

Investigation on the Comparison of the Physical Properties of Stimulants for Petroleum Hydrocarbon Remediation in Soil

Ukpaka Chukwuemeka Peter^{1,*}, Samuel Nkanata Philip², Victor Chukwuemeka Ukpaka³, Joy Chukwuemeka Peter Ukpaka⁴, Abraham Peter Ukpaka⁵

Abstract

Crude oil pollution is a major environmental concern that can cause significant damage to soil ecosystems. Bioremediation, a natural process in which microorganisms degrade pollutants, has emerged as a promising approach for the remediation of crude oil-contaminated soil. Grape leaf powder (Vitis Vinifera), a readily available and inexpensive organic material, has been shown to stimulate microbial activity and enhance bioremediation. This study investigated the effectiveness of grape leaf powder as a biostimulant for the remediation of crude oil-contaminated sandy soil. The study examined the effects of two dosages of grape leaf powder (50g and 100g) for sundried and room-dried samples on the reduction of total petroleum hydrocarbon (TPH) concentrations and microbial counts in the soil. The results showed that both dosages of grape leaf powder were effective at reducing TPH concentrations and increasing microbial counts in the soil. However, the room-dried vitis vinifera achieved higher TPH reduction than sundried at 100g dosage reducing TPH concentrations by up to 96.3% after 35 days. The effectiveness of grape leaf powder is likely due to its high levels of organic matter and nutrients, which provide a food source and stimulate the growth and activity of microorganisms. This study demonstrates that grape leaf powder is a promising, sustainable, and environmentally friendly biostimulant for the remediation of crude oil-contaminated sandy soil.

Keywords: Investigation, comparison, physical properties, stimulants, petroleum, soil

*Author for Correspondence

Ukpaka Chukwuemeka Peter

E-mail: peter.ukpaka@ust.edu.ng

¹Professor, Department of Chemical/Petrochemical Engineering, Rivers State University Port Harcourt, Rivers State, Nigeria

²Research Student, Department of Chemical/Petrochemical Engineering, Rivers State University Port Harcourt, Rivers State, Nigeria

³Research Student, Department of Industrial Engineering, College of Engineering, Computer Studies and Architecture, Lyceum of the Philippines University Cavite, Philippines

⁴Research Student, Department of Pharmacy, MSB Medical School Berlin GmbH - Hochschule für Gesundheit und Medizin

⁵Research Student, Department of Computer Engineering, College of Engineering, Computer Studies and Architecture, Lyceum of the Philippines University Cavite, Philippines

Received date: March 11, 2026

Accepted date: April 22, 2026

Published date: May 10, 2026

Citation: Ukpaka Chukwuemeka Peter, Samuel Nkanata Philip, Victor Chukwuemeka Ukpaka, Joy Chukwuemeka Peter Ukpaka, Abraham Peter Ukpaka. Investigation on the Comparison of the Physical Properties of Stimulants for Petroleum Hydrocarbon Remediation in Soil. International Journal of Environmental Chemistry. 2026; 12(1): 53–68p.

INTRODUCTION

Crude oil spills are a major environmental issue that can have catastrophic consequences for ecosystems and human health. [1–3]. The removal of oil from sandy soil is one of the most difficult aspects of cleaning up crude oil spills. Because sandy soil has a low water-holding capacity and is highly permeable, spilled oil is difficult to contain and clean up [4, 5]. Traditional cleanup methods for crude oil spills on sandy soil, such as excavation and incineration, can be costly and time-consuming. Natural products, such as plant extracts, have recently been investigated by researchers for the remediation of crude oil-contaminated soil [6, 7]. Grape leaf extract is one such natural product that has shown promise as a potential crude oil spill remediation agent [8]. Grape leaf extract is high in polyphenols and antioxidants, which may help to break down crude oil and boost microbial activity in soil. Several studies have demonstrated the potential of various plant extracts, such as those derived from pine needles or coconut husks, for crude oil

remediation [9, 10]. The use of grape leaf extract for crude oil remediation on sandy soil, on the other hand, is a relatively new area of study [11]. As a result, more research into the potential of grape leaf extract as a remediation agent for crude oil spills on sandy soil is required [12].

The purpose of this research is to look into the efficacy of grape leaf extract in the remediation of crude oil-contaminated sandy soil [13]. Experiments will be carried out to determine the effectiveness of grape leaf extract in removing crude oil from sandy soil, as well as an analysis of the chemical and microbial properties of the soil before and after remediation. The study's findings could have significant implications for the development of more effective and long-lasting methods for cleaning up crude oil spills on sandy soil [14].

Plant extracts have several advantages over traditional methods for crude oil remediation, in addition to being environmentally friendly [15]. Plant extracts are inexpensive, easy to obtain, and can be applied with simple methods such as spraying or mixing with soil. Furthermore, plant extracts have been shown to stimulate microbial activity in soil, which can aid in the breakdown of crude oil and the overall health of the soil [16]

To summarize, the use of grape leaf extract for crude oil remediation on sandy soil is an exciting area of research that has the potential to provide a long-term and cost-effective solution to the problem of crude oil spills. The findings of this study could help to develop new and innovative methods for cleaning up crude oil-contaminated soil, with significant implications for human health and the environment.

MATERIALS AND METHODS

Materials used are: Grape leaves from a local vineyard in Rivers State, Nigeria, Sundried and oven-dried grape leaf powder, Sandy soil, Crude oil, Plastic containers, Measuring cups and spoons, pH meter, Electrical conductivity meter, Total organic carbon (TOC) analyzer, Total nitrogen (TN) analyzer, Total phosphorus (TP) analyzer and Potassium (K) analyzer

Methods

Grape leaf preparation

- Grape leaves were collected from a local vineyard in Rivers State, Nigeria.
- Leaves were cleaned to remove impurities and debris.
- Half of the leaves were sun-dried, while the other half were room-dried for a 7days period
- Dried leaves were crushed to produce a nanoparticle distribution.

Nanoparticle Analysis

The Nanoparticle Distribution was Analyzed to Determine it

- Electrical conductivity using an electrical conductivity meter
- pH using a pH meter
- Total organic carbon (TOC) using a TOC analyzer
- Total nitrogen (TN) using a TN analyzer
- Total phosphorus (TP) using a TP analyzer
- Potassium (K) using a K analyzer

Experimental Setup

- Five plastic containers were prepared, each containing 1kg of sandy soil.
- 50ml of crude oil was added to each container, thoroughly mixing the oil into the soil.
- Container A1 received 50g of room-dried grape leaf biostimulant.
- Container A2 received 100g of room-dried grape leaf biostimulant.
- Container B1 received 50g of sun-dried grape leaf biostimulant.
- Container B2 received 100g of sun-dried grape leaf biostimulant.
- Container C served as the control sample without biostimulant.

RESULTS AND DISCUSSION

The results obtained from this project are presented in Tables and Figures.

Result of the physiochemical Properties of Sandy loamy Soil, Biostimulant and Crude Oil Used.

Table 1 shows the physiochemical properties of nitrogen, phosphorus, potassium, HUB (Hydrocarbon Utilizing of Bacteria), HUF (Hydrocarbon Utilizing Fungi), Total organic carbon (TOC), and pH obtained from the analysis of contaminated sandy-loamy soil and uncontaminated sandy-loamy soil.

The percentage value of parameters of contaminated sandy loamy soil is; nitrogen 0.51%, phosphorus 0.93%, potassium 21.86%, and HUB 5.83×10^3 CFU/G and HUF is 1.5×10^2 SFU/G, TOC value of 1.92%, pH value of 6.47. Also, for uncontaminated sandy-loamy soil we have nitrogen 4.13%, phosphorus 17.59%, potassium 270.24% and HUB 1.41×10^3 CFU/G., TOC value of 2.85%, HUF value of 2.4×10^2 SFU/G and pH value of 6.16 and the obtained results for Table 2 shows the physiochemical properties of some parameters of bioremediant of room temperature and sun temperature dried condition

Table 1. Physiochemical properties of some parameters of contaminated and uncontaminated sandy-loamy soil.

Sample	HUB (CFU/G) X 10^3	HUF (SFU/G) X 10^2	N (%)	P (mg/kg)	K (mg/kg)	TOC (%)	pH
Contaminated Sandy -loamy Soil	5.83	1.5	0.51	0.95	21.87	1.92	6.47
Uncontaminated Sandy -loamy Soil	1.41	2.4	4.13	17.59	270.24	2.85	6.16

Table 2. Physiochemical properties of some parameters of bioremediant of room temperature and sun temperature dried condition.

Sample	HUB (CFU/G) X 10^3	HUF (SFU/G) X 10^2	N (%)	P (mg/kg)	K (mg/kg)	TOC (%)	pH
Bioremediant of Room Temperature Dried Condition	10.17	8.4	13.37	94.25	697.37	25.82	6.95
Bioremediant of Sun Temperature Dried Condition	8.46	5.1	10.70	82.09	601.66	19.51	6.52

The analysis of the crude oil sample used revealed density value of 0.861 g/ml and viscosity value of 2.84 mm².

The characteristics of some of the physicochemical properties of nitrogen content, phosphorus content potassium content, total organic content (TOC) pH value, hydrocarbon utilizing bacteria (HUB) and hydrocarbon utilizing fungi (HUF) was monitored as the petroleum hydrocarbon degradate with the action of the available nutrient obtained from the bioremediates used in this investigation as demonstrated in Figure 1 to 20.

Figure 1 shows the nitrogen content behavior in the bioreactor which contained sandy-loamy soil, petroleum hydrocarbon and the bioremediant (Biostimulant). The research shows decrease in the nitrogen concentration within the time range of above zero day to 28 days, before increase in nitrogen concentration was experienced after 28 days.

These characteristics demonstrate that the contaminated sandy – loamy soil nutrient integrity has improved and the soil nutrient regained revealing restoration of the nutrient regained revealing restoration of the sandy – loamy soil for agricultural utilization.

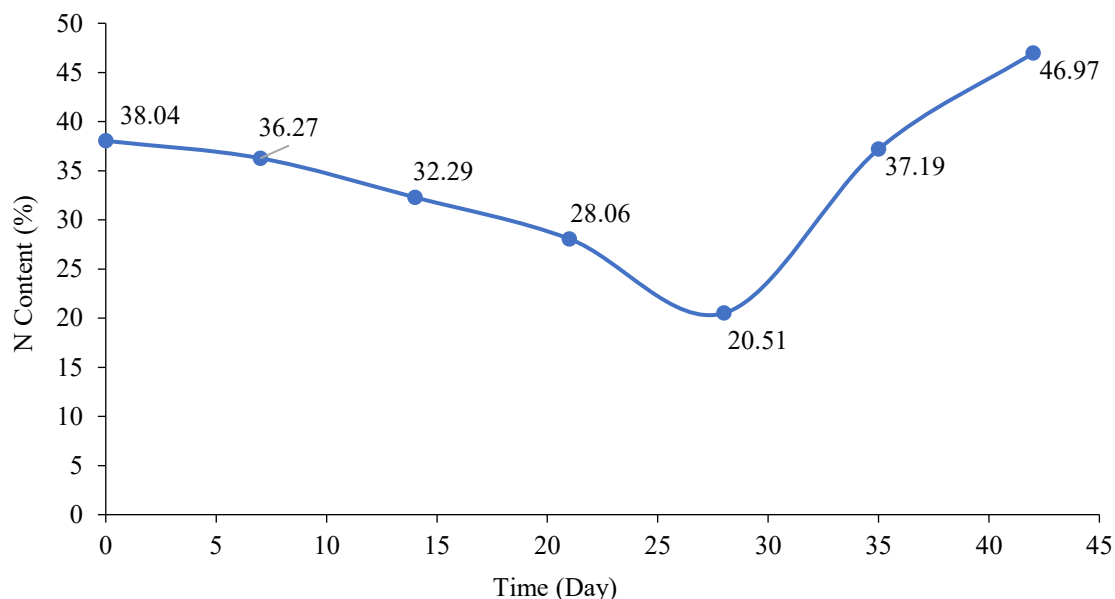


Figure 1. Nitrogen content (N) versus time for petroleum hydrocarbon degradation on the effect of bioremediant of room-dried sample of 50g dosage.

Figure 2 shows the potential of the phosphorous concentration in the remediation of the petroleum hydrocarbon in sandy – loamy soil using the application of the remediate obtained from plant (agro – based materials). The bioremediant used was prepared through room – dried method and the nutrient retained in terms of phosphorous concentration was high at the initial stage and upon utilization by the microbes the phosphorous concentration reduced from above zero day to 28days. Increase in phosphorous concentration was experienced after 28days showing that sandy – loamy soil nutrient in terms of the presence of the phosphorous concentration increases with increase n time, which shows an induction of sandy- loamy soil nutrient restoration and improvement.

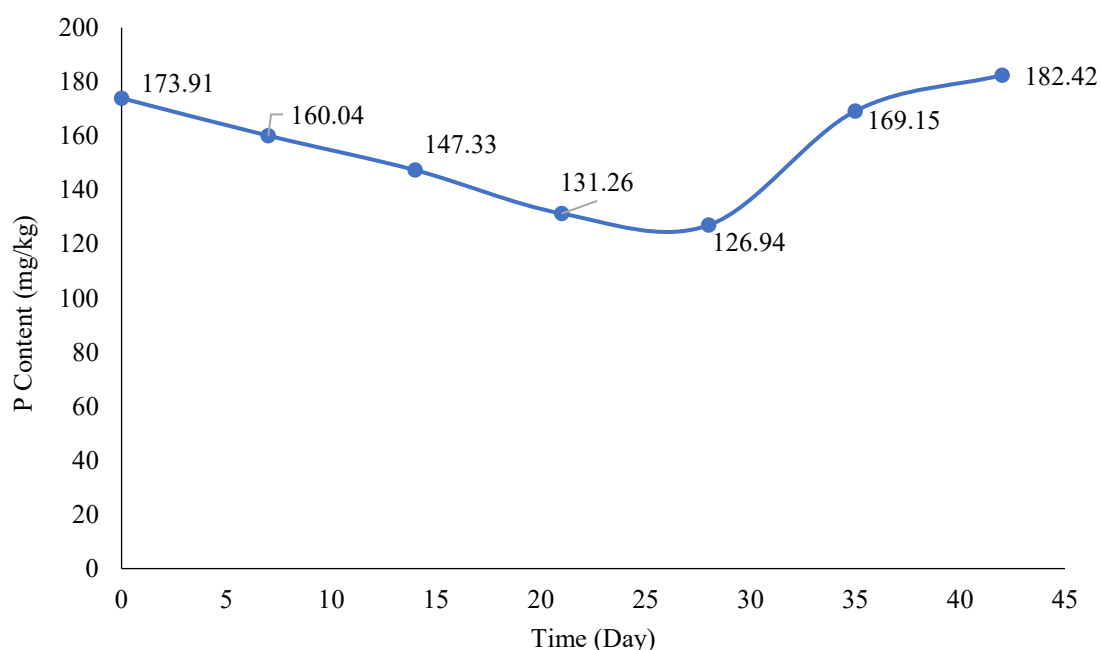


Figure 2. Phosphorous content (P) versus time for petroleum hydrocarbon degradation on the effect of bioremediant of room-dried sample of 50g dosage.

Figure 3 shows the potassium concentration utilization by the microbes during petroleum hydrocarbon degradation in sandy – loamy soil environment using bioremediant (biostimulant). Decrease in potassium concentration was experienced with increase in time for period above zero day to 28 days. Also, after 28 days increase in the potassium concentration was experienced with increase in time revealing the increase nutrient available in the sandy – loamy soil and this further demonstrates that the soil can be found useful for agricultural purpose.

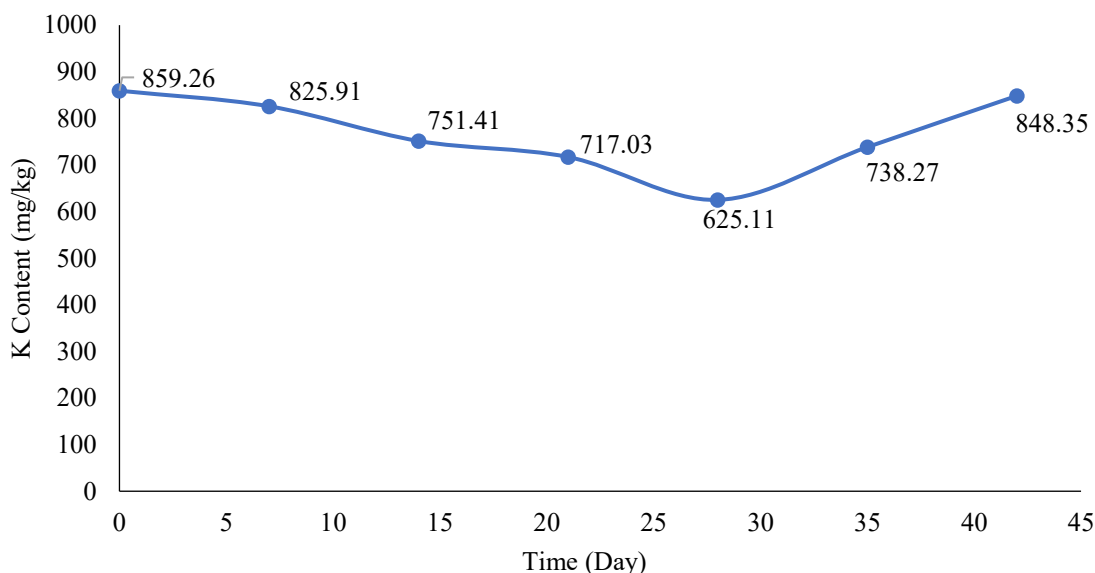


Figure 3. Potassium content (K) versus time for petroleum hydrocarbon degradation on the effect of bioremediant of room-dried sample of 50g dosage.

Figure 4 shows the TOC value upon the effect of time for petroleum hydrocarbon degradation in sandy – loamy soil using bioremediant of room – dried sample. The result demonstrate decrease in the TOC value for the period of above zero day to 28days. Increase in the TOC value in the bioreactor was revealed showing the petroleum hydrocarbon contaminated has be utilized by the microbes, which was favored by the presence of the TOC as one of the available nutrients used by the microorganisms to catalyzed the process. The change in the total organic carbon value was induced by the variation in period of contact time of 42 days sampling.

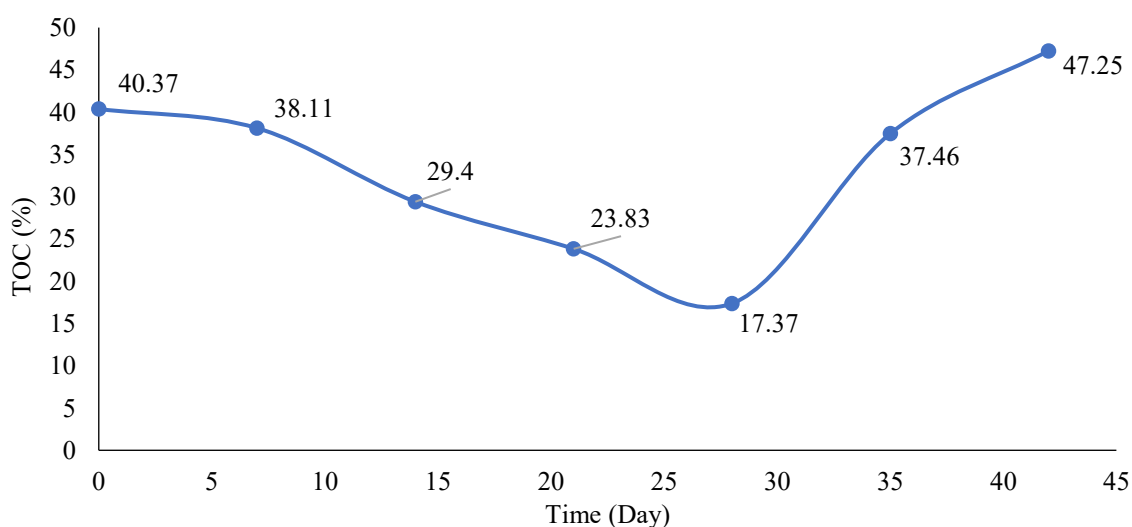


Figure 4. TOC versus Time for Petroleum Hydrocarbon Degradation on the Effect of Bioremediant of Room-Dried Sample of 50g Dosage.

Figure 5 shows the pH value variation in the system upon the remediation of the petroleum hydrocarbon I the bioreactor with increase in contact time (period of exposure) using bioremediatnt of room – dried sample. The research shows decrease in pH from week acid to stronger acid value from above zero day to 21 days, before a sudden increase from strong acids value to alkaline value. This trend of change in the pH value has shown that the acid trend of scale has change and more of microbes' characteristics will change.

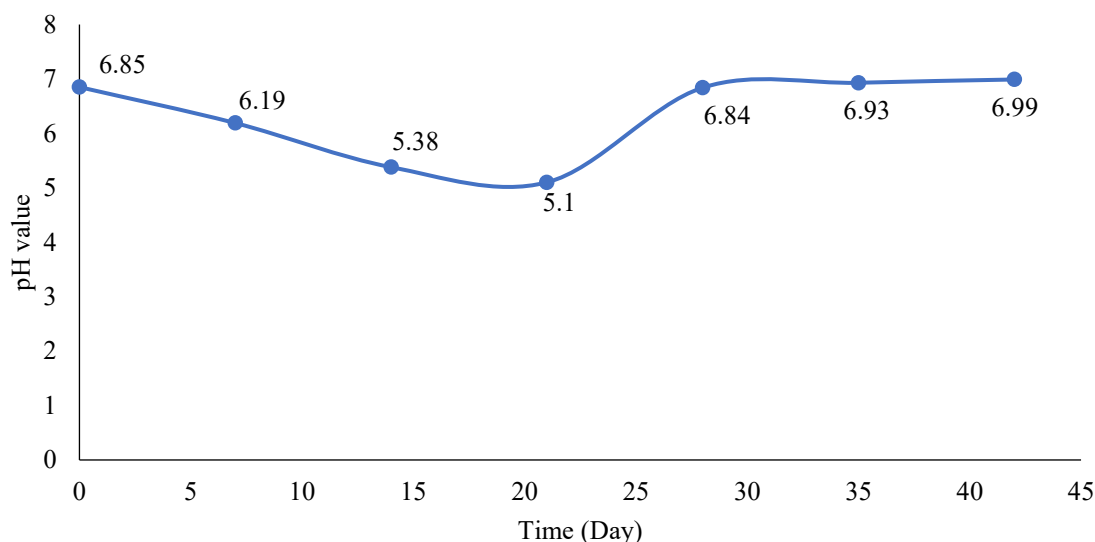


Figure 5. pH Value versus Time for Petroleum Hydrocarbon Degradation on the Effect of Bioremediant of Room-Dried Sample of 50g Dosage.

Figure 6 shows the trend of the comparison of the nitrogen concentration in terms of the dosage and medium in which the bioremediant was prepared for the purpose of bioremediation process. Decrease in nitrogen concentration was experienced with increase in time from above zero day to 28 days before sudden increase was experienced. However, in terms of the comparison of N50G and N100G, the shown high nitrogen utilization of the microbes in the order of N100G > N50G.

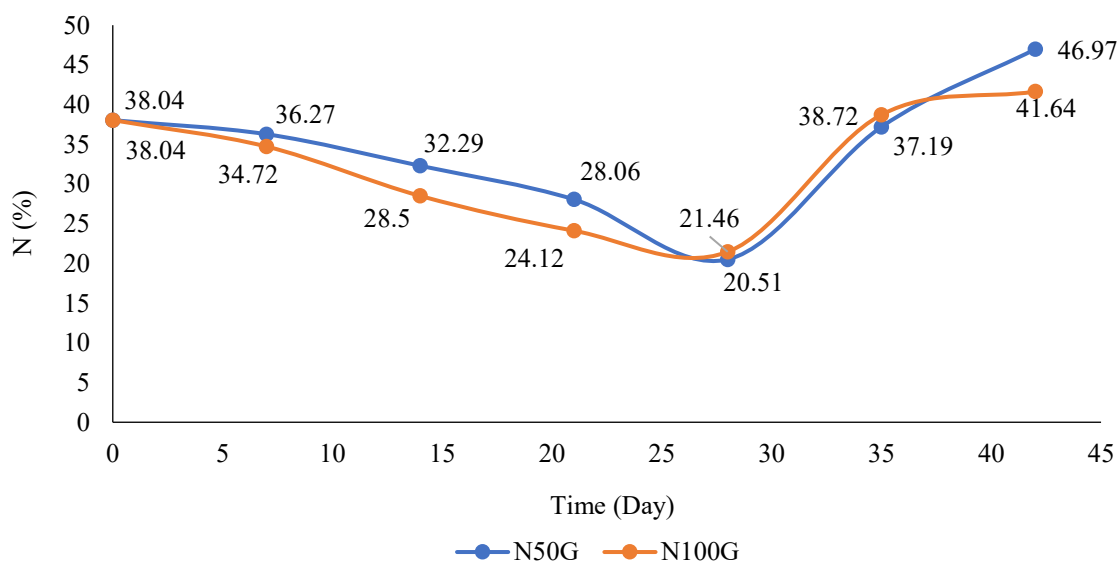


Figure 6. Comparison of nitrogen content (N) versus time for petroleum hydrocarbon degradation on the effect of bioremediant of room-dried sample of 50g and 100g dosage.

Figure 7 shows revealed the phosphorous concentration comparison upon the effect of remediate dosage of 50g and 100g in bioreactors in relationship to time factor. Indeed, the phosphorous utilization by the microbes was experienced to more on 100g dosage than the 50g dosage of the bioremediation (bio stimulant). The trend of the phosphorous utilization was in the order of P100G> P50G, showing that the more the bioremediate (biostimulant) the more the petroleum hydrocarbon utilization will increase.

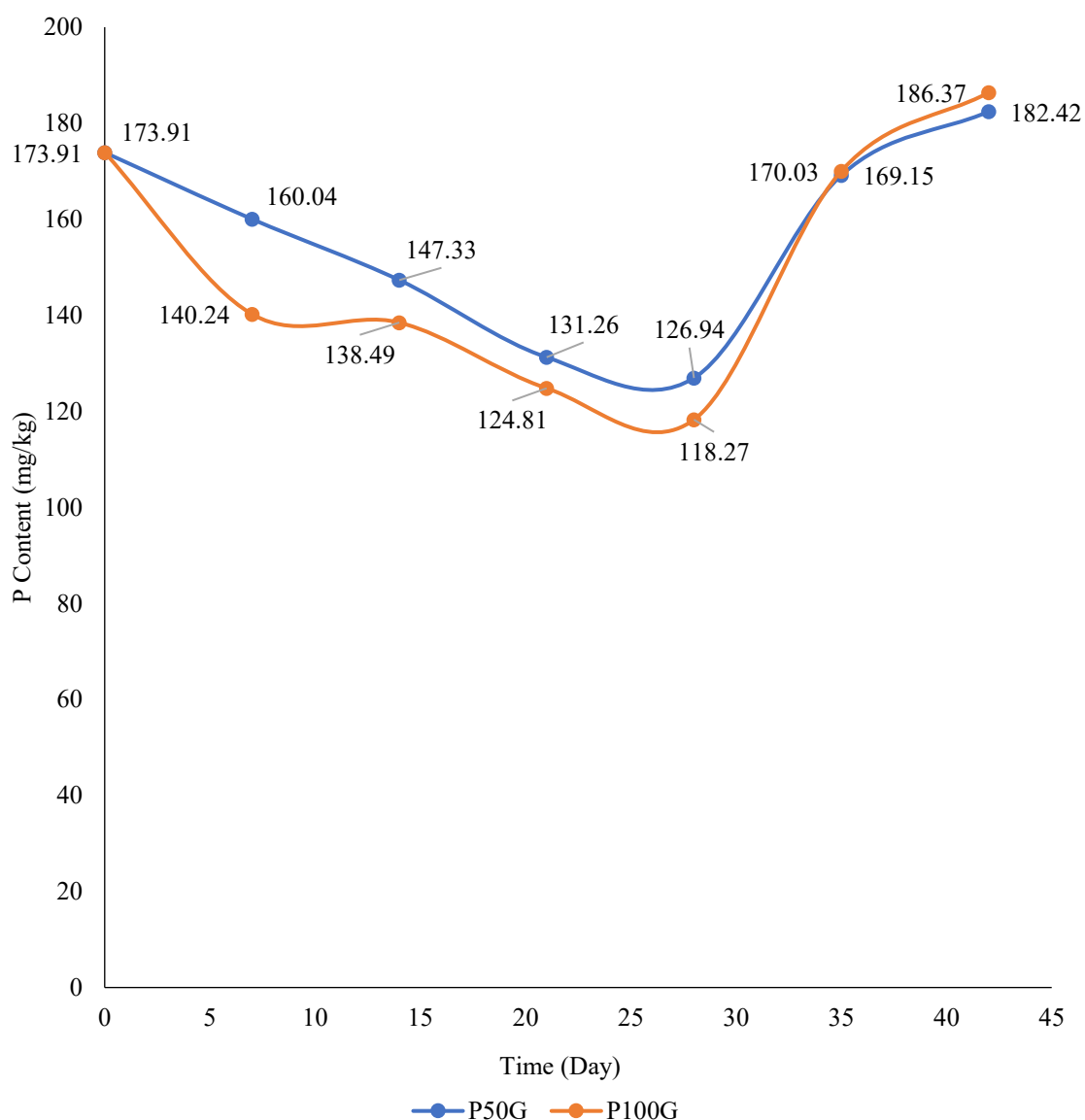


Figure 7. Comparison of Phosphorus Content (P) versus Time for Petroleum Hydrocarbon Degradation on the Effect of Bioremediant of Room-Dried Sample of 50g and 100g Dosage.

Figure 8 shows the trend of the comparison of the potassium concentration in relationship to the dosage effect on petroleum hydrocarbon remediation and the conditions of the available nutrient of the sandy – loamy soil integrity is restored. Decrease in the potassium concentration in different bioreactors was experienced with increase in time. The effective of the bioremediant of room – dried sample was tested and the potential of the potassium revealed initial decrease in concentration without above zero day to 28days, before sudden increase in potassium concentration and the order of utilization was K100G> K50G.

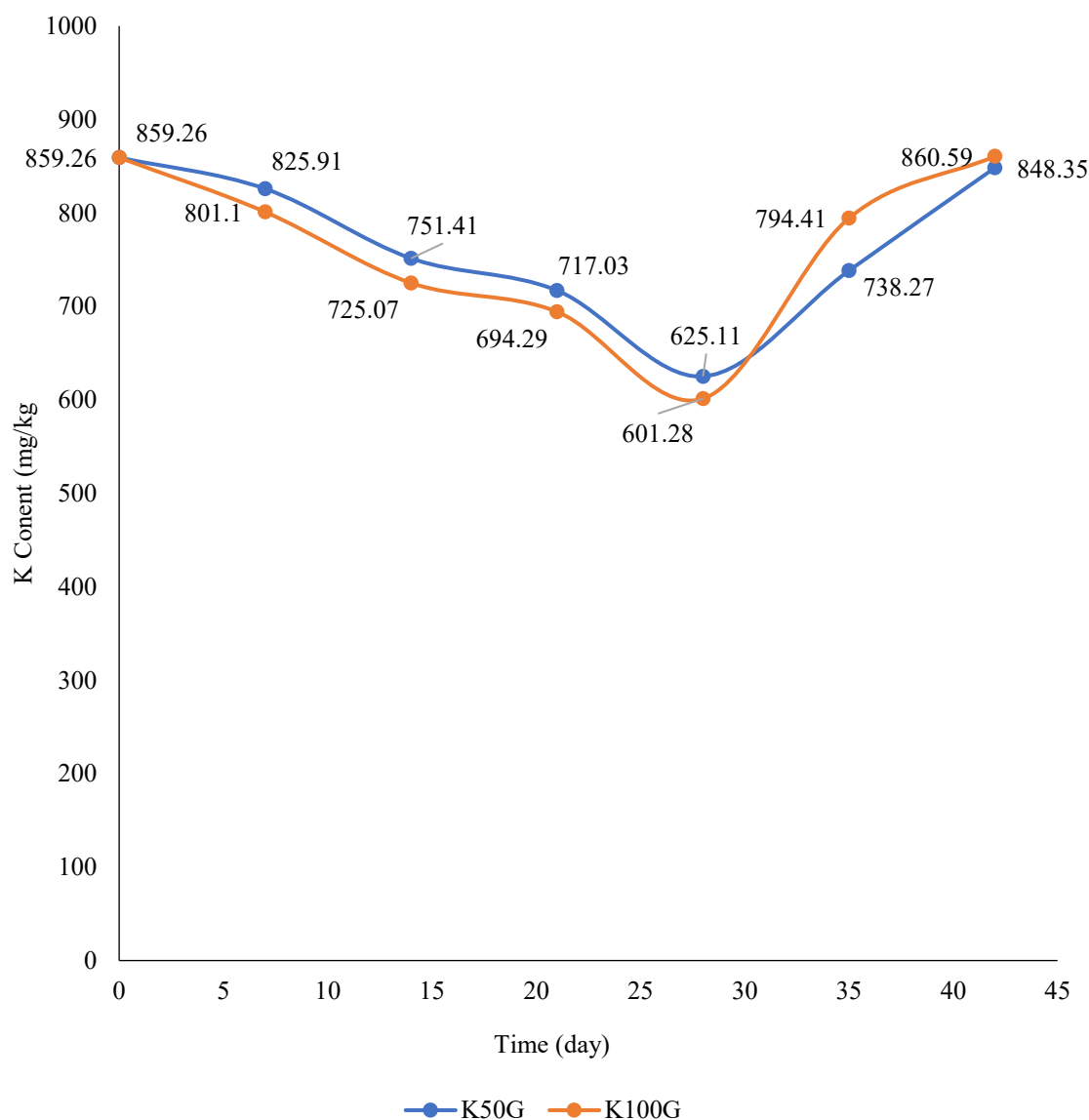


Figure 8. Comparison of potassium content (K) versus time for petroleum hydrocarbon degradation on the effect of bioremediant of room-dried sample of 50g and 100g dosage.

Figure 9 shows the total organic carbon (TOC) utilization in the bioreactors with respect to period of exposure (contact time) in petroleum hydrocarbon remediation to sandy – loamy soil using bioremediant (biostimulant) research shows decrease in the TOC value with increase time for period of above zero day to 28 days, before sudden increase in TOC value demonstrating sandy – loamy soil restoration. The TOC utilization by microbes revealed TOC 100G > TOC 50G and as the process proceed more of the TOC of 100g dosage increases in the sandy – loamy soil compared to 50g dosage and the detail characteristics of the 50g dosage and the detail characteristics of the bioremediant dosage of 100g is shown in appendix.

Figure 10 show the pH valued of the bioreactors of 100g and 50g dosage of the process as remediation of the petroleum hydrocarbon degradation increase with respect to increase in time (period of exposure). In fact, that result revealed that the initial characteristics of the pH changes from week acidic condition to strong acidic condition. Furthermore, as restoration of the sandy- loam soil potential was restored the pH returned to alkaline. The research revealed that pH value change does not influence the microbial activities in the process.

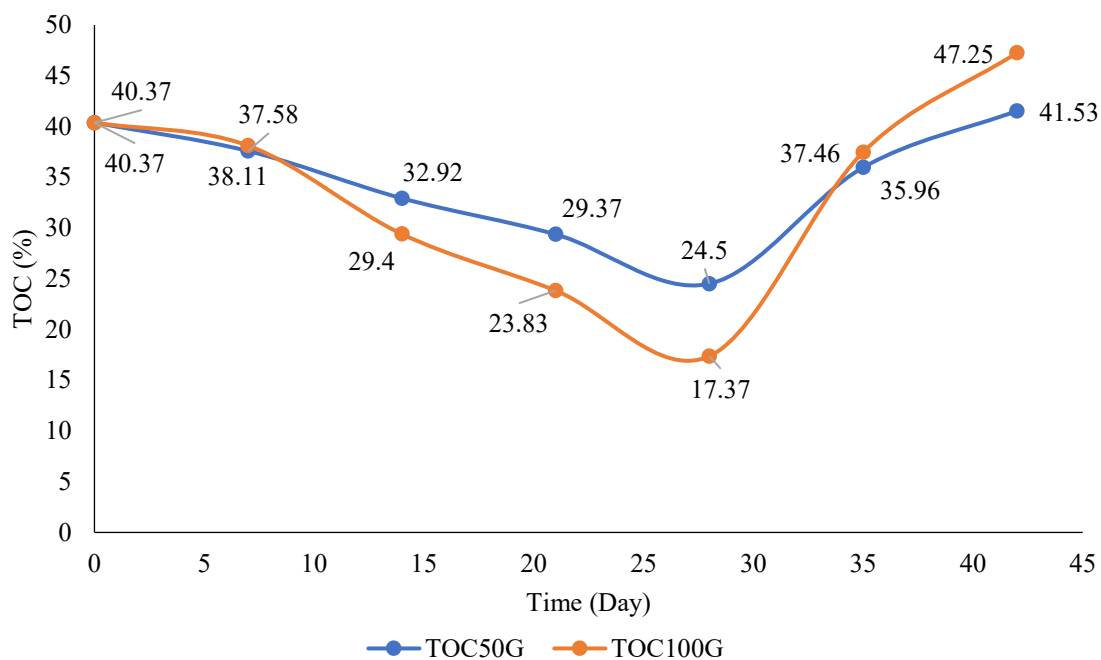


Figure 9. Comparison of TOC versus time for petroleum hydrocarbon degradation on the effect of bioremediant of room-dried sample of 50g and 100g dosage.

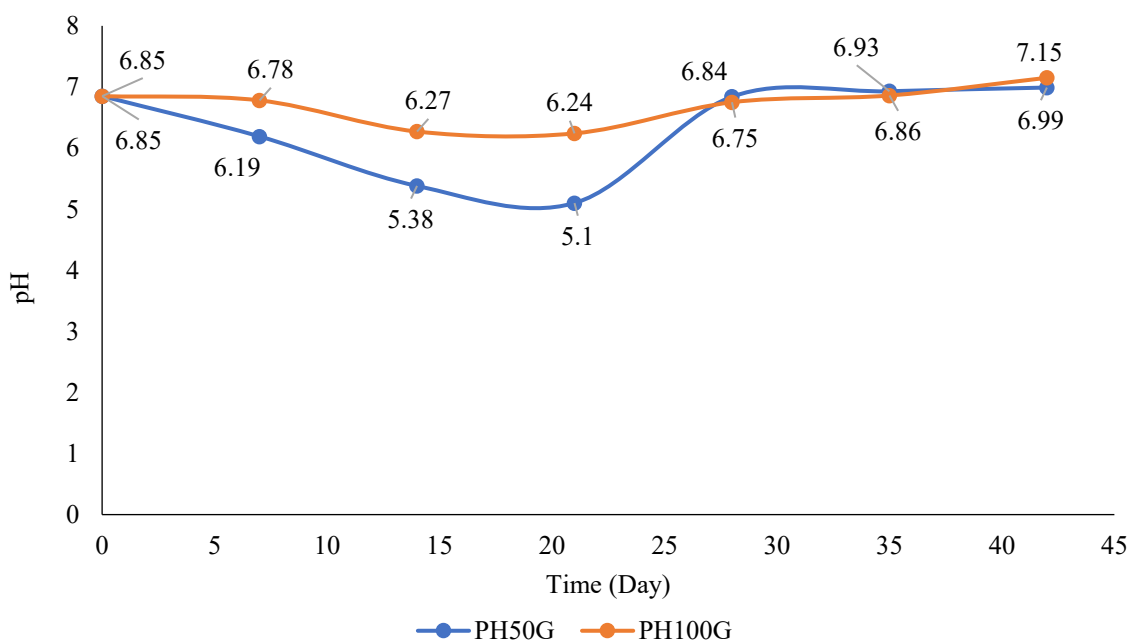


Figure 10. Comparison of pH versus time for petroleum hydrocarbon degradation on the effect of bioremediant of room-dried sample of 50g and 100g dosage.

Figure 11 shows the nitrogen content concentration in bioreactor in which the bioremediant was processed through the concept of sun – dried and then introduced into the sandy – loamy soil contaminated with petroleum hydrocarbon. The trend of change in the nitrogen concentration revealed initial decrease from above zero day to 28 days, before increase in the nitrogen concentration in the sandy – loamy soil with increase in time. This characteristic favors the microbial growths in the bioreactor and improved petroleum hydrocarbon remediation in the process.

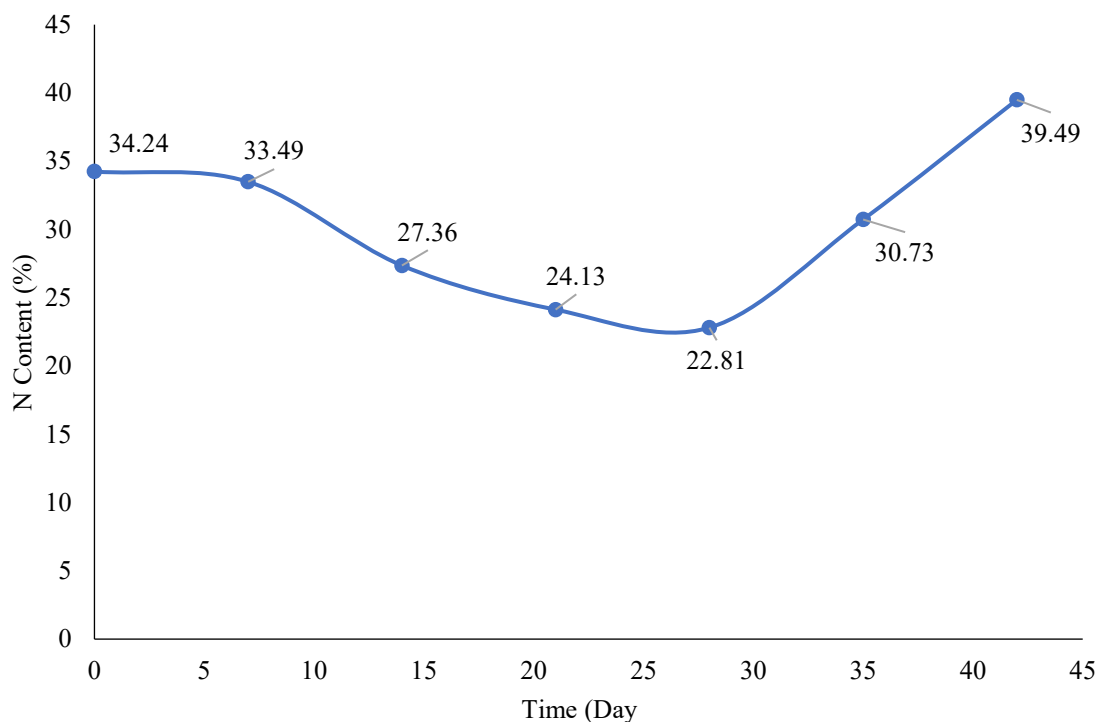


Figure 11. Nitrogen content versus time for petroleum hydrocarbon degradation on the effect of bioremediant of sun-dried sample of 50g dosage.

Figure 12 shows the trend of the phosphorous concentration variation with respect to change the period of exposure (time) in sandy-loamy soil contaminated with petroleum hydrocarbon. The research shows initial decrease in the phosphorous concentration with respect to increase time for above zero day to 28 days and increase in phosphorous concentration experienced from above 28 days to 42 days of experimental period.

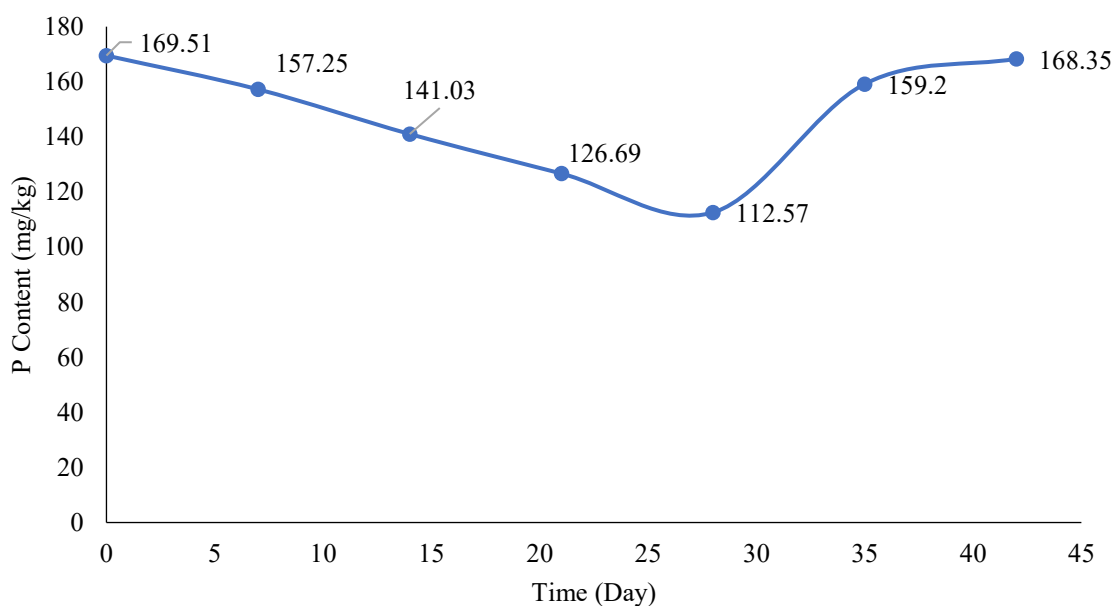


Figure 12. Phosphorous content versus time for petroleum hydrocarbon degradation on the effect of bioremediant of sun-dried sample of 50g dosage.

Figure 13 shows the characteristics the potassium concentration in the remediation of petroleum hydrocarbon in sandy – loamy soil, which received bioremediate of sun – dried materials. However, the obtained data shows decrease in potassium concentration from above zero day to 28 days with decrease in petroleum hydrocarbon experienced in the process. The result obtained further illustrate increase in potassium concentration after 28days.

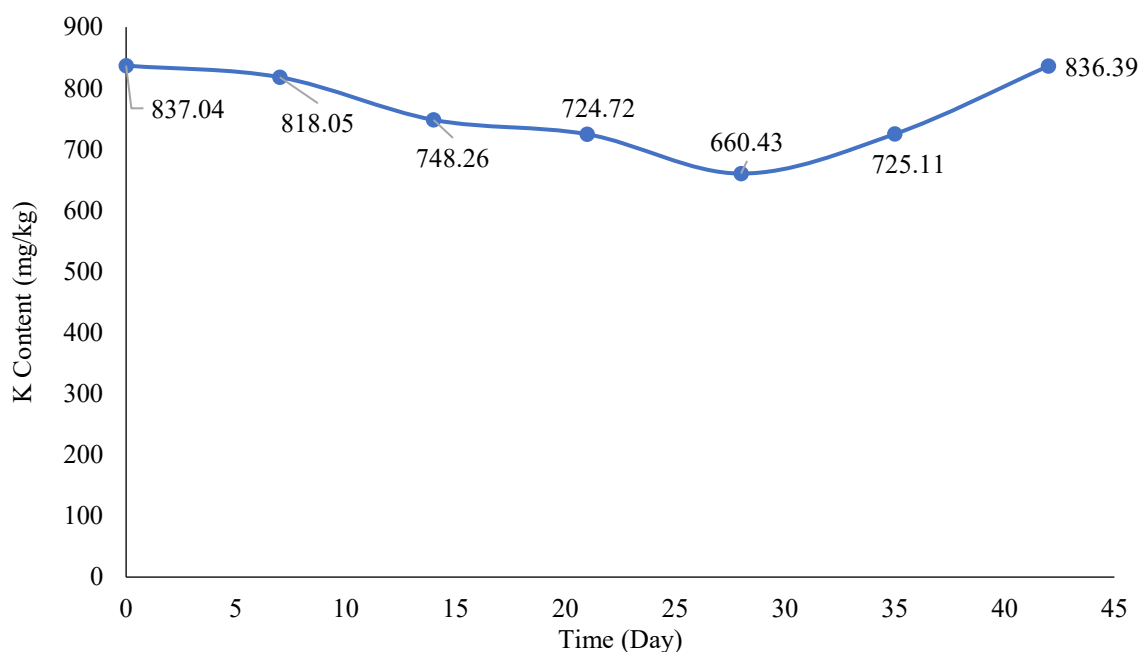


Figure 13. Potassium content versus time for petroleum hydrocarbon degradation on the effect of bioremediant of sun-dried sample of 50g dosage.

Figure 14 show the trend of the total organic content (TOC) value of the bioreactor sampled, which contained contaminated sandy – loamy soil with petroleum hydrocarbon and presence of the sun-dried application of the bioremediate (biostimulant). The research demonstrates decrease in the TOC value with respect to increase in the time of contact for period of above zero day to 28 days. However, increase in the TOC value in the sandy loamy soil increased at time above 28days, revealing nutrient restoration in the bioreactor.

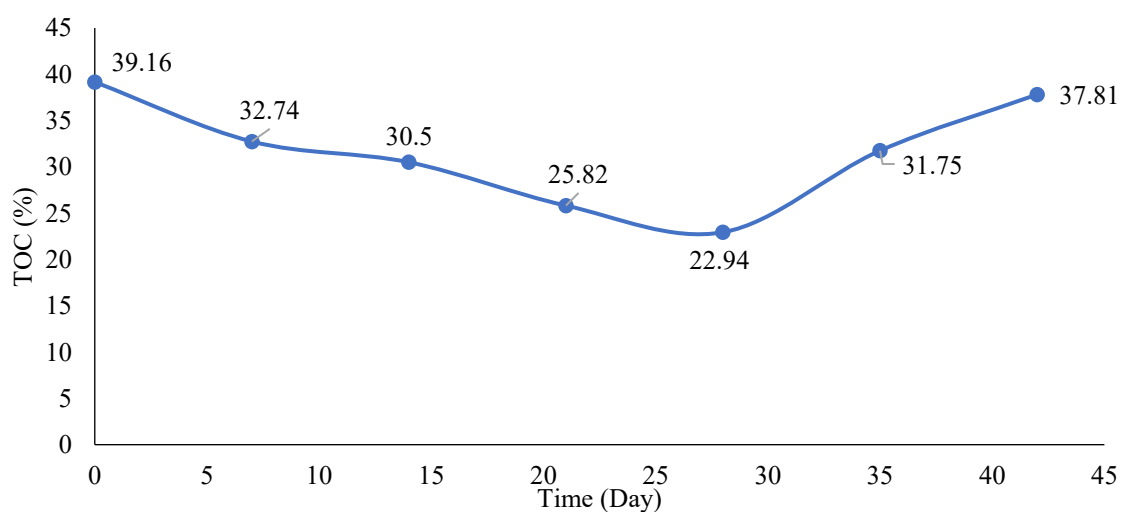


Figure 14. TOC versus time for petroleum hydrocarbon degradation on the effect of bioremediant of sun-dried sample of 50g dosage.

Figure 15 shows the properties of the pH value of the pH in the bioreactor, which received sun – dried bioremediation for the treatment of sandy – loamy soil contaminated with petroleum hydrocarbon. The pH value increased in pH value of week acid to strong acid which from the process without inhibiting the microbial growths. And after the sandy – loamy soil integrity was restored a change in pH occurs form strong acid to week acid. Both process condition favors the degradant process of the petroleum hydrocarbon as well as the microbial growth.

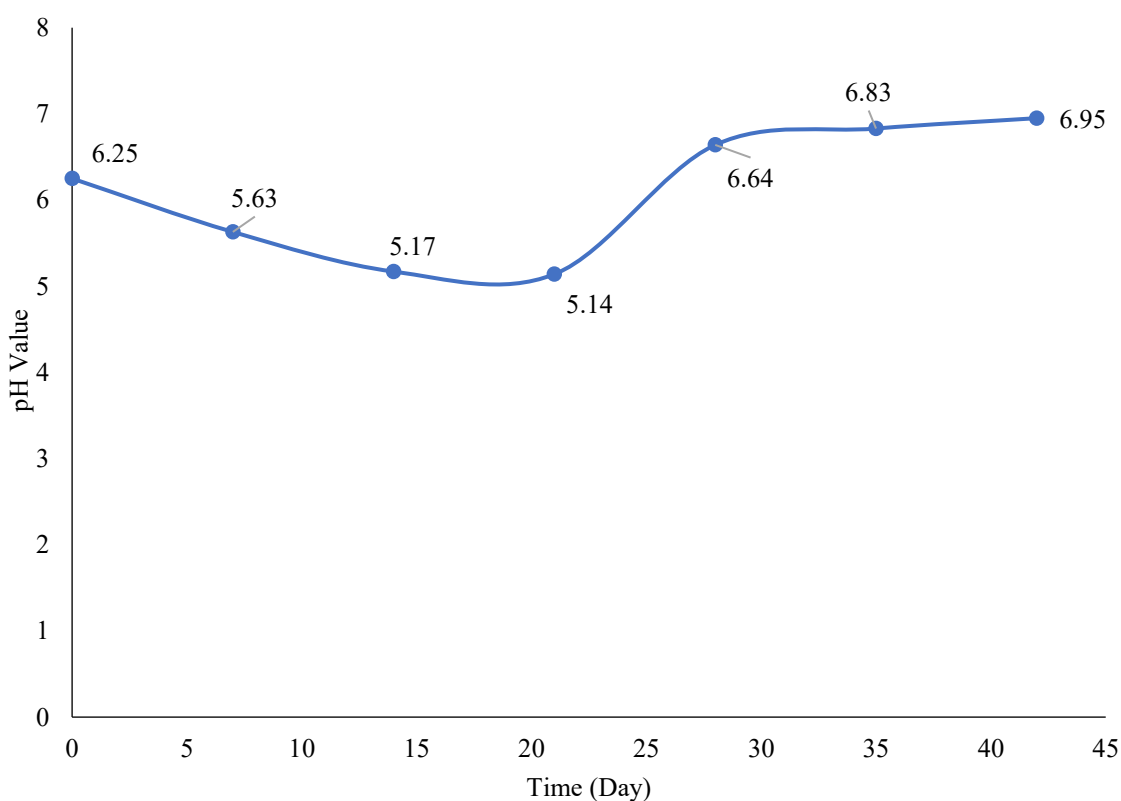


Figure 15. pH versus time for petroleum hydrocarbon degradation on the effect of bioremediant of sun-dried sample of 50g dosage.

Figure 16 shows the comparison of the nitrogen concentration utilization in the two different bioreactors dosed with 50g and 200g dosage of the sun – dried bioremediating (biostimulant). The behaviour of both applications followed the same trend with decrease in the nitrogen concentration after zero day to 28 days showing increase in the nitrogen nutrient utilization by the microbes in each bioreaction with increase in the period of exposure (time). However, the obtained data revealed more nitrogen nutrient utilization of the order of N100G > N50G. this order can be integrated to the available nutrient presence in the bioreactor and the ability of the possible microbes to utilize them for their source of energy for the purpose of catalyzing the process by degrading the petroleum hydrocarbon.

Figure 17 shows the trend of the comparison of phosphorous utilization by the microbes with respect to changes in times (period of exposure). The sandy – loamy soil which was contaminated with petroleum hydrocarbon received bioremediates of 50g and 100g dosage in each bioreactor. the application of the bioremediating is to supply available nutrient for the microbes to make use of while ensuring effectiveness in the petroleum hydrocarbon degradation and remediation in each of the bioreactor set u. the research showcase decrease in the phosphorous concentration for a period of 28 days. It was experienced that after the 28 days an increase in the phosphorous concentration was notices demonstrating the restoration of the available nutrient of phosphorus on the each of the bioreactor. the bioremediant (biostimulant) used was sun – dried sample.

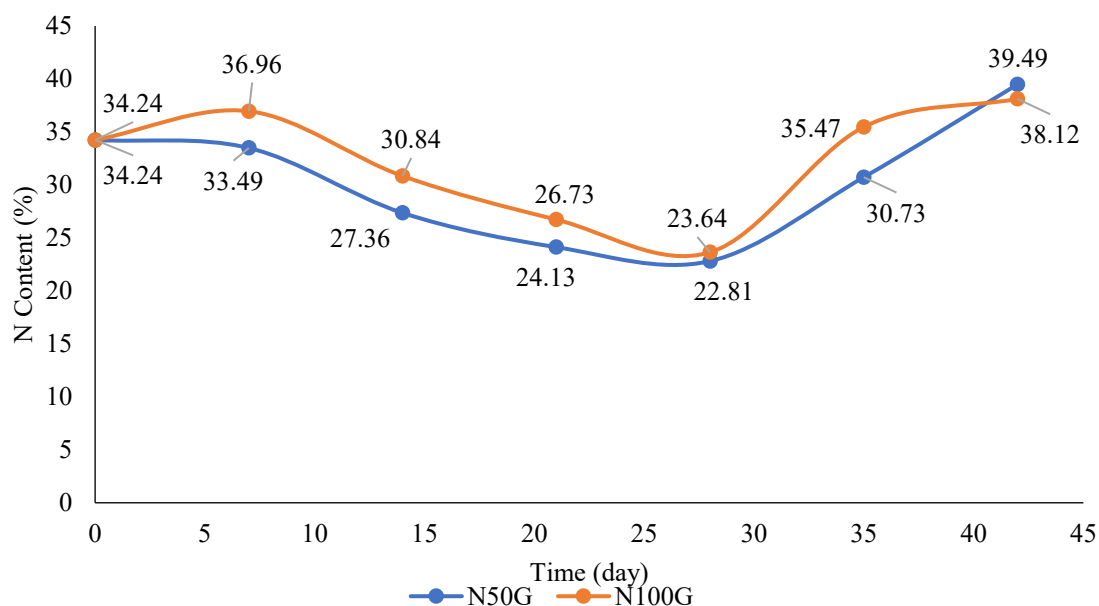


Figure 16. Comparison of nitrogen content versus time for petroleum hydrocarbon degradation on the effect of bioremediant of sun-dried sample of 50g and 100g dosage.

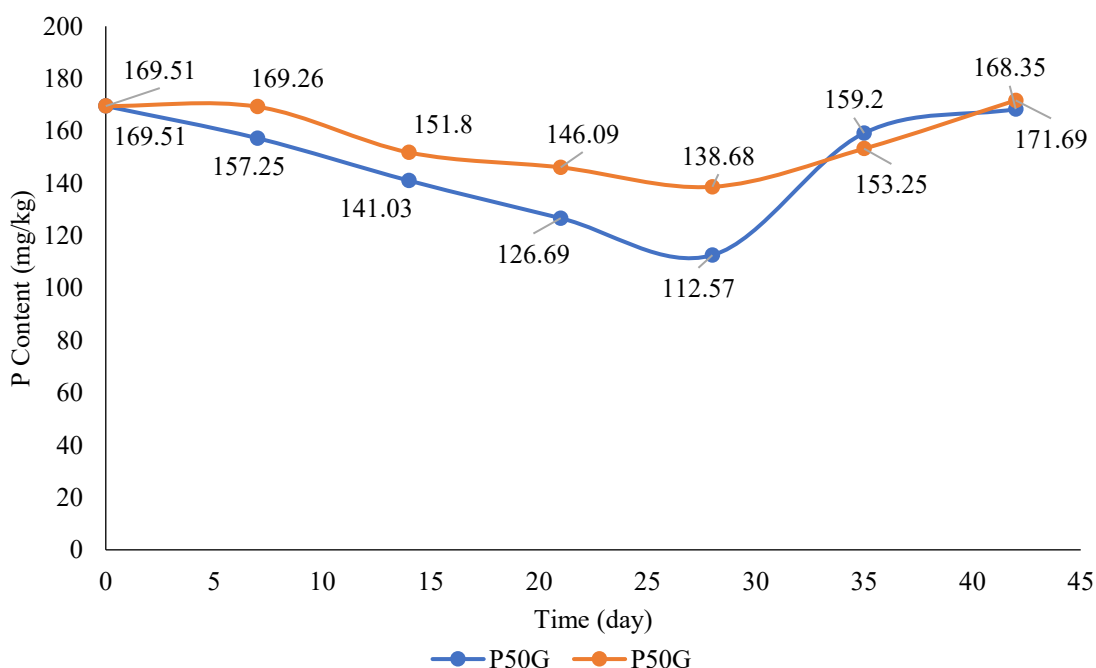


Figure 17. Comparison of phosphorous content versus time for petroleum hydrocarbon degradation on the effect of bioremediant of sun-dried sample of 50g and 100g dosage.

Figure 18 shows the comparison of the potassium concentration obtained from the application of using bioremediant of sun-dried sample of different mass of dosage of 50g and 100g, which was introduced into sandy-loamy soil contaminated with petroleum hydrocarbon. The result of this research revealed decrease in the potassium concentration up to 28 days upon utilization by the available microbes of the hydrocarbon utilizing bacteria and fungi. Furthermore, the trend of the behaviour in terms of the available potassium concentration continuous to increase after 28 days revealing the nutrient restoration due to petroleum hydrocarbon degradation, which yield positive outcomes.

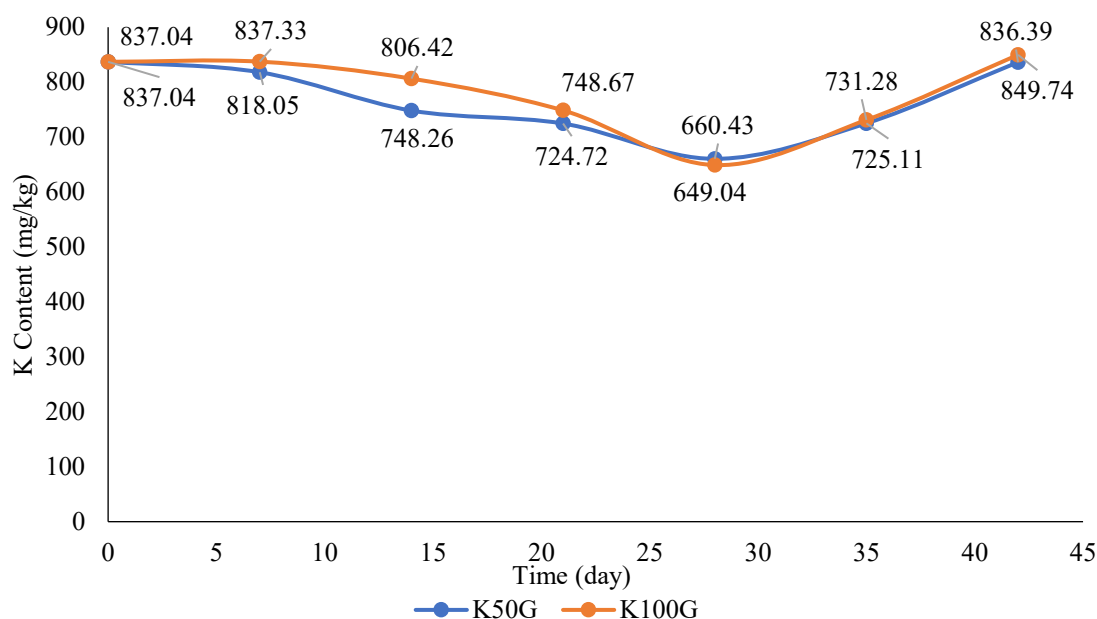


Figure 18. Comparison of potassium content versus time for petroleum hydrocarbon degradation on the effect of bioremediant of sun-dried sample of 50g and 100g dosage.

Figure 19 shows the TOC characteristics in the two different bioreactors dosed with 50g and 100g dosage of the bioremediant (biostimulant). Decrease in TOC value was seen with increase in period of exposure (time) for each of the bioreactor for time period of 28 days and increase in the TOC nutrient availability in sandy – loamy soil after 28 days showing the remediation of the contaminated petroleum hydrocarbon in each bioreactor set up. However, the research has addressed the significance of the TOC restoration after the contaminated sandy -loamy soil has been remedy and the potential of the available nutrient of TOC restored and this process was achieved using sun dried sample of the bioremediant.

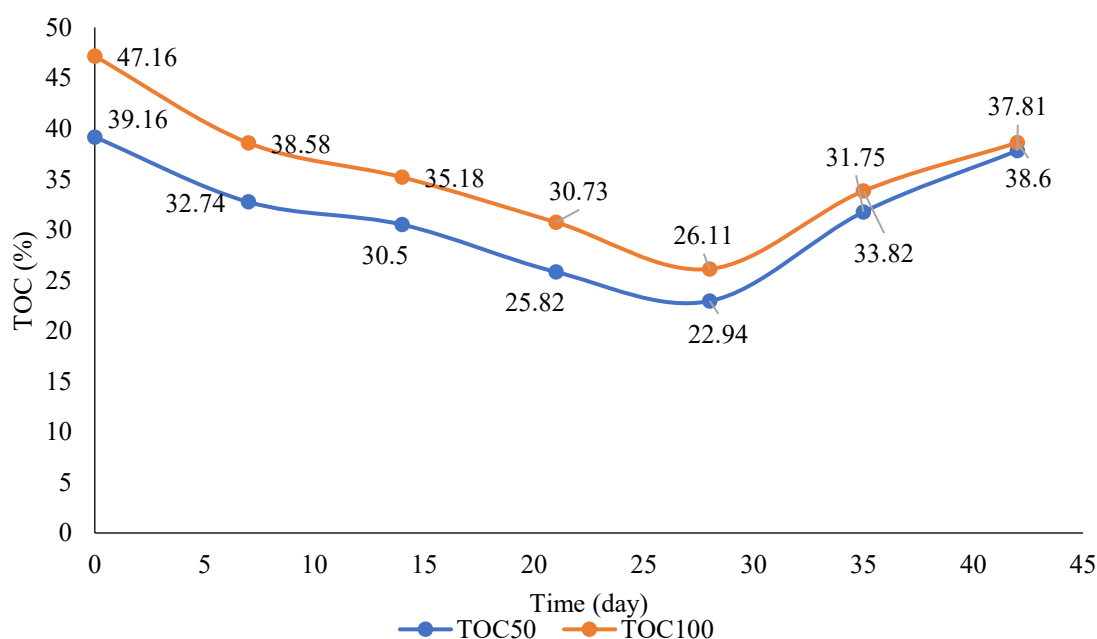


Figure 19. Comparison of TOC versus time for petroleum hydrocarbon degradation on the effect of bioremediant of sun-dried sample of 50g and 100g dosage.

Figure 20 shows the comparison of the pH values trend of 50g and 100g dosage performance of the bioremediate use in the treatment of the contaminated sandy – loamy soil with petroleum hydrocarbon. The result illustrates initial changes in pH values from week acid in nature to stronger acid within the period of 21 days and after this period a change in the trend the pH value was experienced from strong acid in nature to week acid. This behaviour in characteristic was the same for the two bioreactors investigated in this case using sun – dried sample of this bioremediant (biostimulant).

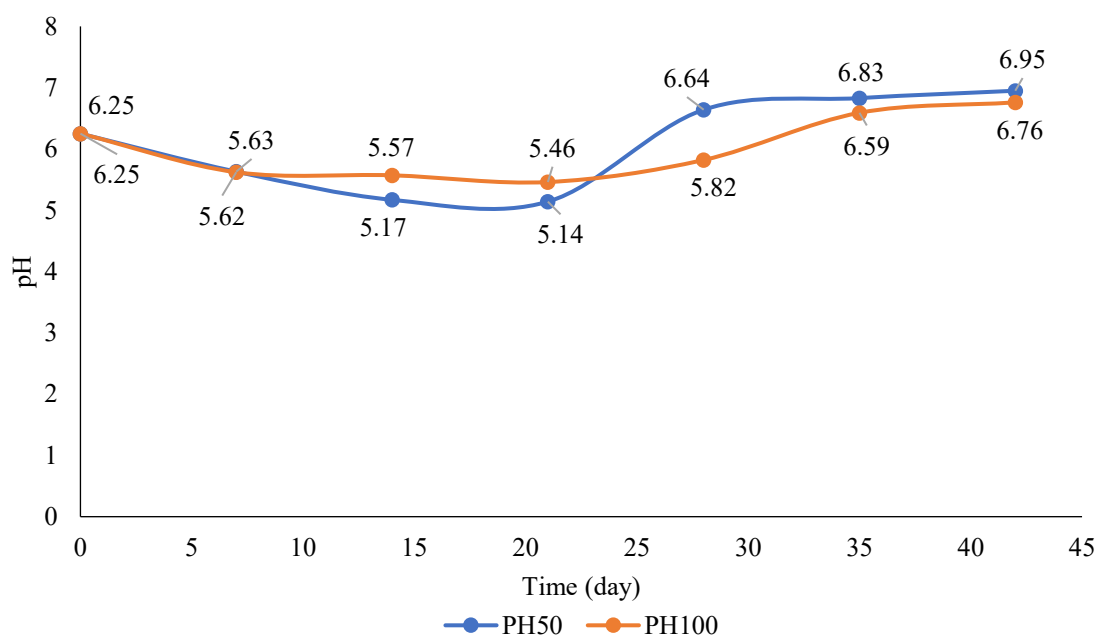


Figure 20. Comparison of pH versus time for petroleum hydrocarbon degradation on the effect of bioremediant of sun-dried sample of 50g and 100g dosage.

CONCLUSION

The concepts of using bioremediant (biostimulant) in treatment of contaminated soil environment is not new but the concepts and the type of the bioremediant used as well as the model in which the bioremediant (biostimulant) is prepared and applied can led to new concept provided the approach and technique used fielded a positive outcome. One of the mechanisms used to achieved this is by determining the physiochemical properties of all the substances involved for the programs to proceed without no negative impact or challenges on the process. To achieve this the following were examined, physiochemical properties of the bioremediant (biostimulant) of sun and room-dried samples, property of sandy loamy soil characteristics of some parameters, crude oil parameters of density and viscosity as well as the total petroleum hydrocarbon.

Examination and Results of the Physiochemical Parameters

The research demonstrates the characteristics of following parameters monitored from the initial raw materials used before introducing them into the bioreactors with different dosage concentration and one used as control sample. The parameters are total organic content (TOC) pH, nitrogen concentration, phosphorus concentration, potassium concentration, hydrocarbon utilizing bacteria and hydrocarbon utilizing fungi as well as the Total Petroleum Hydrocarbon (TPH). The concentration of these parameters' changes with changes in microbial concentration hydrocarbon utilization (decrease in TPH) and increase in time at the progressive phase of the remediation.

REFERENCES

1. Lu Y, Sun Y. Evaluation of grape leaf powder as a biostimulant for the remediation of crude oil-contaminated soil. *Environ Prog Sustain Energy*. 2010;29(1):29–35.

2. Wang Z, Liu W. Effects of grape leaf powder on the bioremediation of petroleum-contaminated soil. *J Environ Sci*. 2011;23(1):137–143.
3. Al-Hawash AB, Dragh MA, Li S, Alhujaily A, Abbood HA, Zhang X, et al. Principles of microbial degradation of petroleum hydrocarbons in the environment. *Egypt J Aquat Res*. 2018;44:71–76.
4. Lin J, Gan J. The use of grape leaf powder for the remediation of crude oil-contaminated soil. *J Environ Sci Health B*. 2010;45(2):177–183.
5. Neha J, Swati S. Phytoextraction potential of Neem (*Azadirachta indica*) for Cd detoxification. *Clim Change Environ Sustain*. 2018;6(2):154–159.
6. Okorundu JN. Bioremediation of crude oil spills on sandy soil using grape leaf. *J Environ Sci Technol*. 2022;15(1):1–10.
7. Ukpaka CP, Nwankwo IC, Igbokwe CC. Potentiality of grape leaves extract for bioremediation of crude oil-contaminated soil. *Int J Environ Pollut*. 2016;52(1):131–140.
8. Jain V, Sharma S, Kaur P. Bioremediation of crude oil-contaminated soil using plant-associated microorganisms. *Int Biodeterior Biodegradation*. 2011;65(1):59–65.
9. Amagbo LG, Ere W. Predictive model for TPH degradation in soil amended with spent mushroom. *Am J Eng Res*. 2019;8(1):160–165.
10. Nwogu TA. Enhanced bioremediation of soil artificially contaminated with petroleum hydrocarbons after amendment with *Capra aegagrus hircus* (Goat) manure. *Biotechnol Res Int*. 2015:1–7.
11. Wu Y, Chu Y, Yu H. Biostimulation of indigenous microorganisms for the remediation of petroleum-contaminated soil with grape leaf powder. *J Environ Manage*. 2010;91(11):2645–2651.
12. Jaiswal D, Patel VC, Singh N. Evaluation of organic amendments for biodegradation of petroleum hydrocarbons in soil. *Environ Sci Pollut Res*. 2010;17(5):759–771.
13. Naveed M, Mitter B, Yousaf S. The endophyte *Enterobacter* sp. FD17: A maize growth enhancer selected based on rigorous testing of plant beneficial traits and colonization characteristics. *Biol Fertil Soils*. 2014:249–262.
14. Liu Z, Wang Q. Enhanced bioremediation of petroleum-contaminated soil by co-stimulation with grape leaf powder and nitrogen-phosphorus-potassium fertilizer. *J Hazard Mater*. 2009;164(1–3):297–304.
15. Uba IA, Anyanwu JO. Potential of grape leaf extract for bioremediation of crude oil-contaminated soil. *J Environ Chem Eng*. 2021;9(1):104645.
16. Nikakhtari H, Kumar P, Nemati M, Hill GA. Mass transfer and bioremediation of aromatics from NAPL in a baffled roller bioreactor. *Process Saf Environ Prot*. 2008;86:252–258.