BIODIVERSITAS
Volume 23, Number 1, January 2022
Pages: 459-468

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d230149

Effect of soil properties on plant growth and diversity at various ages of coal mine reclamation in Indonesia

TEDI YUNANTO[1,♥], FARISATUL AMANAH[2], AYU RATNA WULANSARI[1], NABILA PUTRI WISNU[1]
[1]Politeknik Energi dan Pertambangan Bandung, Ministry of Energy and Mineral Resources. Jl. Jenderal Soedirman No. 623, Bandung 40211, West Java, Indonesia. Tel./fax. +62-813-16444786, ♥email: tedi.yunanto@esdm.go.id
[2]Directorate General Mineral and Coal, Ministry of Energy and Mineral Resources Indonesia. Jl. Prof. Dr. Soepomo, S.H. No. 10, Jakarta 12870, Indonesia

Manuscript received: 27 October 2021. Revision accepted: 28 December 2021.

Abstract. *Yunanto T, Amanah F, Wulansari AR, Wisnu NP. 2021. Effect of soil properties on plant growth and diversity at various ages of coal mine reclamation in Indonesia. Biodiversitas 23: 459-468.* Soil is an essential element for plants to grow. Therefore, it is important to understand the influence of soil properties, especially physical and chemical, on plant growth in coal mine reclamation areas. This study aimed to evaluate the growth and diversity of plants at various ages of reclamation and analyze the factors that most influence their growth and diversity. The study analyzed four soil physical properties and eight soil chemical properties. The research was conducted in mine reclamation areas with different ages: 1, 4, 6, 9, and 11-year-old-plantations for vegetation analysis and soil collection. Principal Component Analysis (PCA) analysis was performed using PAST 4.0 statistics program to analyze the data. The results showed that the 9-year-old plantation had the highest mean Shannon Wiener Index (H'= 1.52), mean basal area (35.04 m^2/ha), and mean density (469 trees/ha), while the 4-year-old plantation had the highest mean diameter (28.42 cm). The 1-year-old plantation had the highest clay content of 56.28% and the lowest pH of 3.27. The physical properties of the soil affected the growth rate and diversity of the reclamation area more than the chemical properties of the soil. This can be seen from the cumulative proportion of the two PCA values that described the original condition of 71.20% for soil physical properties and 63.10% for soil chemical properties. Based on this study, bulk density affected the diversity while pH impacted other soil chemical properties.

Keywords: Diversity, mine reclamation, plant growth, soil properties

Abbreviations: BD: Bulk density, C/N: Carbon/nitrogen, CEC: Cation exchange capacity, DBH: Diameter at breast height, EC: Electrical conductivity, ISO: International Organization for Standardization, OC: Organic carbon, PAF: Potential acid-forming, PCA: Principal Component Analysis, SNI: Standar Nasional Indonesia (Indonesian National Standard)

INTRODUCTION

In addition to having a positive impact on the Indonesian economy, the mining sector also harms the environment. Coal mining activities using the open-pit method can decrease the biodiversity of flora and fauna and changes in soil conditions (Sopialena et al. 2017; Giam et al. 2018; Spasic et al. 2021). Reclamation is mandatory based on Indonesia's Minister of Energy and Mineral Resources Decree No. 1827.K/30/MEM/2018 to prevent and reduce the negative impacts (Ministry of Energy and Mineral Resources 2018). Mine reclamation aims to rehabilitate the function of land and organize, restore, and improve the quality of the post-mining environment and ecosystem services according to its designation. It is also to maintain land stability and increase land productivity and function.

Based on the regulation, mine reclamation consists of two programs: revegetation and utilization into other land-use forms such as housings, agriculture, ranch, etc. (Yunanto et al. 2021). In general, the mine reclamation program includes land recontouring, soil spreading, erosion and sedimentation control, run-off water management, revegetation and maintenance (Amanah and Yunanto 2019). Revegetation is the main mine reclamation program, particularly in the forestry area. In accordance with the revegetation, the soil is essential to support the reclamation success.

Mining activities in particular change soil conditions. Open-pit mining generally has topography. During soil and overburden stripping, soil and overburden are separated to conserve the soil quality. The open-pit mining method will cause changes in the three properties of the soil (Spasic et al. 2021). The overburden may contaminate the soil from its geochemical content, e.g., the Potential Acid-Forming (PAF) material. Therefore, acidic soil requires additional treatments and proper species selection. Another issue is that more overburden used for growing media may decrease the reclamation success because the root cannot penetrate. However, the soil characteristic has to be defined to understand the quality and quantity of the reclamation program since the feasibility study. In addition, soil removal activities cause the mixing of topsoil and subsoil. The topsoil has a higher fertility rate than the subsoil. In addition to lower fertility levels, the subsoil layer usually accumulates toxic metals such as Al, Mn, and Fe.

In general, the soil has three properties, namely physical, chemical and biological. Based on the soil map of the study region, the soil types found in the research area were: gleysol district, alluvial gleyic, cambisol district, oxycol haplic, podzolic candic, and chromic podzolic. Physically, the soil decreases the porosity level, worsening the drainage system and causing waterlogging. If managed incorrectly, soil with a high clay content will become hard, and plant roots will be difficult to grow. Chemically, the soil had a very low pH and a low cation exchange capacity (CEC) (Shrestha and Lal 2011). The low soil pH value and CEC is significant problem in reclamation mining sites. Indirectly, changes in soil physical and chemical conditions cause the number of soil fauna as well as bacteria, fungi, and mycorrhizae to decrease. In general, the soil in the study area involves soils with low-to-medium fertility rates.

In general, ex-mining land is not fertile. Lack of organic matter can cause this condition, low pH, high clay content, or poor nutrition (Hartati and Sudarmadji 2016; Feng et al. 2019; Nadalia and Pulunggono 2020). The form of reclamation in ex-mining areas is revegetation, namely planting fast-growing tree species followed by planting local long-cycle species. Revegetation activities aim to restore productivity and vegetation cover in disturbed areas and improve soil quality and microclimate (Prematuri et al. 2020; Pratiwi et al. 2021).

Soil conditions greatly affect plant growth and diversity (number of living and growing plants). The nutrients that can be made available to plants are controlled by interactions between the soil's physical, chemical, and biological properties. As a growing medium and a provider of needs for plants, an adequate supply of nutrients must be maintained for growth and diversity. Soil fertility is inseparable from the balance of physical, chemical, and biological properties. The soil in the ex-mined site is a mixture of topsoil and subsoil, changing the soil horizon and reducing soil fertility. Its quality can also be degraded when stockpiled in the soil bank (Rai et al. 2014). Soil fertility impacts plant growth and vegetation diversity. Therefore, the purpose of this study was to determine the influence of soil's physical and chemical properties on the growth and diversity of plants at various ages of reclamation.

MATERIALS AND METHODS

Study area

The study was conducted in the coal mine reclamation area of PT Mahakam Sumber Jaya, Kutai Kartanegara Regency, and Samarinda City, East Kalimantan Province, Indonesia (Figure 1). PT Mahakam Sumber Jaya applies open pit mining for coal getting. When stripping the soil and overburden, the soil is piled separately from the overburden to conserve the soil quality. In addition, stripped soil can be directly spread in the mine reclamation area when it is already recontoured.

Vegetation inventory and soil sampling were carried out in five types of stands, namely: 1-yr-old plantation (reclamation of 2015), 4-yr-old plantation (reclamation of 2012), 6-yr-old plantation (reclamation of 2010), 9-yr-old plantation (reclamation of 2007), and 11-yr-old plantation (reclamation of 2005). All the stand types were located in the concession of PT Mahakam Sumber Jaya (Figure 2).

In general, the fast-growing pioneer species planted in the study area were *Enterolobium cyclocarpum* (Jacq.) Griseb., *Samanea saman* (Jacq.) Merr., *Senna siamea* (Lam.) H.S.Irwin & Barneby, and *Paraserianthes falcataria* (L.) I.C.Nielsen from the Fabaceae family. The Fabaceae family or Leguminosae can associate with *Azotobacter* and *Rhizobium* bacteria for nitrogen fixation (Desbrosses and Stougaard 2011; Suharno and Sancayaningsih 2013; Mahmud et al. 2020). The pioneer species can increase soil fertility by producing root exudates that attract certain bacteria, creating a microclimate, and preventing erosion due to the ability of the root system to hold the soil from water scouring (Lee et al. 2020). In addition to species from the Fabaceae family, other pioneer species are also planted in the study area, namely *Hibiscus tiliaceus* L. from the Malvaceae family. The tree selection of the study area also considered the local condition. The local people made a living as farmers, ranchers, cultivators, etc.

Procedures

Vegetation inventory

The study was conducted from June to September 2016. A vegetation inventory was used to evaluate and measure the growth and the diversity. A vegetation inventory was conducted at each of the five reclaimed sites described above. The vegetation survey was conducted using a modified circular plot with a radius of r = 17.8 m or about 0.1 ha (James and Shugart 1970). A total of 10 plots (1 ha) was used as the minimum plot number for silvicultural research (Lamprecht 1989). Thus, the total reclamation area is 50 plots or 5 ha for five different ages of reclamation area. For comprehensive and unbiased data collection, the distance between plots was 50 m. The sampling method was carried out using a systematic grid with a random start. The following parameters: species name, number of species, diameter at breast height/DBH (breast height = 1.3 m; diameter ≥ 10 cm), and total height for planted species and natural regeneration were collected and measured during the vegetation inventory. The plant height was measured using a haga hypsometer, and the diameter was measured using DBH tape.

Soil analysis

Five sample points for each stand type were taken with a depth of 0-40 cm; hence the total number of soil samples was 25 sample points. The plot design was a square plot with a radius of 50 m at each point. Four samples were taken from the corners of the square and one sample in the centre of the plot. The soil samples were taken using a soil auger and soil ring. The analyzed soil physical properties were bulk density, texture, water content, and conductivity. Meanwhile, the analyzed soil chemical properties were pH, organic carbon, C/N ratio, cation exchange capacity, available phosphorus, K exchangeable, Al^{3+}, H^{+}, and Fe total. The soil was analysed in the Southeast Asian Regional Centre for Tropical Biology (SEAMEO BIOTROP), Bogor Regency, West Java Province, Indonesia. Since 2007, the laboratory has implemented national standards of SNI 19-17025-2000 and ISO 17025.

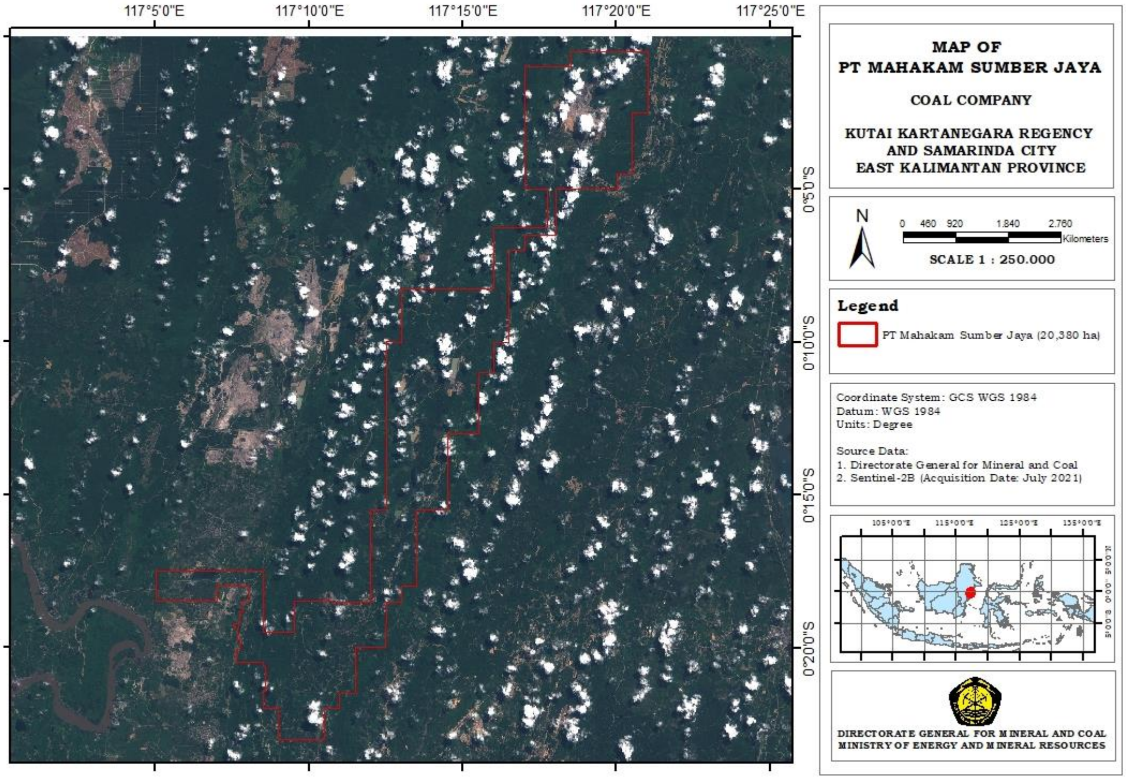

Figure 1. Map of study area: PT Mahakam Sumber Jaya, Kutai Kartanegara Regency, and Samarinda City, East Kalimantan, Indonesia

Data analysis

The vegetation inventory was analyzed using formulas below. Moreover, the vegetation inventory and soil analysis were analyzed using PCA (Principal Component Analysis) using PAST 4.0 statistics program.

Shannon Wiener Index (H`):

$$H' = -\sum pi \ln pi$$ (Magurran 1988)

Where:
pi = the proportional abundance of the ith species (ni/N)
Arithmetic mean diameter ($\bar{d}$):

$$\bar{d} = \frac{\sum_{i=1}^{N} di}{N}$$ (Brodbeck 2004)

Where:
di: diameter of the individual tree
N: total number of trees of the stand

Total stand basal area (G):

$$G = \sum_{i=1}^{N} gi; \text{ and } gi = \frac{\pi}{4}.di^2$$ (Lu 1999)

Where:
gi: basal area of the ith trees
di: dbh of the trees
Arithmetic mean height ($h_{\bar{d}}$):

$$h_{\bar{d}} = \frac{\sum_{i=1}^{N} hi}{N}$$

Where:
hi: height of the individual tree
n: total number of trees of the stand

RESULTS AND DISCUSSION

Results of growth and diversity analysis

In general, the results of the vegetation inventory show that the planted dominant fast-growing pioneer tree species belong to the Fabaceae family, such as *E. cyclocarpum*, *P. falcataria*, *S. saman,* and *S. siamea*. In general, 1, 4, and 9-yr-old plantation were dominated by the species of *E. cyclocarpum* namely 2/ha, 204/ha, and 182/ha, respectively. While the 6-yr-old plantation was dominated by the species of *S. saman* of 157/ha and the *P. falcataria* dominated the 11-yr-old plantation (212/ha). The results of the analysis of plant growth and diversity at various ages of reclamation are presented in Table 1. They were calculated based on the tree stage (height (h) 1.30 m and DBH ≥ 10 cm). However, for the 1-yr-old plantation, the growth rate and diversity analysis were carried out based on the tree stage (height (h) 1.30 m and 1 cm < DBH < 10 cm. Based on vegetation inventory, the diameter (DBH) of the 1-yr-old plantation is still below 10 cm.

The statistical analysis results using the Principal Component Analysis (PCA) method showed that the relationship between growth, diversity, and age of reclamation could be explained by two PCA, namely PC1 and PC2. Based on the cumulative proportion on PC2, the two PCA described the original condition of 79.90%. The results on the loading factor show that density has entered into PC2, while other variables such as basal area, diameter, height, H', and species richness are included in PC1 (Table 2). Biplot results showed that 1-yr-old plantations had different characteristics compared to other reclamation areas. It was shown in **Error! Reference source not found.** that the 1-yr-old plantation had no intersection with other reclamation areas. Meanwhile, 4yr-old, 6-yr-old, 9-yr-old, and 11-yr-old plantations had similar tendencies because of regional offenses.

Figure 1 shows that 1-yr-old plantation had low basal area value, species richness, height, and diameter variables compared to other reclamation areas. Meanwhile, 4yr-old, 6-yr-old, 9-yr-old, and 11-yr-old plantations had similarities where the growth and diversity values were pretty large in the basal area, species richness, height, and diameter variables. The different variables in 1-yr-old plantation with other reclamation areas were caused by the condition of the still very young stands. At the same time, the variable density tended to be different for all ages of reclamation due to the high mortality factors due to illegal logging, illegal planting of rubber trees, and livestock grazing, which were found when the vegetation analysis was carried out.

Soil analysis

Physical condition

In general, soil conditions at the reclamation age of 1, 4, 6, and 9-yr-old plantations had higher clay content, namely 38.9-56.3%, and a higher bulk density of 1.81-2.00 g/cm^3 compared to the soil of 11-yr-old plantation (Table 3). Soil texture in the mine reclamation area was strongly influenced by the soil material (subsoil or overburden) used at the beginning of the reclamation process. The high clay content in the soil was occurred because of the use of mudstone (clay) in the overburden. In addition, the low amount of organic matter (Zhao et al. 2013), soil compaction (excavators use), and livestock grazing activities caused the high bulk density in the reclamation area.

Table 2. Loading factor value for growth and diversity

Variable	PC1	PC2
Eigenvalue	1.936	1.026
Cumulative Proportion	0.625	0.799
Density (trees/ha)	-0.075	0.954
Basal Area (m^2/ha)	-0.429	0.091
Diameter; DBH (cm)	-0.438	-0.263
Height (m)	-0.473	-0.083
H’	-0.426	0.025
Species Richness	-0.461	0.073

Table 1. Species richness, Shannon Wiener (H’), basal area, density, diameter and height the tree stage (height (h) 1.30 m and DBH ≥ 10 cm)

Reclamations area	Species richness (n)	Shannon Wiener Index (H’)	Basal Area (m^2/ha) ± SD	Density (total trees/ha) ± SD	Arithmetic mean diameter ± SD (cm)	Arithmetic mean height ± SD (m)
11-yr-old	10	1.16	23.29 ± 7.23	347 ± 102	27.05 ± 2.72	16.85 ± 3.32
9-yr-old	14	1.52	35.04 ± 11.11	469 ± 116	27.74 ± 5.03	15.87 ± 4.98
6-yr-old	6	1.15	25.66 ± 9.73	394 ± 121	26.42 ± 3.17	12.77 ± 1.99
4-yr-old	4	0.77	19.35 ± 4.69	272 ± 70	28.42 ± 2.83	11.41 ± 2.11
1-yr-old*	1	0.00	0.02 ± 0.02	382 ± 288	3.49 ± 1.95	4.11 ± 1.81

Note: *Calculated from 1 cm ≤ DBH < 10 cm

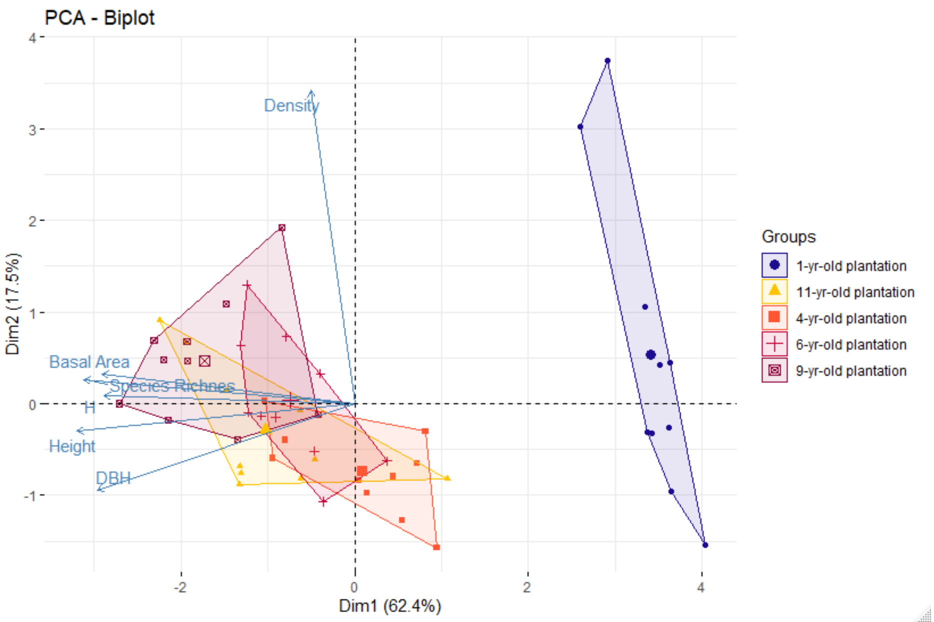

Figure 2. Biplot of reclamation area and variable for growth and diversity

Soil compaction is used during land recontouring in post-mining areas. Nawas et al. (2013) reported that the soil compaction may affect the alteration of root, late and low germination, died plants as well as the decrease of soil biological properties. The 1-yr-old plantation area had the highest electrical conductivity value, which indicated that the reclamation area had a greater nutrient absorption potential than other reclamation areas. This condition was probably caused by the high clay content in the soil. Shresta and Lal (2011) reported that soils with high clay content would simultaneously have high electrical conductivity values.

Based on the cumulative proportion on PC2, the two PCA had described the original condition of 71.20%. The results on the loading factor showed that bulk density and water content entered into PC2, while other variables such as sand, silt, clay, and electrical conductivity are included in PC1 (Table 4). The results of the biplot analysis showed that the 6 and 11-yr-old plantations had the same similarities of variables. Meanwhile, 1, 4, and 9-yr-old plantations also had the same similarities. The similarity between the reclamation ages was shown by intersecting areas of the reclamation age (Figure 3). Figure 3 showed that 6 and 11-yr-old plantations had similar high sand values but low silt and clay values. Meanwhile, 1, 4, and 9-yr-old plantations had high silt and clay values but low sand content. Electrical conductivity in the 1 and 4-yr-old plantation areas had the same higher value than other reclamation areas. Meanwhile, for bulk density and water content, the 4 and 6-yr-old plantation areas had high similarity values compared to other reclamation areas.

Table 4. Loading factor value for soil physical conditions

Variable	PC1	PC2
Eigenvalue	1.654	1.241
Cumulative Proportion	0.456	0.712
BD (g/cm^3)	0.018	-0.679
Sand (%)	0.599	0.013
Silt (%)	-0.527	0.068
Clay (%)	-0.560	-0.061
Water Content (%)	0.045	-0.706
EC (µS/cm)	-0.215	-0.179

Table 3. The analysis of soil physical conditions

Reclamations Area	Mean ± Standard Deviation					
	Sand (%) (50µ-2mm)	Silt (%) (2µ-50µ)	Clay (%) (0.2µ-2µ)	EC (µS/cm)	BD (g/cm^3)	Water Content (%)
11-yr-old	58.82 ± 13.90	14.80 ± 7.16	26.38 ± 6.89	252.16 ± 75.18	1.81 ± 0.15	22.09 ± 5.27
9-yr-old	11.06 ± 3.48	35.34 ± 1.59	53.60 ± 4.02	145.68 ± 85.37	1.83 ± 0.32	20.94 ± 7.42
6-yr-old	41.94 ± 20.39	21.20 ± 5.44	38.86 ± 15.77	123.18 ± 116.87	1.98 ± 0.33	25.00 ± 3.36
4-yr-old	17.98 ± 10.30	26.12 ± 0.23	55.90 ± 4.35	304.62 ± 212.09	2.00 ± 0.15	25.35 ± 4.37
1-yr-old	17.98 ± 7.43	25.74 ± 4.59	56.28 ± 6.23	343.07 ± 469.58	1.83 ± 0.19	19.09 ± 8.99

Note: µS/cm: microsiemens per centimetre; g/cm^3: gram per cubic centimetre; mm: milimetre; µ: micro; electrical conductivity measurement (1: 1; soil: water)

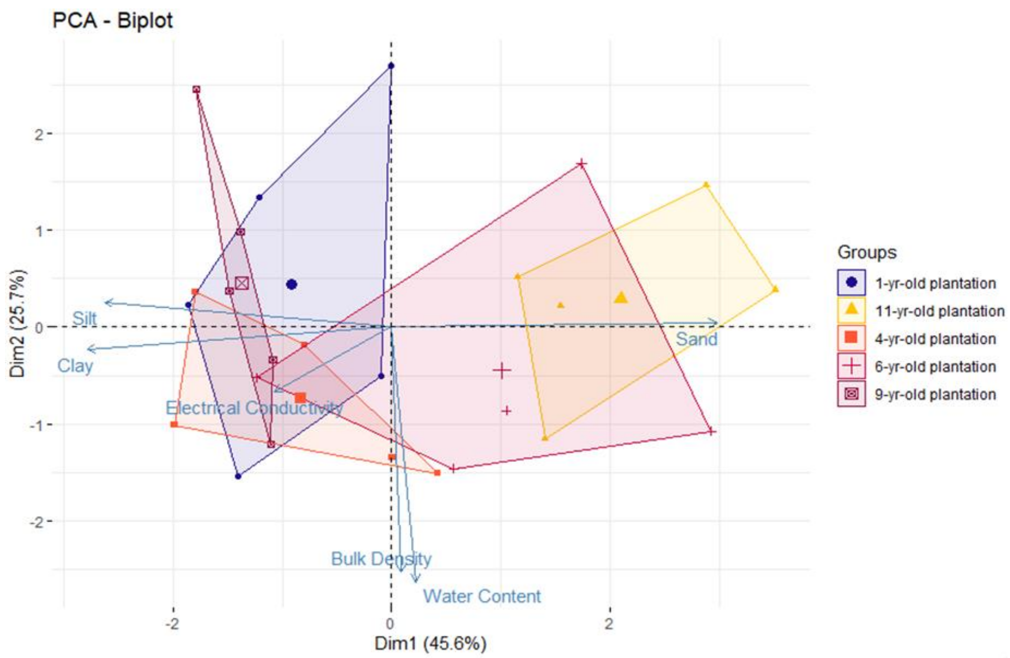

Figure 3. Biplot of reclamation area and variable for soil physical conditions

Chemical condition

The average soil pH value in a 1-yr-old plantation was the lowest among the others, namely pH = 3.27 (H_2O) and pH = 3.23 ($CaCl_2$). On the other hand, the mean value of soil pH in 11-yr-old plantations was the highest, namely pH = 6.35 (H_2O) and pH = 5.67 ($CaCl_2$). Shresta and Lal (2011) reported that the reclamation process increased soil pH. The release of alkaline cations from the soil due to weathering contributes to the high soil pH in the reclamation area (Zhao et al. 2013). The 4 and 9-yr-old plantations had higher organic carbon (OC) and N content than other reclamations, namely 1.38%; 1.49% and 0.22%; 0.25%, respectively (Table 5).

Based on the cumulative proportion on PC2, the two PCA described the original condition of 63.10%. The results on the loading factor showed that pH (H_2O), pH ($CaCl_2$), available phosphorus, Al^{3+}, H^+, and Fe Total entered into PC1. At the same time, other variables such as organic carbon, N total, Ratio C/N, K Exchangeable and CEC were included in PC2 (Table 6). The results of individual biplots (reclamation age) showed that the reclamation of 1 and 11-yr-old plantations had different characteristics than other reclamation areas. The two reclamation age areas indicated had no intersection with other reclamation areas. The reclamation of a 4-yr-old plantation intersected with a 6-yr-old plantation and a 9-yr-old plantation; however, a 6-yr-old plantation had no intersection with a 9-yr-old plantation. Based on the biplot image (Figure 4), reclamation of 1-yr-old plantations had a high value on the Al^{3+} and H^+ variable, while 11-yr-old plantations on available phosphorus. The 4-yr-old plantation had a high value of CEC. Meanwhile, 6-yr-old plantations had small values for the variable of CEC, N total, OC, C/N ratio, and K exchangeable. The 9-yr-old-plantation had dominancy for CEC, N total, OC, C/N ratio, and K exchange.

Table 6. Loading Factor Value for PC1 and PC2

Variabel	PC1	PC2
Eigenvalue	2.017	1.696
Cumulative Proportion	0.370	0.631
pH(H_2O)	-0.466	0.116
pH($CaCl_2$)	-0.442	0.169
OC	0.135	0.543
N	0.096	0.428
C/N	0.202	0.445
P	-0.333	-0.095
K e	0.131	0.243
CEC	-0.118	0.378
Al^{3+}	0.374	-0.091
H^+	0.418	-0.219
Fe	0.251	0.125

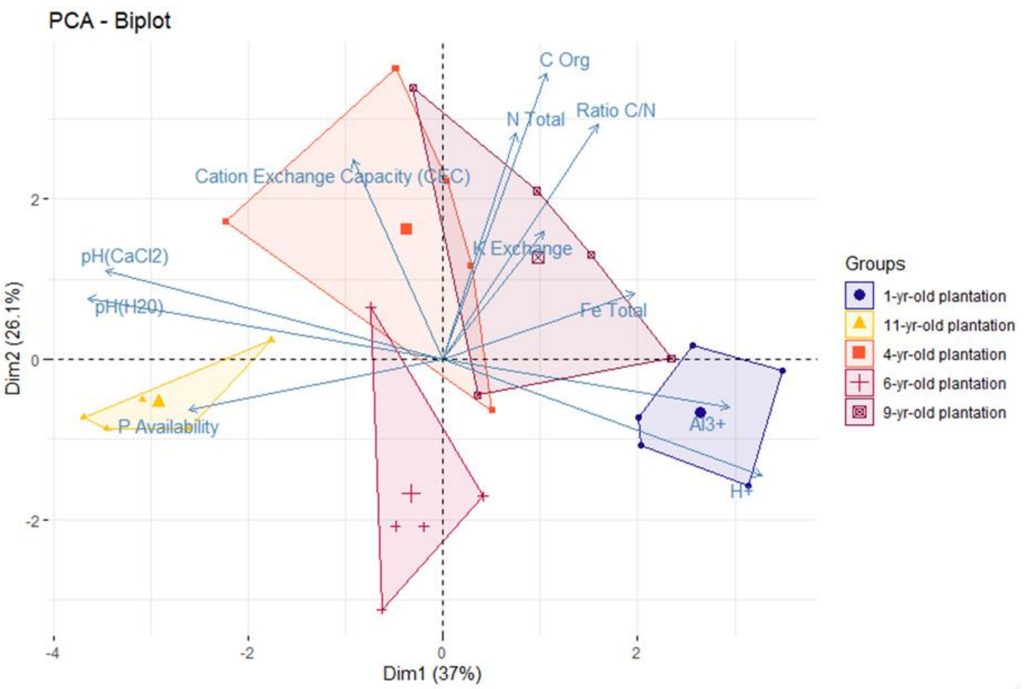

Figure 4. Biplot of reclamation area and variable for soil chemical conditions

Table 5. The analysis of soil chemical conditions

Reclamations Area	Mean ± Standard Deviation										
	pH (H_2O)	pH ($CaCl_2$)	OC (%)	N (%)	C/N	P_2O_5 (ppm)	e K^+ (cmol/kg)	CEC (cmol/kg)	Al^+ (me/100g)	H^+ (me/100g)	Fe-total (%)
11-yr-old	6.35 ± 0.88	5.67 ± 1.09	0.39 ± 0.17	0.12 ± 0.03	3.20 ± 1.30	136.70 ± 100.46	0.46 ± 0.28	19.77 ± 2.15	0.00 ± 0.00	0.14 ± 0.05	0.80 ± 0.96
9-yr-old	4.48 ± 0.75	3.93 ± 0.80	1.49 ± 0.65	0.25 ± 0.05	5.80 ± 1.92	6.56 ± 2.62	0.87 ± 0.38	17.73 ± 3.72	2.89 ± 3.04	1.35 ± 1.07	1.71 ± 2.25
6-yr-old	5.17 ± 0.40	4.29 ± 0.63	0.39 ± 0.31	0.12 ± 0.05	2.80 ± 1.30	20.90 ± 27.23	0.71 ± 0.04	10.19 ± 5.90	1.05 ± 0.70	1.12 ± 0.48	0.64 ± 0.63
4-yr-old	5.36 ± 1.30	4.64 ± 1.49	1.38 ± 0.64	0.22 ± 0.04	6.00 ± 2.45	26.32 ± 31.16	1.03 ± 0.33	17.65 ± 1.96	0.62 ± 1.09	0.61 ± 0.55	2.10 ± 1.47
1-yr-old	3.27 ± 0.44	3.23 ± 0.40	0.82 ± 0.17	0.15 ± 0.05	6.00 ± 2.35	5.02 ± 1.71	0.76 ± 0.16	14.69 ± 4.76	5.96 ± 3.87	2.75 ± 0.76	3.68 ± 1.93

Note: N-total: % dry weight; ppm: part per mille; cmol/kg: centimole per kilogram; me/100g: milliequivalents per 100 grams

Discussion

Due to the high variation of soil conditions of the investigated mining area, it is recommended to select the most appropriate and adaptable tree species. Some aspects of soil conditions that need to be considered during the selection of tree species for reclamation activities are soil texture, salinity, pH, soil fertility, and nutrient availability (Pietrzykowski 2019). The plantation of a legume cover crop in the reclamation area increased soil nitrogen (Buta et al. 2019). It is also strongly recommended for the initial step of land stabilization of the ex-mining area.

The revegetation generally is conducted by planting fast-growing or pioneer species and slower-growing or long-lived (under-shelter) species. The number of pioneer or fast-growing species per hectare was 625 n/ha (spacing 4 m x 4 m). From the study, the mean density of the reclamation area from the age of 1-yr-to 11-yr-old plantations was lower than 625 N/ha, ranging from 272-469 trees (n/ha). This is due to the difference in plant space (8 x 8 m, generally 4 x 4 m) and a very high mortality rate due to grazing (buffalo) carried out by surrounding communities. This condition was found in the field when carrying out the vegetation inventory in the area of the 4-yr-old plantation. There were more fast-growing species within the composition of planted trees than slower-growing species. An increased number of slower-growing species was expected from the growth of other species' natural regeneration in the reclamation area. The fast-growing plantation was intended to create the canopy, increase soil nitrogen (Fabaceae species), humus supply, create microclimate conditions, etc. *Paraserianthes falcataria*, *E. cyclocarpum*, and *S. saman* were the dominant fast-growing species planted in the study area and had a mean diameter growth of 11.3 to 18.7 cm (3-5 years old), 3 m (old stand), 6.6 cm (two-year-old), and mean height 11.7 to 20.5 m (3-5 years old), 20 to 30 m (old stand), 15-25 m (old stand), respectively (Barrientos-Ramírez et al. 2015). Nero (2021) found that the height and DBH of tree species grown in the reclamation area were higher than the natural forests around the study area.

In general, the value of diversity (species richness and Shannon Wiener Index) tended to increase along with the increase in the age of reclamation. However, there was a decrease in the diversity value at the age of 9 and 11-yr-old plantation. The diversity value decreased due to illegal logging in the 11-yr-old plantation (Yunanto, 2018). Reclamation areas with dominant *E. cyclocarpum* tended to have higher basal area and diameter values compared to other areas. The species of *E. cyclocarpum* can grow 20 to 30 m in height and has a trunk diameter of up to 3 m (Barrientos-Ramírez et al. 2015). Meanwhile, the reclamation area with the dominant *P. falcataria* has a higher tree height. The *P. falcataria* is a fast-growing species that can reach heights more than 40 meters (Krisnawati et al. 2011).

The species richness and Shannon-Wiener Index were increased along with the reclamation age. It shows that natural regeneration and growth can be created in the reclamation areas (Haigh et al. 2020; Lewis and Rosales 2020). However, the youngest (1 and 4-yr-old) plantations had the lowest species richness and Shannon-Wiener Index amongst the reclamation areas because of the high mortality rate and limited natural regeneration. The vegetation in the younger ages was easily exposed to sunlight because of an opened area (less canopy cover). Moreover, a grazing activity from the local ranch in the 4-yr-old plantation inhibited the natural regeneration.

Soil removal is one of the mining operation stages used in an open-pit mining method. Excavated soil is removed and then stored in a safe and stable place, such as a soil bank, or directly spread on the reclamation area-the excavation and removal of soil cause the mixture of topsoil and subsoil. Topsoil has a higher fertility rate compared to subsoil. Besides a lower fertility rate, subsoil usually contains accumulated toxic metals such as Al, Mn, and Fe. Several things that can be done to improve the condition of the soil. Planting cover crops and fast-growing tree species, which have characteristics that bind nitrogen from the atmosphere, will increase organic carbon (OC) as well as pH and nitrogen in the soil (Shrestha and Lal 2011; Buta et al. 2019; Ghosh and Maiti 2021). Furthermore, short periods of cover crops can be a source of organic material and improve the soil‘s physical condition, such as its porosity. Regular fertilization using both organic and inorganic matter will improve soil fertility and the biological needs of the soil.

In general, the reclamation soil had a high clay content ranging from 26 to 56%. As Prematuri et al. (2020) and Pratiwi et al. (2021) reported, the clay content was higher than in an ex-mining area. Clay content increases with the reduction of sand content. Medeiros et al. (2018) report that electrical conductivity (EC) demonstrates a positive correlation with soil water content, while Uddin et al. (2021) found that total N increases alongside rising water content. High clay content is well known to cause and influences root growth patterns (Bonomelli et al. 2019). Other authors report that the rate of root growth and the number of root elongation zones are reduced in compacted soils (Colombi et al. 2017; Correa et al. 2019; Vanhees et al. 2021). The mean value for soil bulk density (BD) in the reclamation areas was generally high, and it ranged from 1.83 to 2.00 g/cm^3. The soil BD in the reclamation area was still higher than the soil BD in the ex-mining area located in India (Prematuri et al. 2020; Pratiwi et al. 2021). The mean value for soil BD in the 4-yr-old plantation was the highest among the reclamation ages; this condition is a result of buffalo grazing that has led to compacted soil.

Several treatments have been used, with varying degrees of success, to reduce the harmful effects of soil compaction on plant growth. These treatments include loosening soils (Frelih-Larsen et al. 2018), applying fertilizers, or planting species that can tolerate soil compaction (Correa et al. 2019). A 'rootable' soil profile with suitable root parameters increases tree species under climatic conditions (Tasser et al. 2021). However, mining companies generally use just a 30 cm topsoil depth for revegetation activities. The thickness of the topsoil is very thin, and it will reduce the root growth. This thin topsoil could be one factor that has caused the low amount of living plant species to grow naturally in the reclamation area.

The 1-yr-old plantation had a low soil pH, i.e., pH = 3.27 (H_2O) and pH = 3.23 ($CaCl_2$). It was categorized as extremely acidic (USDA 1998 cited in Asensio et al. 2013), while the 11-yr-old plantation had the highest soil pH among the other reclamation areas, i.e., pH = 6.35 (H_2O) and pH = 5.67 ($CaCl_2$), and was categorized as moderate to slightly acidic (USDA 1998 cited in Asensio et al. 2013). The 11-yr-old plantation had a higher pH than other reclamation areas; this condition may have been caused by the contamination of unweathered overburden containing a significant number of carbonates (Howard 1979 cited in Shresta and Lal 2011). Conversely, the low pH in the 1-yr-old plantation was caused by the mixture of topsoil with overburden material containing potential acid-forming (PAF). If topsoil was absent, the plantation of trees was sometimes carried out directly on overburdened material. Overburdened material's physical and chemical properties will change over time, and if the overburden appears low in nutrients, fertilizers and mulches will be added to enhance tree growth.

The mean values for organic carbon and N in the 4 and 9-yr-old plantations were higher than other reclamation ages. The soil carbon values were often used to indicate soil quality and ecosystem recovery in post-mining soils (Bandyopadhyay et al. 2020). The organic material was generated a more significant carbon from planting pioneer species in post-mining soil (Agus et al. 2016). Moreover, the coal mine reclamation area had the plant carbon sequestration until 2.8 MgC ha^{-1} y^{-1} and it is a potential switch as a carbon neutral project (Fox et al. 2020). The high mean value for total N in the 4-yr-old plantation was probably due to impurities in the manure from cattle grazing. At the same time, the high mean value for total N in the 9-yr-old plantation was perhaps caused by surrounding communities planting rubber trees in the reclamation area. The 11-yr-old plantation had a very high mean value for P compared to other stand types. Mining activities lift the deep, unweathered soil layers increasing available phosphorus (Zipper et al. 2013). Frouz and Franklin (2014) found that P concentration in the 6-12 cm layer of reclamation soil was higher than P concentration in non-mined site soil.

The mean values for exchangeable cation K^+ 4 and 9-yr-old plantations' reclamation ages were higher than other reclamation ages. The weathered mineral increased soil pH by releasing cations such as Ca, Mg, and K (Sadhu et al. 2012). The mean value for cation exchange capacity (CEC) in the reclamation areas was generally high. The soil textures influence CEC; sandy soil texture was reported to have a low CEC (Sadhu et al. 2012). In general, the mean value for CEC in the reclamation areas indicates adequate soil quality. The 1-yr-old plantation had the highest mean values for $Al^{3+,}$ H^+, and Fe-total compared to all reclamation ages. The low soil pH may have caused this condition in the 1-yr-old plantation. The concentration of Al increased in soil with a low pH (Abdulaha-Al Baquy et al. 2017; Bojórquez-Quintal et al. 2017). The mean value for Al^{3+} in the soil of all reclamation areas was categorized as low to very low (Amacher et al. 2007 cited in Asensio et al. 2013).

In conclusion, the study results indicate that the parameters of growth and diversity tend to increase along with the increasing age of reclamation. The growth rate and diversity were affected by the physical and chemical properties of the soil. Bulk density impacted mine reclamation diversity shown in 4 and 6-yr-old plantations. In these areas, the diversity (species richness) was low compared to other reclamation areas. However, this study showed that the difference in reclamation improved soil conditions and natural regeneration. Several disturbances to the reclamation area, such as illegal logging, illegal planting, and livestock grazing, affect the species growing rate, diversity, soil's physical and chemical properties, or soil genesis rate. Protection and security programs for the reclamation area must be carried out so that there is no failure and/or a decrease in the quality of the reclamation area both in terms of growth rate and diversity.

ACKNOWLEDGEMENTS

This study was supported by PT. Mahakam Sumber Jaya, a coal company in East Kalimantan Province, Indonesia. The authors would like to acknowledge the Director of Engineering and Environment of Mineral and Coal, Ministry of Energy and Mineral Resources, Republic of Indonesia, for the opportunity and permission to conduct field activities.

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