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Changes in Soil Chemical Properties of Gold Mine Tailings Land by Applying Oil Palm Empty Bunch Biochar and Rubber Litter Compost

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Abstract

Pollution (Hg) of the soil due to gold mining activities reduces soil fertility and endangers the environment. The purpose of this study was to analyze effectiveness of biochar from palm empty bunches (PEB) and compost from rubber leaf litter as remedial materials to improve the soil chemical properties of Hg-contaminated tailings. An experimental method using a factorial Randomized Group Design was applied with varying doses of biochar and compost. Parameters observed included Hg concentration, pH, Organic C, Total N, and P and K availability. The results showed that the gold mine tailings have chemical properties that are not ideal for supporting plant growth, including a slightly alkaline pH, very low Organic C and total nitrogen contents, and mercury levels that exceed safe limits (The critical concentration of mercury (Hg) in soil is 0.3-0.5 ppm). The use of biochar from oil palm empty fruit bunches and rubber leaf litter compost proved to be able to increase pH, Organic C, total nitrogen, phosphorus, and available potassium. The treatment with the highest dose combination (30 tons PEB biochar and 20 tons rubber litter compost per ha) succeeded in increasing total N to 5.40%, available P by 175.67 mg/1kg, available K by 7.39 mg/100g, and Organic C by 0.98%. However, the amount of mercury remained high, so further remediation using larger doses of ameliorants and stricter tailings management is needed to sustainably reduce heavy metal pollution.

INTRODUCTION

Soil pollution resulting from mining and industrial activities is a serious environmental problem, especially contamination by heavy metals such as mercury (Hg). Mercury is toxic and persistent pollutant in the environment, which can disrupt the balance of ecosystems and endanger human health and other organisms. Mercury contamination in soil can alter soil chemical properties, such as decreased pH, impaired nutrient availability, and decreased cation exchange capacity (CEC) which results in decreased soil fertility. To overcome this problem, effective remediation efforts are needed to reduce the negative impact of mercury on soil chemical properties. One method that can be applied is the use of ameliorants, which can improve the physical, chemical, and biological properties of soil. Various types of ameliorants, such as organic materials (compost, biochar) and inorganic materials (lime, zeolite), have been widely used to stabilize heavy metals in soil and improve the quality of polluted soil. The application of ameliorant materials is expected to reduce the mobility and bioavailability of mercury in soil through adsorption, precipitation, or complexation mechanisms. In addition, ameliorants can also increase soil pH, organic matter content, and cation exchange capacity which contributes to the overall improvement of soil fertility. The application of palm empty fruit bunches (PEB) biochar to the surface layer of agricultural soil can also provide benefits that improve several soil physical properties, such as structure,

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water retention, and erosion prevention, while enriching the soil organic carbon content. PEB biochar affects the pH of acidic sulfate soils and increases base cations (H^+) that bind anions (OH^-), resulting in an increase in soil pH. The results of the study showed that TKKS biochar contains N 1.23%, C 13.21%, C/N 10.74, P 1.74%, K 0.57%, pH 10.64. Compost from rubber leaf litter contains macro nutrients (N, P, K) and micro nutrients (Ca, Mg, Fe, Zn) that are beneficial to plants. These elements are released slowly during the decomposition process, thereby helping to improve soil nutrient status. The use of biochar and compost can improve soil quality and support plant growth. The objective of this study was to analyze changes in the chemical properties of soil in gold mine tailings after treatment with biochar derived from oil palm empty fruit bunches and rubber leaf litter compost.

MATERIALS AND METHODS

This study used a descriptive-quantitative approach with an experimental method. Soil samples were taken from the Unlicensed Mining (PETI) area located in Sukamulih Village, Sukajaya District, Bogor Regency, West Java. The chemical properties of tailings was analyzed at the ICBB-PT Biodiversity Biotechnology Indonesia Laboratory. Soil amendment tests using oil palm empty fruit bunch (PEB biochar and rubber litter compost were conducted at the Testing Laboratory of the Department of Agronomy and Horticulture, Faculty of Agriculture, IPB. The pH test of planting media after incubation was conducted at the Soil and Agroclimate Laboratory, Faculty of Agriculture, Universitas Sultan Ageng Tirtayasa. This research applied factorial Randomized Group Design (RGD) with two factors, namely PEB biochar (B0: without biochar, B1: 20 tons/ha (equal to 17 g/polybag), B2: 30 tons/ha (equal to 25.5 g/polybag)) and rubber litter compost (K0: no compost, K1: 20 tons/ha (equal to 17 g/polybag), K2: 25 tons/ha (equal to 34 g/polybag)) with tailings weight of 1.7 kg/polybag. From the two factors above, nine treatment combinations were obtained, and each treatment was repeated three times, resulting in 27 experimental units. The soil was then incubated for 30 days. The soil was taken by composite collection (5 points), dried, ground, and sieved to pass a 2 mm and 0.5 mm sieve. Chemical parameters analyzed included pH-H_2O (using a pH meter), Organic C (Walkley & Black method), P-available (Bray I method), Total N (Kjeldahl method), K-available (Bray I method), and Hg concentration. The data obtained were analyzed statistically using analysis of variance (ANOVA) followed by Duncan's Multiple Range Test (DMRT) with a 5% confidence level to determine significant differences among treatment means.

RESULTS AND DISCUSSION

Table 1 presents that the chemical properties of gold mine tailings are classified as unfavorable: the soil is slightly alkaline, has very low Organic C and total N contents, moderate P availability, and very high K availability. In addition, the concentration of mercury (Hg) in the gold mine tailings is very high. These conditions make gold mine tailings less suitable for direct use on crops, as gold mine tailings have a high concentration of heavy metals leading very low organic matter and macronutrients. According to Zulfikah et al. (2014), the presence of heavy metals in agricultural soil can reduce agricultural productivity and the quality of agricultural products and endanger human health through the consumption of food derived from heavy metal-contaminated soil. The threshold limit of heavy metal mercury (Hg) in soil is 0.01-0.03 mg/Kg, while the critical concentration is 0.3-0.5 mg/Kg.

The low Organic C content is due to the lack of organic matter present in the gold mine tailings. This is in line with the opinion of Akbar et al. (2018) who stated that the low Organic C in gold mine tailings waste indicates the low content of macro and micro nutrients in the soil. Complete nutrient content can improve living conditions in the soil and become a food source for plants. Thus, in gold processing that uses mercury, tailings should not be disposed of carelessly to prevent environmental pollution. In addition, mercury-containing tailings must be stored

Table 1. Locations, land uses, and coordinates of the study sites

Characteristics		Analysis Results	Criteria *
pH	H_2O	8.10	slightly alkaline
	KCl	7.70	slightly alkaline
Organic C (%)		0.49	Very low
Total N (%)		0.05	Very low
P-available (mg/kg)		8.45	Very low
K-available (mg/kg)		5.88	Very high
Mercury/Hg (mg/kg)		<1.40	Very high

Note: *criteria based on Soil Research Institute (2009) in a special place and handled carefully.

The low content of macronutrients such as Total N in gold mine tailings indicates that the soil has low fertility. This usually occurs as a result of the gold mining process, which leads to the loss of organic matter and the leaching of nutrients. According to Aprila et al. (2023), gold mine tailings have poor physical and chemical characteristics. The majority of these tailings are composed of sandy to muddy materials, have low water storage capacity, and contain low levels of macro- and micronutrients. Therefore, it is necessary to improve the quality of tailings prior to planting. This can be achieved by increasing the organic matter and nutrient contents of the tailings.

Characteristics of oil palm empty fruit bunch biochar

The characteristics of oil palm empty fruit bunch biochar include moisture content, Organic C, pH, Total N, Total P, Total K and C/N ratio with the analysis results presented in Table 2. Based on Table 2, the moisture content of oil palm empty fruit bunch biochar (PEB) was recorded at 12.72%. This shows that the moisture content of the PEB biochar in this study met the requirements of the SNI 7763-2018 standard which sets the limit between 8% and 25%. Meanwhile, the results of the Organic C analysis showed a figure of 48.18%, which means that this PEB biochar has not met the provisions of the SNI 7763-2018 standard, which sets a minimum value of 15%. In addition, the pH of the PEB biochar in this study was recorded at 10.65, which indicates alkalinity. Thus, the pH of the TKKS biochar is not in accordance with the criteria specified by SNI 7763-2018, which requires the pH of organic materials to be in the range of 4 to 9. The quality of PEB (Palm Empty Bunch) biochar is greatly influenced by the raw material, pyrolysis temperature, and duration of the combustion process. A high C/N ratio and low N and P content indicate that the biochar produced is very stable but less reactive as a plant nutrient source. To improve the biochar quality so that it better meets the SNI 8740:2019 standard, one possible approach is co-pyrolysis or the mixing of nitrogen-rich raw materials such as green waste, manure, or leaf litter, prior to the pyrolysis process. This method can reduce the C/N ratio and increase the total N content.

Furthermore, the Total N content obtained was 0.48% and Total P of 0.56%, meaning that the PEB biochar in this study does not meet the SNI 7763-2018 standard, which sets a minimum total N and P of 2%. However, the Total K content in the PEB biochar was recorded at 3.99%, so it is in accordance with the SNI 7763-2018 standard with a minimum value of 2%. The C/N ratio of the PEB biochar in this study was 100.38, exceeding the maximum limit set by SNI 7763-2018 which is 25. The quality of biochar is highly dependent on the type of raw material used. In this study, the raw material for biochar was derived from palm empty bunches (PEB). The standard determined by the Indonesian National Standard (SNI) is used as a guideline to assess the feasibility of biochar as a soil improvement material. The pH obtained is classified as alkaline, indicating that biochar with alkaline properties has an important role in improving soil quality, especially in soils with high acidity. According to Santi and Goenadi (2017), the pH characteristics of biochar used as a soil improver are generally alkaline with an average pH value above 7.

The high C/N ratio was also explained by Asyifa et al. (2019), who stated that biochar is an organic compound with a very high carbon (C) content, which is between 40 to 60%. The high carbon content causes biochar to have a large C/N ratio, while nitrogen (N) levels in biochar are relatively low. This high C/N ratio can be a challenge, as soil microorganisms tend to use more nitrogen to break down carbon, which can limit nitrogen availability to plants. Biochar is utilized to improve soil conditions, resulting in more optimal plant growth and production, and serves to inhibit the release of carbon into the atmosphere. The addition of biochar to the soil can change the physical properties of the soil, including its depth, texture, and structure. Changes in these

Table 2. Results of Biochar Analysis of Oil Palm Empty Bunches

Characteristics	Analysis Results	SNI*
Moisture content (%)	12.72	8-25
Organic C (%)	48.18	Min.15
pH	10.65	4-9
Total N (%)	0.48	Min.2
Total P (%)	0.56	Min.2
Total K (%)	3.99	Min.2
C/N ratio	100.38	Maks.25

Note: *Indonesian National Standard (2018)

Table 3. Results of Rubber Leaf Litter Compost Analysis

Characteristics	Analysis Results	SNI*
Moisture content (%)	70.99	8-25
Organic C (%)	58.48	Min.15
pH	6.80	4-9
Total N (%)	2.74	Min.2
Total P (%)	0.40	Min.2
Total K (%)	0.45	Min.2
C/N ratio	19.15	Maks.25

Note: *Indonesian National Standard (2018)

physical properties will alter the soil chemical properties, such as chemical reactions and microbial habitat conditions. According to Asyifa et al. (2019), the use of biochar as a soil improvement material obtained from burning agricultural waste with limited oxygen has proven to have a good ability to improve soil because Organic C is maintained in the form of black carbon. Biochar produced from this combustion process contains activated carbon containing minerals such as calcium (Ca) and magnesium (Mg) as well as inorganic carbon; therefore, biochar is widely used as an ameliorant to improve soil quality.

Characteristics of Rubber Leaf Litter Compost

The characteristics of rubber leaf litter compost include moisture content, Organic C, pH, Total N, Total P, Total K and C/N ratio with the analysis results presented in Table 3. Based on Table 3, the moisture content in compost from rubber leaf litter was recorded at 70.99%. This shows that the moisture content of the compost does not meet the SNI 7763-2018 standard which regulates the moisture content range between 8% and 25%. On the other hand, the Organic C content of 58.48% shows that the compost from rubber leaf litter is in accordance with the criteria of SNI 7763-2018, which sets a minimum value of 15%. Furthermore, the pH of the rubber leaf litter compost in this study was 6.80, indicating that this pH is classified as neutral and meets the provisions of SNI 7763-2018, which regulates that the pH of organic materials range between 4 and 9.

Meanwhile, the Total N value obtained was 2.74%, indicating that this compost meets the SNI 7763-2018 standard, which specifies a minimum value of 2%. However, the Total P content, which only reached 0.40% and the Total K of 0.45% in rubber leaf litter compost still does not meet the SNI 7763-2018 standard, which requires a minimum value of 2% for each of these elements. On the other hand, the C/N ratio for rubber leaf litter compost is 19.15, which is in accordance with the maximum limit value of 25 according to the SNI 7763-2018 standard.

Rubber leaf litter compost is included in the organic fertilizer category, that has the ability to improve soil fertility. The application of this compost aims to provide nutrients needed by plants, because the composting method can increase nutrient content through the decomposition process by microorganisms, so that macro and micro nutrients become more available. According to Sopiana et al. (2023), the addition of nutrients from rubber leaf litter compost can improve soil physical and biological conditions and increase plant growth. Rubber leaf litter compost that has undergone a good decomposition process can increase the availability of nitrogen in the soil.

Effect of Treatment on Soil Chemical Properties

Results of Hg concentration analysis of gold mine tailings

Environmental pollution caused by mining activities is increasingly concerning, especially with regard to heavy metal pollution such as mercury (Hg). Lembah et al. (2014) revealed that mercury or mercury (Hg) is included in the group of heavy metals with atomic number 80 and atomic mass 200.6. Mercury is used in various fields such as dental amalgam, as a mold control, and in several industrial applications, including in the gold mining process. This mining activity leads to high level of mercury in groundwater and surface water in the mining area. The results of the Hg concentration analysis of tailings after treatment can be seen in Table 4.

Based on Table 4, after treatment, the tailings from gold mining still show similar mercury (Hg) concentrations to the pre-treatment condition, with a relatively constant figure reaching less than 1.40 mg/Kg, which is in the critical category. In accordance with Government Regulation of the Republic of Indonesia Number 22 of 2021, the threshold value of heavy metal mercury in soil is set at 0.3 mg/Kg. The results of the analysis of the tailings show that the figure has exceeded this threshold limit, in

Table 4. Results of Hg concentration analysis of gold mine tailings after treatment

Treatment	Hg (mg/kg)	Description*
B0K0	< 1.40	Critical
B0K1	< 1.40	Critical
B0K2	< 1.40	Critical
B1K0	< 1.40	Critical
B1K1	< 1.40	Critical
B1K2	< 1.40	Critical
B2K0	< 1.40	Critical
B2K1	< 1.40	Critical
B2K2	< 1.40	Critical

Note: *Quality standards of the Minister of Environment Regulation No. 202 of 2004

accordance with the provisions of the Minister of Environment Regulation No. 202 of 2004 concerning wastewater quality standards for the exploitation of gold and copper ores, which is 0.005 mg/L or equivalent to 0.005 mg/kg. Given that the results far exceed the threshold value, it is clear that the gold mining tailings used as planting media in this study show significant mercury contamination. Therefore, more efficient remediation measures are needed to reduce the heavy metal content. Although the use of biochar from oil palm bark and compost from rubber leaves has been applied in this study, the doses used do not seem to significantly improve the mercury-contaminated soil.

Zhang et al. (2013) in Khasanah et al. (2021) emphasized that heavy metals have characteristics that are difficult to decompose naturally and can persist for a long time in contaminated soil. The removal process requires a lot of time and money. Therefore, an increase in dosage can be considered, and evaluation of other environmental factors such as soil pH, organic matter levels, and nutrient availability must be carried out to increase the effectiveness of the remediation process for gold mine tailings. Laboratory analysis results of soil chemical properties due to ameliorant application on gold mine tailings are presented in Table 5.

Soil Acidity (pH)

Soil pH is an important concept in soil chemistry because it reflects the chemical reactions occurring in the soil. The pH result data can be seen in Table 4. The significant increase in pH at doses B2K1 and B2K2 indicates that the combination of biochar and compost successfully optimized the pH of the tailings. Nurida (2014) argued that biochar is alkaline because it contains minerals such as calcium (Ca), magnesium (Mg), and potassium (K) which are released into the soil when biochar is added. The pyrolysis process in biochar production also changes the chemical structure of the original material to become more alkaline. Heryani et al. (2018) supported this by stating that biochar has functional groups that can absorb Al so that it is not hydrolyzed. The mechanism of increasing pH in gold mine tailings after the application of solid organic materials, according to Lembah et al. (2014), is caused by the release of organic acids from the organic material. The added organic matter undergoes decomposition that produces humus, which in turn increases the affinity of OH^- ions from carboxyl groups (COOH) and phenol compounds. The presence of OH^- ions neutralizes the H^+ ions in the soil solution or those

Table 5. Chemical properties of soil due to ameliorant application to gold mine tailings soil

Treatment	pH-H2O	N (%)	P (mg/kg)	K (mg/100 g)	Organic C (%)
B0K0	9.10 e	0.60 h	19.67 h	0.80 i	0.28 h
B0K1	9.07 e	0.70 g	25.67 g	1.20 g	0.35 g
B0K2	9.10 e	0.60 h	20.33 h	0.90 h	0.50 f
B1K0	9.37 bc	2.70 e	90.67 e	3.60 e	0.66 d
B1K1	9.20 d	3.00 d	104.00 d	4.10 d	0.67 d
B1K2	9.30 c	2.00 f	66.33 f	2.69 f	0.60 e
B2K0	9.40 bc	4.30 c	143.67 c	6.00 c	0.98 a
B2K1	9.50 a	5.40 a	175.67 a	7.39 a	0.77 b
B2K2	9.50 a	5.00 b	168.00 b	6.90 b	0.68 c

Remarks: Means followed by same letters in the same column do not differ significantly at p<0.05 by DMRT.

adsorbed onto soil, thereby reducing the concentration of H^+ ions. Basic cations such as Ca, Mg, and K can be replaced by Al_3^+ ions adsorbed in the soil, thereby reducing the concentration of Al_3^+ and H^+ in the soil solution.

Furthermore, the concentration of OH^- ions will increase, resulting in an increase in soil pH. The pyrolysis process can break down the cellulose and hemicellulose content of the three types of biomass. This decomposition of cellulose and hemicellulose produces volatile substances that affect the pH of biochar. As a result, carboxyl functional groups are formed on the surface of biochar. Generally, biochar is alkaline with a pH ranging from 7.1-10.5 (Inyang et al., 2010; Lehmann et al., 2011) due to the presence of carboxyl groups, oxygen and carbonate content (Yuan et al., 2011). According to Mukome et al. (2013), the decomposition of cellulose and hemicellulose into organic acids and phenolics occur during pyrolysis at 200-300°C (Yu et al., 2014). Biochar can improve soil quality by increasing pH, retaining nutrients, and providing more nutrients for plants (Maftu'ah and Nursyamsi, 2015) without disturbing the carbon-nitrogen balance, helping water retention (Santi and Goenadi, 2012), and creating an ideal habitat for soil microbes, which in turn increases the activity of biota in the soil and reduces pollution (Maftu'ah and Nursyamsi, 2015).

Organic C levels

Before the treatment, the gold mine tailings had a Organic C content of 0.49% (Table 1). After being incubated for 15 days with various treatment combinations, Organic C content alters in each type of treatment. As seen in Table 5, B2K0 treatment has a significant effect compared to other treatments. The provision of biochar as much as 30 t/ha (equal to 25.5 g/polybag) was able to increase the Organic C content of the tailings to 0.98%, although it was still in the very low category. According to Febriana et al. (2023), biochar has long-term effects on soil, but its short-term impact is limited. Even so, biochar is very effective in holding nutrients that are easily transferred. Thies et al (2015) said that biochar creates a microhabitat that supports the growth of soil microbes, including microbes that decompose organic matter. This decomposition process accelerates humus formation and increases soil Organic C content. Biochar has the main role in increasing Organic C levels in gold mine tailings, while the combination with compost does not always have a greater enhancement effect. According to Aprianti et al. (2024), a single application of biochar is more effective in increasing Organic C levels in the soil. Liang et al (2010) stated that biochar has a high surface area and porosity, so it is able to absorb and retain dissolved organic matter and plant residues around the root zone. Carbon in biochar can persist in soil for extended periods because it is stable, allowing it withstand weathering processes. This stability is also supported by the results of the analysis of PEB biochar which shows that biochar has a Organic C content of 48.18% (Table 2). Therefore, biochar has a role in maintaining soil Organic C levels.

Total N levels

The results of the Total N content analysis can be seen in Table 5. Based on these data, the B2K1 treatment combination has a significant effect compared to other treatments with N content reaching 5.40%. This figure is in the very high category. It is known that before the treatment was carried out, the tailings only had an N content of 0.05%, which is in the very low category (Table 1). According to Nguyen et al. (2017), the application of biochar can increase soil moisture and pH, thus encouraging the process of nitrogen mineralization and nitrification which increases plant absorption. Biochar also increases the availability of inorganic nitrogen needed by plants, by increasing the soil's ability to hold nitrogen and reducing the effects of leaching.

Based on research conducted by Putri et al. (2017), it was found that the application of PEB biochar had a significant effect on plant height growth. The increase in plant height occurred due to the increase in nitrogen content supported by the provision of biochar. Biochar has a high water-holding capacity, which helps maintain the availability of nitrogen making it not easily washed away and more readily used by plants. The increase in Total N content in the B2K1 treatment was not only influenced by biochar, but also by the contribution of compost given at a dose of 20 tons/ha (equal to 17 g/polybag). This is supported by the results of the analysis of rubber leaf litter compost which showed Total N content of 2.74% (Table 2). The compost that has undergone complete decomposition can increase the availability of nitrogen in the soil, so that plant nutritional needs are met and vegetative growth becomes more optimal. Nitrogen has an important role in promoting overall plant growth, especially in stem development.

Available P levels

The results of the analysis of available P levels are presented in Table 5. Based on these data, the B2K1 treatment combination has a significant effect compared to other treatments. PEB naturally contains P and K. When processed into biochar, these nutrients are not lost, but concentrated in biochar ash. The P and K-rich biochar ash is then slowly released into the soil when the biochar mixes with water and soil solution. Biochar has a high surface area and porosity, as well as a good negative surface charge. This allows biochar to absorb nutrient ions such as K^+ and PO_4^{3-}, thus preventing the leaching of nutrients from the soil. Over time, these nutrients become available more stably and slowly to plants. Based on the results of research by Rahmah et al. (2019), PEB biochar has a significant effect on soluble P content in soil material after a 15-day incubation period. The highest increase occurred in the rice husk treatment. This happens because the decomposition of organic matter can increase the availability of phosphate in the soil through the formation of organic acids and CO_2 gas. The gas then reacts with water to form carbonic acid which can dissolve primary minerals containing phosphate, thus increasing the availability of P in the soil.

Available P content in gold mine tailings after treatment reached 175.67 mg/kg or included in the very high category. According to Zaitun et al. (2022), high availability of P in the soil can occur because P is not mobile in the soil. Biochar as a soil conditioner can significantly increase the available P content in the soil. High P content in the soil can also be caused by the activity of organisms that play a role in the process of dissolving inorganic P into organic P and are involved in the process of immobilizing available P in the soil. Microorganisms can play an effective role if supported by a good habitat. The pore spaces in biochar can act as a place for microorganisms to live. Rubber leaf litter contains phosphorus nutrients which after undergoing decomposition becomes more available to plants. The process converts organic phosphorus into an inorganic form that can be absorbed by plants. According to the opinion of Erisa et al. (2018), phosphorus (P) is absorbed by plants in the form of orthophosphate ($H_2PO_4^-$, HPO_4^{2-}, and PO_4^{3-}) which is called P-available. Meanwhile, unavailable P is found in the form of P-organic and P-inorganic. The proportion of the two forms of P is 25-97% P-inorganic and 3-75% P-organic.

Available K

As seen in Table 5, the B2K1 treatment had a significant impact compared to the other treatments, with the available K content reaching 7.39 mg/100 g, which is in the very high category. Meanwhile, the untreated tailings (B0K0) had the lowest available K content, only 0.80 mg/100g. According to Syah et al. (2022), high potassium levels in soil are closely related to high cation exchange capacity (CEC) values. High potassium (K) content is often associated with high CEC values because both are closely related to soil colloid activity and organic matter. Chemically, CEC indicates the ability of soil or soil amendments (such as biochar and compost) to retain and exchange positively charged cations, including K^+, Ca^{2+}, Mg^{2+}, and NH_4^+. As CEC increases, soil particles have more negative charges that can adsorb cations such as K^+. Therefore, the higher the CEC value, the greater the soil's ability to retain K so that it is not easily washed away, resulting in a high exchangeable K content in the soil.

Suseno et al. (2018) explained that the increase in K availability occurred due to the soil's ability to retain potassium elements and reduce losses due to leaching. On the other hand, Sulakhudin et al. (2017) stated that low K content can be caused by the lack of base cations in soil constituent minerals. These cations are easily leached, especially in areas with high rainfall, because water acts as a nutrient solvent. In soil conditions that are too dry or too wet, nutrients become unavailable to plants. Very high K content is usually found in the surface layer of the soil, while in deeper layers, K content tends to decrease.

PEB Biochar contains total K nutrients of 3.99% (Table 2) which can increase the absorption of K nutrients and plant growth. The level of K availability is strongly influenced by pH and base saturation. pH of tailings after treatment in this study is in the alkaline category. According to Widiowati et al.

(2012), potassium contained in biochar can be in the form of soil solution so that it is easily absorbed by plants and is also susceptible to leaching. At low pH and base saturation, potassium is easily lost to leaching, while at neutral pH and high base saturation, potassium is more easily bound by Ca.

CONCLUSIONS

PEB biochar combined with rubber litter compost improves nutrient status in the soil, but from the environmental perspective, it has not significantly reduced Hg contaminants. The use of biochar and compost can increase the pH of tailings and increase the content of organic carbon, nitrogen, phosphorus, and potassium in the soil. The highest combination treatment, PEB biochar 30 tons/ha and rubber litter compost 20 tons/ha, proved to be the most effective in improving soil fertility with a stable pH, total nitrogen content of 5.40%, phosphorus 175.67 mg/kg, potassium 7.39 mg/100g, and organic carbon 0.98% although these values are still low. However, mercury levels are still high and exceed the quality standard threshold, so additional remediation measures are needed by using larger doses of biochar and compost and managing tailings more strictly so that heavy metal pollution is reduced and soil fertility is maintained.

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