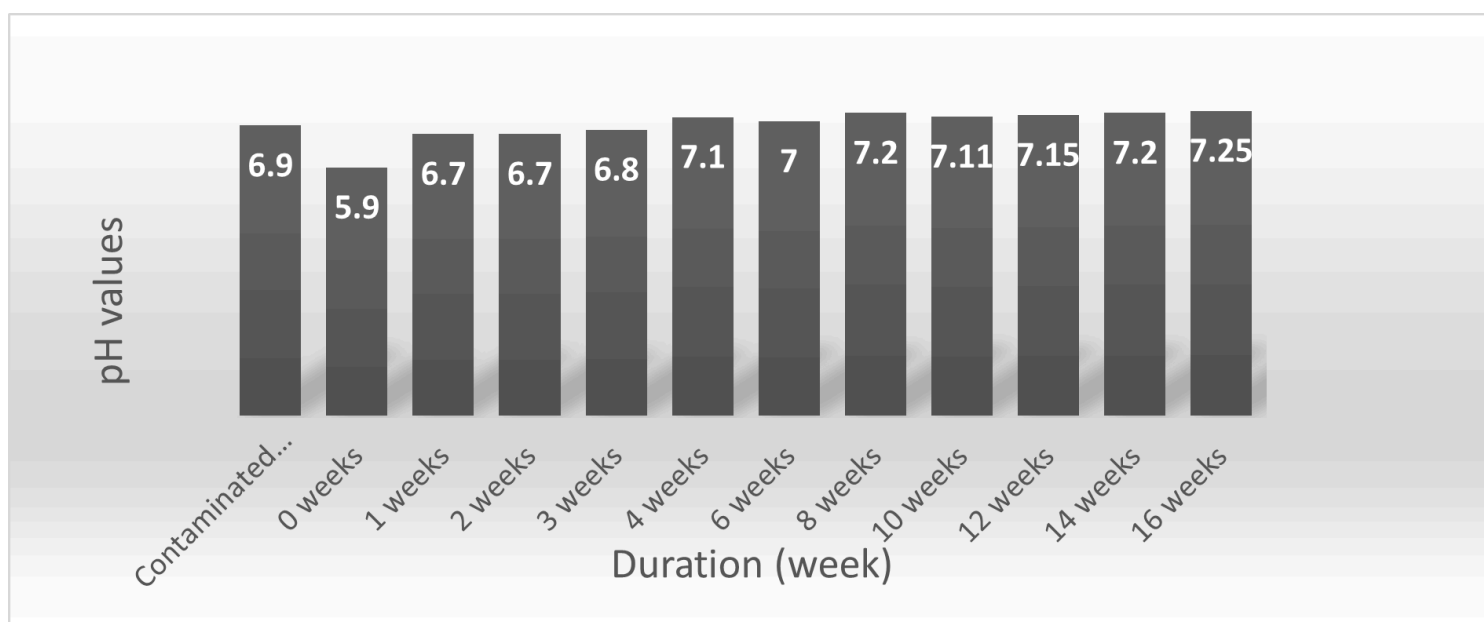


Figure 3

Variation of soil pH values with time for plot A (20% diesel amended with 10% poultry manure)

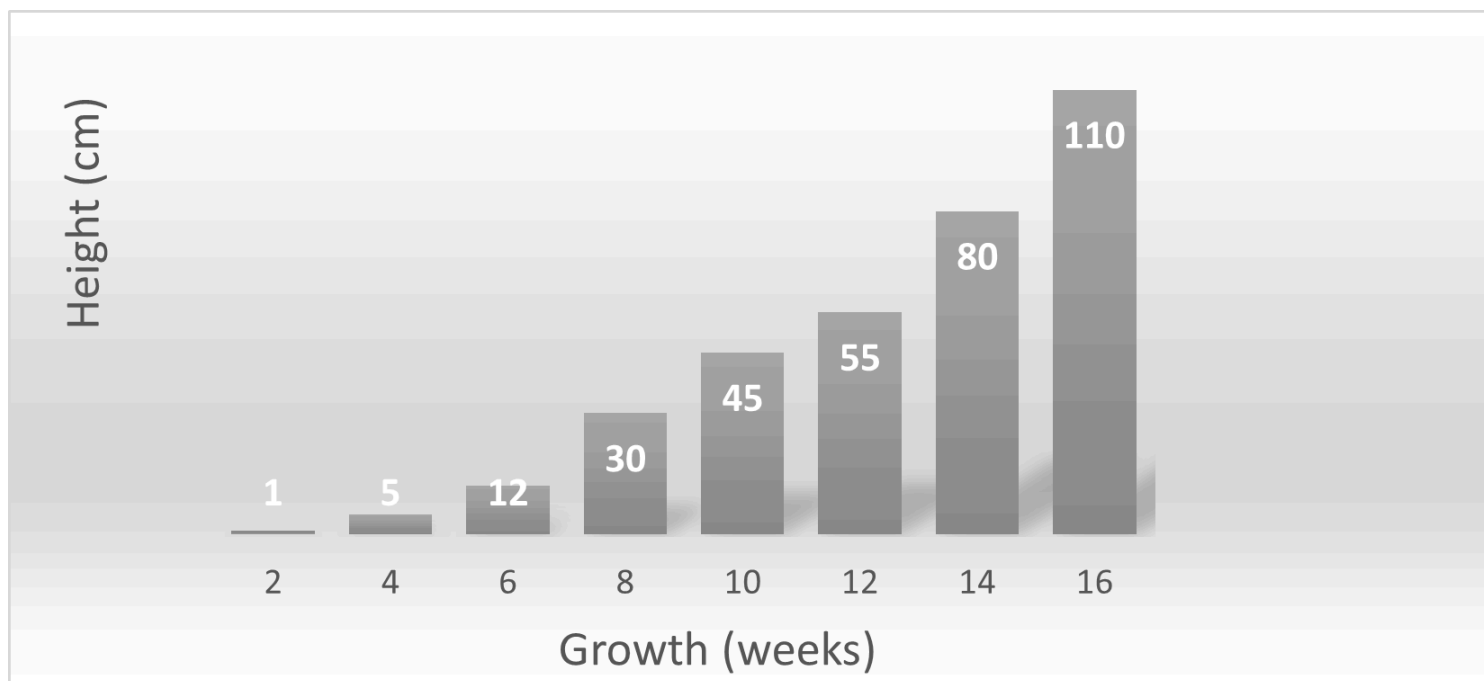


Figure 4

Variation of growth rate for *Megathyrus maximus* in phytoremediation of diesel contaminated soil amended with 10% poultry manure.

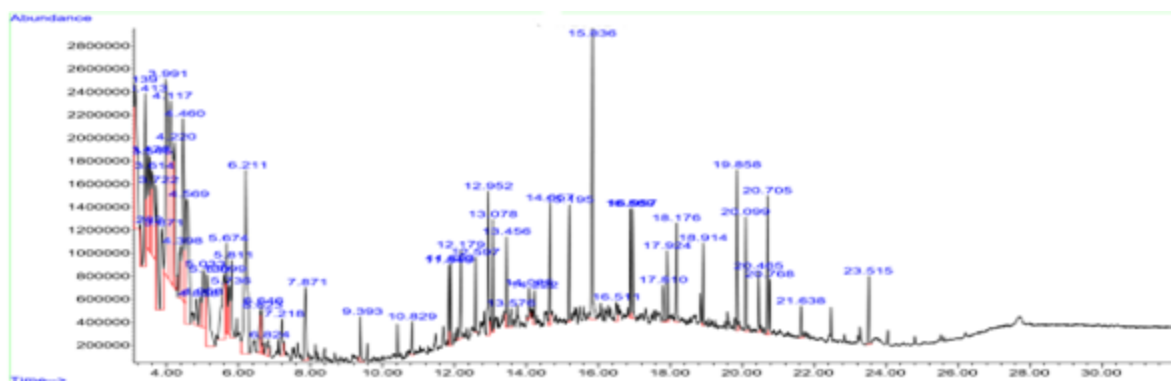


Figure 5

chromatograms for 2 weeks diesel contamination within subplot A (Retention Time, RT, < 24 min).

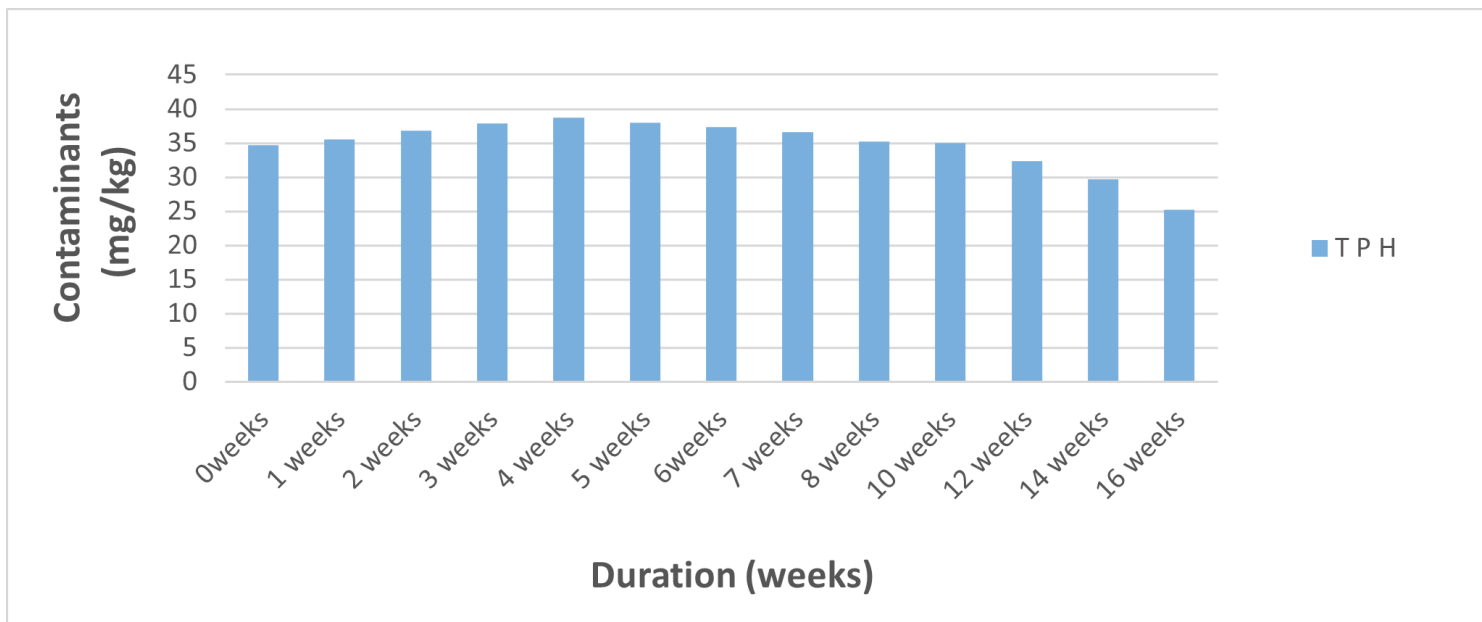


Figure 6

Variation of TPH in Plot B

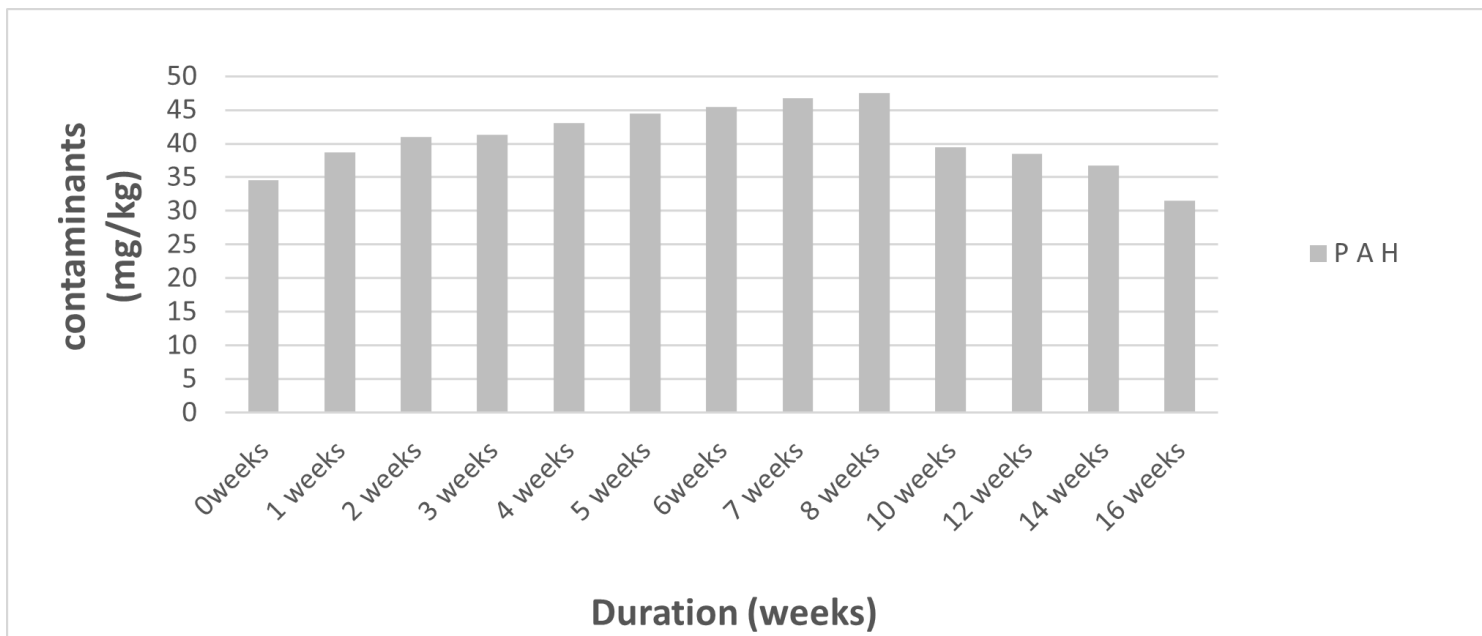


Figure 7

Variation of PAH in Plot B

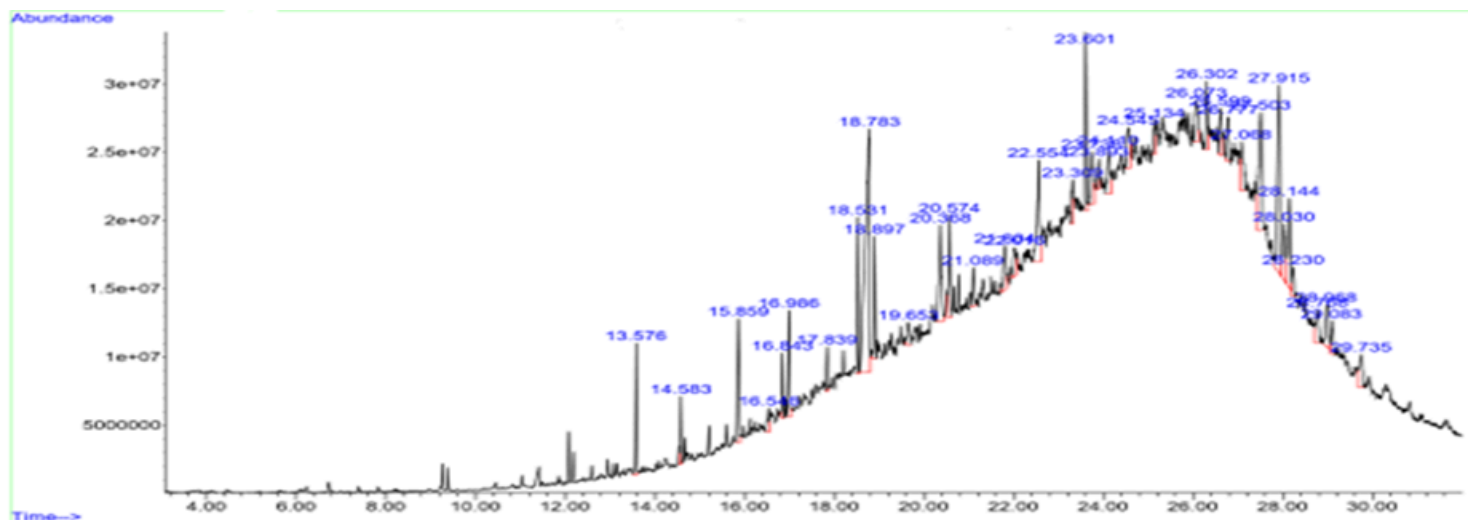


Figure 8

chromatograms for 16 weeks diesel contamination within subplot A (Retention Time, RT, < 24 min)

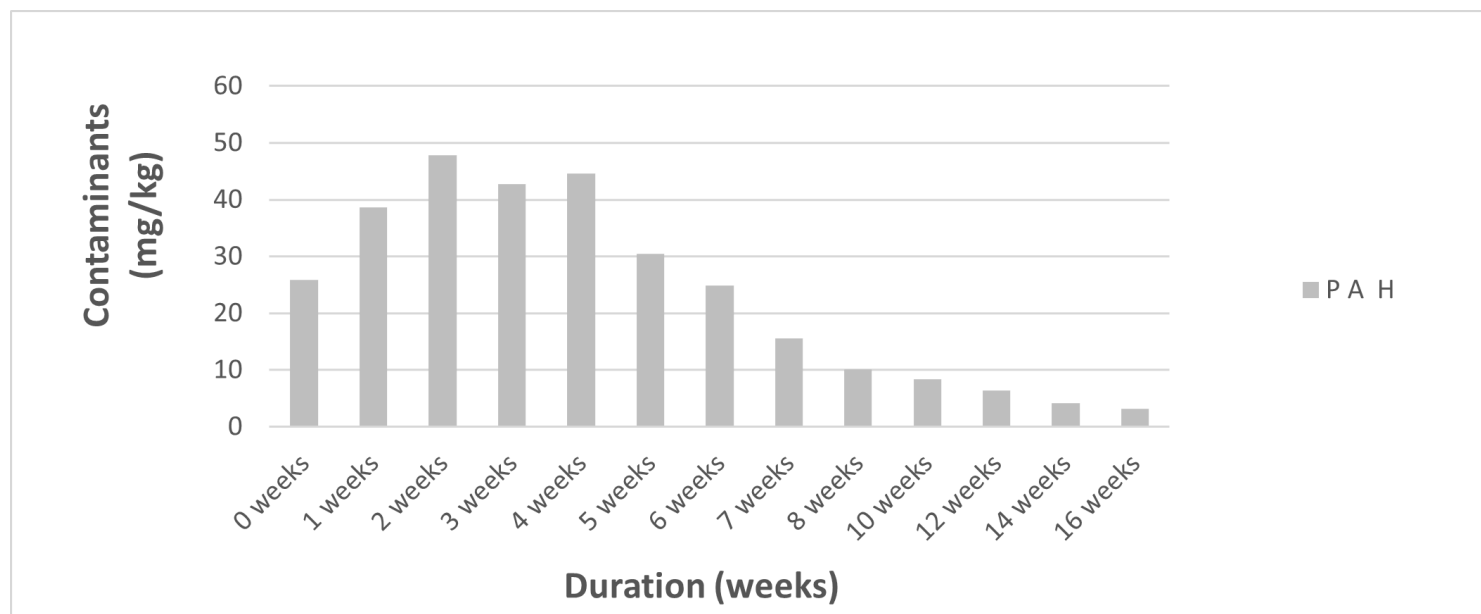


Figure 9

Variation of PAH diesel contamination in subplot A.

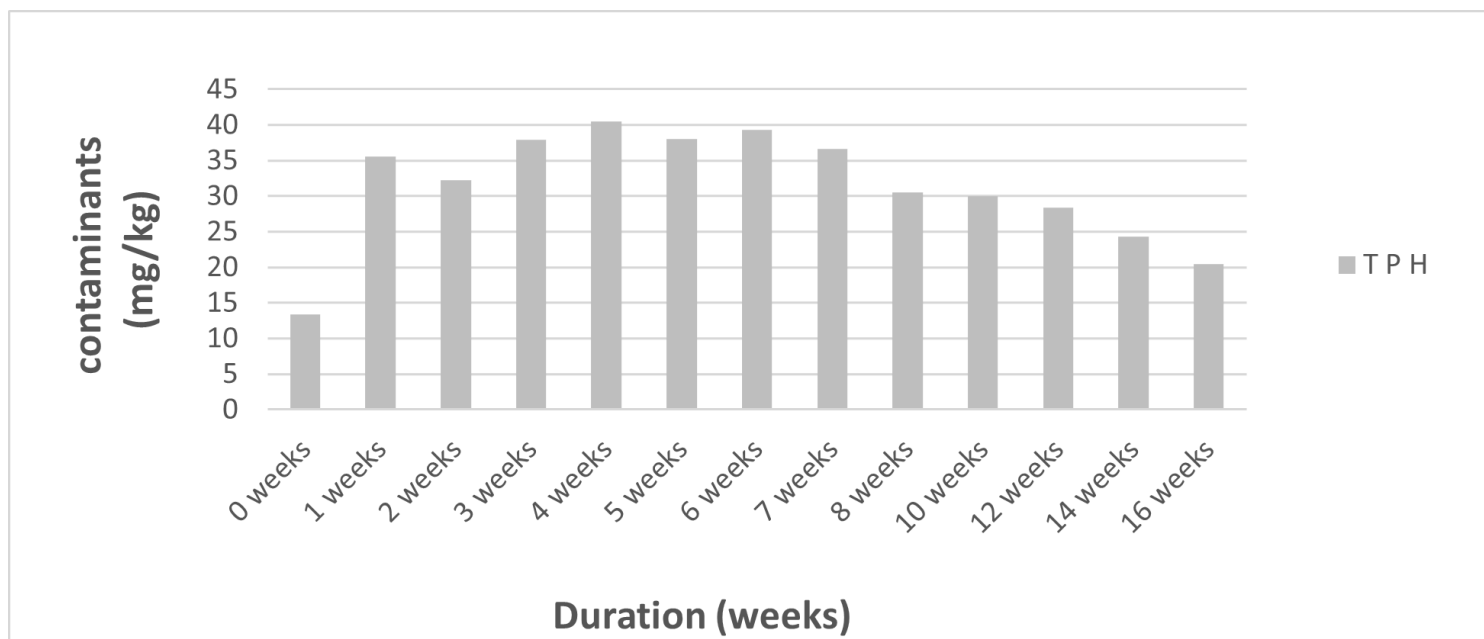


Figure 10

Variation of TPH diesel contamination in subplot A

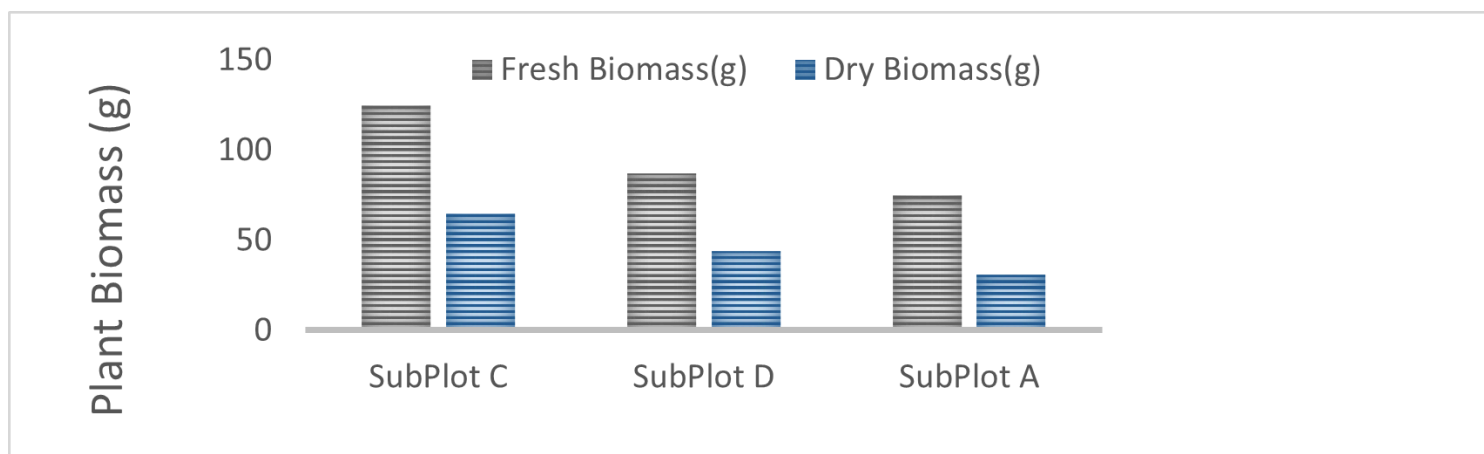


Figure 11

Fresh to Dry Biomass for *Megathyrus maximus* for Subplot A, C and D

Supplementary Files

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