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Potential of *Magathyrsus Maximum* and *Pennisetum Glaucum* for Sustainable Soil Restoration

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Abstract
The Niger Delta is plagued with cases of soil contamination with crude oil. In order to source for locally available low cost materials to remediate such soils, some plant materials such as *Magathyrsus maximum* and *Pennisetum glaucum* were employed to determine their remediation potentials of three soil samples: B1, B2 and B3 with B1 as control, for a period of eighteen weeks. Soil were taken from Highcast demonstration farm, the soil were free from crude oil contamination. 400g of these soils were placed in a plastic container for stimulation. 70g of crude oil was mixed thoroughly with 4000g of loamy soil in plastic containers. This contamination procedure was done in plastic containers. Soil samples were collected with hand trowel and placed in a plastic container for analysis. At the end of the eighteen weeks of investigations, there was an increase in pH values for B2 from 5.750±0.034 to 6.990±0.041 while for B3, it increased to 6.780±0.041. EC values dropped from 427 dS/m to 261 dS/m and 269 dS/m for B2 and B3 respectively, MC values increased from 17.3 ± 0.016% to 26.3 ± 0.057 and 24.9 ± 0.054% for B2 and B3, Samples B2 and B3 exhibited decreases in bulk density, decreasing from 1.386 ± 0.004 g/cm³ to 1.349 ± 0.025 g/cm³ and 1.358 ± 0.082 g/cm³, TNC values for B2 and B3 decreased from 0.131 ± 0.316% to 0.101 ± 0.701% and 0.124 ± 0.105%. The AP values for samples B2 and B3 decreased from 11.610 ± 0.097 mg/kg to 4.000 ± 0.054 mg/kg and 4.420 ± 0.008 mg/kg. The TOC values for samples B2 and B3 decreased from 3.990 ± 0.082% to 1.920 ± 0.035% and 1.940 ± 0.081%. The TOM values for samples B2 and B3 increased from 1.101 ± 0.017% to 1.267 ± 0.048% and 1.195 ± 0.005%, THC values for samples B2 and B3 decreased from 89.280 ± 0.108 mg/kg to 7.900 ± 0.082 mg/kg and 11.780 ± 0.025 mg/kg, respectively. The TPC values for samples B2 and B3 increased from 0.36 ± 0.187 ppm to 0.86 ± 0.057 ppm and 0.79 ± 0.076 ppm, respectively. The results obtained from this investigation show that *Magathyrsus maximum* and *Pennisetum glaucum* has the potential for remediating crude oil contaminated soil.

Keywords: Phytoremediation, Crude Oil, Soil, *Pennisetum glaucum*, *Magathyrsus maximus*

Introduction

The soil stands as a foundational, crucial and indispensable natural resource, acting as a critical intermediary within the environmental components of air, bedrock, water, and biota. Through their intricate interactions, these elements collectively meet essential needs, including the provision of food, fuel, and fiber to sustain various organisms. Contamination of soil by petroleum has emerged as a significant environmental challenge on a global scale, capturing widespread public attention in the past few decades (Fanaei et al., 2020). The release of hydrocarbons, attributed to activities such as agriculture, industry, and bunkering, is predominantly influenced by human actions (Fanaei et al., 2020). In Nigeria, particularly in the South-South region where oil exploration predominates, the incidence of crude oil pollution is escalating. As the area of soil affected by petroleum hydrocarbons expands, initiatives have been undertaken to address and remediate the overall contamination of soil by petroleum hydrocarbons. Incidents such as spills, leaks, and other environmental influences linked to petroleum products pose risks to human health (Ogah & Ekpete, 2021).

Conventional methods for environmental remediation, such as aeration, excavation, transportation, and incineration, are frequently costly, challenging, and ineffective (Njoku et al., 2012). Additionally, these approaches may have significant negative effects on soil structure and fertility. In recent times, biological approaches have become more favoured over chemical and physical methods for remediation because of their cost-effectiveness and their capability to impede the accumulation of contaminants (Osman et al., 2020). Studies indicate that certain plants possess the ability to remediate soils contaminated with crude oil using a technique known as phytoremediation (Njoku et al., 2009). Truu et al. (2015) have described phytoremediation as a technology reliant on the collaborative efforts of plants and their associated microbial communities to break down, eliminate, alter, or immobilize toxic compounds found in soils, sediments, and, more recently, in contaminated groundwater and wetlands. Phytoremediation, a cost-effective and passive approach, has the capacity to address both organic and inorganic contaminants without the drawbacks associated with conventional remediation methods

Materials and Method

This study was carried out at the demonstration farm of HighCast International Academy. It is located at 6, Logos/Holiness Avenue, off NTA-Rumuokwuta road, Mgbuoba, Portharcourt, Rivers State. Mgbuoba is a community in Obio/Akpor LGA of Rivers State. It is located on latitude 4.8421° N and longitude 6.9692° E.

The crude oil (light sweet crude, 36.3 oAPI and 0.16 wt% sulphur) (Enekwe et al., 2012) was obtained from The Port Harcourt Refining Company, (PHRC), Port Harcourt, Rivers State, Nigeria. *Pennisetum glaucum (pearl millet)* and *Magathyrsus maximus (Guinea grass)* were harvested from the demonstration farm of HighCast International Academy. Uncontaminated loamy soil samples were also collected from HighCast International Academy demonstration farm, Mgbuoba, Port Harcourt for stimulation. Soil samples were collected on a single day using a hand trowel at a depth of 12 cm, subsequently sun-dried for two days to eliminate moisture, sieved through a 2 mm mesh, and then stored in a polyethylene bag at ambient temperature.

70g of crude oil was mixed thoroughly with 4000 g of loamy soil in plastic containers. The contamination procedure was done in plastic containers. The soil samples were left for two days to allow for proper settling of the crude oil. Cow dung manure was added to sample B2 and B3 except B1 to enhance plant growth and thus facilitate the remediation process (Njoku et al., 2009). Five seeds of *P. glaucum* were sown in B3 at 2 cm depth (Njoku et al., 2009); *M. maximus* was transplanted to sample B2 while sample B1 served as the control (with no *M. maximus* and *P. glaucum* grown on it). The samples were kept in a greenhouse to prevent contamination from insects and they were moderately watered regularly to keep them moist. The phytoremediation process was allowed for a total period of eighteen weeks.

Before and after contamination, the soil's physicochemical properties were examined to assess the impact of phytoremediation on soil quality: pH, total hydrocarbon content, total organic carbon, total nitrogen content, phosphorus content, potassium content, moisture content, bulk density, electrical conductivity, total organic matter. Soil samples were collected from each container with a hand trowel, placed in a clean plastic container to store the collected sample. Soil samples were collected in every two weeks for analysis. The pH of the soil samples was determined using a glass electrode pH meter. The nitrogen content of the sample was determined by the modified Kjeldahl method. The organic carbon and organic matter present in the samples were determined using the chromic acid wet oxidation method. The available phosphorus in the sample was determined using the colorimetric Molybdenum blue procedure. The amount of potassium was determined using a flame photomer. The amount of crude oil in the soil samples was determined using air-dried soils that were sieved through 1mm mesh.

Results

Table 1 displays the soil's physicochemical characteristics before and after exposure to crude oil contamination. It was observed that the pH decreased from 6.090 ± 0.130 to 5.750 ± 0.034. Organic carbon content increased from 1.920 ± 0.014% to 3.990 ± 0.002%. The potassium levels showed negligible fluctuation, experiencing a minor decline from 0.39 ± 0.201 ppm to 0.360 ± 0.087 ppm. This slight alteration is probably due to the complex interplay between crude oil and soil, exerting only a limited effect on potassium concentrations. It was also observed that the nitrogen content decreased from 0.175 ± 0.101% to 0.131 ± 0.316%. The hydrocarbon levels displayed a notable rise from 0.140 ± 0.006 mg/kg to 89.280 ± 0.008 mg/kg.

Table 1. Physicochemical properties of soil used for the study before and after contamination

Soil Indicators	Before	After
pH	6.090 ±0.130	5.750±0.034
EC(Electrical Conductivity)	271.000±1.300	427.000±0.780
MC (Moisture Content)	31.000±0.401	17.300±0.016
BD (Bulk Density)	1.218±0.011	1.386±0.010
TN (Total Nitrogen)	0.175±0.101	0.131±0.006
AP (Available Phosphorus)	8.42.000±0.216	11.61±0.097
TOC (Total Organic Carbon)	1.920±0.014	3.990±0.002
TOM (Total Organic Matter)	2.463±0.032	1.101±0.017
HC (Hydrocarbon Content)	0.140±0.006	89.280±0.008
PC (Potassium Content)	0.390±0.201	0.360±0.087

TNC, TOC, TOM and MC are expressed in %, AP and HC in mg/kg, BD in g/cm^3, PC in ppm, EC in dS/m, CEC in cmol/kg, pH has no unit.

The phosphorus levels also increased from 8.420 ± 0.216 ppm to 11.610 ± 0.097 ppm. The electrical conductivity (EC) showed a notable increase from 271.000±1.300 µS/cm to 427.000±0.780µS/cm following contamination. This rise suggests a higher concentration of ions in the soil, potentially affecting soil salinity and the availability of nutrients. The moisture content decreased from 31.000±0.401 % to 17.300±0.016 % after contamination. Total organic matter decreased from 2.463±0.032% to 1.101±0.017% after contamination.

Table 2 illustrates the pH variations in soil samples over time. Initially, all samples exhibited acidity upon contamination at week 0. However, during the 18-week observation period, a gradual increase in pH was noted in samples B2 and B3. In contrast, the control sample (B1) showed relatively stable pH values throughout the experiment, suggesting minimal to no remediation in the absence of plant presence. The pH values for B2 increased from 5.750±0.034 to 6.990±0.041 (a 1.24 increase), while B3 increased from 5.750±0.034 to 6.780±0.041 (a 1.03 increase).

Table 2. Soil pH variation with time

Time (Weeks)	**B1**	**B2**	**B3**
0	5.750±0.034	5.750±0.034	5.750±0.034
2	5.780±0.091	6.210±0.092	5.800±0.093
4	5.800±0.331	6.380±0.067	6.020±0.004
6	5.830±0.081	6.520±0.159	6.140±0.001
8	5.850±0.144	6.640±0.021	6.230±0.004
10	5.870±0.202	6.710±0.025	6.310±0.017
12	5.880±0.416	6.740±0.032	6.460±0.066
14	6.010±0.029	6.820±0.051	6.550±0.042
16	6.050±0.142	6.900±0.052	6.630±0.010
18	6.080±0.486	6.990±0.041	6.780±0.041

pH has no unit.

Throughout the 18-week investigation period, the electrical conductivity (EC) of the control sample (B1) exhibited minimal variation, with a slight decrease from 427 dS/m to 413 dS/m, indicating stability as shown in table 3. Conversely, samples containing plants showed a notable decrease in EC, dropping from 427 dS/m to 261 dS/m and 269 dS/m for B2 and B3, respectively. Table 4 displays the moisture content (MC) of soil samples over time. At the conclusion of the 18-week investigation period, the control sample B1 remained relatively stable, experiencing a slight increase from 17.300 ± 0.016% to 19.400 ± 0.024%, representing a 2.1% rise. This modest increase in moisture content is likely attributable to natural environmental factors. In contrast, samples containing plants (B2 and B3) exhibited notable increases in MC, rising from 17.3 ± 0.016% to 26.3 ± 0.057% and 24.9 ± 0.054%, respectively.

Table 3. Soil electrical conductivity (EC) with time

Time (Weeks)	B1	B2	B3
0	427.000±0.178	427.000±0.178	427.000±0.178
2	425.000±0.182	390.000±0.127	400.000±0.086
4	423.000±0.059	371.000±0.049	380.000±0.098
6	421.000±0.098	362.000±0.146	369.000±0.087
8	420.000±0.067	337.000±0.087	342.000±0.067
10	418.000±0.087	344.000±0.086	335.000±0.079
12	417.000±0.145	313.000±0.079	320.000±0.156
14	415.000±0.069	292.000±0.087	306.000±0.163
16	414.000±0.045	270.000±0.090	281.000±0.124
18	413.000±0.146	261.000±0.153	269.000±0.078

EC in dS/m

Table 4. Soil moisture content with time

Time (Weeks)	B1	B2	B3
0	17.300±0.016	17.300±0.016	17.300±0.016
2	17.400±0.021	21.800±0.034	21.100±0.020
4	17.600±0.032	22.300±0.018	21.700±0.017
6	17.900±0.051	22.800±0.019	22.300±0.019
8	18.200±0.042	23.500±0.070	22.800±0.058
10	19.500±0.034	23.800±0.060	23.200±0.021
12	18.800±0.701	24.700±0.072	23.700±0.081
14	19.100±0.903	25.200±0.061	24.100±0.045
16	19.200±0.049	25.800±0.081	24.600±0.067
18	19.400±0.024	26.300±0.057	24.900±0.054

MC is expressed in %

Table 5 displays the bulk density (BD) of soil samples after the 18-week investigation period. The control sample, B1, remained relatively stable, with a minimal decrease from 1.386 ± 0.004 g/cm³ to 1.375 ± 0.008 g/cm³, representing a decrease of 0.011 g/cm³. This slight decrease in bulk density may be attributed to natural factors such as erosion and water drainage through the soil strata. Samples B2 and B3 exhibited decreases in bulk density, decreasing from 1.386 ± 0.004 g/cm³ to 1.349 ± 0.025 g/cm³ and 1.358 ± 0.082 g/cm³, respectively.

Table 5 Bulk density treated with time

Time (Weeks)	B1	B2	B3
0	1.386±0.010	1.386±0.010	1.386±0.010
2	1.385±0.007	1.376±0.005	1.381±0.003
4	1.384±0.087	1.372±0.082	1.378±0.05
6	1.381±0.009	1.371±0.054	1.375±0.001
8	1.380±0.005	1.366±0.001	1.371±0.033
10	1.380±0.006	1.361±0.008	1.368±0.005
12	1.378±0.002	1.358±0.003	1.366±0.005
14	1.377±0.005	1.356±0.002	1.363±0.005
16	1.376±0.001	1.352±0.001	1.371±0.004
18	1.375±0.008	1.349±0.005	1.358±0.002

BD in g/cm^3

Table 6 presents the variations in total nitrogen content (TNC) of soil samples over time. Following the 18-week investigation period, sample B1 (Control) exhibited an increase from 0.131 ± 0.316% to 0.178 ± 0.109%, representing a 0.047% rise, indicating minimal or no remediation activity. In contrast, the total nitrogen content of samples B2 and B3 decreased from 0.131 ± 0.316% to 0.101 ± 0.701% and 0.124 ± 0.105%, respectively, after an initial increase.

Table 6. Total nitrogen content (TNC) with time

Time (Weeks)	B1	B2	B3
0	0.131±0.316	0.131±0.316	0.131±0.316
2	0.201±0.042	0.152±0.008	0.176±0.088
4	0.196±0.045	0.149±0.110	0.157±0.020
6	0.193±0.010	0.138±0.211	0.150±0.070
8	0.190±0.036	0.131±0.209	0.145±0.011
10	0.188±0.095	0.124±0.040	0.141±0.008
12	0.186±0.080	0.118±0.070	0.136±0.204
14	0.183±0.001	0.116±0.090	0.132±0.045
16	0.181±0.049	0.113±0.084	0.128±0.277
18	0.178±0.009	0.101±0.001	0.124±0.105

TNC is expressed in %

Table 7 displays the available phosphorus (AP) levels in soil samples. At the conclusion of the investigation, sample B1 (Control) exhibited a decrease from 11.610 ± 0.097 mg/kg to 8.160 ± 0.034 mg/kg, likely influenced by natural processes or external factors. The AP values for samples B2 and B3 decreased from 11.610 ± 0.097 mg/kg to 4.000 ± 0.054 mg/kg and 4.420 ± 0.008 mg/kg, respectively.

Table 7. Available phosphorus (AP) with time

Time (Weeks)	B1	B2	B3
0	11.610±0.097	11.610±0.097	11.610±0.097
2	11.43±0.091	8.01±0.023	8.270±0.080
4	11.01±0.082	7.53±0.042	7.580±0.020
6	10.72±0.040	7.14±0.059	7.420±0.044
8	10.440±0.070	6.720±0.078	7.050±0.065
10	10.110±0.025	6.44±0.071	6.620±0.029
12	9.620±0.001	5.310±0.054	6.060±0.035
14	9.210±0.072	4.790±0.013	5.500±0.059
16	8.500±0.060	4.450±0.076	4.950±0.082
18	8.160±0.034	4.000±0.054	4.420±0.008

Available Phosphorus (AP) in mg/kg

Table 8 shows the total organic carbon (TOC) levels in soil samples treated with plants over time. Following the 18-week investigation period, sample B1 (Control) exhibited a decrease from 3.990 ± 0.082% to 3.580 ± 0.005% (a 2.07% decrease). The TOC values for samples B2 and B3 decreased from 3.990 ± 0.082% to 1.920 ± 0.035% and 1.940 ± 0.081%, respectively. Table 9 presents the total organic matter (TOM) levels in soil samples treated with plants. Following the 18-week investigation period, sample B1 (Control) showed a slight increase from 1.101 ± 0.017% to 1.113 ± 0.019% (a 0.012% increase). The TOM values for samples B2 and B3 increased from 1.101 ± 0.017% to 1.267 ± 0.048% and 1.195 ± 0.005%, respectively.

Table 8. Total organic carbon (TOC) with time

Time (Weeks)	B1	B2	B3
0	3.990±0.082	3.990±0.082	3.990±0.082
2	3.900±0.074	3.650±0.021	3.750±0.004
4	3.880±0.043	3.410±0.032	3.510±0.007
6	3.850±0.036	3.090±0.051	3.240±0.073
8	3.810±0.063	2.820±0.052	2.910±0.071
10	3.780±0.026	2.640±0.041	2.730±0.001
12	3.750±0.029	2.440±0.043	2.560±0.011
14	3.700±0.082	2.230±0.024	2.410±0.009
16	3.640±0.005	2.060±0.045	2.150±0.020
18	3.580±0.005	1.920±0.035	1.940±0.081

TOC is expressed in %

Table 9. Total organic matter (TOM) with time

Time (Weeks)	B1	B2	B3
0	1.101±0.017	1.101±0.017	1.101±0.017
2	1.102±0.008	1.120±0.006	1.106±0.012
4	1.103±0.001	1.150±0.079	1.111±0.011
6	1.105±0.005	1.159±0.011	1.121±0.012
8	1.106±0.011	1.164±0.010	1.142±0.002
10	1.108±0.009	1.172±0.013	1.152±0.003
12	1.109±0.003	1.193±0.008	1.164±0.015
14	1.110±0.003	1.230±0.010	1.172±0.008
16	1.112±0.017	1.254±0.092	1.181±0.009
18	1.113±0.019	1.267±0.048	1.195±0.005

TOM is expressed in %

Table 10 displays the total hydrocarbon content (THC) of soil samples treated with plants. Following the 18-week investigation period, sample B1 (Control) exhibited a slight decrease from 89.2800 ± 0.108 mg/kg to 88.300 ± 0.086 mg/kg, representing a decrease of 0.98 mg/kg. The THC values for samples B2 and B3 decreased from 89.280 ± 0.108 mg/kg to 7.900 ± 0.082 mg/kg and 11.780 ± 0.025 mg/kg, respectively.

Table 10. Total hydrocarbon content (THC) with time

Time (Weeks)	B1	B2	B3
0	89.280±0.108	89.280±0.108	89.280±0.108
2	89.160±0.091	72.910±0.021	78.870±0.021
4	89.070±0.031	60.380±0.032	64.020±0.055
6	89.000±0.081	56.560±0.051	61.140±0.035
8	88.910±0.044	51.690±0.057	56.230±0.042
10	88.870±0.002	46.710±0.041	50.310±0.024
12	88.820±0.016	38.740±0.043	41.460±0.078
14	88.780±0.029	27.820±0.024	30.550±0.045
16	88.700±0.042	15.900±0.035	18.630±0.065
18	88.300±0.086	7.900±00.082	11.780±0.025

HC in mg/k

Table 11 illustrates the total potassium content (TPC) of soil samples treated with plants. Following the 18-week investigation period, sample B1 (Control) showed a slight increase from 0.360 ± 0.187 ppm to 0.430 ± 0.008 ppm, indicating a 0.07 ppm increase. The TPC values for samples B2 and B3 increased from 0.36 ± 0.187 ppm to 0.86 ± 0.057 ppm and 0.79 ± 0.076 ppm, respectively. This corresponds to an increase of 0.50 ppm for B2 and 0.43 ppm for B3.

Table 11. Total potassium content (TPC) with time

Time (Weeks)	B1	B2	B3
0	0.360±0.187	0.360±0.187	0.360±0.187
2	0.370±0.099	0.750±0.770	0.700±0.088
4	0.380±0.032	0.760±0.552	0.720±0.001
6	0.380±0.093	0.780±0.881	0.730±0.035
8	0.390±0.083	0.800±0.067	0.740±0.078
10	0.400±0.086	0.810±0.009	0.750±0.072
12	0.400±0.060	0.820±0.032	0.760±0.031
14	0.410±0.004	0.840±0.060	0.770±0.908
16	0.420±0.005	0.850±0.053	0.780±0.043
18	0.430±0.008	0.860±0.057	0.790±0.076

PC in ppm

Discussion

Physicochemical properties of the soil used for the study

The physicochemical characteristics of the soil before and after exposure to crude oil showed different variations. The decline in pH is likely attributed to the acidic properties of crude oil, known to lower soil pH upon contamination, as noted by Ogboghodo et al. (2004). This finding is consistent with earlier studies (Akubugwo et al., 2009; Nwaogu & Onyeze, 2010; Egharevba et al., 2017), which reported similar pH values. Additionally, the introduction of crude oil led to an increase in organic carbon content from 1.920 ± 0.014% to 3.990 ± 0.002%. The slight alteration in potassium levels is probably due to the complex interplay between crude oil and soil, exerting only a limited effect on potassium concentrations. The decrease in potassium content might also be attributed to a temporary trapping of nutrients by soil microbes after crude oil contamination, as suggested by Wang et al. (2013). The introduction of crude oil contamination may have caused the inhibition of nitrogen-fixing bacteria in the soil, as well as other microorganisms involved in organic decomposition, ultimately resulting in a reduction in soil nitrogen levels (Wang et al., 2013). The notable rise in hydrocarbon levels is to be expected considering that crude oil primarily contains hydrocarbons (Ogboghodo et al., 2004). This observation corroborates earlier research by Egharevba et al. (2017), which similarly noted heightened hydrocarbon concentrations in soil affected by crude oil contamination. Phosphorus demonstrates its greatest solubility around a pH of 6.5, suggesting that the nutrient becomes more readily available up to this pH threshold (Egharevba et al., 2017). Consequently, the decline in soil pH resulting from crude oil contamination could have played a role in augmenting the accessible phosphorus in the soil. This phenomenon might stem from the breakdown of organic matter contained in crude oil, which releases phosphorus into the soil. The rise in electrical conductivity (EC) suggests a higher concentration of ions in the soil, potentially affecting soil salinity and the availability of nutrients. The decrease in moisture content after contamination may be due to the fact that crude oil contains hydrophobic compounds that repel water, reducing the soil's ability to retain moisture. Crude oil can infiltrate the soil matrix, filling pore spaces and compacting soil particles. This infiltration leads to a reduction in soil volume and an increase in bulk density. Decrease in total organic matter may be as a result of activities of some microorganisms such pseudomonas aeruginosapresent, bacillus and rhodococcus in the soil which are capable of utilizing organic matter, including components of crude oil, as a source of energy. As they metabolize these organic compounds, they break them down into simpler forms, thereby reducing the overall organic matter content of the soil. Exposure to crude oil and its constituents can lead to chemical reactions that result in the oxidation and breakdown of organic matter present in the soil.

Soil pH

The increase in pH after remediation process aligns with previous research, such as Ebere et al. (2011), who observed a similar trend in remediation of crude oil polluted soil, where pH increased from 5.21 to 7.1. Egharevba et al. (2017) also reported comparable results, with pH levels shifting from acidic (4.27) to near-neutral (6.07 to 6.59) post-treatment with specific plant species. Akram and Deka (2021) and Chukwuma et al. (2019) documented similar pH shifts in their respective studies, indicating an increase from acidic levels to more favorable ranges for plant growth, consistent with the guidelines set by the Federal Environmental Protection Agency (FEPA 2002), which stipulate an optimal pH range of 5.5-7 for plant growth. Overall, the observed increase in pH over the 18-week period suggests a successful mitigation of acidic conditions in the soil, moving towards a more neutral range conducive to plant growth.

Soil electrical conductivity (EC)

This decline in EC can be attributed to the natural salt-absorbing and filtering properties of *M. maximus* and *P. glaucum*, along with their capacity to enhance soil structure and diminish salt accumulation over time. It's likely that the plants absorbed and mitigated the salt content in the soil, leading to a reduction in EC. Notably, *P. glaucum's* deep roots facilitate salt movement downward through leaching, thereby contributing to EC reduction. Additionally, the roots play a role in improving soil structure, promoting enhanced water infiltration and drainage, which reduces salt concentration near the soil surface and consequently lowers EC. These findings are consistent with Akram and Deka (2021) who observed similar EC reductions post-treatment with specific plant species. They also align with previous reports such as Okoro et al. (2011) and Anacletus et al. (2017), who documented varying EC values in different soil conditions.

Soil moisture content (MC)

The notable increase in MC may be attributed to the presence of plants in the contaminated soil which likely enhanced its water-holding capacity and facilitated contaminant breakdown through the rhizosphere effect. Microbial activity in the soil further contributed to pollutant breakdown and an increase in moisture content. This observed increase in moisture content can be attributed to various factors, including contaminant breakdown, microbial activity, and the influence of different plant combinations on soil conditions. The presence of plants likely improved soil water-holding capacity, facilitated contaminant breakdown, and promoted soil moisture retention. These findings align with previous studies such as Essien and John (2010) who reported significantly lower moisture content in polluted soil compared to unpolluted soil, and noted that high crude oil concentrations can hinder water and oxygen penetration by clogging soil pores and reducing pore spaces. Additionally, reports by Osuji and Onojake (2006), Nwazue (2011), and Egharevba et al. (2017) support the observed increase in moisture content in treated soils, suggesting that the decrease in hydrocarbon content resulting from crude oil contamination may lead to improved water permeability and subsequently higher moisture content.

Bulk density (BD)

The presence of plant roots played a significant role in breaking up compacted soil and increasing soil porosity, thereby reducing bulk density. Additionally, microbial activity promoted by the presence of plants contributed to contaminant breakdown and improvement in soil structure. The observed decrease in bulk density indicates improved soil structure, porosity, and reduced compaction due to the influence of plant roots and associated microbial activity. It's noted that crude oil in soil can influence physical properties such as bulk density, moisture content, soil air, water holding capacity, and porosity. This aligns with previous research by Ekemube et al. (2022) and Kayode et al. (2009), which noted that crude oil in soil can block pore spaces, impair soil aeration, porosity, bulk density, and water infiltration ability, potentially hindering plant growth and productivity.

Total nitrogen content (TNC)

The initial increase in TNC may be attributed to the addition of animal dung manure following soil contamination with crude oil at the start of the investigation period (Egharevba et al., 2017). The subsequent reduction in nitrogen content in polluted samples could be due to the immobilization of nutrients and minerals by crude oil, indicating a decrease in nitrogen pollutants in the soil. The variation in TNC reduction may be influenced by the ability of plants to uptake and metabolize nitrogen compounds from contaminated soil (Egharevba et al., 2017). Soil type, initial nitrogen levels, and environmental factors can also affect phytoremediation effectiveness.

Available phosphorus (AP)

The decrease in AP may stem from the ability of plants to uptake and accumulate phosphorus, soil-plant interactions, and microbial activity influencing phosphorus availability. Environmental conditions such as temperature, moisture, and soil composition can also impact nutrient dynamics. These findings are consistent with previous report Egharevba et al. (2017) which recorded a reduction in phosphorus content of soil samples. Lower available phosphorus concentrations in polluted soil may be attributed to microbial utilization of petroleum hydrocarbons as a carbon source, leading to the consumption of available phosphorus during hydrocarbon degradation (Wang et al., 2009). Additionally, phosphorus solubility is maximized at pH 6.5, which may influence phosphorus availability (Wang et al., 2013). The significantly lower available phosphorus levels in polluted soil compared to unpolluted soil before planting are likely due to crude oil contamination. This aligns with previous studies that have associated crude oil contamination with decreased soil available phosphorus (Okolo et al., 2005; Wang et al., 2013). This finding corresponds with studies that have linked decreased soil available phosphorus to plant-mediated phosphorus utilization during phytoremediation processes (Ch'ng et al., 2014).

Total organic carbon (TOC)

The TOC results obtained from the investigation align with findings by Akram and Deka (2021) who observed an initial TOC level of 18.75% in an oil-contaminated soil sample, with values decreasing by 8.15% and 9.58%, respectively, after treatment. Additionally, Egharevba et al. (2017) reported a reduction from an initial value of 4.22% to 2.01% and 2.11% for the investigated samples. The observed higher organic carbon content in polluted soil compared to unpolluted soil corroborates previous reports by Osuji and Onojake (2006) and Abdulsalam et al. (2012). This difference may be attributed to metabolic processes following oil spills that promote the agronomical addition of organic carbon from petroleum hydrocarbons. The decrease in organic carbon content of treated soils over time is consistent with findings by Okoro and Adoki (2014), who observed similar changes in total organic carbon during the bioremediation of crude oil-impacted soil. This reduction likely reflects the breakdown and degradation of organic carbon compounds by microbial activity and plant-mediated processes during remediation efforts.

Total organic matter (TOM)

Organic matter content is often used as an indicator of soil fertility and pollution levels. It influences nutrient mineralization, as carbon content directly relates to organic carbon content in the soil, affecting oxygen levels and microbial metabolism. The increase in organic matter during soil remediation in the crude oil-treated soils observed in this study suggests that the selected plants have significant metabolic and absorption abilities, with efficient transport networks that selectively uptake contaminants present in the soil. This underscores the effectiveness of *Magathyrsus maximus* and *Pennisetum glaucum* as amendments in improving soil properties. This finding is consistent with the work of Jude and Tanee (2016) who reported an increase in total organic matter and carbon in polluted amended soil. However, the results differ from those of Ayotamuno et al. (2006) and Njoku et al. (2012) who observed a reduction in organic matter content in vegetated soils compared to non-vegetated soils, possibly due to organic matter removal by plants. The reduction in organic matter content over time may indicate significant decomposition of petroleum hydrocarbons, facilitated by various decomposition factors, as reported by Okoro et al. (2011), similar to findings by Njoku et al. (2012)

Total hydrocarbon content (THC)

The percentage reduction in total hydrocarbon content observed in this study aligns with Tanee and Albert (2011) who reported a decrease in total hydrocarbon content in crude oil-polluted soil. Similarly, Sunday and Aboh (2012) and Nwaichi et al. (2015) reported significant decreases in petroleum hydrocarbon content. Egharevba et al. (2017) observed a reduction of 60.8% and 45.89% in hydrocarbon content of polluted soil samples after treatment, while Chukwuma et al. (2019) recorded a decrease from 17962.11 ± 1000.00 mg/kg to 100.82 ± 46.31 mg/kg after treatment with *F. ferruginea*.

Total potassium content (TPC)

The relatively low concentration of potassium in polluted soil compared to unpolluted soil before planting may be attributed to crude oil pollution. However, after treatment, the potassium concentration in vegetated soils increased. This observation aligns with the findings of Egharevba et al. (2017), who reported an increase in potassium content from 0.30 ppm. The observed increase in potassium content in soil samples may be due to the presence of cow dung, which inherently contains nutrients that improve soil nutrient content. The decomposition of organic matter in cow dung releases various nutrients, including potassium, into the soil through microbial activity. However, these findings contrast with those of Ekperusi and Aigbodion (2015) who reported an increase in potassium concentration after crude oil contamination but a decrease after treatment. Ezeaku and Egbemba (2014) suggested that low pH could lead to potassium loss due to displacement reactions in the soil colloidal complex.

Conclusion

It can be concluded from the study that *Magathyrsus maximum* and *Pennisetum glaucum* have the potential to remediate crude oil contaminated soil as the investigated plants were able to remediate and clean-up the contaminated soil. The investigation also showed that time played an important role in remediation process. The rate of remediation was highest in the eighteenth week for all the parameters that were investigated.

Recommendation

Since plants such as *Magathyrsus maximum* and *Pennisetum glaucum* can be locally sourced and readily available, individuals and government should be encouraged to plant them within the immediate environment.

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