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Soil depth constraints in the revegetation of reclaimed coal mine land

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Abstract. *Hartati W, Syahrinudin, Sudarmadji T. 2024. Soil depth constraints in the revegetation of reclaimed coal mine land. Biodiversitas 25: 1838-1845.* Plants require adequate root space, nutrients, water, and air for optimal growth. This study analyzed the relationship between plant growth (i.e., diameter) and soil properties (i.e., thickness, organic matter content, texture) on revegetated post-coal mining land in East Kalimantan, Indonesia. Field research was conducted at revegetated area primarily planted with four species (*Hibiscus tiliaceus*, *Enterolobium cyclocarpum*, *Samanea saman* and *Acacia* sp.) with age of 8 years. Data was collected from 30 plots of 0.05 ha. Plant diameter were recorded and soil samples were taken from 0-10, 10-30, and >30 cm depths using soil auger at three points per plot. Organic matter content was determined by the Walkley-Black method, and texture by the Pipette method. Multiple regression analysis was used to used to investigate the relationship between plant diameter and soil properties. The study found that different species showed varying correlations between soil properties and growth. *Acacia* sp. and *S. saman* exhibited strong correlations (r=0.78), while *E. cyclocarpum* had a low correlation (r=0.35), and *H. tiliaceus* a moderate one (r=0.49). Soil thickness had a stronger influence on *H. tiliaceus* (α=0.05) and *S. saman* (α=0.01) than other tested properties. For some species, diameter growth was primarily determined by soil thickness in the revegetated area. The study highlights the importance of considering species-specific soil requirements for successful revegetation and plant growth on post-coal mining sites.

Keywords: Plant growth, post-coal mining, revegetation, soil organic matter, soil thickness, SOM

Abbreviations: SOM: Soil Organic Matter

INTRODUCTION

Soil thickness or depth is a crucial land physical element to consider in the assessment of land suitability for plant growth as it represents a permanent condition which is relatively difficult to change compared to, for example soil biological and chemical properties (Jiang et al. 2020; Blanco and Lal 2023). The presence of shallow soil or solum often leads to a horizontal spreading of roots (Goebes et al. 2019). In addition, in compacted soils, the vertical growth of roots as a means of plant reinforcement and their ability to penetrate deeper into the soil layer diminishes (Helliwell et al. 2019). On the contrary, in soils with a deep solum and low Bulk Density (BD), plant roots exhibit a tendency to distribute themselves evenly in both vertical and horizontal directions. This enables the roots to access a wider range of nutrients, resulting in stronger anchorage for the plants. The vertical growth of roots is particularly pronounced in these conditions, leading to accelerated and enhanced plant growth. The growth and stability of tree-type plants are positively correlated with the thickness of the solum, enabling them to withstand external forces, such as wind and body weight. The dense soil layer is believed to have a significant impact not only on the vertical development of vegetation but also on its overall growth (Bachmann et al. 2008). For example, the growth of revegetated plants at a post-silica mining environment in the Holcim Educational Forest (HEF) Cibadak, Sukabumi, West Java was found to be influenced by the depth of solum (Widiyatmoko et al. 2017).

Soil Organic Matter (SOM) has a crucial role in determining soil fertility and plant nutrition (Wiesmeier et al. 2016). The presence of SOM is particularly important for maintaining ecosystem sustainability and promoting forest productivity in forest environments (Raj et al. 2019; Ferreira et al. 2019). Tropical mineral soils may comprise up to 5 percent of organic matter (Wiesmeier et al. 2016), although low soil organic matter levels are often found because organic matter weathering in wet tropical climate areas is very fast. Nonetheless, extreme land degradation such as post-mining area might result in minimal to negligible amounts of soil organic matter (Hartati and Sudarmadji 2013). Consequently, land degradation is assessed in part by examining the reduction in soil organic matter (Geissen et al. 2013)

In East Kalimantan, Indonesia, post-coal mining land generally contains a high concentration of clay particles due to the mixing of the subsoil with the overlying soil layers, where the high clay concentration comprises the argillic horizon typical of the dominant Ultisols found in this region (Hartati and Sudarmadji 2013). At specific concentrations, clay particles correlate with SOM levels. The correlation between SOM content and clay content is relatively strong in medium to fine textured soils with 35-

50% clay content. However, the correlation is weaker for very fine textured soils with clay content exceeding 50% (Hartati and Sudarmadji 2016; Adhikari et al. 2014). Soil with a granular texture or clay content exceeding 40% retains water and nutrients to the point where they are inaccessible to plant growth. Similar to clay, clay loam and clay sand retain water and nutrients that are unavailable for plant growth (Jien et al. 2019).

According to the above description, it is necessary to test how closely soil thickness, SOM levels, and soil texture relate to the growth of revegetation plants. Although, it does not rule out the possibility that some soil chemical properties also correlate closely with plant growth on post-mining land. The close relationship between the three soil characteristics and plant growth can be an early clue, and it is anticipated to be a useful measurement to assess the stage of post-mining soil recovery in terms of soil function for plant growth. In this regard, plant diameter is an accurate and simple to measure plant growth parameters in the field. This study aims to determine the relationship between plant growth, as indicated by plant diameter, and soil function, as reflected by soil thickness, organic matter content, and soil texture in post-coal mining land revegetation. The results of this study might be useful for the development of sound reclamation strategy of coal mine land.

MATERIALS AND METHODS

Research location

The present research was carried out within the mining concession area of PT Kitadin Site Embalut, with a specific focus on the land that underwent reclamation efforts after coal mining activities in 2015. The research site is situated in Embalut Village, Tenggarong Seberang Sub-district, Kutai Kartanegara District, East Kalimantan Province, Indonesia at the geographical coordinates of 0°18’00.0” - 0°22’30.0” S and 117°5’00.0” - 117°7’49.9” E (Figure 1). The concession area encompasses an elevation range of 50 to 100 meters above sea level, with a minor portion characterized by lowland or marsh terrain exhibiting rather uniform slopes. The climatic classification of the region is categorized as A-type according to the Schmidt-Ferguson (Ekayanti 2021).

The selection of the revegetation site was based on the reclamation of previous mining excavation, which involved reshaping the ground surface to create a sloping terrain with an average gradient of 15%. The geological formations under consideration are sedimentary rocks, characterized by a combination of sandstone, silt, muck, shale, coal, and occasional occurrences of silicified wood. Prior to mining activity, the natural vegetation consisted of trees and shrubs typical of secondary tropical rainforests, as observed at the PT Kitadin Site Embalut in 2003. After the mining operation end, revegetation was conducted using primarily comprises fast-growing species.

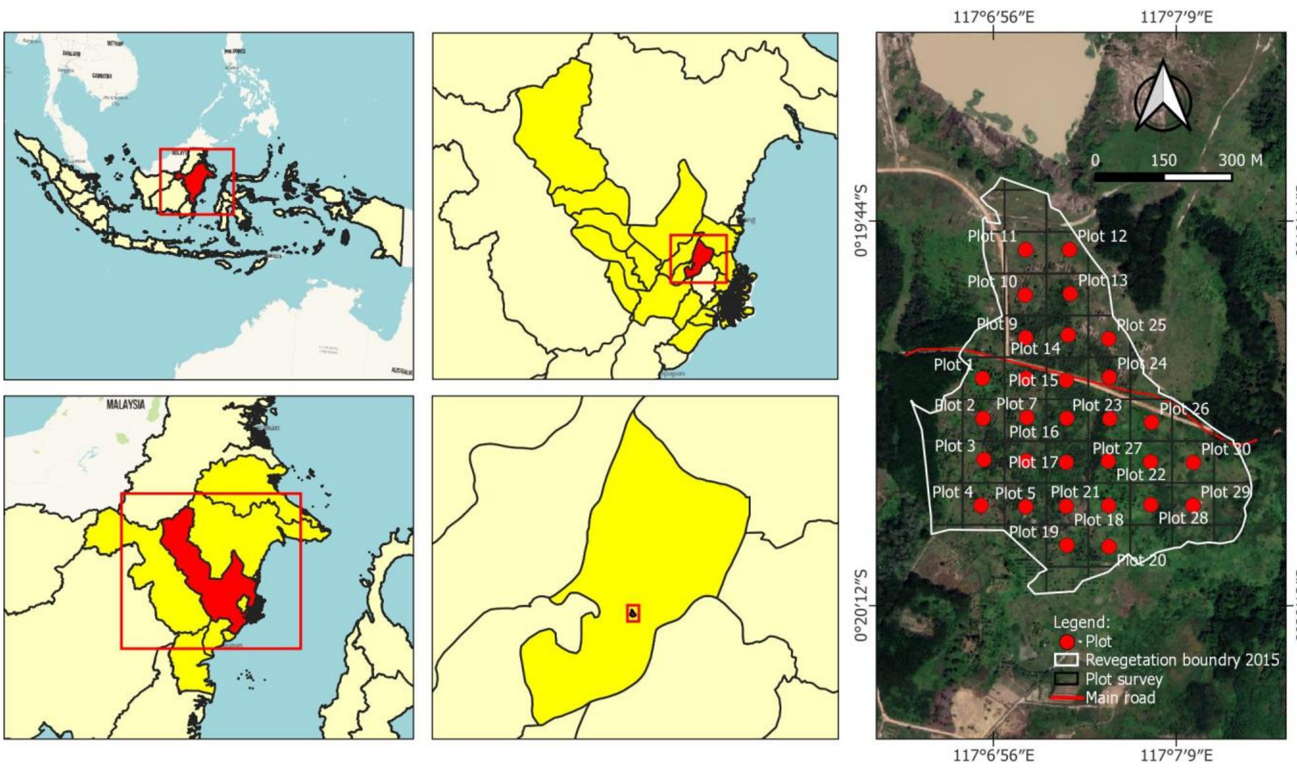

Figure 1. Research location at post-coal mining land of PT Kitadin Site Embalut in Tenggarong Seberang Sub-district, Kutai Kartanegara District, East Kalimantan Province, Indonesia

Research design

Field orientation

The study commenced with a field orientation on lands undergoing revegetation after coal mining in order to ascertain their suitability in relation to the research aims. Several factors were considered when evaluating a potential site for data collection. These factors included the uniformity of plant age (8-year-old), the practicality of the area, which should be a minimum of 30 hectares, the presence of overgrown forestry plants, the known history or management practices of the site, and its accessibility. The research area covered 35 hectares that had been revegetated through plantings carried out in 2015

Construction of research measuring plots

The development of a measurement plot commenced with the establishment of a functional map. Based on the available study literature and empirical findings, we employed drones for shooting purposes. Moreover, the identification of plots was conducted in a methodical manner inside the operational map, where each plot was spaced at a distance of 100 meters or corresponds to an area of 1 hectare. In this investigation, a total of 30 plots were identified (Figure 1). A circular area with a radius of 12.5 meters or an area of 0.05 hectares was constructed in the plot field.

Data collection procedures

Soil and plant data were collected from each plot. Data collection in the field in the form of soil thickness, diameter at chest height and number of each type of plant.

Soil thickness

Soil thickness data collection was preceded by drilling the soil with a soil auger until it met the overburden layer. The determination of soil thickness was done by measuring the depth from the bottom of the hole to the ground surface. At each plot, 3 (three) points were set to measure the thickness of the soil, namely at the centre of the circle and other points each 5 m from the centre of the circle and located on one line (Figure 2). Soil thickness data in each plot was the average soil thickness of the 3 points.

Soil Organic Matter (SOM) content and soil texture

Data collection of organic C content and soil texture was carried out in the laboratory on soil samples taken from 3 points at each plot with soil auger for 0-10 cm (I) layer; >10-30 cm (II) and >30 cm (III). Soil sampling was carried out at the same time as the determination of the thickness of the soil. Soil samples from these three points were composited for each layer to test organic C levels and soil texture in the laboratory. Organic C content was determined by Walkey-Black dichromate method (Adhikari et al. 2014; Malik et al. 2019) while soil texture was determined by particle size analysis of soils based on International Pipette method (Igaz et al. 2020). The SOM rate is calculated by the following formula:

SOM content (%) = C-organic content (%) x 1.724

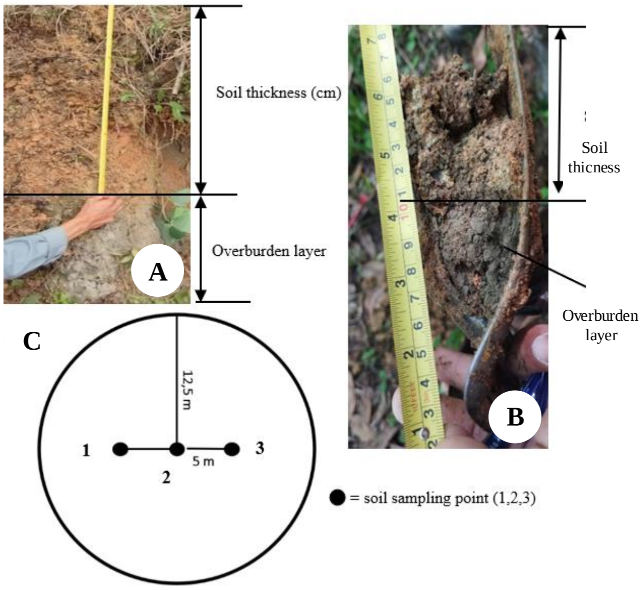

Figure 2. Soil sample collection: A. Soil profile of post-coal mining land; B. Measurement of soil thickness in post-coal mining land using a soil auger soil; C. Sampling points (1, 2, 3) within the research plot

Plant diameter

Revegetation plant diameter data was collected by census from each plot by measuring the circumference of plant stems. The measuring tape was looped only on the stems of revegetation plants with a circumference of >15.7 cm or a diameter of >5cm at the height of the plant at chest level or at a plant height of 1.3 meters from ground level. Next, the diameter data was calculated by the following formula:

Diameter (cm) = (circumference (cm))/π

In the process of measuring plant diameter, there were several things considered to get accurate results, such as when the tree is leaning, on sloped ground, or has an irregular form. In those cases, the diameter measurement should follow the guidelines recommended by Luoma et al. (2017).

Data analysis

We analysed the relationship between predictor variables X (soil thickness, SOM content and clay, silt and sand) and response variable Y (diameter of revegetation plants) using a multiple linear regression analysis in Microsoft Excel 2019 with the following equation:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5$$

Where: Y = diameter of each type of revegetation plant; X_1, X_2, X_3, X_4 and X_5, respectively are soil thickness, SOM content, sand content, silt and clay content; a = constant; b_1, b_2, b_3, b_4 and b_5 regression/determination coefficients are the proportional proportions of variation of the response variable (Y) described by the predictor variable (X)

(Williams et al. 2019; Pardoe 2020). If the value of the coefficient of determination in an estimate is close to number one, it can be said that the response variable is well described by the predictor variable. Conversely, if the coefficient of determination moves away from one (1) or is close to zero (0), then the less good the predictor variable explains the response variable.

RESULTS AND DISCUSSION

Growth of revegetated plants in post-coal mining land

Plant diameter is a parameter that is almost always used in evaluating plant growth, including in this study because this parameter is easy and practical to measure. In this study, diameter at breast height (1.25 m) was used as a parameter. All sample trees with a diameter > 5cm were measured, but only species with more than 10 occurrences in the plots were considered statistically viable for analyzing their relationship with soil characteristics. The selected species were *Hibiscus tiliaceus* (*Waru*), *Samanea saman* (*Trembesi*), *Enterolobium cyclocarpum* (*Sengon buto*) and *Acacia mangium* (*Akasia*) (Table 1). The *H. tiliaceus* was found in 28 out of 30 studied plots and was the most abundant species followed by *S. saman* (17 plots out of 30 plots), *E. cyclocarpum* (16 plots out of 30 plots) and *A. mangium* (13 plots out of 30 plots). These species are fast-growing species commonly planted as part of the plant composition in addition to native long-rotation species in post-mining land rehabilitation (Ministry of Forestry Regulation No. P.60/Menhut-II/2009; Ministry of Energy and Mineral Resources Regulation No. 7 of 2014).

At 8 years old, *S. saman* and *E. cyclocarpum* had the largest diameters with 28.5 cm and 28.9 cm respectively, or 3.6 cm yr^{-1} diameter increment, making them as fast-growing revegetation plants in post-mining land. The diameter of *S. saman* and *E. cyclocarpum* were not significantly different from those planted in the reclamation area of PT. Antang Meratus (Mulidan et al. 2021) and in the urban forest in BSD City (Putri 2021) at the age of 7 years. The growth rate of *Acacia* sp. has been observed to increase rapidly up to 15 cm in stands less than 3 years old, but slows down after the fifth year, with the diameter remaining around 25 cm by age 8 years (Adams et al. 2016). Diameter increment for *A. mangium* can range from 1.4-7.3 cm yr^{-1}, with the highest increment exceeding 4 cm yr^{-1} at less than 3 years old (Silva et al. 2020), indicating relatively slow growth of Acacia in this study, with a diameter of 9.1 cm at 8 years (Table 1). The result of iut study is lower compared to Acacia planted in Sumatran at 6 years of age which had a diameter of 18 cm (Hardiyanto and Wicaksono 2008), and 23.8 cm at 7 years of age in the Industrial Plantation Forest (HTI) of PT Arara Abadi (Suhartati et al. 2013), and 28 cm at 7 years of age in the Industrial Plantation Forest in South Kalimantan (Arsad 2011). The average stem diameter of 16 provenances of *A. mangium* in Wonogiri at 5 years of age was 14.66 cm (Susanto et al. 2013).

Soil characteristics of post-coal mining revegetation land

Soil thickness

Solum thickness or depth (soil depth) is the vertical distance from the soil surface to the layer that limits the flexibility of root system development (Kodikara et al. 2019) which is measured from the soil surface as an initial value of 0 (zero) towards the bottom to the upper limit of horizon C or to a depth that limits plant roots recorded in centimeters (cm). The soil material above the overburden refers to as topsoil in general post-mining reclamation practices (Pratiwi et al. 2021). The boundary of plant roots in post-mining land is generally overburden layer which is a layer overlaid on the land before soil distribution is carried out during land reclamation so that soil thickness is measured from the soil surface to the upper limit of the overburden layer. The range of soil thickness in the revegetated land studied was 11.0 cm - 48.3 cm with an average of 28.44 + 8.34 cm. According to the soil thickness classification made by Arsyad (2010), of the 30 plots studied, 10 plots of soil depth were classified as very shallow and the other 20 plots were classified as shallow. The soil thicknes in the study area is listed in Table 2.

In the Forest Reclamation Guidelines prescribed in the Regulation of the Minister of Forestry of the Republic of Indonesia Number P.4 / Menhut-II / 2011 (*Peraturan Menteri Kehutanan Republik Indonesia Nomor P.4/Menhut-II/2011 tentang Pedoman Reklamasi Hutan*) states that topsoil is a growing medium for plants and is one of the determining factors for the success of plant growth in reclamation activities so it needs to be managed properly. The shallowness of the soil layer in post-coal mining land is partly due to reduced soil matter both before and after soil spreading activities. At the beginning of revegetation activities, soil loss due to erosion can reach >480 ton ha^{-1} $year^{-1}$ (Sudarmadji et al. 2013).

Table 1. Diameter growth of revegetated plants at the studied area of post-coal mining rehabilitation land in Kutai Kartanegara District, East Kalimantan Province, Indonesia

Species	No. of Plots	No. of Planted Trees	No. of Tree Sampling	Diameter*) cm	Std	Diameter Increment (cm yr^{-1})
Waru (*Hibiscus tiliaceus*)	28/30	10,645	267	12.3^b	3.48	1.5
Trembesi (*Samanea saman*)	17/30	4,445	70	28.5^a	12.17	3.6
Sengon (*Enterolobium cyclocarpum*)	16/30	1,325	42	28.9^a	13.17	3.6
Akasia (*Acacia mangium*)	13/30	-	23	13.9^b	5.72	1.7

Note: *) Numbers followed by the same letter are not significantly different at the α = 0.05 level

Table 2. Soil thickness at the studied area of post-coal mining rehabilitation land in Kutai Kartanegara District, East Kalimantan Province, Indonesia

Classification of soil thickness (Arsyad 2010)			
Very shallow (<25 cm)		**Shallow (25-50 cm)**	
Plot	**Soil thickness (cm)**	**Plot**	**Soil thickness (cm)**
11	11.00	17	26.00
25	14.33	10	26.67
27	16.67	28	26.67
26	17.33	4	27.33
12	20.00	16	28.33
20	20.33	5	29.67
29	20.33	19	30.00
18	21.67	8	32.33
30	23.67	24	32.33
22	24.00	21	32.67
		7	33.33
		15	33.67
		6	34.00
		13	34.00
		14	35.67
		1	36.00
		2	37.67
		23	37.67
		9	41.67
		3	48.33
Average	18.93		33.20
Maximum	24.00		48.33
Minimum	11.00		26.00
Std.	3.90		5.37
n	10		20

The topsoil of the former open-pit coal mining land is very heterogeneous and has high bulk density, low pore total, low N, P and K content, low CEC, low base saturation compared to the surrounding forest soil (Ma et al. 2020). According to a study by Wang et al. (2019), the research findings indicate that the soil acidity levels range from very acidic to neutral. Additionally, the soil exhibits low calcium exchangable, high magnesium exchangable, very low aluminum exchangable, large total pore volume, very slow permeability, and medium bulk density. The decrease of top soil fertility will reduce the carrying capacity of the soil for plant growth.

Soil texture

The soil texture in the revegetated land studied was dominated by groups of fine-textured, Clay (C) and Clay Loam (CL). This is common in post-mining fields because the soil returned to the land for revegetation has been mixed between subsoil and top soil. Subsoil is a layer of soil that generally has a higher clay content than topsoil, especially Ultisol which have argillic horizon, i.e. the clay accumulation horizon (Wijewardana et al. 2019). The research area in the mining concession in East Kalimantan province predominantly consists of Ultisols, which cover about 80% of the land. Ultisols are characterized by their reddish or yellowish clay accumulation in the subsurface horizon, indicating the presence of iron oxide. These soils have unique properties such as low nutrient content, high bulk density, and low CEC, which can impact their fertility and suitability for plant growth (Hernandez-Ochoa and Asseng 2018).

Excessive clay and silt fractions exceeding 70% in the soil texture result in poorer physical properties including higher bulk densities that restrict root growth (Ahmad and Li 2021). The particle size distribution between sand, silt and clay of the soil in this revegetation area is actually balanced. While texture is not the only factor determining Bulk Density (BD), it makes a significant contribution in determining bulk density (Ahad et al. 2015; Yu et al. 2024). The soil texture in the study area is listed in Table 3.

Soil Organic Matter (SOM)

Organic matter levels in the soil of post-coal mining revegetation land are generally higher in the top soil layer (I) and decreasing as the layer going deeper (Hartati and Sudarmadji 2013). This condition is common because the main source of organic matter is the vegetation growing on the site. Likewise, in this study, the accumulation of organic matter in the upper layer can certainly be originated from the litter of the plants themselves. The level of SOM according to Soil Research Center (*Pusat Penelitian Tanah*) (1983) is moderate (M) in the top layer (I) and very low (VL) in the next layer (II and III) (Table 4).

Table 3. Soil texture at the studied area of post-coal mining rehabilitation land in Kutai Kartanegara District, East Kalimantan Province, Indonesia

Soil depth		***H. tiliaceus***				***S. saman***				***E. cyclocarpum***				***Acacia* sp.**			
		Sand	**Silt** %	**Clay**	**T**	**Sand**	**Silt** %	**Clay**	**T**	**Sand**	**Silt** %	**Clay**	**T**	**Sand**	**Silt** %	**Clay**	**T**
I	Av.	23.62	38.08	38.30	CL	24.34	37.97	37.69	CL	24.31	36.22	39.47	CL	20.35	37.63	42.02	C
(0-10 cm)	Std	11.65	12.31	11.99		9.76	11.01	9.11		8.23	11.98	8.66		9.94	12.66	10.47	
	n	28	28	28		17	17	17		16	16	16		13	13	13	
II	Av.	24.31	35.05	40.64	C	22.73	39.47	37.80	CL	22.44	36.88	40.69	C	20.87	35.53	43.60	C
(- 30 cm)	Std	10.78	14.39	10.87		10.71	14.78	8.57		12.34	15.88	9.03		10.80	12.76	9.28	
	n	28	28	28		17	17	17		16	16	16		13	13	13	
III	Av.	22.46	34.68	42.86	C	18.92	36.00	45.08	C	22.83	31.83	45.34	C	23.31	35.47	41.21	C
(> 30 cm)	Std	14.34	14.53	9.50		9.25	12.17	9.40		12.78	12.55	9.82		13.46	12.90	9.69	
	n	15	15	15		10	10	10		11	11	11		7	7	7	

Note T**:** Soil Texture; C: Clay; CL: Clay Loam

The difference in the chemical status of SOM levels between layer I and layers II and III was too wide, indicating that SOM accumulated at the top only. Decomposition of organic matter in wet tropical areas occurs quickly but because the soil texture is relatively fine-medium, it is difficult to transport it to the lower layers

Correlation between soil characteristics and growth parameters of revegetation plants

The relationship between the diameter of revegetated plants and the parameters of soil characteristics studied at the study site can be determined by conducting multiple linear regression analysis. The regression model used in this study is formulated as $Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5$. There are five independent variables to explain the relationship with diameter of *H. tiliaceus* (Y_1), *S. saman* (Y_2), *E. cyclocarpum* (Y_3), and *A. mangium* (Y_4) as dependent variables, and the predictor variables are soil thickness (X_1), SOM content (X_2), sand content (X_3), silt content (X_4), clay content (X_5). Of the four regression models obtained, the significance of the regression coefficient is presented in Table 5.

A close correlation between soil characteristics and diameter was shown to occur in *S. saman* and *Acacia* sp. with a correlation coefficient value of 0.78 (Table 5) and the predictor variables affected the response variable by 61%. The following Table 6 presents the regression equation between plant diameter and soil properties for each species.

Based on the significance test in Table 5, it can be seen that the P value of all variables in each model has a value higher than the α 95% (i.e. 0.05) except for the soil thickness variable in the *H. tiliaceus* (*Waru*), and *S. saman* (*Trembesi*). It can be interpreted that at the real level of 95% (α = 5%), the soil character that actually has a correlation with the diameter of *H. tiliaceus* and *S. saman* is soil thickness, which is a parameter of root anchoring. This finding suggests that thinner soil might hinder the upright standing of the two types of plants. The growth of *E. cyclocarpum* and *A. mangium* tends to be influenced more by soil texture than soil depth (Table 5). As a leguminous plant, Acacia's growth is influenced by soil microbial conditions. Soil microbial activity gradually and significantly increases to a maximum at 20-30 cm depth, then decreases at 30-50 cm depth (Fterich et al. 2014). The roots of *E. cyclocarpum* develop in the upper layer, with more than 50% of the total main roots growing horizontally (Rusdiana et al. 2000). Root development of *E. cyclocarpum* is also closely related to soil fertility (Azizah et al. 2019). In addition to affecting root anchoring, soil thickness also relates to the amount of nutrients that can be explored by plant roots. Therefore, when stripping the topsoil, it should be stored in a place that is safe from erosion and drying since topsoil has the highest fertility and is able to support plant growth (Pratiwi et al. 2021).

Table 4. Soil organic matter at the studied area of post-coal mining rehabilitation land in Kutai Kartanegara District, East Kalimantan Province, Indonesia

Soil Depth		***H. tiliaceus***		***S. saman***		***E. cyclocarpum***		***Acacia* sp.**	
		SOM (%)	**Status**	**SOM (%)**	**Status**	**(%)**	**Status**	**C (%)**	**Status**
I	Av.	3.77	M	3.85	M	3.47	M	3.66	M
(0-10 cm)	Std	1.25		1.28		1.50		1.64	
	n	28		17		16		13	
II	Av.	2.41	L	2.05	L	2.08	L	2.33	L
(-30 cm)	Std	0.97		0.64		0.65		1.22	
	n	28		17		16		13	
III	Av.	1.80	L	1.85	L	1.81	L	1.87	L
(> 30 cm)	Std	1.13		1.37		1.30		1.65	
	n	15		10		11		7	

Note: VL: Verry Low; L: Low; M: Medium; H: High

Table 5. Regression coefficient of significance test between soil characteristic and plant diameter at the studied area of post-coal mining rehabilitation land in Kutai Kartanegara District, East Kalimantan Province, Indonesia

Predictor	**P-Value (α=0.05) Diameter (cm)**			
	***H. tiliaceus* (Y_1)**	***S. saman* (Y_2)**	***E. cyclocarpum* (Y_3)**	***Acacia* sp. (Y_4)**
Soil thickness (cm), X_1	**0.05***	**0.01***	0.53	0.08
SOM content (%), X_2	0.93	0.75	0.49	0.72
Sand (%), X_3	0.35	0.95	0.45	0.06
Silt (%), X_4	0.35	0.95	0.45	0.06
Clay (%), X_5	0.35	0.95	0.45	0.06
Correlation coefficient (r)	0.49	**0.78****	0.35	**0.78****
Determination coefficient (R^2)	0.24	0.61	0.12	0.61

Note: *: significance at α=0.05; **: Correlation coefficient (r) showing close correlation

Table 6. Regression equation to model plant diameter using soil characteristics at the studied area of post-coal mining rehabilitation land in Kutai Kartanegara District, East Kalimantan Province, Indonesia

Species	Regression equation
H. tiliaceus	$Y_1 = -19,625.18 + 0.21 X_1 + 0.08 X_2 + 196.30 X_3 + 196.33 X_4 + 196.30 X_5$
S. saman	$Y_2 = -4,603.76 + 1.16 X_1 + 1.15 X_2 + 45.69 X_3 + 45.98 X_4 +46.06 X_5$
E. cyclocarpum	$Y_3 = -89,225.22 + 0.40 X_1 + 3.64 X_2 + 892.36 X_3 + 892.30 X_4 + 892.29 X_5$
Acacia sp.	$Y_4 = 89,030.31 + 0.49 X_1 + 0.49 X_2 -890.30 X_3 - 890.57 X_4 - 890.10 X_5$

Some conclusion remarks that can be drawn from this work are: among the four species planted in the post-coal mining land, only two species (*H. tiliaceus* and *S. saman*) demonstrated an adequate diameter growth rate owing to shallow soil thickness. Of the soil properties investigated (soil thickness, relative soil grain size, and soil organic matter), only soil thickness had considerable effects on the growth of some tree species (*H. tiliaceus* and *S. saman*) planted on the rehabilitated post-coal mining land. However, plant growth is not only influenced by topsoil thickness but also by other physical and chemical soil properties, such as nutrient and water availability, bulk density, penetrability, etc.

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