Science World Journal Vol. 20(No 3) 2025 https://dx.doi.org/10.4314/swj.v20i3.18
www.scienceworldjournal.org
ISSN: 1597-6343 (Online), ISSN: 2756-391X (Print)
Published by Faculty of Science, Kaduna State University

Full Length Research Article

PHYTOREMEDIATION OF ALIPHATIC HYDROCARBONS FROM ABANDONED LANDFILL SOIL USING *ACALYPHA WILKESIANA*

*[1,2]Naseer Inuwa Durumin Iya and [1]Zaini Bin Assim

[1]Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia
[2]Department of Chemistry, Faculty of Science, Federal University Dutse, Ibrahim Aliyu Bye-Pass, 7156, Dutse, Jigawa State, Nigeria

*Corresponding Author Email Address: nasduruminiya@fud.edu.ng

ABSTRACT
This study assessed the potential of *Acalypha wilkesiana* for phytoremediation, a plant-based method used to clean hydrocarbon-contaminated landfill soil, which poses long-term risks to human health and the environment. The plants were transplanted into the landfill soil and harvested at intervals of 2, 4, and 6 months for analysis of aliphatic hydrocarbons (AHs), using Gas Chromatography coupled with Flame Ionization Detector (GC-FID). Results revealed that *A. wilkesiana* successfully absorbed and translocated AHs throughout the study period. It demonstrated uptake of n-alkanes ranging from C_{14} to C_{33}, with absorption levels increasing over time. Notably, hydrocarbons such as C_{29}, C_{25}, C_{33}, and C_{31} were detected in the plant leaves at concentrations of 16.18, 15.27, 11.04, and 10.36 mg/kg, respectively, at the 6-month harvest. Morphological measurements indicated statistically significant differences in the ratios of root length to stem height (RL/SH), root length to stem diameter (RL/SD), and stem height to stem diameter (SH/SD), all exceeding the least significant difference (LSD) value of 3.62. *A. wilkesiana* demonstrated the ability to absorb and retain hydrocarbons in both its roots and leaves, indicating its effectiveness for cleaning up hydrocarbon-contaminated landfill soils through phytoremediation.

Keywords: Phytoremediation, Landfill Soil, GC-FID, *Acalypha wilkesiana* Aliphatic Hydrocarbon, Matang.

INTRODUCTION

The quantity of aliphatic hydrocarbons in soil from old landfills poses a significant environmental risk due to their potential toxicity and persistence. Straight-chain, branched-chain, and cyclic alkanes are examples of aliphatic hydrocarbons that are frequently found in soil and landfill leachate due to the breakdown of organic waste, petroleum products, and other man-made sources (Wang *et al.,* 2018). Over time, these substances may build up in the soil and cause long-term contamination that endangers both human health and ecosystems. According to studies, the number of aliphatic hydrocarbons in landfill soils can vary greatly based on a number of variables, including the landfill's age, the waste's composition, and the physicochemical characteristics of the soil (Zhang *et al.,* 2020). High concentrations of these hydrocarbons have the potential to disturb soil microbial populations, lower soil fertility, and contaminate groundwater through leaching. Gas chromatography-mass spectrometry (GC-MS) is frequently used in the investigation of aliphatic hydrocarbons in soils from former landfills in order to identify and measure particular chemicals. According to research by Li *et al.* (2019), aliphatic hydrocarbon concentrations in decommissioned landfill sites can range from hundreds to thousands of milligrams per kilogram of soil. Because long-chain alkanes (C_{20}–C_{40}) are more resistant to biodegradation and can linger in the environment for decades, their presence is especially worrisome. Furthermore, environmental variables including temperature, moisture content, and oxygen availability can impact the pace of microbial degradation, which in turn affects the breakdown of aliphatic hydrocarbons in landfill soils (Kuppusamy *et al*., 2020). Determining the environmental impact of abandoned landfills and creating efficient remediation plans require an understanding of the distribution and behavior of these substances. Aliphatic hydrocarbon-contaminated soils in former landfills are frequently remedied using physical, chemical, and biological techniques. Because it is economical and environmentally benign, bioremediation which uses microorganisms to break down hydrocarbons is a viable strategy. According to studies, aliphatic hydrocarbon concentrations in contaminated soils can be considerably decreased by adding fungi and bacteria that break down hydrocarbons (Varjani *et al*., 2021). Achieving effective cleanup in cases of severe contamination may require a combination of methods, such as soil washing followed by bioremediation, as the success of bioremediation depends on optimizing conditions for microbial activity, such as nutrient availability and soil pH (Chen *et al*., 2022). To guarantee the safe reuse of these sites and to reduce the environmental concerns related to aliphatic hydrocarbons in soils from abandoned landfills, more research and monitoring are necessary.

Heavy metals and hydrocarbons are among the pollutants that have been investigated for removal from waste soils using phytoremediation, the process of using plants to clean up contaminated settings. Although there are few studies specifically examining the phytoremediation of aliphatic hydrocarbons in landfill soils, studies on the remediation of petroleum hydrocarbons in contaminated soils offer important new information. To illustrate the existence of hydrocarbons in landfill soils, Uzoekwe and Anekwe (2020) evaluated the physicochemical properties and total hydrocarbon concentration of soil from an abandoned landfill site in Igbogene, Bayelsa State, Nigeria. The possibility of phytoremediation for polycyclic aromatic hydrocarbons (PAHs) in polluted soils was also covered in a function of plants in breaking down these intricate substances. Although more study is required to precisely target aliphatic hydrocarbons, these results implies that phytoremediation may be a viable strategy for treating hydrocarbon pollution in landfill soils (Allamin and Shukor, 2021).

An investigation into *A. wilkesiana*'s capacity for development, accumulation, and survival was carried out. The plant has been studied for its phytoextraction capabilities in soil contaminated with heavy metals and the results indicate that Fe exhibited the highest accumulation among the metals analysed, with concentrations of 5002.4 mg/kg, followed by Cu at 542.7 mg/kg, Mn at 492.2 mg/kg, As at 396.7 mg/kg, and Zn at 308.2 mg/kg. The concentrations of Cr, Ni, and Co were 101.2 mg/kg, 99.09 mg/kg, and 89.63 mg/kg,

respectively (Durumin Iya *et al*., 2021). But there has been little research on the plant's ability to remove hydrocarbons from soil. The plant belongs to the Euphorbiaceous family, grows quickly, and, depending on cultivation, has a variety of leaf colors (Durumin Iya *et al*., 2021). The potential of *A. wilkesiana* for phytoremediation is not well understood. It was reported that the plant absorbed and accumulated AHs from the soil spiked with crude oil. Assessing the phytoremediation capacity of the chosen plant cultivated on landfill soil was the primary goal of this investigation. *A. wilkesiana* was cultivated in soil from an abandoned landfill in order to assess the AHs' growth, survival, accumulation in the roots, and translocation to aboveground plant part during the study period.
The main objective of this study was to evaluate the phytoremediation potential of the selected plant. *A. wilkesiana* was grown on the abandoned landfill soil to evaluate the survival, growth, accumulation of AHs in the root and translocation of AHs to aboveground parts within the study time.

MATERIALS AND METHODS

Setup for Field Experiments

In order to guarantee and maintain a suitable and favorable propagation condition for the plant at the Universiti Malaysia Sarawak (UNIMAS) greenhouse, this experiment was carried out through a number of field tests. The capacity of particular plants to absorb and accumulate hydrocarbons from Matang, Kuching (Malaysia), dump sites was the main focus of the study.

Gathering Soil Samples

About 16.00 km from UNIMAS, a landfill soil sample was taken at the Matang old dump site. The GPS coordinates were N 0° 03'03'6.6" and E 11° 010° 014' 39.2". Because there are many undesirable things on the top surface, including trash, broken bottles, degraded plastics, and some grasses, the soil was gathered between 15 and 30 cm below the surface. Three unique places were chosen, each 120 meters apart from the others. The samples were gathered from three distinct locations. A stainless-steel scoop was used to gather the soil sample, which was then wrapped in aluminum foil. During transit, it was stored in a cooler box.

The Poly Bag Experiment

To get constant moisture levels, twelve (12) soil samples were divided equally and allowed to air-dry inside for the purposes of this investigation. After that, the soils were well mixed to guarantee consistency. The dirt from the dump was subjected to hydrocarbon analysis. Plant cuttings were later grown in poly bags containing around 1.5 kg of the dry soil. For the experiment, 50 poly bags in total were used. Twenty of these were used as controls: ten poly bags for soil control A and ten more for soil control B (to be used as initial and final soil controls, respectively) were allocated to two- and six-month harvesting periods.

Fractionation and Extraction of Plant Parts

A. wilkesiana plants were carefully uprooted, cleaned, and separated into roots and leaves on harvest day. After that, the plant tissues were allowed to air dry for 72 hours at room temperature (31 °C) the dark. According to Sheng-You *et al*. (2005), harvesting occurred toward the end of the second, fourth, and sixth months.
The method delineated by Durumin Iya et al. (2021) was employed to extract aliphatic hydrocarbons with few changes (AHs) and polycyclic aromatic hydrocarbons (PAHs) from the plant tissues. In a Soxhlet extractor, 2.0 g of plant material was put in a cellulose thimble and extracted for 8 hours using 300 mL of dichloromethane. As an internal standard for AHs, 50 µL of 50 µg/g *n*-eicosene was added prior to extraction. A vacuum rotary evaporator was then used to evaporate the solvent, producing a crude extract that was kept for additional examination at 4 °C.

A silica gel column chromatography was used in this research work to fractionate the crude extract. The crude extract was put in to chromatography column that included 5.0 g of activated silica gel (230–400 mesh) that had been diluted in 1 mL of n-hexane as described by El Nemr *et al*. (2016). F1 (AHs) and F2 (PAHs) were separated by sequential elution using 40 mL of n-hexane and 40 mL of an n-hexane/dichloromethane (1:1 v/v) combination. A vacuum rotary evaporator was used to concentrate the fractions after they were gathered in a 100 mL pear-shaped flask. Following the evaporation process, F1 and F2 were dissolved in 1 milliliter of dichloromethane, sonicated, and then transferred using a Pasteur pipette into 5 mL bottle. The fractions were then dissolved in 3 mL of GC-grade dichloromethane, gently dried under filtered nitrogen gas, and kept at 4 °C the dark until they were analyzed using gas chromatography–flame ionization detection (GC-FID).

Measurement of AH in the Sample

The internal standardization approach was used to measure the amounts of AHs in plant roots and leaves. This method used *n*-eicosene as the internal standard, and the chromatogram's peak regions were examined in relation to this standard. The procedure involves mixing a fixed quantity of the internal standard (IS) into all samples, including calibration standards and unidentified samples. The response ratio between the IS and the target analyte is used to establish calibration (Sheng-You *et al*., 2005). This method was followed in this research work.
A standard combination of n-alkanes was analyzed in order to identify the response factors (RF) for each n-alkane. The following formulas were used to determine the RF and analyte concentration:

Calculating the Response Factor

Equations were used to determine the n-alkanes' RF and concentration.
Equation 1:

$$RFx = \frac{(Ais \times Cx)}{(Ax \times Cis)}$$

where Ax is the peak area for analyte x, Cx is the analyte x concentration, and RFx is the response
factor for analyte x;

Calculating Analyte Concentration

Equation 2 below is used to calculate this analyte x concentration.

$$Cx = \frac{RFx\,(Ax \times Cis)}{(Ais)}$$

Cis is the internal standard concentration, while Ais is the internal standard peak area.

Analysis of Statistics

Unless otherwise noted, all experimental data were reported as the mean ± standard deviation from five replicates. The Least Significant Difference (LSD) test was used to identify significant differences between means at a significance level $p<0.05$ after statistical analysis was completed.

Science World Journal Vol. 20(No 3) 2025 https://dx.doi.org/10.4314/swj.v20i3.18
www.scienceworldjournal.org
ISSN: 1597-6343 (Online), ISSN: 2756-391X (Print)
Published by Faculty of Science, Kaduna State University

RESULTS AND DISCUSSION

Plant growth and survival in landfill soil

Haider and Azmat (2012), stated that plants can live in the soil of landfills. They create defense mechanisms to survive in such circumstances, which could involve producing more lignin and other secondary metabolites. And phenolic compounds are essential during hydrocarbon stress because they function as metal chelators, binding harmful metals to reduce their negative effects.

Additionally, by neutralizing reactive oxygen species, phenolic substances reduce oxidative stress in plant cells and act as antioxidants. Despite their benefits, these processes may have detrimental effects on the growth and metabolism of plants. Physiological disruptions may result from the overproduction of phenolic compounds and other secondary metabolites during heavy metal stress. As stress-induced changes in stomatal conductance restrict the uptake of CO_2 and other gases necessary for photosynthesis, one significant effect is the restriction of gas exchange.

This limitation affects vital physiological functions like transpiration, photosynthetic efficiency, and nutrient absorption, which eventually lowers total plant growth and output. Stress-induced growth inhibition is exacerbated by the decrease in CO_2 assimilation, which also impacts biomass accumulation, chlorophyll synthesis, and enzymatic activities. Plants have developed homeostatic systems to control the levels of vital nutrients and metal ions in their cells in spite of these difficulties. By preserving equilibrium, these systems let plants withstand and adjust to environmental disturbances. Plants can lessen the negative consequences of heavy metal buildup by ion transporter modulation, antioxidant defense activation, and toxic metal sequestration. Long-term exposure to metal stress, however, can overtax these defensive mechanisms, resulting in oxidative damage, weakened cells, and further slowing of growth. Developing techniques to improve plant resistance under heavy metal pollution, especially in phytoremediation initiatives aimed at repairing damaged ecosystems, requires a detailed understanding of these intricate relationships.

Biomass from Plants

In this research work, *A. wilkesiana* showed consistent development over the course of the five harvest intervals, with considerable gains in root and leaf weight, root height, stem height, and stem diameter. The results of Taheri *et al.* (2018), however, are in opposition to the observed results for root height, stem height, and stem diameter. The study indicates a possibility for growth augmentation rather than any detrimental effects on plant life or development.

It was reported that, crude oil contamination may alter soil microbial communities, particularly by fostering bacteria that enhance plant growth-bacteria help plants flourish by providing nitrogen and reducing harmful soil conditions (Dilfuza, 2007; Durumin Iya *et al*., 2021). Some green plants may even benefit from specific amounts of crude oil in the soil, through biophysical and biochemical processes such enzyme production, pollutant uptake and accumulation, and rhizosphere microorganism stimulation, plants play a major role in soil remediation (Liao *et al*., 2015). The root length, stem height, stem diameter, root weight and leaf weight of the dry biomass of *A. wilkesiana* was presented on Table 1.

Table 1: Root length, stem height, stem diameter, dry biomass weight of *A. wilkesiana* plant tissue on different harvesting time

	Root Length	Stem Height	Stem Diameter	Root Weight	Leaf Weight
Initial Control	3.84±0.06	8.14±0.01	0.93±0.01	0.54±0.01	0.64±0.21
Two Months	4.17±0.11	7.83±0.03	1.41±0.04	0.46±0.02	0.59±0.03
Four Months	5.89±0.09	12.09±0.05	1.54±0.02	1.22±0.04	2.33±0.15
Six Months	9.37±0.06	16.12±0.01	1.72±0.03	2.48±0.02	2.98±0.07
Final Control	8.92±0.03	14.56±0.02	1.63±0.01	2.69±0.03	2.82±0.11

Average value ±standard deviation (n=8) and control values of the plant tissue

Plant Biomass Statistical Analysis

A single-factor analysis of variance (ANOVA) and the Least Significant Difference (LSD) test were used to statistically analyze plant biomass. Table 2 indicates that the computed p-value (0.002) was less than the alpha value (0.05). To ascertain whether there were significant differences between the two, the LSD test was used because the p-values for root weight (RW) and leaf weight (LW) were greater than 0.05, in which the findings are displayed on Table 3.

Table 2: Shows the sum, average and variance of three groups

SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
Root Length	5	32.19	6.438	6.73767
Stem Height	5	58.74	11.748	13.87677
Stem Diameter	5	7.23	1.446	0.09633

Table 3: Shows the results of ANOVA single factor

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	265.41228	2	132.70614	19.222772	0.00018119 7	3.885293835
Within Groups	82.84308	12	6.90359			
Total	348.25536	14				

Science World Journal Vol. 20(No 3) 2025 https://dx.doi.org/10.4314/swj.v20i3.18
www.scienceworldjournal.org
ISSN: 1597-6343 (Online), ISSN: 2756-391X (Print)
Published by Faculty of Science, Kaduna State University

Table 4: The Statistical Analysis of Data

Alpha Values	DFW	MSW	t-critical	LSD
0.05	12	6.9	2.18	3.62

Table 5: Absolute values of square difference of the mean

Root length (RL) and Stem height (SH)	Root length (RL) and Stem diameter (SD)	Stem height (SH) and Stem diameter (SD)
5.31	4.99	10.30
The absolute value between RL/SH is greater than the LSD 3.62 in Table 4, therefore, a statistically significant difference was found. The absolute value between RL/SD, and SH/SD are also greater than the LSD 3.62 in Table 4, therefore, a statistically significant difference has been found in both.		

Hydrocarbon Concentration in Landfill Soil
The concentration of AHs in landfill soil is shown in Table 6.0 below; this concentration served as the first control of the landfill soil.

Initial concentration of AHs in landfill soil
Depending factors such as trash content, landfill age, and environmental conditions can greatly influence the starting concentration of AHs in landfill soils. AH concentrations in various settings have been documented in the studies. For example, total aliphatic hydrocarbon contents ranged from 2.94 to 114.7 mg/kg dry weight, with a mean of 25.4 mg/kg in a study focused on urban runoff sediments in Tehran, Iran were lower than those found in some coastal regions but greater than those found in the sediments of urban rivers in Brazil and France. AH concentrations in surface soils during the dry season varied from 99.02 to 389.84 mg/kg in a different study that focused on soils close to hot mix asphalt facilities. These differences highlight the importance of conducting site-specific evaluations to determine the initial AH concentrations in landfill soils, which is crucial for developing effective remediation plans, displays the chemical formula, retention duration, and AH content in landfill soil. For the GC analysis, eight (8) duplicates of landfill soil were used. The concentrations of nonacosane and pentadecane hydrocarbons were found to be greater at 38.09 and 30. Comparing other AHs, the comparable amounts were 15 mg/kg.

Table 6: Retention time, molecular formula and AHs concentration in landfill soil

n-alkane	Molecular Formula	Retention time (min)	Concentration (mg/kg) n=8
Decane	$C_{10}H_{22}$	10.253±0.01	9.63±0.03
Undecane	$C_{11}H_{24}$	13.434±0.04	11.77±0.08
Dodecane	$C_{12}H_{26}$	16.561±0.06	16.31±0.06
Tridecane	$C_{13}H_{28}$	19.550±0.02	12.82±0.11
Tetradecane	$C_{14}H_{30}$	22.380±0.03	19.34±0.08
Pentadecane	$C_{15}H_{32}$	25.053±0.05	30.15±1.33
Hexadecane	$C_{16}H_{34}$	27.612±0.02	16.32±0.91
Heptadecane	$C_{17}H_{36}$	30.029±0.08	18.63±0.85
Octadecane	$C_{18}H_{38}$	32.330±0.02	25.24±0.93
Nonadecane	$C_{19}H_{40}$	36.527±0.01	19.01±1.41
Eicosane	$C_{20}H_{42}$	36.620±0.03	23.84±0.83
Henicosane	$C_{21}H_{44}$	38.639±0.05	25.39±1.02
Docosane	$C_{22}H_{46}$	40.568±0.01	12.64±0.32
Tricosane	$C_{23}H_{48}$	42.420±0.04	25.09±0.71
Tetracosane	$C_{24}H_{50}$	44.197±0.08	12.88±0.08
Pentacosane	$C_{25}H_{52}$	45.911±0.01	25.03±0.99
Hexacosane	$C_{26}H_{54}$	47.559±0.04	13.64±0.31
Heptaosane	$C_{27}H_{56}$	49.156±0.06	17.39±1.03
Octacosane	$C_{28}H_{58}$	50.696±0.12	11.02±0.07
Nonacosane	$C_{29}H_{60}$	52.184±0.07	38.09±1.11
Triacontane	$C_{30}H_{62}$	53.632±0.01	14.11±0.51
Hentriacontane	$C_{31}H_{64}$	55.031±0.03	14.62±0.06
Dotriacontane	$C_{32}H_{66}$	56.389±0.06	29.06±1.05
Tritriacontane	$C_{33}H_{68}$	57.706±0.04	14.22±0.23

Phytoremediation of hydrocarbons from Landfill Soil
Remediation is crucial since many dump sites are found in less populated or non-urban areas, where the leachate is either partially or completely untreated and contaminates the flora. According to Jones et al. (2006), phytoremediation techniques make use of the natural or intentionally managed soil-plant relationship's capacity to eliminate toxic materials and break down and inactivate potentially hazardous hydrocarbons from landfill soil.

GC Chromatograms of AHs in landfill soil
The GC chromatogram of AHs in landfill soil is displayed in Figure 1.0. Petroleum hydrocarbons and polycyclic aromatic hydrocarbons are examples of organic pollutants that can be stabilized within the soil matrix, broken down and changed, or preserved in a form that is not phytotoxic (Chuluun et al., 2014).

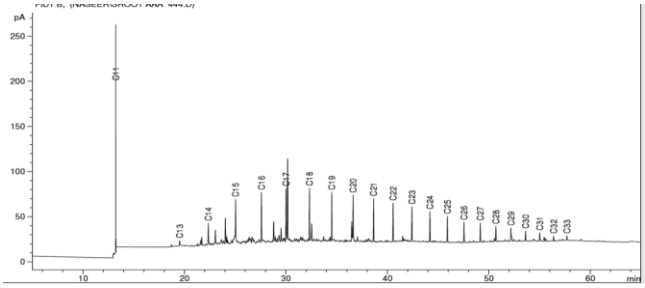

Figure 1.0 GC chromatograms of AHs in landfill soil

Accumulation of AH in plants
Plant accumulation of AH
The GC-FID chromatogram for the internal standard (*n*-eicosene) and the *n*-alkanes standard were presented in Figure 1.0. *A. wilkesiana* absorbed and accumulated AHs in its roots, allowing it to thrive on landfill soil. The concentration of AHs that were extracted from the plant root of the plant harvested on three different periods by GC-FID analysis was presented in Figure 1.0.

Science World Journal Vol. 20(No 3) 2025 https://dx.doi.org/10.4314/swj.v20i3.18
www.scienceworldjournal.org
ISSN: 1597-6343 (Online), ISSN: 2756-391X (Print)
Published by Faculty of Science, Kaduna State University

AH uptake by plant roots

Table 7: Concentration (mg/kg) of AH in control soil and the root of *A. wilkesiana* grown on Landfill soil within three different harvesting period (n=8)

n-alkane	Initial Control	2 months	4 months	6 months	Final Control
Decane	9.63±0.03	nd	nd	nd	1.31±0.05
Undecane	11.77±0.08	nd	nd	nd	3.15±0.14
Dodecane	16.31±0.06	nd	nd	nd	2.98±0.07
Tridecane	12.82±0.11	nd	nd	nd	1.77±0.01
Tetradecane	19.34±0.08	nd	nd	nd	3.94±0.21
Pentadecane	30.15±1.33	nd	nd	nd	5.31±0.16
Hexadecane	16.32±0.91	nd	nd	nd	3.26±0.08
Heptadecane	18.63±0.85	nd	nd	nd	2.73±0.12
Octadecane	25.24±0.93	3.40±0.02	4.06±0.02	5.51±0.11	4.22±0.23
Nonadecane	19.01±1.41	3.84±0.05	5.972±0.03	7.69±0.06	5.11±0.32
Eicosane	23.84±0.83	3.09±0.01	6.09±0.15	9.17±0.12	8.01±0.04
Henicosane	25.39±1.02	4.34±0.12	7.88±0.01	10.71±0.14	5.72±0.01
Docosane	12.64±0.32	1.38±0.01	4.53±0.06	6.26±0.09	3.43±0.03
Tricosane	25.09±0.71	4.59±0.06	8.84±0.19	11.34±0.08	9.61±0.11
Tetracosane	12.88±0.08	3.29±0.02	4.97±0.03	5.69±0.02	2.31±0.07
Pentacosane	25.03±0.99	4.90±0.13	5.79±0.11	11.74±0.31	6.04±0.03
Hexacosane	13.64±0.31	3.25±0.03	4.32±0.12	4.85±0.02	3.64±0.13
Heptaosane	17.39±1.03	2.67±0.01	4.07±0.08	7.61±0.03	2.05±0.09
Octacosane	11.02±0.07	1.34±0.01	4.09±0.12	5.63±0.04	4.18±0.05
Nonacosane	38.09±1.11	5.11±0.31	7.33±0.35	10.72±0.16	6.18±0.13
Triacontane	14.11±0.51	2.44±0.07	4.66±0.07	6.73±0.21	3.47±0.07
Hentriacontane	14.62±0.06	1.93±0.01	3.87±0.04	5.19±0.07	2.81±0.01
Dotriacontane	29.06±1.05	2.67±0.03	5.93±0.08	11.07±0.18	4.15±0.03
Tritriacontane	14.22±0.23	1.56±0.01	4.46±0.15	6.02±0.2	2.02±0.06

nd = not detected or below detection limit

One important component of phytoremediation, which uses plants to clean up contaminated soils, is the accumulation of aliphatic hydrocarbons in plant roots. It is possible for plant roots in contaminated soils to absorb aliphatic hydrocarbons, which are often found in petroleum products. Hydrocarbons were found in soil from an abandoned landfill site in Igbogene, Bayelsa State, Nigeria, according to a study by Uzoekwe and Anekwe (2020). These hydrocarbons may be absorbed by plants through their root systems. These hydrocarbons can either be digested in the roots or moved to the plant's aerial portions after absorption. The physicochemical characteristics of the hydrocarbons, the presence of root-associated bacteria, and the architecture of the roots all affect how efficiently hydrocarbons are absorbed and accumulated by different plant species.

Optimizing phytoremediation techniques to reduce soil pollution requires understanding the mechanisms behind the buildup of aliphatic hydrocarbons in plant roots. *A. wilkesiana* did not absorb AHs in the C_{10}–C_{17} range, but it did absorb and accumulate AHs in the C_{18}–C_{33} range from landfill soil to its roots (see Table 7.0), significant amounts of C_{26}, C_{23}, C_{21}, C_{24}, and C_{29} were accumulated by the plants with concentrations of 11.25, 10.59, 10.34, 10.29, and 10.11 mg/kg, respectively. A. C_{21}, C_{23}, C_{29}, C_{26}, and C_{27} were found to accumulate in *A. wilkesiana* at significant concentrations of 14.88, 14.84, 14.33, 14.32, and 14.07 mg/kg, respectively. By the conclusion of the 4th month, there was a noticeable increase in the accumulation of various hydrocarbons compared to the adsorption at the end of the 2nd month, there was a two-fold increase in absorption of several AHs at the end of the 4th month. *A. wilkesiana* has shown a low concentration of C_{32} at the end of the 2nd month. After 15 days of growth on soil contaminated with crude oil, Kosesakal *et al.* (2016) observed that *Azolla filiculoides* Lam had accumulated low molecular weight hydrocarbons after the alkanes had been totally eliminated from the soil at a concentration of 0.05% crude oil. The amount of AH absorbed by the root of A is displayed in Table 7.0. *A. wilkesiana* on six months of soil from a landfill. The roots of plant A did not absorb AHs from the C_{10}–C_{17} range. The concentration of C_{18}-C_{33} absorbed by the plant's roots varied from 4.90 to 11.74 mg/kg, concentrations of 10.72, 11.34, and 11.07 mg/kg, respectively, a notable buildup of AHs was noted for n-C_{29}, n-C_{23}, and n-C_{32} in the root. With a concentration of 11.74 mg/kg, the largest accumulation in the root was for C_{25} in the sixth month. However, throughout the harvesting period, there was an increase in the accumulation of AHs in the root, which followed the trend observed over six months. sixth month, the plant's roots accumulated a noteworthy 10.72 mg/kg of C_{29}. By the end of the sixth month, the *A. wilkesiana* plant had absorbed C_{25} in its roots at a noteworthy concentration of 11.74 mg/kg. As plant accumulation increases, so does the percentage of AHs absorb.

Table 8: Concentration (mg/kg) of AHs in control soil and the leaves of *A. wilkesiana* grown on Landfill soil within three different harvesting period (n=8)

n-alkane	Initial Control soil	2 months	4 months	6 months	Final Control soil
Decane	9.63±0.03	nd	nd	nd	2.31±0.01
Undecane	11.77±0.08	nd	nd	nd	3.18±0.04
Dodecane	16.31±0.06	nd	nd	nd	2.93±0.01
Tridecane	12.82±0.11	nd	nd	nd	1.57±0.01
Tetradecane	19.34±0.08	nd	nd	nd	4.94±0.11
Pentadecane	30.15±1.33	0.19±0.01	0.43±0.01	0.67±0.01	15.08±0.12
Hexadecane	16.32±0.91	3.11±0.06	5.78±0.04	7.79±0.68	3.41±0.03
Heptadecane	18.63±0.85	2.38±0.02	7.75±0.06	9.66±1.05	2.71±0.01
Octadecane	25.24±0.93	3.64±0.05	5.38±0.08	7.95±1.14	6.36±0.24
Nonadecane	19.01±1.41	4.86±0.14	6.78±0.03	9.53±0.87	3.21±0.32
Eicosane	23.84±0.83	1.33±0.01	4.63±0.06	8.52±0.69	4.01±0.04
Henicosane	25.39±1.02	5.31±0.16	7.72±0.09	9.78±0.84	2.72±0.07
Docosane	12.64±0.32	2.38±0.02	5.29±0.11	7.50±0.56	1.43±0.03
Tricosane	25.09±0.71	4.69±0.08	6.68±0.12	8.79±0.67	3.51±0.6
Tetracosane	12.88±0.08	1.09±0.01	3.61±0.07	7.69±0.1.22	2.50±0.03
Pentacosane	25.03±0.99	4.72±0.12	8.29±1.05	15.27±2.53	2.04±0.01
Hexacosane	13.64±0.31	2.06±0.01	4.99±0.06	7.78±0.96	3.27±0.12
Heptaosane	17.39±1.03	4.44±0.15	6.43±0.05	9.83±1.28	1.05±0.01
Octacosane	11.02±0.07	3.83±0.07	6.91±0.10	9.86±0.79	2.18±0.04
Nonacosane	38.09±1.11	8.93±1.03	12.73±0.75	16.18±2.74	4.38±0.12
Triacontane	14.11±0.51	3.72±0.64	5.49±0.06	9.23±0.68	2.68±0.05
Hentriacontane	14.62±0.06	4.17±0.12	7.51±0.12	10.36±2.04	1.39±0.01
Dotriacontane	29.06±1.05	2.66±0.01	5.89±0.14	8.75±0.56	2.06±0.03
Tritriacontane	14.22±0.23	4.27±0.05	7.43±0.68	11.04±1.13	1.05±0.02

nd = not detected or below detection limit

Translocation of AHs to the leaf of plants

AHs' translocation to plant leaves

One of the most important processes in comprehending phytoremediation mechanisms is the movement of AHs from plant roots to leaves. After being taken up by the roots, AHs can go to the plant's aerial portions, such as the leaves, via the vascular system. This plant may be used for phytoremediation of hydrocarbon-contaminated soils, according to a study that showed a progressive rise in AHs absorption, accumulation, and translocation from roots to leaves. The physicochemical characteristics of the hydrocarbons, the type of plant, and the surrounding environment are some of the variables that affect how effective this translocation process is. Optimizing phytoremediation techniques and choosing suitable plant species for the remediation of AH-contaminated settings require an understanding of these processes.

As indicated in Table 8.0, the plant moved hydrocarbons C_{15}–C_{33} to the leaf in two months. The study identified high concentrations of C_{21} and C_{28} hydrocarbons at 17.31 and 13.83 mg/kg, respectively, compared to other AHs. In contrast, the C_{10}–C_{14} hydrocarbons did not translocate to the leaves. go to the leaf. C_{21} was found to be translocated to the leaf by the plant at a high quantity of 17.31 mg/kg. Additionally, C_{20} was transferred to the plant's leaf at a dosage of 1.33 mg/kg. The concentrations of C_{14}–C_{33} hydrocarbons that were translocated to the leaf varied from 3.21 to 15.19 mg/kg. With concentrations of 8.88 and 15.19 mg/kg, respectively, C_{15} and C_{29} showed a high translocation. But after four months, the plant moved C_{15}–C_{33} to the leaf (see Table 8.0).

The range of AHs translocated concentrations was 0.19 –16.18 mg/kg. With concentrations of 10.36, 11.04, 15.27 and 16.18 mg/kg in the leaves for C_{31}, C_{33}, C_{25} and C_{29}, respectively, showed high accumulation. From Table 8. 0 for the two-fold increase in translocation of C_{17}, C_{27}, and C_{32} over the course of four months. It was noted that *A. wilkesiana* moved AHs to the leaf from C_{15} to C_{33}.

CONCLUSION

Acalypha wilkesiana's capacity to endure and thrive in landfill soil has been assessed. Heavy metals can be extracted and accumulated by the plant in the root, and at different harvest times, they can then go to the leaf. Scientists are paying close attention to phytoremediation, which may provide a workable answer to contamination issues. Because it is an alternative to soil replacement, heavy metal and hydrocarbon removal, and other soil remediation techniques, plant-based remediation of polluted soil has attracted a lot of interest. For all of the heavy metals that were the focus of this investigation, the order of metal accumulation in plant sections was leaf > stem > roots. Additionally, research demonstrated that the harvesting period has a significant impact on the accumulation of heavy metals by plant parts. It was discovered that the roots could absorb heavy metals from soil that had been spiked. Therefore, in soil that has been contaminated with heavy metals, both plants may be an excellent choice for phytoremediation. In the sixth month, the BCF showed that A. With the exception of Cu, Mn, Pb, and Zn, *A. wilkesiana* exhibits a BCF value greater than 1. Translocation of Cr to the leaves of both plants was higher than that of other heavy metals in terms of how easily the metals were transferred from the roots to the aerial parts of the plant. The study looked at the two plants' growth and reactions after they were planted in landfill soil, as well as the

buildup of hydrocarbons in the various plant sections. After first adhering to plant cell walls, hydrocarbons progressively permeate subcellular tissues. The amount of lipophilic chemical accumulation is determined by the lipid contents of intracellular components, and the diffusion rate is correlated with the concentration gradient between cell walls and internal organelles that was generated over the course of cultivation. The concentrations of AHs in the plants were determined by this investigation. The range of AHs concentrations in the roots was 1.34 – 11.34 mg/kg. In comparison to the control soil and plants, the plants' accumulated hydrocarbon contents were greater.

A conflict of interest
We affirm that no conflicts of interest exist.

Acknowledgement
The authors would like to thank Federal University Dutse in Jigawa State, Nigeria, and the Faculty of Resource Science and Technology, Universiti Malaysia, Sarawak (Unimas).

REFERENCES:

Allamin, I. A., & Shukor, M. Y. (2021). Phytoremediation of PAHs in Contaminated Soils: A Review. *Bioremediation Science and Technology Research*, 9(2), 1–6.

Chen, J., Wang, X. & Zhang, Y. (2022). Combined remediation techniques for hydrocarbon-contaminated soils: A review. Environmental Science and Pollution Research, 29(12), 17845–17860.

Chuluun, B., Shah, S.H. & Rhee, J.S. (2014). Bioaugmented Phytoremediation: A Strategy for Reclamation of Diesel Oil-contaminated Soils. *International Journal of Agriculture and Biology*, 16(3): 624–628.

Dilfuza, E. (2007). The effect of plant growth promoting bacteria on growth and nutrient uptake of maize in two different soils. Applied Soil Eco, E., 36, 184 – 189. DOI: 10.1016/j.apsoil.2007.02.005

Durumin Iya, N. I., Assim, Z. B., Omorinoye, O. A., Samling, B., Aquisman, A. E. & Ajlan, N. B. (2021). Phytoremediation of soil spiked with crude oil using *Acalypha wilkesiana* plant. UMYU Journal of Pure and Industrial Chemical Research, *UJPICR Volume 1 Number 2 :1-23.*

El Nemr, A., El-Sadaawy, M.M., Khaled, A. & Draz, S.O. (2013). Aliphatic and polycyclic aromatic hydrocarbons in the surface sediments of the Mediterranean: Assessment and source recognition of petroleum hydrocarbons. *Environment Monitoring and Assessment*, 185(6): 4571-4589.

El Nemr, A., Moneer, A.A., Ragab, S. & El Sikaily, A. (2016). Distribution and sources of n-alkanes and polycyclic aromatic hydrocarbons in shellfish of the Egyptian Red Sea coast. *Egyptian Journal of Aquatic Research*, 42: 121-131.

Haider, S. & Azmat, R. (2012). Failure of survival strategies in adaption of heavy metal environment in lens culinaris and Phaseolus mungo. *Pakistan Journal of Botany*, 44(6): 1959-1964.

Jones, D.L., Williamson, K.L. & Owen, A.G. (2006). Phytoremediation of landfill leachate. *Waste Management*, 26: 825–837.

Keshavarzifard, M., Zakaria, M. P., Yusoff, I. & Magam, S. M. (2019). Aliphatic hydrocarbons in urban runoff sediments: a case study from Tehran, Iran. Environmental Monitoring and Assessment, 191(6), 1-14.

Kosesakal, T., Unal, M., Kulen, O., Memon, A. & Yuksel, B. (2016). Phytoremediation of petroleum hydrocarbons by using a freshwater fern species *Azolla filiculoides Lam*. *International Journal of Phytoremediation*, 18(5): 467-476.

Kuppusamy, S., Thavamani, P., Venkateswarlu, K. & Naidu, R. (2020). Biodegradation of petroleum hydrocarbons in contaminated soils: A review. Journal of Environmental Management, 256, 109887.

Li, X., Wang, Y. & Liu, Z. (2019). Distribution and sources of aliphatic hydrocarbons in landfill soils. Environmental Pollution, 247, 1035–1044.

Liao, C., Xu, W., Lua, G., Liang, X., Guo, C., Yang, C . & Dang, Z. (2015). Accumulation of Hydrocarbons by Maize (Zea mays L.) in Remediation of Soils Contaminated with Crude Oil. International Journal of Phytoremediation, 2015, 17: 693–700. https://doi.org/10.1080/15226514.2014. 964840

Oladimeji, A. A. & Abayomi, O. O. (2022). Phytoremediation of soil spiked with crude oil using *Acalypha wilkesiana* plant. *Environmental Technology & Innovation*, 25, 102045.

Olajire, A. A. & Brack, W. (2016). Occurrence and sources of aliphatic hydrocarbons in soils within the vicinity of hot mix asphalt (HMA) plants in *Nigeria. Journal of Applied Sciences and Environmental Management*, 20(3), 601-611.

Sheng-You, X., Ying-Xu, C., Qi, L., Wei-xiang, W., Shen-Guo, X. & Chao-Feng, S. (2005). Uptake and accumulation of phenanthrene and pyrene in spiked soils by rye grass (*Lolium perenne* L.). *Journal of Environmental Sciences*, 17: 817-822.

Taheri, M., Motesharezadeha, B., Zolfaghari, A. A. & Javadzarrin I. (2 0 1 8) . Phytoremediation modeling in soil contaminated by oil-hydrocarbon under salinity stress by eucalyptus (A comparative study), Computers and Electronics in Agriculture, 2018, 346. doi: 10.1016/j.envpol.2008.06.031

Uzoekwe, S. A. & Anekwe, U. L. (2020). Physicochemical Characteristics, Particle Size Distribution and Total Hydrocarbon Content in Soil from Abandoned Landfill Site in Igbogene, Bayelsa state, Nigeria. *Journal of Applied Sciences and Environmental Management*, 24(4), 715–719.

Varjani, S. J., Joshi, R. R. & Srivastava, V. K. (2021). Microbial degradation of petroleum hydrocarbons: An overview. Bioresource Technology, 319, 124220.

Wang, Z., Yang, C. & Hollebone, B. P. (2018). Aliphatic hydrocarbons in environmental samples: Sources and fate. Environmental Chemistry Letters, 16(3), 1073–1089.

Zhang, H., Li, Q. & Sun, Y. (2020). Factors influencing the concentration of aliphatic hydrocarbons in landfill soils. Journal of Hazardous Materials, 389, 121918.