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Research Article

Effect of biochar and Tithonia compost on physical properties of post-coal mining soil

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Abstract

Biochar and Tithonia compost are alternative materials used to ameliorate soil properties. The application of these two types of ameliorants in ex-coal mining areas aims to improve the physical properties of the soil and its effect on soybean growth and yield. The research was designed in the form of a polybag experiment conducted in a greenhouse. The soil used for this research was taken from the surface layer of ex-coal mining pits. The treatment levels tested consisted of three biochars and four Tithonia composts. Each treatment level was 0, 5, and 10 t biochar ha^{-1} and 0, 5, 10, and 15 t Tithonia compost ha^{-1}. The research units were arranged in a completely randomized design. The results showed that applying 10 t biochar ha^{-1} and 15 t Tithonia compost ha^{-1} decreased soil bulk density, increased total pore space, aggregate stability, and soil water content capacity, and improved soybean growth and yield. The soil physical properties and soybean improvement were not significantly different from those due to the application of 5 t Tithonia compost ha^{-1}.

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Introduction

Jambi Province had verified coal reserves of 1,658,592 million tons in 2021, with some of these reserves located in Batanghari Regency (Ministry of Energy and Mineral Resources, 2022). After mining, ex-mining land undergoes a decline in the quality of its physical and chemical properties, affecting its function as a plant-growing medium. Soil structure damage, high bulk density, high soil acidity, and low organic matter content were observed in the five coal-mined reclamation soil profiles studied (Khaidir et al., 2019). The acidity of the surface layer of reclaimed coal mine soil ranges from pH 4.34 to 4.65, with organic content between 0.87% and 1.07% and an average bulk density of 1.5 g cm^{-3} (Khaidir et al., 2022). The structure damage, high consistency, and loss of organic matter in ex-coal mining soil increase without returning the top and subsoil layers to the soil surface. The addition of organic cementing agents and inorganic building units leads to the occlusion of free particles and microaggregates into macroaggregates (Guhra et al., 2022). Soil organic particles interact with inorganic particles to promote soil aggregation, increase porosity, and stabilize soil structure (Kay, 1997). Soils with high soil organic carbon (SOC) content are more friable, have better tillage properties, and are less compact than soils with low SOC content (Saxton and Rawls, 2006). Particles move within the soil and increase in size due to the absorption of organic material on the mineral surface and the attachment of fine and amorphous mineral material to the organic particles. Organic absorption causes the particles to stick together, forming aggregates (Philip and Gregg, 2017).

The utilization and development of post-coal mining land for soybean cultivation require the application of ameliorants to enhance physical, chemical, and biological soil fertility. Various efforts can be made to improve and restore the physical and chemical properties of ex-coal mining soil, including the application of compost and biochar.

Agricultural waste in the form of biochar and compost from Tithonia can be employed to enhance the physical properties of damaged soil, thereby increasing soil productivity. Kolawole et al. (2014) reported that Tithonia reduces bulk density, likely due to increased soil organic matter from plant residue decomposition. Biodegradable Tithonia compost should be combined with biochar to ensure a lasting impact. According to Glaser et al. (2002), biochar is a soil-ameliorating material with stable properties that can sustainably restore soil properties. The applications of biochar and compost have been shown to effectively reduce soil bulk density (BD) and particle density (PD), enhance total porosity, and promote an increase in fast drainage pores (FDP). Additionally, these applications increase water content, organic carbon, and soil pH, as reported by Barus (2016).

The stable nature of biochar causes it to last a long time when added to the soil, thereby increasing carbon storage. Biochar is almost 100 times more stable compared to other forms of soil organic matter (Jeffery et al., 2011). Coal mine spoil typically exhibits high bulk density, low water retention, and reduced aggregate stability and water-holding capacity. The application of biochar as an amendment can effectively restore these properties, making it a valuable option for the reclamation of coal mine spoil (Ghosh and Maiti, 2020). According to Chan et al. (2007), the dose of organic matter combined with biochar affected the soil bulk density (1.00-0.91 g cm^{-3}) and was significantly different from that without treatment (1.11 g cm^{-3}). Biochar, characterized by its high surface area and porosity, has the potential to enhance the overall surface area of the soil. This enhancement is associated with improved soil water retention capacity, aeration, tensile strength, and a reduction in bulk density (Palansooriya et al., 2019).

The research aimed to determine the optimal dose of biochar and Tithonia compost for enhancing the physical properties of the soil and to examine the optimal growth and production of soybeans resulting from improvements in the physical properties of soil derived from former coal mining land.

Materials and Methods

The soil under investigation originates from the reclaimed post-coal mining area of PT. Nan Riang Jebak Block, Muara Tembesi District, Batanghari Regency, Jambi Province. This research spanned from April to October 2019. It commenced with acquiring reclaimed coal mine soil, which was conducted in polybags in the greenhouse of the Faculty of Agriculture at Jambi University. Soil materials were systematically collected from a section of the coal reclamation land by consistently taken to a depth of 20 cm from the surface. The collected soil was subsequently crushed, sieved, and mixed until homogeneity was achieved. Other materials used in this research were corncob biochar, Tithonia compost, Anjasmoro variety soybean seeds, fertilizer (urea, triple super phosphate, KCl), and fungicide (Dithane M-45). Corncob biochar and Tithonia compost were the treatments tested for their effect on the physical and chemical properties of coal mine reclaimed soil.

The research was conducted in the form of a polybag experiment utilizing a factorial design within a completely randomized design with two types of treatment factors tested. The first factor was biochar with three dosage levels (0, 5, 10 t ha^{-1}), while the second factor was Tithonia compost with four levels (0, 5, 10, 15 t ha^{-1}). A total of 12 treatment combinations were tested, each replicated three times. Therefore, the total of experimental units was 36 polybags. The placement of each experimental polybag unit in the greenhouse used the distance between replicates and rows, which was 30 cm x 25 cm. Each experimental polybag unit was filled with 15 kg of prepared coal mine reclaimed soil. The polybag used measures 35 cm in height and 25 cm in diameter. The reclaimed coal mine soil was initially analyzed for its physical and chemical properties. The results of laboratory tests on various physical and chemical soil properties, indicating the initial conditions of the reclaimed soil used, are presented in Table 1.

Before treating with corncob biochar and Tithonia compost, the soil of each of the experimental units received inorganic fertilizers (urea, triple super phosphate) at the same dosage, based on half the recommended soybean fertilizer as basal fertilizers. The corncob biochar and Tithonia compost treatments were applied at predetermined doses. After application, the mixture was incubated for two weeks before planting Anjasmoro variety soybean seeds. Watering and pest and disease control were carried out as needed. Pest control involved spraying the plants with Diazinon 60 EC at a rate of 2 mL L^{-1} of water, while disease control included spraying the plants with Dithane M-45 at a rate of 2 g L^{-1} of water. The pest and disease control were performed for the first two weeks after planting and continued at two-week intervals.

The physicochemical variables of reclaimed mine coal soil were observed after being treated. Soil samples were taken before harvesting to analyze several physical properties, whereas disturbed soil samples that were used for the analysis of chemical properties and soil texture were taken after harvest. Laboratory analysis methods for soil samples included determining soil texture using the pipette method. This involved destroying organic matter and dispersing the soil with sodium hexametaphosphate. The USDA classification system was employed to identify soil textural classes. The bulk density of the core samples was estimated after drying in an oven at 105°C for 24 hours. The soil total porosity was calculated by the bulk density and particle density values. Soil water content was determined using the gravimetric method, and the stability of soil aggregates was measured using the technique of Nimmo and Perkins (2002). Soil organic carbon content was determined by the Walkley and Black method using $K_2Cr_2O_7$ oxidation method (Nelson et al., 1996).

Table 1. Some initial physical and chemical properties of soil from reclaimed coal mine land.

Soil Properties	Value	Criteria
Coarse sand (%)	28	
Fine sand (%)	10	Clay loam
Silt (%)	29	
Clay (%)	33	
Bulk density (g cm^{-3})	1.6	High
Water content (% vol)	12.8	
Total pore space (% vol)	39.20	Low
pH H_2O	3.85	Very acid
Organic C (%)	0.29	Very low
Total N (%)	0.09	Very low
C/N	8.40	Low
P_2O_5 (ppm)	2.40	Very low
Exchangeable Al ($cmol_{(+)}$ kg^{-1})	6.30	Very high
K_2O (ppm)	15.96	Low

*Soil physical properties criteria according to Soil Research Institute of Indonesia (2009).

Analysis of soil chemical properties included pH (using a pH meter), total nitrogen (using the Kjeldahl method), available phosphorus (using the Bray II method), potassium (K), and aluminum-exchangeable (from initial soil analyses). Post-incubation parameters that included pH, N, P, and K were measured using the methods developed by Nelson et al. (1996).

Results and Discussion

Soil bulk density, total pore space, and soil water content

According to the analysis of the variance, the interaction between biochar and Tithonia compost application on post-mining land did not significantly affect soil bulk density, total pore space, and soil water content. However, each primary biochar treatment and compost application significantly affected soil bulk density, total pore space, and water content (Table 2). The application of biochar up to a dosage of 10 t ha^{-1} effectively reduced soil bulk density by 1.24% (from 1.25 to 1.22 g cm^{-3}), and increased total soil pore space by 1.8% (from 53.08 to 54.04%), compared to the soil with no biochar application.

The changes in soil physical properties due to increased biochar application indicate an increase in the amount of organic compounds, such as organic acids, contained within the biochar. The increase in organic compounds leads to improvements in the soil physical properties. The mechanism involves organic compounds acting as colloidal substances that function as soil aggregators, thereby making the soil more friable. Additionally, organic compounds serve as substrates for soil biota, increasing their population and activity and ultimately increasing soil porosity (Mateus et al., 2017).

Table 2. The effect of biochar and Tithonia compost on bulk density, total pore space, and water content of soil from a former coal mine land.

Ameliorant	Bulk Density (g cm^{-1})	Total Pore Space (% vol)	Soil Water Content (%)
Biochar (t ha^{-1})			
0	1.25 a	53.41 a	14.17 a
5	1.24 a	53.23 a	14.38 a
10	1.22 a	54.38 a	14.62 a
Tithonia compost (t ha^{-1})			
0	1.37 a	52.20 c	12.97 b
5	1.24 b	53.23 bc	13.77 ab
10	1.23 b	52.84 ab	14.88 ab
15	1.19 b	56.43 a	15.95 a

Note: the numbers followed by the same letter in the same column are not significantly different from the confidence level $\alpha = 5\%$ in the Duncan New Multiple Range Test (DNMRT).

Omondi et al. (2016) reviewed studies on biochar application and found that bulk density generally decreases with biochar application. Soil density gradually decreases with increasing amounts of biochar applied. This is in line with the research conducted by Verheijen et al. (2010) that biochar application can reduce the bulk density of mineral soil because adding biochar to the soil can increase the soil surface area, thereby increasing the pore space within the soil. The addition of biochar dosage to the soil affects the increase in soil porosity. The increase in porosity is associated with a decrease in soil density, meaning the amount of soil mass in a certain volume can determine the magnitude of pore space contained in that type of biochar. With an increase in the organic C fraction, humic, and fulvic acids, organic polymer compounds can be formed, which enhance soil aggregation and make the soil more porous, ultimately reducing bulk density. Research conducted by Busscher et al. (2011), Mankasingh et al. (2011), Herath et al. (2013), and Mukherjee and Lal (2013) showed that biochar application can reduce soil density. According to Mukherjee and Lal (2013), the application of biochar can reduce soil bulk density due to its high porosity, which significantly affects soil bulk density reduction and increases soil pore volume when applied to the soil. Several studies show that biochar has high porosity (Downie et al., 2009), a large surface area, and high charge, thereby improving soil structure, bulk density, water-holding capacity, and soil nutrient content. Hardie et al. (2014) reported that biochar amendments increase hydraulic conductivity close to saturation and reduce density. This is believed to be caused by the formation of macropores due to increased bioturbation activity.

Data presented in Table 2 show that the application of Tithonia compost up to 15 t ha^{-1} significantly reduced soil bulk density by 7.5% (from 1.37 to 1.19 g cm^{-3}) and increased total soil pore space by 5.8% (from 52.20 to 56.43%) compared to without compost application. The decrease in soil bulk density correlated with increasing Tithonia compost usage. This decrease in bulk density was due to the addition of compost to the soil, thus increasing the organic matter content that forms and stabilizes soil aggregates. The increase in organic matter in the soil leads to increased microbial activity. Increased soil microbial activity results in improved soil structure, making the soil more friable and reducing soil bulk density. Additionally, organic matter has lower density and bulk density compared to mineral soil, resulting in a lower tested soil bulk density. Tithonia compost increased the organic matter content in the soil, thus improving physical properties such as bulk density, infiltration rate, and dispersion ratio. The decomposition of Tithonia also releases essential nutrients such as P, K, Ca, and Mg, which are crucial for plant growth and development (Kimetu et al., 2004).

The results of this study indicated that the application of Tithonia compost reduced bulk density and increased total soil pore space due to the increase in soil organic matter. It is known that soil density decreases with increasing organic matter content; thus, soil density will decrease, as reported by Muddarisna and Prijono (2014) after green manure application. Celik et al. (2004) also observed a decrease in soil density and an increase in organic matter density in their study evaluating the impact of different inputs on soil physical properties. This indicates a strong negative correlation between bulk density and organic matter, as reported in the study by Chaudhari et al. (2013).

The effects of varying doses of biochar have not shown a significant influence on soil moisture content, but there are differences among treatments, while the effect of Tithonia compost has shown a significant impact on soil moisture content (Table 2). The impact of using Tithonia compost mainly affects soil moisture content. Soil moisture content increases with the addition of more Tithonia compost. The formation of soil pores resulting from the application of biochar and Tithonia compost is related to their ability to form soil aggregates, thus increasing soil water-holding capacity. Overall, there is an increase in soil water content with the addition of a biochar dose of 10 t ha^{-1} by 3.2% (from 14.17% to 14.62%) and the addition of Tithonia compost up to 15 t ha^{-1} by 23% (from 12.97% to 15.95%) compared to no biochar and compost application. Soils with low bulk density and high porosity allow water to easily penetrate and be absorbed by organic soil matter, thus increasing soil moisture content. This is consistent with the research conducted by Bruun (2011), who reported that biochar enhances soil water absorption capacity depending on the type of biochar. Other studies have shown that biochar improves water storage in sandy and sandy mixture soils and reduces overall water usage at high application doses (Brockhoff et al., 2010). The enhancement of soil water retention capacity due to biochar application is highly beneficial for improving water availability.

Several studies reported that after applying biochar to the soil, there is an increase in field capacity water content. Furthermore, Olness et al. (2005) stated that testing is needed to determine the effectiveness of various biochar doses in enhancing soil water retention capacity in sandy-textured soils. Research conducted by Basso et al. (2012) indicated that adding biochar to sandy soil increases water retention capacity, thereby improving water availability for plant use. Evidence showing the contribution of biochar and its influence on soil stability and aggregation, water management, porosity, and surface area indicates that understanding the function and impact of biochar in soil will help in selecting specific biochar for particular agricultural soils, thereby obtaining maximum benefits from biochar. The application of biochar into the soil can enhance the soil's capacity to provide water for plants. According to the research by Liu et al. (2017), the application of biochar to sandy soil will increase the soil's water retention capacity, thus enhancing the availability of water for plants. Biochar has the ability to improve groundwater storage. As total porosity increases, the amount of retained water increases due to changes in soil structure.

The increase in compost dosage from 0 t ha^{-1} to 15 t ha^{-1} resulted in an approximately 23% increase in soil moisture content. The addition of compost increases the amount of organic matter interacting with the existing soil matrix. This helps in the formation of stable soil aggregates, which are important for good soil structure. These aggregates increase soil porosity and create a better environment for root growth and microbial activity. High organic matter content can enhance soil water retention capacity. According to Acharya et al. (1988), the increase in soil water retention capacity is due to adding organic fertilizers, compared to using inorganic fertilizers alone. In addition to providing essential nutrients for plants and soil, organic fertilizers improve soil structure by increasing water retention capacity, aeration, and drainage, thereby promoting root formation and good plant growth (Cook et al., 1995). The application of organic fertilizers to the soil medium influences the amount of water in the soil, which is related to the soil density, where the lighter/fluffier the soil density, the better the infiltration rate, aeration, soil drainage, and water in the soil. According to Barus (2016) and Kannan et al. (2021), biochar effectively increases soil moisture content and pores because porous soil structure can enhance the presence and activity of microorganisms, ultimately increasing nutrient availability.

Soil organic C

Analysis of variance on the effects of the interaction between biochar and Tithonia compost application on soil organic carbon content showed significant impacts. However, the effects of each main treatment of biochar and Tithonia compost have shown an influence on the soil's organic carbon parameter. In Table 3, the application of biochar at a dose of 10 t ha^{-1} did not significantly impact soil organic carbon content, but there was an increase in soil organic carbon content by 6.46% compared to the control (from 2.32% to 2.47%). There is a tendency for carbon content to increase with increasing biochar dosage (Table 3). The addition of biochar to the soil has been proven to increase carbon, water, and nutrient retention (Guo et al., 2020).

Table 3. The effect of biochar and Tithonia compost on soil organic carbon in a former coal mine land.

Ameliorant	Organic C (%)
Biochar (t ha^{-1})	
0	2.32 a
5	2.22 a
10	2.47 a
Tithonia compost (t ha^{-1})	
0	1.63 b
5	2.29 ab
10	2.64 a
15	2.78 a

Note: the numbers followed by the same letter in the same column are not significantly different from the confidence level α = 5% in the Duncan New Multiple Range Test (DNMRT).

The use of Tithonia compost to increase soil organic matter can lead to an increase in soil carbon content by releasing organic carbon from the compost. Additionally, palm kernel biochar has been found to significantly impact increasing soil organic matter, with biochar serving as a long-term carbon source in the soil. As the dosage of biochar applied to the soil increases, the carbon stock in the soil also increases. Tithonia compost significantly affected soil organic carbon content compared to the control. There was an increase in soil organic carbon content by 7.1% (from 1.63% to 2.78%) with the application of 15 t ha^{-1} of Tithonia compost. The decomposition of Tithonia compost added to the soil resulted in increased soil organic carbon. According to Olness et al. (2005), adding compost to the soil is a practical effort to maintain and improve soil organic matter.

The use of Tithonia compost can affect soil aggregation through the activity of soil microorganisms. High organic matter content can lead to low bulk density and increase total soil pore space, and vice versa (Barus, 2016). Soil organic matter (SOM) also plays a crucial role in controlling soil quality and resilience due to its fundamental role in determining various soil properties, including buffering capacity, microbial biodiversity, water retention, and structural stabilization (Šimanský et al., 2013; Šimanský and Polláková, 2016). For instance, humic substances (part of SOM) regulate buffering capacity, cation exchange, and soil water retention capacity (Šimanský and Polláková, 2016), as well as the formation and stabilization of aggregates resistant to (Šimanský et al., 2013; Polláková et al., 2017).

Formed aggregate and aggregate stability

Analysis of variance on the effects of the interaction between biochar and Tithonia compost application on the percentage of formed aggregates and soil aggregate stability has not shown significant influence. However, the effects of each main treatment of biochar and Tithonia compost have demonstrated an influence on the parameters of the percentage of formed aggregates and aggregate stability (Table 4). Biochar at a dose of 10 t ha^{-1} has not shown a significant effect on the content of the percentage of formed soil aggregates, but there was an increase in the content of the percentage of formed aggregates by 7.5% compared to the control (from 49.54% to 53.25%). Similarly, there was an increase in aggregate stability by 1.5% (from 53.14% to 53.94%) due to the increased application of biochar dosage up to 10 t ha^{-1}.

There is a trend of increasing percentage of formed aggregates and aggregate stability with increasing biochar dosage (Table 4). The addition of rice husk biochar to the soil greatly influences soil structure and has the effect of reducing soil bulk density. Consistent with the findings of Toková et al. (2020), the application of biochar combined with other organic matter or inorganic N fertilizers to the soil is a technology that enhances the sustainability of intensive agriculture by improving the physical and hydro-physical properties of soil that affect soil structure.

The application of biochar to the soil can also improve soil structure, promote the agglomeration of soil mineral particles, and enhance the stability of aggregates (Dong et al., 2016; Liu et al., 2017). The application of biochar to the soil can enhance the soil's capacity to provide water for plants. According to the research by Liu et al. (2017), adding biochar to sandy soil increases the soil's water retention capacity, allowing for increased water availability for plants. Biochar can improve groundwater storage. As total porosity increases, the amount of retained water also increases due to changes in soil structure. This is believed to be due to macropores forming due to greater bioturbation activity (Hardie et al., 2014). However, there were no significant effects on aggregate stability

Table 4. The effect of biochar and Tithonia compost on the percentage of aggregates formed and aggregate stability in soil from a former coal mining land.

Ameliorant	Formed Aggregate (%)	Aggregate Stability (%)
Biochar (t ha^{-1})		
0	49.54 a	53.14 a
5	52.34 a	52.87 a
10	53.25 a	53.94 a
Tithonia compost (t ha^{-1})		
0	44.78 b	49.63 b
5	47.95 ab	51.44 b
10	51.54 ab	51.72 b
15	52.57 a	60.47 a

Note: the numbers followed by the same letter in the same column are not significantly different from the confidence level α = 5% in the Duncan New Multiple Range Test (DNMRT).

Tithonia compost significantly affects the content of the percentage of formed aggregates and aggregate stability. There was an increase in the percentage of formed aggregates by 17.4% (from 44.78% to 52.57%), and the stability of aggregates increased by 21.48% (from 49.63% to 60.47%) with the application of 15 t ha^{-1} of Tithonia compost. The increase in aggregate stability through organic treatment in this research can be attributed to the increase in soil organic matter content, which seems to act as a cementing element in soil particle flocculation, thus forming stable aggregates (Bronick and Lal, 2005; Hafifah et al., 2016). This agrees with Wiesmeier et al. (2015), who reported an increase in macro and micro-aggregates given *Tithonia diversifolia* green manure. This varies according to the composition of organic matter in manure, the rate and time of application.

Treatment with manure also performs better in increasing soil aggregate stability compared to control and the only inorganic fertilizer treatment in corn. This could also be due to the increase in soil organic matter and the improvement of soil structure with stable aggregates in the soil (Bronick and Lal, 2005; Wiesmeier et al., 2015). Ibrahim (2018) found that mixing compost materials with agricultural soil enhances the formation and stability of macroaggregates in semi-arid land conditions.

The treatment biochar up to 10 t ha^{-1} (Table 4) has not significantly affected the increase in the Percent aggregate formed and aggregate stability. There was a tendency for an increase in formed aggregate percent with increasing biochar doses. Different from biochar treatment, Tithonia compost has significantly affected the percent aggregates formed and aggregates stability compared to controls. The percentage of aggregate that is formed and the possibility of soil aggregate is caused by the improvement of other soil physical properties due to the provision of biochar and Tithonia compost. Organic carbon content plays a role in improving soil water infiltration and binding soil particles so that a solid aggregate or crumbly soil structure is formed, so that permeability is higher, and the absorbing ability of soil water is faster.

Soil organic matter has a different ability to granulate soil grains and aggregate formation. Soil friability is an indication that describes the amount of aggregate formed, where organic matter plays a role in the aggregation of soil particles and stabilizes the formed soil aggregate. Laird et al. (2010) indicated that the fraction of organic carbon as a soil aggregate stabilizer can maintain and improve the physical condition of the soil. Furthermore, Wolf (2008) discovered the mechanism causing the increase in soil physical properties is the presence of organic acids that can form organo minerals, leading to soil aggregation and the functional components of organic material added to the soil. The use of Tithonia compost can affect soil aggregation through the activity of soil microorganisms. High organic matter content can lead to low bulk density and increase total soil pore space, and vice versa (Barus, 2016).

Soil organic matter also plays a crucial role in controlling soil quality and resilience due to its fundamental role in determining various soil properties, including buffering capacity, microbial biodiversity, water retention, and structural stabilization (Šimanský et al., 2013; Šimanský and Polláková, 2016). For instance, humic substances (part of SOM) regulate buffering capacity, cation exchange, and soil water retention capacity (Šimanský and Polláková, 2016), as well as the formation and stabilization of aggregates (Šimanský et al., 2013; Polláková et al., 2017).

Hafifah et al. (2016) reported a significant increase in soil aggregate stability, with the highest increase observed in *Tithonia diversifolia* combined with cow dung and NPK, while the lowest was the treatment with single inorganic fertilizer, with soil aggregate stability increased from 0.69% to 23.54% compared to the initial soil. Tithonia decomposes to form organic matter, which can bind soil aggregates and stabilize the soil from dispersion (Sinkeviciene et al., 2009).

Plant growth

The effect of the application of biochar and Tithonia compost on the growth of soybean plants from 2 to 7 weeks after planting is presented in Figure 1. Soybean plant growth varies based on plant height, depending on the application of Tithonia, biochar compost, or a combination of both. However, the treatments had no significant difference in soybean plant height. The plant growth variability after the application of biochar and Tithonia compost is presented in Figure 1. The improvement in the soil physical and chemical fertility of coal mining land due to the application of biochar and compost affected soybean growth and yield. The increased growth of soybean plant height is attributed to the interaction of biochar and compost because both ameliorants can improve growth media by increasing pH, nutrient availability, water retention capacity, and soil density. Organic matter in the form of compost applied to the soil surface reduces evaporation and provides a more suitable environment for root growth while releasing nutrients that enhance vegetative cover. Furthermore, the decomposition of Tithonia increases soil organic matter content, thus improving physical properties such as bulk density, infiltration rate, and dispersion ratio. The decomposition of Tithonia also releases essential nutrients such as P, K, Ca, and Mg, which are crucial for plant growth and development (Kimetu et al., 2004). The higher growth of soybean plants with the higher dosage biochar and compost of Tithonia was by giving in to the ex-coal mining soils.

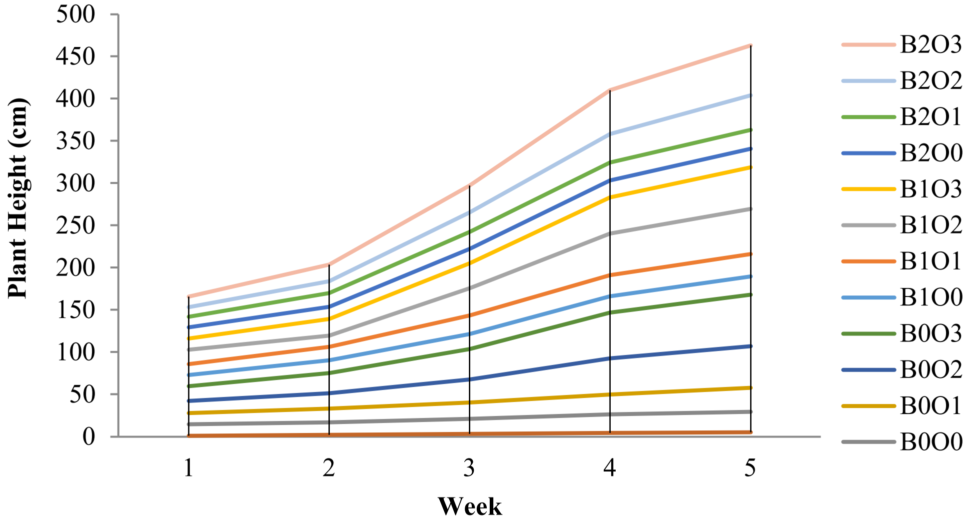

Figure 1. Soybean height data of ex-coal mining soil in the greenhouse pot experiment after being treated with biochar and Tithonia compost. Notes: B0 = biochar, 0 t ha^{-1}, B1 = biochar, 5 t ha^{-1}, B2 = biochar, 10 t ha^{-1}, C0 = Tithonia compost, 0 t ha^{-1}, C1 = Tithonia compost, 5 t ha^{-1}, C2 = Tithonia compost, 10 t ha^{-1}.

Figure 1 illustrates the increase in the height of the soybean plant as contributed to improvements in the plant growing environment. Soil conditions greatly influence plant growth as a growing medium, which provides transportation and physical properties that support the development of plant roots. Plant height is an indicator of plant growth, which is influenced by the physical and chemical properties of the soil. This is following Magdoff and Weil (2004), who stated that adding organic matter to the soil can improve the chemical characteristics of the soil, such as the availability of nutrients either through increasing nutrients in organic matter or improving the physical conditions of the soil which supports the absorption of nutrients by plants. Data presented in Table 5 show that the interaction between biochar and *Tithonia diversifolia* did not significantly affect soybean yield. However, the main effects of each treatment have already shown an influence on soybean yield. The application of 10 t ha^{-1} biochar significantly increased soybean yield by 10.70% compared to the control (from 5.61 g pot^{-1} to 6.21 g pot^{-1}).

Table 5. The effect of biochar and Tithonia compost on soybean yield in a former coal mining land.

Ameliorant	Soybean Yield (g pot^{-1})
Biochar (t ha^{-1})	
0	5.61 a
5	5.83 a
10	6.21 a
Tithonia compost (t ha^{-1})	
0	4.80 c
5	5.11 c
10	5.95 b
15	7.68 a

Note: the numbers followed by the same letter in the same column are not significantly different from the confidence level α = 5% in the Duncan New Multiple Range Test (DNMRT).

Lehmann et al. (2003), who conducted a pot experiment using cowpea (*Vigna unguiculata* (L.) Walp.) and rice (*Oryza sativa* L.), reported that the addition of biochar significantly enhances plant growth and nutrition. Plant growth is greatly determined by the soil conditions as a growing medium that provides nutrients and physical properties conducive to the development of plant roots. Plant height is one of the parameters that describe plant growth and is influenced by the physical and chemical properties of the soil.

Biochar may reduce the soil bulk density and increase the total porosity of the soil due to its porous structure and large specific surface area; it also improves the root system development, enhances the plant nutrient uptake ability, and promotes the growth and yield of soybean (Ibrahim et al., 2021). Tithonia compost significantly affected soybean yield. There was a 60% increase in yield percentage (from 4.8 g pot^{-1} to 7.68 g pot^{-1}). Increasing the compost application rate can benefit soil chemical characteristics, such as nutrient availability through the addition of nutrients in organic matter, as well as favorable physical conditions to enhance nutrient availability to plants (Magdoff and Weil, 2004).

Conclusion

Applying biochar and Tithonia compost improved the physical properties of the soil of ex-coal mining land by increasing the total pore space, field capacity moisture content, percent formed aggregate, aggregate stability, organic carbon, and decreasing soil bulk density. The best dose for biochar treatment was found at 10 t biochar ha^{-1} and 15 t Tithonia compost ha^{-1}.

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