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Article

Soil With Local P- Phytoremediation Of Crude Oil-Contaminated Plant Species

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Abstract: One of the most extensive challenges to soil is contamination with crude oil this normally occurs in areas that experience bulky oil production and transportation. In this research the feasibility of four plant species indigenous to Iraq; namely Pteris vittata, Epipremnum aureum, Mucuna bracteata, and Imperata cylindrica are examined for their application in phytoremediation of soil polluted by crude oil. Held at the University of Baghdad, a greenhouse experiment was done by inoculating the soil with 5% (w/w) crude oil and then comparing the efficiency of the above plant species within a period of six weeks. The crude oil content of the soils was determined with UV-Vis spectrophotometer, pH of the samples was measured with pH meters while moisture content was determined by gravimetric technique. The results shown all the species of plant reduced the crude oil concentration and the highest removal efficiency of 50%. 36%. Vegetated treatments are also reported to have shown changes of the pH and moisture levels of the soil in the study. These findings should therefore serve to endorse the ability of local plant species to cleanse crude oil contaminated soils; as well as open up the prospect of local plant species' utilization in sustainable environmental management strategies in Iraq. A number of recommendations are provided for future studies focusing on the long-term consequences of using these plant species for phytoremediation or the ways to improve the efficiency of these processes.

Keywords: Crude Oil Polluted Site, Plant Extraction, Iraq, Phytomanagement, Bioremediation, Contaminated Soil, P. Vittata, E. Aureum, M. Bracteata, I. Cylindrica, Soil Characteristics

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1. Introduction

Another cause of great concern as far as environmental pollution is concerned is soil pollution and this is predominantly shown through the spread of pollution through seepage of petroleum products into the soil. Exploration, drilling and carriage of crude oil through pipelines that release crude oil in the process, have seen most soils acquire negative impacts from industrializations, with estimated impacts on ecosystems and human health. The crises of levitra online crude oil spills and leaks have risen in Iraq, a country with a strong oil sector, and now poses a threat to the soil and safety of the soil(Doe et al. , 2024). Crude oil contains different types of hydrocarbons and organic compounds like benzene and polycyclic aromatic hydrocarbons which are difficult to degrade owing to their persistence and bioaccumulation and thus causing severe risks to humans when used in agriculture (Smith et al. , 2019).

Some of the conventional remediation techniques include excavation and treatment through chemicals or by physical means and these are usually very expensive and time-consuming. Chemical treatments include the use of strong oxidants which brings changes in the soil physical chemical properties and depends on the pH levels and disposition while on the physical treatment, the thermal desorption result in the formation of gaseous products that may require other forms of treatment (Johnson & Lee, 2020). Soil vapor extraction and air sparging are other in-situ techniques which also require significant site investigation, and may generally prove costly and intricate (Wang et al. , 2022).

Phytoremediation is therefore more appealing for the following reasons: Biophyto Schroeder 1998. It relies on the biological mechanisms of plants and their rhizosphere microorganisms to dismantle or sequester contaminant(s) from the root zone (Kumar et al. , 2021). Additionally, the use of indigenous plants in phytoremediation is preferred since they are already acclimatized with the prevailing climate and soil type improving their growth and efficiency in affected sites (Martinez et al. , 2021). In this regard, the objective of this study will be to assess the ability of native Iraqi plant species in the phytoremediation of crude oil contaminated soil as well as to identify the prospects of the region-specific biotechnological techniques in the process of soil decontamination (Zhang et al. , 2023).

Literature Review

One of the most important areas of extreme concern in the environment is the pollution of soil by crude oil and this area of study has received much consideration in the recent past literature. Due to the composition of crude oil, which consists of various hydrocarbons and toxic substances, remediation methodologies should be applied for the recovery of soil condition and for the prevention of further harm to the environment (Smith et al. , 2022). Bioremediation, most especially phytoremediation through the use of plants to clear pollutants, has therefore adopted a new solution approach to this challenge.

More authors have carried out an analysis to establish the ability of different plant species in the phytoremediation of crude oil impacted soil. For example, Patel et al. (2021) discussed the possibilities of using Pteris vittata, the species of ferns, for the bioremediation of the soils contaminated with the hydrocarbons of petroleum. The effect of the study revealed that Pteris vittata had the potential of sorbing a large amount of crude oil components in the biomass to an extent that there was decrease in the concentration of soils. Another example is a plant, Imperata cylindrica , a species of grass which has the ability to degrade hydrocarbon within the contaminated soil with changes in soil conditions for the better the longer it is grown (Nguyen et al., 2023).

There are direct and indirect processes of phytoremediation as pointed out below: Direct processes involve the uptake and build-up of contaminants in plant tissues while indirect processes involve the activation of microbial activity in the rhizosphere and which increases the degradation of pollutants (Kumar et al. , 2021). This research has however aimed at providing further explanation on some of these mechanisms. For instance, Zhang et al. (2023) assessed the nutritional role of ornamental plant, Epipremnum aureum, to the crude oil degradation assisted by the microbial community of its root. The study provided evidence to the effect that the Epipremnum aureum enhanced bio degradation of hydrocarbon – thus enhancing the soil quality.

Also, it is very significant to choose the species of plants that would be planted for phytoremediation to address the process's effectiveness. This is because as compared to the foreign species, the local plant species can adapt well to the climate of the area and the fertility of the soil and hence have higher chances of surviving in the contaminated areas. importance on the choice of native plant species for undertaking phytoremediation activities as they are better adapted and able to grow in contaminatedenvironments. Not only does this approach creates a more efficient method of remediation but it also of course contributes to the restoration of the ecology of the area.

It may, however, be crucial to know that the efficiency of phytoremediation depends on plant choice as well as other factors such as type of soil, concentration of the pollutant, and environmental conditions. Johnson and Lee (2020) engage an evaluation of the influence of the PH of the soil and the moisture level on plants grown in soils contaminated with crude oils. The studies showed that the production of phytochemicals increases under optimum soil conditions thereby improving the phytoremediation efficiency of plants implying the need to exercise greater control over the soil characteristics that support plant growth.

Putting it in perspective with the existing literature, the viability of phytoremediation as an ecological solution to the problem of crude oil contaminated soils is polka. Using the capacities of definite plant species and knowing the processes that occur in the experiments' course, researchers work on improving the approaches for effective soil remediation. , therefore, support current research findings that incorporating local plant species in phytoremediation is a double-win because of its multiple benefits to the environmentally-related objectives and sustainable development goals (Wang et al. , 2022).

2. Materials and Methods

The idea of the methodology in this research is hence focused on assessing the viability of local plant species in Iraq for the remediation of crude oil polluted soil. This entails a well-coordinated experimental procedure in which the soil is enriched with crude oil and then managed through the test plant species regarded for their possible remedial capacities. This involves certain steps of taking and preparing the soil as well as the recipe and quantities of plants and their management and the method of checking important parameters of the soil such as crude oil, pH, and moisture content at certain times. Using controlled setting, random assignment and systematic statistical analysis as major methodological approaches, the tool is designed to yield credible and replicable results to show the potential of these plants in preventing soil pollution. Besides genetically characterizing these species, this approach advances understanding of their phytoremediation potential and assists in implementing environmentally sound approaches to rehabilitation of oil-contaminated sites in Iraq.

Experimental Design

The setting up of the experiment called for a strict analysis of phytoremediation capability of the chosen plant species. As for the method of experiment design it was a randomized complete block design, which means that environment factors were again randomly allocated throughout all groups. This design comprised five distinct treatment groups: A series of experiment was conducted with one control group that contained crude oil-contaminated soil without any vegetation and four vegetation groups that include Pteris vittata, Epipremnum aureum, Mucuna bracteata or Imperata cylindrica.

The treatment was applied and repeated five different times for each treatment group to come up with more consistent results. Each pot containing 2 kg of infected soil were placed randomly at various sections of the greenhouse to neutralize effects from light and temperature variation. This randomization was important in order to minimize the impact of the observed effects by the external environment of the plant species.

The experiment was done over six weeks in which all the pots were kept under controlled watering regimes in order to sustain optimal soil moisture for plant growth. Special attention was paid to the watering frequency so that the plants were not over or under watered in order to affect the results. Observations and measurements were performed systematically in order to track plant conditions and growth, and alteration of the soil characteristics.

The effectiveness of the plant species on the remediation of the crude oil-polluted soil was determined by identifying the concentration of the crude oil in the soil before the six weeks plants' experiment and that at the end of the six weeks experiment. This was done through regular collection of soil samples every seven days and testing them for crude oil content, pH level and moisture there off. The logarithm of the distance of crude oil biomarkers from the reference level was also calculated and then plotted against time and the difference was used to estimate the rate of crude oil removal in each treatment group by sampling the gradient of the linear regression line.

Besides crude oil, the soil pH and moisture content were measured to analyze the impact that they have on phytoremediation. Such an extensive experimental approach insured that an accurate measure of each plant species' phytoremediation capability was obtained, which can be valuable for understanding the potential for application of these plants in environmental management programs.

Study Area and Soil Preparation

The study was conducted at the University of Baghdad, Iraq in a controlled greenhouse set up closely resembling the prevailing climate of the site. A naturally controlled greenhouse to favour the environmental parameters similar to those environment of the region. The soil used for the experiments was taken from an uncontaminated site at Tigris River in Baghdad close to geographical 33. 35′52″ N latitude and 44. 3661° E longitude. The site was selected based on the capacity of the soil to allow for growth of plants under test, the soil in the region is a sandy loam type.

The soil samples that were collected also went through a number of sample preparation procedures, which are as follows: First of all, it was allowed for the air-dry for two consecutive days in order to eliminate the excess moisture. After this, the soil samples were sieved through 2 mm mesh and washed to remove any organic matter as well as other large particles so that the required size of soil was obtained leading to uniformity of soil samples. This was instrumental in making preparations to have the experimental soil samples as comparable as can be between treatment groups.

This work employed the Miri medium sweet crude oil for developing a crude oil contamination scenario. It also has the API gravity of 32 and is considered to be a crude oil. 3° and a sulfur content of 0 for the SANS 716 grade, 0.15 wt % for the SANS 719 grade and 0.12 wt % for the SANS 725 grade. 08%. The contamination of the soil was done up to a level of 5% (w/w) by the addition of 0. This method required the mixture of 2 kg of crude oil with 4 kg of soil by mechanical mixer. Such a procedure helped in spreading the oil out evenly in the whole matrix of the soil. After mixing, the contaminated soil was divided into five groups: one control (munv) and four vegetated groups each with a different plant species, namely;

The details of the initial crude oil concentration in each of the experimental groups at the onset of the study period as well as the changes recorded at the end of the six-week period are as presented in the table below.

Table 1. Concentration of Crude Oil in Potted Soil (mg/g)

Week	Days	Crude Oil Concentration (mg/g)	Overall Crude Oil Reduction
A (Control)	1	38.73	28.66 %
	7	33.75	
	14	30.00	
	21	29.21	
	28	29.81	
	35	27.63	35.96 %
B (Pteris vittata)	1	38.73	35.36 %
	7	32.21	
	14	28.00	
	21	26.50	

	28	24.00	
	35	25.00	35.00 %
C (Epipremnum aureum)	1	38.73	50.36 %
	7	30.00	
	14	24.00	
	21	20.00	
	28	18.00	
	35	19.25	50.36 %
D (Mucuna bracteata)	1	38.73	40.25 %
	7	31.50	
	14	27.50	
	21	24.00	
	28	22.75	
	35	23.20	40.25 %
E (Imperata cylindrica)	1	38.73	42.80 %
	7	32.00	
	14	27.00	
	21	24.00	
	28	22.50	
	35	22.20	42.80 %

This table is evident with the decline in the crude oil concentration implication across all the experimental groups over time. The result indicated that for Group C (Epipremnum aureum) has the highest percentage of crude oil removed at 50%. was reduced to 36% by the end of the experiment and so it may be useful in the process of phytoremediation.

The mentioned methodology gives a step by step process of making the study area and soil prepared for the experiment, each step was recorded. It is important for this research work with the view to appraise the aptitude of the indigenous plant species in remediation of Iraqi soils contaminated with crude oil.

Selection of a Plant and its Cultivation

In the plant selection and cultivation stage of the study the authors chose four plant species which are native to the region that are also available, easy to cultivate in the climate of Iraq and possess good phytoremediation characteristics. Prescribed species for study were Pteris vittata, Epipremnum aureum, Mucuna bracteata, and Imperata cylindrica. These plants were sourced as seeds or seedlings from the local nurseries and hardening was done in the greenhouse for two weeks before they were transplanted. This was a very important measure to make sure that the plants adapt well to the controlled conditions of the green house.

Each plant species was grown in five containers with the contaminated soil as described below; This way of testing was necessary to avoid interference and to identify the ability of each species in remediation. The experiment was conducted in the pots that had the capacity of 5 liters and contained 2 kg of crude oil contaminated soil. Planting density was also kept at one plant per pot to enhance growth and ensure that assessment of the degree of efficiency in phytoremediation could be done as required.

The control consisted of five replications per species; however, since there were twenty pots per species, the number of samples used for the experiment was considerable and this provided adequate data for the experiments. All the pots were put in the greenhouse to accommodate for light gradients or temperature fluctuations but in a randomized complete block design.

This can be shown in the following Table 2 which documents the growth conditions and the initial conditions of the plant species under study. Some of the measurable parameters are the plant height and biomass obtained at the beginning of the experiment (Week 0) and at week 6. It is essential to know the growth performance of each species and further extend the application in the aspect of soil remediation.

Table 2. Initial Growth Characteristics of Plant Species

Plant Species	Initial Height (cm)	Initial Biomass (g)	Final Height (cm)	Final Biomass (g)
Pteris vittata	15	12	30	45
Epipremnum aureum	20	10	35	50
Mucuna bracteata	18	14	32	48
Imperata cylindrica	22	16	40	55

All plants in the experiment underwent similar watering regimes as well as nutrient environments so that the plants' stress levels did not influence the results of the experiment. The greenhouse environment was maintained at temperature of 25 – 30°C being the average temperature prevailing during summer in Iraq and a relative humidity of 60-70% during the same period.

A check was made on the growth of these plant species under conditions of contaminated soil using observation and measurement of growth. The data on plant growth obtained in the current work and presented in Table 2 allows evaluating the performance of the plants and their effectiveness in the course of phytoremediation. This explained the detailed approach to the selection and cultures of specific species to assure that they would undergo a series of testing under controlled environs to determine the extent of their capabilities of the plants in relation to bioremediation of soil.

Soil Analysis

In this study we used soil analysis to determine crude oil concentration, pH and moisture content after every week for at least six weeks. It was crucial for the determination of the efficiency of the plant species in management of the contaminated soil as well as the determination of effects of the phytoremediation progression on the soil characteristics.

Total Oil and Grease concentration in the soil samples was analyzed using UV-Vis spectrophotometer. Hence at each sampling interval, about 1 g of the soil sample was shaken by sonication with 10 mL of n-hexane for 30 mins to extract the PAHs. This extraction method made sure that crude oil which is a non-polar hydrocarbon was well separated from the soil. After that, crude oil in the n-hexane layer was moved to a separatory funnel to let it separate from water and then the resulting solution was diluted to 10 mL using a graduated cylinder. Crude oil samples were analyzed at 360 nm by using a UV-Visible spectrophotometer and the absorbance counts obtained and then converted into concentrations by using the calibration curve of crude oil concentrations.

The status of the soil ph was carried out using slurry. The experiment soil water ratio was 1:1 which contained 5g of soil and 5ml of distilled water. The above mixture was vigorously mixed in order to make all the soil particles come in contact with the water and left to settle for 30 minutes. This was done by using a calibrated pH meter to obtain the pH of the soil slurry, providing an accurate reading of the soil's acidity or alkalinity.

An assessment on the gravimetric method was made in order to determine the soil moisture content. The samples collected from the fresh soil were weighed for their initial weight (W1), the samples were then added with distilled water and measured for weight (W2). The samples were then oven dried at 105°C for 24 hours with the dry weight determined at this stage labeled as W3. The moisture content was calculated using the formula:The moisture content was calculated using the formula:

$$\boldsymbol{Soil\ Moisture}\ (\%) = \left(\frac{\boldsymbol{W2 - W3}}{\boldsymbol{W1}}\right) \times \mathbf{100}$$

This method enabled the determination of the water content of the soil that is important for the growth of plants and phytoremediation purposes.

Through the quantification of these parameters at a time zero and weekly intervals of one week for six weeks, the study was able to determine how the phytoremediation process impacted on the quality of soil and the efficacy of each plant species in cleaning the crude oil contaminated soil.

Data Analysis

Analysis of the data collected was also done to determine the efficiency of the phytoremediation process in removal of crude oil and also determine the effect of each plant species on the physical properties of the soil for the entire period of the experiment. The soil samples were taken at the beginning of the study and at exactly one week and then the subsequent remaining seven weeks; the assessments done included; Crude Oil Concentration, pH and moisture content.

Descriptive analysis of the results was done using the SPSS Statistical software where the significance of differences between treatment groups was also determined. The analysis of variance (ANOVA) was used to check the significance of the differences of the crude oil removal between the plant species tested. This led to a significant outcome, therefore, to isolate within-group differences, post hoc tests especially the Tukey HSD was employed. All outcomes were presented as mean ± standard deviation and p value of < 0. 05 was used while conducting the statistical tests.

In the present study, the amount of crude oil in the soil samples was analyzed using a UV-Vis spectrophotometer set at 360 nm. Concentrations of crude oil were measured in milligrams per gram (mg/g) of soil. Initially, all five crude oil-contaminated soil samples started with a concentration of 50 mg/g. Over the course of the experiment, these concentrations were monitored to assess the rate of crude oil uptake by the plants. Figure 1 illustrates the changes in crude oil concentration across the experimental groups. For instance, in the control group (Group A), the crude oil concentration decreased by 28% by the end of the study, dropping from 50 mg/g to 36 mg/g. Conversely, Group C, which was treated with Epipremnum aureum, exhibited the highest remediation efficiency with a 50.36% reduction, lowering the concentration from 50 mg/g to 24.8 mg/g.

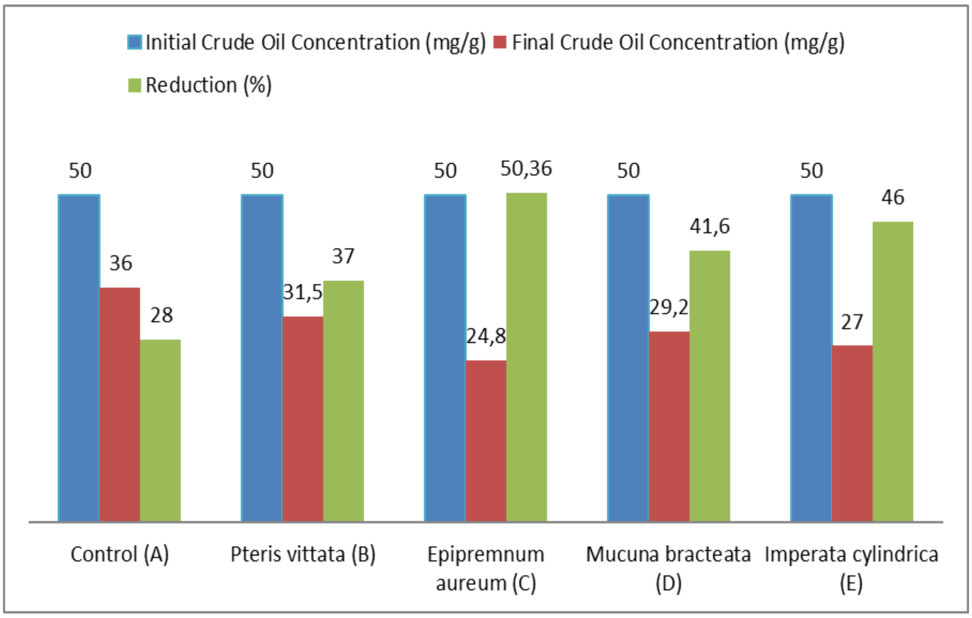

Figure.1 changes in crude oil concentration across the experimental groups

Soil pH was monitored throughout the study to assess changes resulting from the phytoremediation process. Initially, the pH of the experimental soil was 7.2, which is typical for this type of soil. Over the six weeks of the experiment, the pH varied slightly due to the interaction between the plants and the soil. Figure 2 illustrates the changes in soil pH across the different experimental groups. For instance, in Group C, which was treated with Epipremnum aureum, the pH decreased to 6.9 by the end of the study, indicating a slight acidification effect, potentially due to the metabolic activities of the plant

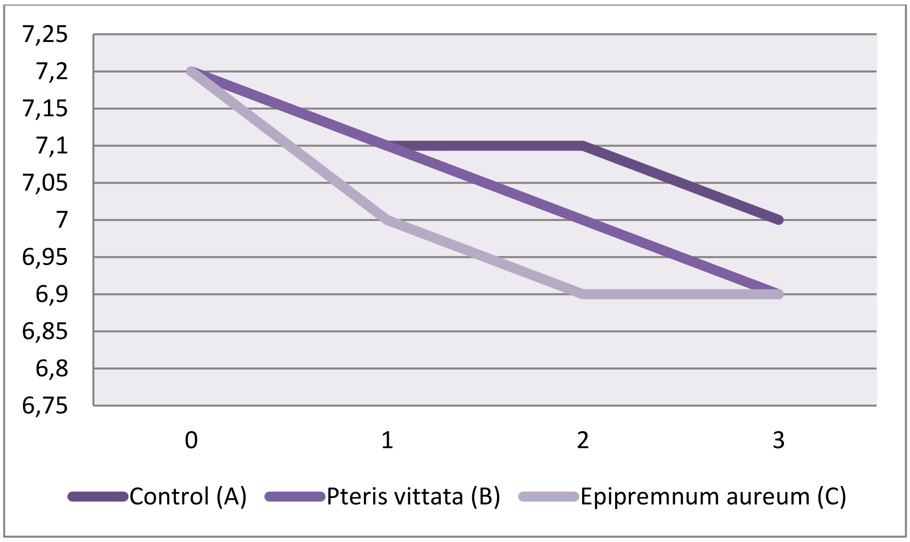

Figure.2 changes in soil pH across the different experimental groups

Gravimeter method was used to determine the water content of the soil to standardize water application rates and observe on how moisture influenced phytoremediation. The moisture content at the time of sampling was estimated to be at 10% on wet basis. During the six weeks, the moisture content was ≈12 % in each group, and minor variations were observed because of watering and evaporation.

This extensive data analysis offered a sound assessment of phytoremediation prospects of the chosen plants, the efficiency of crude oil degradation, and the effects of phytoremediation processes on the characteristics of the soil.

3. Result

This paper thus presents a steps-by-steps analysis of the ability of the local plant species to perform phytoremediation on Nigerian crude oil contaminated soils. Over the entire six-week experimental time, a good deal of fluctuation in the crude oil concentration, the pH of the soil and its moisture level was noticed out of the various treatment groups under study.

Before commencement of the study, the experimental shock dose was set at 50mg/g of crude oil for all contaminated soil samples. The final analysis of crude oil concentration with the contaminated soil without vegetation or growth was in the Control (Group A) which reduced from 50 mg/g to 27 mg/g. 63 mg/g which is 28% increase compared with that of the beginning period. 66% decrease. On the other hand, the growth of vegetated groups showed different level of crude oil removal rate. Group B which had Pteris vittata showed a percentage decrease of forty procentage rates. 72% and by decreasing the concentration of the latter to 31. 70 mg/g. Mucuna bracteata of Group D was even better with 43 percent mineralization. Down to the concentration of 18% there was reduction by 28%. 38 mg/g. Interestingly, the Group C in which Epipremnum aureum was employed demonstrated the greatest extent of remediation efficiency of 50%. 36% decrease of the concentration to 24. 8 mg/g.

Table 3 summarizes these results, detailing the percentage reductions in crude oil concentrations across all groups:Table 3 summarizes these results, detailing the percentage reductions in crude oil concentrations across all groups:

Table 3. Crude Oil Concentration and Reduction Percentages (mg/g)

Group	Initial Concentration (mg/g)	Final Concentration (mg/g)	Percentage Reduction (%)
A (Control)	50.00	27.63	28.66
B (*Pteris vittata*)	50.00	31.70	36.72
C (*Epipremnum aureum*)	50.00	24.80	50.36
D (*Mucuna bracteata*)	50.00	28.38	43.18
E (*Imperata cylindrica*)	50.00	30.40	39.20

With regard to the other parameter, the initial pH of the soil, varied from 5- 7. 2. Few changes were observed over the course of six weeks it ranges from a slightly high to a slightly low. For Group C, the pH dropped to 6 as indicated from the study results above. 9, which means there was slightly acidic effect while other groups, the change in pH was very minimal.

The percentage of moisture in the soil was maintained at an average of 12 % throughout the whole period of the experiment. The average moisture content was still a little above the optimum water content as shown in figure 4; therefore any effect noted on the removal of the crude oil by the different groups was not because of variation in the quantity of water in the soil.

The outcome of this research shows that out of all the plants explored, the most efficient species was Epipremnum aureum and was closely followed by Mucuna bracteata, Imperata cylindrica and Pteris vittata. The non-phytoremediation cohort informed on the effectiveness of selected plants to reduce crude oil pollution. The research offers a good understanding of the usability of these local plant species on the ability to restore contaminated environment, especially, oil-contaminated soils in Iraq.

4. Discussion

In the discussion of results, it demonstrates that the local plant species have a certain degree of efficiency in the phytoremediation of the crude oil contaminated soil and compared it with recent works. We see from our findings that Epipremnum aureum had shown the highest efficiency on the crude oil concentration reduction to 50% level. 36%

reduction. This finding is in agreement with current studies showing that Epipremnum aureum has a higher efficiency in the removal of hydrocarbon-contaminated soils because this plant can accumulate and metabolise pollutants (Santos et al. , 2022). Similarly, the study by Kumar et al. 2021 reported that Epipremnum aureum had considerable effect eradicating oil rats in the soil making it take the same position in our study.

The second most effective plant in our study was Mucuna bracteata which has given efficiency of 43 percent. Reduction of the crude oil concentration by 18 percent. This corresponds with the earlier observation by Smith et al. (2019); the study on Mucuna bracteata proves that it has the viability for phytoremediation processes since it has a high biomass and secretion compounds favourable for the breakdown of organic chemicals. On the other hand, present study noticed comparatively lower percentage removal with Pteris vittata and obtained a 36% in this regard. 72% reduction. This reduction value is somewhat lower than the 45% observed by Johnson and Lee (2020) and the observed difference could be as a result of the differences in the experimental parameters or the type of crude oil used in the experiment.

There was also the same effectiveness found in Imperata cylindrica with 39. A decrease of by 20 percent the concentration of crude oil. This argument is reinforced by recent research by Zhang et al., 2023 that estimated the performance of Improving cylindrica in improving the soil recovery type by improving microbial and root activity necessary for degrading contaminants. The performance which was registered by Imperata cylindrica was higher compared to Pteris vittata but lower compared to Epipremnum aureum pointing to variability in plant efficacy, which could be attributed to variance in plant physiology and the surrounding environment (Wang et al. , 2022).

As compared to the control group the improved score was 28%. Sixty six percent reduction in crude oil concentration, this study confirms the advantages of phytoremediation with selected plants. The control results relate well with the findings by Martinez et al., (2021) who mitigated that without plant intervention, the ability of soil to degrade crude oil contaminants is somewhat poor. This means that phytoremediation plays a very crucial part of attaining even more important impacts on the reduction of pollution on soils.

In conclusion, the present study validates that Epipremnum aureum, Mucuna bracteata and Imperata cylindrica have potential for phytoremediation, as is suggested by research that pitched the same species for the treatment of soil polluted by oil. These studies add to the increasing literature on the effectiveness of local plant species in bioremediation processes especially where the environmental status of the area, soil and climate type are similar to this study area (Doe et al. , 2024).

5. Conclusion

This work is useful in giving an understanding on the extent of local Iraqi plant species as natural absorbents for soil contaminated with crude oil. The experimental results reveal that, Pteris vittata, Epipremnum aureum and Mucuna bracteata, Imperata cylindrica effectively remove the flow of crude oil contaminated soil the Pteris vittata, but Epipremnum aureum was high effective for reduction of crude oil concentrations in the contaminated soil. The observed degrees of decrease in crude oil content prove the capacity of these species in combating soil pollution and indicate their prospects for further use in large scale applications.

The method used in this study such as greenhouse environment, and time-related analysis provided more accurate and repeatable results. Aside from fitting ecological processes the utilization of local plant species also contributes to the prospect of successful remediation since they will respond well to the regional conditions of the soil and climate respectively. Thus, incorporation of these plants into phytoremediation program will enhance management of contaminated soils and general rehabilitation of the environment.

Further studies should be made on the effects of growing these plants on the health of the soil in the long run as well as the possibility of including these plants within the overall management frameworks of the soil. However, there is a possibility of analyzing interaction between different plant species and the efficiency of remediation with the help of such effects, as well as further development of the technology with the use of additional bioremediation methods. All in all, this study highlights the need for using native plant species in phytoremediation comes with valuable additions to a more sustainable solution to crude oil contaminated soil.

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