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A Study on the Influence of Cashew and Pawpaw Leaf on Soil Density Treatment of Contaminated Swampy and Clay Soils

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Abstract

Soil density is a key parameter in assessing soil health and structure, often employed as a potential index in bioremediation studies. This study investigates the impact of bioremediation treatments using Cashew Leaf (Anacardium occidentale) and Pawpaw Leaf (Carica papaya) on the density of swampy and clay soils over time. The results show that both treatments, in varying quantities, influence the soil's density by reducing the post-contamination density to levels closer to the pre-contamination state. This research aims to contribute to understanding the relationship between soil density and bioremediation using organic amendments, with implications for improving soil structure and fertility. The behavior of Total Bacterial Count (TBC) and Total Petroleum Hydrocarbons (TPH) in clay soil mirrored that observed in swampy soil. During model evaluation, the correlation coefficient values (R^2) derived from the Michaelis-Menten model were consistently higher than those from the first and second-order degradation rate models. Specifically, the R^2 values ranged from 0.9063 to 0.9894 for the first-order degradation rate, 0.8004 to 0.9396 for the second-order degradation rate, and 0.9639 to 0.9979 for the Michaelis-Menten equation. Therefore, the Michaelis-Menten equation provided a more accurate prediction of residual TPH compared to both the first and second-order degradation rate models.

Keywords: Bioremediation, cashew leaf, Michaelis-menten, soil density, total petroleum hydrocarbons

INTRODUCTION

Soil density, a measure of mass per unit volume is a fundamental physical property that influences key soil characteristics such as porosity, permeability, and compaction. These characteristics, in turn, play a critical role in determining soil functions like water infiltration, root penetration, aeration, and microbial activity. The density of soil is shaped by various factors, including texture, organic matter content, and external influences such as pollution. In contaminated soils, shifts in density often reflect changes in soil structure and function, potentially impairing the soil's capacity to support plant life and sustain ecological processes. As a result, soil density is a useful indicator for assessing the success of soil remediation and restoration efforts, particularly bioremediation [1,2].

Bioremediation involves the use of living organisms—primarily microorganisms or plants—to detoxify, degrade, or remove contaminants from polluted soils, with the goal of restoring soil health and fertility. Among the many bioremediation strategies explored, the incorporation of organic amendments—especially plant materials—has received considerable attention for their ability to promote ecological recovery. While numerous studies have focused on how these treatments affect

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chemical properties (e.g., pH, nutrient availability) and microbial communities, comparatively little research has addressed their impact on physical soil properties, such as density [3].

Understanding how bioremediation influences soil density is vital because changes in density can reveal how treatments are affecting the soil's structure and functionality over time. This is especially important in polluted environments, where contamination can lead to increased bulk density, soil compaction, reduced porosity, and impaired root development. Measuring changes in soil density can therefore provide insight into the physical recovery of soil and the overall effectiveness of bioremediation efforts [4].

Recently, there has been growing interest in the use of specific plant materials—such as Cashew Leaf (*Anacardium occidentale*) and Pawpaw Leaf (*Carica papaya*)—as organic amendments in bioremediation. Cashew Leaf contains high concentrations of tannins and other organic compounds that may assist in pollutant adsorption and detoxification. Pawpaw Leaf, on the other hand, is rich in nutrients and enzymes that support microbial activity, potentially enhancing the degradation of contaminants. These materials are believed to not only improve chemical and biological soil conditions but also alter physical properties such as density by enriching organic matter content and promoting microbial activity [5].

Although plant-based bioremediation has shown promise, the specific effects of Cashew and Pawpaw leaves on soil density remain understudied. Some previous research has indicated that organic amendments can reduce compaction and improve porosity [6, 7], but few studies have directly measured changes in density or linked them to specific plant-based treatments. Where density was considered, the findings suggest that organic matter additions like compost or leaf litter can lower bulk density in polluted soils, enhancing aeration and water retention [8, 9]. However, the role of Cashew and Pawpaw leaves—especially in challenging soil types like swampy or clay soils—has not been well documented.

To address this knowledge gap, the present study investigates how the application of Cashew Leaf and Pawpaw Leaf affects soil density in swampy and clay soils following contamination. By monitoring density variations over time, this research aims to clarify the role of these plant materials in restoring soil structure and function. Given that soil density is both an indicator of soil quality and a determinant of plant growth, this study offers valuable insights into the long-term efficacy of bioremediation strategies involving organic amendments [10–12].

METHODOLOGY

Study Objective and Experimental Design

This study was designed to evaluate the effect of organic amendments—specifically Cashew Leaf (*Anacardium occidentale*) and Pawpaw Leaf (*Carica papaya*)—on the density of contaminated swampy and clay soils. The research also explored the influence of a yeast and NPK fertilizer combination, with the goal of comparing natural restoration (control) against various treatment strategies. The primary novelty of this work lies in its direct investigation of soil density variation in response to plant-based bioremediation—an area that has received limited attention, particularly in swampy and clay soils, and using these specific organic materials.

Soil Selection and Preparation

Two distinct soil types were selected based on their contrasting physical characteristics:

i. *Swampy Soil:* Collected from a water-logged area with high moisture retention and low permeability.
ii. *Clay Soil:* Collected from an upland site with fine particle size, high compaction, and low aeration.

Each soil type was air-dried, sieved using a 2 mm mesh to remove debris, and homogenized to ensure uniformity before contamination.

Contamination Procedure

Soils were artificially contaminated to simulate polluted conditions. The contaminant used was a mixture of *motor oil and urea-based chemical fertilizer,* combined in a 3:1 ratio. This mixture was chosen for its relevance to real-world environmental pollution scenarios, particularly in agricultural and industrial areas. Contaminants were applied at a concentration of *5% by weight* of the soil (i.e., 50 g of contaminant per 1,000 g of soil). After mixing, the soils were left undisturbed ***for** 7 days* to allow for stabilization and integration of pollutants into the soil matrix.

Treatment Groups and Amendment Application

i. Following contamination and stabilization, each soil type was divided into 10 treatment groups, including a control. The treatments were applied as follows:
ii. *Control Group:* No amendments were added. This group served to monitor natural changes in soil density due to contamination and environmental exposure alone.
iii. *Cashew Leaf Treatment:* Dried Cashew leaves were pulverized into a fine powder and applied in five increasing doses—20g, 40g, 60g, 80g, and 100g—per 1,000 g of contaminated soil. The amendment was thoroughly mixed to ensure even distribution.
iv. *Pawpaw Leaf Treatment:* Dried and powdered Pawpaw leaves were applied in the same quantities as the Cashew Leaf treatments, using the same application method.
v. *Yeast + NPK Fertilizer Treatment:* A 1:1 mixture of baker's yeast (*Saccharomyces cerevisiae*) and NPK fertilizer (15:15:15) was added to the soils at equivalent doses of 20g, 40g, 60g, 80g, and 100g. This treatment served as a comparative synthetic-organic hybrid method to assess the synergistic impact on soil remediation.
vi. All treatments were incorporated uniformly into the soil samples by mixing manually in sterile containers to prevent microbial cross-contamination.

Experimental Setup

i. Each treatment, including the control, was conducted in triplicate (3 replicates per condition), yielding 60 containers per soil type (10 treatments × 3 replicates × 2 soil types = 60 per type; 120 total).
ii. Samples were kept in open plastic containers (20 cm diameter × 15 cm height) under controlled ambient conditions: temperature 27–30°C and relative humidity 70–80%.
iii. Moisture content was maintained at field capacity by periodic watering using distilled water every three days.

Soil Density Measurement Protocol

Soil density was evaluated as bulk density (g/cm^3), using the core method recommended by the American Society for Testing and Materials (ASTM D7263-09). At each sampling interval:

1. A known volume (100 cm^3) of soil was collected using a stainless-steel core sampler.
2. The samples were oven-dried at 105°C for 24 hours
3. Dry mass was measured using a precision balance (±0.01 g accuracy).

Measurement Intervals

Soil density was measured at seven intervals: Day 7, 14, 28, 42, 56, 70, and 84. This schedule captured both short-term responses and long-term trends in soil structural recovery.

Novelty of the Study

This study distinguishes itself in several key ways:

It is one of the first to systematically evaluate soil density changes due to plant-based bioremediation, particularly using Cashew and Pawpaw leaves, in two distinct and challenging soil types (swampy and clay).

The work explores dose-dependent effects of amendments, providing insight into the optimal quantity required for effective soil recovery.

It incorporates a comparison between organic and semi-synthetic treatments, offering a broader perspective on remediation strategies.

The focus on physical soil recovery (density) adds a new dimension to bioremediation research, which often emphasizes only chemical or microbial parameters.

The First Order Biodegradation Rate Kinetic Model

The first-order biodegradation rate kinetic model for predicting TPH reduction was developed based on the principle of mass conservation in a batch reactor. The principle of mass conservation is expressed as follows:

$$\begin{Bmatrix} Inflow\ of \\ mass\ into \\ system \end{Bmatrix} = \begin{Bmatrix} Outflow\ of \\ mass\ from \\ system \end{Bmatrix} + \begin{Bmatrix} Rate\ of \\ degradation \\ due\ to\ \ldots \end{Bmatrix} + \begin{Bmatrix} Rate\ of \\ accumulation \\ of\ mass \\ within\ system \end{Bmatrix} \quad (1)$$

The degradation reaction that takes place in the reactor can be represented by equation (2).

$$\mathrm{TPH} + \mathrm{E} + \mathrm{Z} \xrightarrow{k_s} P + E + Z \quad (2)$$

Where,

TPH = Total hydrocarbon (pollutant) (g)

E = Bacteria

Z = Soil (kg)

P = Products

k_d = Degradation rate constant (unit according to model used)

From equation (1) we have

Inflow of mass into system $= Q_o C_{TPH(o)}$ (3)

Outflow of mass from system $= QC_{TPH}$ (4)

Rate of TPH degradation $= -r_{TPH}V$ (5)

Rate of accumulation $= -\dfrac{d(C_{TPH}V)}{dt}$ (6)

The Second Order Biodegradation Rate Kinetic Model

The degradation rate of TPH would be further tested with the second order rate kinetics, and it is expressed as:

$$-r_{TPH} = -\frac{dC}{dt} = k_d C^2 \quad (7)$$

Upon integration of equation (7), we have as follows.

$$\int_{C_o}^{C_t} C^{-2} dC = -\int_0^t k_d dt$$

$$\frac{1}{C_t} - \frac{1}{C_0} = k_d t \quad (8)$$

Where,
C_0 and C_t are the initial and concentration of TPH at any time, *t*; while k_d is the degradation rate constant for the second order.

A plot of $\frac{1}{C_t}$ against t will give slope as k_d and $\frac{1}{C_0}$ as intercept.

The Michaelis-Menten Biodegradation Rate Model

Similarly, the degradation rate of TPH was tested with the Michaelis-Menten biodegradation rate, and it is expressed as:

$$r_{TPH} = \frac{\mu_{\max} C_{TPH(t)}}{K_s + C_{TPH(t)}} \quad (9)$$

Upon linearization, equation (9) becomes:

$$-\frac{1}{r_{TPH}} = -\frac{dC_{TPH(t)}}{dt} = \frac{1}{\mu_{\max}} + \frac{K_s}{\mu_{\max}}\left(\frac{1}{C_{TPH(t)}}\right) \quad (10)$$

where: $\mu_{\max}$ is the maximum specific degradation rate, $C_{TPH(t)}$ is TPH concentration with time *t*, K_s is the degradation rate constant relating to Michaelis-Menten.

A plot of $\frac{1}{r_{TPH}}$ against $\frac{1}{C_{TPH(t)}}$ gives the slope as $\frac{K_s}{\mu_{\max}}$ and $\frac{1}{\mu_{\max}}$ as intercept.

Table 1. Density Analysis in Swampy Soils with Cashew Leaf.

Time (Day)	Density(g/ml)					
	Control	***20g***	***40g***	***60g***	***80g***	***100g***
0	1.86	1.86	1.86	1.86	1.86	1.86
14	1.83	1.82	1.79	1.75	1.72	1.7
28	1.78	1.76	1.68	1.64	1.56	1.53
42	1.76	1.73	1.63	1.59	1.51	1.48
56	1.72	1.7	1.62	1.56	1.48	1.43
70	1.69	1.65	1.61	1.49	1.47	1.4
84	1.66	1.59	1.54	1.46	1.42	1.39

Table 2. Density Analysis in Swampy Soils with Papaya Leaf.

Time (Day)	Density (g/ml)					
	Control	***20g***	***40g***	***60g***	***80g***	***100g***
0	1.86	1.86	1.86	1.86	1.86	1.86
14	1.83	1.81	1.77	1.72	1.69	1.67
28	1.78	1.74	1.63	1.59	1.53	1.5
42	1.76	1.71	1.61	1.55	1.49	1.45
56	1.72	1.68	1.56	1.52	1.46	1.41
70	1.69	1.63	1.53	1.47	1.44	1.38
84	1.66	1.57	1.48	1.42	1.39	1.37

Tables 1 and 2 shows results obtained from Density Analysis in Swampy Soils for both Cashew Leaf and Papaya leaf respectively.

The results shows the respective flow of decline and increase in different days of the analysis which was carried out to examine the available density in the soil and the effect of Cashew Leaf and Papaya leaf on soil remediation of the investigated soil environment.

RESULTS AND DISCUSSION

Figure 1 illustrates the variation in soil density over time for swampy soil treated with Cashew Leaf. Although soil density has rarely been used as a key indicator in bioremediation studies, significant changes in density were observed across the treatment samples in this study. Notably, soil density increased with both time and the amount of treatment applied. The density of swampy soil before contamination was 1.37g/ml, which rose to 1.86g/ml following contamination. Subsequently, the density decreased to 1.66g/ml, 1.59g/ml, 1.54g/ml, 1.46g/ml, 1.42g/ml, and 1.39g/ml in the control and treatment samples of 20g, 40g, 60g, 80g, and 100g of Cashew Leaf in powdered form, yeast, and NPK, respectively, at the 84th day.

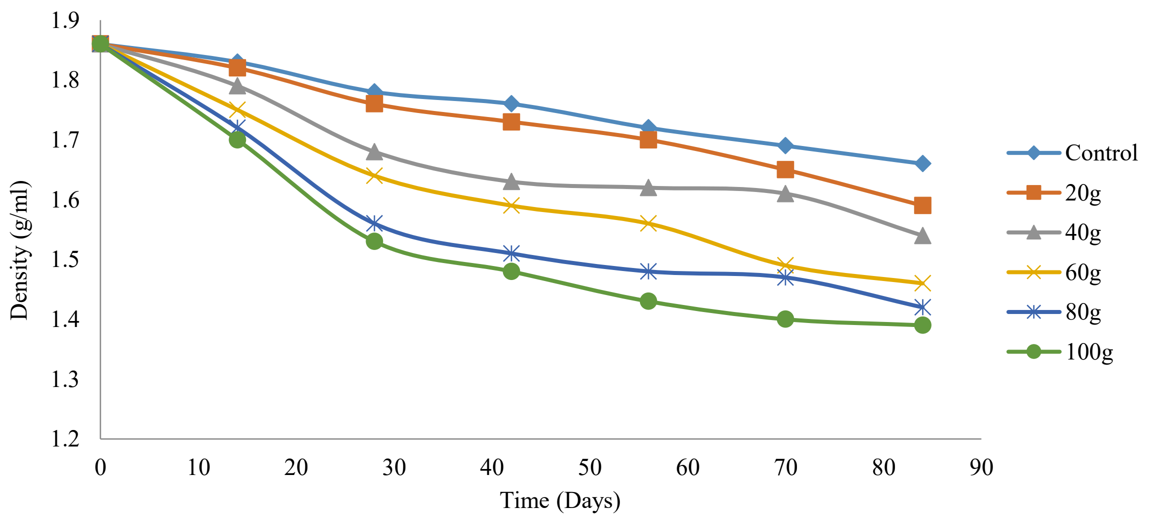

Figure 1. Variation of Density in Swampy Soil against Time for Cashew Leaf.

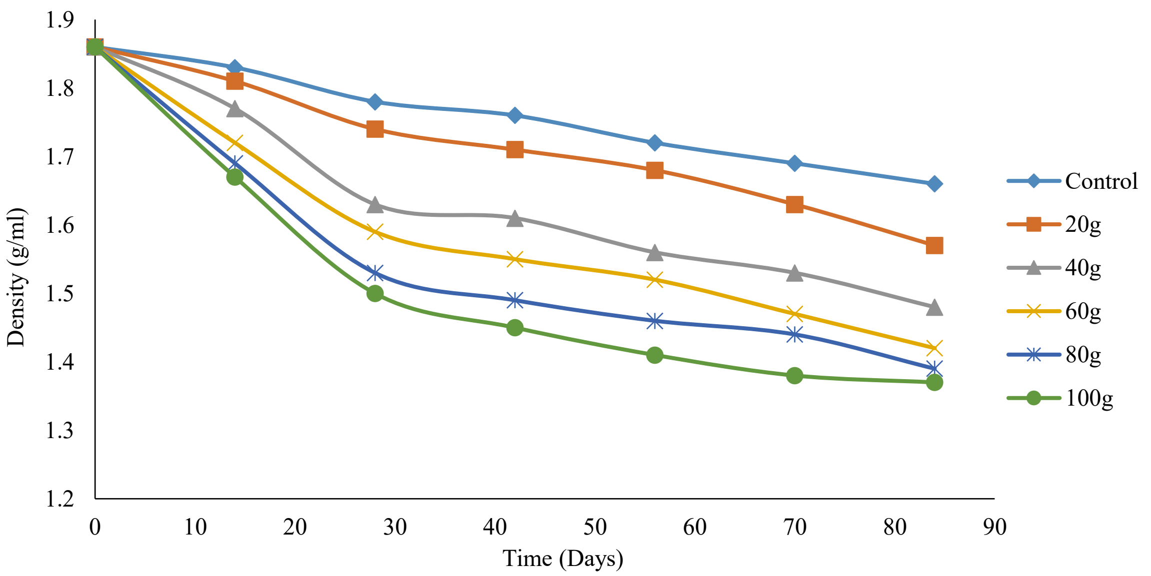

Figure 2. Variation of Density in Swampy Soil against Time for Pawpaw Leaf.

Figure 2 presents the profiles of soil density over time for swampy soil treated with Pawpaw Leaf. While soil density is rarely used as a primary indicator in bioremediation studies, notable changes in density were observed across the treatment samples in this study. Specifically, soil density increased with both time and the amount of treatment applied.

Prior to contamination, the density of swampy soil was recorded at 1.37g/ml, which increased to 1.86g/ml after contamination. Subsequently, the density decreased to 1.66g/ml, 1.57g/ml, 1.48g/ml, 1.42g/ml, 1.39g/ml, and 1.37g/ml in the control and treatment samples with 20g, 40g, 60g, 80g, and 100g of Pawpaw Leaf, respectively, at the 84th day. These values represent the measured density in swampy soil treated with Pawpaw Leaf.

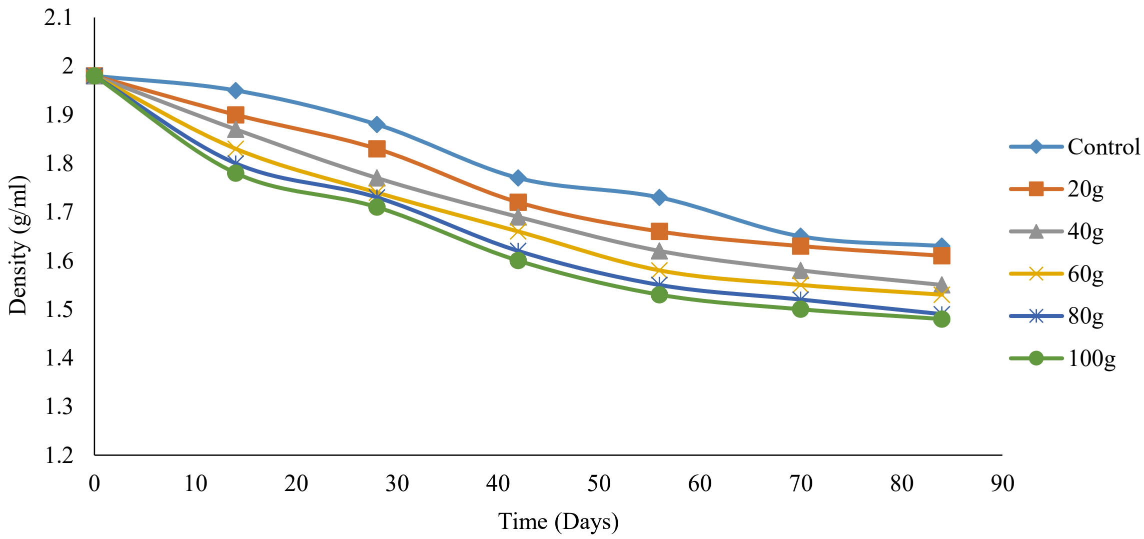

Figure 3. Variation of Density in Clay Soil against Time for Cashew Leaf.

Figure 3 illustrates the profiles of soil density over time for clay soil treated with Cashew Leaf. The figure demonstrates that the density of clay soil treated with Cashew Leaf increased as both the duration of bioremediation and the amount of treatment applied increased. By the end of the bioremediation process, the soil density approached the natural density of the clay soil, which was measured before contamination.

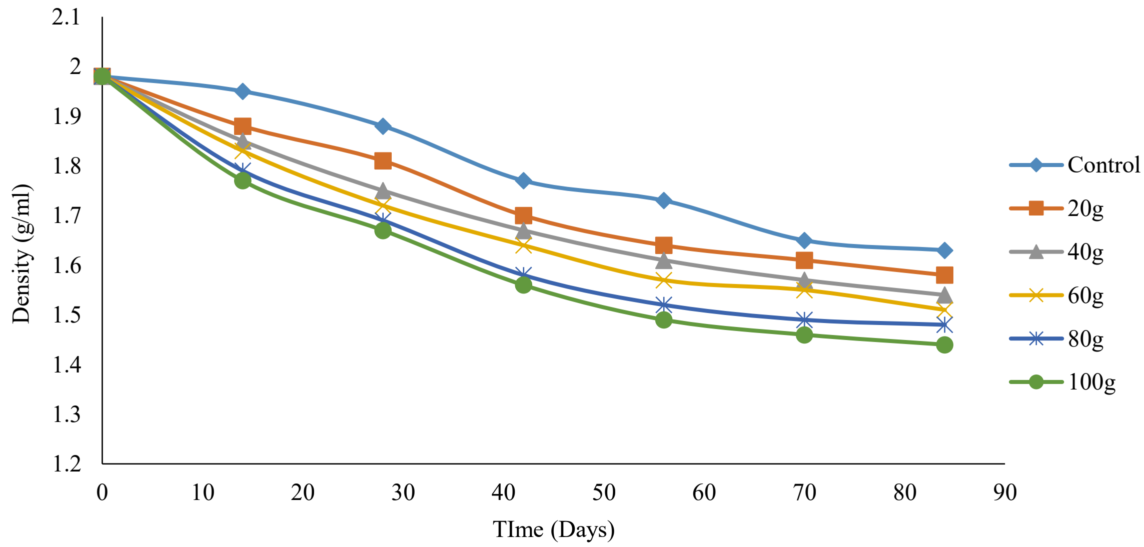

Figure 4. Variation of Density in Clay Soil against Time for Pawpaw Leaf.

Thus, the density of clay soil before pollution was recorded as 1.42g/ml, but increased to 1.98g/ml after contamination, and thereafter decreased to 1.63g/ml, 1.61g/ml, 1.55g/ml, 1.53g/ml, 1.49g/ml and 1.48g/ml respectively in control, 20g, 40g, 60g, 80g and 100g samples treated with Cashew Leaf at the 84^{th} day.

Figure 4 presents the profiles of soil density over time for clay soil treated with Pawpaw Leaf. The figure illustrates that the density of clay soil increased as both the bioremediation duration and the amount of treatment were increased. By the end of the bioremediation process, the soil density closely approached the natural density of the clay soil measured before contamination.

Before pollution, the density of clay soil was recorded at 1.42 g/ml, which increased to 1.98 g/ml after contamination. Following this, the density decreased to 1.63 g/ml, 1.58 g/ml, 1.54 g/ml, 1.51 g/ml, 1.48 g/ml, and 1.44 g/ml in the control and treatment samples with 20g, 40g, 60g, 80g, and 100g of Pawpaw Leaf, respectively, at the 84th day.

CONCLUSION

This study demonstrates that Cashew Leaf and Pawpaw Leaf treatments can effectively reduce the density of both swampy and clay soils following contamination. The bioremediation process leads to a gradual improvement in soil density, moving it closer to its pre-contamination state, which has positive implications for soil health. Further research should focus on optimizing the treatment doses and exploring other potential organic amendments for improving soil density in various types of polluted soils.

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