Phytoremediation of Used Engine Oil Contaminated Soil Using Lemon Grass

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Abstract- This work investigates the use of lemon grass to remediate mechanic workshop soil. *Contamination of soil with engine oil and other petroleum hydrocarbons is a problem in Nigeria.* It has been reported previously by Pam et al. 2013 and Fayinminnu and Abimbola, 2016 respectively that analysis of samples of the soils in mechanics workshops revealed that the concentrations for most heavy metals such as Cadmium (Cd), Copper (Cu), Manganese (Mn), Nickel (Ni), Lead (Pb) and Zinc (Zn), in the soils are above background levels and permissible limits recommended for soils. Hence the need to remediate contaminated mechanic workshops soil in Nigeria. Phytoremediation was studied for 96 days. After the 52 days of planting, the heavy metals uptake in each sample was analyzed for root, stem and leaves at an interval of 21 days specifically for Lead (Pb), Nickel (Ni) and Cadmium (Cd). Absorption Atomic Spectroscopy (AAS) analysis showed that lemon grass uptakes lead, Nickel and Cadmium. The percentage removal of these heavy metals from the residual oil contamination soil was 95% lead (Pb), 67 % Nickel (Ni) and 83 % Cadmium (Cd) respectively while the 99.3 % Total petroleum hydrocarbon (TPH) of the contaminated soil before planting decreased to 31.20 % after the 96 days period. Lemon grass remove significant amount of heavy metals (Pb, Ni and Cd) from the mechanic workshop contaminated soil. Thus, lemon grass has a hyper-accumulative uptake capacity for bioavailable residual oil heavy metals, therefore it is suitable for the phytoremediation of the contaminated soil.

Keywords: Contaminated soil, Lemon grass, Phytoremediation, Heavy metals, Total petroleum Hydrocarbon.

1. Introduction

Engine oil contamination of soil has become a major prob lem in recent decades, owing to the significant growth in petr oleum hydrocarbons, lead, solvents, pesticides, and other hea vy metals from industrial wastes and human activities [1]. Heavy metal contamination can be attributed to industrial operations causing the rising input of heavy metals into the soil thereby initiating serious environmental hazard [2-4]. There has been a great deal of research focusing on heavy metal contamination due to drawbacks such as long incubation, non-biodegradation, deposition in soil and water, bioaccumulation, and biomagnification through the food chain [5-6].

Petroleum hydrocarbons, lead, polynuclear aromatic hydroca rbons (including naphthalene and Benzo, pyrene), solvents, p esticides, and other heavy metals are the most common chem ical compounds involved in the contamination of soil. The degree of industrialization and the intensity of the chemical usage are linked to this prevalent soil problem [5]. Health risk such as direct contact with tainted soil, vapour from contaminants, and secondary contamination of water supplies inside and beneath the soil, are the most common cause contamination [7]. Hence there is need to carry out remediation of the soil using environmentally friendly techniques. Pb, Ni and Cd are hazardous elements that cause cytotoxicity and carcinogenicity upon persistent environmental exposure, for long period of time–and the International Agency for Research on Cancer classifies Pb, Ni and Cd compounds as group 1 carcinogens for human in 1993 [8]. As a result, it's critical to keep the possible health risk of Pb and Cd exposure in the soil under control. Excavation, dumping, solidification, soil flushing, electrophoresis, and chemical reduction are common methods of physical and chemical rehabilitation for heavy metal contaminated soil [9]. These traditional approaches on the other hand are very expensive, degrades the soils physicochemical properties *and* rely on a complicated set of processes and devices that limit their use on a broad scale [10]. There is a need for a better approach, phytoremediation has been reported to be cost effective, efficient, novel, environmentally friendly, and solar-powered technology with high public acceptance [11]. Following this discussion, this current work investigates the use of lemon grass to remediate mechanic workshop soil.

Phytoremediation is the direct application of green plants and their associated microorganisms to stabilize or reduce contamination in soils, sludge, sediments, or groundwater. Plants are used in phytoremediation to clean up contaminants in the environment. Metals, pesticides, explosives, and oil are just a few of the toxins that plants may help clean up [11]. The plants also help to keep contaminants from being carried away from locations by wind, rain, and groundwater [12]. When soil is contaminated with engine oil, it loses its shape and texture, which lowers water penetration and plant photosynthesis, reducing oxygen supplies for aquatic life and endangering our natural resource. As a result, proper and effective strategies for controlling and cleaning up polluted soils are required [13]. Lemon grass is one of the plants that could be used for phytoremediation because it is hyper-accumulative and it has the ability to take heavy metals from the soil via its roots, then deposit them in various sections of the plant [14]. Phytoremediation has advantage of avoiding the excavation and shipping of site, filthy media, reducing the risk of contamination spreading, and it has the capability to cope with polluted areas with different types of pollutants [15]. A typical site in Nigeria contaminated with used engine oil is depicted in Figure 1.

Fig.1. Used engine oil contaminated soil at a location in Nigeria [14]

Figure 1 depicts a typical environmental impact of a contaminated site of mechanic workshop in Nigeria. This pollutant is non-biodegradable, highly hazardous and contains heavy metals dangerous to humans such as lead, cadmium, nickel and zinc. Furthermore, this pollutes water and soil, posing a risk to both humans and the environment, necessitating the search for less expensive methods of resolving this environmental blight.

Gautam et al. [7] evaluated the effects of heavy metal on soil properties, plant growth performance and metal accumulation in lemongrass. They conclude that based on translocation and bioconcentration factors, lemongrass acted as a potential phytostabilizer of Fe, Mn, and Cu in roots. They reported that composition of red mud with sewage sludge is suitable for lemongrass cultivation and can potentially be used for the phytoremediation of red mud contaminated sites. However, the use of lemon grass for phytoremediation of mechanic workshop contaminated soil has not been reported till date. Lemongrass, including the root, stem and leaves can accumulate an excessive amount of heavy metals in their various parts [5]. Because of their quick growth and huge biomass, plants have a significant amount of phytoextraction of heavy metals, making them easier to harvest mechanically [15]. As a result, fast a growing vegetation with high tolerance and large biomass, such as lemongrass can be examine for use in phytoremediation to remove heavy metals from contaminated soil. Due to their large fibrous root systems. Lemongrass (Cymbopogon citratus) is expected to make sophisticated vehicles for phytoremediation. Grass root systems have the greatest root surface area (per m^3 of soil) of any plant and can penetrate the earth up to three meters [6]. They also have a high level of genetic variety, which could give them an edge in the market. Because of their ability to restore nitrogen, legumes are expected to have an advantage over non-leguminous plants in phytoremediation [10]. That is, legumes should not compete with microbes and other plants for limited resources of accessible soil nitrogen at oil contaminated areas. The kind of pollutant, bioavailability, and soil conditions all influence phytoremediation methods [13].

Diesel and wasted engine oil are two major hydrocarbon derivatives of crude oil that may contribute to environmental pollution. These have an impact on the health and socioeconomic well-being of communities whose primary source of income is agricultural and aquatic habitats. These pollutants reduce the amount of oxygen accessible in the soil, change its physical and chemical properties and harm soil micro and macro-organisms [11]. Unfortunately, the clean-up of hydrocarbons by product polluted sites has relied on physical, chemical, and thermal procedures, which employ fairly sophisticated, demanding, and expensive technical techniques that occasionally have negative effect on the environment. As a result, research has focused on the potential of organic techniques such as phytoremediation, as cost-effective methods for cleaning up polluted hydrocarbon by-product site [16-17]. This in situ remediation method takes advantage of developing plants' natural ability to bio-accumulate pollutants. It is a solar-powered, environmentally friendly clean up system that uses natural approaches to clean up the environment. Plants passively repair modest to mild levels of pollution in the growing medium as they mature and are harvested. Metals, pesticides, solvents, explosives, crude oil, polyaromatic hydrocarbons, and landfill leachates can be cleaned up with phytoremediation in soils, sludge, sediments and water bodies [18]. Nigeria, as an oil producing country is faced with the problem of petroleum hydrocarbon disposal in soil in the absence of effective and environmentally benign repair technique [19].

Pam et al [20] carried out evaluation of heavy metals in soils around auto mechanic workshop clusters in Gboko and Makurdi, Central Nigeria. Based on their report, analysis of samples of the soils revealed that for the majority of heavy metals such as Cd, Cu, Mn, Ni, Pb and Zn, the concentrations in the soils are above background levels and permissible limits recommended for soils. Hence the need to remediate contaminated mechanic workshop. They concluded that these auto mechanic workshops do have a negative (pollution) impact on the surrounding environment. The uses of plants to remediate mechanic workshop soil have not been reported so far in literature, thus, this work investigate the potentials of lemon grass to remediate mechanic workshop soil. Contamination of soil with engine oil and other petroleum hydrocarbons is problem for a country known for its agricultural prowess and history. Traditional and mechanical remediation procedures such as solidification and vitrification have recently been attempted to remediate environmental heavy metals. These, on the other hand, are usually costly, harmful and hazardous to the environment [7-19]. As a result, there is a compelling need to investigate alternate methods of cleaning up used engine oil-contaminated soils without incurring excessive costs or harming the environment. This study looked at the ability of lemon grass to survive, develop, and bio-accmmulate heavy metals in soils contaminated with used engine oil, with a focus on biomass accumulation methods for Lead, Nickel, and Cadmium. It looks into the potential of lemon grass to remediate used engine oil-contaminated soil and to figure out which parts of lemon grass are more effective in adsorbing heavy metals.

2. Materials and Methods

Soil sample was collected from a mechanical workshop at Sabon gari L.G.A. Kaduna state, Nigeria and taken to the National Research Institute for Chemical Technology (NARICT) laboratory Zaria for RXF analysis. Lemon grass was also obtained from plant science department in faculty of agriculture, Ahmadu Bello University (ABU), Zaria and taken to Herbarium, Botany department ABU, Zaria for identification. Seven different concentrations of the contaminated soil was prepared into different containers and the lemon grass planted into each of them and watered for a total period of 104 days while the analysis is carry out at an interval of three weeks over the total length period of time. The change in petroleum hydrocarbon concentration with time was monitored while the amount (concentration) of heavy metals taken up by the lemon grass was analysed and recorded. The soil samples (contaminated used engine oil soil) were collected from a motor mechanical workshop in Sabon gari Zaria in polythene bags and transported to chemical engineering department, ABU, Zaria. Also, cow dung (manure) was obtained from the faculty of veterinary medicine ABU, Zaria. Also, eighteen (18) samples bottles and seven (7) plastic containers were obtained. The uncontaminated soil was obtained from ABU stadium while the deionized water was obtained from chemical engineering department using a deionizer machine which was used to water the lemon grass planted on the contaminated soil.

The soil samples (contaminated soil) obtained from motor mechanic workshop was finely grounded using piston and mortar. 2000g (2kg) of the contaminated soil was measured equally into five (5) plastic containers while the same quantity of 1000g (1kg) of cow dung manure was added to each sample to aid the growth of the plant and it was then thoroughly mixed using mechanical stirrer for homogeneity. Also, the same quantity of deionized water was added to each sample to avoid impurity like presence of Iron (Fe), Hydrogen (H) in the soil samples. Likewise, the same size of lemon grass was planted into each sample and monitor for 13weeks.

Fig. 2. Sample of used engine oil contaminated soil obtained from a location in Nigeria.

Similarly, 2000 g (2kg) of uncontaminated soil obtained from ABU stadium was finely grounded while the same quantity of cow dung manure (1000 g) (1kg), deionized water and same size of lemon grass was planted in two containers to serve as a controlled experiment.

Harvesting in triplicate was done by taking the whole lemon grass from the rubber bowl container. Then the roots were washed using running water to eliminate some soil particles. Thereafter, plant elements were washed twice using deionized water to keep away from steel contamination. Afterward, roots, stem and leaves were separated and oven-dried at 80 ^{0}C till consistent weights were attained. Dry weights of roots, stem and leaves was measured for biomass determination. Dried samples of roots, stem, and leaves. Contents of Al, P, Si, Na, K, Mn, Ni, Ti, Pb, Cr, S, Zn, Cd, Mg and Sr were determined by Atomic Absorption

Spectrophotometer (AAS) (Analyst-800, PerkinElmer Inc., Norwalk, CT, USA) after acid digestion (HNO_3 and $HClO_4$) following the technique of Gautam et al. (2017).The preference of metals such as Pb, Ni and Cd is primarily based on their excessive concentrations in contaminated soil before planting lemon grass and probably phytotoxic effects [19].

Fig. 3: Lemon grass cultivated on used engine oil contaminated soil

Figure 2 shows the used engine oil contaminated soil collected for the purpose of the experiment from a location in Nigeria while Figure 3 shows the lemon grass cultivated on used engine oil contaminated soil. The TPH determination for used engine oil contaminated soil samples (A-E) before and after planting the lemon grass was obtained according to the method of [5].

2.1. Computation of Total Petroleum Hydrocarbon (TPH)

The detectable amount of petroleum based hydrocarbon in an environmental media is referred to as TPH. As a result, it is based on a study of the medium in which it is discovered. Environmental sampling and analytical data are specifically linked to TPH. The TPH is calculated using:

$$TPH = \frac{(W1)-(W2)}{(W1)-(W3)} \times 100$$

Where,

W1= weight of bottle + sample (g)
W2= Weight of bottles + dried sample (g)
W3 = weight of bottles (g)

3. Results and Discussion

3.1. Elemental composition of the contaminated soil

Table 1 shows the elemental composition of sample A, as well as their relative quantities in ppm in the motor mechanic workshop soil prior to planting the lemon grass, as determined by XRF analysis.

Table 1. XRF analysis of the elements presents in the contaminated soil before planting the lemon grass.

Element presents	Concentration (ppm)	Element presents	Concentration (ppm)
Na	0.169	Cd	2.248
Mg	0.623	Zn	0.187
Si	61.500	Mn	0.121
Al	13.070	Ti	1.521
Pb	11.071	P	1.537
Ni	4.685	K	0.408
Cr	0.027	S	2.796
Sr	0.036	Cd	2.248

According to the XRF analysis presented in Table 1, Pb, Ni, and Cd, which are the specific elements of interest in this study, were all present in the used engine oil contaminated soil, with lead (Pb) having 11.071ppm, Ni having 4.685ppm, and Cd having 2.248ppm, respectively. The trend of total heavy metal content in used engine oil-contaminated soil before planting was determined, and the sequence of decreasing concentration is shown below:

Si>Al>Pb>Ni>S>Cd>P>Ti> Mg>K>Zn>Na>Mn>Sr>Cr.

The maximum Si is 61.500 ppm, while the lowest Cr is 0.027 ppm. Pb, Ni and Cd were chosen for testing because of their toxicity and negative effects on both humans and the environment. This is comparable to the findings of [11]. The specific concentration is far higher than the regulatory agency's standard concentration, necessitating the treatment using low cost, environmental friendly procedures such as phytoremediation. The amount of heavy metals absorbed by lemongrass at various weeks/days was determined using Atomic Absorption Spectroscopy (AAS) measurement of the used engine oil pollution, as shown in Figures 4 to 6 carried out on three heavy metals to determine the amount absorbed by lemon grass at various weeks/days and the result presented in Figure 4 to 6.

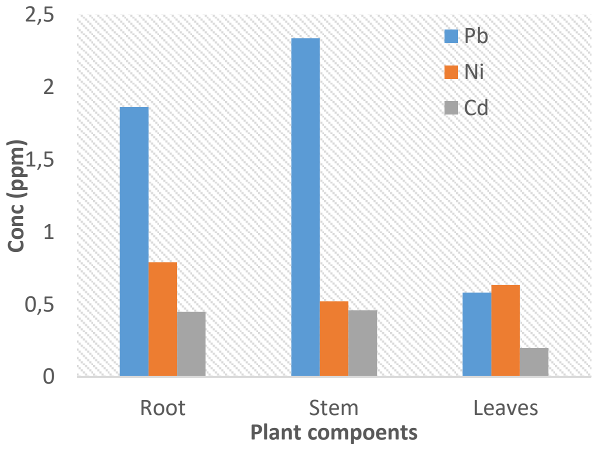

Fig. 4. the concentration (amount) of heavy metals (Pb, Ni and Cd) in lemon grass (root, stem and leaves) after planting at week 7. (52 days).

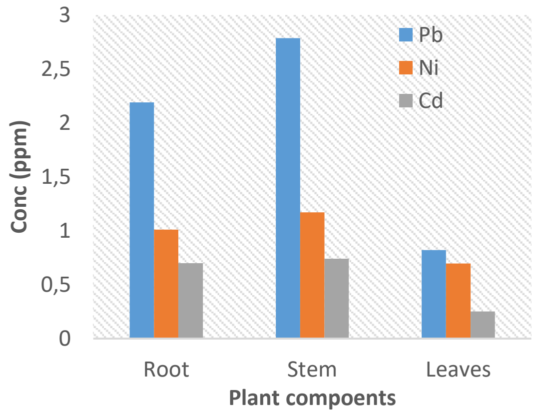

Fig. 5. Amount (ppm) of heavy metal (Pb, Ni and Cd) absorbed (uptake) by lemon grass (Root, Stem and Leaves) at week 10 (72 days) after planting.

Figure 4 shows that Pb and Cd uptake by lemongrass is highest in the stem 2.338ppm and 0.46ppm respectively, while Ni uptake is highest in the root; 0.792 ppm. As a result of the plant absorbing and desorbing the heavy metals (Pb, and Cd) in the stem after 7 weeks (52 days) of growing the lemongrass on the contaminated soil, the stem has the maximum concentration of heavy metals (Pb and Cd). In the case of Ni, the roots adsorbed the heavy metal more than the leaves. As a result, the maximum concentration of heavy metals can be found in the stem, as the plant has already absorbed and deposited it there.

After planting at week 10, the amount of heavy metals (P b, Ni, and Cd) absorbed (uptake) by lemon grass is shown in Figure 5. (72 days). The amount of heavy metals (Pb, Ni and Cd) absorbed by lemongrass via the root, stem and leaves at week 10 (72 days) show comparable trends for all heavy metals, with the greatest concentrations of 2.788, 1.170, and 0.740 ppm for Pb, Ni, and Cd respectively. This was found to be consistent with the report of [13] who carryout similar work in different part of Nigeria. Although at week 10, the concentration of heavy metals uptake via the root, stem and leaf is higher than at week 7, the concentration of heavy metals uptake via the root, stem and leaf is lower. This may be as a result of these heavy metals bioavailability for lemongrass to take-up as the period of cultivation increases, a demonstration that lemongrass is suitable plant for phytoremediation as also reported by Peng et al., (2018) in their work. After planting at week 13 (96 days), the amount of heavy metal (Pb, Ni, and Cd) absorbed by lemongrass is shown in fig. 6.

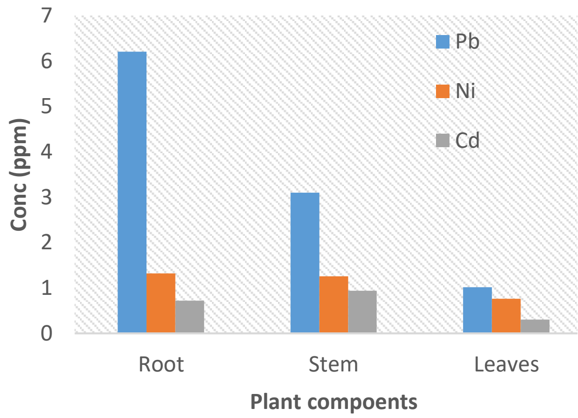

Fig. 6. Concentration of heavy metals (Pb, Ni and Cd) absorbed (uptake) by lemon grass (Root, Stem and Leaves) at week13 (96 days) after planting.

Figure 6 shows that the amount of heavy metals uptake is higher in week 13 than in weeks 7 and 10, indicating that the heavy metals are available for uptake by the lemon grass. Lemon grass had the highest heavy metal lead (Pb) uptake of 6.202 ppm at week 13 (96 days), compared to 1.864 ppm at week 7 and 2.192 ppm at week 10. This indicates that as the period of cultivation increases, the amount of heavy metal uptake. Similar trends were observed for both Ni and Cd as the concentration of these metal increases with period of cultivation. Both Ni and Cd recorded the highest concentration of 1.318 ppm and 0.940 ppm respectively at week 13 compared to week 7 and week 10. Lead (Pb) and Nickel (Ni) have the highest uptake via the root than the stem and leave while Cadmium (Cd) was absorbed more via the stem compared to root and leaves. This result consistent with that obtained by [20].

3.2. For control experiment.

The concentration of these heavy metals (Pb, Ni and Cd) is approximately zero in the control experiment (uncontaminated soil) indicating the absence of heavy metal in the uncontaminated soil. For control experimental set up, the result is shown in Table 2. The summary of concentration of heavy metals uptake via the root, stem and leaves as summarized in Figure 7 to Figure 9. Figure 7 shows the summary of concentration (ppm) of heavy metal (Pb, Ni and Cd) absorbed (uptake) by lemon grass through the root, stem and leaf respectively at various weeks.

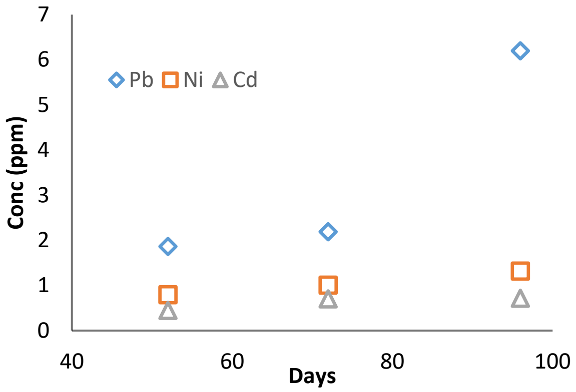

Fig.7. Summary of concentration (ppm) of heavy metal (Pb, Ni and Cd) absorbed (uptake) by lemon grass through the root at various weeks

Initially, from day 1 to 40 days, was the period lemon grass was planted in the contaminated soil and allowed to grow to enable bioaccumulation of these heavy metals and after 50 days, the analysis for bioaccumulation by lemon grass was evaluated. It can be observed that the concentration of these heavy metals (Pb, Ni and Cd) increases as the period of cultivation (planting) of lemon grass increases from 52days to 96 days indicating that lemon grass can be used to remediate used engine oil contaminated soil hence, its show the bio availability of the lemon grass to accumulate the heavy metals.

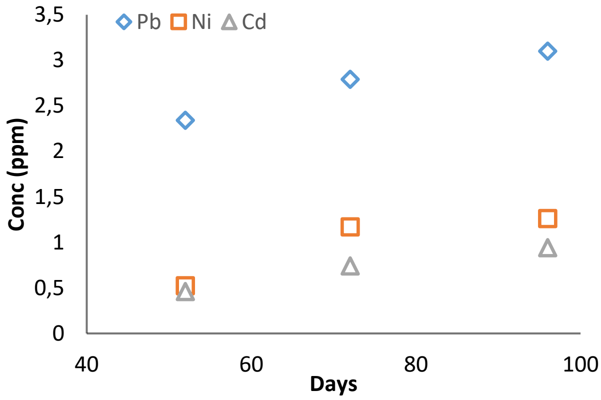

Fig. 8. Concentration (ppm) of heavy metal (Pb, Ni and Cd) absorbed (uptake) by lemon grass through the Stem at various weeks

For lead (Pb) the amount of heavy metal uptake through the root increases from 1.864 pmm at 52days to 6.202 ppm at the end of the experiment. Likewise for Nickel (Ni) and Cadmium (Cd) the concentration increases from 0.792 ppm to 1.318 ppm and 0.45 ppm to 0.72 ppm respectively. As the period of planting lemon grass on contaminated soil increases, the amount of heavy metal uptake by the lemon grass increases indicating that the heavy metals present in the soil is bioavailable for the plant to uptake and that since lemon grass has fibrous root which diluting the concentration of these heavy metals in the soil hence, Pb and Ni are absorbed more via the roots. Fayinminnu and Abimbola [17] observed similar trends in their work where they reported that Pb and Ni are absorbed more via the roots. It can also be observed that after 100 days, the concentration of Pb Ni and Cd may continue to increases indicating lemon grass could effectively remove all the concentrations of heavy metals as the numbers of days increases. This indicates the concentration of heavy metal uptake via the stem of the lemon grass during the various period of cultivations. The concentration of Pb decrease in the stem while that of Ni and Cd increases via the stem. This also conform to the work of [18]. Although there was a general increase in concentration of heavy metals via the stem as the period of planting the lemon on contaminated soil increases from 52days to 96 days.

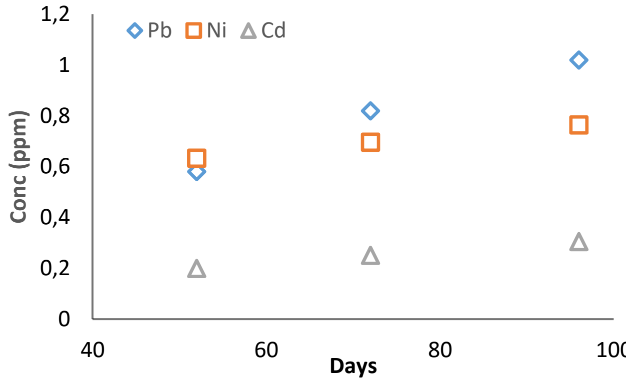

Fig. 9. Concentration (ppm) of heavy metal (Pb, Ni and Cd) absorbed (uptake) by lemon grass through the leaf at various days

Figure 9 illustrate the concentration of heavy metals uptake through the leaves within the various period of experimental investigation. There is a general decrease in the uptake of heavy metals via the leaves compared to that of root and stem. This result is consistent with that obtained by [2] and [5] respectively. It shows a slight increase in the concentration of heavy metal uptake throughout the period of investigation hence, it indicates that heavy metal uptake is more achievable via the root and stem than through the leave.

3.3. Soil total petroleum hydrocarbon (TPH) determination;

TPH is used for any mixture hydrocarbons found in crude oil or petroleum contaminated soil and they represent total volatile petroleum hydrocarbons and extractable petroleum hydrocarbons. This is carried out to quantifying residual TPH as index for assessing a post-phytoremediated contaminated soil. The TPH determination for used engine oil contaminated soil samples (A-E) before and after planting the lemon grass was obtained according to the method of [5] Table 2 shows the TPH of the contaminated soil before and after planting of lemon grass.

Table 2. Total Petroleum Hydrocarbon in the contaminated soil before and after remediation

Time	Samples(A-E) weight	Weight of bottles (g)	Initial weight + sample (g)	Final bottle weight + dried sample (g)	TPH (%)
Before Planting	2000	19.000	21.000	19.015	99.3
After planting	2000	19.001	21.049	20.410	31.20

The TPH was calculated to assess the post-phytoremediation ability of lemon grass in the contaminated soil. As it can be seen in Table 2, the TPH was calculated prior before planting of lemon grass which is 99 % indicating that the soil contained high amount of hydrocarbons. However, after 96 days of phytoremediation using lemon grass, the TPH was drastically reduced to about 31 g/Kg showing that lemon grass can be a suitable phytoremediation plants since it's reduced the TPH from 99 % to 31 %.

4. Conclusion

Lemon grass remove significant amount of heavy metals (Pb, Ni and Cd) from the used engine oil contaminated soil after it was planted for a period of 13 weeks (96days) from 11.071 ppm to 0.61 ppm for Pb, 4.685 ppm to 1.565 ppm for Ni and 2.248 ppm to 0.378 ppm for Cd respectively. Hence lemon grass is suitable for phytoremediation dues to its ability for hyper-cumulative of these heavy metals which are bioavailable for uptake. The percentage removal of heavy metals from the used engine oil contamination soil is 95% for lead (Pb), 67 % for Nickel (Ni) and 83 % for Cadmium (Cd) respectively. The lemon grass absorbed (uptake) higher amount of these heavy metals through the root for lead (Pb) and nickel (Ni) than through the stem and leaf while Cadmium is absorbed more through the stem as compared to through the root and leave. Also as the period of planting the lemon grass increases, the concentration of the heavy metals (Pb, Ni and Cd) uptake increases significantly indicating that lemon grass is suitable for phytoremediation due to its fibrous root that expand during growth thereby removing more of the concentration of the heavy metal presence in the contaminated soil. Finally, there was a decrease in total petroleum hydrocarbon (TPH) of the contaminated soil from 99.3 % to 31.20 % before and after planting respectively hence lemon grass can potentially be used as a substitute for remediation of contaminated soil. Thus Phytoremediation is a promising and sustainable method for reclaiming soils contaminated with these toxic metals.

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Declarations

Conflict of interest: The authors declare no competing interests.

References

[1] J. Tang, Y. Liao, Z. Yang, L. Chai, W. Yang, "Characterization of arsenic serious contaminated soils from Shimen realgar mine area, the Asian largest realgar deposit in China", J Soils Sediments. 16(5):1519–1528, 2016. DOI: 10.1007/s11368-015-1345-6.

[2] L. Chai, H. Li, Z. Yang, X. Min, Q. Liao, Y. Liu, S. Men, Y. Yan, J. Xu, "Heavy metals and metalloids in the surface sediments of the Xiangjiang River, Hunan, China: Distribution, contamination, and ecological risk assessment", Environ Sci Pollut Res. 24, 1, 874885, 2017, DOI:10.1007/s11356-016-7872-x.

[3] Y. Liu, Z. Guo, X. Xiao, S. Wang, Z. Jiang, P. Zeng, "Phytostabilisation potential of giant reed for metals contaminated soil modified with complex organic fertiliser and fly ash: A field experiment", Sci Total Environ. 576:292–302,2017, DOI: 10.1016/j.scitotenv.2016.10.065.

[4] S. Xue, L. Shi, C. Wu, H. Wu, Y. Qin, W. Pan, W. Hartley, M. Cui, "Cadmium, lead, and arsenic contamination in paddy soils of a mining area and their exposure effects on human HEPG2 and keratinocyte cell-lines", Environ Res. 156:23–30. 2017, DOI:10.1016/j.envres.2017.03.014.

[5] M.A. Amusat, K. C. Eneh, and F.A. Mohammed, "Safety Evaluation of Oil Polluted Soil by Phytoremediation", International Journal of Environmental Sciences. Vol. 5 No. 1. 2016. Pp. 52-57.2016

[6] B. Huang, Z. Guo, W. Tu, C. Peng, X. Xiao, P. Zeng, Y. Liu, M. Wang, J. Xiong, "Geochemistry and ecological risk of metal (loid)s in overbank sediments near an abandoned lead/zinc mine in Central South China", Environ Earth Sci. 77(3):68. 2018. DOI:10.1007/s12665-018-7249-1.

[7] G. Meenu, D. Pandey and M. Agrawal, "Phytoremediation of metals using lemongrass (Cymbopogon citratus (D.C.) Staff.) grown under different levels of red mud in soil amended with bio wastes", International Journal of Phytoremediation, 19:6, 555-562,2017, DOI: 10.1080/15226514.2016.1267701

[8] Y. Liu, L. Lin, Q. Jin, X. Zhu, "Cadmium accumulation and tolerance in the Cd-accumulator Capsella bursa-

pastoris", Environ Prog Sustainable Energy. 34(3):663–668, 2015, DOI:10.1002/ep.12037.

[9] L. Wang, B. Ji, Y. Hu, R. Liu, W. Sun, "A review on in situ phytoremediation of mine tailings", Chemosphere. 184:594–600.2017, Doi: 10.1016/ j.chemosphere.2017.06.025.

10] P. Zeng, Z. Guo, X. Xiao, X. Cao and C. Peng, "Response to cadmium and phytostabilization potential of Platycladus orientalis in contaminated soil", International Journal of Phytoremediation, 20:13, 1337-1345, 2018. DOI:10.1080/15226514.2018.1501338

[11] S.O. Olajuyigbe, O. O. Fayinminnu, A. O. Ayoade, "Phytoremediation of diesel and spent engine oil contaminated soil using Kariya (Hildergardia barteri Mast.) seedlings Nig", J. Biotech. Vol. 36 (2): 139 –149, 2019 DOI: https://dx.doi.org/10.4314/njb.v36i2.14

[12] O. D. Idowu, and O. O. Fayinminnu, "Phytotoxicity Effect of Spent Oil on Jatropha curcas Seedlings used in Soil Phytoremediation", Ethiopian J. Env. Stud. Mgt. 8 (2): 906 – 915, 2015

[13] J. A. Onwugbuta-Enyi and B. A. Onuegbu, "Remediation of dredge spoils with organic soil amendments using Paspalum vaginata L. As a test crop", Adv. Environ. Biol. 2(3):121-123, 2008

[14] L. F. Zitte, G. D. B. AWaadu, C. G. Okorodike, "Used-Oil Generation and Its Disposal along East-West Road, Port Harcourt Nigeria", Int. J Waste Resource 6: 195, 2016 DOI: 10.4172/2252-5211.1000195

[15] Z. Luo, J. He, A. Polle, H. Rennenberg, "Heavy metal accumulation and signal transduction in herbaceous and woody plants: Paving the way for enhancing phytoremediation efficiency", Biotechnol Adv.34 (6):1131–148.2016, DOI:10.1016/j.biotechadv.2016.07.003.

[16] P. Schwab, M. K. Banks, W. A. Kyle, "Heritability of phytoremediation potential for the alfalfa cultivar Riley in petroleum contaminated soil", Water, Air, Soil Pollut. 177:239-249, 2006

[17] O. O. Fayinminnu, and M. O. Abimbola, "Assessment of Heavy Metals and Total Petroleum Hydrocarbons Accumulation in Tomato (Solanum lycopersicon L.) Grown on Spent Oil Polluted Soil. Nigerian", J. Ecol. 15 (2):19-29. 2016

[18] S. O. Olajuyigbe, and T. O. Sijuola, "Phytoextraction of Heavy Metals from Diesel Oil Contaminated Soil using Terminalia ivorensis", A. Chev. Seedlings. Ibadan J. Agric. Res., 11 (2): 63-72, 2015.

[19] L. A. Fontem and D. Chikoye, "The potential of kyllingaerecta Schumach and Cyperus rotundus Linn to remediate soil contaminated with heavy metals from used engine oil in Cameroon", International Journal of Phytoremediation, 20:13, 1346-1353, 2018 DOI: 10.1080/15226514.2018.1501339.

[20] A. P. Aloysius, S. Rufus and O. O. John, "Evaluation of heavy metals in soils around auto mechanic workshop clusters in Gboko and Makurdi, Central Nigeria", Environ. Chem. Ecotoxicology, 2013. DOI:10.5897/JECE2013.0295.