Libyan Journal of Ecological & Environmental Sciences and Technology
(LJEEST)
LJEEST
ISSN: 2710-5237
www.srcest.org.ly/jou

DOI: https://doi.org/10.63359/zeg90602

Phytoremediation of Petroleum Hydrocarbons-Contaminated Soil using *Haloxylon salicornicum*

Janaen Ya'rub Al-Saeedi

ARTICLE INFO

Vol. 8 No. 2 Agusts, 2026

Pages (122-129)

Article history:
Revised form 16 July. 2026
Accepted 06 August 2026

Authors affiliation
Department of Biology, College of Science, University of Basrah, Iraq
Email: janaen.yarub@uobasrah.edu.iq

Keywords:
Contaminated soil, Phytoremediation, Haloxylon salicornicum, Hydrocarbon degradation.

ABSTRACT

One of the serious environmental issues affecting soil quality, plant growth, and ecosystem stability in areas near oil refineries or oil fields is petroleum hydrocarbon contamination. Phytoremediation is an environmentally friendly approach for restoring contaminated soils. In this work, Haloxylon salicornicum was used to remediate crude oil-contaminated soil and to investigate changes in soil physicochemical properties during remediation. Experimental soil was collected from Safwan city near South Rumaila Oil Field and contaminated with crude oil at concentrations of 15, 30, 45, and 60 g kg^{-1}. The experiments were conducted under controlled conditions over 4 months. Changes in soil pH, electrical conductivity (EC), moisture, total nitrogen, organic matter, and total organic carbon (TOC), as well as the carbon-to-nitrogen ratio, were monitored and recorded every 30 days throughout the experiment. As remediation progressed, noticeable changes in most soil properties were observed, indicating recovery toward the original properties of the uncontaminated soil. Soil with lower contamination levels recovered faster than soil with higher levels. The results showed that Haloxylon salicornicum reduced hydrocarbon concentrations and clearly contributed to tolerance of the negative effects of petroleum contamination. Based on that, this plant can be considered a sustainable phytoremediation agent for oil-polluted soils in arid environments.

المعالجة النباتية للتربة الملوثة بالهيدروكاربونات النفطية باستخدام نبات الرمث (*Haloxylon salicornicum*)

جنائن يعرب السعيدي

يعتبر تلوث التربة بالهيدروكاربونات النفطية أحد المشاكل البيئية المهمة التي تؤثرعلى جودة التربة ونمو النبات والاستقرار البيئي في المناطق القريبة من المصافي والحقول النفطية. المعالجة النباتية للتربة هي أحد الوسائل الصديقة للبيئة المستخدمة لاستعادة جودة التربة. في هذه الدراسة، تم استخدام نبات الرمث (*Haloxylon salicornicum*) لمعالجة التربة الملوثة بالنفط الخام مع دراسة التغيرات في الخصائص الفيزيائية والكيميائية للتربة خلال مراحل المعالجة. تم جمع نماذج التربة المستخدمة في التجارب من مناطق زراعية في مدينة سفوان القريبة من حقل الرميلة النفطي الجنوبي ولوثت بنفط خام بتراكيز مختلفة عند تراكيز 15 و30 و45 و60 غم/كلغم. أجريت التجارب تحت ظروف مسيطر عليها خلال 4 أشهر. تم مراقبة وتسجيل التغيرات في قيمة pH التربة، التوصيلية الكهربائية، الرطوبة، كمية النتروجين، تركيز الكربون العضوي الكلي إضافة لنسبة الكربون الى النتروجين في التربة بشكل دوري كل 30 يوما خلال فترة التجربة. مع الاستمرار في عملية المعالجة النباتية، تم ملاحظة تغيرات في معظم خصائص التربة باتجاه العودة الى خصائص التربة الاصلية قبل إضافة التراكيز النفطية اليها. حدثت هذه التغيرات بشكل أسرع في التربة التي لوثت بتركيز اقل من الملوثات النفطية مقارنة مع تلك التي لوثت بتراكيز اعلى. أظهرت النتائج ان نبات الرمث قد عمل على تقليل نسبة المواد الهيدروكاربونية في التربة وساهم بشكل واضح في تقليل الاثار السلبية للتلوث في التربة. بناء على ما سبق، يمكن اعتبار هذا النبات عاملا مستداما للمعالجة النباتية للتربة الملوثة بالنفط في البيئة الصحراوية او القاحلة.

INTRODUCTION

Optimal plant growth depends on environmental conditions, such as suitable temperature, adequate sunlight, good soil conditions, and regular irrigation. However, agricultural areas near oil refineries and petroleum facilities are often contaminated by hydrocarbons from accidental crude oil spills, pipeline leaks, and produced water. Over time, the accumulation of petroleum hydrocarbons in agricultural soils may degrade soil quality, microbial activity, and plant growth, posing a real environmental challenge to ecosystem stability and human health. Additionally, increasing petroleum hydrocarbon levels in the soil reduced soil aeration and water infiltration, altered soil physicochemical properties, and negatively affected soil microbial communities, or transferred pollutants through the food chain to humans. Therefore, the remediation of petroleum-contaminated soils is an important issue, and considerable research efforts have focused on mitigating their negative effects using various remediation techniques, including physical, chemical, thermal, biochemical, and phytoremediation. Low cost-effectiveness and suitability for large-scale applications are the main criteria researchers use to choose this technique. Therefore, phytoremediation has been widely applied to remediate petroleum-contaminated soils (Tang, 2019).

Because this technique relies on plants' natural ability to tolerate soil hydrocarbon concentrations, several plant species have been successfully used for their tolerance to contaminated conditions. For example, the ability of Pennisetum purpureum cv. Mahasarakham for remediation of the Polycyclic Aromatic Hydrocarbons (PAHs) in contaminated soils has been evaluated by Somtrakoon and Chouychai (2024). Considerable remediation capacity, in addition to strong growth of this plant, was observed, especially after applying Thidiazuron (plant growth regulator), which improved plant tolerance to contamination-induced stress. In another study, the removal of total petroleum hydrocarbons (TPHs) from oil-contaminated soil by Alhagi camelorum has been investigated. The findings of Nemati et al., (2024) demonstrated that this plant can be considered a promising candidate for reducing contaminant concentrations and for remediation of petroleum-polluted environments. In addition, the study showed that this plant can remove heavy metals (HMs) from oil-contaminated soil. The phytoremediation of another plant species, Sesuvium portulacastrum (L.), was investigated by Qzar et al., (2025) using five contaminated soil samples with crude oil concentrations of 25, 50, 75, and 100 g kg^{-1}. The experiments were carried out over 90 days. The results demonstrated that the plant has high potential for removing hydrocarbons from contaminated soil, and its ability increased with increasing crude oil concentration over time.

Haloxylon salicornicum is a perennial xerophytic shrub belonging to the Chenopodiaceae family and plays important ecological roles in stabilising the desert. It has a strong ability to adapt to harsh drought conditions, including high temperatures, high salinity, and low soil nutrient levels. The purpose of this work is to evaluate the phytoremediation potential of Haloxylon salicornicum, a locally native plant found in the desert regions of Iraq, for removing hydrocarbons from contaminated soil, thereby providing a sustainable approach for mitigating petroleum pollution using natural materials.

MMATERIALS AND METHODS

Soil Preparation and Experimental Setup

The experiments were conducted for 120 days at the Petroleum Refining and Testing Laboratory at the University of Basrah, between January and May 2026. Samples were selected from three farms located in Safwan city, southwest of Basrah, southern Iraq, and mixed. The samples were exposed to sunlight for five days, then sieved through a 2 mm mesh to remove large plant residues and stones. Approximately 20 Kg of the sample was divided into four 5 kg portions, which were weighed precisely and placed in a suitable pot. The crude oil was obtained from the Rumaila oil field, and mixed separately with the soil in the pots at contamination levels of 15, 30, 45, and 60 g kg^{-1} (w/w), respectively.

Under controlled laboratory conditions, five stem cuttings (approximately 4 cm long) of the experimental plant (Haloxylon salicornicum) were distributed among the four pots. The last stem planted in a control soil sample pot, without crude oil, was placed in a suitable pot. The control pot, without crude oil, will be used for comparison purposes with the soil and plants in the other four pots. The five pots containing plants were irrigated regularly to maintain a sufficient moisture level for plant growth. Each treatment was carried out in triplicate to ensure data reliability. At the end of the growing period, soil samples were collected for further analysis, and plants were carefully uprooted. The roots and shoots were gently washed with tap water and dried under the sun for twelve hours before measuring their lengths.

Soil Physicochemical Properties

Several physicochemical properties were determined during the experimental period. Following the standard methods outlined by Estefan et al., (2013), soil pH, electrical conductivity (EC), and carbon-to-nitrogen ratio (C/N) were measured. While total nitrogen was determined according to Bremner and Mulvaney (1987), total organic carbon was measured according to Nelson and Sommers (1996).

Determination of Total Petroleum Hydrocarbons (TPHs)

The Soxhlet apparatus was utilised to extract petroleum hydrocarbons from contaminated soils and plant tissues (roots and shoots) at 30, 60, 90, and 120 days. The extracted hydrocarbons were quantified using a Gas Chromatograph equipped with a Flame Ionisation Detector (GC-FID) according to the method described by Zubair et al., (2015).

For soil samples, the hydrocarbon degradation percentage was measured according to Al-Mansoory et al., (2017) using the following equation:

$$\text{Degradation Percentage (\%)} = \frac{C_0 - C_t}{C_0} \times 100$$

Where;

C_0: the concentration of hydrocarbons before contamination;

C_t: the concentration of hydrocarbons at the end of each experimental period.

Each treatment was replicated three times in a Randomised Complete Block Design (RCBD). IBM SPSS Statistics version 20 was used to analyse data.

Bartlett's test was first applied to verify the homogeneity of variances at a significance level of $P \leq 0.05$. Differences among treatment means were then compared using the Least Significant Difference (LSD) test at $P \leq 0.05$. Analysis of variance (ANOVA) was conducted to evaluate the significance of variation among the experimental treatments. The results are presented in Table 1.

Table 1. Analysis of variance (ANOVA) for the studied soil parameters under different experimental conditions.

Source of variation	Degrees of Freedom (df)	EC (mS cm^{-1})	pH	Moisture (%)	Total Nitrogen (%)	Organic matter (%)	C/N ratio	TOC (%)
R stratum	2	0.123	0.086	0.155	0.093	0.120	0.072	0.181
Time	2	**31.47	*1.64	**2.86	**24.62	**27.90	**11.26	**0.83
Concentration	3	**1.53	NS	*0.95	NS	**2.30	NS	**1.92
Concentration* Time	6	**1.06	NS	*0.59	*0.28	**1.04	*0.32	**0.64
Residual	18	0.017	0.007	0.050	0.012	0.008	0.002	0.021

NS = not significant; * = significant at $P \leq 0.05$; ** = highly significant at $P \leq 0.01$.

RESULTS & DISCUSSION

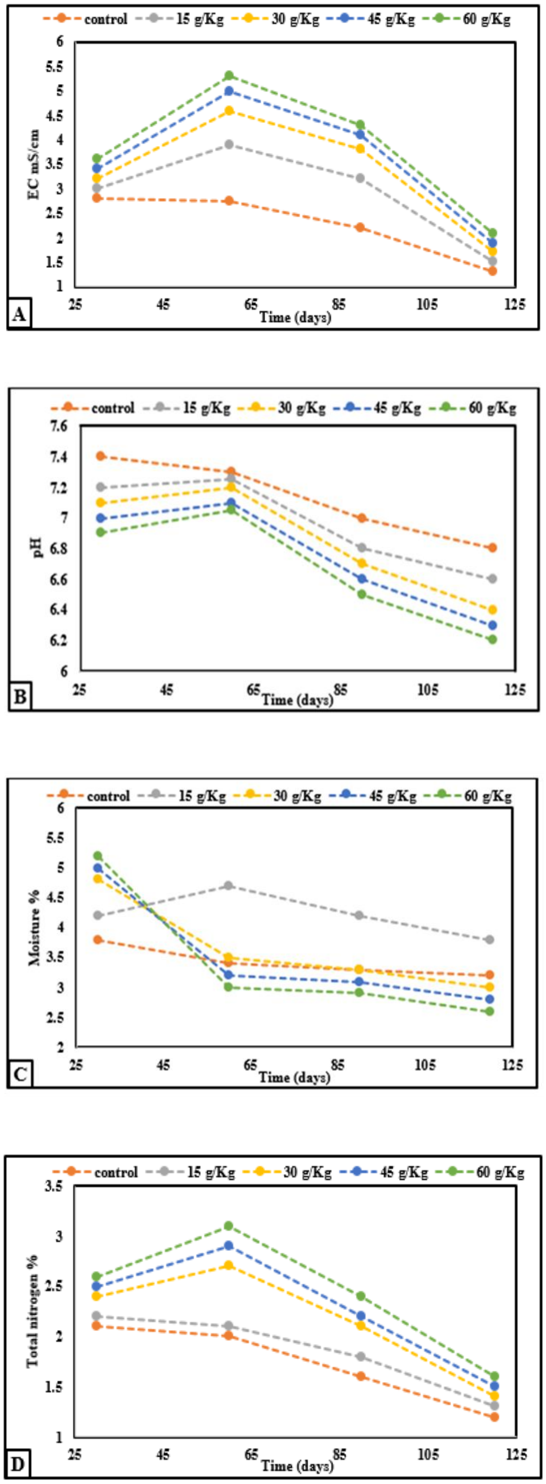
Physical and chemical characteristics of soil

The soil analysis before contamination (in the first control pot) indicated that total petroleum hydrocarbons were about 0.055 g kg^{-1} (Table 2). This value is lower than the 0.015 g kg^{-1} reported by Al-Ali et al., (2016). This may be due to differences in the sites from which the soil samples were taken, or to agricultural activity that increased over the last decade in these lands, thereby strengthening microbial activity. The analysis showed moderate values for pH, electrical conductivity (EC), total organic carbon (TOC), and organic matter. At the same time, the moisture content and the carbon-to-nitrogen ratio were lower than normal for soils due to the high nitrogen content.

Table 2. Physical and chemical characteristics of soil.

Parameter	pH	EC (Ms cm^{-1})	Moisture (%)	TOC (%)	Total Nitrogen (%)	Organic matter (%)	C/N ratio	TPHs in soil (g kg^{-1})
Value	7.4	2.96	3.9	2.28	0.29	3.96	7.9	0.055

Following contamination and increased remediation time, significant variations in the soil's physical and chemical characteristics were observed (Figure 1).



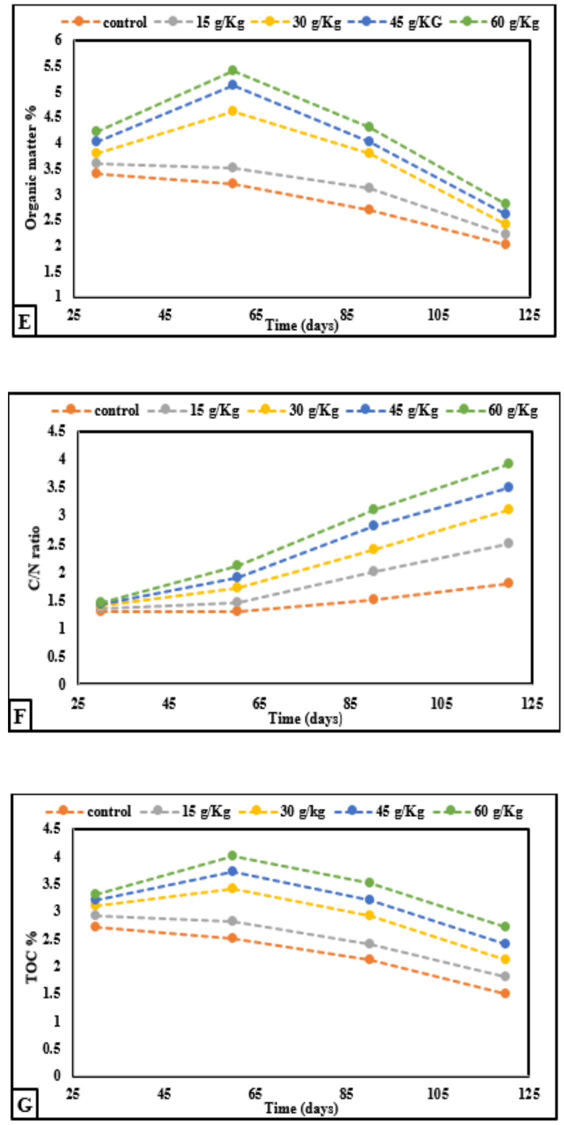


Fig. 1. Physical and chemical characteristics of the soil over time during the experiments. (A) Electrical conductivity (mScm^{-1}). (B) pH value. (C) Moisture %. (D) Total nitrogen %. (E) Organic matter %. (F) Carbon/Nitrogen ratio. (G) Total organic carbon %.

After 30 days, compared with the control pot, increasing crude oil concentrations increased electrical conductivity (EC), soil moisture content (per cent), total nitrogen, and organic matter. In fact, increasing organic matter (including petroleum hydrocarbons) can form a coating on soil particles, elevating soil hydrophobicity (Hallett, 2008). The high value recorded for total nitrogen may be due to increasing microbial activity after planting the plants in the soil and redistribution of nitrogen in the soil sample, while increasing EC can be attributed to dissolved ions from crude oil-produced water in the soil after 30 days. It is important to note that, except for pH and moisture content, the values for the phytochemical properties of the treated soils are higher than those recorded for the control pot soils.

In the second period, after 60 days, some parameters reached their highest values, including EC, total nitrogen, organic matter, and TOC, especially in highly contaminated soils (60 g kg⁻¹), indicating the soil matrix has been affected by the accumulation of hydrocarbon compounds and soluble ions. In contrast, pH and moisture content, except for soil treated with 15 g kg⁻¹ crude oil, have decreased. This may be because the plant has grown significantly and is absorbing more water from the soil. Additionally, microorganisms begin to break down the hydrocarbons, a process that requires water. Therefore, the moisture content has decreased (Kebede et al., 2021).

By 90 days, and as a result of continued development of root biomass, microbial degradation, and plant nutrient uptake, the gradual recovery processes associated with phytoremediation activity can be clearly observed. Electrical conductivity, pH, total nitrogen, TOC and organic matter have decreased clearly. The C/N ratio has increased, while moisture content has remained relatively unchanged, suggesting reduced water retention capacity. All parameters have continued at the same trend until the end of the experimental time (120 days).

It is important to note that soil moisture dynamics are closely linked to changes in soil physicochemical properties and can be significantly influenced by hydrocarbon contamination. Water availability in soil can play a significant role not only in regulating soil nutrient balance but also in overall soil function (Wang et al., 2021). In this work, the moisture content, except for the values that registered after mixing the soil with crude oil (15 g kg⁻¹), showed a sharp decline between 30 and 60 days and a slight decline after that, and the values were lower than those in the control pot at the end of the experimental time. The progressive decline was observed in the pots with high contamination levels. The reduction in soil's water retention capacity may contribute to the accumulation of petroleum hydrocarbons on soil particles (Hewelke & Gozdowski, 2022). Moreover, a gradual decrease in soil pH was observed in petroleum-contaminated treatment soils compared to the control. This decrease was observed between 60 and 120 days. According to total nitrogen content, although a similar trend of decreasing was observed, the values in contaminated treatments were higher than those in the control pot throughout the experimental period. These results are consistent with those obtained by Liu et al., (2023), who observed similar variations in nitrogen dynamics under hydrocarbon-contaminated soil conditions.

Overall, the results suggest that prolonged phytoremediation improved the contaminated soil conditions, with clear physicochemical fluctuations in the first and second stages (30–60 days), followed by gradual stabilisation in the final stages (90–120 days).

Total hydrocarbons in soil

Figure 2 shows the residual concentration of total petroleum hydrocarbons (TPHs) in contaminated soil that was measured four times in sequence every 30 days over the experimental period (120 days).

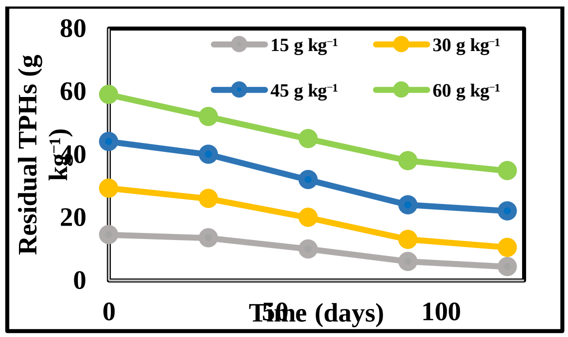


Fig. 2. Residual TPHs in soil over experimental time.

From the first to the final stage of the experiment, a gradual reduction in hydrocarbon concentration was observed across all soil treatments. The soil treated with the lowest crude oil concentration (15 g kg⁻¹) presented the highest degradation efficiency (71%). The degradation efficiency for all treated samples (15, 30, 45 and 60 g kg⁻¹) is shown in Figure 3.

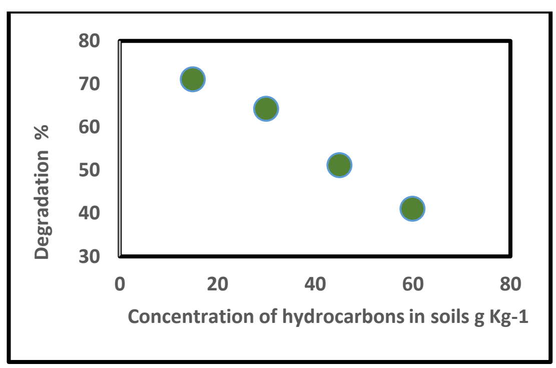


Fig. 3. Degradation percentage of hydrocarbons in soils

The relatively Higher degradation in the low-concentration treatment soils may be attributed to reduced toxic stress on plants, which supports better plant growth and enhances phytoremediation. Saraeian et al., (2018) confirmed this conception. They reported that the plant cultivation system and remediation efficiency were severely affected, leading to increased toxic effects from elevated soil hydrocarbon concentrations. Other processes can play a significant role in removing petroleum hydrocarbons from contaminated soil, such as microbial degradation, photooxidation, volatilisation, and rhizosphere-assisted biodegradation. Additionally, Mekonnen et al., (2024) referred to a strong relationship between the degradation efficiency of hydrocarbons, the composition of petroleum hydrocarbons in soil, and soil microbial activity**.**

The low degradation efficiency observed in highly contaminated treatments suggests that excessive hydrocarbon accumulation negatively impacted plant physiological performance and reduced microbial degradation rates. The results obtained by Gao et al., (2022) align with that. They explained that the soil's ecological function, along with biological degradation processes, had been negatively affected by increasing concentrations of petroleum hydrocarbons.

According to Table 1, statistically significant differences have been observed among treatments ($P < 0.05$), indicating that phytoremediation efficiency was clearly affected by crude oil concentration and remediation time.

Total hydrocarbons in the plant

The root and stem lengths of Haloxylon salicornicum were measured after soil treatment. Table 3 showed that the lengths of the two plant parts declined during the remediation period as soil contamination concentrations increased, and the plant cultivated under the lower contamination treatment (15 g kg^{-1}) had better growth performance than the others. Conversely, as expected, the plant cultivated in a control soil consistently recorded the highest growth values at all-time points. The phytotoxic effects of petroleum compounds have negatively affected root elongation, normal physiological processes, and nutrient absorption in plants (Saraeian et al., 2017; Correa et al., 2022). In addition, soil aeration can be drastically impacted by crude oil contamination. In general, pollutants can create unhealthy rhizosphere conditions that hinder plant establishment and development (Mohanta et al., 2024).

Table 3. Growth developments of *Haloxylon salicornicum* under different petroleum hydrocarbon concentrations.

Time/treatment	control	15 g kg^{-1}	30 g kg^{-1}	45 g kg^{-1}	60 g kg^{-1}
After 30 days	Root = 3.0	2.6	2.3	1.9	1.7
	Stem = 8.0	7.2	6.6	5.8	5.1
After 60 days	Root = 4.7	4.1	3.5	3.0	2.5
	Stem = 11.1	9.9	8.7	7.4	6.3
After 90 days	Root = 6.6	5.7	4.8	3.9	3.2
	Stem = 15.2	13.3	11.5	9.7	8.1
After 120 days	Root = 8.3	7.1	5.9	4.8	4.0
	Stem = 18.0	15.8	13.3	10.9	9.2

* Roots and stems are expressed in cm.

In plant tissues, petroleum hydrocarbon accumulation was determined at the end of each experimental period. Figure 4 showed a direct relationship between the hydrocarbon concentration in plant tissues and the petroleum concentration in the contaminated soil, with increasing exposure time.

The capacity of accumulated hydrocarbons in the studied plant (Haloxylon salicornicum) that was cultivated under 15 g kg^{-1} was the lowest at 30 days. The values of hydrocarbon accumulation increased with increasing experimental time, and the hydrocarbon concentration to 30, 45, and 60 g kg^{-1}. The highest value was recorded in plants exposed to 60 g kg^{-1} at the end of the 120-day experimental period. The roots of plants growing in petroleum-contaminated soils played a significant role in absorbing petroleum-derived compounds and translocating them into plant tissues (Correa et al., 2022). In addition, rhizosphere microbial communities may enhance the biodegradation of petroleum hydrocarbons by metabolising organic compounds into less toxic substances (Truu et al., 2015).

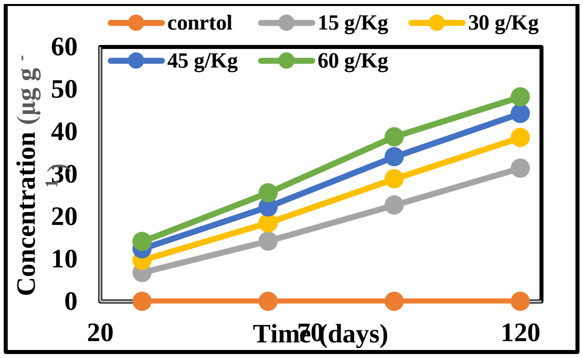


Fig. 4. Total hydrocarbon concentration in plant tissues during the experiment.

Lengths of roots and shoots

In general, root elongation and shoot development in any plant are drastically affected by increased soil pollutant levels. In this work, as shown in Table 3, the growth of root and shoot of Haloxylon salicornicum in contaminated soils was lower than that in the control soil, indicating the plant's sensitivity to hydrocarbon stress throughout the experimental period. The plants that were cultivated in contaminated soil with the highest concentrations of hydrocarbons (60 g kg^{-1}) exhibited the greatest growth inhibition. Therefore, reductions in both root elongation and shoot development occurred throughout the experimental time. Conversely, the best growth was observed in plants cultivated in uncontaminated soil (control soil), where petroleum hydrocarbon stress was absent.

The results agree with those of Kamranifar et al., (2025) regarding the effects of petroleum compound toxicity, which interfere with water and nutrient absorption, on inducing physiological stress and suppressing plant growth.

CONCLUSION

The results indicated that the quality and physicochemical properties of soil, including electrical conductivity, moisture content, total nitrogen, organic matter, total organic carbon, C/N ratio, and soil pH, were drastically affected by increasing soil pollution levels.

The results showed that Haloxylon salicornicum is a promising plant candidate for tolerating petroleum hydrocarbon stress and contributing to the rehabilitation of contaminated soils through phytoremediation. Gradual improvements in most soil properties were observed over the 120-day experimental period, suggesting a progressive reduction in petroleum hydrocarbon contamination. Increased TPH concentrations in plant tissues affected root and stem length. The recovery and remediation efficiency of soils with low contamination levels were faster than those with high levels of pollutants. In general, the findings shed light on the potential use of some plants as part of a cost-effective, environmentally sustainable strategy for the remediation of oil-polluted soils in arid and semi-arid regions.

REFERENCES

Al-Ali, B. S., Al-Aradi, H. J., Al-Khion, D. D., & Al-Saad, H. T. (2016). Petroleum hydrocarbons in water, soil and tomato plant (Lycopersicon esculentum L.) at Basra City. Journal of Biology, Agriculture and Healthcare, 6, 55–64.

Al-Mansoory, A. F., Idris, M., Abdullah, S. R. S., & Anuar, N. (2017). Phytoremediation of contaminated soils containing gasoline using Ludwigia octovalvis. Environmental Science and Pollution Research, 24, 11998–12008. https://doi.org/10.1007/s11356-017-8787-3

Bremner, J. M., & Mulvaney, C. S. (1982). Nitrogen—Total. In A. L. Page, R. H. Miller, & D. R. Keeney (Eds.), Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties (2nd ed., pp. 595–624). American Society of Agronomy.

da Silva Correa, H., Blum, C. T., Galvão, F., & Maranho, L. T. (2022). Effects of oil contamination on plant growth and development: A review. Environmental Science and Pollution Research, 29(29), 43501–43515. https://doi.org/10.1007/s11356-022-19779-1

Estefan, G., Sommer, R., & Ryan, J. (2013). Methods of soil, plant, and water analysis: A manual for the West Asia and North Africa region. ICARDA. https://doi.org/10.1201/b12214-11

Gao, H., Wu, M., Liu, H., Xu, Y., & Liu, Z. (2022). Effect of petroleum hydrocarbon pollution levels on the soil microecosystem and ecological function. Environmental Pollution, 293, 118511. https://doi.org/10.1016/j.envpol.2021.118511

Hallett, P. D. (2008). A brief overview of the causes, impacts and amelioration of soil water repellency: A review. https://doi.org/10.17221/1198-swr

Hewelke, E., & Gozdowski, D. (2020). Hydrophysical properties of sandy clay contaminated by petroleum hydrocarbon. Environmental Science and Pollution Research, 27(9), 9697–9706. https://doi.org/10.1007/s11356-019-07534-2

Kamranifar, M., Pourzamani, H., Khosravi, R., Ranjbar, G., & Ebrahimpour, K. (2025). Phytotoxic effects of petroleum hydrocarbons on germination and growth of the native halophyte Salicornia sinus persica in oil-contaminated soil. Scientific Reports, 15(1), 8459. https://doi.org/10.1038/s41598-025-92512-9

Kebede, G., Tafese, T., Abda, E. M., Kamaraj, M., & Assefa, F. (2021). Factors influencing the bacterial bioremediation of hydrocarbon contaminants in the soil: Mechanisms and impacts. Journal of Chemistry, 2021, 9823362. https://doi.org/10.1155/2021/9823362

Liu, H., Wu, M., Gao, H., Gao, J., & Wang, S. (2023). Application of ^{15}N tracing and bioinformatics for estimating microbial-mediated nitrogen cycle processes in oil-contaminated soils. Environmental Research, 217, 114799. https://doi.org/10.1016/j.envres.2022.114799

Mekonnen, B. A., Aragaw, T. A., & Genet, M. B. (2024). Bioremediation of petroleum hydrocarbon contaminated soil: A review on principles, degradation mechanisms, and advancements. Frontiers in Environmental Science, 12, 1354422. https://doi.org/10.3389/fenvs.2024.1354422

Mohanta, S., Pradhan, B., & Behera, I. D. (2024). Impact and remediation of petroleum hydrocarbon pollutants on agricultural land: A review. Geomicrobiology Journal, 41(4), 345–359.

Nelson, D. W., & Sommers, L. E. (1996). Total carbon, organic carbon, and organic matter. In D. L. Sparks (Ed.), Methods of Soil Analysis. Part 3. Chemical Methods (pp. 961–1010). Soil Science Society of America. https://doi.org/10.2136/sssabookser5.3.c34

Nemati, B., Baneshi, M. M., Akbari, H., Dehghani, R., & Mostafaii, G. (2024). Phytoremediation of pollutants in oil-contaminated soils by Alhagi camelorum: Evaluation and modeling. Scientific Reports, 14(1), 5502. https://doi.org/10.1038/s41598-024-56214-y

Qzar, I. A., Qasim, D. A., & Jamel, F. A. (2025). Phytoremediation of petroleum hydrocarbon-contaminated soil using Sesuvium portulacastrum (L.). Basrah Journal of Agricultural Sciences, 38(2), 330–341. https://doi.org/10.37077/25200860.2025.38.2.24

Saraeian, Z., Haghighi, M., Etemadi, N., HajAbbasi, M. A., & Afyuni, M. (2018). Phytoremediation effect and growth responses of Cynodon spp. and Agropyron desertorum in a petroleum-contaminated soil. Soil and Sediment Contamination: An International Journal, 27(5), 393–407. https://doi.org/10.1080/15320383.2018.1460586

Somtrakoon, K., & Chouychai, W. (2024). Enhancing growth and phytoremediation efficiency of Pennisetum purpureum cv. Mahasarakham in weathered PAH-contaminated soil through thidiazuron application. International Journal of Phytoremediation, 26(14), 2336–2347. https://doi.org/10.1080/15226514.2024.2389561

Tang, K. H. D. (2019). Phytoremediation of soil contaminated with petroleum hydrocarbons: A review of recent literature. Global Journal of Civil and Environmental Engineering, 1, 33–42. https://doi.org/10.36811/gjcee.2019.110006

Truu, J., Truu, M., Espenberg, M., Nõlvak, H., & Juhanson, J. (2015). Phytoremediation and plant-assisted bioremediation in soil and treatment wetlands: A review. The Open Biotechnology Journal, 9(1), 85–92. https://doi.org/10.2174/1874070701509010085

Wang, L., Cheng, Y., Naidu, R., & Bowman, M. (2021). The key factors for the fate and transport of petroleum hydrocarbons in soil with related in/ex situ measurement methods: An overview. Frontiers in Environmental Science, 9, 756404. https://doi.org/10.3389/fenvs.2021.756404

Zubair, A., Pappoe, M., James, L. A., & Hawboldt, K. (2015). Development, optimization, validation and application of faster gas chromatography–flame ionization detector method for the analysis of total petroleum hydrocarbons in contaminated soils. Journal of Chromatography A, 1425, 240–248. https://doi.org/10.1016/j.chroma.2015.10.003