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Efficiency of Pulverized *Glycine max* as a Treatment For Bonny Light Crude Oil-impacted Soil Ecosystems of the Niger Delta Region

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ABSTRACT

This research study investigated how well pulverized Glycine max can aid in bioremediation of crude oil–polluted soils. This research study was conducted over a 60-day study period with 0g (control), 200g, and 400g of pulverized Glycine max added to contaminated soils as treatments. Soil recovery was determined by monitoring physicochemical parameters including pH, organic matter, phosphates, potassium, and population of microorganisms. 0g (control) recorded a low TPH recovery of 7.64% whereas both 200g and 400g treatments recorded TPH recovery of 72.30% and 73.35%, respectively. Results demonstrated groundwater quality to be greatly enhanced, including population of microorganisms, which verified the biostimulation potential of Glycine max to be a natural organic soil amendment. An analysis of variance indicated that TPH degradation was statistically significantly different across the treatment groups ($F(2,18) = 9.220$, $p = 0.002$) with post hoc comparisons indicating that the 200g and 400g treatments were both statistically significantly different from the control but were not statistically significantly different from each other. In addition, the soil pH increased from an acidic pH of 5.21 to a neutral pH of 7.50, as well as the population of hydrocarbon utilizing bacteria which increased from 3,700 in the control treatment to 4,500,000 and 4,800,000 CFU/g in the 200g and 400g treatment, respectively. With the rise in microbial activity, the potassium and organic matter content fell, indicating the assimilation of the nutrients during the biodegradation process. The study concludes that Glycine max significantly improves the recovery of nutrient enriched hydrocarbon-polluted soils as well as the activity of native microorganisms. The positive correlation between the concentration of PGM and the remediation efficiency confirms the attributes of PGM as a cost-effective, sustainable bioremediation material.

Keywords: *Glycine max*, bioremediation, crude oil–polluted soil, total petroleum hydrocarbons, microbial activity,

INTRODUCTION

The growth of industry and economies around the world cannot be done without the use of energy, and petroleum is one of the most accessible and efficient energy sources (Yuniati, 2018). Since the discovery of crude oil – a hydrocarbon material in sedimentary basin formations – it has been a transformative element of modern civilization. It has altered the way we survive and progress as a people (Prasad, 2011). It is predominantly extracted from sedimented land. The resource is a non-substitutable and finite resource, and thus has a very high value in the market for both the domestic and the international market. This is especially the case for Nigeria where crude oil is the mainstay of the country's economic development. This oil has resulted in substantial financial upliftment for the country, but paradoxically, it has also resulted in considerable damage to the environment in the areas producing the oil (Anoliefo et al, 2006; Brandt et al, 2006).

The first drilling in Petroleum exploration in Nigeria began in the Iho near Owerri area from 1939 Shell D'arcy SPDC (1996). The discovery of oil was first found in 1956, in the Oloibiri area of Niger Delta. After the discovery, oil production began quickly on a large scale, light and medium oil such as Bonny Light was produced (Amund & Akangbou, 1993). Petroleum is a versatile oil and is very important in the production of oil, in the production of fuels used in the transportation of goods and people. It is also used in the generation of electricity and in the production of petrochemicals (White et al, 2006). There is a large scale production of oil and ongoing transportation of oil, and within this oil down stream is large scale oil tap accidents where oil is freely spilled. It also creates a large amount of soil and water pollution from the active oil spill and even from the accidents in oil production and oil transportation from the production sites and even the refineries and the global markets (Asthana & Asthana, 2006).

Because of the enormous need for petroleum products, the demand for exploration and refining, especially in Nigeria, has grown, bringing in an oil spillage environment problem. These spills wipe out ecosystems, ruin water, lower soil quality, and trigger health complications in humans and other animals. Studies have pointed out the degradation of biodiversity and the disruption in economies sustained through farming and fishing caused the crude oil pollution on land and in water. The pollution efforts made by government and private institutions seem pointless as incidents of pollution continue to heighten, especially in the already unbalanced Nui delta, Nigeria.

Because of the continuing impact of pollution, bioremediation has developed as an alternative for cleaning contaminated environments. As per Azubuike et al. Bioremediation is described as a biological mechanism of the degrading, detoxifying, mineralizing, or transforming of wastes into harmless substances. Of all the other methods, bioremediation is the only one that uses living organisms, more specifically microorganisms, to break pollutants into harmless substances. Reduced toxic effects. Bioremediation is cost-effective and reduces the toxic effects of crude oil residues. Considering these benefits, this bioremediation technique has been adopted in environmental management in the impacted oil producing areas in Nigeria as a tool of ecosystem restoration and environmental sustainable development.

Soil plays a vital role in ecosystem functioning and sustenance. It supports vegetation, aids in the balance of the environment, and regulates the hydrological and nutrient cycles of an ecosystem (Kibblewhite et al., 2008; Kassam, 2009). However, soil is now facing severe degradation and contamination as a result of industrialization, urbanization and exploitation of crude oil. Oil spills disrupt soil chemistry, reduce microbial activity and impair nutrient cycling of the soil. This in turn decreases agricultural potential and natural regeneration. Furthermore, the loss of healthy, functioning soil not only threatens food security; it also increases emissions of greenhouse gases and exacerbates climate change.

Around the world, oil spills such as the 2010 Gulf Mexico oil spill, the 1989 Exxon Valdez oil spill, and the Texaco and Forcados oil spill incidents in Nigeria have shown oil spills and petroleum oil pollution's terrible impacts (Oku, 2014). According to the investigations of Ekwezor (1985), Etuk (2008), Sokubo (2008), and Oku (2014), the pollution of the environment from oil oil and petroleum oil leads ecological system to become out of balance and more unstable in the long term. The pollution of soil has become a global crisis, and in the Niger Delta region, soil pollution continues to erode the systems of the environment and the livelihood of people (humans). According to the research investigations of Oyedeji et al. (2012), Nwaugo (2006), Osam (2011a), Ogboghodo et al (2004), Osuji and Onojake (2004), White et al. (2006), and Tanee and Kinako (2008), the pollution of the environment because of oil transforms free (drinking) water of the people into poisonous water, destroys plant life (vegetation), and as a result, the ecosystems (ecological systems) in the water and in the land are degraded. The improper control of the situation and the inadequate restoration of the natural environment from the pollution have become of utmost importance.

Below is Table 1.1 showing major oil spills in the world by order of quantity in barrels as adapted (Eja & Ogri, 2003; Wang, et. al. 2011 and Oyedeji et. al. 2012).

Table 1.1: Major oil spills in the world by order of quantity in barrels

Date	Location	Spill type	Tonnes of crude oil	Barrels
14/5/1910-10/0/1911	U.S. Kern County, California	Lakeview Gusher	1,200,000	9,000,000
20/4/10-15/7/10	U.S. Gulf of Mexico	Deep water horizon	560,000-585,000	4,100,000-4,300,000
23/1/1991	Iraq, Persian Gulf and Kuwait	Gulf water oil spill	270,000-820,000	2,000,000-6, 000,000
3/6/1979-23/3/1980	Mexico, Gulf of Mexico	Ixoc I	454,000-480,000	3,329,000-3,520,000
19/7/1979	Trinidad and Tobago	Atlantic Empress/ Aegean Captain	287,000	2,105,000
2/3/1992	Uzbekistan	Fergana Valley	285,000	2,090,000
4/2/1983	Iran, Persian Gulf	Nowruz Field Platform	260,000	1,907,000
28/5/1991	Angola	ABT Summer offshore	260,000	1,907,000
6/8/1983	South Africa, Saldanha Bay	Castillo de Bellver	252,000	1,848,000
16/3/1978	France, Brittany	Amoco Cadiz	223,000	1,635,000
11/4/1991	Italy, Mediterranean sea near Genoa	MT Haven	144,000	1,056,000
10/11/1988	Canada	Odyssey	132,000	968,000
24/3/1989	U.S. Prince William Sound Alaska	Exxon Valdez oil tanker	35,065-103,896	257,000-750,000

Source: Adapted from Eja and Ogri, 2003; Wang, Zhang, Klassen and Oyedeji (2016)

The disposal of oil-contaminated soil has been a challenge in oil-producing countries, particularly Nigeria. The increased interest in phytoremediation (the use of plants to remove contaminants from soil) has paralleled the challenge of oil-contaminated soil. The crude oil contamination of soil poses serious implications to the environment and the people dependent on the resources. Several scholarly works have documented the successful use of specific plant species in the remediation of oil-contaminated soil. The following scholarly works add to the above (Gunther et. al.1996; Carmen, 1998; Pichtel and Liskanen 2001; Banks et. al. 2003; Jones et al. 2004; White et al. 2006; Kaimi et. al. 2006; Brandt et al. 2006; Muratova et. al. 2018).

Additionally, in 2013, Triastuti highlighted the vetiver plant as instrumental in the restoration of mercury-contaminated soil to a level of 65.25%. This was achieved through the application of 10% compost. The study of Njoku, Akinola & Oboh (2012) investigated the impact of the growth of Glycine max (G. max) on the physico chemistry and crude oil content of soil contaminated with varying levels of crude oil to determine plants that could potentially enhance the remediation of oil contaminated soil. Liestianty et al, also reported.

(2014) stated that incorporating compost with soybean (Glycine max (L) Merril) was able to accomplish phytoremediation of Cu- contaminated soil.

Research in phytoremediation has gained popularity for the cleanup of contaminated soils, but numerous obstacles such as the location-specific requirements for cleanup, types of contaminants, time frame, and effectiveness on the pollutants to be cleaned remain unresolved. Most contaminated sites contain complex heterogeneous mixtures of varying physico-chemical properties, toxicity, and bioavailability. Areas with complex mixture of contaminants present further technical difficulties due to the nature of the constituents and the additional complications that arise from the coupling of two (or more) distinct groups of contaminants (Chirakkara et al. 2016). The mixture of inorganic and organic compounds present can synergistically interact to alter the efficacy of the remediation technology positively or negatively. The organic contaminants can positively influence the mobilization and removal of the Trace Element (TE) while the TE toxicity can be inhibitory to the microorganisms in soils resulting in the recalcitrance of the organic contaminants due to the pathogenic nature of the TE (Chirakkara et al., 2016).

The high input of carbon (C), due to co - contamination, crude oil polluted soils result in an imbalance of ratios for nitrogen (N), and Phosphorus (P). It has also been shown that microbial activity can lead to N and P immobilization or depletion (Adam and Duncan, 2002). Additionally, before successful implementation of phytoremediation on large scale, it is also a site specific process that needs feasibility investigations. Laboratory scale preliminary studies can be useful to predict degradation rates, but are not an accurate representation of field conditions and thus phytoremediation must be approached from a multi-scale perspective. Integrating and complementing studies on phytoremediation with an ecotoxicological analysis considering bioavailable contaminants and their interactions is of utmost importance. Phytoremediation is a heavily researched field but only a small number have assessed the effectiveness of phytoremediation from a chemical and eco – toxicological perspective.

As a result, this research seeks to analyze the efficiency of glycine max (PGM) on soil impacted by the bonny light crude oil, with the hope that glycine max will provide a remediation treatment to crude oil contaminated soil. Focusing on this challenge will provide practical benefits of soil restoration to humanity & will help this country Nigeria economically. Commercializing this innovative approach will provide economic value. This research will provide a direct contribution towards understanding this pervasive phenomenon within the context of terrestrial ecosystem management, & will assist in the attainment of the sustainable development goal.

Aim and objectives of the study

This study is to investigate effectiveness of pulverized glycine-max as a treatment for Bonny light crude oil- impacted soil ecosystems of the Niger Delta Region. To achieve this aim the following objectives were posited.

To assess the effectiveness of pulverized glycine max in the remediation of crude oil contaminated soil recovery.

1. To monitor the rate of the *naturally attenuated plot*
2. To monitor the rate of recovery from the different treatment plots using different quantities pulverized glycine max.
3. To compare the variations between the plots treated with different quantity of pulverized glycine max and the control plot.

5. To identify the effects of pulverized glycine max remediation on the nitrogen (N), potassium (k) and phosphorus (P) for bonny light crude oil impacted soil.

Research questions

1. How effective is pulverized glycine max in the recovery of bonny light crude oil impacted soil?
2. What is the recovery rate of the naturally attenuated soil?
3. What is the rate of recovery of contaminated soils under the different pulverized glycine max treatments?
4. How do the plots treated with different quantity of pulverized glycine max vary from the naturally attenuated plots?
5. What is the effect of pulverized glycine max remediation on the nitrogen (N), potassium K and phosphorus (P) ratios of the soil impacted by Bonny light crude

METHODOLOGY

An experimental approach was implemented to examine Glycine max (soybean) ability to remediate crude oil polluted soil. This approach provided a systematic framework for measurement and assessment and even predicted alterations in the soil recovery. The data utilized for this study came from comparative experiments where soil was intentionally and uniformly contaminated with crude oil and then treated with pulverized Glycine max. Soil samples were collected and then analyzed to check for changes in targeted soil physicochemical and biological parameters.

Following the framework of Oku (2014), the study utilized 2 m by 2 m experimental plots which were each subdivided into four 100 cm by 100 cm sub-plots representing the various treatment conditions. The treatment conditions included: a natural (uncontaminated) soil plot; a control plot without treatment but containing crude oil; a plot containing 200 g of pulverized Glycine max and crude oil; and a plot containing 400 g of pulverized Glycine max and crude oil. The layout of the design ensured that the crude oil contamination was kept within the specified area. 25 sampling points were created in each sub-plot by applying a 20 cm by 20 cm grid, and simple random sampling was used to choose seven points to sample from each plot, determined with a random number table.

The Ignatius Ajuru University of Education, Rumuolumeni, Port Harcourt, Rivers State, is where the study was carried out. For the study, twenty (20) litres of crude oil was evenly spread across the contaminated and tilled plots to achieve mixing and aeration. Soil samples were taken every ten (10) days for a duration of sixty (60) days, using the methodology of Filho et al (2017) at two depth intervals, 0-15 cm and 15-30 cm. From the four plots, samples were taken, and for the treated plots, a composite sample was made and analyzed for nitrates, phosphorus, potassium, soil organic matter (SOM), soil pH, soil moisture, total petroleum hydrocarbon (TPH), and total hydrocarbon-utilizing bacteria (THUB) counts.

Results from the laboratory tests were done according to procedures that have been documented. The Kjeldahl method described by Ijah et al. (2013) was used to determine nitrate from total nitrogen content which was done using acid digestion, distillation, and titration. The phosphorus content of the soil was examined using the colorimetric method of Bray and Kurtz (1945) whereby the phosphorus that was extracted was reacted with ammonium molybdate and stannous chloride and then spectrophotometrically measured. Soil organic matter was determined using the Loss on Ignition (LOI) method documented by Gavlak et al. (2005), which estimated organic content based on the sample weight that was lost after burning at 360°C. Soil hydrogen ions (pH) was measured with a pH meter and soil moisture content was determined using the gravimetric method by drying samples at 105°C in accordance with the method that was validated by Oku (2014) and computed moisture.

TPH levels were ascertained using a Fourier Transform Infrared Spectrophotometer (FTIR, Genesis Series). The method involved the sequential extraction of 5 g soil samples with carbon tetrachloride (CCl_4), filtration, and CCl_4 extract analysis by the spectrophotometer and calibration using standard curves. The hydrocarbon using bacteria (HCUB) quantification was done using the spread plate technique. Minimal medium containing hydrocarbon as the only carbon source was inoculated with diluted soil suspensions and colony-forming units (cfu) were determined. HCUB quantification indicates the potential of the treated plots for the microbial degradation of hydrocarbons (Okaka et al., 2001).

Laboratory analysis results were processed using Statistical Package for Social Science (SPSS). A dependent sample t-test together with a single factor Analysis of Variance (ANOVA) was carried out to establish and compare the means of the different treatments to determine the levels of significance of the variation of soil recovery across the treatments. Observable patterns were determined using simple percentages, and the rate of remediation of the investigated experimental plots was recognized. This analytical approach ensured the study was complete with appropriate statistical measures and scientific approach (Okaka et al., 2001).

RESULTS

Table 1: Soil Recovery Indices of Crude Oil-Impacted Soil Treated with Pulverized *Glycine max* (PGM) over 60 Days

Parameter	Day	Control A (Natural Soil)	Control B (Soil + Crude)	Soil + Crude + 200g PGM	Soil + Crude + 400g PGM	Mean ± SD (Treated Plots)
Nitrate (mg/kg)	1	3.70	3.40	3.71	3.89	3.80 ± 0.13
	10	3.42	5.10	5.20	5.15 ± 0.07	
	30	3.84	4.56	4.55	4.56 ± 0.01	
	60	4.75	3.40	3.29	3.35 ± 0.08	
Phosphorus (mg/kg)	1	0.70	0.69	0.69	0.70	0.70 ± 0.01
	10	2.01	3.41	3.30	3.36 ± 0.08	
	30	2.89	3.00	2.89	2.95 ± 0.08	
	60	3.46	1.82	1.66	1.74 ± 0.11	
Potassium (mg/kg)	1	72.12	72.00	72.32	71.98	72.15 ± 0.24
	30	66.78	33.18	32.08	32.63 ± 0.78	
	60	71.34	13.23	11.14	12.18 ± 1.48	
Organic Matter (mg/kg)	1	11.67	11.66	11.66	11.67	11.67 ± 0.00
	30	11.79	14.00	13.28	13.64 ± 0.51	
	60	13.12	6.21	6.05	6.13 ± 0.11	
Soil pH	1	5.20	5.20	5.21	5.15	5.18 ± 0.03
	30	5.18	7.20	7.25	7.23 ± 0.04	
	60	5.00	7.45	7.50	7.48 ± 0.04	
Soil Moisture (%)	1	6.80	6.81	6.80	6.80	6.80 ± 0.00
	30	6.78	6.28	6.22	6.25 ± 0.04	
	60	10.60	4.77	4.61	4.69 ± 0.11	
TPH (mg/kg)	1	100.24	526.55	526.55	526.55	526.55 ± 0.00
	30	501.32	212.60	200.32	206.46 ± 8.65	
	60	486.34	145.83	140.33	143.08 ± 3.89	
HCUB (cfu/g)	1	3.7×10^3	3.7×10^3	3.7×10^3	3.7×10^3	–
	30	6.3×10^4	9.5×10^5	9.7×10^5	$9.6\times10^5 \pm 1.4\times10^4$	
	60	6.2×10^4	4.5×10^6	4.8×10^6	$4.65\times10^6 \pm 2.1\times10^5$	

Source: Researcher's Field Work and Laboratory Analysis (2020)

Over the 60-day period, treatment with *Glycine max* (PGM) showed consistent improvements in soil recovery compared to the crude oil-impacted control. Nitrate and phosphorus levels increased initially and then stabilized, suggesting microbial activity enhancement. Potassium and organic matter gradually declined, possibly due to utilization by microbial biomass during biodegradation. Soil pH rose from acidic (5.0–5.2) to near-neutral or slightly alkaline (7.2–7.5) in treated plots, indicating successful bioremediation. Total Petroleum Hydrocarbon (TPH) content reduced sharply from over 520 mg/kg to about 140 mg/kg in the PGM 400g treatment, reflecting over 70% degradation efficiency. Hydrocarbon-utilizing bacterial counts rose exponentially, confirming microbial proliferation as a key mechanism for hydrocarbon breakdown. The soil treated with *Glycine max* showed marked biochemical recovery across parameters compared with the untreated crude oil-contaminated control. Notably, Total Petroleum Hydrocarbon (TPH) concentrations declined by over 70% in the 400g treatment, accompanied by a fourfold increase in Hydrocarbon-Utilizing Bacteria (HCUB) counts, indicating robust microbial activity.

Table 2: Comparative Soil pH under Natural Attenuation and *Glycine max* Treatment

Time (Days)	**Control A**	**Soil + Crude (B)**	**Soil + Crude + 200g PGM (C)**	**Soil + Crude + 400g PGM (D)**	**Mean ± SD**
1	5.20	5.20	5.21	5.15	5.19 ± 0.03
10	5.19	5.20	5.52	5.55	5.54 ± 0.02
20	5.22	5.19	6.70	6.78	6.74 ± 0.06
30	5.18	5.18	7.20	7.25	7.23 ± 0.04
40	5.18	5.10	7.05	7.22	7.14 ± 0.09
50	5.19	5.08	7.23	7.33	7.28 ± 0.07
60	5.25	5.00	7.45	7.50	7.48 ± 0.04
Mean ± SD	5.201 ± 0.026	5.136 ± 0.077	6.623 ± 0.893	6.683 ± 0.943	–

Source: Field Work (2020)

The pH of crude oil-contaminated soil (Control B) remained acidic throughout the experiment, while soils treated with *Glycine max* showed gradual neutralization and stabilization between pH 7.0–7.5. This confirms that PGM enhanced microbial remediation and soil detoxification, creating favorable conditions for ecological recovery. Soil pH shifted from acidic to near-neutral levels, suggesting detoxification and restoration of microbial-friendly conditions. Nutrient indicators such as nitrate and phosphorus increased in the early phase and stabilized, confirming effective organic stimulation. These results validate the bioremediation potential of *Glycine max* in petroleum-impacted soils.

Summary of ANOVA Results Showing Recovery Rate of Naturally Attenuated and Crude Oil Impacted Soils Treated with Pulverized *Glycine Max*

Source of Variation	N	Mean (mg/kg)	Std. Deviation	F-Value	p-Value	Remark
Naturally Attenuated Soil	7	506.31	15.40			
200g PGM Treatment	7	276.84	141.87			
400g PGM Treatment	7	269.70	144.56	9.220	0.002	Significant
Total	**21**	350.95	167.83			

Source: SPSS Output (2021)

The one-way ANOVA result, $F(2,18) = 9.220$, $p = 0.002$, shows a statistically significant difference in the recovery rate of total petroleum hydrocarbon (TPHC) among the naturally attenuated soil, and the crude oil impacted soils treated with 200g and 400g of Pulverized *Glycine Max*. Post hoc comparisons further revealed that the naturally attenuated soil differed significantly from both treatment groups ($p < 0.05$), while there was no significant difference between the 200g and 400g PGM treatments ($p = 0.911$). This indicates that treatment with *Glycine Max* significantly enhances hydrocarbon degradation compared to natural attenuation, though the difference between 200g and 400g treatments was minimal.

DISCUSSION OF FINDINGS

The findings of the study demonstrated clearly that pulverized *Glycine max* (PGM) significantly enhanced the remediation of crude oil–impacted soils, underscoring its potential as a sustainable bioremediation agent. After the 60-day experimental period, soils treated with 200g of PGM achieved a recovery rate of 72.30%, while those treated with 400g recorded a slightly higher 73.35% recovery, compared to the control plot that exhibited only 7.64% recovery through natural attenuation. This improvement was attributed to the rich nitrogen and organic content of *Glycine max*, which provided nutrients essential for microbial growth and hydrocarbon degradation. The observed pattern corresponds with the work of Njoku, Akinola, and Oboh (2016), who established that leguminous plants enhance the breakdown of hydrocarbons in polluted soils. Similarly, Ijah et al. (2013) reported that soybean waste accelerates crude oil degradation, suggesting that PGM can serve as an effective bio-enhancer for oil spill remediation. The early phase of the experiment showed a notable increase in recovery within the first 10 days (24.10% for 200g and 25.88% for 400g treatments), indicating that the initial nutrient surge from the PGM rapidly stimulated microbial activity.

Statistical analysis further validated the effectiveness of PGM in soil recovery. The ANOVA results confirmed these findings with $F(2,18) = 9.220$ and $p = 0.002$, indicating significant differences among naturally attenuated soil, 200g-treated soil, and 400g-treated soil. Post hoc analysis showed that both treatment groups differed significantly from the natural attenuation plot, while the difference between 200g and 400g treatments was not statistically significant. This suggests that although increasing PGM quantity enhances soil recovery, there may be a limit beyond which additional treatment yields diminishing returns. Overall, the results affirm that the use of PGM significantly improves the rate of biodegradation of total petroleum hydrocarbons (TPHC) in contaminated soils, thus supporting the rejection of the null hypotheses.

The effects of PGM treatment on soil physicochemical properties revealed vital insights into the remediation process. Phosphate levels in treated soils initially rose before declining toward baseline, suggesting that nutrients released by PGM were actively utilized by hydrocarbon-degrading microorganisms during remediation. Moisture content exhibited initial increases followed by a gradual decrease, indicating microbial metabolism and water consumption during biodegradation. Organic matter levels decreased in treated plots compared to untreated and uncontaminated soils, signifying decomposition of hydrocarbons and organic residues. Similarly, potassium levels dropped significantly in treated soils, suggesting nutrient uptake and transformation during microbial activity. The pH of the soil improved remarkably from highly acidic levels (5.0–5.2) in the untreated soil to near-neutral levels (7.45

for 200g and 7.50 for 400g), aligning with Ijah et al. (2013), who observed that neutral pH conditions promote microbial hydrocarbon degradation.

Microbial analysis further strengthened the conclusion that PGM enhances biological remediation. Hydrocarbon-utilizing bacterial (HCUB) counts increased sharply in treated soils—from 3,700 in untreated soil to 4,500,000 and 4,800,000 in soils treated with 200g and 400g of PGM, respectively. This exponential microbial growth indicates that *Glycine max* provided both nutrients and an enabling environment for bacterial proliferation, consistent with Abioye et al. (2009). The t-test for the second hypothesis also showed that increasing the PGM concentration from 200g to 400g improved recovery, implying that future studies using higher concentrations may yield even better results. These findings corroborate Adams et al. (2015), who emphasized that nutrient enrichment is crucial for efficient TPH degradation, as degradation rates are influenced by both contaminant concentration and nutrient availability. Overall, the study confirmed that *Glycine max* significantly enhances the recovery of crude oil–impacted soil by stimulating microbial growth, improving soil chemical balance, and accelerating hydrocarbon breakdown.

CONCLUSIONS

The study on analysis of the efficiency of pulverized glycine max as treatment for soil impacted by the Bonny light crude oil observed that pulverized glycine max could be used in soil recovery processes of impacted sites. The study therefore concludes that pulverized glycine max is an ideal phytoremediation agent and should be extended for longer duration of study most especially in heavily impacted sites of over 20000 TPH /kg. The addition of pulverized glycine max also increased the soil pH making it alkaline which could favour most crude oil degrading microorganism.

RECOMMENDATIONS

Based on the findings from the study, the following recommendations are made:

1. Better attention needs to be given to the characterization of soil before and after phytoremediation for a better management of environmental problems.
2. There is need to integrate several remediation strategies for a single project this may offer a promising pathway for practitioners to enhance contaminant reduction with a bid to restoring soil performance.
3. There is need to find robust microbes which can be combined with plants that are efficient enough to degrade this lethal hydrocarbon pollution.
4. Government and Industry stake holders should ensure that there is proper environmental education for all stake holders of the dangers of oil spill to the ecosystem.
5. Community leaders should encourage their youths to stop all forms of pipeline vandalism because of its eminent dangers to the human environment especially in the Niger Delta region.
6. Glycine Max research should be extended to heavy crude oil impacted sites for industrial use at a scale of 200g per 10000cm sq. and for longer duration. This is because the 200g of glycine max has more economical value

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