ENHANCING MICROBIAL POPULATION AND BIOMASS OF WATER SPINACH GROWN IN TAILING AND INCEPTISOLS BY MANURE AMENDMENT

PENINGKATAN POPULASI MIKROBA DAN BIOMASA KANGKUNG DI TAILING DAN INCEPTISOLS MELALUI PENAMBAHAN PUPUK KANDANG

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ABSTRACT

The impact of tailings accumulated on agricultural land is the loss of soil profile and decreased soil quality, making plants ~~are~~ difficult to grow. This study aimed to observe the effect of cow dung manure (CM) doses to gold mine tailings on total fungal and bacterial populations of soil surrounding roots and water spinach biomass and to analyze the correlation between fungal and bacterial populations with water spinach growth parameters. The experiment was designed in a randomized block design with five treatments and five replications. The treatments included without CM (control) and 5, 10, 15, and 20% of CM in tailing. Similar treatments were added to plants grown in mineral soil, i.e. Inceptisols. The results determined the retarded plant growth in tailing compared to that in Inceptisols. The plant grown in tailing was more responsive to manure amendment. The CM increased total fungal and bacterial populations in the soil around the roots, plant height, leaf number, stem thickness, wet weight, and dry weight of intact plants. Applying 5% of CM caused better growth of water spinach than other treatments. Total fungal and bacterial populations were strongly correlated with water spinach height and dry weight.

Keywords: Biomass, Correlation, Organic matter, Soil microbes

ABSTRAK

Dampak negatif penumpukan *tailing* di lahan pertanian adalah hilangnya profil tanah dan penurunan kualitas tanah sehingga tanaman sulit tumbuh. Penelitian ini bertujuan untuk mengobservasi pengaruh pemberian dosis pupuk kotoran sapi (PKS) pada *tailing* tambang emas terhadap populasi jamur dan bakteri total biomassa kangkung darat (*Ipomoea reptans* (L.) Poir.) serta menganalisis korelasi antara populasi jamur dan bakteri di tanah sekitar perakaran dengan parameter pertumbuhan kangkung. Percobaan pot di rumah kaca disusun dalam rancangan acak kelompok dengan lima perlakuan dan lima ulangan. Perlakuan percobaan adalah tanpa dan dengan penambahan 5, 10, 15 dan 20% PKS ke dalam *tailing*. Perlakuan yang sama diberikan

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pada tanaman kangkung dengan tanah Inceptisol. Hasil percobaan menunjukkan bahwa pertumbuhan kangkung di *tailing* terhambat dibandingkan di tanah Inceptisols, tetapi tanaman di *tailing* lebih responsif terhadap aplikasi PKS. Pupuk kotoran sapi mampu meningkatkan populasi jamur dan bakteri total di sekitar perakaran, tinggi tanaman, jumlah daun, ketebalan batang, bobot basah serta bobot kering tanaman di *tailing*. Pemberian 5% PKS lebih meningkatkan pertumbuhan tanaman kangkung dibandingkan dengan perlakuan lainnya. Populasi jamur dan bakteri masing-masing berkorelasi positif dengan hubungan yang sangat kuat dengan bobot kering serta tinggi tanaman kangkung. Percobaan ini menjelaskan bahwa bahan organik penting untuk memperbaiki kualitas *tailing* dan pertumbuhan tanaman.

Kata kunci: Bahan organik, Biomassa, Korelasi, Mikroba tanah.

INTRODUCTION

Tailings are the residual materials of crushed ore left after extracting valuable metals (Kossoff et al., 2014). The volume of gold mine tailings far exceeds that of the extracted metal. The gold content in artisanal and small-scale gold mining (ASGM) of East Sentani, Papua Province, is only 45 mg m^{-3} (Ayomi et al., 2015; Prematuri et al., 2020); the rest is tailings. Without appropriate management, many mine tailings piles in agricultural areas reduce soil quality through soil compaction, nutrients, and organic matter deficiency (Sheoran, 2010). The solid fraction of mine tailings is generally dominated by high clay, dust, or sand, which limits water availability, soil respiration, and nutrient uptake. The macronutrients, organic matter, and cation exchange capacity (CEC) of tailing are usually low, but the soil reaction is acidic or alkaline (Hindersah et al., 2018; Hindersah et al., 2024); these characteristics do not support plant cultivation. The imbalanced composition of soil fraction and lack of vegetation coverage trigger rainfall-induced erosion and landslides of the tailing pile (Xue et al., 2024). Moreover, gold extraction by amalgamation process causes gold-mine tailing to contain mercury that could contaminate soil, water, and air (Hindersah et al., 2024 ; Rachman et al., 2023).

To minimize the risks of tailing disposal, the establishment of a vegetation cover is the best strategy (Hagner et al., 2021), but revegetation is limited by low organic carbon and nutrient levels. Organic matter has been used to enhance the quality of poor soil and mining rehabilitation programs. They can improve essential soil properties such as soil carbon sequestration (Antonelli et al., 2018), lowering bulk density, and increasing water availability (Xuan et al., 2022). After 7-year revegetation, enhanced physical properties and nutrient content showed the effectivity of long-term organic matter amendment for rehabilitation of former mine soil (Proto & Courtney, 2023).

Organic matter is a source of energy, carbon, and nitrogen (N) for heterotrophic microbes (Zhang et al., 2020). The microbes decompose complex organic matter into inorganic compounds; the nutrients that are available for plant uptake (Ramadhani & Nuraini, 2018; Sutanto et al., 2020). Soil bacteria and fungi play an important role in soil nutrient availability; bacteria facilitate the nutrient cycle, while fungi are essential in decomposing organic matter (Rashid et al., 2016). The role of bacteria in the nitrogen and phosphate cycles and hormone production has been reported (Rashid et al., 2016; Egamberdieva et al., 2017).

Several studies on mineral soils have shown that microbial populations correlate with plant growth. The population of phosphate-solubilizing bacteria (PSB) in the soil is positively correlated with the dry weight of corn plants and tomato yields (Lovitna et al., 2021; Setiawati et al., 2023). The PSBs produce organic acids such as citric, oxalic, and malic acid, which dissolve phosphate compounds bound to soil particles or phosphate minerals. Thus, phosphate becomes available for root uptake (Sonia & Setiawati, 2022). A positive correlation between N-fixing bacteria and plant canopy caused by increased N availability and phytohormones has been reported (Kuan et al., 2016).

Organic matter increases plant growth in mining areas or mine tailings (Dharmawan & Siregar, 2014; Hindersah et al., 2024). However, research on the correlation between microbes and plant growth parameters in tailing-based substrates is still limited. This experiment grew water spinach as an indicator plant for tailings improvement after organic matter amendment since this plant is responsive to the organic matter (Oematan et al., 2022). Application of a dose of 20 t ha^{-1} cow manure increases the growth and yield of water spinach in mineral soil (Telaumbanua & Adiwirman, 2018). However, the manure dose should be adjusted to the low organic C and total N, and an imbalanced solid fraction composition in tailing. The purpose of this study was to determine the effect of cow manure (CM) doses on the total fungal and bacterial populations, as well as the height and dry weight and the yield of water spinach, and to analyze the correlation between bacterial populations and the growth parameters of water spinach grown in tailing-based substrate.

MATERIAL AND METHODS

The pot experiment was conducted in the greenhouse of the Faculty of Agriculture, Universitas Padjadjaran, Jatinangor Campus, Sumedang Regency, from November 2022 to February 2023. The altitude of the experimental location is 752 m above sea level, with a temperature and humidity of 14.3 ^{0}C-27.8 ^{0}C and 77.6%-96.3%, respectively. Gold mine tailings were taken from the artisanal and small-scale gold mining (ASGM) of Karangpaningal located in Karanglayung Village, Karang Jaya District, Tasikmalaya Regency. The geographical coordinates of the ASGM are 7˚26’40.574608’’S and 108˚21’23.417662’’E at 430 m above sea level.

The tailing texture was silty clay, containing 2% sand, 57% silt, and 41% clay, with a slightly alkaline acidity (8.08). The Organic Carbon (C) content was 1.57 (low), total N was 0.16 (low), and C/N was 9.81 (low). Available P was 9.45 mg kg^{-1} (moderate), and potential K_2O was 12.28 mg 100 g^{-1} (low). The soil cation exchange capacity and base saturation were 3.51 cmol kg^{-1} (very low) and 63.2% (high), respectively.

The treatments were the weight ratio of CM and tailings as follows:

m_o: Without CM treatment (control)
m_1: CM 5%, Tailings 95%
m_2: CM 10%, Tailings 90%
m_3: CM 15%, Tailings 85%
m_4: CM 20%, Tailings 80%

Regarding the 20-cm planting distance of water spinach in the field, the amount of CM was equivalent to 10, 20, 30, and 40 t ha^{-1}. The experiment was arranged in a completely randomized block design with five replications. The same experiment using Inceptisols soil was conducted to compare the growth of water spinach in soil originating from agricultural fields.

The tailings were air-dried for 2 days, grounded particularly for large chunks, and filtered using a 2-mm sieve. The acidity of CM before the experiment was 6.05, with a water content of 19.03%; it contained 41.09% of organic C, 2.06% of total N, a C to N ratio of 19.95, 0.56% of total P, and 0.29% of total K. Meanwhile, the total bacteria population in gold mine tailings and cow manure reached 10^{10} CFU g^{-1}, and the population of gold mine fungi in tailing and CM was approximately 10^3 and 10^4 CFU g^{-1}, respectively.

A total of 1 kg of tailings-CM mixture was transferred into a polybag. Three water spinach seeds were planted in three plant holes that formed a triangle with a distance between holes of 5 cm. The seeds were covered with the same substrate, and the surface of the substrate was watered with 50 mL of groundwater. At 15 days after sowing, each pot received NPK fertilizer (16-16-16) as much as 2.25 g per plant (equivalent to 450 kg ha^{-1}). All experimental pots were placed in a greenhouse for 5 weeks. The pesticide was not used during the experiment.

Plant height, number of leaves, and stem diameter of plants grown in tailing-based substrate and Inceptisols were measured at 4 and 5 weeks. At the end of the experiment, the fresh and dry weight of the shoot and the total bacterial and fungal populations surrounding the roots were determined only for plants grown in the tailing-based substrate.

Analysis of variance (F test; $p<0.05$) was conducted for all parameters, while the Duncan Multiple Range (DMR) test was performed to analyze the significant difference between treatments. Pearson Correlation analysis at $p<0.05$ was conducted to determine the correlation coefficient between variables and the magnitude of that relationship. Statistical analysis was performed using IBM SPSS Statistics, version 25.

RESULTS AND DISCUSSION

Microbial population

The tailing reaction (pH) before the experiment was slightly alkaline (8.06) and naturally contained fungi and bacteria (Figure 1). The pH was reduced to somewhat neutral after growing the water spinach with CM amendment (Figure 2a). In this experiment, the pH of untreated tailing was similar to that of tailing receiving 5%-15% CM, but significantly reduced pH was found in tailing with 20% CM amendment. The acidity generally determines the diversity of microbes. Nonetheless, there was no significant change in bacterial count in the tailing surrounding plant roots; the bacterial population was similar before and after treatments, i.e., log 10 (equal to 10^{10} CFU g^{-1}). Figure 2b demonstrated that the fungal count was enhanced up to log 4 (equal to 10^4 CFU g^{-1}) compared to log 3 (equal to 10^3 CFU g^{-1}) before the experiment. Based on the DMR test, a more significant population of fungi and bacteria were in soil with 5% CM amendment, which was log 4.85 and 10.44, respectively. Cow manure contains complex organic matter, which provides a carbon source for fungi. Meanwhile, the heterotrophic bacteria need. Heterotrophic bacteria require longer to increase their population in organic-matter amendment substrates because they prefer simple, easily soluble organic matter over complex ones. Bacteria and fungi play a role in the nutrient cycle that benefits plants. However, this study did not characterize both microbes.

The pH of tailing collected from the mining was 8.06 and then decreased following CM amendment. Cow manure acidity was 6.05; mixing it with slightly alkaline tailing decreased pH to very slightly acid 6.1-6.5 (Figure 2a). A lower pH was found in the substrate with 20 % CM. A plant's rhizosphere might contribute to lowering the substrate acidity. Root-released exudate contains organic matter, including fixed carbon, amino acid, organic acid, and enzymes that lead to the lowering of the rhizosphere acidity (Ma et al., 2022). Otherwise, root exudates provide energy and nutrients for soil microbes living in the rhizosphere (Pascale et al., 2020). The pH 6.1-6.5 is the best ~~pH~~ for most plants to grow well due to the increased N, P, K, S, and Mg uptake while decreasing the metal uptake. Plants in neutral soil are protected from nutrient deficiency and metal toxicity. Macro and micronutrient uptake in sufficient levels will promote better photosynthesis.

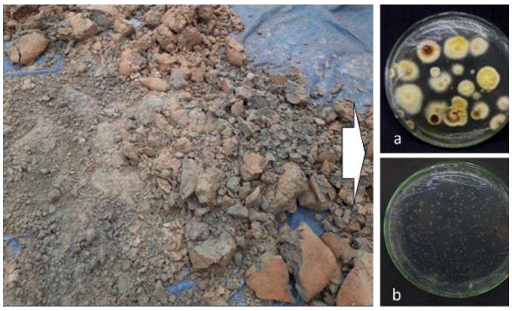

Figure 1. Fungi (a) and bacteria (b) isolated from gold-mine tailings

Figure 2 shows that the bacterial and fungal counts were approximately 10^{10} and 10^{4} CFU g^{-1} (equal to log 10 and 4). In nature, the bacterial count dominates the fungi. A lower count of fungi in the tailing-based substrate was also found in agricultural soil. The fungal count increased by one log after the CM amendment, but the bacterial count likely remained unchanged. Both bacterial and fungal counts of untreated tailing were slightly lower since low organic matter limited heterotrophic metabolisms.

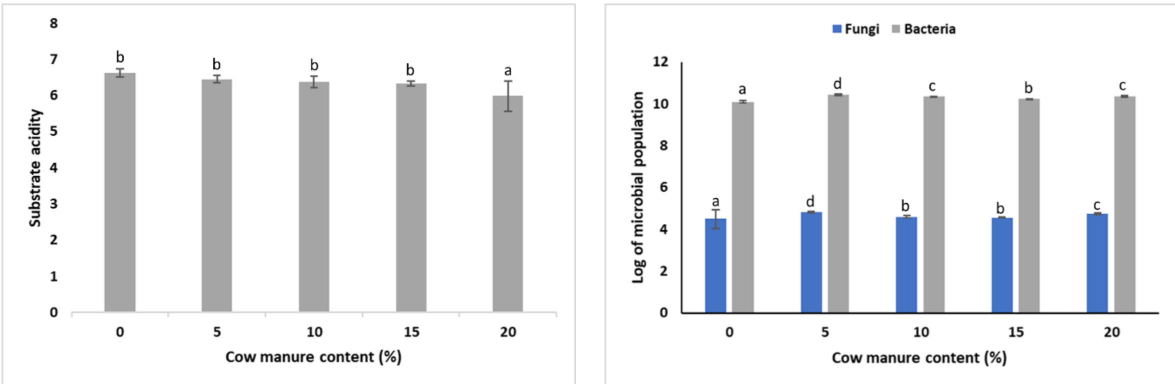

Figure 2. The acidity (a) and microbial count (b) of the substrate added by various concentrations of cow manure at 5 weeks after sowing

Fungal population enhancement was induced by manure, which provided carbon and nitrogen. Fungi are heterotrophic microbes that rely on carbon from dead organic matter in soil. Low substrate aeration might limit bacterial and fungal proliferation, mainly in low-manure conditions. Increasing organic matter facilitates bacterial and fungal growth. Certain species of both microbes produce exopolysaccharides that significantly affect soil aggregate and porosity improvement. Moreover, fungal mycelia are essential in soil aggregation.

Cow manure, similar to other sources of organic matter, has a low bulk density. The organic matter amendment reduces the bulk density of the soil, which affects the increase in soil pores that regulate soil aeration. A negative correlation (r = -0.69) between bulk density and soil organic matter was found in the Coimbatore soils (Athira et al., 2019). This indicates that soils with higher organic matter tend to have lower bulk density. High organic matter makes soils more friable, porous, and chemically active, which contributes to reduced bulk density.

In this experiment, bacteria and fungi were counted using a serial dilution plate method that only allowed the growth of aerobic microbes. This isolation method also cannot distinguish the function of microbes. Despite a similar population, both bacterial and fungal diversity might be different. Therefore, the change in microbial structure that assists gold mining revegetation should be analyzed.

Microbes support mine revegetation through symbiosis with plants; they remove pollutants through adsorption, degradation, and metabolic transformation into harmless forms (Deng et al., 2024). Moreover, microbes also secrete growth-promoting substances that enhance plant tolerance to heavy metals and improve soil conditions through coevolution and mutual adaptation with plants.

Plant growth and biomass

During the experiment, the plant growth in tailings was retarded even in manure-treated tailing compared to that in Inceptisols (Figure 3). Plant growth in potted tailing was lowered by approximately 50% compared to in potted Inceptisols. Nonetheless, the plants that grew in tailing were more responsive to CM amendment than plants in Inceptisols.

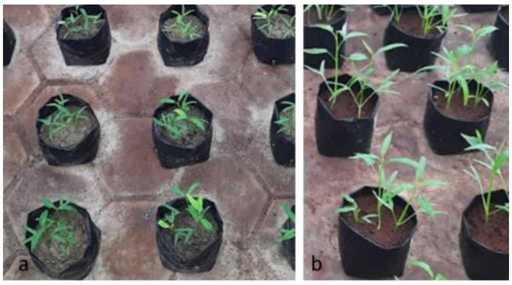

Figure 3. The water spinach that grew in tailing (a) and Inceptisols (b) at two weeks after sowing

An analysis of variance verified that manure concentration affected shoot height, stem thickness, and leaf number of water spinach grown in tailing or Inceptisols. The increase in shoot height, stem thickness, and leaf number of plants in tailing at four weeks after 5% CM amendment was 69%, 20%, and 23%, while at five weeks, the increase was 55%, 40%, and 39% compared to the control (Tables 1 and 2). Despite the higher growth of plants in Inceptisols, the plants in tailings were more responsive to the CM since the fertility of the tailing-base substrate before trial was lower than in the soil. The CM causes better soil nutrient availability and physics (Ramadhani & Nuraini, 2018; Rabot et al., 2018). At four weeks, the stem thickness of plants grown in Inceptisols with 5% and 10% CM was 59% and 79% higher than that of the control, but higher levels of CM did not change stem thickness and leaf number (Table 1).

Table 1. The increase of plant height, stem diameter, and leaf number of water spinach grown in potted tailings compared to that in Inceptisols at four weeks after sowing.

Cow manure	Shoot height	Stem Thickness	Leaf number
	Potted tailing		
m_o (control)	9.49 ± 0.26a	1.66 ± 0.04a	4.27 ± 0.28a
m_1: CM 5%	16.08 ± 1.01d	2.00 ± 0.13c	6.53 ± 0.19d
m_2: CM 10%	14.61 ± 1.32c	1.88 ± 0.07bc	6.20 ± 0.30bc
m_3: CM 15%	11.99 ± 0.48b	1.73 ± 0.10a	6.06 ± 0.13bc
m_4: CM 20%	13.55 ± 0.85a	1.78 ± 0.08ab	6.40 ± 0.15 cd
	Potted Inceptisols		
m_o (control)	27.00 ± 1.60 a	1.85 ± 0.07 a	11.53 ± 0.38 ab
m_1: CM 5%	32.47 ± 1.90 cd	2.95 ± 0.17 b	11.93 ± 0.37 b
m_2: CM 10%	29.70 ± 2.09 b	3.32 ± 0.29 c	11.60 ± 0.55 ab
m_3: CM 15%	34.30 ± 0.93 d	3.19 ± 0.04 c	11.07 ± 0.28 a
m_4: CM 20%	31.57 ± 2.23 bc	3.24 ± 0.11 c	11.27 ± 0.36 a

The values in a column followed by the same letters were not significantly different based on DMR Test at $p<0.05$.

At five weeks, the application of 5% CM resulted in better plant growth in either tailings or Inceptisols (Table 2). The shoot height, stem diameter, and leaf increment of plants in tailings were still higher than in soil. Higher concentrations of CM (10% and 20%) decreased plant growth traits in tailing compared to plants with 5% CM, but they were higher than the control (Table 2).

However, incorporating 15% and 20% CM into the Inceptisols resulted in similar stem thickness and leaf number as the control plant. The data in Tables 1 and 2 verified that any concentration of CM improved plant performance in tailings.

Table 2. The increase of plant height, stem diameter, and leaf number of water spinach grown in potted tailings compared to that in Inceptisols at five weeks after sowing.

Cow manure	Shoot height	Stem Thickness	Leaf number
	Potted Tailing		
m_o (control)	11.55 ± 1.52 a	1.66 ± 0.03a	5.53 ± 0.65a
m_1: CM 5%	17.89 ± 0.69d	2.29 ± 0.16c	7.73 ± 0.28c
m_2: CM 10%	15.29 ± 1.29c	2.11b ± 0.37c	7.00 ±0.62b
m_3: CM 15%	13.60 ± 0.54 b	2.03 ± 0.21b	7.00 ±0.33b
m_4: CM 20%	16.09 ± 0.53 c	2.11 ±0.15bc	7.53 ±0.38bc
	Potted Inceptisols		
m_o (control)	31.53 ± 0.87 a	4.00 ± 0.37 a	13.33 ± 0.47 ab
m_1: CM 5%	38.20 ± 2.37 c	4.93 ± 0.49 c	13.80 ± 0.74 b
m_2: CM 10%	33.60 ± 1.86 ab	4.57 ± 0.43 bc	13.47 ± 0.56 ab
m_3: CM 15%	39.03 ± 1.82 c	4.21 ± 0.07 ab	12.60 ± 0.49 a
m_4: CM 20%	36.47 ± 3.18 bc	4.25 ± 0.24 ab	12.87 ± 0.76 a

The values in a column followed by the same letters were not significantly different based on DMR Test at $p<0.05$.

Retarded growth in tailing was caused by limited nutrients and physical constraints usually found in gold tailing (Prematuri et al., 2020). Mineral soil, such as Inceptisols, has good soil structure, although its macronutrient content is generally low. The tailing in this experiment was dominated by silt (57%) with 2% sand compared to the texture of Inceptisols that support plant growth. The Inceptisols Jatinangor contained 7-14% sand (Fitriatin et al., 2017; Dewi et al., 2020); higher sand content compensates for high silt and clay in Inceptisols, enabling better root growth.

Manure's contribution to enhancing the growth and biomass of water spinach grown in tailing was significant. Organic matter contains a small number of nutrients compared to chemical fertilizers, but they are enzymatically decomposed to provide inorganic N, P, and K for plants (Ramadhani & Nuraini, 2018; (Sutanto et al., 2020). In this experiment, the tailing texture was silty clay that limited root growth due to low porosity. Organic matter amendment is essential to improve soil porosity and reduce the weight-to-volume ratio of tailing (Xuan et al., 2022).

The CM dose determined the dry weight, shoot-to-root (S/R) ratio, and water spinach yield grown in tailing. The shoot dry weight was only enhanced by 5% CM, while the root DW increment was found in all CM-treated plants (Table 3). Plants grown in a higher CM (15% and 20%) had an S/R ratio of less than one, indicating that the root growth was better than those treated with 5% and 10% CM. Higher organic matter amendment resulted in the reduce the bulk density and increase the porosity that support root growth. Yield increment was only found in tailing with 5% CM amendment, which referred to the shoot growth over the roots.

Table 3. Water spinach biomass and yield growth in potted tailings at five weeks after sowing.

Cow manure	Dry weight (g)		Shoot-to-root ratio	Yield (g)*
	Shoot	Root		
m_o (control)	0.034 ± 0.013a	0.028 ± 0.008a	1.25 ± 0.49b	1.05 ± 0.07a
m_1: CM 5%	0.090 ± 0.025b	0.060 ± 0.014c	1.58 ± 0.66b	1.76 ± 0.12ab
m_2: CM 10%	0.046 ± 0.005a	0.042 ± 0.008b	1.13 ± 0.22ab	1.51 ± 0.06a
m_3: CM 15%	0.040 ± 0.007a	0.042 ± 0.004b	0.95 ± 0.12a	1.37 ± 0.07a
m_4: CM 20%	0.036 ± 0.011a	0.042 ± 0.004b	0.85 ± 0.22a	1.21 ± 0.07a

The values in a column followed by the same letters were not significantly different based on DMR Test at $p<0.05$. *Shoot fresh weight

Manure amendment supports heterotrophic bacteria and fungi proliferation and function in the rhizosphere. The contribution of both microbes to plant metabolism and growth through the synthesis of phytohormones such as auxin and cytokinin (CK) is reported (Egamberdieva et al., 2017). The C/N ratio of plants receiving lower concentrations of manure might be related to the high release of CK but low auxin by microbes in the rhizosphere. Previous research verified that the increased endogenous cytokinin-to-auxin ratios could induce plant cells's morphogenesis and growth since CK promotes shoot and inhibits root growth (Kurepa & Smalle, 2022). Otherwise, this experiment verified no significant effect of CM on biomass and yield; the nutrient content in tailing-based substrate enriched with organic matter had not yet provided sufficient nutrients for photosynthate production. Good soil physics was not the only growth factor. CM contained low P and

K, which limited plant growth. Biomass production depended on the rate of photosynthesis. CM did not immediately offer plant nutrients because they had to be decomposed to release the essential nutrients, mainly Nitrogen, which was low in the tailing.

Correlation between microbial and plant parameters

The Pearson test showed that bacterial and fungal populations in soil positively correlated with plant height and dry weight; there appeared to be sufficient to very strong positive correlation (Table 4). There were robust correlations between the bacterial population and shoot height, the fungal population and shoot height, and the fungal population and the bacterial population. Strong correlations were found between the bacterial population and root dry weight, plant height with shoot dry weight, plant height with root dry weight, and root dry weight and shoot dry weight. A sufficient correlation was found between shoot dry weight and bacterial and fungal populations.

Table 4. Pearson correlation between total microbial population in tailing and biomass of spinach water at five weeks after sowing

	BP	FP	PH	RDW	SDW
BP		0,83*****	0,90*****	0,69****	0,56***
FP	0,83*****		0,83*****	0,67****	0,60***
PH	0,90*****	0,83*****		0,68****	0,67****
RDW	0,69****	0,67****	0,68****		0,62****
SDW	0,56***	0,60***	0,67****	0,62****	

*****very strong positive correlation; ****strong positive correlation; ***sufficient positive correlation. BP: bacterial population, FP: fungal population, PH: plant height, RDW: root dry weight, SDW: shoot dry weight

Plant height at five weeks positively correlated with a powerful relationship with the bacterial (r = 0.90) and fungal population (r = 0.83), verifying the essential role of both microbes in boosting plant height. The population of bacteria had a powerful correlation (r = 0.83) with fungal count in soil; this verified the positive interaction between the two microbial groups. Root weight positively correlated with microbial count, but a sufficient correlation was found between shoot dry weight and bacterial (r = 0.56) and fungal population (r = 0.60). Microbes likely had a more significant role in plant rooting improvement. The root growth is determined by auxin (Kurepa & Smalle, 2022); many soil microbes synthesize the phytohormones, including auxin (Egamberdieva et al., 2017).

The correlation analysis between the total bacterial population and the growth of water spinach plants showed a robust positive correlation. Cow manure was a prominent soil ameliorant that boosted appropriate physical soil conditions and directly served nutrient heterotrophic microbes.

Soil aggregates and their stability have significant consequences for soil function, such as water infiltration and gas exchange with the atmosphere to support plant growth (Rabot et al., 2018). Further, improved pore spaces between and within soil aggregates provide soil fauna, microbes, and plants with nutrients, niches, and space

(Chen et al., 2022). Therefore, better soil physics ensures the proliferation and metabolisms of both aerobic microbes. The bacteria and fungi in the soil, mainly in the rhizosphere, directly and indirectly enhanced plant growth (Taylor et al., 2007). The presence of plants grown in soil ensures better nutrient provision and physical protection for microbes through the rhizosphere effect.

In the rhizosphere, the interaction between bacteria and fungi occurs. Fungi and bacteria play a crucial role in plant debris decomposition to produce dissolved organic matter, but fungi play a more prominent role in either soil C loss through priming effects or C protection through aggregation (Husain et al., 2024). The robust ability of fungi in litter decomposition provides dilute substances for soil bacteria. Both microbes in healthy soil should be in a balanced composition that maintains their role in enhancing plant growth. Their natural metabolisms in the nutrient cycle and production of plant-growth substances are key to better plant growth.

CONCLUSION

The growth of water spinach in tailings was not better than in Inceptisols soil, but plants in tailings were more responsive to CM amendment. The CM increased the total fungal and bacterial population around the roots, plant height, number of leaves, stem thickness, fresh weight, and dry weight of plants in tailings. Nonetheless, plants grown in tailing and soil treated with 5% CM had better growth traits and biomass than the control and other treatments. The fungal and bacterial populations were each positively correlated with a firm relationship with dry weight and height of water spinach. This experiment explains that CM application resulted in appropriate plant and microbial growth. However, further research related to the function of bacteria and fungi in tailing after CM amendment is needed.

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REFERENCES

Antonelli, P., Fraser, L., Gardner, W., Broersma, K., Karakatsoulis, J., & Phillips, M. (2018). Long term carbon sequestration potential of biosolids-amended copper and molybdenum mine tailings following mine site reclamation. *Ecological Engineering*, *117*. https://doi.org/10.1016/j.ecoleng.2018.04.001

Athira M., Jagadeeswaran, R., & Kumaraperumal, R. 2019. Influence of soil organic matter on bulk density in Coimbatore soils. *International Journal of Chemical Studies, 7*(3),3520–3523. https://www.chemijournal.com/archives/2019/vol7issue3/PartBF/7-3-360-895.pdf

Chen, J., Song, D., Liu, D., Sun, J., Wang, X., Zhou, W., & Liang, G. (2022). Soil Aggregation shaped the distribution and interaction of bacterial-fungal community based on a 38-year fertilization experiment in China. *Frontiers in Microbiology*, *13*. https://doi.org/10.3389/fmicb.2022.824681

Deng, Y., Xiao, W., Xiong, Z., Sha, A., Luo, Y., Chen, X., & Li, Q. (2024). Assembly mechanism of rhizosphere fungi in plant restoration in lead zinc mining areas. *Genes, 15*, 1398. https://doi.org/10.3390/genes15111398

Dewi, E., Haryanto, R., & Sudirja, R. (2020). Pengaruh penggunaan lahan dan posisi lereng kandungan C-Organik dan beberapa sifat fisik tanah Inceptisols Jatinangor, Jawa Barat. *AGROSAINSTEK: Jurnal Ilmu Dan Teknologi Pertanian*, *4*(1), 49–53. https://doi.org/10.33019/agrosainstek.v4i1.37

Dharmawan, I. W. S., & Siregar, C. A. (2014). Rehabilitasi lahan di areal penambangan emas menggunakan jenis lokal dan pemanfaatan *tailing*. *Indonesian Forest Rehabilitation Journal*, *2*(1), 55–66.

Egamberdieva, D., Wirth, S. J., Alqarawi, A. A., Abd_Allah, E. F., & Hashem, A. (2017). Phytohormones and beneficial microbes: Essential components for plants to balance stress and fitness. *Frontiers in Microbiology*, *8*. https://doi.org/10.3389/fmicb.2017.02104

Fitriatin, B. N., Rahardiyan, A., & Turmuktini, T. (2017). Pengaruh aplikasi pupuk hayati mikroba pelarut fosfat dalam meningkatkan kandungan P tanah, pertumbuhan dan hasil jagung pada Ultisols. *SoilREns*, *14*(2). https://doi.org/10.24198/soilrens.v14i2.11033

Hagner, M., Uusitalo, M., Ruhanen, H., Heiskanen, J., Peltola, R., Tiilikkala, K., Hyvönen, J., Sarala, P., & Mäkitalo, K. (2021). Amending mine tailing cover with compost and biochar: effects on vegetation establishment and metal bioaccumulation in the Finnish subarctic. *Environmental Science and Pollution Research*, *28*(42), 59881–59898. https://doi.org/10.1007/s11356-021-14865-8

Hindersah, R., Handyman, Z., Indriani, F. N., Suryatmana, P., & Nurlaeny, N. (2018). Azotobacter population, soil nitrogen and groundnut growth in mercury-contaminated tailing inoculated with Azotobacter. *Journal of Degraded and Mining Lands Management*, *5*(3), 1269–1274. https://doi.org/10.15243/jdmlm.2018.053.1269

Hindersah, R., Wangi, A. P., Suryatmana, P., Sule, M. I. S., Handayani, S., & Bang, S. (2024). Effect of various manure doses on the choy sum grown in mercury-contaminated tailing substrate. *International Journal of Design & Nature and Ecodynamics*, *19*(4), 1439–1446. https://doi.org/10.18280/ijdne.190436

Husain, H., Keitel, C., & Dijkstra, F. A. (2024). Fungi are more important than bacteria for soil carbon loss through priming effects and carbon protection through aggregation. *Applied Soil Ecology*, *195*, 105245. https://doi.org/10.1016/j.apsoil.2023.105245

Kossoff, D., Dubbin, W. E., Alfredsson, M., Edwards, S. J., Macklin, M. G., & Hudson-Edwards, K. A. (2014). Mine tailings dams: Characteristics, failure, environmental impacts, and remediation. *Applied Geochemistry*, *51*, 229–245. https://doi.org/10.1016/j.apgeochem.2014.09.010

Kuan, K. B., Othman, R., Abdul Rahim, K., & Shamsuddin, Z. H. (2016). Plant growth-promoting rhizobacteria inoculation to enhance vegetative growth, nitrogen fixation and nitrogen remobilisation of maize under greenhouse conditions. *PLOS ONE*, *11*(3), e0152478. https://doi.org/10.1371/journal.pone.0152478

Kurepa, J., & Smalle, J. A. (2022). Auxin/cytokinin antagonistic control of the shoot/root growth ratio and its relevance for adaptation to drought and nutrient deficiency stresses. *International Journal of Molecular Sciences*, *23*(4), 1933. https://doi.org/10.3390/ijms23041933

Lovitna, G., Nuraini, Y., & Istiqomah, N. (2021). Pengaruh aplikasi bakteri pelarut fosfat dan pupuk anorganik fosfat terhadap populasi bakteri pelarut fosfat, P-tersedia, dan hasil tanaman jagung pada Alfisol. *Jurnal Tanah dan Sumberdaya Lahan*, *8*(2), 437–449. https://doi.org/10.21776/ub.jtsl.2021.008.2.15

Ma, W., Tang, S., Dengzeng, Z., Zhang, D., Zhang, T., & Ma, X. (2022). Root exudates contribute to belowground ecosystem hotspots: A review. *Frontiers in Microbiology*, *13*. https://doi.org/10.3389/fmicb.2022.937940

Oematan, S. S., Gandut, Y. R. Y., Ndiwa, A. S. S., & Huki, C. F. F. H. (2022). Pengaruh komposisi media tanam (perbandingan tanah, pupuk kandang, dan arang sekam) terhadap pertumbuhan dan hasil tanaman kangkung darat (*Ipomoea reptans* Poir). *Wana Lestari*, *4*(02), 314–322. https://doi.org/10.35508/wanalestari.v7i02.9556

Prematuri, R., Turjaman, M., Sato, T., & Tawaraya, K. (2020). Chemical characteristic of forest soil and gold mine tailings and their effect to the plant growth of two leguminous trees. *International Journal of Plant & Soil Science*, 11–20. https://doi.org/10.9734/ijpss/2020/v32i230241

Proto, M., & Courtney, R. (2023). Application of organic wastes to subsoil materials can provide sustained soil quality in engineered soil covers for mine tailings rehabilitation: A 7 years study. *Ecological Engineering*, *192*, 106971. https://doi.org/10.1016/j.ecoleng.2023.106971

Rabot, E., Wiesmeier, M., Schlüter, S., & Vogel, H.-J. (2018). Soil structure as an indicator of soil functions: A review. *Geoderma*, *314*, 122–137. https://doi.org/10.1016/j.geoderma.2017.11.009

Rachman, R. M., Mangidi, U., & Trihadiningrum, Y. (2023). Solidification and stabilization of mercury-contaminated tailings in artisanal and small-scale gold mining using tras soil. *Journal of Degraded and Mining Lands Management*, *10*(4), 4575. https://doi.org/10.15243/jdmlm.2023.104.4575

Ramadhani, S., & Nuraini, Y. (2018). The use of pineapple liquid waste and cow dung compost to improve the availability of soil N, P, and K and growth of pineapple plant in an Ultisol of Central Lampung. *Journal of Degraded and Mining Lands Management*, *06*(01), 1457–1465. https://doi.org/10.15243/jdmlm.2018.061.1457

Rashid, M. I., Mujawar, L. H., Shahzad, T., Almeelbi, T., Ismail, I. M. I., & Oves, M. (2016). Bacteria and fungi can contribute to nutrients bioavailability and aggregate formation in degraded soils. *Microbiological Research*, *183*, 26–41. https://doi.org/10.1016/j.micres.2015.11.007

Setiawati, M. R., Afrilandha, N., Hindersah, R., Suryatmana, P., Fitriatin, B. N., & Kamaluddin, N. N. (2023). The effect of beneficial microorganism as biofertilizer application in hydroponic-grown tomato. *SAINS TANAH - Journal of Soil Science and Agroclimatology*, *20*(1), 66. https://doi.org/10.20961/stjssa.v20i1.63877

Sonia, A. V., & Setiawati, T. C. (2022). Aktivitas bakteri pelarut fosfat terhadap peningkatan ketersediaan fosfat pada tanah masam. *Agrovigor: Jurnal Agroekoteknologi*, *15*(1), 44–53. https://doi.org/10.21107/agrovigor.v15i1.13449

Sutanto, A., Widowati, H., Achyani, F. T., Hendri, N., Rifai, M. R., & Yulistiana, E. (2020). The effectiveness of pumakkal organic waste bioremediator. *International Journal of Advanced Science and Technology*, *29*(7s), 132–143. http://sersc.org/journals/index.php/IJAST/article/view/9422

Telaumbanua, A. N., & Adiwirman, A. (2018). Respon tanaman kangkung darat (*Ipomoea reptans* Poir.) terhadap pemberian pupuk kotoran sapi. *Jurnal Online Mahasiswa Bidang Pertanian*, *5*(2), 1–11.

Xuan, K., Li, X., Yu, X., Jiang, Y., Ji, J., Jia, R., Wang, C., & Liu, J. (2022). Effects of different organic amendments on soil pore structure acquired by three-dimensional investigation. *European Journal of Soil Science*, *73*(4). https://doi.org/10.1111/ejss.13264

Xue, Y., Sattari, F., & Lefsrud, L. (2024). A quantitative analysis method for ecological-health risks caused by rainfall-induced soil erosion at the Laronde Mine. *Engineering Geology*, *330*, 107410. https://doi.org/10.1016/j.enggeo.2024.107410

Zhang, S., Sun, L., Wang, Y., Fan, K., Xu, Q., Li, Y., Ma, Q., Wang, J., Ren, W., & Ding, Z. (2020). Cow manure application effectively regulates the soil bacterial community in tea plantation. *BMC Microbiology*, *20*(1), 190. https://doi.org/10.1186/s12866-020-01871-y