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ASSESSMENT OF SWEET POTATO (*IPOMOEA BATATAS)* FOR PHYTOREMEDIATION OF MOTOR OIL CONTAMINATED SOIL

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Abstract
The high cost, adverse effects on the environment and low efficiencies of the physical, chemical and thermal techniques currently being used to remediate hydrocarbon contaminated soils calls for evaluation of plant based methods. In this work, phytoremediation study was made with laterite soil artificially contaminated with motor oil. Three replicates of 3 kg of the air dried soil fertilized with 10% (w/w) organic fertilizer were each contaminated with 200ml of motor oil thoroughly mixed and placed in a 35 cm high plastic bowl. Six young plants of sweet potato were transplanted to each of the plastic bowl and allowed eight weeks to grow and stabilize. Hydrocarbon removal from the soil in the presence of the plant species were measured at two weekly intervals for a period of 16 weeks. Our results indicate that sweet potato plant (Ipomoea batatas) can grow, sustain growth and survive in the contaminated soil environment; the plant reduced the initial TPH content in the soil from 75.46mg/g to 19.876mg/g in 16 weeks. It is predicted that it will take about 27 weeks to reduce the TPH content to zero. The study concluded that sweet potato plant (Ipomoea batatas) has potential phytoremediation application in remediating hydrocarbon contaminated soils.

Keywords: Phytoremediation, Sweet potato, hydrocarbon. Motor oil, Laterite soil, Contamination.

1. Introduction

Environmental pollution has become a global problem affecting both developed and developing countries [1] and it has assumed global concern as it is a threat to the well-being of all life forms including humans. In Nigeria, petroleum exploration, exploitation and distribution activities have led to the pollution of land and waterways in the Niger Delta region of the country where oil exploration and exploitation are carried out [2] resulting in agricultural lands in the area becoming less productive [3] while the creeks and fishing waters have become more or less dead [4]. Hydrocarbons are widespread in the environment; their major source is petroleum but they are also formed by synthetic processes and by biological processes by bacteria and plants [5]. Petroleum and petroleum products enter soil from ruptured crude oil pipelines, land disposal of refinery products, petroleum wastes, leaking storage tanks and accidental spills [6, 7]. Petroleum hydrocarbons found in the environment usually originate from crude oil distillates like gasoline, lubricating oils and other petroleum products used by humans for a variety of activities like fuelling of vehicles. Natural gas and motor oil has been on the increase due to industrialization that has resulted in increased consumption of petroleum products resulting in increased contamination of sites with petroleum and petroleum by- products [8]. According to [9], petroleum and its products are of specific concern in pollution studies because of their structural complexity, slow biodegradability, biomagnification potential and the serious health hazards associated with their release into the environment.

Contaminated land has elevated concentrations of chemicals or other substances derived from man's use of land and soil contaminants influence human health, surface and ground water quality, the nature and viability of ecosystems, condition of buildings and other materials within the ground as well as the visual amenity of an area [10].This therefore calls for urgent and cost effective measures for the remediation of the hydrocarbon contaminated lands and waterways in the Nigerian environment. Various physical, chemical and thermal processes or methods are already being used to remediate oil contaminated sites [11, 12] but the enormous costs, adverse effects on the environment and low efficiencies associated with these remediation techniques present limitations to their availability and usage. It is reported in the literature [12] that organic pollutants derived from treated soils are seldom thoroughly removed or degraded from the environment and thus still threaten human health and that the cost of these remediation methods are usually as high as US$ 100 – 300 per m^3 of soil hence limiting their application in developing countries like Nigeria. Thus, in recent times biological techniques like phytoremediation are being evaluated as alternative options for removal of environmental pollutants e.g. from sites contaminated with petroleum [2] due to its low cost and safety of implementation [13].

Phytoremediation is the use of plants and their associated microorganisms to degrade, contain or render harmless contaminants in soil or groundwater [14, 15]. The use of plants in phytoremediation is gaining support as plants have intrinsic abilities to extract and metabolize contaminants and their cooperation with soil microorganisms and endophyte microbes that live inside plants may enhance the removal of contaminants from the environment hence the three major advantages of phytoremediation include low cost, possible *in situ* remediation and less impact on the environment [16]. According to [17], phytoremediation is a cost effective alternative for remediation of recalcitrant hydrocarbon contaminated soils.

Plants can provide a favourable environment for bioremediation and also reduce runoff and leaching from the contaminated site [18]. Phytoremediation has been shown to be effective for different kinds of pollutants e.g heavy metals, radio nuclides and broad range of organic pollutants [7]. The application of plants for remediation of soil contaminated with petroleum hydrocarbon is one of the promising cost and environmentally effective approaches and for successful phytoremediation both plant and microorganism must survive and grow in the hydrocarbon contaminated soil.

Various plants with their associated microorganisms have been found to increase the removal of petroleum hydrocarbons from contaminated soil [19, 20]. According to [21], plants to be used for phytoremediation should be appropriate for the climatic and soil conditions of the contaminated sites and such plants should also have the ability to tolerate conditions of stress. That is, plants in phytoremediation must tolerate the pollutants at concentrations present in contaminated environment [22]. Of the various plants identified in the literature for their potential to facilitate the phytoremediation of sites contaminated with petroleum hydrocarbons, grasses and legumes are singled out for their potential in this regard [19,23]. Grasses are said to make superior vehicles for phytoremediation because they have extensive fibrous system and in particular grass root systems have maximum root surface area (per m^3 of soil) of any plant and may penetrate up to 3m [19] while legumes are thought to have advantage over non- leguminous plants in phytoremediation because of their ability to fix nitrogen, that is, legumes do not have to compete with microorganism and other plants for limited supply of available soil nitrogen at contaminated sites.

As plant uptake of contaminant is plant species dependent [22], not all species possess superior capability to extract and metabolize contaminants hence additional research work is needed to investigate other plants (particularly local plant species) with potential phytoremediation applications [24] as plant uptake, accumulation and translocation of organic pollutants vary greatly depending on plant species, organic pollutant characteristics and environmental conditions. The main goal of this investigation therefore was to evaluate the potential of sweet potato (*Ipomoea batatas*), a dicotyledonous plant species which grows in tropical Nigeria for phytoremediation of laterite soil contaminated with motor oil. Sweet potato (*Ipomoea batatas)* has been selected for investigation based on its root morphology and propagation characteristics [25]; it's extensive widely branded fibrous root system results in a large root surface area per unit volume of surface soil with the fibrous roots being capable of providing larger surface for colonization by soil microorganisms.

The study is significant in the sense that only few researches have been carried out on phytoremediation in the tropics especially with respect to laterite soils contaminated with petroleum hydrocarbons even when conditions in the tropics favour the technique [15]. Laterite is a soil type found in the Niger Delta region in Nigeria [26] where pollution due to oil activities is high [2].

The specific objectives of the study were to:

- characterize the soil and motor oil to be used for the study
- ascertain the ability of sweet potato plant to grow , sustain growth and survive in motor oil contaminated laterite soil
- evaluate the potential of sweet potato plant to stimulate biodegradation process of petroleum hydrocarbons in the soil.
- determine the amount of hydrocarbon removed from the soil with time and hence calculate the efficiencies of removal and on the

basis of which determine the potential of sweet potato plant for use in phytoremediation of motor oil contaminated laterite soil.

2. Materials and methods

This study was carried out in two phases namely: (i) Field work and (ii) Laboratory work.

2.1 Field work

The field work involved the collection of soil samples, soil preparation and obtaining and transplanting of the plants (sweet potato). The soil used for the study was a sandy loam obtained from an agricultural land in Ugbowo Quarters, Benin City in Nigeria a site where the likelihood of previous petroleum hydrocarbon contamination was very remote. Soil samples were collected from both surface and subsurface. The subsurface soil was collected at a depth of 30 – 35 cm. The motor oil used for contaminating the soil was obtained from a motor / lubricating oil retail outlet in Benin City. The plant (Sweet potato – *Ipomoea)* used for the study was obtained from a botanical garden in Benin City. The plant species is a root crop cultivated throughout tropical Africa and warm temperate regions wherever there is sufficient water to support their growth [27]. Sweet potato can grow on a variety of soils but well drained light and medium textured soils with pH range of 5.8 to 7.0 are more favorable for the plant [28].

The plant is readily available and is grown in all geo-political zones of Nigeria [27]

Soil preparation was done in order to simulate a polluted land; 12kg of the air dried soil was fertilized with 10% (w/w) organic fertilizer. Three replicates of 3kg of the soil were each contaminated with 200ml of motor oil and the balance 3kg of the soil was left uncontaminated. The contaminated soil replicates and uncontaminated soil were each placed in a plastic bowl with a height column of about 35cm.The soils in the four bowls were watered and left for two days to absorb moisture. Eighteen young plants of sweet potato obtained from a research garden near the University of Benin in Benin City were transplanted (6 each) into the 3 bowls with contaminated soil and the bowls housed the plants throughout the duration of the experiments(Plate 1). The bowl with the uncontaminated soil was left with no plants and it thus served as control (Plate 2). The 4 bowls were stationed in the research garden under normal environmental conditions.

2.2 Laboratory Experiments

The laboratory experiments for this study were carried out at two laboratories in Benin City. They are Civil Engineering Laboratory, University of Benin, Benin City and Franej Laboratory, Benin City. The following laboratory works were carried out in the laboratories:

i. Characterization of motor oil sample
ii. Characterization of the soil
iii. Total Petroleum Hydrocarbon analyses of the soil samples

Plate1: Experimental setup photo of sweet potato plants

Plate 2: Experimental setup photo of uncontaminated soil (Control)

2.2.1 Characterization of motor oil

The motor oil used for the study was characterized for following properties: density, specific gravity, kinematic viscosity, moisture content, flash point, temperature, and pH. The ASTM specifications /procedures were adopted. The results are given in Table1.

2.2.2 Characterization of soil

The soil used for the study was characterized for the following properties using the indicated test procedures/ specifications:

i. Specific gravity [BS1377]
ii. Organic matter content [BS1377]

iii. Total Nitrogen content [IUPAC]
iv. Total phosphorus content [ASTM]
v. Total potassium content[ASTM]
vi. pH(soil) [ASTM]
vii. Sieve Analysis (BS1377]

The results are presented in Table2.

2.2.3 Total Petroleum Hydrocarbon Analyses

After an initial eight weeks period allowed for the growth and stabilization of the plants in the contaminated soil environment, soil samples were collected randomly from each of the three bowls at the top and below and then mixed and labeled and taken to the laboratory for determination of the total petroleum hydrocarbon content (TPH) remaining in the soil in each bowl. The mean value of the TPH content remaining in the soil was recorded. The procedures were subsequently repeated every two week for a period of 16 weeks. The TPH content of the soil was determined using ASTM test procedures. However, the initial TPH of the soil was taken immediately after contaminating the soil with motor oil. The TPH content of the uncontaminated soil (control) was also determined to check the presence of hydrocarbon in the soil prior to artificial contamination.

2.2.3.1 Amount of Hydrocarbon removed from the soil

The amount of hydrocarbon removed from the soil was estimated using the equation [29]:

$$q = \frac{C_o - C_e}{m} \qquad (1)$$

Where q is the amount of hydrocarbon removed from the soil (mg/g), C_o is the initial concentration of hydrocarbon in the soil (mg/g), C_e is equilibrium concentration of hydrocarbon in the soil (mg/g) and m is the number of plants.

2.2.3.2 Efficiency of removal of hydrocarbon from the soil

The efficiency of removal of hydrocarbon from the soil was estimated using the equation [30]:

$$\in = \left(\frac{C_o - C_e}{C_o}\right) 100 \qquad (2)$$

Where ∈ is the efficiency of removal of hydrocarbon from soil (%), C_o is the initial concentration of hydrocarbon in the soil (mg/g) and C_e is the equilibrium concentration of hydrocarbon in soil (mg/g).

3. Results and discussion

The physico- chemical properties of the motor oil and soil samples are presented in Table 1 and Table 2.

Table 1: Properties of the motor oil used for contamination of the soil

Parameters	Results
Density(g/cm3)	0.878
Dynamic viscosity(g/cms)	2.37 x 10^{-5}
Kinematic viscosity (cm^2/s)	2.70 x 10^{-5}
Specific gravity	1.444
Flash point (^{o} C)	136
Temperature (^{o} C)	35
pH	5.71
Moisture content (%)	1

Table 2: Physico- chemical properties of the laterite soil used for the study

Parameters	Results
Coarse sand (%)	1.18
Medium sand (%)	1.28
Fine sand (%)	85.01
Fine silt (%)	2.61
Fine gravel (%)	0.01
Clay (%)	10.02
Organic matter content (%)	5.6
Total Nitrogen content (%)	0.14
Total Phosphorus content (%)	4.25
Total Potassium content (mg/100mg Soil)	0.76
pH	7.98
Specific gravity	2.5

From the mechanical analysis of the soil as given in Table 2 (sand 85.01%, silt 2.61%, and clay 10.02%) the laterite soil texture is determined as loamy sand using Figure 1 which is given in [32].

This soil texture type affects the phytoremediation process as it influences the bioavailability of the contaminant [11]. For example, clay is capable of binding molecules more than silt and sand resulting in the bioavailability of contaminants being lower in soils with high clay contents. As shown in Table 2 the soil has high organic matter content of 5.6% (> 5%) which leads to strong adsorption and therefore low bioavailability [33]. Adequate soil nutrients are required to support the growth of plants and their associated micro-organisms during phyto-remediation when the plant/microbe community is under stress from the contaminants especially as petroleum hydrocarbons greatly reduce availability of plant nutrient in soil [34] due to the fact that petroleum hydrocarbons have high carbon content but are poor suppliers of nitrogen and phosphorus and as soil microorganisms degrade the hydrocarbons, they use up or immobilize available nutrients(N and P) creating nutrient deficiencies in the contaminated soil. Nutrient deficiencies which arise due to petroleum hydrocarbon contamination

of soil may however be offset by application of fertilizer [11], addition of cow dung [2] to the soil.
Observation during the initial growth period of the plant in the contaminated soil environment showed initially weak growth of the plant at the early period in the contaminated environment (first three weeks) but after eight weeks of transplanting to the contaminated environment the sweet potato plants showed steady growth. This indicates that sweet potato plants can grow, sustain growth and can survive at the concentration in the contaminated soil environment and is therefore a potential candidate which can be evaluated for phytoremediation capability. This is in agreement with the position of [22] that plants to be used for phytoremediation must tolerate the pollutants at the concentration present in the contaminated environment.
The weak growth of plants observed at the early stages could be attributed to the inhibited water and nutrient uptake due to the hydrophobic character of motor oil. The result of the TPH analysis carried out on the control soil indicated that there is no hydrocarbon contamination of the test soil prior to the artificial contamination with motor oil. The results of TPH analyses of the contaminated soil carried out on 2 weekly bases after the initial eight week growth period are presented in Table 3. The table presents the TPH (mg/g) content remaining in the soil, amount of hydrocarbon removed from the soil per plant and the efficiency of removal of hydrocarbon from the contaminated soil.

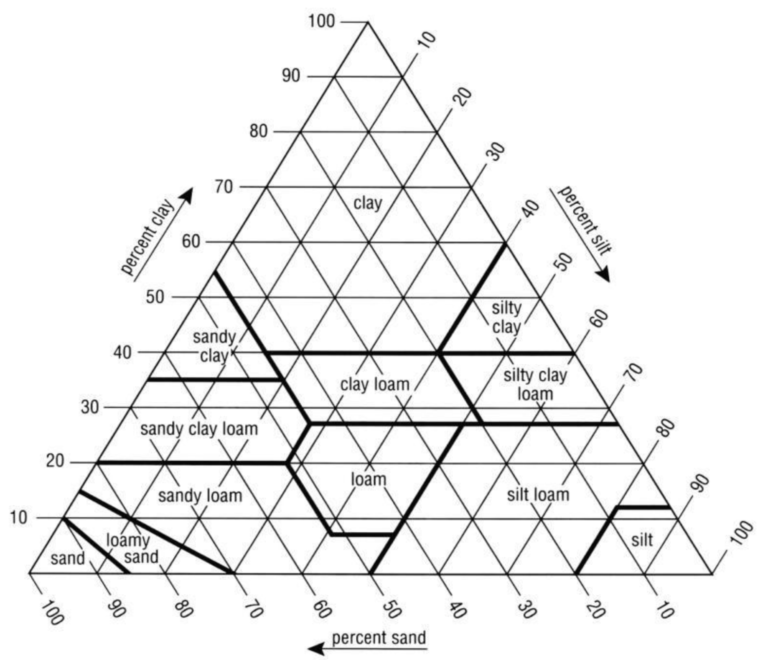

Figure 1: Triangle of soil textures for describing various combinations of sand, silt and clay [31]

Table 3: Results of phytoremediation experiments and hydrocarbon removal efficiency computation

Time (weeks)[After initial 8 weeks plant growth/ stabilization Period]	TPH(mg/g) content (mean)remaining in sweet potato soil	Amount of hydrocarbon removed from sweet potato soil q (mg/g) (per plant)	Efficiency of removal of hydrocarbon from sweet potato soil ∈ (%)
2	49.648	4.302	34.206
4	43.064	5.390	42.931
6	39.894	5.928	47.132
8	36.976	6.414	50.10
10	35.184	6.713	53.374
12	29.749	7.619	60.578
14	25.312	8.538	66.456
16	19.876	9.264	73.66

Initial concentration of TPH in the contaminated soil ($\mathbf{C_o}$) = 75.46 mg/g

From Table 3, it can be seen that the sweet potato plants reduced the initial content of TPH in the contaminated soil from 75.46mg/g to 49.648mg/g in two weeks after plant stabilization and to 19.878 mg/g after 16 weeks of plant stabilization. The plot of TPH remaining in the soil against time is presented in Figure 2.

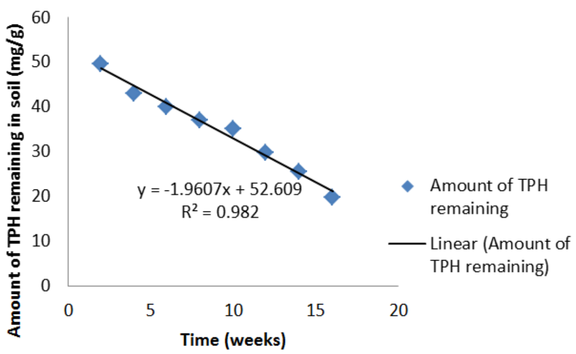

Figure 2: Plot of TPH remaining in soil

From the plot, a linear model: **y = - 1.9607x + 52.609** is developed from which it is predicted that it will take about 27 weeks after the stabilization of the plants to reduce the total petroleum hydrocarbon (TPH) content in the contaminated soil to zero. Even though this period (27 weeks) may appear long due to the fact that the rate of detoxification of organic contaminants in plant tissue is slow [35], the rising cost of physic – chemical cleanup methods of contaminated sites make phytoremediation a more attractive alternative [36] especially in developing countries.
The degradation of the motor oil in the contaminated soil by sweet potato plants may have occurred due to one or more of the many mechanisms of phytoremediation which include; phytodegradation, phytovolatilization, phytotransformation, phytostabilization and rhizofiltration [12]. The ability of the sweet potato plants to effect phytoremediation of the hydrocarbon contaminated soil may likely be due to its capacity to enhance microbial activity in the rhizosphere [37] especially as sweet potato has extensive widely branched fibrous root system in addition to the activities of the detoxifying enzymes of the plant themselves [38].The efficiency of the phytoremediation process is often associated with the high number of degrader microorganisms and their degradative activities in the rhizosphere of plants [39]. The production of root exudates and plant materials which serve as source of carbon, nitrogen and phosphorus for petroleum degrading microbes [40] is particularly important in this process especially as nitrogen fixed in the soil by legumes tends to reduce plant/microbes competition for nitrogen thereby increasing plant growth exudates production and thereby increasing the ability of the plants to increase the degradation of the contaminants [2].
It is also shown in Table 3 that the amount of hydrocarbon removed per plant from the contaminated soil ranges from 4.302mg/g after 2 weeks to 9.264mg/g after 16 weeks of testing with corresponding removal efficiency ranging from 34.206% to 73.66%. This is a steady increase in the rate of degradation/ removal of hydrocarbon present in the soil with time as given in Table 3 and amplified in Figure 2.
However, it is important to note the main limitations associated with the application of phytoremediation to contaminated soils namely; that phytoremediation is not effective if contaminants have spread into the soil profile. That is, contaminants must be confined to surface or near surface because plant roots reach only a limited depth [41] and also that phytotoxicity limits the use of phytoremediation at high concentrations hence phytoremediation is recommended only at low to moderate levels of contamination. Toxic concentrations are plant species and contaminant dependent and it has been reported in literature [42] that low molecular weight and aromatic hydrocarbons can decrease germination and growth of plants.

4. Conclusions

From the study the following conclusions are made:

- Sweet potato plant (*Ipomoea batatas*) can grow, sustain growth and can survive in a motor oil contaminated laterite soil environment at a concentration of 75.46 mg/g.
- At a concentration of 75.46 mg/g in motor oil contaminated laterite soil environment, Sweet potato plant (*Ipomoea batatas*) will stabilize and grow steadily after 8 weeks.
- Sweet potato plant (*Ipomoea batatas*) enhances the degradation of motor oil in contaminated laterite soil. The degradation of the motor oil in the contaminated soil is due to one of the many mechanisms of phytoremediation which include; phytodegradation, phytovolatilization, phyto extraction, phytotransformation, phytostabilization and rhizofiltration [12].
- Sweet potato plant (*Ipomoea batatas*) reduced the initial TPH content in the

contaminated soil from 75.46mg/g to 49.648 mg/g in two weeks after plant stabilization and to 19.876 mg/g after 16 weeks of plant stabilization.

- From the plot of TPH remaining in the soil against time, a linear model fit of the form:
  y = - 1.9607x + 52.609; is developed.
- From the model equation it is predicted that it will take about 27 weeks after the stabilization of the plants to reduce the total petroleum hydrocarbon (TPH) content in the contaminated soil to zero.
- The amount of hydrocarbon removed per plant from the contaminated soil ranges from 4.302 mg/g after 2 weeks to 9.264 mg/g after 16 weeks of testing with corresponding removal efficiency ranging from 34.206% to 73.66%.
- Sweet potato plant (*Ipomoea batatas*) can thus be used for the phytoremediation of petroleum hydrocarbon contaminated soil.

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