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Original Research Article

Reclaiming Former Coal Mines with Goat Manure and Rice Husk Charcoal for Oil Palm Growth

Anis Tatik Maryani[1], Sarman[1], Rosyani[2], Yardha[3], Adri[3], Atman[3*], Firdaus[3], dan Busyra B. Saidi[3], Yudha Gusti Wibowo[4]
[1]Department of Agroecotechnology, Faculty of Agriculture, Universitas Jambi, Jambi, Indonesia
[2]Department of Agribusiness, Faculty of Agriculture, Universitas Jambi, Jambi, Indonesia
[3]National Research and Innovation Agency, Jakarta, Indonesia
[4]Department of Mining Engineering, Faculty of Technology Industry, Institut Teknologi Sumatera, Lampung, Indonesia
*Corresponding Author, email: anis_tatik@yahoo.co.id

Abstract
This study focuses on the impact of goat manure and rice husk charcoal distribution on oil palm cultivation in former mining lands. The objective is to determine the optimal combination of goat manure and rice husk charcoal that enhances the growth of oil palm plants on these lands. Conducted in Pijoan Village, Muaro Jambi District, Jambi Province in 2021, the research utilized a completely randomized block design (RCBD) with 8 treatments and 3 repetitions, yielding 24 experimental units. The eight treatments consisted of varying ratios of goat manure to rice husk charcoal: (P1) 150 g goat manure + 325 g rice husk charcoal per planting hole, through (P8) 325 g goat manure + 150 g rice husk charcoal per planting hole. Results indicated that the combination of 325 g goat manure + 150 g rice husk charcoal (P8) provided the best outcomes in plant height, stem diameter, leaf balance at the third frond, and total frond count on reclaimed land.

Keywords: rice husk charcoal; coal mining; environment; goat manure; organic fertilizer; reclamation; oil palm

1. Introduction

Indonesia is a country with a substantial potential in mineral reserves, a factor that has spurred extensive mining activities (Gusti Wibowo et al., 2024; Wibowo et al., 2023b). Although mining significantly enhances state revenue, it adversely impacts the environment due to chemical use and soil dredging, leading to pollution and soil structure degradation (Wibowo et al., 2022a). The mining sector is a major driver of Indonesia's economy and national development, including coal mining, which is estimated to hold about 2-3% of the global coal resources (Setiawan, 2022).

Mining operations are temporary and conclude once they become economically nonviable or resources are depleted. Post-mining, the soil typically exhibits reduced chemical, physical, and biological fertility, necessitating rehabilitation for agricultural use (Pratiwi et al., 2021). Generally, coal mining in Indonesia employs open-pit methods, which involve removing overburden and extracting materials directly from the Earth's surface, eventually leaving large pits (Wibowo et al., 2023a, 2022b). These practices contribute to forest degradation, soil and water quality decreaed and impacted on human health.(Ramadan et al., 2021; Wibowo et al., 2024, 2022a). Reclaiming former mining lands is crucial, requiring an understanding of both biotic and abiotic environmental factors and processes (Feng et al., 2019).

In Sumatera island, the geological structure, characteristics of the overburden, and the condition of the underlying coal seam dictate the use of open-pit mining methods (Singhal, 2022). This process entails the removal of the overburden and subsequent excavation and transportation of mined materials, leaving behind considerable open pits. The adverse impacts primarily include land degradation and soil fertility loss, leading to widespread critical land, loss of topsoil, organic material, and essential plant nutrients, ultimately extinguishing native flora and fauna and reducing plant nutrition (Agus et al., 2019; Yang et al., 2022).

To restore the damaged post-mining landscapes to a functional state, reclamation efforts aim to rehabilitate the physical condition of the soil to prevent landslides, create reservoirs to improve water quality, and reforest the land. These activities are intended to restore the land's functionality and maintain environmental quality in post-mining areas, typically characterized by acidic and nutrient-poor soils, thereby enhancing soil fertility through fertilization. The novelty of this study lies in its focus on reclaiming and rehabilitating post-mining landscapes in Indonesia, with a particular emphasis on the unique biotic and abiotic challenges presented by the acidic and nutrient-poor soils typically found in these areas. Unlike other studies, which often focus on general environmental impacts of mining, this research delves into specific approaches that address soil fertility and the restoration of ecological function through targeted reclamation strategies, such as reforestation and soil nutrient enhancement. By addressing both soil structure and microbial activity, the study aims to provide a comprehensive strategy for restoring the ecological balance and productivity of post-mining soils.

Soil conditions significantly influence plant growth and diversity. Soil nutrients are controlled by interactions among soil's physical, chemical, and biological properties. Soil microorganisms play a crucial role in terrestrial ecosystems, affecting soil structure dynamics, energy transfer, nutrient cycling, and other ecological processes. Due to their short life cycles, soil microbes are particularly sensitive and respond quickly to minor environmental changes or stresses. In addition, the aims of this study are (1) Determine the optimal combination of goat manure and rice husk charcoal that maximizes the growth of oil palm plants on former mining land, (2) assess the impact of these organic amendments on plant growth parameters, including plant height, stem diameter, leaf balance, and total frond coun, (3) Explore the effectiveness of these organic materials in enhancing soil fertility and supporting sustainable agricultural use of rehabilitated mining areas

2. Methods

2.1. Materials

This study was conducted in Pijoan Village, Muaro Jambi District, Jambi Province, in 2021. The materials used included oil palm plants, goat manure, rice husk charcoal, water, and soil from a former coal mining site. Tools employed in the research were shovels, measuring instruments, calipers, writing equipment, cameras, paper, and a measuring tape. The soil nutrient content before the experiment (four weeks prior to planting) was as follows: pH H_2O (5.41; acidic), organic C (0.16%; very low), N (0.36%; medium), and C/N ratio (0.44; very low). The nutrient content of goat manure was: organic C (40.0%), total N (9.09%), C/N ratio (4.4), P (0.014%), and K (0.223%).

2.2. Data Collection and Data Analysis

The research was structured using a completely randomized block design (RCBD) with 8 treatments and 3 replications, resulting in 24 experimental units. Each experimental unit (plot) was planted with 3 oil palm seedlings, totaling 72 plants. Plants were spaced 9 m x 9 m apart in a triangular pattern, covering an area of 121.5 m^2. The treatments consisted of combinations of goat manure and rice husk charcoal, as follows:

P1: 150 g goat manure + 325 g rice husk charcoal per planting hole;

P2: 175 g goat manure + 300 g rice husk charcoal per planting hole;

P3: 200 g goat manure + 275 g rice husk charcoal per planting hole;

P4: 225 g goat manure + 250 g rice husk charcoal per planting hole;
P5: 250 g goat manure + 225 g rice husk charcoal per planting hole;
P6: 275 g goat manure + 200 g rice husk charcoal per planting hole;
P7: 300 g goat manure + 175 g rice husk charcoal per planting hole;
P8: 325 g goat manure + 150 g rice husk charcoal per planting hole.

Planting holes measured 30 cm x 30 cm x 30 cm (length x width x height). A basic fertilizer mix (20 g of NPK Phonska) was initially mixed with the topsoil in each planting hole. One week later, goat manure and rice husk charcoal were applied to the planting holes according to the treatment dosages. Seedlings, sourced from Marihat (North Sumatra Province), were planted one week after treatment application.

The variables observed included plant height (cm), stem diameter (cm), leaf balance on the third frond, and total number of fronds. Observations were made when the plants were 6, 7, 8, and 9 months after planting (MAP). Data collected were tabulated and analyzed for variance using the F-test, and significant differences were further analyzed using Tukey's HSD at the 5% level.

3. Result and Discussion

3.1. Plant Height (cm)

Diversity analysis revealed that the application of goat manure and rice husk charcoal at various doses significantly affected plant height (Table 1). Table 1 displays the heights for eight different fertilizer treatments. Treatment P8 yielded the highest mean effect among treatments P1 through P5, with an average height of 282.83 cm. The application of goat manure and rice husk charcoal at varying doses significantly influenced plant height. Among the eight treatments, Treatment P8 exhibited the highest average plant height of 282.83 cm, outperforming all other treatments. This finding underscores the synergistic effect of combining 325 g of goat manure and 150 g of rice husk charcoal in promoting optimal growth.

Table 1. Oil palm plant height after application of goat manure and rice husk charcoal at various doses at 9 months after planting (MAP*)*.

Treatment	Plant Height (cm)
P1	150 g goat manure + 325 g rice husk charcoal per planting hole
P2	175 g goat manure + 300 g rice husk charcoal per planting hole
P3	200 g goat manure + 275 g rice husk charcoal per planting hole
P4	225 g goat manure + 250 g rice husk charcoal per planting hole
P5	250 g goat manure + 225 g rice husk charcoal per planting hole
P6	275 g goat manure + 200 g rice husk charcoal per planting hole
P7	300 g goat manure + 175 g rice husk charcoal per planting hole
P8	325 g goat manure + 150 g rice husk charcoal per planting hole

Letters following the values indicate significant differences based on Tukey's HSD test at the 5% level. Figure 1 shows the significant growth increase each month resulting from the application of different doses of goat manure and rice husk charcoal. The combination of 325 g goat manure + 150 g rice husk charcoal (P8) contributed the most to plant growth enhancement.

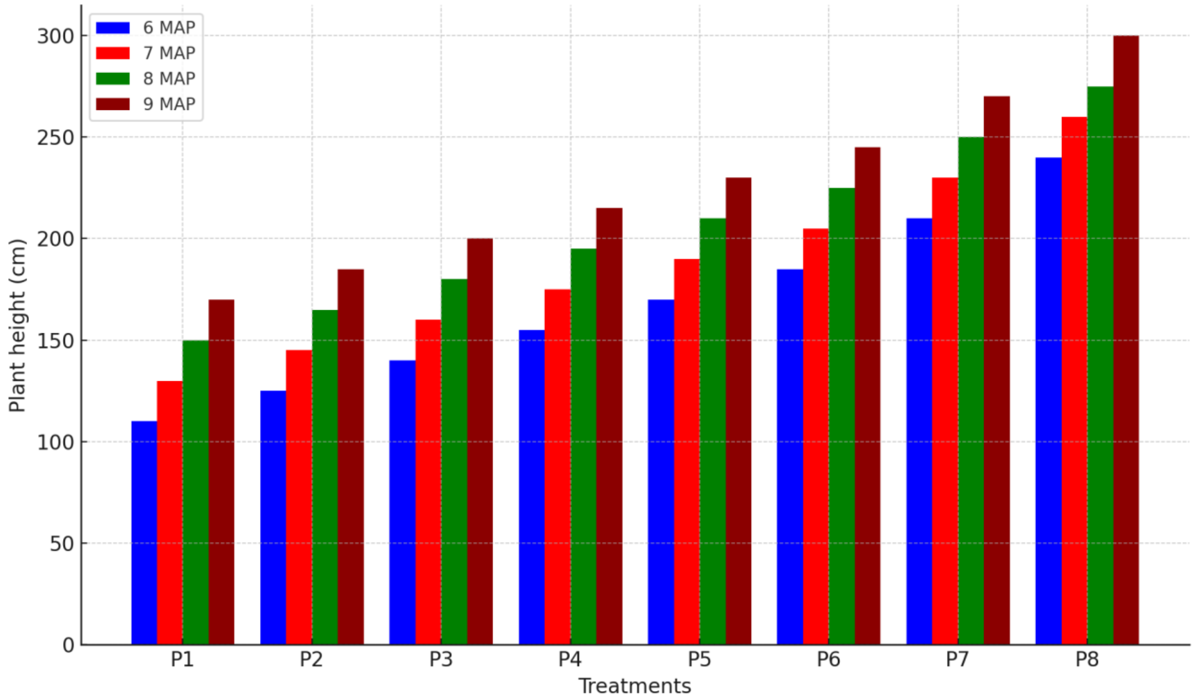

Figure 1. Influence of goat manure and rice husk charcoal dosage combinations on the height of oil palm plants (cm) at 6, 7, 8, and 9 months after planting (MAP)

3.2. Stem Diameter (cm)

The variability analysis indicated that the application of goat manure and rice husk charcoal at various doses also affected stem diameter (Table 2). Treatment P8 provided the highest average stem diameter and was not significantly different from treatments P5, P6, and P7 but showed a significant difference from treatments P1 through P4. The average stem diameter for treatment P8 was 97.83 cm. Stem diameter was also significantly affected by the application of goat manure and rice husk charcoal (Table 2). Treatment P8 achieved the highest stem diameter of 97.83 cm, showing significant improvement compared to treatments P1 to P4. However, no significant difference was observed between treatments P8, P5, P6, and P7.

Table 2. Stem diameter of oil palm plants after application of goat manure and rice husk charcoal at various doses at 9 MAP.

Treatment	Stem Diameter (cm)
P1	47.67a
P2	48.00a
P3	59.00b
P4	69.67b
P5	78.33b
P6	78.33b
P7	88.67c
P8	97.83d

Figure 2 illustrates the increase in stem diameter resulting from the application of goat manure and rice husk charcoal at various doses. The combination of 325 g goat manure + 150 g rice husk charcoal (P8) showed the best improvement in stem diameter.

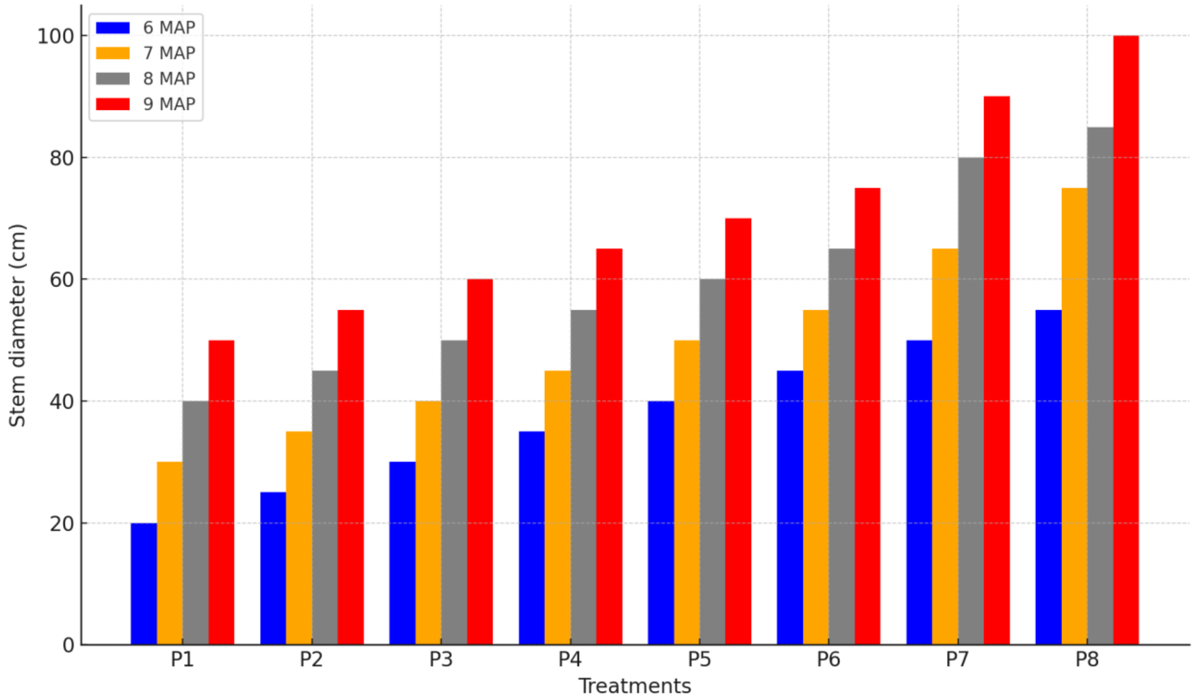

Figure 1. Effect of goat manure and rice husk charcoal dosage combinations on the stem diameter of oil palm plants (cm) at 6, 7, 8, and 9 months after planting (MAP).

3.4. Total Number of Fronds

The analysis indicated that the application of goat manure and rice husk charcoal at various doses affected the total number of fronds (Table 4). Treatment P8 resulted in the highest average number of fronds, significantly influencing all other treatments.

Table 4. Total number of fronds after application of goat manure and rice husk charcoal at various doses at 9 MAP.

Treatment	Number of Fronds
P1	8.00a
P2	7.50a
P3	7.67a
P4	8.67ab
P5	8.67ab
P6	8.83ab
P7	10.33b
P8	13.17c

Figure 3 shows a significant increase in the number of fronds each month due to the application of different doses of goat manure and rice husk charcoal. The treatment of 325 g goat manure + 150 g rice husk charcoal (P8) had the most substantial effect on increasing the number of fronds.

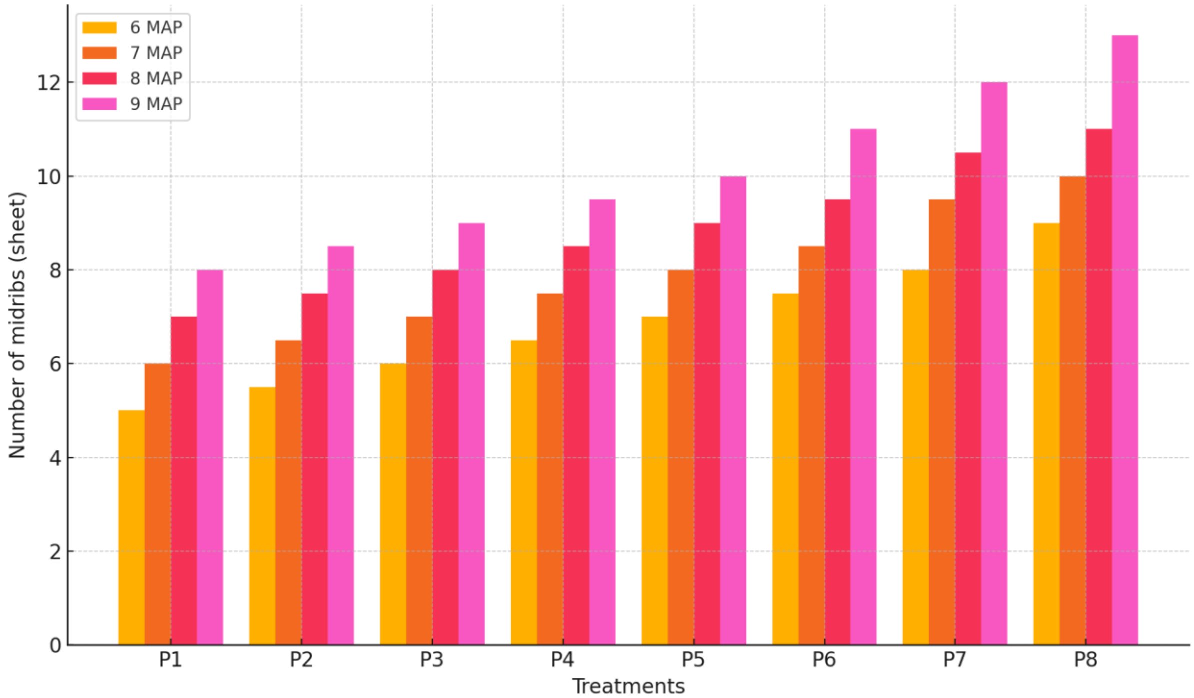

Figure 2. Impact of goat manure and rice husk charcoal dosage combinations on the number of fronds (leaves) of oil palm plants at 6, 7, 8, and 9 months after planting (MAP).

4. Discussion

The application of organic amendments, particularly goat manure and rice husk charcoal, has proven to be a highly effective strategy for rehabilitating degraded soils. These soils, especially those impacted by open-pit mining, often suffer from severe physical disruption, nutrient depletion, and chemical imbalances that make them unfit for sustained plant growth. Open-pit mining exposes subsoil layers that are generally low in organic matter, have poor water retention, and are prone to compaction, all of which hinder the establishment of vegetation. The combined use of goat manure and rice husk charcoal represents an environmentally sustainable and efficient approach to address these challenges.
In the study, the application of goat manure and rice husk charcoal significantly enhanced plant growth parameters, including plant height, stem diameter, and total number of fronds. These parameters are critical indicators of plant health and productivity. Treatment P8, which achieved the highest plant height of 282.83 cm, demonstrated the optimal balance of nutrients and improved soil conditions resulting from the amendments (Haryuni et al., 2022).

Plant height, as a key measure of vegetative growth, is directly influenced by nutrient availability and soil structure. Goat manure, a rich source of nitrogen, phosphorus, and potassium, contributes essential nutrients for chlorophyll synthesis and photosynthesis, which drive vertical growth. The rice husk charcoal complements this by enhancing the soil's water-holding capacity, ensuring that plants receive consistent moisture levels critical for cell elongation and metabolic processes (Rahmaniah and Azwana, 2023). This synergy highlights the importance of integrating organic amendments to achieve sustainable soil fertility and plant growth.

Similarly, the observed improvements in stem diameter under Treatment P8 underscore the structural benefits provided by these amendments. A robust stem ensures the development of a strong vascular system for nutrient and water translocation. Phosphorus, supplied abundantly by goat manure, supports energy transfer and structural integrity, while potassium helps regulate water uptake and maintain turgor pressure. These nutrients are crucial for developing thicker and more resilient stems capable of withstanding environmental stressors (Kharisun et al., 2019).

The total number of fronds, indicative of the plant's photosynthetic capacity, also increased significantly with the application of these amendments. The production of additional fronds is directly related to the plant's ability to synthesize chlorophyll, a process heavily reliant on nitrogen and magnesium. These nutrients, supplied by goat manure and facilitated by the enhanced aeration provided by rice husk charcoal, enable efficient nutrient absorption and root expansion (Mishra et al., 2017). Together, these factors promote vigorous foliage growth, improving the plant's photosynthetic efficiency and productivity.

The transformative effects of goat manure and rice husk charcoal on soil properties are pivotal to understanding their role in restoring degraded soils. Goat manure is a nutrient-rich organic amendment containing macronutrients (N, P, K) and organic carbon that enhances soil fertility. It provides a steady nutrient supply while promoting microbial activity, essential for organic matter decomposition and the conversion of nutrients into plant-available forms. The microorganisms involved in this process also produce compounds that improve soil structure by enhancing soil aggregation and porosity (Suyanto et al., 2023).

Rice husk charcoal, on the other hand, acts as a physical and chemical enhancer for soils. It improves porosity, which facilitates better air and water movement, and increases the cation exchange capacity, allowing the soil to retain and supply nutrients more effectively. The biochar-like properties of rice husk charcoal make it an excellent agent for long-term soil improvement, as it remains stable and resistant to decomposition over time. This stability ensures that nutrients remain available to plants, reducing the need for frequent fertilization and contributing to the sustainability of agricultural systems (Supriyadi et al., 2022).

The combination of goat manure and rice husk charcoal also addresses soil acidity, a common problem in degraded soils. Organic amendments help buffer soil pH, mitigating the effects of acidity or alkalinity, and thereby increasing the availability of essential nutrients such as phosphorus and potassium (Fitriana et al., 2020). This buffering capacity, coupled with improved soil aggregation and water retention, creates an environment conducive to root development and plant growth.

The implications of these findings extend beyond individual plant growth parameters to the broader field of land restoration. Post-mining soils are often characterized by poor fertility, low organic matter content, and compacted structures that impede root penetration. The application of organic amendments such as goat manure and rice husk charcoal provides a holistic solution to these challenges. By improving both the chemical and physical properties of the soil, these amendments create a favorable environment for vegetation establishment and growth, an essential step in ecosystem restoration (Steiner et al., 2007).

These amendments also enhance soil resilience to environmental stressors such as drought and nutrient leaching. The water-holding capacity provided by rice husk charcoal ensures that plants have access to moisture even during dry periods, reducing the risk of water stress. Moreover, the nutrient retention capabilities of goat manure and rice husk charcoal minimize losses due to leaching, ensuring that nutrients remain available to plants over extended periods (Koyama and Hayashi, 2017). The use of goat manure and rice husk charcoal also aligns with the principles of sustainable agriculture and a circular economy. By recycling agricultural waste into valuable soil conditioners, these practices reduce reliance on synthetic fertilizers, which are energy-intensive to produce and contribute to greenhouse gas emissions. Improved soil fertility reduces the need for external inputs, lowering the environmental footprint of agricultural practices. Additionally, the long-term benefits of these amendments, such as increased organic carbon levels and enhanced microbial activity, support the natural nutrient cycling processes critical for sustainable land management (Kharisun et al., 2019).

Economically, the use of locally available organic materials such as goat manure and rice husk charcoal can significantly reduce input costs for farmers, particularly in resource-constrained settings. These amendments not only improve crop yields but also enhance soil health, providing long-term benefits that outweigh the initial investment. This makes them an attractive option for smallholder farmers and large-scale agricultural operations alike.

While the benefits of goat manure and rice husk charcoal are well-documented, certain limitations warrant further investigation. For instance, the long-term effects of these amendments on soil health and productivity need to be evaluated to establish their sustainability. Additionally, potential environmental impacts, such as greenhouse gas emissions during the decomposition of organic materials, should be carefully monitored. Future research could explore the integration of these amendments with other soil restoration strategies, such as the use of cover crops, compost, or advanced biochars, to further enhance their efficacy (Haryuni et al., 2022). Moreover, site-specific conditions such as soil type, climate, and cropping systems must be considered to optimize the application rates and combinations of these amendments. Tailoring these practices to local contexts will maximize their benefits and ensure their successful adoption.

5. Conclusion

The application of goat manure in combination with rice husk charcoal has markedly influenced plant growth parameters, including stem diameter, leaf arrangement on the third frond, and the overall frond count. Specifically, the treatment involving 325 grams of goat manure mixed with 150 grams of rice husk charcoal (P8) demonstrated substantial improvements in plant height, stem robustness, and foliar development in areas previously subjected to mining. These findings underscore the transformative impact of this organic mixture on vegetation rehabilitation in degraded lands. Given the positive outcomes observed, it is imperative that further research be conducted to explore the long-term effects and sustainability of using goat manure and rice husk charcoal on oil palm plants. Future studies should aim to expand the experimental scope to multiple growth cycles and varying environmental conditions to validate and potentially optimize the restorative benefits of these treatments. Thus, this research highlights the promising potential of integrating goat manure and rice husk charcoal into land rehabilitation strategies, particularly in post-mining landscapes. Continued investigation will be crucial in establishing robust, scalable methods for ecological restoration and enhancing agricultural productivity in compromised soils.

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