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THE RECLAMATION OF NICKEL POST-MINING LAND THROUGH THE PROVISION OF ORGANIC MATTER AND SELECTION OF LOCAL CROPS

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Abstract

The handling of topsoil at the beginning of mining is often neglected, and the conditions in reclamation activities decrease fertility, causing the growth of plants to be hampered. Therefore, this study aims to increase soil fertility through the provision of organic matter and the growth of reclaimed plants. The method used was an experimental approach. Organic matter was collected from modified komba-komba plants and was applied at 7 kg per planting hole. Furthermore, the reclamation plants, including Johar (Senna siamea), Cemara Angin (Gymnostoma rumphianum), Mango–Mango (Mangifera sp), Kusambi (Schleichera oleosa), Tumbeua (Kjellbergiodendron celebicum), Kamoni-Moni (Syzygium acuminatissimum), Angsana (Pterocarpus indicus), Waru (Hibiscus tiliaceus), Damar (Agathis dammara), Red Bintangor (Calophyllum inophyllum), Wola (Vitex cofassus), and Cholama Wood (Parinary corimbosa) were tested. The soil was observed at the beginning and end of the study, and plant growth, such as the canopy's height, diameter, and width, was examined every six months for 3.5 years (2019-2022). The results showed that the initial soil conditions had very low fertility. Plant growth variables had varying responses to applying organic matter from the time of observation. The growth speed of reclaimed plants also varies. Additionally, Kusambi, Angsana, and Wola are the most adaptable and fastest-growing reclamation plants concerning pH, C-organic, and soil moisture.

Keywords: organic matter, plant growth, reclaimed plants, post-mining nickel, soil moisture.

Introduction

The extraction of nickel ore begins with removing ground-level cover vegetation, then peeling and stockpiling the top soil layer. These will degrade the horizon and soil structure, eliminating biodiversity above and below the surface. The biological process of nutrient recycling decreases land productivity and atmospheric and aquatic quality (Sugden et al., 2004). Mining companies should revegetate post-mining land to prevent erosion, convert insoluble heavy metals into plant biomass, and restore the function of soil ecosystems (Kanzler et al., 2015). The problem is that topsoil is limited as a suitable medium for plant growth around the mining area. Landfilling in nickel ore mining areas (including in Southeast Sulawesi) has a laterite behavior characterized by a low number of paramagnetic particles, low hydraulic conductivity, high plasticity, low organic matter content, and fertility, as well as low abundance and activities of soil organisms (Minasny & Hartemink, 2011; Safiuddin et al., 2011). Consequently, the physical, chemical, and biological

characteristics do not follow the optimal growth needs of plants (Sobati-Nasab et al., 2021).
Other impacts of these mining activities include changes in landforms as well as the physical and chemical conditions of the soil, loss of natural vegetation in the environment, and fertile topsoil layers of organic matter and nutrients (Setyowati et al., 2018). The impacts of soil physical properties include changes in soil structure, decreased environmental aesthetics, soil compaction, decreased permeability and soil infiltration, and a high risk of soil erosion (Ikbal et al., 2016). The chemical properties cause changes in the soil elements, the high content of ni soil minerals, and their accompanying minerals (Dan et al., 2008). Therefore, reclaiming or revegetating the land is necessary to restore its minimum possible function.
Land reclamation is the final stage of the nickel mining process. This requires land handling and crop selection based on the reclaimed land condition. The soil characteristics of the land to be reclaimed are already adequate to accommodate the proper plant selection. Reclamation is considered successful when it meets the established criteria. Therefore, it is necessary to consider the type of plant selected and its growth condition to meet the criteria for effective reclamation (Setyowati et al., 2018). On the other hand, this reclamation plant will be able to increase carbon stocks (Malki et al., 2022)
Post-mining land reclamation often experiences some limitations, including selecting the right plants from a particular location, pretreatment of the soil for crop sustainability, and provision of topsoil. There is no effort to store topsoil in a particular place, and the price for its stacking and removal operation is relatively high. Therefore, its provision in post-nickel mining land is complicated to obtain and neglected. This condition requires technological innovation to provide adequate soil conditions for the growth and development of reclaimed plants.
The soil's good physical and chemical characteristics and the choice of reclaimed plants corresponding to local conditions are in demand. Similarly, the placement of site-specific crops, commonly called local plants, is the leading choice considering that they have adapted to the local environment. The supply of local organic matter and inorganic fertilizers as primary food sources is needed for reclaimed plants' sustainability. Therefore, this study aims to increase soil fertility by providing organic matter and reclaimed plants' growth and selecting reclaimed plants with good speed and growth.

Materials and Methods

Description of the study area

This study was conducted from June 2019 to July 2022 in the mining site area of PT. Anugerah Harisma Barakah (AHB) in South Kabaena District with Planting Location Code A2-S3. The soil was analyzed at the Soil Department Laboratory, Faculty of Agriculture, UHO. Figure 1 presents the study location.

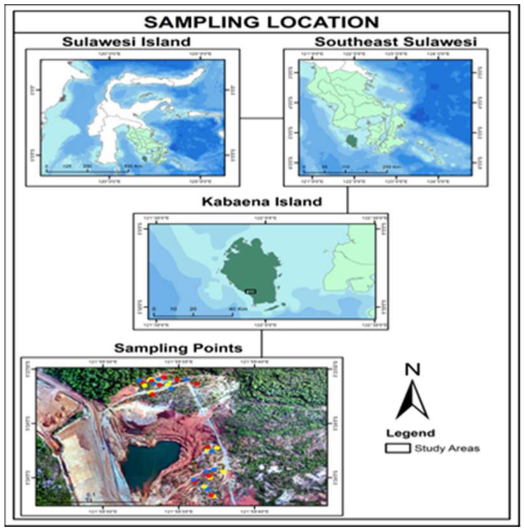

Figure 1. Study and sampling Locations

The materials used in this study are mining block maps, organic fertilizers, plastic bags, label paper, the company's microclimate, rainfall data for the Bombana Regency area, and chemicals for laboratory analysis purposes. The tools include GPS (Global Positioning System), roll meter, paul, shovel, field knife, machete, earth drill, sample ring, raffia rope, stationery, and equipment for laboratory analysis.

Field Testing Phase

The followings are the field implementation stages.

a. Land Determination and Study Area

This study was conducted using experimental methods in the mine reclamation site. The experimental land is selected based on an area of 2 ha that was mined and declared completed. The site's height is 27 m above sea level and is more than 30 m from the beach, with the highest and lowest tides. According to the incline of the slope, the fireplace in question involves the creation of stepped shoulder land.

b. Profile observation and early soil sampling

The soil profile is drawn directly through the surrounding excavated soil's surface appearance up to the parent material's layer. Before the experiment, soil sampling was observed at 36 points in the composite. Finally, soil fertility was accessed for texture, pH, C-organic, N-total, P_2O_5, K_2O, Ca, Mg, and KTK.

c. Spacing and planting holes

Planting distances are set at a size of 3 m x 3 m. The testing area of 2 ha was obtained from around 2,222 planting holes. Furthermore, the planting pits are created in the dry season at a size equivalent to a 1 pc 200 excavator bucket.

d. Regulation of Plant Nutrition

The prepared planting pits are given nutrients from organic matter (compost fertilizer) derived from cow dung and komba-komba leaves, of approximately 7 kg. Additionally, NPK fertilizer of 50 gr per hole should be applied to speed up the initial nutrient supply process. The reports of the initial testing of soil conditions with a low pH and the administration of dolomite lime at 100 gr per hole were provided. Organic fertilizers, NPK, and lime are applied simultaneously, stirred evenly, and covered with 7-10 m thick smoothed soil until the rainy season.

e. Reclaimed Crop Arrangements

The used plants are local species that grow and develop before mining. The seeds of the tested plants will be transferred when they are 3 to 8 months old. Furthermore, the plants used are Johar (Senna siamea), Cemara Angin (Gymnostoma rumphianum), Mangga–Mangga (Mangifera sp), Kusambi (Schleichera oleosa), Tumbeua (Kjellbergiodendron celebicum), Kamoni-Moni (Syzygium acuminatissimum), Angsana (Pterocarpus indicus), Waru (Hibiscus tiliaceus), Damar (Agathis dammara), Bintangor Merah (Calophyllum inophyllum), Wola (Vitex cofassus), and Kayu Kolasa (Parinari corimbosa). Table 1 shows the position and condition of the plant.

Table 1. Location of Observation Coordinates of Soil and Plant Samples

No.	**Plant Type**	**Deuteronomy**	**Koordinat**	**No.**	**Plant Type**	**Deuteronomy**	**Coordinates**
1	Johar (*Senna siamea*)	1	S = 05°23'56,25" E = 121°55'34,30"	7	Waru (*Hibiscus tiliaceus*)	1	S = 05°24'2,26" E = 121°55'37,52"
		2	S = 05°23'55,95" E = 121°55'34,89"			2	S = 05°23'56,35" E = 121°55'36,19"
		3	S = 05°23'55,96" E = 121°55'35,51"			3	S = 05°24'02,44" E = 121°55'36,92"

2	Cemara Angin (*Gymnostoma rumphianum*)	1	S = 05°23' 57,13" E = 121°55'1 33,16"	8	Damar (*Agathis dammara*)	1	S = 05°24'6, 71" E = 121°55' 37,30"
		2	S = 05°23'57, 33" E = 121°55'3 3,26"			2	S = 05°24'0 6,64" E = 121°55' 37,13"
		3	S = 05°23'56, 33" E = 121°55'3 4,19"			3	S = 05°24'0 6,03" E = 121°55' 36,89"
3	Mangga–Mangga (*Mangifera* sp)	1	S = 05°23'55, 92" E = 121°55'3 3,13"	9	Bintangor Merah (*Calophyllum inophyllum*)	1	S = 05°24'5, 84" E = 121°55' 36,68"
		2	S = 05°23'56, 09" E = 121°55'3 3,22"			2	S = 05°24'0 5,40" E = 121°55' 36,03"
		3	S = 05°23'56, 29" E = 121°55'3 3,39"			3	S = 05°24'0 5,18" E = 121°55' 35,99"
4	Kusambi (*Schleichera oleosa*)	1	S = 05°23'56, 42"	10	Wola (*Vitex cofassus*)	1	S = 05°24'2, 45"

			E = 121°55'34,25"				E = 121°55'36,88"
		2	S = 05°23'56,45" E = 121°55'33,73"			2	S = 05°24'02,19" E = 121°55'36,91"
		3	S = 05°23'56,78" E = 121°55'34,50"			3	S = 05°24'02,58" E = 121°55'37,16"
5	Kamoni-Moni (*Syzygium acuminatissimum*)	1	S = 05 23'56,06" E = 121°55'33,59"	11	Tumbeua (*Kjellbergiodendron celebicum*)	1	S = 05°24'05,01" E = 121°55'37,08"
		2	S = 05°23'55,75" E = 121°55'34,02"			2	S = 05°24'4,84" E = 121°55'37,01"
		3	S = 05°23'55,95" E = 121°55'33,66"			3	S = 05°24'04,252" E = 121°55'37,31"
6	Angsana (*Pterocarpus indicus*)	1	S = 05°23'56,50" E = 121°55'32,75"	12	Kayu Kolasa (*Parinari corimbosa*)	1	S = 05°24'04,45" E = 121°55'37,96"

2	S = 05°23'S56,17" E = 121°55'32,56"	2	S = 05°24'04,52" E = 121°55'36,75"
3	S = 05°23'56,05" E = 121°55'32,41"	3	S = 05°24'04,43" E = 121°55'36,81"

The plant arrangements in PT's mining area are adjusted to the growing habits of local species. The number of plants planted in the field is not distributed proportionally. Hence, the amount of each crop type in 2 ha varies. Furthermore, the tested plants are then planted in the second rainy season by excavating a planting hole in the center of the fertilizer distribution and are estimated to be as high as the blanket soil in the nursery (not crushed or decomposed. Hence, the roots of the plant are visible).

f. Maintenance of Reclaimed Plants

Due to the distance between the study site and the community, livestock disturbances are deemed to have minimal impact. Test plants should be protected from forest animals like monkeys and pigs. Furthermore, there is no weeding, alternation, or disturbance of plant-bearing organisms, as this study focused solely on the resistance of plants to adapt to the environment.

g. Soil and Plant Observations

In addition to plant observations, soil observations, and sampling were conducted in June 2019, January 2020, June 2020, January 2021, June 2021, November 2021, and July 2022. Three test samples of observational soil were collected per plant and then composted to yield 12 observational soil samples. Furthermore, they were obtained using an earthen drill. The pH, C-organic, and soil moisture were observed with a pH meter in the laboratory and a soil potentiometer.

Observations were conducted on proportionally selected plants that were planted in reclaimed areas. Plants are measured in height, stem diameter, and canopy width. The height is calculated in cm from the soil surface to the tip of the stem. Diameter rods are measured with calipers and then with cm-measured tape. Meanwhile, the width of the canopy is determined from the left, and the suitable outermost leaves are symmetrical in cm.

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Data Analysis and Laboratory Phase

Before and after the study, the field test data was analyzed compositely using the soil's physical and chemical parameters. The physical analysis includes soil texture and soil moisture. Chemical analysis of the soil consists of pH, C-organic, N-total, P_2O_5, K_2O, Ca, Mg, and KTK. Furthermore, the data of the selected plant was obtained by simple and statistical analysis. A correlation analysis was conducted to determine the relationship between the growth of reclaimed plants and soil conditions.

Result

Condition of ex-mining land

The study site has a laterite soil type. Furthermore, the development of the laterite profile is influenced by humid and hot climatic conditions with high rainfall (Ito et al., 2021; Paul et al., 2022). The surface of this sedimentary soil is reasonably complicated, resistant to erosion, red, brown, and dark reddish brown due to the presence of iron, aluminum, and magnesium, and rusty red due to high iron oxide content. (Ito et al., 2021; Mustafa et al., 2022; Onyelowe et al., 2021; Rusdiansyah et al., 2021; Zainuddin et al., 2021). This relatively old soil is characterized by (i) illuviation of clay with argillic and Candice epi pedons and (ii) leaching of bases from the surface to a profile depth of <35% of the alkaline fertilization capacity (Candra et al., 2021; Lowe, 2019). The post-nickel mining soil at the study site has a relatively good topsoil thickness from the land fireplace, allowing the soil surface to be reached. However, the planting pit has significant challenges. Figure 1 indicates the fireplace condition in the local field.

Figure 2. Land fireplace condition of the study site

Figure 2 shows that the soil depth condition is limited. The land fireplace has lower soil compaction and has caused damage to the structure, texture, porosity, and bulk density. The soil surface is cleaned up and covered with a layer of topsoil, but the planting hole contains only a small amount of topsoil. However, the planting pit contains a small amount of topsoil. This decreases the fertility of the soil for plant growth. Table 1 presents the initial condition of the soil at the study site.

Table 1. Results of Analysis of Physical and Chemical Properties of Soil Study Sites

No.	Variable	Unit	Value	Dignity
1	Texture			
	Sand	%	13	
	Dust	%	38	Clay
	Clay	%	49	
2	Soil pH (H_2O)		5.3	Sour
3	C-organic	%	1.08	Low
4	N-total	%	0.22	Medium
5	P_2O_5 (HCl 25%)	$mg.100g^{-1}$	7.02	Low
6	K_2O (HCl 25%)	$mg.100g^{-1}$	11.85	Very low
7	Ca^{2+}	$cmol(+).kg^{-1}$	1.03	Very low
8	Mg^{2+}	$cmol(+).kg^{-1}$	0.37	Very low
9	CEC	$cmol(+).kg^{-1}$	9.88	Low

According to Table 1, the soil conditions after mining indicates a clay texture with a predominance of clay and dust, acidic soil pH, low C-organic, medium N-total, medium P_2O_5, shallow, interchangeable bases (K_2O, Ca^{2+}, and Mg^{2+}), and low CEC.

Conditions of the tested plants

The plants inspected are those that existed before mining activities. The plant grew and spread throughout the mining region. As shown in Figure 2 shows the condition of the plant.

Johar (*Senna siamea*)

Cemara Angin (*Gymnostoma rumphianum*)

Mangga-Mangga (*Mangifera* sp)

Kusambi (*Schleichera oleosa*)

Tumbeua (*Kjellbergiodendron celebicum*)

Kamoni-Moni (*Syzygium acuminatisicum*)

Angsana (*Pterocarpus indicus*)

Waru (*Hibiscus tiliaceus*)

Damar (*Agathis dammara*)	Bintangor Merah (*Calophyllum inophyllum*)	Wola (*Vitex pinnata*)	Kayu Kolasa (*Parinari corimbosa*)

Figure 3. Conditions of the tested reclaimed plants

Figure 3 shows that the types of reclaimed plants piloted vary from the stem's height, diameter, and width of the plant canopy.

Plant growth

The piloted reclaimed plants used indicators of the plant canopy's height, diameter, and width, as presented in Figures 4, 5, and 6, respectively.

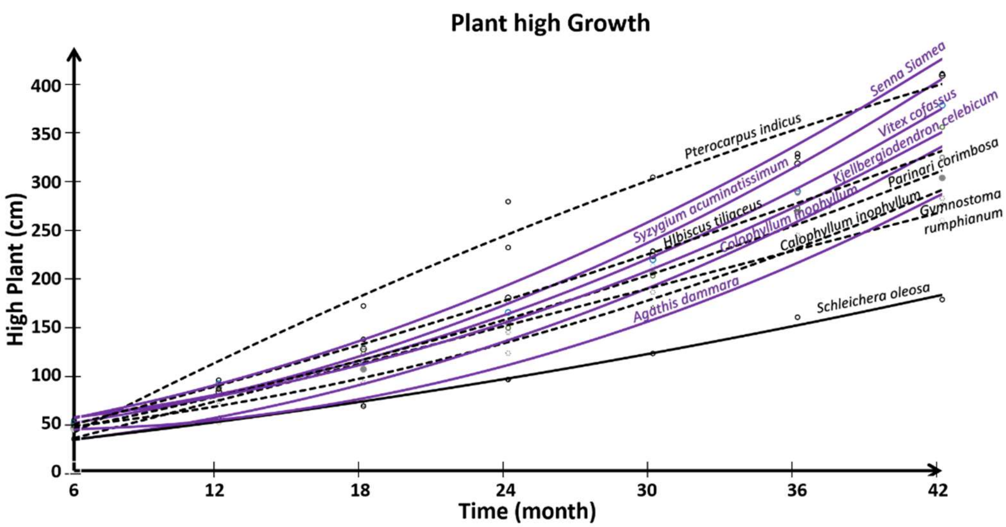

Figure 4. Height of Reclaimed Plants against Observation Time

Figure 4 shows that the reclaimed plants tested had the same high-rise tendency as a function of observation time. However, Senna siamea, Pterocarpus indicus, Syzygium acuminatissimum, and Vitex cofassus rapidly increase in plant height compared to other plants. Figure 4 shows that the increase in the height of Pterocarpus indicus has slowed down in the 42nd month.

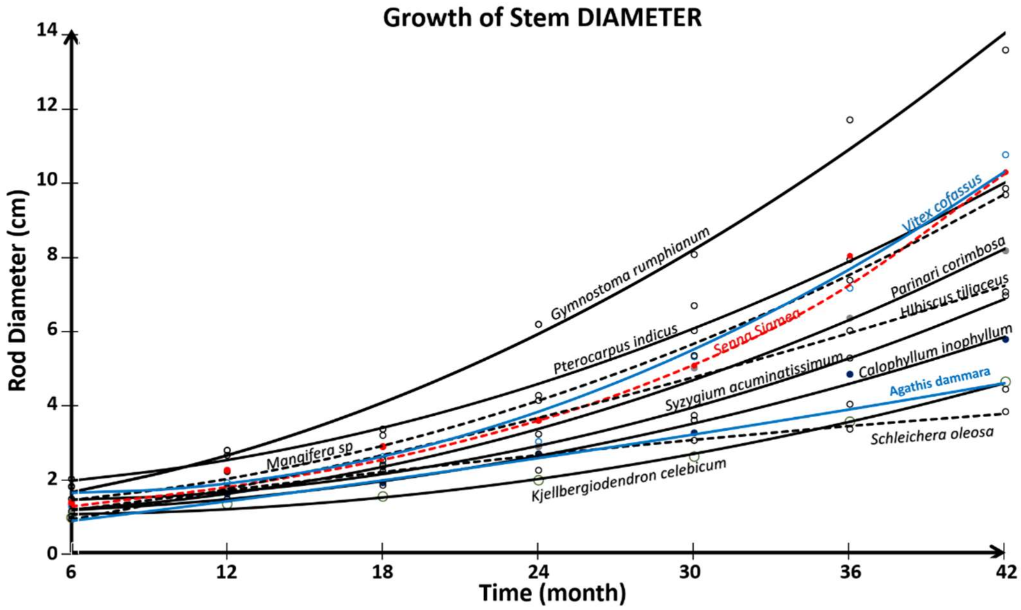

Figure 5. Reclamation Plant Diamater to Observation Time

Figure 5 shows that Gymnostoma rumphianum, Pterocarpus indicus, and Wola Vitex cofassus rapidly increase in stem diameter compared to other reclaimed plants. Meanwhile, Schleichera oleosa experiences a slowdown in the increase in stem diameter.

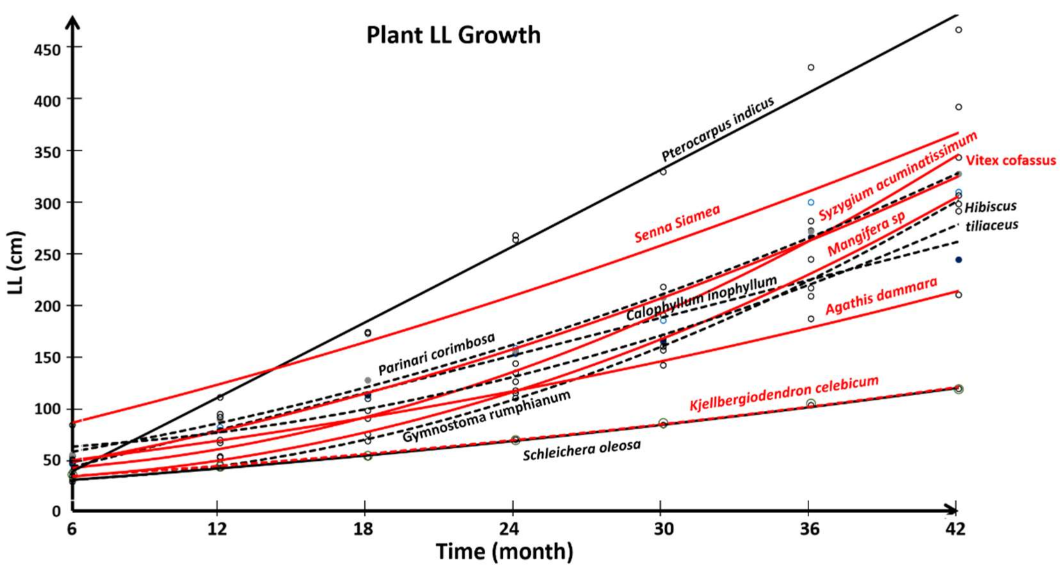

Figure 6. Canopy width of the Reclamation plant against the Time of Observation

The width of the canopy of reclaimed plants is the character of the crops owned. The highest heading width is obtained from Pterocarpus indicus, Senna siamea, and Syzygium acuminatissimum. Meanwhile, Kjellbergiodendron celebicum has a slow but comprehensive development of the crown. The analysis results of plant growth are included in the resultant equation and presented in Figure 6. It showed a linear increase over time and had a very high correlation. Furthermore, Figure 7 indicates the growth of reclaimed plants against time.

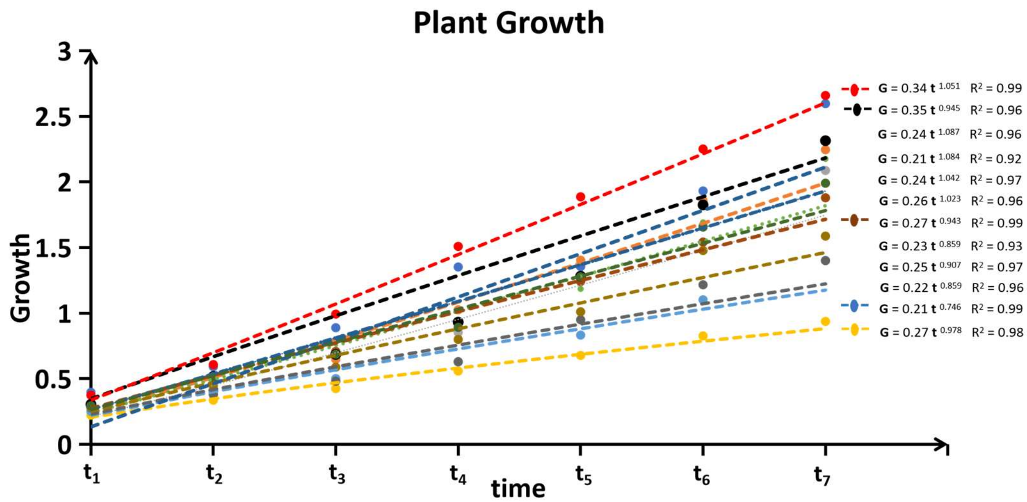

Figure 7. Reclaimed Plant Growth

Figure 7. shows that all reclaimed plants tested can grow well at the study site. Pterocarpus indicus has good growth results, followed by Agathis dammara and Vitex cofassus. However, when viewed from the speed of each plant, it shows a different pattern, as presented in Figure 8.

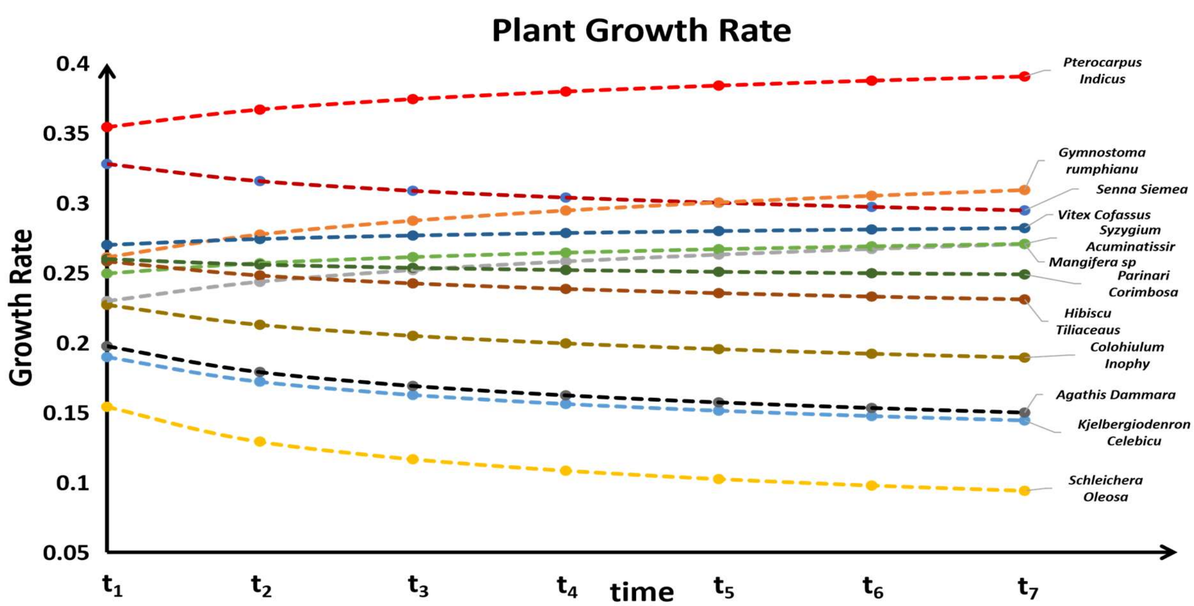

Figure 8. Growth Speed of Reclaimed Plants

Growth is a function of increasing plant height, stem diameter, and canopy width with observation time. Figure 8 shows that each plant has a different growth speed pattern towards the same organic matter treatment. Pterocarpus indicus, Gymnostoma rumphianum, Syzygium acuminatissimum, and Mangifera sp demonstrate an increased growth speed, while others decrease. This indicates that the tested reclaimed plants have a different growth reaction to previous environmental conditions.

According to Figure 9, growth acceleration is a change in speed to time. The two behaviors of growth acceleration are increasing and decreasing. However, the whole plant is geared towards constant growth. Figure 9 shows the change and overhaul of the soil's organic matter into nutrients plants absorbed in the 1st to 12th months.

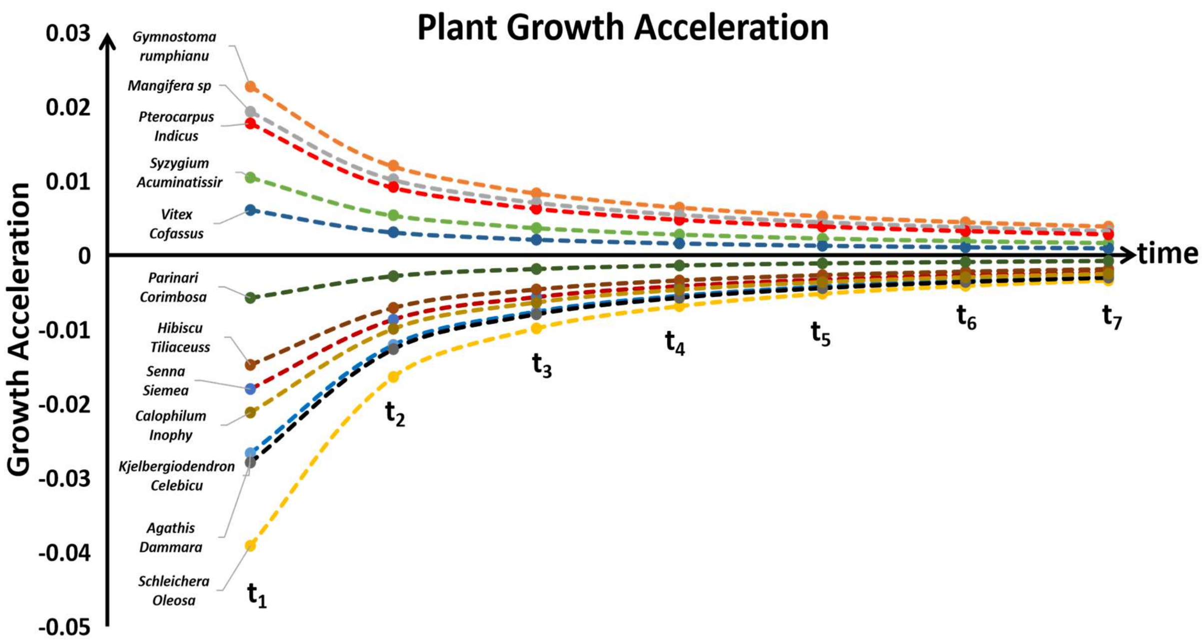

Figure 9. Accelerated Growth of Reclamation Plants

Schleichera oleosa, Agathis dammara, and Kjellbergiodendron celebicum showed increased acceleration compared to other reclaimed plants. Meanwhile, Gymnostoma rumphianum, Mangifera sp, and Pterocarpus indicus show a decreased acceleration than others.

Relationship between plant growth and soil properties

The relationship between plant growth and soil properties was analyzed using correlation analysis, and the results are presented in Table 2.

Table 2. Relationship between plant growth and soil properties

Plant Growth Vs. Soil Properties	Plant											
	1	2	3	4	5	6	7	8	9	10	11	12
	Coefisien of Cerrelation (R)											
Plant Growth Vs. pH	0,75	0,92	0,72	0,87	0,69	0,59	0,91	0,60	0,62	0,61	0,80	0,49
Plant Growth vs. C-Organic (%)	0,74	0,83	0,51	0,91	0,56	0,57	0,85	0,84	0,80	0,84	0,80	0,78

Plant Growth vs. Moisture (%)	0,00	0,12	0,65	-0,02	0,18	0,15	-0,34	-0,32	0,32	0,58	0,01	0,59
$y_1 = a_o + a_1 X_1 + a_2 X_2$	0,78	0,93	0,76	0,92	0,69	0,68	0,92	0,88	0,81	0,85	0,84	0,79
$y_2 = a_o + a_1 X_1 + a_2 X_2 + a_3 X_3$	0,95	0,93	0,80	1,00	0,76	0,88	0,97	0,95	0,92	0,94	0,96	0,78

Information: Y1, Y2 = Plant Growth; $\mathbf{X_1}$ = pH; $\mathbf{X_2}$ = C- organic ; $\mathbf{X_3}$ = Humidity; a_o, a_1, a_2 are respectively constants that express the contribution of soil properties to the Plant Growth; 1=Johar (*Senna siamea*), 2=Cemara Angin (*Gymnostoma rumphianum*), 3=Mangga–Mangga (*Mangifera sp*), 4=Kusambi (*Schleichera oleosa*), 5=Tumbeua (*Kjellbergiodendron celebicum*), 6=Kamoni-Moni (*Syzygium acuminatissimum*), 7=Angsana (*Pterocarpus indicus*), 8=Waru (*Hibiscus tiliaceus*), 9=Damar (*Agathis dammara*), 10=Bintangor Merah (*Calophyllum inophyllum*), 11=Wola (*Vitex cofassus*), 12=Kayu Kolasa (*Parinari corimbosa*)

Table 2 shows a real relationship between plant growth with pH and C-Organic, but an unreal relationship with soil moisture. However, when the three soil properties are linked, it demonstrates an honest and genuine relationship. The relationship of plant growth with soil pH is highest in Gymnostoma rumphianum, Schleichera oleosa, and Vitex cofassus. The relationship of plant growth with C-organic is highest in schleichera oleosa plants, Pterocarpus indicus, and Calophyllum inophyllum. Meanwhile, the relationship between plant growth and soil moisture is highest in Mangifera sp, Calophyllum inophyllum, and Parinari corimbosa plants. A noticeable relationship is obtained in gymnostoma rumphianum and Pterocarpus indicus plants when the growth is linked with pH and C-Organic, however, when connected with all observation variables, a very close relationship is obtained in schleichera oleosa, Pterocarpus indicus, and Vitex cofassus.

Discussion

Preliminary soil conditions show that the post-mining soil has a clay texture with a predominance of clay and dust. This is because the topsoil layer has been mixed with the soil of the mining base, which has a sandy clay texture. According to (Anda et al., 2022), there is a change in texture from sandy clay to sand in the post-mining profile. Acidification is one of the important chemical properties of soil in the growth process of reclaimed plants that reflects the availability of macro and microelements. It promotes the biogeochemical cycle in the soil (Zheng et al., 2022).

Table 1 shows that the soil pH of the study site is acidic. This causes the condition of other soil chemical elements to be poor regarding organic carbon and the exchange capacity of cations and bases to be extremely low. Other deficient nutrients include potassium, calcium, and magnesium, while the total Nitrogen content is low.

The growth of the tested reclaimed plants tends to increase the planting height based on the observation time. According to (Iskandar et al. 2022), plant growth at 0-2 and 2-4 years after recovery is dominated by the young growth rate and demonstrates identical growth. It can be stated that growth is affected by pH, C-organic, and soil moisture. The pH value of the soil shows an increase, but this occurs per field for every observation. This is in line with (2019), which revealed that the plants would increase significantly with an elevating soil pH in each reclaimed acreage. Applying organic matter in mine reclamation soils can increase the growth of plants (Ye et al., 2001). Organic matter in fertilizer enhances plant growth in soils contaminated with heavy metals (Wang et al., 2022). Furthermore, plant growth increases carbon accumulation at the reclamation site (Xie et al., 2021). Soil moisture and pH significantly determine the solubility of organic matter for plant growth (I. Ameh & J. Onuh, 2020).

The speed and acceleration of reclamation plant growth are determined by overhauling organic matter, plant characteristics, and soil conditions. According to Turisová et al. (2020), the overhaul of organic matter in the soil increased the growth of the tested reclaimed plants in greenhouses. The character of the reclaimed plant can provide different environmental adaptations (Saijo & Loo, 2020; Xie et al., 2021). According to (Agbeshie & Abugre, 2021), adequate soil conditions can increase nutrient availability, absorption, and growth.

Conclusion

This study concluded that (1) the provision of organic matter can increase the natural growth of reclaimed plants, (2) there is a relationship between plant growth with pH, C-organic, and soil moisture, (3) the growth speed and acceleration of Schleichera oleosa, Pterocarpus indicus, and Vitex cofassus indicates that they are good reclaimed plants.

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