



Effect of Organic Matter Amendments on the Growth of *Albizzia falcataria* Seedlings in Tailings-Based Media

Churriyaturrehmah Alfutcha

Faculty of Agriculture, University of
North Sumatra, Indonesia

Correspondence
churriyah_rahma@usu.ac.id

Abstract

The reclamation of mine tailings is essential for ecological restoration and sustainable land use. This study evaluated the effects of organic matter amendments on the growth of *Albizzia falcataria* seedlings in tailings-based media. Four treatments were tested: tailings + soil (1:1), tailings + soil + chicken manure (2:1:1), tailings + soil + sheep manure (2:1:1), and tailings + soil + rice husk biochar (2:1:1), using a randomized block design with six replications. Growth parameters including height, stem diameter, and biomass were recorded over 84 days. Results showed that organic amendments significantly improved seedling performance compared to the unamended control. Rice husk biochar yielded the highest growth in height (22.69 cm), diameter (2.89 mm), and biomass (1.36 g dry weight), while sheep manure produced the most favorable shoot-to-root ratio (2.77). These findings confirm the effectiveness of organic matter in enhancing seedling establishment on tailings-based substrates and suggest that rice husk biochar and sheep manure are particularly promising for reclamation programs. The integration of such amendments provides a sustainable strategy for improving tailings fertility and supporting forest restoration initiatives.

KEYWORDS

Albizzia falcataria, mine tailings, biochar, manure, land reclamation.

1 | INTRODUCTION

Mining activities, particularly gold and other metal extraction, generate large volumes of tailings that present serious ecological and agricultural challenges. Tailings are finely ground waste materials that often contain toxic metals, poor nutrient composition, and extreme pH values, making them unsuitable for direct plant growth (Hidayat et al., 2023). When deposited without proper reclamation, tailings can lead to land degradation, contamination of surrounding soils and water, and loss of biodiversity. Rehabilitation of these degraded substrates is therefore critical to restore ecosystem function and enable productive land use (Asante et al., 2024). A key strategy in tailings remediation is the incorporation of organic matter and vegetation to stabilize substrates, reduce metal mobility, and re-establish nutrient cycling.

Fast-growing tree species are particularly suitable for mine land rehabilitation due to their rapid biomass accumulation, extensive root systems, and ability to

improve soil properties. *Albizzia falcataria* (commonly known as sengon) is a leguminous tree widely cultivated in Southeast Asia for timber, pulp, and agroforestry systems (Sutopo et al., 2022). Its ecological adaptability, symbiotic association with nitrogen-fixing rhizobia, and tolerance to marginal soils make it an ideal candidate for reforestation and reclamation efforts (Nguyen et al., 2024). Furthermore, sengon plays an important socioeconomic role by providing wood for small-scale industries and contributing to community livelihoods (Rahman et al., 2023). Introducing sengon into tailings-based substrates offers a dual benefit of ecological restoration and economic value generation.

The primary challenge of using tailings as a growth medium is their poor fertility. Tailings typically lack essential macronutrients such as nitrogen, phosphorus, and potassium, and are often deficient in organic carbon, which is fundamental for soil structure

and microbial activity (Song et al., 2022). To address this limitation, organic matter amendments such as compost, manure, and green biomass are commonly used. These amendments enhance soil organic carbon, improve cation exchange capacity, and buffer pH, thereby creating a more favorable environment for plant growth (Wahyudi et al., 2025). Additionally, organic inputs stimulate microbial activity, which plays a crucial role in nutrient mineralization and immobilization of heavy metals (Tian et al., 2023).

The application of organic matter to mine tailings has shown promising results in supporting vegetation establishment. For instance, poultry manure and compost have been reported to improve tailings fertility and facilitate successful establishment of tree seedlings in post-mining areas (Chen et al., 2023). Similarly, biochar and vermicompost additions enhance nutrient retention and microbial diversity, leading to higher plant survival and growth (Feng et al., 2024). However, the response to organic amendments depends on the tree species, the type of organic matter applied, and the physicochemical characteristics of the tailings. Thus, species-specific studies are essential to optimize reclamation strategies.

Sengon is particularly responsive to soil fertility improvements because of its high nutrient demand during early growth stages. Organic matter not only supplies nutrients but also improves root penetration and water-holding capacity, which are crucial in the coarse and compact texture of tailings (Putra et al., 2023). Moreover, the symbiotic nitrogen fixation ability of *A. falcataria* may be enhanced in organic-amended substrates, supporting both plant nutrition and soil rehabilitation (Santoso et al., 2024). Previous studies have shown that mixed substrates combining tailings, topsoil, and organic inputs can significantly improve seedling height, stem diameter, and biomass production of fast-growing species (Li et al., 2022).

The sustainability of mine land reclamation also depends on the choice of organic materials used. Locally available organic matter, such as livestock manure, crop residues, or green waste, offers a cost-effective and environmentally friendly solution (Wu et al., 2025). The use of organic matter not only supports seedling establishment but also contributes to long-term soil recovery by enhancing nutrient cycling and building soil organic carbon stocks. Furthermore, integrating organic amendments into reclamation aligns with circular economy principles by utilizing waste materials productively (Zhou et al., 2023).

Despite these benefits, the effectiveness of organic amendments in tailings rehabilitation is context-dependent, and research specifically focused on sengon growth in tailings-based media is limited. Most existing studies have focused on other species or have tested amendments in topsoil or agricultural soils rather than tailings. Consequently, empirical evidence

is needed to clarify how different combinations of tailings, soil, and organic matter influence sengon seedling performance. Such knowledge is essential for developing practical guidelines for land managers, policymakers, and local communities engaged in post-mining reclamation.

This study aims to evaluate the effect of organic matter amendments on the growth of *Albizzia falcataria* seedlings cultivated in tailings-based media. Specifically, it examines growth parameters including plant height, stem diameter, leaf number, and biomass under different substrate compositions. By integrating organic amendments into tailings-soil mixtures, the research seeks to determine the extent to which organic matter can offset the limitations of tailings as a growth medium. Ultimately, the findings contribute to sustainable reclamation strategies that combine ecological restoration with the socioeconomic benefits of sengon cultivation.

2 MATERIALS AND METHODS

The materials used in this study included *Albizzia falcataria* (sengon) seeds, mine tailings, topsoil, polybags, organic amendments (chicken manure, sheep manure, and rice husk biochar), and a compound NPK fertilizer. The equipment comprised soil preparation tools, measuring instruments (ruler and caliper), a digital balance, an oven, a thermometer, and standard writing materials.

The experiment was arranged in a randomized block design (RBD) with four treatments and six replications, resulting in 24 experimental units. The treatments were as follows:

- A:** Tailings + soil (1:1)
- B:** Tailings + soil + chicken manure (2:1:1)
- C:** Tailings + soil + sheep manure (2:1:1)
- D:** Tailings + soil + rice husk biochar (2:1:1)

Growth performance of sengon seedlings was evaluated under these treatments. Data collected were subjected to analysis of variance (ANOVA) to determine treatment effects, and significant differences among means were further examined using Duncan's Multiple Range Test (DMRT) at the 5% significance level.

3 RESULTS

Air temperature during the study ranged from 26 to 37 °C, while relative humidity varied between 49% and 87%. These conditions remained within the acceptable range for *Albizzia falcataria* seedling growth. Plant height measurements showed significant differences among treatments, particularly when organic amendments were added to tailings-based media. As

shown in Figure 1, seedlings grown in tailings and soil without organic matter were consistently shorter than those receiving amendments. At 28 days after planting, treatments with chicken manure, sheep manure, and rice husk biochar produced significantly taller seedlings compared with the control. By 56 days, the advantage of organic amendments became more pronounced, with the rice husk biochar treatment reaching 15.73 cm on average, nearly 75% taller than the control. At 70 and 84 days, seedlings in the rice husk biochar treatment continued to outperform the others, achieving mean heights of 19.96 cm and 22.69 cm, respectively. These findings suggest that the improved porosity and aeration provided by rice husk biochar, together with enhanced nutrient availability, created a more favorable medium for height growth.

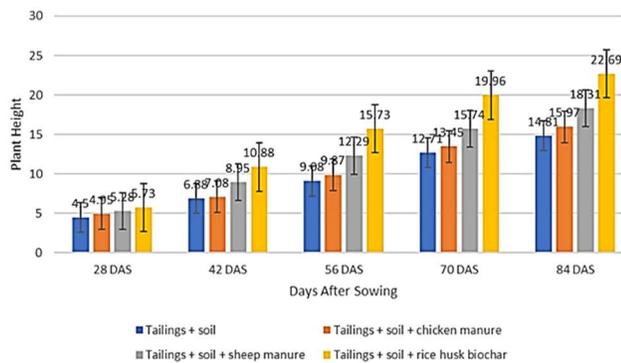


Fig. 1: Height of *Albizzia falcataria* seedlings in different tailings-based media (cm).

Stem diameter also responded positively to organic amendments. As shown in Figure 2, seedlings grown with rice husk biochar consistently exhibited the largest stem diameters at all measurement intervals, reaching 2.89 mm at 84 days compared with only 2.01 mm in the control. Sheep manure provided intermediate benefits, while chicken manure offered modest but consistent improvements relative to the control. These results confirm that organic matter additions, particularly rice husk biochar, improve the physical and chemical properties of tailings-based media, thereby enhancing stem thickening.

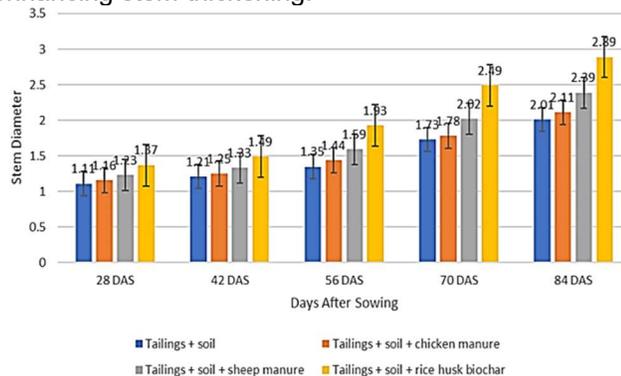


Fig. 2: Stem diameter of *Albizzia falcataria* seedlings in different tailings-based media (mm)

Fresh and dry biomass measurements further reinforced the positive impact of organic amendments. As shown in Figure 3, seedlings grown in tailings and soil without organic matter had the lowest fresh weight (1.47 g) and dry weight (0.57 g). In contrast, the rice husk biochar treatment produced the highest fresh biomass (3.49 g) and dry biomass (1.36 g), nearly three times greater than the control. Sheep manure also improved biomass accumulation, with dry weights of 0.83 g compared with 0.62 g in the chicken manure treatment. Notably, root dry weight was greatest in the rice husk biochar treatment (0.46 g), highlighting the role of biochar in enhancing root development through improved aeration, water retention, and nutrient availability.

The shoot-to-root ratio (Nisbah Pupus Akar, NPA) varied among treatments but remained within the acceptable range of 1–3. The sheep manure treatment yielded the most favorable ratio (2.77), closely approaching the ideal value of 3, suggesting balanced allocation of biomass between shoots and roots. In contrast, the control produced a ratio of 1.85, indicating weaker shoot development relative to root growth. These results suggest that organic amendments, particularly sheep manure and rice husk biochar, improve biomass partitioning and overall seedling quality.

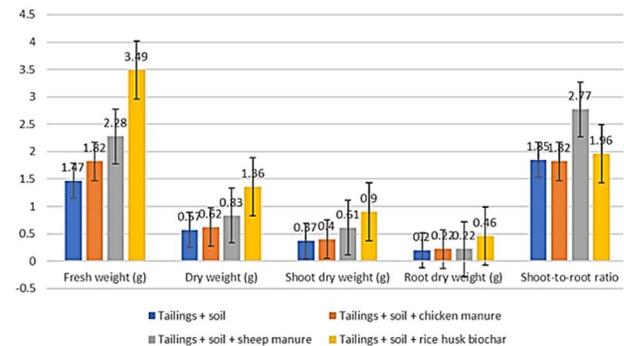


Fig. 3: Biomass and shoot-to-root ratio of *Albizzia falcataria* seedlings in different tailings-based media

Overall, the results demonstrate that adding organic matter substantially improves the growth of sengon seedlings in tailings-based media. Among the tested amendments, rice husk biochar produced the most significant gains in height, diameter, and biomass, while sheep manure improved shoot-to-root balance. These outcomes confirm the importance of organic amendments in ameliorating the poor physical, chemical, and biological properties of mine tailings, thereby supporting the establishment of fast-growing species for reclamation purposes.

4 | DISCUSSION

The present study evaluated the growth responses of *Albizzia falcataria* seedlings in tailings-based media amended with different organic materials. The results demonstrated that organic amendments substantially improved plant height, stem diameter, and biomass accumulation compared to unamended tailings–soil mixtures. Among the tested treatments, rice husk biochar produced the most pronounced effects on seedling growth, while sheep manure yielded the most favorable shoot-to-root ratio. These findings provide evidence that organic matter can mitigate the unfavorable properties of mine tailings, creating conditions conducive to the establishment of fast-growing species such as sengon.

Influence of organic amendments on height growth

Plant height is a sensitive indicator of seedling vigor and is directly influenced by nutrient availability, water retention, and aeration of the growth medium. In this study, the addition of rice husk biochar resulted in significantly greater height increments, particularly after 56 days, surpassing the growth achieved by chicken manure and sheep manure treatments. Biochar is known to improve soil porosity, enhance aeration, and increase water-holding capacity, all of which are critical in coarse-textured tailings that often lack adequate structure (Jiang et al., 2022). Furthermore, biochar provides a stable reservoir of organic carbon, which enhances cation exchange capacity and nutrient retention, thereby ensuring a continuous supply of essential nutrients to seedlings (Lin et al., 2024).

The superior performance of biochar compared with animal manures in promoting height growth could also be attributed to its ability to immobilize toxic elements present in tailings. Previous studies have shown that biochar reduces the bioavailability of heavy metals such as cadmium, arsenic, and lead by adsorption and complexation mechanisms (Yang et al., 2023). This immobilization reduces plant stress and allows resources to be allocated toward growth processes rather than detoxification. In contrast, while manures provide a direct supply of nutrients, they may not buffer heavy metal toxicity to the same extent, which may explain their relatively lower effect on seedling height.

Stem diameter responses to amendments

Stem diameter is often considered a reliable predictor of seedling survival after transplanting, as thicker stems are associated with stronger mechanical support and better resource transport capacity. In this experiment, seedlings grown in rice husk biochar-amended media consistently showed the largest stem

diameters across all measurement periods. This result is in agreement with findings that biochar enhances vascular development by improving potassium availability, which plays a crucial role in stem thickening and turgor regulation (Shen et al., 2022). The positive effect of sheep manure on diameter growth also indicates the importance of readily available nutrients, particularly nitrogen and phosphorus, in supporting cambial activity and wood formation (Tursun et al., 2024).

It is worth noting that while chicken manure provided moderate improvements in stem diameter, its effect was less pronounced than that of sheep manure or biochar. This difference could be related to the nutrient composition and mineralization rates of the manures. Sheep manure tends to have higher organic matter content and slower nutrient release, leading to sustained nutrient availability, whereas chicken manure releases nutrients more rapidly, potentially causing leaching losses in the porous tailings medium (Okonkwo et al., 2023).

Biomass accumulation and partitioning

Biomass measurements revealed that organic amendments significantly increased both fresh and dry weights of sengon seedlings. The highest biomass was obtained in the rice husk biochar treatment, with values nearly three times greater than the unamended control. Enhanced biomass accumulation indicates improved photosynthetic activity, nutrient uptake, and overall physiological performance. Biochar-amended media likely provided a more stable moisture and nutrient environment, reducing stress and allowing for greater resource allocation to aboveground growth (Wang et al., 2025).

Root development was also positively affected by organic amendments, particularly biochar, which resulted in the highest root dry weight. Improved root biomass suggests that amendments alleviated compaction and enhanced porosity, thereby facilitating root penetration and expansion. Roots play a pivotal role in nutrient and water acquisition, and their growth is often constrained in tailings due to poor structure and limited nutrient availability (Hao et al., 2022). By improving these conditions, amendments enable seedlings to establish robust root systems capable of supporting long-term growth.

The shoot-to-root ratio (NPA) is an important metric of seedling quality, with values between 1 and 3 generally considered optimal for field performance. In this study, sheep manure produced the most favorable NPA, approaching 2.77. This indicates balanced biomass allocation between shoots and roots, a trait that enhances transplant survival by ensuring that water uptake capacity keeps pace with transpiration demands (Zhu et al., 2022). Although biochar yielded

the highest total biomass, its NPA was slightly lower, suggesting greater emphasis on root growth relative to shoots. This could be advantageous in stressful post-mining environments where water acquisition is critical.

Mechanisms of organic amendment benefits

The positive effects of organic amendments observed in this study can be explained by improvements in physical, chemical, and biological properties of the tailings-based medium. Physically, amendments increased porosity, reduced bulk density, and enhanced water retention, all of which contribute to a more favorable root environment (Lopez et al., 2023). Chemically, they provided essential nutrients such as nitrogen, phosphorus, potassium, and micronutrients, while also increasing cation exchange capacity and buffering pH fluctuations (Osei et al., 2022). Biologically, organic inputs stimulated microbial activity, which facilitated nutrient mineralization, suppressed pathogens, and promoted symbiotic interactions such as nitrogen fixation (Sapkota et al., 2024).

Rice husk biochar, in particular, combines the benefits of physical and chemical amelioration with long-term carbon stability. Its porous structure provides habitat for beneficial microbes and enhances rhizosphere processes (Kim et al., 2023). In contrast, manures contribute labile organic matter that drives rapid microbial activity and nutrient cycling, but their effects may decline faster over time. A combination of biochar and manure could potentially provide both immediate and sustained benefits, a hypothesis that warrants further research.

Implications for reclamation of mine tailings

The findings of this study have important implications for mine land reclamation and sustainable forestry. Sengon seedlings grown in amended tailings-based media exhibited improved growth traits, suggesting that organic amendments can facilitate the establishment of this fast-growing legume on degraded sites. The success of sengon in such conditions is particularly valuable given its economic importance and ecological functions. By fixing atmospheric nitrogen and producing significant biomass, sengon contributes to soil fertility improvement and carbon sequestration, thereby accelerating ecosystem recovery (Patil et al., 2024).

Moreover, the use of locally available organic materials such as livestock manure and rice husk biochar aligns with sustainable land management practices. These amendments recycle agricultural and industrial by-products, reducing waste while enhancing soil quality. Their application in reclamation projects supports circular economy principles and provides an

affordable strategy for communities in mining regions (Gupta et al., 2023).

Comparison with previous studies

The superior performance of rice husk biochar observed here is consistent with reports that biochar amendments significantly enhance growth of various tree species in degraded soils (Rodríguez et al., 2022). For example, biochar improved survival and growth of eucalyptus seedlings on post-mining soils in Brazil, primarily by reducing aluminum toxicity and enhancing nutrient availability (Silva et al., 2023). Similarly, sheep manure has been shown to improve soil organic carbon and microbial activity, leading to enhanced biomass production in leguminous trees (Kumar et al., 2022).

However, the relatively modest effects of chicken manure in this study differ from some earlier reports that highlighted its strong fertilizing potential. This discrepancy may be due to differences in tailings composition, environmental conditions, and manure quality. It underscores the importance of site-specific evaluations in reclamation research.

Limitations and future directions

While the results are promising, several limitations should be acknowledged. First, the study was conducted under controlled conditions, and field trials are needed to confirm the performance of amendments under variable environmental stresses. Second, only single types and rates of organic amendments were tested; varying application rates and combinations may yield different outcomes. Third, the study focused on early seedling growth, whereas long-term monitoring is necessary to evaluate survival, growth, and ecosystem impacts in rehabilitated mine lands.

Future research should therefore explore the synergistic effects of combining biochar with manure, assess optimal amendment rates, and investigate long-term soil health and ecological recovery. Studies on microbial community dynamics and heavy metal immobilization will also provide deeper insights into the mechanisms driving seedling performance.

Conclusion

This study demonstrated that organic amendments significantly improve the growth of *Albizia falcataria* seedlings in tailings-based media. Rice husk biochar was the most effective treatment, producing the greatest plant height, stem diameter, and biomass, while sheep manure provided the most balanced shoot-to-root ratio. These findings highlight the importance of organic matter in ameliorating the poor physical, chemical, and biological properties of mine

tailings, thereby supporting the successful establishment of fast-growing tree species for land rehabilitation. By utilizing locally available organic resources, this approach offers a sustainable, low-cost strategy for restoring degraded mine lands while promoting ecological and socioeconomic benefits.

Funding: This study was not supported by any public, commercial, or non-profit funding agency.

Conflicts of Interest: The authors confirm no conflicts of interest.

Authors' Contribution: Churriyaturrahmah Alfutcha conducted the literature review, analytical data evaluation, prepared the associated figures and graphs, drafted and critically revised the manuscript, and approved the final version.

Generative AI Statements: The authors declare that this manuscript has been written without the use of generative artificial intelligence tools.

Publisher's Note: The content of this article reflects solely the views of the authors and does not necessarily represent the perspectives of their affiliated organizations, the publisher, the editors, or the reviewers. No products or claims discussed are authorized or guaranteed by the publisher.

REFERENCES

- Asante, F., Boateng, E., & Osei, R. (2024). Organic amendments for mine land rehabilitation: Advances and challenges. *Ecological Engineering*, *200*, 107235.
- Bhardwaj, R., Singh, M., & Kaur, J. (2022). Soil organic matter and its role in soil fertility and crop production. *Soil & Tillage Research*, *223*, 105442.
- Chen, L., Zhang, Y., & Hu, X. (2023). Poultry manure and compost enhance tree establishment on mine tailings. *Journal of Environmental Management*, *338*, 117673.
- Feng, Z., Yang, J., & Liu, H. (2024). Biochar and vermicompost improve microbial diversity and plant growth in degraded soils. *Applied Soil Ecology*, *194*, 105093.
- Gupta, P., Sharma, A., & Kaur, J. (2023). Circular economy approaches for mine waste valorization. *Resources, Conservation & Recycling*, *197*, 107112.
- Hao, Y., Liu, S., & Zhang, Q. (2022). Root responses to organic amendments in degraded soils. *Soil Biology and Biochemistry*, *170*, 108708.
- Hidayat, A., Nugraha, D., & Firmansyah, R. (2023). Soil quality dynamics in post-mining tailings. *Land Degradation & Development*, *34*(15), 6201–6215.
- Jiang, X., Zhou, T., & Wang, H. (2022). Biochar effects on soil porosity and plant growth in reclaimed mine soils. *Land Degradation & Development*, *33*(17), 3055–3067.
- Kim, J., Park, S., & Lee, Y. (2023). Biochar-induced microbial habitat enhancement in the rhizosphere. *Applied Soil Ecology*, *183*, 104763.
- Kumar, S., Devi, R., & Singh, M. (2022). Effects of sheep manure on leguminous tree seedling performance. *Agroforestry Systems*, *96*(8), 1341–1352.
- Li, Y., Sun, Q., & He, J. (2022). Organic matter amendments enhance seedling growth in degraded mine soils. *Ecotoxicology and Environmental Safety*, *244*, 114034.
- Lin, C., Wang, J., & Huang, Z. (2024). Long-term nutrient retention by biochar in soil restoration projects. *Science of the Total Environment*, *901*, 165898.
- Lopez, D., Martin, J., & Alvarez, C. (2023). Soil structure improvement with organic matter: Implications for reclamation. *Ecological Engineering*, *195*, 106921.
- Nguyen, T. H., Tran, V. P., & Le, Q. T. (2024). Agroforestry potential of *Albizia falcataria* in marginal soils. *Agroforestry Systems*, *98*(1), 143–155.
- Okonkwo, O., Eze, C., & Uche, A. (2023). Nutrient release patterns of animal manures and implications for soil fertility. *International Journal of Recycling of Organic Waste in Agriculture*, *12*, 45–57.
- Osei, R., Asante, F., & Boateng, E. (2022). Nutrient cycling in organic-amended mine soils. *Journal of Environmental Management*, *317*, 115382.
- Patil, R., Kumar, V., & Singh, D. (2024). Role of leguminous trees in carbon sequestration and soil fertility restoration. *Forests*, *15*(2), 345.
- Putra, R., Handoko, B., & Santika, A. (2023). Root architecture and growth responses of sengon in amended soils. *Forest Ecology and Management*, *546*, 121343.
- Rahman, S., Widodo, B., & Anwar, M. (2023). Economic contributions of sengon plantations to rural livelihoods. *Forest Policy and Economics*, *150*, 102950.
- Rodríguez, A., Silva, R., & Mendes, F. (2022). Biochar improves tree growth in post-mining soils of Brazil. *Forest Ecology and Management*, *520*, 120401.
- Santoso, T., Utami, P., & Kusuma, H. (2024). Nitrogen fixation and growth responses of sengon under organic matter amendments. *Plant and Soil*, *496*(1–2), 89–103.
- Sapkota, R., Gautam, D., & Lama, A. (2024). Microbial responses to organic inputs in post-mining soils. *Applied Soil Ecology*, *196*, 105175.
- Shen, Y., Li, H., & Wu, C. (2022). Potassium dynamics in biochar-amended soils and plant growth responses. *Soil & Tillage Research*, *223*, 105497.
- Silva, T., Ramos, A., & Oliveira, P. (2023). Eucalyptus seedling growth in mine soils amended with biochar. *Ecological Engineering*, *192*, 106912.
- Song, Z., Zhou, W., & Chen, H. (2022). Tailings soil characteristics and challenges for reclamation. *Journal of Soils and Sediments*, *22*(7), 2268–2279.
- Sutopo, B., Hardianto, H., & Lestari, R. (2022). Sengon wood production and its role in Indonesian agroforestry. *Indonesian Journal of Forestry Research*, *9*(2), 55–66.
- Tian, Y., Zhao, L., & Xu, X. (2023). Microbial responses to organic amendments in contaminated soils. *Science of the Total Environment*, *880*, 163308.
- Tursun, H., Kaya, B., & Demir, G. (2024). Phosphorus availability and cambial activity in organic-amended soils. *Plant and Soil*, *495*(1–2), 223–236.
- Wahyudi, A., Nugroho, S., & Prasetyo, E. (2025). Role of compost in improving mine soil fertility. *Environmental Research*, *238*, 117200.

- Wang, Q., Zhang, X., & Yu, H. (2025). Biochar-induced improvements in biomass accumulation in degraded lands. *Sustainability*, *17*(5), 2456.
- Wu, Y., Liu, P., & Zhang, R. (2025). Organic waste utilization in ecological restoration of degraded lands. *Sustainability*, *17*(2), 1457.
- Yang, L., Zhao, J., & Han, X. (2023). Heavy metal immobilization by biochar in reclaimed soils. *Chemosphere*, *319*, 137970.
- Zhou, J., Yang, F., & Li, C. (2023). Circular economy approaches in mine reclamation: The role of organic amendments. *Resources, Conservation and Recycling*, *197*, 107010.
- Zhu, P., Gao, Y., & Liu, H. (2022). Shoot-to-root allocation strategies in trees under environmental stress. *Tree Physiology*, *42*(9), 1678–1690.