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Research Article

Bioremediation of Ex-Mining Soil with the Biocompost in the Incubation Experiments

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A process called bioremediation can be used to turn abandoned mining sites into useful agricultural land. An alternative to enhancing the quality of the ex-siltstone mining soil so that it can be used again as agricultural land is the application of biocompost fertilizer. This study intends to investigate how biocompost might enhance the ex-siltstone mining soil's quality in incubation treatments. The composition of biocompost used in this study is ingredient I: (a) cow manure = 50%; (b) chicken manure = 30%; (c) sand = 10%; (d) bacteria (bioactivator) = 10%; ingredient II: ingredient I is mixed with cow manure in a composition ratio of 1 : 2. The ex-mining soils were gathered in the ex-cement mining region of Lhoknga Subdistrict, Aceh Besar District (5.45°N, 95.2°E). Incubation experiments were conducted in incubation pots (approximately 5 kg per pot) that were randomly placed in a greenhouse using a 4 × 4 factorial completely randomized design (CRD) with three replications. The first factor is the ratio of ex-siltstone mining soil : biocompost, which consists of four levels of comparison: control (ex-mining soil not incubated), 1 : 1 (50 : 50), 1 : 2 (33 : 67), and 1 : 3 (25 : 75). The second factor is the incubation period, which has four levels: 0, 2, 4, and 6 weeks with 48 experimental units. Indicators of the impact of biocompost on the physical and chemical quality of ex-siltstone mining soil were examined. The result shows that bioremediation of ex-siltstone mining soil with biocompost application improves the quality of ex-siltstone mining soil by decreasing bulk density and permeability and also increasing porosity, decreasing soil pH from alkaline to neutral, and increasing soil organic C, total N, available P, and total K. The incubation period of ex-siltstone mining soil influences the changes and dynamics of the soil's chemical properties.

1. Introduction

Land and environmental degradation in mining areas can become a major issue if not properly managed. Indonesia's mining area is estimated to be 93.36 million hectares, and this mining area is growing in line with government policies that encourage mining exploration [1]. This condition is inversely proportional to the shrinkage of agricultural land [2]. The addition of mining areas will exacerbate land damage and cause critical land to expand. Mining for cement is one of the causes of critical land [3]. Degradation or deterioration of mining land causes changes in the landscape, physical, chemical, and biological soil conditions, microclimate, and changes in flora and fauna [4, 5]. During the process of open-pit mining, all vegetation and topsoil are removed, the soil fertility in each horizon is shuffled, and chemical, physical, and biological conditions rapidly deteriorate [6].

If the treatment of open-pit mining is not careful, it appears that the issues that may arise include changes in landforms, harm to the soil structure, and loss of topsoil. The biota of degraded land typically differs from the original ecosystem community, and the richness of flora, fauna, and microbial species tends to decline. Additionally, the drainage system is hampered by the emergence of excavated shells, which makes it challenging to use the property in the future [7]. The arid and uneven soil surface conditions (expanses), high soil pH (alkaline), many rocks with coarse soil texture, and very dense soil conditions due to the passage of heavy equipment (because mining activities are still on-going/active) were the obstacles discovered during the preliminary survey at the former silt mine site. As a result of machine activity during the mining process, a dense surface soil layer is created, which leads to the closure of soil pores [8]. The soil's composition will be harmed by issues discovered near old siltstone mines as a result of mining activity. By removing topsoil to access a deeper layer of mining material, the topography and soil composition of the surface soil are altered, resulting in harm to the physical and chemical qualities of the soil [9]. The loss of the heap's soil structure also reduces the soil's stability by altering the distribution of soil pores, which are crucial for holding water, destroying soil pore channels, which are crucial for allowing water to permeate the soil, and raising the risk of erosion. The soil's ability to support plant development will be reduced by the loss or sinking of fertile topsoil. When compared to intact soils, topsoil loss causes in lower yearly yields and inferior physical qualities (aeration, permeability, and aggregate stability) [10].

Aceh Province will have 28 IUPs (mining business permits) operating in various areas of Aceh in 2022. This area's mining business fields include gold, petroleum, cement, coal, and minerals B and C. The mining area in Aceh Province is estimated to be 70,761.10 ha [11], and it is estimated to be around 2,193.08 ha in Aceh Besar district [12]. Siltstone mining is one of the mining areas in this area, and it is processed into "Portland" as a raw material for making cement. Open-pit mining is one method of extracting the siltstone used as the primary building block of cement. The former mining terrain can be described as in a bedrock condition due to open-pit mining. If this is permitted, mining activities will result in more significant quantities and intensities of environmental harm, expanding the area of essential land. In the vicinity of previous open-pit mining systems, including old mines for cement raw materials, damaged land from former mines is typically challenging to reclaim and abandon [13].

The following are the quick steps in mining siltstone: (a) clearing the land of bushes and shrubs to make mining siltstone easier, (b) stripping/removal of top soil between 2 and 3 m and then stockpiled in a certain location using an excavator, (c) drilling is done to make it easier to take apart the materials, (d) blasting: siltstone material is destroyed by blasting so that it is easier to transport, and (e) loading: when loading, the blasted stone is immediately loaded into a dump truck and driven to the stone crushing plant using an excavator tool (Siltstone Crusher).

Mining activities cause vegetation loss, soil horizon damage, compaction, and damage to soil texture and structure, all of which are essential soil physical properties for plant growth [14]. Because the top soil layer (topsoil) is relatively good and the layer below it has been taken or removed, the subsoil layer in the form of horizon C or a layer of soil parent material and bedrocks occurs [15]. Furthermore, heavy equipment traffic during the mining and stockpiling processes contributes to the formation of a dense surface soil layer, which leads to the closure of soil pores, a process known as surface sealing and crusting [8]. These former mining sites are classified as damaged land and must be reclaimed or rehabilitated. Ex-mining land typically has a high density and has lost soil constituent components such as organic matter and clay content (colloids), leaving a soil layer that is less fertile and critical due to damage to its physical and chemical properties [5, 16].

In general, the reclamation of ex-mining soil entails converting damaged land caused by the mining process into productive land or ecosystems to create a useful landscape and fulfill the purpose of reclamation, such as converting it into fertile agricultural land [17]. Mine reclamation is a routine part of modern mining practices in developed countries such as the United States and Europe [18]. For developing countries, the approach to the reclamation of ex-mining land can be made in situ or ex situ, namely, through the use of bioremediation and phytoremediation methods [19–21]. Using biocompost amendments enriched with microorganisms is one of the simplest bioremediation methods [22].

Biocompost is a type of biological fertilizer that combines different types of bacteria in one carrier to deliver nutrients and boost crop productivity [23]. Biocompost is an organic material used as a soil supplement that has been enhanced with microorganisms. Biodegradable processes are brought about through the use of biocompost. A process called biodegradation uses bacteria to transform toxic chemicals into a simpler form and restores an ecosystem that has been harmed by them. According to [24], biodegradation is the process by which microorganisms are able to break down or degrade both synthetic and natural polymer molecules. Lignin and cellulose are examples of natural polymers, whereas polyethylene and polystyrene are examples of synthetic polymers.

Rice straw and animal manure are two examples of the agricultural and livestock waste that is typically used to make biocompost. According to [25], adding FMA and organic fertilizer (compost) can improve soil chemical properties and increase the growth of sunflower plants. The benefits of using biocompost over other forms of biofertilizers include the fact that the author's biocompost is well populated with microorganisms (decomposer bacteria). Making biocompost also does not take a long time because it uses aerobic methods in an open atmosphere and the decomposition process does not require a lengthy fermentation period so that the biocompost can be placed directly to the soil or land after the composition of the necessary raw materials has been mixed.

This organic fertilizer (biocompost) is excellent because it may assist plants by providing nutrients they need, affordable, of high quality, and ecologically friendly. It can also improve soil structure, soil aeration, soil porosity, and the composition of microorganisms in the soil [26]. so it can also be used as a soil amendment to improve soil properties as a good planting medium. The purpose of this research is to improve the physical quality of ex-mining soil by modifying the composition of the growing media and the incubation stage of biocompost fertilizer.

Since the purpose of incubation is to ensure that the reaction between organic matter and soil proceeds smoothly, incubation treatment must be carefully examined in order for plants to have access to nutrients in the future. According to [27], incubation is done to give microorganisms a chance to grow and metabolize in order to break down the content of organic matter into inorganic compounds that would subsequently be absorbed by plants. The results of the study of [28] showed that the application of biocompost was able to lower the pH of the tailings from 9.1 to 6-7 in the time period 30 days after incubation. This is due to the fact that the formation of organic acids occurs as a result of the decomposition of organic matter. Some chemical properties such as organic C, N, P, and K which were originally low also increased after being incubated for 30 days. Improved soil pH is a very important factor for increased plant growth. With regard to the use of amendment materials in improving the pH of the soil of former siltstone mines, it is possible to increase soil biological activity so that the decomposition of soil organic matter increases and ultimately affects the increase in N, P, and K elements [29].

2. Materials and Methods

This study was carried out in the Green House of Abulyatama University's Faculty of Agriculture in Aceh Besar District, Aceh Province, Indonesia. The research was carried out between February and July of 2021. The basic soil left behind from the mining process is the soil that is the subject of bioremediation experiments (at a depth of 10 m above the ground level after mining). Although there is still some soil in the siltstone area's bottom soil, silt rock particles with a coarser texture predominate there. The biocompost used is prepared by the researcher/author himself. Biocompost fertilizer made from cow manure, chicken manure, sand, and decomposing bacteria is used (bioactivator). The composition of biocompost used in this study is as follows: ingredient I: (a) cow manure = 50%; (b) chicken manure = 30%; (c) sand = 10%; (d). bacteria (Bioactivator) = 10%; ingredient II: ingredient I is mixed with cow manure in a composition ratio of 1 : 2.

Generally, biocompost contains low macronutrients (N, P, and K) and contains micronutrients Ca, Mg, Zn, Cu, B, Mo, and Si in sufficient quantities which are indispensable for plant growth (Sutanto, 1997). Biocompost nutrients content is as follows: C = 13.94; N = 1.41%; P = 7.06%; K = 2.65%; pH = 8.65; CaO = 3.26%; MgO = 1.30%; water content = 32.4% (laboratory results). However, the author's own processed biocompost includes bacteria: *Rhizobium*, *Azospirillum* sp., *Bacillus* sp., Lactobacillus sp., and *Trichoderma* sp.

The research location of ex-siltstone mining soil is located at a cement processing plant in Lhoknga Subdistrict, Aceh Besar District. Figures 1 and 2 depict the ex-mining location. A mining company that has long been operating in Aceh Province is the research location with the type of minerals in the form of siltstone (Figure3). The mining area is in the Lhoknga Subdistrict, Aceh Besar District. The mining location is 17 kilometers from Banda Aceh City. Mining operations have been on-going since 1980, producing ex-mining land that requires reclamation (Figure 4) in an area of 94 located at the coordinates 5.45°N, 95.25°E. The environmental conditions surrounding the production operation permit area are hills at the foot of the Northern Bukit Barisan Mountains formed by coastal sediment deposits.

The initial conditions and mining environment in this hill system have been overgrown by tropical forests, but the majority of them have been converted to arable land for nutmeg and young plants. There are various types of wood (trees) with very good growth in areas where dense tropical forests still exist. The siltstone mining operation is situated on the banks of the Krueng Raba River, not far from the beach. This area is classified as Other Use Areas, with the land having use rights and not being included in the protected forest area. Local residents have attempted to use the ex-mining areas in this area but have been unsuccessful due to several obstacles and the need for testing to obtain appropriate management methods. This former mining area is now abandoned, and some of it has grown into shrubs [30].

The ex-mining soil sampling for the experiment was collected from various locations on the mining site (Figure 5), then composited and evenly stirred. The soil retrieval site used for research tests and the soil taken for examination of the initial soil characteristics are the same. Before the experiment, some soil samples from this area were collected for laboratory analysis to determine the physical and chemical characteristics of the soil. Soil texture, bulk density, porosity, permeability, pH (H_2O), organic C content, total N, available P, and total K were among the soil quality indicators studied. Soil samples were collected using ring samples for measuring physical properties, and disturbed soil samples were collected compositely at a depth of 0–20 cm for soil chemical analysis. The soil from the mine site was air-dried for a week before analysis and use in incubation experiments. Samples for preliminary analysis were crushed and sieved through a 10-mesh sieve.

The experiment was carried out in incubation pots (5 kg capacity per pot) placed randomly in a greenhouse using a 4 × 4 factorial completely randomized design (CRD) with three replications. The first factor is biocompost which is given in four levels of comparison, namely, control (ex-mining soil not incubated), 1 : 1 ratio (50 : 50) or 1.50 litres of ex-siltstone mining: 1.50 litres of biocompost which is equivalent to 300 $t{\cdot}ha^{-1}$ of biocompost, 1 : 2 ratio (33 : 67) or 1 litres of ex-siltstone mining soil: 2 litres of biocompost which is equivalent to 446.7 $t{\cdot}ha^{-1}$, and 1 : 3 ratio (25 : 75) or 0.75 litres of ex-siltstone mining soil: 2.25 litres of biocompost which is equivalent to 500 $t{\cdot}ha^{-1}$ of biocompost. The second factor is the incubation period, which has four levels: 0, 2, 4, and 6 weeks, for a total of 48 experimental units. For the pot incubation experiment, air-dried soil from

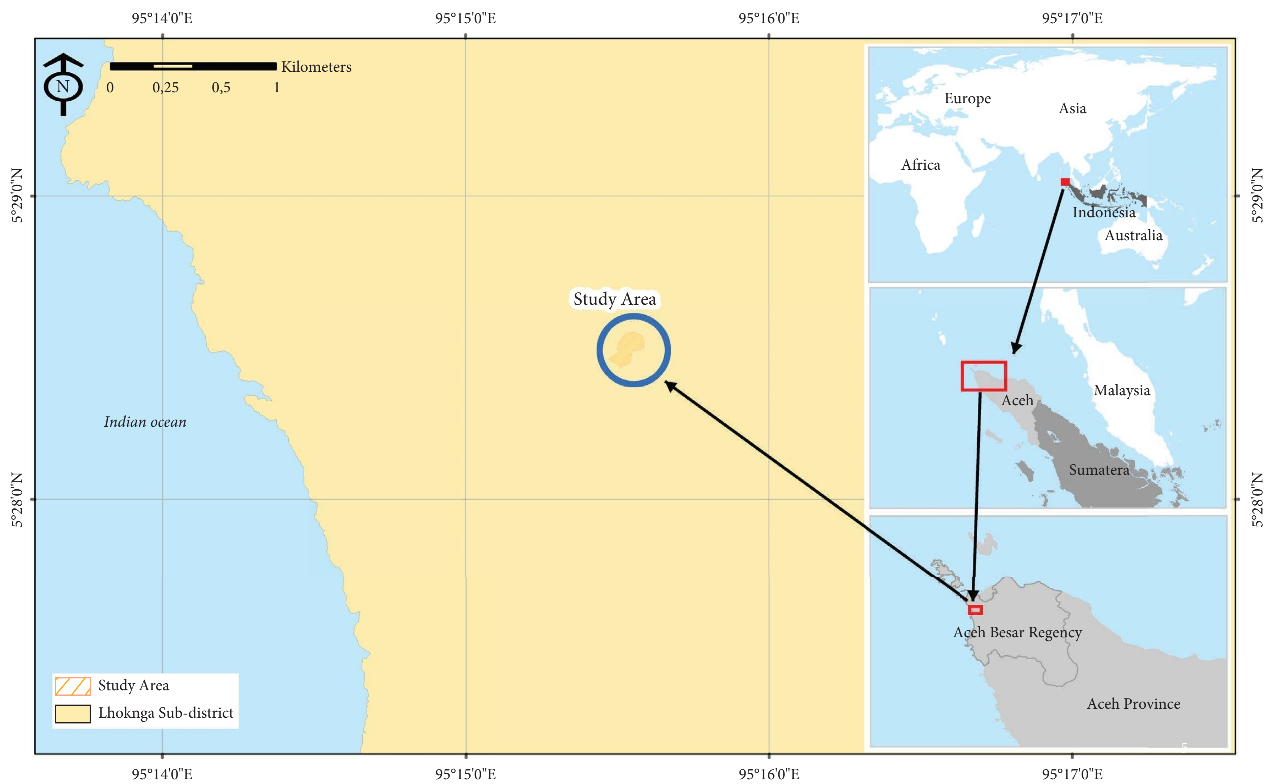


Figure 1: Research location in Lhoknga Subdistrict, Aceh Besar District.

Figure 2: Ex-mining location.

Figure 3: Ex-siltstone mining material location.

Figure 4: Visual condition of reclamation area.

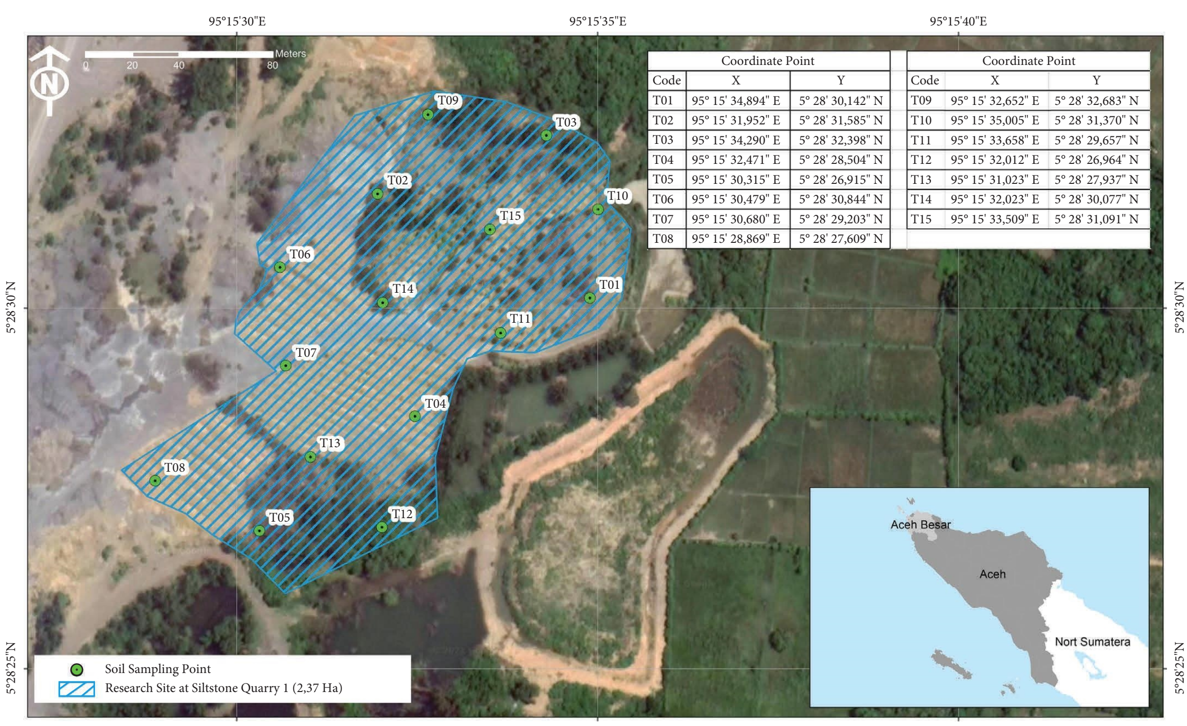


Figure 5: Ex-siltstone mining soil sampling.

the sample location is sieved with a sand sieve to separate rock or gravel from the soil and then placed in incubation pots. The basis for determining several doses of biocompost has been tested based on reference [31] and based on consideration of the target soil organic C content of 3–5%. In addition, biocompost is an amendment expected to improve

Table 1: Selected physical [33, 34] and chemical characteristics of the ex-siltstone mining soil before the incubation experiment [35].

Soil characteristics	Method	Value ± SD	Criteria
Soil texture (i) Sand (%) (ii) Silt (%) (iii) Clay (%)	Gravimetric	Sandy	Coarse
Bulk density ($Mg{\cdot}m^{-3}$)	Ring sample	2.04 ± 0.01	Very high
Porosity (%)	Gravimetric	7.43 ± 0.28	Poorly
Permeability ($cm{\cdot}h^{-1}$)	Permeameter	6.53 ± 0.21	Slightly fast
pH H_2O (1 : 2.5)	Electrometric	8.40 ± 0.43	Slightly alkaline
Total N (%)	Kjeldahl	0.11 ± 0.01	Low
Organic C (%)	Walkley and Black	0.70 ± 0.02	Very low
P_2O_5 Bray ($mg{\cdot}kg^{-1}$)	Bray II	6.00 ± 0.27	Low
Exchangeable K ($cmol{\cdot}kg^{-1}$)	1 N NH_4OAc pH 7	0.30 ± 0.06	Moderate
Total K (mg K_2O/100 g)	25% HCl	9.45 ± 0.02	Very low

the characteristics of ex-siltstone mining soil. The consequence requires a larger dose than if it is only used as fertilizer.

Furthermore, according to the level of treatment, each pot was added and mixed with biocompost in a volume ratio. After homogeneous mixing, pure water was poured into each pot until it reached the field capacity condition, and the pots were then covered with black plastic to prevent light exposure. This soil mixture is then left for 6 weeks, and soil samples are taken from each pot for analysis in the laboratory at weeks 0, 2, 4, and 6 (depending on the incubation period) to determine changes in several selected soil quality indicators, namely, bulk density (BD), permeability, porosity, pH (H_2O), organic C content, available P, total N, and total K.

The experimental data were processed using the analysis of variance at the P level (0.05) and the least significant difference (LSD 5%) test to determine differences between the biocompost treatments on soil physical parameters during each incubation period. Soil chemical data are presented as a histogram, and a line graph is used to determine the dynamics of changes in the chemical properties of ex-mining soil due to the application of biocompost. Pearson's correlation analysis was used to determine the relationship between soil quality indicators at each incubation period [32].

3. Results and Discussion

3.1. Descriptions of Sampling Sites

3.1.1. Initial Characteristics of Ex-Mining Soil. Table 1 shows that the characteristics and properties of the ex-siltstone mining soil used for the experiment presented numerous challenges in terms of soil quality. These limitations include coarse soil texture (sand), extremely high bulk density (BD) (2.04 $Mg{\cdot}m^{-3}$), low soil porosity (7.43%), and medium permeability (6.53 $cm{\cdot}h^{-1}$). Soil with a sand texture cannot bind water and does not form a good soil structure, so it is easily eroded and lacks colloids that absorb water and nutrients [36, 37]. Soil texture is one of the soil characteristics that greatly influence the soil's ability to support plant growth [38]. To ascertain the association between soil quality parameters at different incubation times, Spearman correlation analysis is performed. Table2 shows the best treatment of correlation matrix between several soil chemical properties after incubation experiment and biocompost application.

Table 2: Correlation matrix between several soil chemical properties of ex-siltstone mining after the incubation experiment and biocompost application.

Soil chemical properties	pH H_2O	Organic C	Total N	Available P	Total K
pH H_2O	1.0000				
Organic C	−0.0030	1.0000			
Total N	−0.6611*	0.5845*	1.0000		
Available P	−0.1870	0.3296	0.3372	1.0000	
Total K	−0.3887	0.7910**	0.7972**	0.4503	1.0000

The very high BD value indicates that this ex-mining soil has lost its function as a good plant growth medium because the soil becomes solid, making it difficult for roots to penetrate [39] and reflecting that the ability to transport water has been decreased and diminished [40]. Furthermore, poor porosity indicates that this soil lacks sufficient or balanced macrospore and microspore space, which reduces the rate of water infiltration [41] and makes runoff more likely [42]. The relatively rapid permeability will have implications for the easy loss of water from the soil solum, reducing the ability to hold water [43].

Based on the physical properties of the soil (Table 1), it is possible to conclude that the physical condition of the ex-mining soil under study is very poor and that improvements are required. Because soil physics is an indicator of soil and water conservation [38], many researchers are interested in soil erosion and water quality [44]. Soil physical properties such as bulk density, infiltration, aggregation, and hydraulic conductivity will be affected by land management, which is critical for soil and water conservation efforts [45, 46].

Table 1 also shows that the initial soil analysis reveals that this ex-mined soil has a very high pH (alkaline), organic C content, total N, and low available P. The exchangeable K level is moderate [47]. The chemical quality of the ex-mining soil is not good for plant growth based on its chemical

Table 3: The bulk density value of ex-siltstone mining soil due to the application of biocompost at various incubation periods.

Ratio of soil: biocompost	Incubation period (weeks) 0	2	4	6	Average
	.($Mg{\cdot}m^{-3}$).				
Before incubation (control)	2.04[b]	2.04[b]	2.04[b]	2.04[b]	2.04[b]
1 : 1 (50 : 50)	2.02[b]	2.01[b]	2.02[b]	1.96[b]	2.00[b]
1 : 2 (33 : 67)	1.92[b]	1.93[b]	1.93[ab]	1.64[a]	1.86[b]
1 : 3 (25 : 75)	1.08[a]	1.45[a]	1.75[a]	1.46[a]	1.44[a]
Average	1.77[a]	1.86[a]	1.94[a]	1.78[a]	

Numbers followed by the same letter in the same column were not significantly different according to the LSD 0.05 test (0.18).

Table 4: The porosity of ex-siltstone mining soil due to the application of biocompost at various incubation periods.

Ratio of soil: biocompost	Incubation period (weeks) 0	2	4	6	Average
	..(%).				
Before incubation (control)	7.43[a]	7.43[a]	7.43[a]	7.43[a]	7.43[a]
1 : 1 (50 : 50)	51.68[b]	52.36[b]	51.69[c]	51.93[c]	51.92[b]
1 : 2 (33 : 67)	52.29[c]	52.68[c]	51.18[b]	51.61[b]	51.94[b]
1 : 3 (25 : 75)	52.28[c]	52.28[b]	52.79[d]	52.16[c]	52.38[c]
Average	40.92[a]	41.19[b]	40.77[a]	40.78[a]	

Numbers followed by the same letter in the same column were not significantly different according to the LSD 0.05 test (0.30).

characteristics. The total N content is approximately 0.11%, or 1.10 $g{\cdot}kg^{-1}$, or 22 kg·N per hectare, while the available P is 6 $mg{\cdot}kg^{-1}$ P_2O_5, or approximately 12 $kg{\cdot}P_2O_5$ per hectare. Exch. K is 0.3 $cmol{\cdot}kg^{-1}$, which is approximately 117 $mg{\cdot}kg^{-1}$ K, or the equivalent of 282 kg K_2O per hectare.

3.1.2. Biocompost Effects on Ex-Siltstone Mining Soil Physics. According to the analysis of variance, applying biocompost to the media/soil of ex-siltstone mining significantly improved the soil's physical quality by decreasing bulk density (BD) and soil permeability and increasing soil porosity. The length of the incubation period has an impact on the soil porosity, soil bulk density, and soil permeability.

Table 3 shows that the higher the biocompost dose, the lower the ex-mining soil's bulk density (BD). The best biocompost application on ex-mining soil treatment was at a ratio of 1 : 3 (25 : 75), or 25% ex-mined soil + 75% biocompost. In general, the 1 : 3 (25 : 75) treatment differed significantly from the 1 : 1 (50% ex-mining soil + 50% biocompost) and 1 : 2 (33% ex-mining soil + 67% biocompost) treatments. Biocompost application is able to increase BD from a slightly hard condition to being lighter or porous when compared to the BD value before the incubation experiment. Furthermore, Table 4 shows that the average of the porosity of ex-mining soil increased from 7.43% before incubation to 51.68% after the biocompost treatment (1 : 1) and become higher to 52.28% and 52.29 (1 : 3 and 1 : 2 treatments). There was the difference before incubation with another treatment ratio of soil: biocompost, but 1 : 3 treatment was different from 1 : 1 treatments ratio and there was no difference with 1 : 2 treatments ratio, and there is also a change at incubation periods of 2, 4, up to 6 weeks.

Based on the results of this experiment, it can be stated that the application of biocompost can increase soil porosity from poor or very low to good or medium [48]. The 1 : 3 ratio (25% ex-mined soil + 75% biocompost) had a slightly better effect because it was able to increase higher porosity. Prior to the incubation experiment (Table 1), the permeability of the ex-mining soil was 6.53 $cm{\cdot}h^{-1}$ (slightly fast). However, after a week of incubation, the permeability of this soil decreased to 2.55 $cm{\cdot}h^{-1}$ (medium) when a 1 : 1 (50 : 50) biocompost was applied. At a higher biocompost dose, namely, 1 : 3 (25 : 75) or 25% ex-mined soil + 75% biocompost, soil permeability decreased to 2.14 $cm{\cdot}h^{-1}$ (medium), and there is also a change at incubation periods of 2, 4, up to 6 weeks, but it is still classified in the criteria medium (Table 5). As a result of the interaction, there was a slightly inconsistent change in soil permeability during incubation, as shown in Table 5. The application of biocompost at a 1 : 3 (25 : 75) at 2-week incubation times treatment which was 3.62 $cm{\cdot}h^{-1}$ slightly lowered the permeability value of the soil. However, it is still within the moderate criteria. Organic matter is very important in improving soil physical properties, such as improving soil structure and increasing soil aggregation into crumbs, which improves permeability and porosity. Improving soil quality means being able to increase and decrease the physical and chemical properties of the soil.

The changes in the physical properties of the soil following incubation of ex-mining soil with biocompost, as indicated by a decrease in bulk density and an increase in soil porosity and permeability, are a positive impact of biocompost as an amendment material that functions as a soil

Table 5: The permeability of ex-siltstone mining soil due to the application of biocompost at various incubation periods.

Ratio of soil: biocompost	Incubation period (weeks) 0	2	4	6	Average
	..($cm \cdot h^{-1}$).				
Before incubation (control)	6.53[c]	6.53[c]	6.53[c]	6.53[c]	6.53[c]
1 : 1 (50 : 50)	2.55[ab]	3.04[a]	1.80[a]	2.32[a]	2.43[a]
1 : 2 (33 : 67)	2.67[b]	3.02[a]	2.32[b]	2.63[ab]	2.66[ab]
1 : 3 (25 : 75)	2.14[a]	3.62[b]	2.67[b]	2.85[b]	2.82[b]
Average	3.47[ab]	4.05[c]	3.33[a]	3.58[b]	

Numbers followed by the same letter in the same column were not significantly different according to the LSD 0.05 test (0.43).

bioremediation agent. This improvement in the physical quality of ex-mining soil occurs because biocompost is a type of organic fertilizer that, in addition to microorganisms [49], contains humus compounds such as humic acid and fulvic acid, which act as agents for the formation of soil aggregates [50] in order to improve soil structure. With the influence of this humus compound, heavy clay soils with coarse and strong lump structures will change into a finer structure and crumb consistency, making the soil easier to cultivate and increasing water penetration into the soil [51]. Because biocompost is an organic material with a very low BD ($0.3\,Mg \cdot m^{-3}$), mixing it with soil reduces the soil BD [52, 53].

Low bulk density indicates that the soil or growing media is light, crumb, porous, and high in soil organic matter, which will support plant root growth [54]. The study's findings [55] revealed that using organic matter-based ameliorants could improve the bulk density and permeability of the tailings soil. The study in [56] added that the higher the amount of soil organic matter applied, the lower the bulk weight of the soil and the higher the total porosity, lowering the soil's resistance to penetration. Groundwater conductivity decreases as soil density increases; however, in less compacted soils, the bulk density of the soil becomes relatively lower, and groundwater conductivity increases [57]. Increased application of organic matter improves soil structure and reduces consistency, increases soil porosity, and decreases soil bulk density [58, 59].

One of the functions of organic matter is to produce a high total pore space and a low soil volume weight, which allows water to enter the soil and increase soil permeability [60]. Overall, there was a wide range of research data tested, particularly during the incubation period. However, the composition of the planting media with a ratio of 1 : 3 (25% ex-mining soil: 75% biocompost) produced better results because the proportion of organic matter was higher than that of the treatment (1 : 1 or 1 : 2). The findings of this experiment are consistent with previous research, indicating that the use of organic amendments includes biocompost and other materials such as biochar [61, 62], manure, and a combination thereof. It can improve soil quality in terms of physical, chemical, and biological soil properties [63, 64], making nutrients more available for plant growth and development [65].

3.1.3. Change of Soil Chemical Properties. The analysis of variance results (Table 6) show that the biocompost factor and the incubation period, as well as their interactions, have a significant effect on the chemical properties of the ex-mining soil. This demonstrates that using biocompost in various ratios can improve soil chemical quality as measured by changes in pH (H_2O), organic C content, total N, available P, and total K.

Figure 6(a) shows that the pH value (H_2O) of the exmined soil before incubation had a very high value of 8.40 and included the criteria for being slightly alkaline. Furthermore, after a week of incubation, the soil pH (H_2O) decreased to 7.40–7.48 or became neutral with the addition of biocompost in several comparisons (50 : 50, 33 : 67, and 25 : 75). This pH value continued to fall until it reached 7.08 at the end of the incubation period (6 weeks).

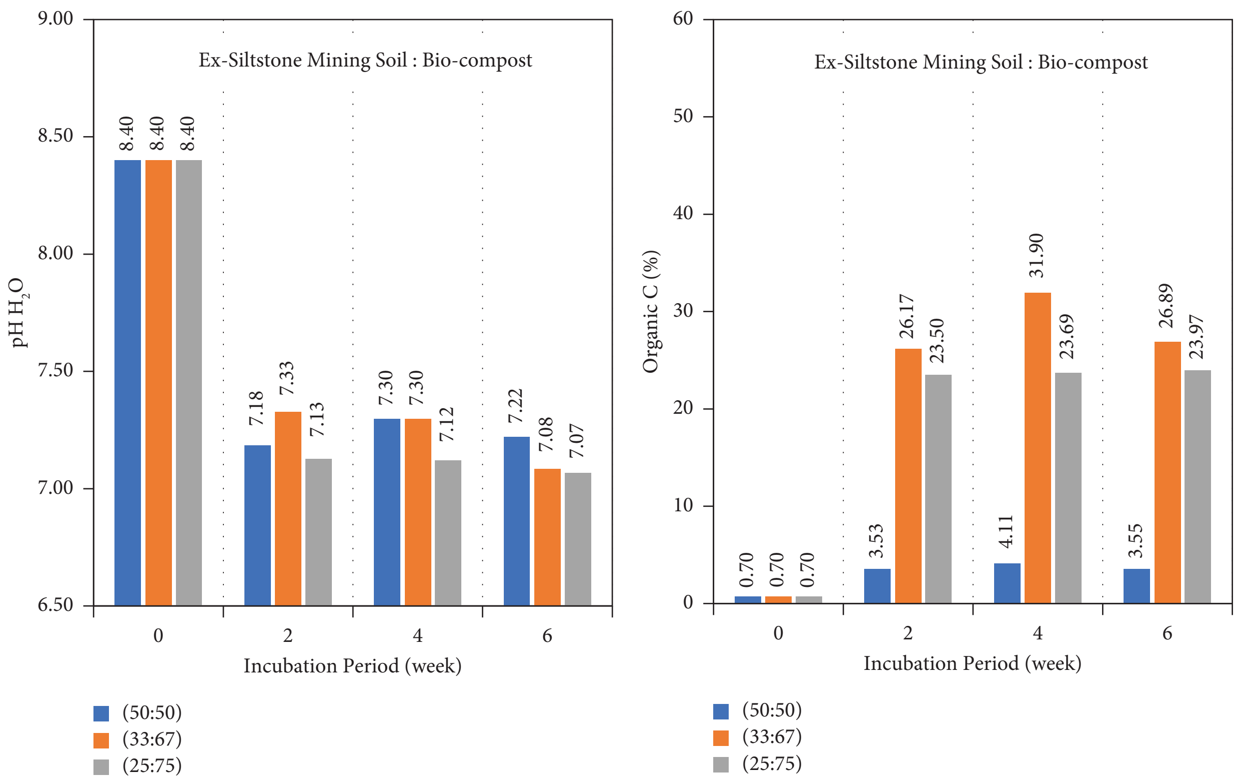
When comparing the biocompost treatments, it appears that there is a difference in the levels of biocompost treatment, but the difference is inconsistent. This occurs as an effect of the interaction between the ratio of soil: biocompost and the incubation period. This interaction effect is thought to be related to the activity of microorganisms found in biocompost in the process of organic matter decomposition. Microorganisms use organic matter (biocompost) as an energy source [63]. The shift in soil pH from slightly alkaline (8.40) to neutral (7.08) demonstrates that biocompost can be used as a material for the bioremediation of polluted soils, including ex-mining soils. Several other researchers have reported that one of the benefits of using biocompost is that it can improve soil chemical properties such as pH [66].

Figure 6(b) also shows that biocompost can raise the organic C content of ex-siltstone mining soil from very low to high to very high status. More specifically, it appears that the ratio of ex-siltstone mining soil to a biocompost level that has the greatest effect on increasing soil organic C is obtained at 1 : 3 or 25 : 75 treatment, namely, 25% ex-siltstone mining soil: 75% biocompost, followed by treatment 1 : 2 or 33 : 67 (33% ex-siltstone mining soil: 67% biocompost). These two treatments increased the C content of the ex-siltstone mining soil by 23.7–31.9 percent, whereas the 1 : 1 or 50 : 50 treatment (50% ex-siltstone mining soil: 50% biocompost) only increased the C content of the ex-siltstone mining soil by 5.95%.

This increase in soil C content occurs because biocompost is one of the organic amendments that contain

Table 6: *F* test values of several chemical properties of ex-siltstone mining soil after incubation experiments.

Sources of variance	d*F*	*F* test value ($P < 0.05$)				
		pH (H_2O)	Organic C	Total N	Available P	Total K
Biocompost (B)	2	12.95^{**}	$67{,}896.14^{**}$	185.89^{**}	58.18^{**}	105.74^{**}
Incubation period (T)	3	35.57^{**}	485.18^{**}	32.29^{**}	13.40^{**}	4.55^{**}
Interaction (B × T)	6	3.37^{*}	196.85^{**}	3.50^{*}	112.68^{**}	2.60^{*}
Error	24					
Total	35					



(a) (b)

Figure 6: The average of pH (H_2O) and organic C content of ex-siltstone mining soil at each incubation period due to biocompost application.

a number of compounds that improve the physical, chemical, and biological properties of the soil [67]. The results of the composition analysis of the biocompost revealed that the C content in this material was 34%. This high C content has the potential to supply C to the ex-mining soil under investigation. Furthermore, increasing the C content of ex-mining soil with biocompost will increase the development and activity of microorganisms, as well as the type and number of soil microbes [68].

The use of biocompost also increased the total N content, available P, and total K of the ex-siltstone mining soil. Figure 7(a) shows that the N content of the ex-siltstone mining soil is very low (0.1%) and increases from 0.22 to 0.46%, classifying it as moderate [47]. The biocompost treatment with the highest total N yield was obtained at a 1 : 3 ratio, or 25% ex-mining soil: 75% biocompost. This treatment differed significantly from the 1 : 1 (50 : 50) and 1 : 2 (33 : 67) treatments in general. Figure 7(b) shows that after biocompost application and incubation, the soil's available P content increased from 6.0 mg·kg^{-1} (before incubation) to 159.6 to 197.1 mg·kg^{-1}. This demonstrates that applying biocompost in a specific ratio to ex-mining soil can increase the available P content of the soil from low to very high. Although there was a statistical difference between biocompost treatments, the difference was not as stark when compared to changes in total N, especially after 2 weeks of incubation. Furthermore, Figure 7(c) shows that the results of biocompost application in each incubation period could increase the total soil K from 9.54 mg K_2O/100 g (very low) to 13.77 mg K_2O/100 g (low) at a ratio of 1 : 3 (25 : 75). Based on the results of this incubation experiment, the higher the dose of biocompost, the higher the increase in total N, available P, and total K of ex-siltstone mining soil.

The increase in total N, available P, and exchangeable K in ex-mining soil incubated with biocompost occurs because biocompost contains a variety of nutrients as an amendment

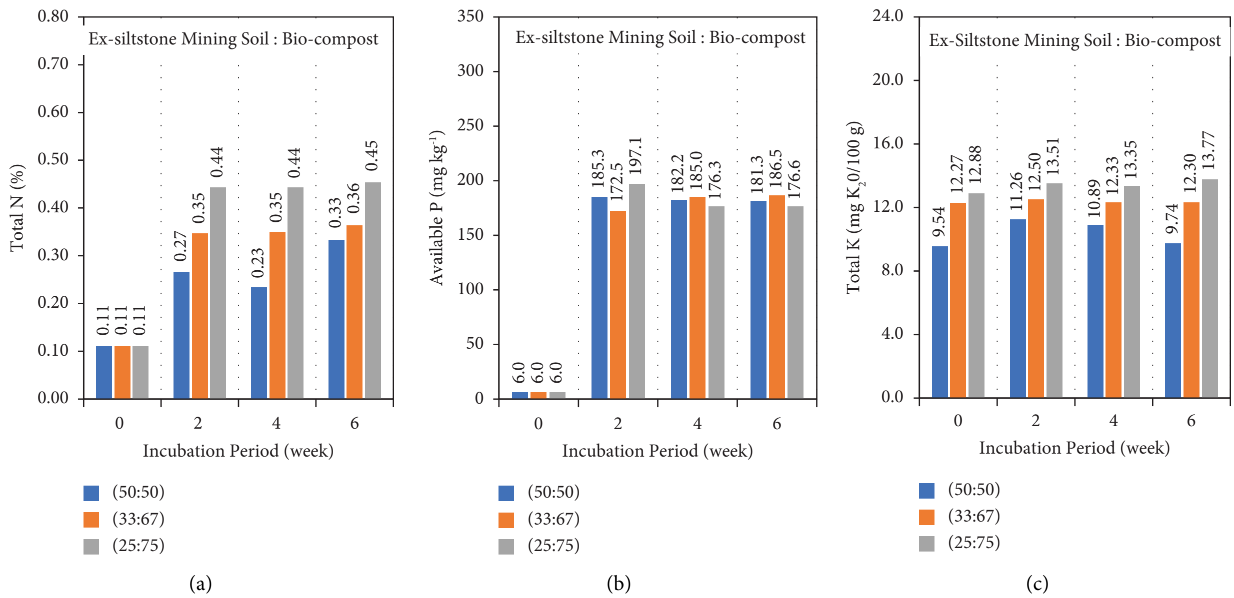


Figure 7: The average of total N, available P, and total K of ex-siltstone mining soil at each incubation period due to the application of biocompost.

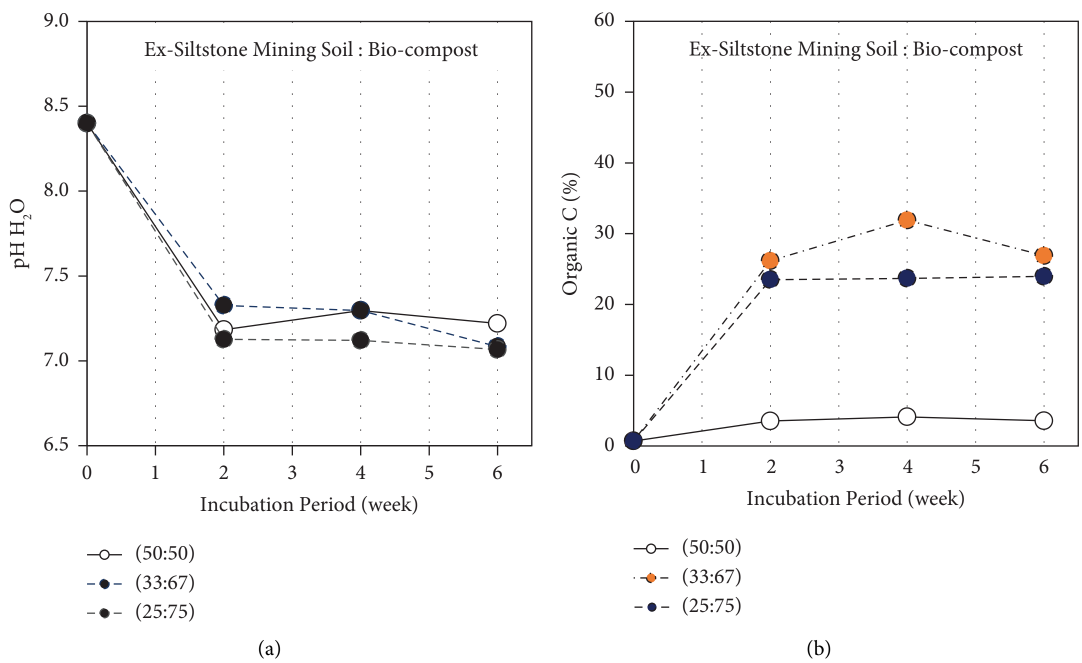


Figure 8: The dynamics of changes in pH (H_2O) and organic C of ex-siltstone mining soil due to the incubation period in each biocompost treatment.

material, including N, P, K, and other elements such as Ca, Mg, S, and trace elements [69]. Microorganisms decompose these nutrients during the incubation process, allowing them to dissolve into the soil solution as available forms such as NO_3^-, NH_4^+, $H_2PO_4^-$, $HPO_4^=$, and K^+, Ca^{++}, Mg^{++}, and $SO_4^=$ as plant macronutrient ions [67]. Microorganisms can use the nitrification process to convert biocompost (organic matter) into soluble ionic forms such as NH_4^+ and NO_3^- [70]. *Nitrosomonas* sp. and *Nitrobacter* are among the microorganisms involved [71]. Phosphate-solubilizing bacteria such as *Pseudomonas* sp., *Bacillus* sp., *Thiobacillus* sp., *Mycobacterium*, Micrococcus, Flavobacterium, and others transform and release P from biocompost into soluble P (available P) [72]. The acidification of organic acids such as humic acid (H.A.) and fulvic acid (F.A.) can result in the solubility of basic cations such as K^+, Ca^{++}, and Mg^{++}. Apart

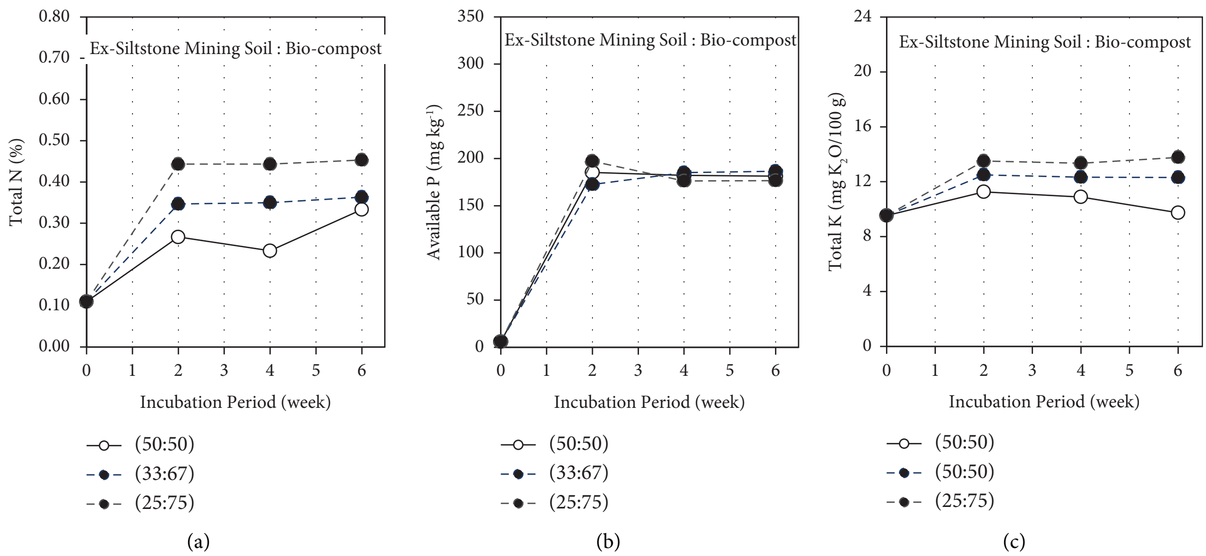


Figure 9: The dynamics of changes in total N, available P, and total K of ex-siltstone mining soil due to the incubation period in each biocompost treatment.

from dissolving minerals and cations from complex organic compounds, these acids can also act as colloids for soil ion exchange [73].

Figures 8(a) and 8(b) and 9(a)–9(c) show the pattern of changes in several selected chemical properties during the incubation experiment. The pH (H_2O) of the ex-siltstone mining soil that was given biocompost after 1 to 2 weeks of incubation decreased dramatically from slightly alkaline conditions to neutral, as shown in Figure 8(a). After that, the changes were relatively stable until a 6-week incubation period. The pattern of pH changes was similar between the biocompost treatments. On the other hand, after 1-2 weeks of incubation, the organic C (Figure 8(b)), total N (Figure 9(a)), available P (Figure 9(b)), and total K (Figure 9(c)) parameters of ex-mining soil with biocompost increased dramatically.

Figure 7(a) also shows that the pattern of changes in organic C content differs greatly between biocompost treatments. Similarly, the pattern of changes in total N (Figure 7(b)) and K (Figure 7(c)) content can be swapped, whereas the available P content parameters are relatively similar across biocompost treatments (Figure 9(b)). The activity of soil microorganisms in the decomposition process of organic compounds from the given biocompost is related to the difference in patterns and dynamics of changes in soil chemical properties caused by incubation with biocompost [74]. The higher the biocompost dose, the higher the C content, and thus the product of the compound released [75]. Organic matter decomposition is closely related to C and N elements. If the remodelled material has a high C content, soil microbes will use N, P, and other elements as a source of nutrients [76], and N will be released back into the soil solution once stable [77, 78]. According to the findings of this experiment, intensive reshuffling and transformation activity occurred from the first to the second week of incubation, after which the activity became sloping or stable. Based on these findings, if the biocompost-treated ex-mining soil is to be used as a planting medium, it should be used after 2 weeks of incubation to avoid N immobilization in plants. The treatments that can be applied in the field based on the results of this study are as follows: ex-siltstone mining soil and biocompost of ratio 1 : 3 (25% ex-siltstone mining soil: 75% biocompost).

3.1.4. Soil Chemical Properties Correlation. The correlation analysis results (Table 2) show that there is a significant correlation between several chemical properties after ex-siltstone mining soil incubation with biocompost. pH (H_2O) has a negative correlation with total N ($r = -0.66^*$), organic C has a negative correlation with total N ($r = 0.59^*$) and total K ($r = 0.79^{**}$), and total N has a negative correlation with total K ($r = 0.79^{**}$).

The correlation between pH (H_2O) and total N in ex-siltstone mining soil is linearly negative, implying that the higher the pH values of the soil, the lower the total N content of the soil. This can be explained by the fact that when the pH of the ex-siltstone mining soil reaches an alkaline criteria, soil microbe development and activity become less active or unfavourable [79], affecting the development of the microbial population [80]. Furthermore, there is a positive relationship between organic C, total N, and total K. This means that as the organic matter or C content of the ex-siltstone mining soil increases, so does the supply of N and K into the soil, which is also relevant to the positive correlation between total N and total K availability. Nitrogen (N) is a constituent element of organisms that ranges from 3 to 5% in composition, and this N element accounts for 1/10 of the C content of organisms in the rhizosphere [81]. As a result, as the organic C content increases, so does the N.

4. Conclusions

Bioremediation of ex-siltstone mining soil with biocompost application improves the quality of ex-siltstone mining soil by decreasing bulk density and permeability, and also increasing porosity, decreasing soil pH from 8.40 (alkaline) to neutral (7.04–7.50), and increasing soil organic C, total N, available P, and total K. The incubation period of ex-siltstone mining soil influences the changes and dynamics of the soil chemical properties. The intensity of changes of ex-siltstone mining soil properties caused by the biocompost application increased during the 2-week incubation period. The best biocompost treatment for improving the quality of ex-siltstone mining soil was obtained at ex-siltstone mining soil and biocompost ratio of 1 : 3 (25% of ex-siltstone mining soil: 75% of biocompost).

Data Availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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