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Crude Oil Remediation Potentials of *Pennisetum purpureum* in Oil Producing Communities of Akwa Ibom State, Nigeria

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Abstract

The phytoremediation of hydrocarbon impacted soil using selected plant species (*Pennisetum purpureum*) in oil producing communities of Akwa Ibom State, Nigeria was investigated using standard techniques. The selected plant species were cultivated on soils from Mbo, Ikot Abasi and Esit Eket contaminated with graded concentration (5, 10, 15 and 20%) of crude oil. Analyses of the crude oil remediating potential of the test plants revealed that at 5% contamination, the concentration of residual hydrocarbon in the rhizosphere soil of *P. purpureum* reduced from between 1928 – 1934 mg/kg to between 114.60 – 114.63 mg/kgafter 90 days. At 10% contamination, the concentration reduced from between 3124 – 3127 mg/kg and between 482.49 – 482.51 mg/kgafter 90 days. At 15% contamination, the concentration of the residual hydrocarbon, in the Control as well *P. purpureum* rhizosphere reduced from between 5146 – 5151 mg/kg to between 511.60 – 511.59 mg/kgafter 90 days. Similarly, at 20% contamination, the concentration of the residual hydrocarbon, in the Control as well as *P. purpureum* rhizosphere soil reduced from between 6021 – 6025 mg/kg to between 1131.21 – 1133.2 mg/kgafter 90 days. *P. purpureum* exhibited high hydrocarbon remediating potentials. Contamination of the soil samples with crude oil increased the organic matter and hydrocarbon content in the soil while decreasing the soil total nitrogen and phosphorous contents. The pH of the soil samples tended towards acidity as the concentration of the crude oil increased. The potentials of *P. purpureum*to phytoremediate hydrocarbon contaminated soil as reported in this study can be explored for broader use in remediating crude oil polluted environment.

Keyword: crude oil, oil producing communities, phytoremediation, *pennisetum purpureum*, remediation

INTRODUCTION

Environmental contamination from petroleum hydrocarbons have been an age-long phenomenon in Nigeria. This was previously considered a relatively rare event with a poor understanding of its associated impacts (Ndimele et al., 2018; Onwuka et al., 2021). However, experiences in the last few decades have been so alarming. There have been records of large-scale contamination, destruction and or disturbance of the environment (i.e. soil, water, air and biota) (Adegbite et al., 2020). Its challenges on livelihood and the environment have been highlighted by several authors (Ite et al., 2013; Linden & Palsson, 2013; Fentiman & Zabbey, 2015; Tinsley & Farewell, 2015; Elum et al., 2016).

Phytoremediation is an effective, solar driven and low-cost strategy that uses plants for the removal of contaminants from the soil of large, contaminated area. Plants have the ability to grow in polluted soil by metabolizing or accumulating the harmful compounds in their roots or shoots (De Boer & Wagelmans, 2016).

In-situ phytoremediation strategy exploits natural or genetically engineered plant species to accumulate toxic substances (heavy metals, radioactive compounds, organic pollutants) directly from the soil. Partial or complete degradation of organic substances has been demonstrated in some cases (Döberl et al., 2013). Rhizosphere microorganisms are especially critical for plant colonization of unfavourable soils since they can alleviate biotic and abiotic stress of plants. In some cases, rhizosphere microbes are even the main contributors to the degradation process. Rhizospheres are also stable physically, avoiding the potentially adverse effects of naturally occurring disturbances on microbial community composition or activities (Piceno et al., 2000). Several plants that possess phytoremediation capabilities had been studied (Linden & Palsson, 2013; Fentiman & Zabbey, 2015; Elum et al., 2016).

This research used an indigenous weed species: *Pennisetum purpureum,* for phytoremediation cum rhizoremediation. This plant was purposively selected because *Pennisetum purpureum* is a robust perennial grass widely naturalized in tropical and subtropical regions of the world. It is of the Family - Poaceae; Genus – Pennisetum. Common Name - Elephant grass. This grass is included in the Global Compendium of Weeds where it was listed as an agricultural and environmental weed as well as an invasive species (Randall, 2012). *Pennisetum purpureum* is an aggressive grass that grows rapidly, colonizing new areas and forming dense thickets. Once established, it can change features of ecosystem functions by altering fire regimes, hydrology cycles, biophysical dynamics, nutrient cycles, and community composition (D'Antonio & Vitousek, 1992; Nnaji & Egwu, 2020). *Pennisetum purpureum* is well adapted to drought conditions and can also dominate fire-adapted grassland communities (Randall, 2012). This species has the capability to resprout easily from small rhizomes left after disturbance, resulting in the outcompeting, and smothering of native plant communities (D'Antonio & Vitousek, 1992; Langeland et al., 2008). *P. purpureum* is considered one of the most successful invasive grasses in the world. The aim of this study was to investigate the phytoremediation of hydrocarbon impacted soil using selected plant species (*Pennisetum purpureum*) in oil producing communities in Akwa Ibom State.

MATERIALS AND METHOD

Soil samples were scientifically collected from Ewang Community in Mbo, Ekpene Obo in EsitEket and Ikpa Ibekwe in Ikot Abasi LGAs. The test plant: *Pennisetum purpureum* was first raised in a nursery, afterwards, transplanted into perforated bottom wooden boxes (height - 17cm by width - 30cm) containing 9kg of soil from the oil producing communities. The levels of contamination were 0%, 5%, 10%, 15%, 20%, the 0% contamination level served as control. All contamination levels were in triplicates. The simulation of hydrocarbon contamination was done using Bonny Light.

The location of study for this experimental set up was the Green House, Department of Botany and Ecological Studies, University of Uyo, Uyo, Akwa Ibom State. It was monitored daily for the expected bloom preceding examination of rhizosphere for requisite analyses. In each perforated bottom wooden box, four to five stands of the test plants were grown. The experiment ran for five (5) months (February to June 2023). Rhizospheric soil samples were collected for analyses using the "destructive approach" on once in thirty days bases at the same interval and period.

Particle Size Analysis was carried out using hydrometer method. Determination of Soil pH was done using The pH meter (HACH Sension 3). Electrical Conductivitywas determined according to AOAC (2005). Organic carbon in soil was determined using the dichromate wet oxidation method of Watkley and Black (1934). For determination of Exchangeable acidity in soil, titration method was deployed. Calcium in soil was determined using EDTA titration method. To determine (Calcium + Magnesium), the concentration of Magnesium was

determined by subtracting the value of calcium from (calcium + magnesium) value and the result multiplied by the extraction factor normally of EDTA solution and the volume of the soil extract. The concentration of sodium was determined according to AOAC (2005), using flame analyzer. Determination of Potassiumwas carried out as described by AOAC (2005). Effective Cations Exchange Capacity (ECEC) was determined by finding the sum of calcium, magnesium, sodium, potassium and exchange acidity. Base saturation was determined by dividing the product of total exchangeable bases and 100 by the effective cations exchange capacity of the soil sample. The Micro-Kjedahl method was deployed in the determination of Total Nitrogen. Available Phosphorus was determined using The Bray No. 1 method. Heavy metals in the soil sample were determined by the Perchloric acid digestion method as described by Udo (1986).

All qualitative and quantitative data were analyzed using IBM SPSS version 26. Analysis of Variance (ANOVA) was carried out to test for significant difference in the treatment. Post hoc test was done using Duncan multiple range - DMR tests. Pearson's correlation analysis was used to determine the relationship between microbial densities in the rhizosphere of test plants.

RESULTS

Changes in the Physicochemical Properties of the Rhizosphere Soils of *P. Purpureum*

Physicochemical properties such as sand, exhibited a significant difference ($p<0.05$) while sand, clay, silt, conductivity, organic matter, total nitrogen, calcium, magnesium, potassium, sodium, ECEC, exchangeable acidity and base saturation showed no significant difference ($p>0.05$) between the samples from the three different locations (Table 1).At day 90, the pH of the rhizosphere soil of *P. purpureum* on Mbo, Esit Eket and Ikot Abasi soil with varying crude oil concentration were 6.70, 6.72 and 6.74 for soil contaminated with 0% crude oil, 6.08, 6.07 and 6.08 for soil contaminated with 5% crude oil and 5.54, 5.59 and 5.60 for soil contaminated with 20% crude oil respectively. The organic matter content of the *P. purpureum* rhizosphere soil samples from Mbo, Esit Eket and Ikot Abasi was 0.050%, 0.051% and 0.050% in soil not contaminated with crude oil, 0.128%, 0.127% and 0.127% in soil contaminated with 20% crude oil. The THC concentrations in the *P. purpureum* rhizosphere soil was 224.63 mg/kg, 224.60 mg/kg and 224.62 mg/kg in Mbo soil, Esit Eket soil and Ikot Abasi soil contaminated with 5% crude oil and 1131.21 mg/kg, 1133.26 mg/kg and 1132.20 mg/kg in soil contaminated with 20% crude oil respectively. Available phosphorous in the *P. purpureum* rhizosphere soil from Mbo, Esit Eket and Ikot Abasi were 44.31%, 44.27% and 44.28% respectively in soil not contaminated with crude oil, 24.04%, 24.07% and 24.05% in soil contaminated with 5% crude oil and 10.20%, 10.22% and 10.21% in soil contaminated with 20% crude oil. Similarly, the concentration of Nitrogen was 0.24%, 0.26% and 0.27% for *P. purpureum* in uncontaminated Mbo soil, Esit Eket soil and Ikot Abasi soil respectively, 0.21%, 0.23% and 0.22% for soil contaminated with 5% crude oil and 0.08%, 0.08% and 0.07% for Mbo soil, Esit Eket soil and Ikot Abasi soil contaminated with 20% crude oil respectively.

Table 1: Physicochemical properties of the *P. purpureum* Rhizosphere Soil Samples when Contaminated with 0%, 5%, 10%, 15% and 20% Crude Oil on Day 90

PHYSICOCHEMICAL PARAMETERS	0%			5%			10%			15%			20%		
	Mbo	EsitEket	Ikot Abasi	Mbo	EsitEket	Ikot Abasi	Mbo	EsitEket	Ikot Abasi	Mbo	EsitEket	Ikot Abasi	Mbo	EsitEket	Ikot Abasi
Sand (%)	84.30[b]	89.00[a]	84.40[b]	89.00	88.20	88.30	88.35	88.20	88.70	88.50	89.00	88.40	89.20	90.20	90.00
Silt (%)	4.30	4.10	4.20	4.10	4.70	4.60	4.55	4.70	3.70	3.70	4.10	4.20	4.00	3.93	4.15
Clay (%)	7.40	6.90	7.40	6.90	7.10	7.10	7.10	7.10	7.60	7.60	6.90	7.40	6.80	5.87	5.85
Conductivity (us/cm)	6.34	6.38	6.37	6.24	6.22	6.23	6.15	6.18	6.17	6.05	6.06	6.06	5.60	5.68	5.71
pH	6.70	6.72	6.74	6.08	6.07	6.08	6.01	6.00	6.00	6.00	6.00	6.01	5.54	5.59	5.60
Organic matter (%)	0.050	0.051	0.050	0.063	0.064	0.062	0.08	0.08	0.07	0.125	0.128	0.127	0.128	0.127	0.127
Total Nitrogen (%)	0.24	0.26	0.27	0.21	0.23	0.22	0.18	0.19	0.18	0.11	0.11	0.13	0.08	0.08	0.07
Total Hydrocarbon content (mg/kg)	0.00	0.00	0.00	224.63	224.60	224.62	482.49	482.51	482.50	815.40	815.28	815.25	1131.21	1133.26	1132.20
Calcium (cmol/kg)	2.40	2.37	2.38	2.30	2.30	2.31	2.30	2.31	2.31	2.20	2.23	2.22	2.30	2.29	2.31
Magnesium (cmol/kg)	1.00	1.00	1.02	1.00	1.00	1.01	0.80	0.70	0.80	0.80	0.80	0.84	0.89	0.85	0.85
Available phosphorus (mg/kg)	44.31	44.27	44.28	24.04	24.07	24.05	13.47	13.50	13.49	11.74	11.73	11.75	10.20	10.22	10.21
Potassium (cmol/kg)	0.12	0.11	0.11	0.12	0.13	0.12	0.12	0.13	0.13	0.11	0.13	0.12	0.11	0.13	0.11
Sodium (cmol/kg)	0.02	0.04	0.04	0.04	0.03	0.05	0.03	0.03	0.04	0.04	0.04	0.03	0.04	0.04	0.05
Exchangeable acidity (cmol/kg)	2.10	2.00	2.00	2.05	2.00	2.10	2.00	2.10	2.00	2.20	2.19	2.18	2.19	2.20	2.21
Effective cation exchange capacity (cmol/kg)	5.64	5.52	5.55	5.51	5.46	5.59	5.25	5.27	5.28	5.35	5.39	5.39	5.53	5.51	5.53
Base Saturation (%)	62.76	63.76	63.96	62.79	63.36	62.43	61.90	60.15	62.12	58.87	59.36	59.55	60.39	60.07	60.03

Values with different superscripts (a > b >c) are significantly different ($p < 0.05$) while values with no superscript are not significantly different ($p > 0.05$).

Changes in the Heavy Metal Concentration of the Rhizosphere Soils of *Pennisetum purpureum*

Heavy metal such as copper (Cu), Manganese (Mn), Lead (Pb), Zinc (Zn), Iron (Fe), Cobalt (Co), Cadmium (Ca) and Nickel (Ni), showed no significant difference ($p>0.05$) between the samples from the three different locations for the Rhizosphere Soils of *Pennisetum purpureum* for uncontaminated and contaminated soil at 90 days (Table 2).

Analysis of the changes in the concentration of heavy metals Cu, Mn, Pb, Zn, Fe, Co, Ca and Ni rhizosphere soil of *P. purpureum* cultivated in the uncontaminated (0% crude oil) and contaminated (5%, 10%, 15% and 20%) soil samples from Mbo, EsitEket, Ikot Abasi was monitored for 90 days revealed that the concentration of the heavy metals increased as the concentration of the crude oil increased and decreased slowly over a period (90 days). The concentration of Co, Mn, Pb, Zn, Fe, Co, Cd and Ni in the rhizosphere soil of *P. purpureum* cultivated in uncontaminated Mbo soil was 2.81 mg/kg, 3.11 mg/kg, 1.07 mg/kg, 2.02 mg/kg, 3.01 mg/kg, 0.01 mg/kg, 0.10 mg/kg and 0.01 mg/kg respectively. However, the concentration of 2.80 mg/kg, 3.10 mg/kg, 1.07 mg/kg, 2.00 mg/kg, 3.02 mg/kg, 0.02 mg/kg, 0.10 mg/kg and 0.02 mg/kg was observed for Co, Mn, Pb, Zn, Fe, Co, Cd and Ni in *P. purpureum* rhizosphere soil cultivated on EsitEket soil and 2.80 mg/kg, 3.11 mg/kg, 1.06 mg/kg, 2.01 mg/kg, 3.02 mg/kg, 0.01 mg/kg, 0.11 mg/kg and 0.02 mg/kg in *P. purpureum* rhizosphere soil cultivated on Ikot Abasi soil respectively.

Hydrocarbon Accumulating potentials of the *P. purpureum.*

The potential of the *P. purpureum* that survived the varying concentration (5%, 10%, 15%, 20%) crude oil after 90 days to accumulate the hydrocarbon contaminants in its tissues was determined using standard analytical techniques (Table 3). The finding revealed that the plant accumulated varying concentrations of the pollutant in its tissues.

Table 2: Concentrations of the heavy metal in the rhizosphere soil of *P. purpureum* cultivated uncontaminated and contaminated soil of Mbo, EsitEket and Ikot Abasi at day 90.

HEAVY METALS	0%			5%			10%			15%			20%		
	Mbo	EsitEket	Ikot Abasi	Mbo	EsitEket	Ikot Abasi	Mbo	EsitEket	Ikot Abasi	Mbo	EsitEket	Ikot Abasi	Mbo	EsitEket	Ikot Abasi
Copper (mg/kg)	2.78	7.76	7.78	3.96	3.94	3.92	5.82	5.80	5.81	6.60	6.70	6.67	7.61	7.65	7.63
Manganese (mg/kg)	3.09	3.08	3.07	5.00	5.00	5.01	6.70	6.68	6.64	7.12	7.10	7.11	8.67	8.60	8.61
Lead (mg/kg)	1.05	1.04	1.03	2.24	2.25	2.23	2.75	2.70	2.70	3.20	3.12	3.15	3.75	3.81	3.76
Zinc (mg/kg)	1.99	1.98	2.00	3.51	3.56	3.58	3.62	3.64	3.63	4.65	4.66	4.65	5.24	5.26	5.22
Iron (mg/kg)	3.00	2.97	2.96	4.60	4.57	4.58	4.61	4.68	4.67	5.04	5.00	5.02	6.43	6.40	6.42
Cobalt (mg/kg)	0.01	0.01	0.01	0.09	0.10	0.09	0.20	0.19	0.19	0.30	0.25	0.28	0.28	0.32	0.31
Cadmium (mg/kg)	0.09	0.09	0.10	0.70	0.69	0.65	0.83	0.85	0.86	0.96	0.92	0.92	1.02	1.01	1.01
Nickel (mg/kg)	0.01	0.01	0.02	0.20	0.15	0.19	0.32	0.30	0.31	0.40	0.40	0.42	0.39	0.41	0.42

Values with different superscripts ($a > b > c$) are significantly different ($p < 0.05$) while values with no superscript are not significantly different ($p > 0.05$).

Table 3: Hydrocarbon Accumulation Potentials of *P. purpureum* (mg/g)

Day	5%			10%			15%			20%		
	Mbo	EsitEket	Ikot Abasi	Mbo	EsitEket	Ikot Abasi	Mbo	EsitEket	Ikot Abasi	Mbo	EsitEket	Ikot Abasi
0	0	0	0	0	0	0	0	0	0	0	0	0
30	0.04	0.04	0.03	0.07	0.05	0.06	0.04	0.05	0.04	0.04	0.05	0.03
60	0.8	0.6	0.6	0.8	1.2	0.9	0.9	0.9	1.2	0.7	0.6	0.6
90	1.00	0.9	1.1	1.1	1.2	1.3	1.4	1.2	1.3	0.8	1.0	0.9

DISCUSSION

The findings of this study have shown that the physicochemical properties of soil from the three study areas (Mbo, Ikot Abasi and EsitEket) were altered when contaminated with vary concentrations of crude oil. Soil pH is fundamental to the understanding of soil systems because it is an indicator of many reactions in the soils. (Okon and Ogba, 2018). In this study, the concentrations of Total Nitrogen and Available Phosphorus decreased as the concentration of the crude oil increased. This corroborates with the reports of (Chukwumati and Abam, 2021; Nwite and Alu, 2015) who reported significantly higher Total Nitrogen in spent oil contaminated soil over control. The high Nitrogen content reported in these locations collaborates with the findings of Ichikogu (2012) who while researching on the total nitrogen and available phosphorus dynamics in soils regenerating from degraded abandoned rubber plantation in Orogun area of the rainforest zone of Southern Nigeria reported a mean value of total nitrogen for the 1-year, 5-year and 10- year fallows and for mature forest are 0.18%, 0.22% 0.34% and 0.53% respectively for the topsoil.

The Phosphorous content in the uncontaminated soil samples ranged from 44.35 to 44.36 mg/kg and decreased with increasing level of contamination by crude oil. The reduction of the concentration of Phosphorus after contamination may be due to immobilization of this nutrient by microorganisms (Nwite and Alu, 2015). Available phosphorous contents were generally moderate in all the location and higher than the findings of Ekundayo (2004) who reported near mean value of 10 mg/kg for arable soils of South-Eastern Nigeria. The available phosphorous concentration in the soil samples reported in this study were also higher than those reported by Moses and Uwah (2015) who while investigating the effect of crude oil pollution on some soil fertility parameters in Ikot Oboreyin, Ikot Abasi, Akwa Ibom State, reported that the concentration of phosphorous ranged from 2.28 to 7.13 mg/kg in the studied samples and 8.20 to 10.11 mg/kg in the control. The greater the carbon content, the higher the level of organic pollutants present (Sharma et al., 2017). The Organic Carbon (OC) content increased from between 0.050 – 0.051% in uncontaminated soil to between 0.180 – 0.183% in soil contaminated with 20% crude oil. This implies that contamination of the soil with crude oil increased the percentage total organic carbon over uncontaminated (control) samples. This finding agrees with the work of Chukwumati et al., (2019), Chukwu and Udoh, (2014) who reported higher percentage of Organic Carbon in crude oil contaminated soil over control.

The increase in total Organic Carbon in the contaminated soil over control samples could possibly be as a result of the carbon substrate which may have been added into the soil by the crude oil. Ihem et al., (2015) attributed it to high mineralization process in the organic content of the soil. A similar finding was reported by Okonokhua et al., (2007). This contrasted

with the observation of Kayode et al., (2009) who adduced a reduction in nitrogen content in soil treated with spent lubricant oil. The Base Saturation of the soil samples ranged 62.89 to 64.02% in the uncontaminated soil and 60.16 – 63.96% in the contaminated soil. These values agree with the reports by Okon and Ogba (2018) who reported a percent Base Saturation of 60 to 90 and 55 to 85 for surface and sub-surface soil samples respectively. The impact of crude oil contamination cannot be overemphasized; several techniques have been developed to remedy polluted soils. The concentration of THC in the soil samples was observed to decrease over time. This decrease can be attributed to natural attenuation. Natural attenuation is a passive remedial approach that depends on natural mechanisms to degrade and remove contaminants in soil and groundwater (Chen et al., 2010, Declercq et al., 2012, Neuhauser et al., 2009, Dai et al., 2014). Natural attenuation has been considered a potential method for the cleanup of petroleum-hydrocarbon contaminated sites because of its economic benefits and low impact on the environment.

In nature, plants have also been reported to have potential to bioaccumulate heavy metals. Analysis of the heavy metal concentration in the uncontaminated, contaminated and plant rhizosphere soils from the contaminated cultivation boxes revealed a variation in the residual heavy metal concentration. These variations were also observed to vary based on duration of the study and the concentration of hydrocarbon pollutant. According to Clemens (2006), plants can resist the effect of heavy metals by either restricting the uptake of the heavy metal or by accumulation with tolerance mechanism application. The findings of the study also agree with several reports which have shown that most plants have limits to which they can tolerate hydrocarbon pollutants.

CONCLUSION

The result of this study has provided information on the phytoremediation of hydrocarbons impacted soil using *Pennisetum purpureum* in oil producing communities in Akwa Ibom State. The contamination of the soil samples with varying concentration of petroleum hydrocarbon altered the physical and chemical properties of the soil. Residual petroleum hydrocarbon and organic matter content in the soil samples increased as the concentration of the hydrocarbon pollutant increased. The concentration of heavy metals increased as the concentration of the crude oil increased and decreased slowly over a period (90 days). On the other hand, increasing concentration of the hydrocarbon lead to the decrease in the concentration of available phosphorus and nitrogen in the soil. The findings also revealed that the *P. purpureum*was not only resistant to hydrocarbons but was able to accumulate hydrocarbons at varying concentration. Based on the findings of the study, it can be recommended that *P. purpureum*is one of the potent plants that can be explored for the phytoremediation of hydrocarbon contaminated sites.

References

Adegbite, K. A., Adekiya, A. O., Adebiyi, O. T. V., Alori, E. T., Ejue, W. S., Olayanju, A. & Aremu, C. (2020). Baseline Fertility Status of a Gravelly Alfisol in a derived Savannah Agro-Ecological Zone of Nigeria. *Open Agricultural Journal* 5: 573–581.

Association of Official Analytical Chemist (AOAC) (2005). Methods of Soil Analysis. 12th Edition. Washington D.C.

Bray, R. H. & Kurtz, L. T. (1945). Determination of Total Organic and Available forms of Phosphorus in Soils. *Soil Science*. 59: 39 – 54.

Chen, K. F., Kao, C.M., Chen, C.W., Surampalli, R. Y. & Musheng, L. (2010) Control of Petroleum-hydrocarbon Contaminated Groundwater by Intrinsic and Enhanced Bioremediation. *J. Environ. Sci.* 22: 864-871(2010).

Chukwu, E. D. & Udoh, B. T. (2014). *Effect of Crude oil and Industrial Wastes Pollution on some soil Chemical Properties in Ikot Abasi, Niger Delta Area, Nigeria.* Proceedings of the 38th Annual Conference of the Soil Science Society of Nigeria, 83-88.

Chukwuemeka, S. S. Chukwuebuka, I. F & Ijeoma, K. G. (2017). Determination of Heavy Metals and Physicochemical Parameters of Crude Oil Polluted Soil from Ohaji Egbema Local Government in Imo. *Open Journal of Yangtze Oil and Gas* 2(3): 161-167.

Chukwumati, J. A & Abam, P. (2021). Influence of Grasses Amended with Organic Manures on Soil Physico-Chemical Properties in Crude Oil Polluted Soil in Niger Delta of Nigeria. *International Journal of Scientific Engineering and Applied Science*. 7(2): 188-199.

Chukwumati, J. A, Ibanibo, G. C & Adedokun, O.M. (2019). Response of Maize on Crude oil Polluted Soil after one month of Remediation with spent mushroom substrate. *Advances in Research.* 20(4), 1-8.

Clemens, S. (2006) Toxic Metal Accumulation, Responses to Exposure and Mechanisms of Tolerance in Plants. *Biochimie* 88:1707–1719.

Dai, Z. (2014). Probabilistic evaluation for shallow groundwater resources at a potential carbon sequestration site. *Scientific Reports*, 4: 4006.

D'Antonio, C. M. & Vitousek, P. M. (1992). Biological Invasions by Exotic Grasses, the Grass/Fire Cycle, and Global Chance. *Annual Review in Ecology and Systematics.* 23:63-87.

De Boer, J. & Wagelmans, M. (2016). Polycyclic aromatic hydrocarbons in soil–practical options for remediation. *CLEAN-Soil, Air, Water* 44(6): 648-653.

Declercq, I., Cappuyns, V. & Duclos, Y. (2012) Monitored natural attenuation (MNA) of contaminated soils: state of the art in Europe-A critical evaluation. *Sci. Total Environ.* 426:393–405.

Döberl, G., Ortmann, M. & Frühwirth, W. (2013). Introducing a goal-oriented sustainability assessment method to support decision making in contaminated site management. *Environ. Sci. Policy*. 25: 207-217.

Ekundayo, E.O. (2004). Influence of Different Soil Types on Abundance of Vesicular-Arbuscal or Mycorrhizal Fungi in Arable Soils of Southern Nigeria. Nigeria Journal of Soil Science, 14, 40-47.

Elum, Z., Mopipi, K. & Henri-Ukoha, A. (2016). Oil exploitation and its socioeconomic effects on the Niger Delta region of Nigeria Environ. *Sci.*Escobar-Zepeda, A., Vera-Ponce de Leon, A. and Sanchez-Flores, A. (2015). The road to Metagenomics: from microbiology to DNA sequencing technologies and Bioinformatics. *Frontier in Genetics*. 6:348.

Fentiman, A. & Zabbey, N. (2015). Environmental degradation and cultural erosion in Ogoniland: a case study of the oil spills in Bodo.*Extractive Industries Society Journal* 2(4): 615-624.

Ichikogu, V. I. (2012). Total Nitrogen and Available Phosphorus Dynamics In Soils Regenerating From Degraded Abandoned Rubber Plantation In Orogun Area Of The Rainforest Zone Of Southern Nigeria. *Ethiopian Journal of Environmental Studies and Management* 5(1): 92-99.

Ihem, E. E., Osuji, G. E., Onweremadu, E.U., Uzoho, S. O., Ndukwe, B. N., Osisi, A. S & Okoli, N. H. (2015). Variability in selected properties of crude oil polluted soil of Izombe Northern Niger Delta, Nigeria. Agriculture, Forestry and Fisheries Special Issue. *Environment Applied Science Management in Changing Global Climate.* 4(3-1): 29-33.

Ite, A.E., Ibok, A.E., Ite, M.U. & Petters, S.W. (2013). Petroleum exploration and production: past and present environmental issue in the Nigeria's Niger Delta. *American Journal of Environmental Protection* 1 (4): 78-90.

Kayode, J., Oyedeji, A. A. & Olowoyo, O. (2009). Evaluation of the effect of pollution with spent lubricating oil on the physical and chemical properties of soil. *The Pacific Journal of Science and Technology.* 1(10):387-391.

Langeland, K. A., Cherry, H. M., McCormick, C. M. & Craddock Burks, K. A. (2008). *Identification and Biology of Non-native Plants in Florida's Natural Areas.* Gainesville, Florida, USA: University of Florida IFAS Extension. .

Lin, Q. & Mendelssohn, I. A. (1998). The combined effects of phytoremediation and biostimulation in enhancing habitat restoration and oil degradation of petroleum contaminated wetlands [J]. *Ecological Engineering*, 10 (3): 263-274.

Linden, O. & Palsson, J. (2013). Oil contamination in Ogoniland, Niger Delta. *Ambio*, 42(6): 685-701.

Moses, E. A. & Uwah, E. I. (2015). The effect of crude oil pollution on some soil fertility parameters in Ikot Oboreyin, Ikot Abasi, Akwa Ibom State, Nigeria. *Merit Research Journal of Environmental Science and Toxicology* 3(2): 017-024.

Ndimele, P. E., Saba, A. O., Ojo, D. O., Ndimele, C. C. & Anetekhai, M. A. (2018). Remediation of Crude Oil Spillage In the Political Ecology of Oil and Gas Activities in the Nigerian Aquatic Ecosystem, pp. 369-384.

Neuhauser, E.F. (2009). Monitored natural attenuation of manufactured gas plant tar mono and polycyclic aromatic hydrocarbons in ground water: a 14-year field study. *Ground Water Monit. Rem. 29*: 66–76 (2009).

Nwite, J. N & Alu, M. O (2015). Effect of different levels of spent engine oil on soil properties, grain yield of maize and its heavy metal in Abakaliki Southeastern Nigeria. *Journal of Soil Science and Environmental Management.* 5(4), 44-51.

Okon, I. E. & Ogba, C. O. (2018) The Impacts of Crude Oil Exploitation on Soil in Some Parts of Ogoni Region, Rivers State, Southern Nigeria. *Open Access Library Journal,* 5: e4297. https://doi.org/10.4236/oalib.1104297

Okonokhua, B. O., Ikhajiagbe B., Anoliefo, G. O & Emede, J. O (2007). The effect of spent engine oil on soil properties and growth of maize (Zea mays L.). *J. Appl. Sci. Environ. Mgt* 11(3):147-152.

Onwuka, C., Eboatu, A. N., Ajiwe, V. I. E. & Morah, E. J. (2021). Pollution Studies on Soils from Crude Oil Producing Areas of Rivers State, Niger Delta Region, Nigeria. *OpenAccess Library Journal* 8(9):1-17.

Randall, R. P. (2012). A Global Compendium of Weeds. Perth, Australia: Department of Agriculture and Food Western Australia, 1124 pp.

Sharma, A., Sharma, P., Sharma, A., Tyagi, R. & Dixit, A. (2017). Hazardous effects of petrochemical industries: A review [J], Recent Advances in Petrochemical Science, 2017, 3(2), (10.19080/RAPSCI.2017.03.555607).

Tinsley, A. & Farewell, T. (2015). Soil degradation: a growing concern. Dissecting soil: safeguarding an invaluable natural resource. *Environ.* pp. 14-17.

Udo, E. J. (1986). Some Studies on the Effect of Crude Oil of Soil on Plant Growth. *Journal of Biological and Applied Chemistry.* 11:26 – 29.

Watkley, A. & Black, I. A. (1934). An Examination of the Degtjereff Method for Determining Soil Organic Matter and a Proposed Modification of the Chronic and Titration Method. *Soil Science.* 37: 29 – 38.