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The potential of *Pterocarpus indicus* as a revegetation plant for coal mine Reclamation Land

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ABSTRACT

Coal mining exploitation generally uses open-pit mining techniques that have implications for environmental degradation, particularly changes in the physical, chemical, and biological properties of the soil. Revegetation of reclaimed land is a strategy for restoring ecosystem functions that have been disrupted by mining activities. This study aimed to evaluate the growth potential of *Pterocarpus indicus* through direct planting methods and to assess the effect of fertiliser type on plant growth acceleration on post-coal mining land. Field observations were used to measure plant growth parameters, including height, stem diameter, and number of leaves. The planting material used was stem cuttings, with variations in fertiliser treatment. Plant material type, fertiliser type, and application dose had a significant effect on plant growth variables ($P<0.05$). Duncan's multiple range test indicated that the use of bokashi fertiliser at a dose of 3 kg per planting hole gave the best results, as evidenced by an average plant height of 104.38 cm, an average stem diameter of 37.692 cm, and a total of 21.99 leaves. Therefore, the direct planting method using stem cuttings as planting material with the application of bokashi fertiliser at a dose of 3 kg plays an important role in accelerating vegetation recovery in coal mine reclamation.

Keywords: adatif plants, bokashi and coal ferlitizer, direct planting, post coal mining, vegetation recovery

INTRODUCTION

Coal mine reclamation is the restoration of land degraded by mining activities. The reclamation process involves civil and environmental engineering through land management, restoring the physical and chemical conditions of the soil, controlling erosion, and replanting vegetation to support plant growth and prevent further land degradation (Frouz, 2020). The ecological engineering process in post-coal mining reclamation is time-consuming, and it is difficult to identify factors that influence the rate of recovery (Kompała-Bąba et al., 2020). Revegetation methods using various plant species have been adopted by many countries in an effort to improve soil structure, increase organic matter content, and restore soil fertility (Ahirwal et al., 2018; Zhang et al., 2020).

Revegetation is the process of replanting vegetation on land that has been damaged or degraded. Various problems encountered in post-mining land reclamation activities often include soil compaction, low soil pH, lack of soil nutrients, the presence of toxic substances, and a lack of organic matter (Arifin et al., 2025). These conditions affect plant growth and reduce the success of reclamation, so it is necessary to improve the soil and select the right types of plants to overcome these problems (Albert, 2015). Vegetation succession in post-mining land reclamation involves the selection of pioneer plant species (ground cover), main plants (trees), and understory plants (companion plants) to create a complex structure (Delgado et al., 2021). Plants with strong root systems and nitrogen fixation capabilities can effectively improve soil quality that has been degraded by mining activities.

Plant selection for post-mining reclamation must consider climate, soil type, and land slope. Plants such as *Gliricidia sepium*, *Senna siamea*, and *Acacia mangium* serve as ground cover while improving soil structure and organic content and providing habitat for soil organisms (Singh & Kumar, 2021; Festin, et al., 2019). *Azolla* and *Limnocharis increase* soil fertility and accelerate the formation of organic soil (Soendjoto et al., 2015), while large trees such as *Pterocarpus indicus* provide shade and maintain soil moisture conducive to growth (Noor et al., 2021). Of the various types of plants, *P. indicus* was chosen because of its adaptability to environmental conditions and its ability to live for hundreds of years. Angsana can grow to a height of 20–40 m, thrives optimally at temperatures of 22–32 °C with humidity levels of 60–90%, and is easily cultivated through vegetative propagation using stem cuttings (Saputra et al., 2018).

Amelioration is a method for improving the quality of soil degraded by mining to make it productive and support plant growth and ecosystem recovery. Amelioration techniques such as liming and fertilisation can improve aeration, pH, and soil water availability (Frank et al., 2020), stimulate plant growth, and restore the ecological function of the land (Navarro-ramos et al., 2022). The application of coal (futura) and bokashi fertilisers increases the content of essential nutrients such as N, P, and K that plants need to grow (Gashua et al., 2023; Liu et al., 2017). Cuttings are a popular method in post-mining land reclamation activities, such as Gamal, Sengon, and Mahogany plants that are propagated vegetatively through cuttings to accelerate the revegetation process (Flores et al., 2021). To optimise this method, further research is needed, particularly on *P. indicus*. The objective of this study was to evaluate the potential of *P. indicus* as a reclamation plant and the effect of fertiliser type on the growth rate of plants grown directly on post-mining land. The results of this study were expected to provide information on the most effective fertiliser specifications to support vegetative mass growth, including plant height, stem diameter, and leaf bud growth.

MATERIALS AND METHODS

Study Area

This study focuses on post-mining reclamation land in the concession area of Pit 3 West IUP Banko Barat PT. Bukit Asam, Tanjung Enim, South Sumatra, was located at coordinates 3° 44' 41.01" S to 103° 48' 45.371" E (Figure 1). PT. Bukit Asam, Tbk was a company that holds a coal mining business license and applies the open-pit mining method. The initial stage of mining activities was the clearing of the concession area to be exploited, followed by the removal of the topsoil. To maintain quality, the soil was stored separately. Subsequently, the stripped soil could be directly used to cover the mine reclamation area after contour re-shaping, thereby supporting the restoration of former mining land in accordance with its ecological function.

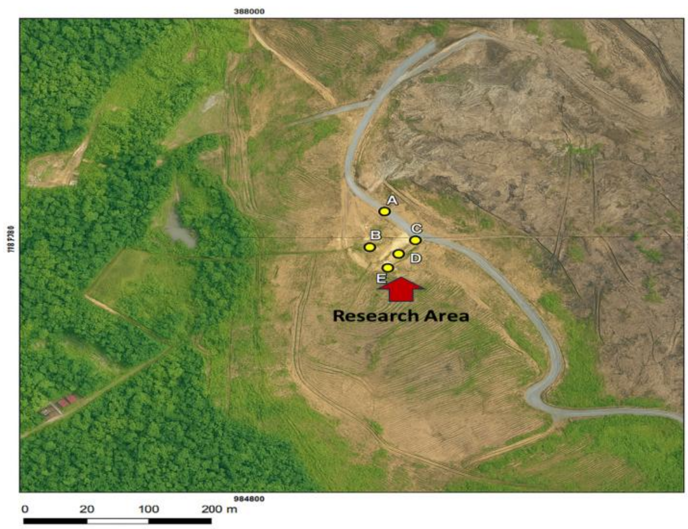

Figure 1. Research site for direct planting of *Pterocarpus indicus* in a post-coal mining reclamation area

The study area was dominated by podzolic, organosol, grumosol, mediterranean, and regonosol soil types, which have distinctive mineral content and physical characteristics. Soil profiles indicate a pH of 6-8 (relatively alkaline and moist), with varying mineral content at different soil depths. Grumosol soil contains calcium (Ca) and magnesium (Mg), which contribute to the alkaline properties of the soil. Meanwhile, regosol soil was rich in phosphorus (P) and potassium (K), while Mediterranean soil had a high content of the main nutrients potassium (K) and magnesium (Mg). The natural vegetation in the study area was generally covered by secondary forests that ecologically indicate low stability due to anthropogenic pressures, such as smallholder farming activities, the dominance of *Imperata cylindrica grass*, and the spread of shrubs. Commonly found plant species include *Pithecellobium jiringa*, *Eleocharis dulcis*, *Bambusoideae*, *Scleria sumatrana*, *Hevea brasiliensis, Melastoma malabathricum*, *Clidemia hirta*, *Eupatorium odoratum*, *Ageratum conyzoides*, *Oplismenus burmannii*, and *Leea indica*.

The variables observed included fertiliser dose variation, stem height and diameter, and shoot and leaf development. Plant height and stem diameter were measured using a tape measure, while the number of leaves was noted at 40 observation intervals. The number of leaves was calculated based on the total number per sample. Each treatment group was assigned a specific code as follows: C (Control), BF3 (3 kg bokashi fertiliser), BF5 (5 kg bokashi fertiliser), BF7 (7 kg bokashi fertiliser), FF1 (1 kg of coal fertiliser), FF2 (2 kg of coal fertiliser), and FF3 (3 kg of coal fertiliser).

Plant Sample Preparation and Data Collection

This study was conducted on a 1-year-old reclamation site with an area of 630 m2. The study was conducted over a period of 4 months to evaluate the results of the treatment. The quadrat method was used to inventory the vegetation on the study site with a plot size of 22.5 x 28 m. The plants grown in each plot were arranged randomly to avoid treatment bias. The planting distance used was 3x3 m with a distance of 5 m between plots. The placement and determination of plant growth were carried out randomly with a comparison of three doses of coal fertiliser, 1-5 kg per planting hole, and bokashi fertiliser, 3-7 kg per planting hole (Nutayla et al., 2023). Plant samples for the cutting method begin with the selection of *Pterocarpus indicus* stems with a diameter of approximately 1.5-3 cm and a length of 10-15 cm, free from pests and diseases. Then, the stems were cut at a 45° angle, leaving 2-3 leaf nodes. To prevent decay, the leaves at the bottom of the cutting stem were removed. (Figure 2).

Soil Sampling and Analysis

Soil sampling was conducted using purposive sampling with a grid and systematic methods that represented the overall land conditions. Sampling was carried out at a soil depth of 0-50 cm using a soil drill, with 3 kg per planting hole. Soil samples were taken using an aerator and a 0.5'x0.5' soil ring, then collected and dried in the air (Nutayla et al., 2023). The samples were then sieved and homogenised to remove impurities or coarse organic matter without altering their original properties (Figure 3). Soil analysis was performed to determine the physicochemical characteristics of the soil in the study area (Table 1).

Statistical Analysis

This study applied quantitative methods based on mean and standard deviation, followed by normality and variance homogeneity tests prior to one-way ANOVA and Duncan's Multiple Range Test (DMRT) to determine significant differences between treatments, thereby identifying the best treatment. Regression analysis was used to determine the relationship between treatment doses and plant growth. Statistical analysis aims to identify the effect of fertiliser type and dose on the growth of *Pterocarpus indicus* plants and to test for significant differences between treatments. If the significance value was less than 0.05 ($P<0.05$), it can be concluded that there was a significant difference between the treatments given, and if the significance value ($P>0.05$), there was no significant difference in the growth of the planting material using two different types and doses of fertiliser treatments. Meanwhile, the Duncan test results indicate which treatment group had a significantly different average plant growth (Table 2).

RESULTS

Soil Characteristics of Post-Coal Mining Areas

Physical and morphological analysis of post-coal mining soil indicates that the soil had a lateritic structure with a predominantly dusty texture and a base saturation level of less than 50%. The soil originates from new layered deposits with relatively low organic content. The results of chemical and physical property measurements (Table 3) show an increase in the clay fraction along with a decrease in sand content of 8.10%. The colour of the soil varies from greyish brown to bright red due to oxidation and contamination, while at depths of more than 50 cm, the soil tends to be darker in colour. The porosity value was noted at 53.21%, indicating a sufficiently high availability of pore space for water movement, although the distribution of macropores and micropores had the potential to affect hydraulic properties. Soil acidity indicates low pH, both in H_2O and KCl pH, which indicates very acidic soil conditions. This was related to the oxidation of pyrite minerals into sulfuric acid (H_2SO_4) and low cation exchange capacity (CEC).

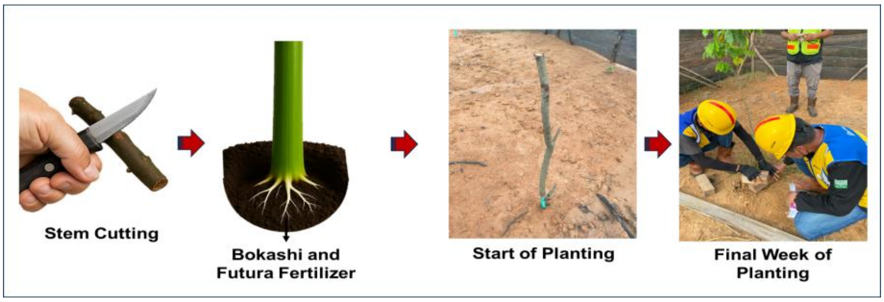

Figure 2. Stages of vegetative propagation through the stem cutting method

Figure 3. Observation and location of soil sampling in the West Banko area

Table 1.Physical and chemical characteristics of mining soil and soil quality index scores

Soil Properties Variable	Very Low	Low	Moderate	High	Very High	Literature
C organic (%)	<1.0	1.0-2.0	>2.0	>3.0	>5.0	(ICSR, 1983)
N total (%)	<0.1	0.1-0.2	0.21-0.50	0.51-0.75	>0.75	
Exch Ca (Cmol/kg)	<2.0	2-5	5-10	10-20	>20	
Exch K (Cmol/kg)	<0.1	0.1-0.3	0.4-0.5	0.6-1.0	>10	(Dierolf et al., 2001)
Exch Na (Cmol/kg)	<0.1	0.1-0.3	0.3-0.7	0.7-2.0	>2	
Bulk density (g/cm)	<1.1	-	-	1.1-1.6	>1.6	
Al saturation (Cmol/kg)	<35	35-50	50-70	>70		
P available (mg/kg)	<3	3-7	7-15	15-30	>30	
Cation Exchange Capacity	<5	16	17-24	25-40	>40	
Fe (mg/kg)	-	<4.5	4.5-10	>10	-	
Mn (mg/kg)	0.5	0.5-2	2-5	>5	-	
Mg (Cmol/kg)	<0.4	0.4-1.0	1.1-2.0	2.1-8.0	>8.0	(ICSR, 1983)
H dd (Cmol/kg)	<0.5	0.5-1.5	1.5-4.0	4.0-8.0	>8.0	
pH H2O	<4.5	4.5-5.5	5.5-6.5	6.5-7.5	7.5-8.5	
	Extreme acidity	Acid	slightly acidity	Neutral	Slight alkalinity	

Table 2. Physical and chemical characteristics of coal mine soil after fertiliser treatment

Soil Parameters	Initial Content	Changes in Quantity of Nutrients Occurring						Normal Range
		B3	B5	B7	F1	F2	F3	
Chemistry								
pH H2O	3.40	4.55	4.32	4.15	4.25	4.35	4.19	Extreme acidity
pH KCL	3.10	3.38	3.46	3.43	3.59	3.38	3.38	Extreme acidity
C-Organic (%)	0.56	0.29	0.37	0.51	0.92	0.72	0.92	Very low
N-total (%)	0.06	0.03	0.03	0.03	0.06	0.05	0.06	Very low
K-dd (Cmol/kg)	0.72	0.26	0.26	0.26	0.45	0.26	0.26	Very low
Cation Exchange Capacity (Cmol/kg)	22.31	10.88	13.05	15.23	15.23	15.23	15.23	Low
Al-dd (Cmol/kg)	5.45	0.98	1.02	1.21	0.51	1.01	1.03	Low
H-dd (Cmol/kg)	9.85	0.26	0.23	0.38	0.18	0.2	0.32	Very low
P-available (mg/kg)	6.30	1.80	1.80	2.10	2.10	3.45	3.15	Very low
Fe (mg/kg)	0.88	0.10	0.10	0.29	0.10	0.39	0.39	Low
Mn (mg/kg)	0.20	0.99	0.20	0.20	0.59	0.79	0.59	Very low
Physics								
Texture								Sand clay
Sand (%)	8.10							
Dust (%)	14.1							
Clay (%)	77.8							
Permeability (cm/hour)	2.81							
Porosity (%)	53.21							

Table 3. Coal and bokashi fertilizer content

Variable	Results		Fertilizer Quality Standards
	Coal Fertiliser	Bokashi Fertiliser	
pH H_2O	6.97	7.20	5.5 – 7.5
Nitrogen (%)	1.12	1.52	>2
Phosphorus (%)	0.04	0.53	>2
Kalium (%)	0.24	0.389	>1
Kalsium (mg/kg)	150	200	>100
Magnesium (mg/kg)	60	80	>50

Characteristics of Coal and Bokashi Fertilizers

The results of the analysis of the content of coal and bokashi fertilisers refer to the standards set in Minister of Agriculture Regulation No. 70/Permentan/SR.140/10/2011 concerning organic fertilisers, biofertilizers, and soil conditioners. The pH value of coal fertiliser shows an optimal range for plant growth, namely between 5.5 and 7.5. However, the nitrogen (N), phosphorus (P), and potassium (K) content does not show the same suitability. The pH of coal and bokashi fertilisers was alkaline, indicating that neither had the potential to lower the pH of the soil to which it was applied. The measurement results indicate that the macro nutrient content in coal fertiliser consists of 1.12% N, 0.04% P, and 0.24% K, while in bokashi fertiliser, the N, P, and K content was 1.52%, 0.53%, and 0.389%, respectively. The low content of major nutrients, especially N, P, and K, in both types of fertiliser was due to the low composition of the raw materials used in the manufacturing process. However, coal and bokashi fertilisers have relatively high calcium and magnesium content, two essential elements that play an important role in supporting plant growth and improving soil structure.

Results of Growth and Diversity Analysis on Reclaimed Land

The results indicated that the height of *Pterocarpus indicus* plants on post-mining reclamation land increased with age. A significant increase was noted in the treatment with coal and bokashi fertiliser at a dose of 3 kg per planting hole, especially in the period 3 to 21 weeks after planting. Other treatments, namely bokashi fertiliser at a dose of 5–7 kg and coal fertiliser at a dose of 2 kg, also showed an upward trend in plant height, although not as optimal as the 3 kg treatment. This indicates that the availability of macro nutrients from fertiliser decomposition plays an important role in supporting the stem elongation process in the stem propagation method. In addition, in the 1 kg coal fertiliser treatment (FF1), plant height growth was relatively stable, indicating limited availability or efficiency of nutrient uptake at that dose (Table 4).

The average diameter of *Pterocarpus indicus* stems increased gradually during the treatment period for all types of planting materials. A decrease in stem diameter occurred in weeks 3 to 9 after planting, followed by a significant increase that tended to stabilise between weeks 12 and 27. Stem diameter growth indicates the physiological efficiency of plants in absorbing and utilising nutrients from coal and bokashi fertilisers, and shows a positive correlation with plant height growth (Table 5). The activity of the vascular system, particularly the xylem and phloem, plays a role in the translocation of nutrients and photosynthetic products, whereby assimilates from the leaves were transported to the roots, stems, and reproductive organs. This transport process contributes to biomass accumulation, which was characterised by an increase in stem diameter (Taiz et al., 2018).

The number of leaves was a variable that influences the vegetative growth phase. During this phase, meristematic activity produces new shoots that develop into a progressive increase in the number of leaves (Figure 4). This development was influenced by the availability of nutrients and environmental factors such as light, humidity, and temperature (Wahba et al., 2016).

Leaf growth in *P. indicus* plants treated with bokashi fertiliser indicated a relatively normal vegetative growth response, but the growth of leaves in the control group was much higher, as indicated by an increase in the number of leaves (Table 6). However, one to two weeks after treatment, defoliation began to occur in some of the leaves. In the early stages of treatment, the leaves appeared healthy, fresh, and green, but over time, the plants began to indicate physiological symptoms indicative of stress, such as necrosis and chlorosis. Changes in leaf colour from green to yellow (chlorosis), yellowish-brown (bronzing), to dark brown, accompanied by the appearance of black spots characteristic of necrosis, became clearly visible on the leaf surface (Figure 5). In the 27th week, or towards the end of the study period, there was a significant increase in the number of leaves. This phenomenon was thought to be related to the emergence of new shoots and leaves, which outnumber the leaves that fell.

Table 4. The average growth of *Pterocarpus indicus* tree height (Weeks After Planting)

Treatment/Dose	Average Height *Pterocarpus indicus*									
	0 WAP	3 WAP	6 WAP	9 WAP	12 WAP	15 WAP	18 WAP	21 WAP	24 WAP	27 WAP
Control	112.06	105.10	97.60	60.20	108.14	109.70	106.90	98.90	90.90	90.52
BF 3 kg	107.80	106.10	101.50	100.06	95.70	74.20	78.00	78.20	83.00	93.40
BF 5 kg	100.2	103.8	104.6	105.6	105.81	105.84	105.74	105.54	104.80	103.00
BF 7 kg	106.00	95.00	95.60	95.60	99.46	96.60	96.70	98.00	82.60	81.40
FF 1 kg	95.20	95.20	95.20	95.20	95.20	95.20	95.20	96.20	95.20	95.20
FF 2 kg	91.10	91.10	91.00	91.00	91.00	91.20	91.20	92.80	91.80	91.90
FF 3 kg	105.94	105.20	105.50	105.4	105.50	105.50	106.00	106.50	106.36	106.20

Table 5. Average growth of *Pterocarpus indicus* tree diameter to fertilizer type and doses (Weeks After Planting)

Treatment/ dose	Average Diameter of *Pterocarpus indicus*									
	0 WAP	3 WAP	6 WAP	9 WAP	12 WAP	15 WAP	18 WAP	21 WAP	24 WAP	27 WAP
Control	26.13	24.50	18.03	17.25	19.01	21.50	22.08	22.98	22.98	23.05
BF 3 kg	9.25	9.21	9.13	9.13	9.18	9.25	9.28	9.30	9.30	9.30
BF 5 kg	9.17	9.16	9.16	9.16	9.18	9.18	9.20	9.20	9.21	9.21
BF 7 kg	7.48	7.19	6.91	6.91	11.71	8.64	6.54	6.53	6.46	6.46
FF 1 kg	6.5	5.5	5.25	5.42	5.45	5.45	5.61	6.71	6.71	6.80
FF 2 kg	9.43	9.43	9.51	9.51	9.56	9.58	9.59	9.63	9.63	968
FF 3 kg	10.89	10.71	10.61	10.61	10.72	10.82	10.91	11.09	11.15	11.50

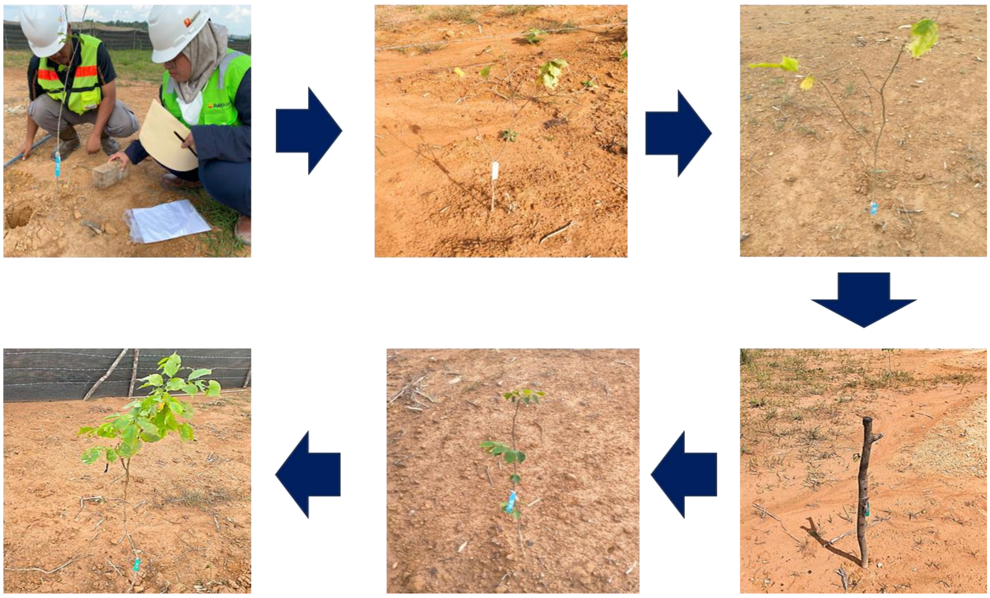

Figure 4. *Pterocarpus indicus* leaf growth

Table 6. Average number of *Pterocarpus indicus* (Weeks After Planting)

Treatment/Dose	Average Number of *Pterocarpus indicus*									
	0 WAP	3 WAP	6 WAP	9 WAP	12 WAP	15 WAP	18 WAP	21 WAP	24 WAP	27 WAP
Control	0	2	10	16	15	16	16	12	5	12
BF 3 kg	0	5	6	3	4	6	17	24	0	11
BF 5 kg	0	4	1	1	3	3	6	7	0	1
BF 7 kg	0	10	9	8	7	7	11	13	0	7
FF 1 kg	0	0	0	0	0	0	0	2	0	3
FF 2 kg	0	0	0	0	0	0	0	4	2	5
FF 3 kg	0	1	3	4	5	5	6	9	0	3

Figure 5. *Bronzing* and *necrosis* of *Pterocarpus indicus* plants

Evaluation of *Pterocarpus indicus* Growth Through ANOVA and Duncan's test

This study was conducted using a Completely Randomized Design (CRD) to evaluate the effect of various treatments on the direct planting of Pterocarpus indicus. The main variables observed included the type of planting medium, type of fertiliser, and fertiliser dosage. The results of the analysis of variance indicated that the application of coal and bokashi compost fertilisers had a significant effect on plant height, stem diameter, number of shoots, and number of leaves.

The results of the analysis indicate that the combination of planting material types and treatment dose variations had a significant effect ($P<0.05$) on the growth of *Pterocarpus indicus*, as assessed by the parameters of plant height, stem diameter, and number of leaves (Table 7). This increase in growth response was related to the role of treatment in increasing soil cation exchange capacity, thereby improving the availability of macro and micro nutrients required in plant physiological processes. Further analysis using Duncan's Multiple Range Test (DMRT) confirmed significant differences between treatments, through evaluation of the average plant height, stem diameter, and number of leaves produced.

The interaction between the three treatment factors indicates that the effects of each variable cannot be analysed separately, thus requiring further analysis using Duncan's Multiple Range Test (DMRT) to identify significant differences between treatments (Table 8). In terms of plant height, the application of 3 kg of bokashi per planting hole produced the highest average, namely 104.38 cm, which indicates the effectiveness of this dose in supporting the vertical growth of *P. indicus.* Analysis of the stem diameter showed no significant difference between the bokashi and coal fertiliser treatments, indicating that the effectiveness of coal fertiliser in stimulating stem diameter growth is relatively low. Meanwhile, in terms of the number of leaves, the combination of *P. indicus* and bokashi fertiliser produced higher results than the other treatments, with an average of 21.99 leaves. The application of 3 kg of bokashi per planting hole also produced the highest number of leaves, with an average of 20.67 leaves, confirming the effectiveness of this dose in stimulating leaf formation compared to other doses.

Table 7. ANOVA test to evaluate the effect of treatment on the vegetative growth of *Pterocarpus indicus* (height, stem diameter, and number of leaves)

Variable	Height		Diameter		Number of Leave	
	F-Count	Sig.	F-Count	Sig.	F-Count	Sig.
Plant material	-	-	-	-	-	-
Fertilizer	10.356	0.002^{+}	46.168	0.000^{+}	24.402	0
Dose	8.092	0.000^{+}	39.407	0.000^{+}	1.228	0.298
Plant material x Fertilizer x Dose	-	-	-	-	-	-

Note: Significant at $P<0.05$, $P<0.01$

Table 8. Results of Duncan's Multiple Range Test (DMRT) analysis of the effect of treatment on the growth parameters of *Pterocarpus indicus*

Variables Treatment	Average Height (cm)	Average Diameter (cm)	Average Number of Leaves (blade)
Control	91.55	32.214	21.26
Coal Fertilizer	97.38	32.652	4.41
Bokashi Fertilizer	101.94	35.553	21.99
Dose Fertilizer/Planting Hole	Average Height (cm)	Average Diameter (cm)	Average Number of Leaves (blade)
0 Kg	91.55	32.214	21.99
1 Kg	95.31	35.966	1.59
2 Kg	90.99	36.886	1.60
3 Kg	104.38	37.692	21.99
5 Kg	103.03	31.138	15.04
7 Kg	101.22	31.796	20.67

Note: Control, Bokashi Fertilizer (3 kg), Bokashi Fertilizer (5 kg), Bokashi Fertilizer (7 kg), Batubara Fertilizer (1 kg), Batubara Fertilizer (2 kg), Batubara Fertilizer (3 kg).

DISCUSSION

The characterisation of post-coal mining soil shows a lateritic structure with low organic matter content, indicating nutrient-poor soil conditions. An increase in the clay fraction along with a decrease in sand can improve the soil's water retention capacity, but meanwhile, it also increases the risk of compaction, which can disrupt air circulation and water availability for roots. Soil colour variations from brown to bright red indicate mineral extraction and oxidation processes, which directly affect the chemical and biological properties of the soil (Pérez-Lizasuain et al., 2022). Additionally, sufficiently large pore spaces allow for free water movement, but the ratio between macropores and micropores can affect soil hydraulic properties, such as infiltration, drainage, and water-holding capacity (Gu et al., 2020).

Extreme soil acidity is one of the main limiting factors. The oxidation of pyrite, which produces sulfuric acid, causes the pH to be low, significantly reducing the availability of macro nutrients such as phosphorus (P) and potassium (K). This condition is consistent with soil fertility theory, which emphasises that soil pH is an important indicator of ion exchange and nutrient uptake by plants. Amelioration efforts involving the addition of coal and bokashi fertilisers are indicating potential for improvement, although they are not yet optimal in neutralising acidic conditions (Meetei et al., 2020).

Low cation exchange capacity indicates the soil's limited ability to store and provide nutrients. A decrease in CEC is generally associated with a reduction in organic matter and colloid surface area, which weakens the soil's ability to retain essential cations (Nešić et al., 2015). This condition not only reduces soil productivity but also has implications for changes in physical properties, such as decreased effective porosity and infiltration capacity. Previous research conducted by Purnamasari et al. (2021), examined the potential of CEC to inhibit plant growth due to limitations in water, air, and nutrients in the root zone.

Aplikasi bokashi dengan dosis 3 kg per Applying 3 kg of bokashi per planting hole provided the most optimal response to the initial growth of *Pterocarpus indicus,* particularly in terms of plant height. The effectiveness of this treatment is closely related to the availability of macronutrients, particularly nitrogen (N), phosphorus (P), and potassium (K), which can support important physiological processes such as stem elongation (Neta et al., 2020). These nutrients play a role in facilitating metabolism and new tissue formation, thus enabling more intensive vegetative growth. This finding aligns with the research results of Chemutai et al. (2019); J. Liu et al. (2024). Carvajal et al. (2023), which emphasized that nutrient availability in a balanced composition is a crucial factor for optimal plant growth.

However, analysis of stem diameter parameters showed no significant difference between the bokashi and coal fertiliser treatments. This indicates that coal fertiliser has not yet significantly contributed to stem enlargement. This limitation is likely influenced by the low availability of readily absorbable nutrients, the fertiliser's chemical properties that do not support nutrient release, and its limited interaction with the physical and chemical conditions of the soil. Several previous studies have also confirmed that the effectiveness of carbon-based fertilisers, such as coal fertiliser, is largely determined by the quality of the raw materials, the production process, and their suitability to the characteristics of the soil used as the planting medium (Taiz et al., 2018).

In addition to growth, leaf number is an important indicator of treatment effectiveness. Application of 3 kg of bokashi per planting hole resulted in the highest number of leaves, indicating that nutrient availability and environmental factors such as light, humidity, and temperature play a significant role in leaf growth (Wahba et al., 2016). Nitrogen (N) is an essential element that supports vegetative growth by increasing nutrient absorption, photosynthetic organ formation, and photosynthetic efficiency (Yousaf et al., 2021). Conversely, suboptimal environmental conditions can cause bronzing and necrosis symptoms due to nutrient deficiency or toxicity, which ultimately leads to damage to plant cells and tissues (Sawyer, 2004). These disorders are usually associated with metabolic disorders, including photosynthesis, respiration, protein synthesis, hormonal balance, and DNA replication (Singh et al., 2016). This indicates an increase in nitrogen availability, which plays a crucial role in chlorophyll synthesis and photosynthetic activity. Increasing leaf number directly expands the plant's photosynthetic surface, which in turn increases assimilate accumulation to support vegetative growth. Therefore, applying 3 kg of bokashi per planting hole not only increases plant height but also encourages greater leaf formation, which overall strengthens the productivity capacity of *P.indicus* in its early growth phase.

CONCLUSION

The direct planting method has proven effective in accelerating the growth rate of *Pterocarpus indicus* planted directly on post-coal mining land. Plant growth at various fertiliser doses showed variations in growth rates. The results of the analysis of variance (ANOVA) howed a significant interaction between the type of planting material, fertiliser, and application dose on plant growth variables, with a significance of P<0.05. Bokashi fertiliser at a dose of 3 kg per planting hole gave the best results, characterised by an average plant height of 104.38 cm, an average stem diameter of 37.692 cm, and an average number of leaves of 21.99 pieces. Therefore, the application of bokashi fertiliser at a dose of 3 kg is recommended to support optimal revegetation on mine reclamation land.

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