Root Development and Nodulation Response of Groundnut (*Arachis hypogaea* L.) Seedling on Post-Tin Mining Soil Enriched with Organic Planting Media

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Abstract

Post-tin mining soils in Bangka Belitung are severely degraded, making them unsuitable for legume cultivation. This is because the root systems of the plants and their symbiotic relationships with root-associated bacteria require a high-quality growing medium. This study investigated how incorporating an organic planting medium influences the growth of groundnut (Arachis hypogaea L.) seedlings in such soils. The organic medium, consisting of compost, tea leaves, topsoil, manure, and biofertilizer, was mixed with post-mining soil in four ratios: P0 (100% mining soil), P1 (85% mining soil: 15% organic medium), P2 (75% mining soil: 25% organic medium), and P3 (60% mining soil: 40% organic medium). Growth parameters measured included shoot and root dry weight, shoot/root dry weight ratio, shoot and root length, shoot/root length ratio, shoot length per shoot biomass, root volume, and number of nodules. Adding organic media significantly affected the shoot/root dry weight ratio and nodule formation. The control treatment (P0) had the highest shoot/root dry weight ratio, although it was not significantly different from P1 and P2. Treatment P3 produced the highest number of nodules, which was significantly greater than that of the control but not significantly different from P1 and P2. These results highlight the potential of organic planting media to rehabilitate post-mining soil and support groundnut growth.

Keywords: *Arachis hypogaea L., groundnut, post-tin mining soil, organic planting media, root nodulation.*

INTRODUCTION

Bangka Belitung is an Indonesian province known for its tin mining. Sukarman & Gani (2020) reported that the Bangka Belitung region consists 1.294.050 hectares, with 27.56 percent declared as a tin mining concession area. This tin mining operation provides income for both the local population and the government, but it also results in environmental degradation. This activity results in a deterioration of land quality, affecting the physical, chemical, and biological properties of the soil. This includes areas characterized by tailings with irregular topographies, sandy texture classes, very low soil fertility, highly acidic pH levels, and minimal concentrations of organic carbon, nutrients (nitrogen, phosphorus, potassium), cation exchange capacity, and base saturation (Lestari et al., 2020). These soil characteristics often create conditions that are inadequate for many crop commodities. Ismail et al. (2025) stated that the addition of ameliorants to improve soil characteristics is essential for optimal plant growth. For certain leguminous plants, post-mining soil may present inadequate conditions for nodule formation. According to Manasikana et al. (2019), parameters such as soil acidity, aeration, sand and clay percentages, soil type, and organic matter concentration affect the limited growth capacity of root bacteria, including Rhizobium sp.

Groundnuts (*Arachis hypogaea* L.) are a significant food crop in Indonesia, ranked second in importance among legumes after soybean (Lolowang et al., 2022). In 2016, Statistics Indonesia (BPS) recorded a decrease in groundnut production in 2015 vs to 2014 of roughly 5.24% (Badan Pusat Statistik, 2025). Groundnuts are widely consumed by humans because they can be processed into various types of food and have high nutritional content. Groundnuts are also more resistant to pest attacks because their

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fruits, which are pods, develop underground. According to Sianipar et al. (2020), groundnuts contain 40–50% fat, 27% protein, 18% carbohydrates, and vitamins. Groundnuts are used as a direct food ingredient or as a component in food products such as bread, seasonings, industrial raw materials, and animal feed, so the demand for peanuts continues to increase every year in line with population growth.

Insufficient organic matter, inadequate soil fertility, and insufficient application of mineral fertilizers without organic amendments reduced groundnut productivity (Bekele et al., 2022). Additionally, inadequate root systems and nodule Development contribute to reduced groundnut yield. Enhancing groundnut production is essential, as yields have the potential to decline annually without appropriate management practices. Moreover, groundnuts, classified as legumes, possess the capacity to enhance soil chemical characteristics, particularly nitrogen availability. Groundnuts enhance soil nitrogen (N) content via symbiotic biological nitrogen fixing (Witcombe & Tiemann, 2022) . Legumes can assimilate nitrogen via a symbiotic association with nitrogen-fixing bacteria, specifically from the genus Rhizobium or Bradyrhizobium. Roots of legumes exude chemical substances, including flavonoids, that attract soil microorganisms. Upon infection, the bacteria establish root nodules in which nitrogen fixation proceeds. Inside the nodules, bacteria synthesize the enzyme nitrogenase, which converts atmospheric nitrogen (N_2) into ammonium (NH_4^+), a nitrogen form accessible to plants (Zhang et al., 2024).

Organic planting media, such as compost, is organic matter that has decomposed through the action of microorganisms, including bacteria and fungi, resulting in a stable, soil-like, nutrient-dense substance. Compost is an organic fertilizer that can substitute chemical fertilizers, which contribute to increased land degradation and greenhouse gas emissions. Compost enhances the pH of acidic soils and improves the physical, chemical, and biological properties of saline soils (Ho et al., 2022). The incorporation of compost into post-mining sites has demonstrated an enhancement in plant height, stem diameter, total biomass, root biomass, and shoot biomass in the growth of Octomeles Sumatrana Miq. seedlings (Muryati et al., 2022) reported that growing maize on a post-mining soil mixed with compost (3:2 ratio = 9 kilograms of post-mining soil + 6 kg of compost per bucket) yielded optimal results regarding plant height, leaf count, and stem diameter, although not for root volume. Moreover, no studies have examined the use of post-tin mining soil combined with organic planting media, which is made of a combination of compost, topsoil, tea leaves, manure, and biofertilizer.

This study aims to evaluate the growth performance of groundnuts, with a focus on root development and nodule formation, when cultivated in post-tin mining soils. The experiment employed varying ratios of post-mining soil and a commercial organic growing medium consisting of compost, tea leaves, topsoil, manure, and biofertilizer, and placed the mixture in a polybag to mimic application at the post-mining site. The 3:2 ratio was adapted from previous research on secondary crops, particularly corn, which identified this proportion as optimal when using compost. However, the composition of the organic medium in this study differs from that formulation. To assess the impact of enhancing the organic growing media on post-tin mining soil, two supplementary treatments were implemented: post-tin mining soil at 85% and organic growing media at 15% (17:3), and post-tin mining soil at 75% and organic growing media at 25% (3:1). The control treatment of 100% post-tin mining soil served as the basis for comparison.

This study was limited to the seedling stage of groundnut plants, so it focused on the first response to adjustments in the composition of the organic growth media, excluding the generative phase. This study attempts to serve as a reference for the effective use of organic growing media as planting media or soil fertilizers, while also offering practical dose recommendations for farmers, researchers, and sustainable agricultural practices.

MATERIALS AND METHODS

Place and Time

This research was conducted from August to September 2025 at the Green House of the Politeknik Manufaktur Negeri Bangka Belitung, Indonesia, located at 1°51’08.01” S; 106°07’51.27” E, at an altitude of 8 m above sea level.

Materials and Tools

The materials used in this study included post-mining soil, Tanah Subur organic material, and groundnut (*Arachis hypogaea* L.) seeds. The tools used consisted of a weighing balance, 1-kg capacity polybags, seedling trays for germination, a ruler, labels, stationery, and a watering can.

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Research Method

The experiment was conducted with a Completely Randomized Design (CRD) with a single factor and five replications. The experimental factor was the mixing ratio of post-tin mining soil and compost, consisting of the following treatment percentages, based on volume: P0 = Control (100% ex-mining soil), P1 = 85% post-tin mining soil and 15% organic planting media (17:3 ratio), P2 = 75% post-tin mining soil and 25% organic planting media (3:1 ratio), and P3 = 60% post-tin mining soil and 40% organic planting media (3:2 ratio).

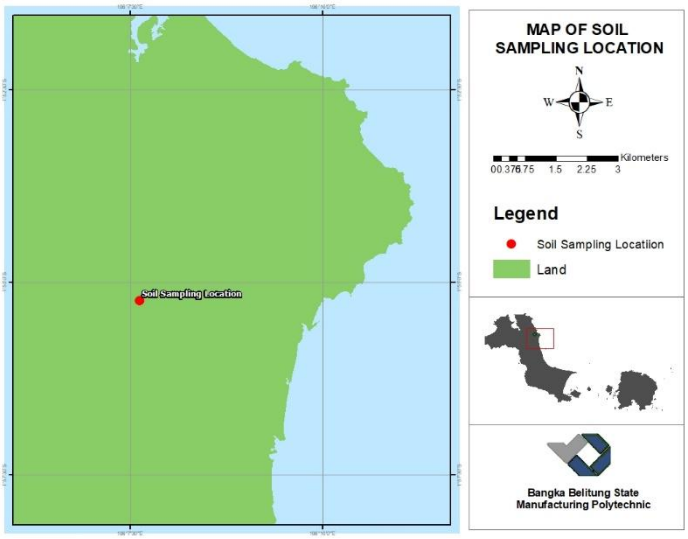


Figure. 1. Map Showing the Soil Sampling Location in the Ex-Tin Mining Area of Sungailiat, Bangka Regency, Bangka Belitung Islands Province.

The post-tin mining soil used in this study was obtained from a post-tin mine site located at Jalan Pattimura, Air Kenanga Village, Sungailiat District, Bangka Regency, Bangka Belitung Islands Province, at the coordinates 1°55'14.48"S and 106°7'37.65"E. The map of the soil sampling location is presented in Fig 1. The planting medium, used in combination with the post-tin mining soil, was a commercial planting medium from Tanah Subur, with no additional fertilizer applied. The manufacturer's information states that the components of this planting media are tea leaves, topsoil, manure fertilizer, compost, and biofertilizer bacteria. The combined medium was then placed in a 1 kg polybag. Measurements were conducted on the following parameters: root length, shoot length, shoot/root length ratio, shoot dry weight, root dry weight, shoot/root weight ratio, shoot length/shoot biomass ratio, root volume, and number of nodules. The shoot/root ratio was used as an indicator of biomass allocation and plant adaptive response to treatment conditions. Root volume was measured using the water displacement method based on Archimedes' principle (Cannell, 1980). The roots were washed free of adhering soil, immersed in a graduated cylinder filled with water, and the displaced water volume was recorded as root volume. The parameters were evaluated six weeks after planting. The shoot/root length ratio (1), shoot/root dry weight ratio (2), and shoot length/shoot biomass (3) were determined by:

$$Shoot/root\ length\ ratio\ = \frac{Shoot\ length\ (cm)}{Root\ length\ (cm)}\ (\mathbf{1})$$

$$Shoot/root\ dry\ weight\ ratio = \frac{Shoot\ Dry\ Weight\ (g)}{Root\ Dry\ Weight\ (g)}\ (\mathbf{2})$$

$$\text{Shoot length/shoot biomass} = \frac{\text{Shoot length (cm)}}{\text{Shoot biomass (g)}}\ (\mathbf{3})$$

Data Analysis

Statistical analyses were performed using SPSS software (version 27). Data were subjected to one-way Anova, and mean comparisons were conducted using Tukey's HSD test at a 95% confidence level.

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RESULTS AND DISCUSSION

Shoot and Root Morphological Response

The use of post-tin mining soil added with organic planting media soil at various ratios had no significant effect on the growth of shoot length, root length, and the shoot/root length ratio of groundnut seedlings (Table 1). This suggests that the ratios used for adding organic planting media have not substantially enhanced the physical and chemical characteristics of the post-tin mining soil used in the groundnut plant nursery phase. Bekele *et al.* (2022) stated that the limitations on groundnut production arise not solely from rainfall and soil fertility but also from the soil's physical, chemical, and biological characteristics, which require enhancement through a combination of inorganic and organic fertilizers.

Table 1. Change of Shoot Length, Root Length, and Shoot/Root Length Ratio as the Effect of Organic Growing Media

Treatment	Parameters		
	Shoot Length (cm)	Root Length (cm)	Shoot/root length ratio
P0 = Control (100% ex-mining soil)	19.26	32.28	0.60
P1 = 85% post-tin mining soil and 15% organic planting media (17:3 ratio)	17.32	34.92	0.50
P2 = 75% post-tin mining soil and 25% organic planting media (3:1 ratio)	17.92	39.82	0.45
P3 = 60% post-tin mining soil and 40% organic planting media (3:2 ratio)	15.52	32.08	0.48

Using small-sized polybags ensured controlled root conditions, which likely contributed to a uniform growth response among treatments, thereby minimizing the observable impact of different organic media ratios. In addition, the short duration of the seedling phase limited the plants' ability to utilize nutrients from organic sources, especially since organic growing media tend to have nutrients that are slowly available (Shaji *et al.,* 2021) stated that although organic fertilizers support sustainability, they are categorized as slow-release fertilizers, meaning that they release nutrients gradually into the soil and plant roots rather than dissolving immediately after application.

Despite the observation results indicating that the combination of post-tin mining soil with organic planting media did not result in a significant difference, the control treatment showed greater growth in shoot length and the shoot/root length ratio. This suggests that the condition of the post-tin mining soil used is still capable of supporting the growth of groundnut seedlings without the addition of organic planting media. It is important to recognize that soils following tin mining typically exhibit a compact structure, lower organic matter content, and limited water retention capacity, which may result in a decline in their long-term growth potential over time. Wulandari *et al.* (2022) examined the properties of post-tin mining soils in Bangka Belitung and found that the levels of organic carbon, nitrogen, and cation exchange capacity in this soil were significantly lower than those in natural forest and agroforestry soils. Consequently, the positive effects of organic planting media may become more evident during the later growth period, when the root system requires greater aeration, increased nutrient availability, and enhanced soil microbial activity.

Shoot and Root Biomass Response

Measuring shoot and root biomass is essential for evaluating groundnut growth and adaptation in post-mining soils, as these parameters provide insight into overall plant vigor and resource allocation. Investigation of shoot dry weight and root dry weight parameters showed no significant differences in the treatment containing a combination of organic planting media with post-mining soil on the growth of groundnut seedlings (Table 2). P2, with 75% post-tin mining soil and 25% organic planting media (3:1 ratio), generally yields greater root dry weights than the control treatment and other ratios. This tendency indicates that the application of moderate organic planting material in post-tin mining soil is considered preferable to other ratios. The absence of significant difference is probably related to the short duration of the experiment during the nursery phase (six weeks) and the delayed nutrient availability from the organic medium, which requires more time to degrade and become accessible to the plants (Shaji *et al.,*

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2021). Nutrients obtained from organic materials may not have been completely assimilated by the plants during the experiment.

Table 2. Change of Shoot Dry Weight, Root Dry Weight, and Shoot/Root Dry Weight Ratio as the Effect of Organic Growing Media

Treatment	Parameters		
	Shoot Dry Weight (g)	Root Dry Weight (g)	Shoot DW/root DW ratio
P0 = Control (100% ex-mining soil)	0.75	0.36	2.08 a
P1 = 85% post-tin mining soil and 15% organic planting media (17:3 ratio)	0.87	0.51	1.69 ab
P2 = 75% post-tin mining soil and 25% organic planting media (3:1 ratio)	0.93	0.55	1.70 ab
P3 = 60% post-tin mining soil and 40% organic planting media (3:2 ratio)	0.65	0.51	1.27 b

Note: Values followed by the same letter within a column are not significantly different at p <0.05 according to Tukey's Honest Significant Difference (HSD) test. No significant differences were observed among treatments.

The organic planting medium used in this study contained compost, tea leaves, topsoil, manure, and biofertilizer, which have been extensively researched and demonstrated to enhance the physical, chemical, and biological characteristics of the soil, along with its water retention capacity. Abbas *et al.* (2024) reported that adding 3% biochar, alongside 1% compost manure and 1% *Arbuscular mycorrhizae* as a biofertilizer, significantly improved soil carbon reserves, microbial biomass, and overall soil health, thereby enhancing yields in low-fertility soils. The organic planting medium used in this study is believed to enhance root development and the distribution of photosynthates inside the plant (Mariana, 2017), hence increasing the biomass of groundnut seedlings.

The shoot-to-root dry weight (DW) ratio is an important indicator of biomass allocation in peanut plants grown in post-mining soils. This ratio reflects how plants distribute resources between above-ground shoots and below-ground roots, providing insight into adaptive strategies under nutrient-limited and physically constrained conditions. A lower shoot/root DW ratio typically indicates increased allocation to roots, which may enhance water and nutrient uptake in degraded soils, whereas a higher ratio suggests more investment in shoot growth, potentially improving photosynthetic capacity.

This study revealed a significant difference in the shoot/root dry weight ratio resulting from the use of post-mining soil combined with organic planting media (Table 2). The control treatment showed the highest shoot/root dry weight ratio, which was not significantly different from P1 (85% ex-mining soil and 15% organic planting media, 17:3 ratio) and P2 (75% ex-mining soil and 25% organic planting media, 3:1 ratio). An increased proportion of organic planting media suggests a greater allocation of biomass to the shoot rather than the root.

The shoot/root dry weight ratio reflects a shift in biomass partitioning toward shoot growth as an adaptive response to improved media conditions, where enhanced nutrient uptake efficiency does not necessarily require a proportional increase in root biomass. However, under post-mining soil development conditions, an excessively high shoot/root ratio does not always correspond to improved plant establishment, as limited root development may constrain long-term water and nutrient acquisition. Therefore, improving soil conditions, including loosening soil structure, adjusting pH, and increasing organic matter content, is essential to support balanced shoot and root development (Azam *et al.,* 2025; Lynch, 1995). Treatments with a higher proportion of organic planting media (P3) appeared to positively influence the balance between root and shoot growth, showing no significant difference compared to P1 and P2 but significantly different from the control. This suggests the possibility of plant adaptation to media conditions characterized by improved aeration and increased organic matter content, as well as the potential for adjusting the pH of the planting medium so that the availability of nutrients for plants becomes more optimal. However, this study has limitations because the pH of the growing medium was not measured during the experiment. Therefore, the hypothesis that increasing the proportion of organic matter contributes to adjusting the pH of the growing medium remains indicative and needs to be confirmed through direct measurements in future research.

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Table 3. Change of Shoot Length/ Shoot Biomass and Root Volume as the Effect of Organic Growing Media

Treatment	Parameters	
	Shoot Length/Shoot Biomass (cm/g)	Root Volume (cm^3)
P0 = Control (100% ex-mining soil)	25.56	3.1
P1 = 85% post-tin mining soil and 15% organic planting media (17:3 ratio)	19.99	3.0
P2 = 75% post-tin mining soil and 25% organic planting media (3:1 ratio)	19.23	3.8
P3 = 60% post-tin mining soil and 40% organic planting media (3:2 ratio)	24.00	2.6

The shoot length to shoot biomass ratio (cm/g) and root volume (cm^3) are important parameters for evaluating groundnut growth in post-mining soil as they reflect plant growth efficiency and adaptation to degraded soil conditions. The shoot length/shoot biomass ratio indicates the relationship between shoot elongation and biomass accumulation, providing insight into how plants allocate resources for above-ground growth under nutrient-limited environments. Root volume represents the development and spatial expansion of the root system, which is essential for soil exploration and the uptake of water and nutrients in post-mining soils that are typically compacted and low in fertility. Together, these parameters help assess the balance between shoot development and root system establishment, providing a better understanding of plant responses to soil improvement treatments in reclaimed mining substrates.

In Table 3, it can be seen that shoot length/shoot biomass and root volume were not significantly affected by the addition of organic growing media to post-mining soil at various ratios. For the shoot length/shoot biomass parameter, although the trend shows that P0 was higher than the treatments with the addition of organic growing media at different ratios, this indicates that in pure post-tin mining soil, the plant shoots grew longer relative to the formed biomass, resulting in a higher proportion of shoot length to its weight.

Treatments receiving organic growing media (P1, P2, and P3) tended to exhibit a lower shoot length/shoot biomass ratio, suggesting more balanced shoot growth due to improved nutrient availability and soil structure. This indicates that the plants developed their shoots more efficiently, without excessive elongation relative to biomass accumulation. The physical and chemical properties of soil play a crucial role in determining crop productivity. Organic amendments have been shown to increase soil organic carbon by 38%, total nitrogen by 20%, microbial biomass carbon by 51%, and microbial biomass nitrogen by 24% compared to mineral-only fertilization. Moreover, organic amendments enhance soil microbial enzyme activity related to carbon acquisition (C-acq; 39%), nitrogen acquisition (N-acq; 22%), phosphorus acquisition (P-acq; 48%), and oxidative decomposition (OX; 58%). The improved nutrient acquisition and oxidative decomposition processes likely explain the positive impact of organic amendments on crop growth and yield (Luo *et al.,* 2018).

In the context of root volume parameters, it was observed that treatment P2 (75% ex-mining soil and 25% organic planting media, 3:1 average ratio, 3.8 cm^3) yielded better results, which was confirmed by the highest root length of 39.82 cm. Conversely, treatment P3 (60% ex-mining soil and 40% compost, 3:2) exhibited the lowest root volume at 2.6 cm^3. This tendency suggests that moderate levels of organic medium may enhance root development, while excessively high or low levels do not seem to confer significant advantages in root volume under these experimental settings.

Root Nodulation Response

Nodulation response is an important parameter for evaluating peanut performance in post-mining soils because it reflects the establishment of symbiosis between the plant and nitrogen-fixing bacteria. Effective nodulation indicates the plant's capacity to biologically fix atmospheric nitrogen, which is particularly critical in post-mining substrates that are typically characterized by low nitrogen availability and poor fertility. The number or activity of nodules can therefore serve as an indicator of soil biological quality and plant adaptation to the growth medium. Improved nodulation may also suggest that soil amendments enhance microbial activity and create more favorable conditions for symbiotic interactions, ultimately contributing to better nutrient acquisition and plant growth in degraded soils.

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Figure 2 shows the influence of nodule quantity on the roots of groundnut seedlings cultivated in post-mining soil combined with organic growth media in different ratios. The addition of organic growth media led to a markedly increased nodule number in comparison to the control (P0). Treatment P3 (60% post-mining soil + 40% organic media) had the largest nodule number, which was not substantially different from P1 and P2, but was significantly different from P0.

The increase in nodules (P3) is likely related to various enhancements in soil conditions resulting from the addition of organic media: reduced bulk density and enhanced porosity improve aeration and reduce mechanical limitations to root elongation, while increased water-holding capacity offers a more consistent supply of water and nutrients for the regulation of root system architecture (RSA) characteristics (Tao *et al.,* 2024; Voothuluru *et al.,* 2024). More flexible physical conditions promote root hair development and enhance the relationship between roots and microorganisms in the rhizosphere. Furthermore, organic media offers a readily biodegradable carbon source that enhances rhizosphere microbial activity, including Rhizobium populations, hence increasing the potential for root colonization and nodule formation (Cabrerizo *et al.,* 2001; Qin *et al.,* 2024). A greater proportion of organic media seems to modify the microphysical and microbiological environment, hence enhancing root exploration and nodulation, which leads to a more advantageous root-shoot growth ratio than the control.

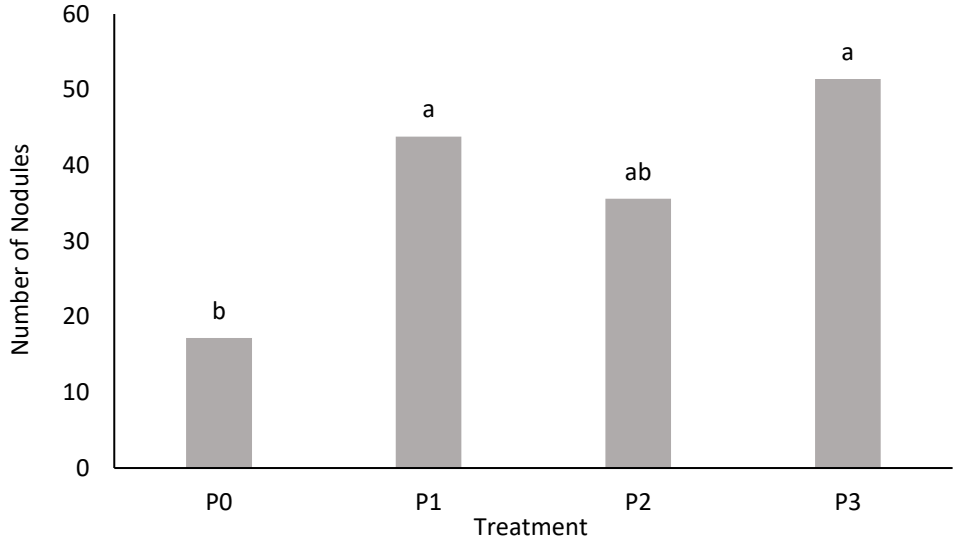


Figure. 2. Number of Nodules of Groundnut Grown in Ex-Tin Mining Soil with Different Ratios of Organic Planting Media. Bars Represent Mean ± Standard Error (n = 5). Values Followed by the Same Letter Are Not Significantly Different at p < 0.05 According to Tukey's HSD test.

The rise in nodule numbers indicates that incorporating organic matter into post-mining soil can create conditions favorable to nitrogen-fixing microorganisms, especially Rhizobium sp. Amaya-Gómez *et al.* (2025) reported in their systematic analysis of legumes that planting media enriched with compost, on average, enhanced nodule quantity by 66%. Fig. 3 shows the morphology of the roots and the resulting nodules. The organic matter content of commercial planting media used in this experiment, which is a mixture of manure, tea leaves, biofertilizers, and compost, likely enhances soil structure, improves aeration, and supplies a carbon source for soil microbes. These conditions indirectly enhance the probability of root infection by nitrogen-fixing bacteria and facilitate the development of further nodules. The presence of sufficient organic matter can improve soil biological activity through the improvement of the diversity of bacterial and rhizobial communities, particularly the symbiotic relationship between legumes and Rhizobium bacteria, which is essential for biological nitrogen fixation (Vanlauwe *et al.,* 2019; Qin *et al.,* 2024).

However, increasing the proportion of organic matter (P3) did not consistently ensure a much higher increase in nodule counts relative to the intermediate proportions (P1 and P2). This is probably due to the ideal balance of nutrients and soil aeration at the intermediate ratio, in which the addition of further organic matter stopped having a substantial impact on nodule formation.

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Figure 3. Root Morphology and Nodule Formation of Groundnut Seedlings Grown in Post-Tin Mining Soil Mixed with Different Ratios of Organic Planting Media.

CONCLUSION

The addition of organic planting media to post-tin mining soil affects the growth parameters of groundnut seedlings, particularly shoot/root dry weight and the number of nodules. Among the treatments tested, P3 (60% post-tin mining soil: 40% organic planting media) is recommended, as it promoted the most balanced root–shoot growth and the highest nodule formation, both favorable for seedling establishment in post-mining soils. Organic planting media improved soil physical and chemical properties and promoted nodule formation, which is generally associated with symbiotic nitrogen fixation in legumes. This indicates post-tin mining sites have potential as groundnut cultivation areas with organic media incorporation. Further research measuring soil pH, nutrient availability, and microbial activity is needed to confirm the role of organic amendments in post-mining soil rehabilitation.

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