Reforestation on ex mining reclamation area

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Abstract

Ex-mining land is categorized as land with a high level of degradation. The loss of biodiversity, low soil fertility, loss several layer of soil horizon, very unbalance texture, and even contamination can occur due to mining activities. Reforestation of mining land has been carried out with the approaches of improving the physical properties of the soil, selecting plant types, and improving soil biology in ex-gold mining land in Bogor. The addition of compost significantly increased organic matter content, C/N ratio, macro nutrients (N,P,K) content and improving soil texture. The application of Mycorrhiza and rhizobium significantly increase the growth of forest plant such as trembesi (*Samanea saman*), gmelina (*Anthocepalus cadamba*) and ganitri (*Elaeocarpus angustifolus*), in ex-gold mining areas. The application of those significantly improved vegetation diversity on ex-gold mining land including more than 8 types of understory plants and more than 5 plants were from the trees group. This show that reforestation of ex-mining land is feasible if it is carried out with a comprehensive approach.

Keyword: Reforestation, Arbuscular Mycorrhiza Fungi, Biodiversity, Compost, Tailing

Introduction, scope and main objectives

Mining activities, apart from contributing to the economy, also have a serious impact on land quality. Stripping of land to the lower horizon, disturbs physical, chemical and biological properties of the soil which causes loss of vegetation and the decrease of biodiversity. Tailings are one of the mining wastes from the amalgamation process of soil and ore. A very large amount of tailings has the potential to form land with critical characters such as lower organic content, lower water holding due to sandy texture domination and little macronutrient content, while it contains high micronutrient content as well as potentially toxic heavy metals (Setyaningsih et al, 2018). Such conditions are not only become a big obstacle for land revegetation activities but also cause a danger for the life around them. Revegetation or reforestation on land with those extreme characters certainly requires a comprehensive approach by carrying out appropriate land management, selecting plant species, introducing microorganisms, as well as providing organic materials (Setiadi et al 2002, Setyaningsih et al, 2020).

There are some considerations in choosing plant species for revegetation on reclamation land which include: being able to adapt and become pioneer species, growing fast, and intolerant of shading; catalytic in nature, which stimulates the development of other organisms; following the procedure of land use and quickly cover land with easily decomposed litter (Setiadi 2002, Setiadi et al 2011). Waru (*Hibiscus decaspermus* Koord. & Valeton), rasamala (*Altingia excelsa*), trembesi (*Samanea saman*), gmelina (*Anthocepalus cadamba*) and ganitri (*Elaeocarpus angustifolus*) are local tree species known to grow well around the Pongkor gold mining area (PT ANTAM Tbk UBPE, 2018).

Compost resulted from decomposition of organic matter (plants and manure) is known to increase the organic content of the land, so it is very potential to be applied to ex-mining land (Wasis & Fathia, 2011). Arbuscula mycorrhizal fungi (AMF) and rhizobium bacteria (Rhi) are known as symbiotic microorganisms with plants which are able to increase the absorption macro-nutrients such as P and N, and have other beneficial effect including water absorption (Wu et al 2015, Chen at al. 2018), so that their utilization in revegetation is expected provide good contribution.

In this paper, several issues regarding critical aspects in ex-mining reforestation are presented, including the improvement of the physical and chemical properties of tailings, the application of heavy metals stabilization by plants, utilization of mycorrhizae and rhizobium to support growth of forest plants, and biodiversity management as a result of reforestation activities in the reclamation area.

Methodology/approach

Location

The revegetation area observed was in the concession area of PT ANTAM Tbk. Pongkor Gold Mining Business Unit, located in Bantar Karet Village, Nanggung District, Bogor Regency, West Java Province. Geographically, it is located at coordinates 106o 30' 1.0" - 106o 35' 38.0" East Longitude and 02^{o} 6o 36' 37.2" - 6^{o} 43' 11.0" South Latitude with an altitude of 400 - 1800 M, precisely on revegetation plots aged 1-years.

Preparation of revegetation land, microbial inoculants

Each plot of revegetated area was arranged by leveling the surface of the land, mixing it with top soil, making drainage channels according to the flow of water, and making planting holes of 50x50x50 cm, with a spacing of 3 x 4 m. AMF was developed by bioassay (Brundrett et al 1996) using sorghum as host plant and zeolite as carriers. Rhi was prepared using rice-husk charcoal as carrier.

Preparation of planting and microbial inoculation.

Seedlings of various local plants with the height average of 50-75 cm were planted in the provided holes. In each planting hole, a 6 kg of compost was added. Arbuscular Mycorrhiza Fungi (AMF) and Rhizobium (Rhi) inoculants were applied at the nursery and at the planting time in the field.

Observation of plant growth, stability of contamination, and plant diversity. Observation of plant growth (survival rate, plant height, canopy cover) and measurement of diversity (type, number, frequency) were carried out periodically. Heavy metal stabilization was observed by analyzing Pb content in plant tissue. Vegetation analysis was carried out by calculating the Important Value Index (INP) (Muller-Dombois & Ellenberg, 1974).

Results

Characteristics of post-mining land

There were 2 main characters of land ex-gold mining activities in Aneka Tambang Inc. Pongkor that have been revegetated, i.e.: (1) land with stripped mineral soil, and (2) land with tailings. The physical and chemical properties of mineral soil and tailings on the ex- gold mine reclamation land are shown in Table 1. The type of stripped mineral soil was red-yellow podzolic with a balanced texture (the proportion of sand-dust-clay content in the range of 30%), with pH value of 3.5-5.8 or tended to acid, the organic matter content of 2.82%, and the available macronutrient content (N, P, K) varied from low to moderate. On the other hand, in the tailings land, the texture was dominated by sand (65%) with very low clay content, very low organic C content (0.24%), very low macro nutrients availability (P=7.78 ppm, N=0.04%), while heavy metal content (Pb) tended to be high (reaching 17.3 ppm).

source

The application of compost increased the C-organic content of the tailings up to 1.1%, decreased the pH, increased the clay content (13%) and increased the macronutrient content (N, P), while it decreased the solubility of Pb (6.2 ppm).

Table 1: Physic and Chemist Properties of reclamation land of PT ANTAM Tbk. Pongkor Gold-mining Unit Business, West Java, Indonesia

Properties	Soil		Tailing		Mix Tailing - Compost	
pH H_2O	5.06	TA	8	TAk	7.3	N
C %	2.82	L	0.24	VL	1.1	R
N %	0.22	L	0.02	VL	0.1	R
C/N	12.69	A	12	A	12	A
KTK cmol/kg	39.47	A	3.85	VL	19.6	A
P_2O_5 Tersedia ppm	9.90	L	6	R	255	VH
K_2O Tersedia ppm	106.72	VH	73	VH	107	VH
Ca cmol/kg	0.04	VL	22.23	VH	16.92	VH
Mg cmol/kg	0.03	VL	0.73	L	1.75	A
Pb Total ppm			114	CT*	90	
Pb available ppm			17.3	H**	6.2	H**
Sand (%)			65		46	
Dust (%)			30		41	
Clay (%)			5		13	

Note :
TAk = tend to alkaline; TA = tend to acid; VL = very low; VH = very high; L = Low; A = Average, N = neutrale (Balai Penelitian tanah 2009); * = according Alloway (1995), ** = According PP 85 tahun 1999, CT = critical threshold, H = High

Plant growth and the biodiversity

Observation of the effect of AMF+Rhi application on plant growth was only carried out on 12 and 24 months old *S. saman* in the tailings area. Application of AMF and Rhizobium has increased the survival, growth height, diameter, biomass and root length of *S. saman*, reaching 87%, 190.3 cm, 35.5 mm, 167.8 g, 77.9 cm, respectively (Table 2).

On tailings land, other local plant species have also been planted, such as gmelina (*Anthocepalus cadamba*), and ganitri (*Elaeocarpus angustifolus*), mahogany (*Swietenia macrophylla*). Since 6 months of planting, there have appeared various groups of shrubs and grasses. In the second year of observation, at least 13 species of shurb and 5 types of grass were identified, including *Acmella paniculata, Ageratum conyzoides, Mimosa pigra, Mimosa pudica, Imperata cylindrical*, *Polygala paniculata.*

Table 2. The growth of *S. saman* age 12 and 24 month after planting with AMF+Rhi application on tailing area of ex gold mining Pongkor

Growth variable	Control		AMF+Rhi	
	12M	24M	12M	24M
Survival (% life)	91.3	81	97.6	87
High (cm)	22.90	145.7	34.5	190.3
Diameter (mm)	6.03	31.4	8.13	35.5
Biomass (g)	52.3	135.3	55.8	167.8
Root length (cm)	31.2	46.2	41.9	77.9

Biodiversity observation on reclamation land of gold mining, Pongkor of 201.74 Ha have been identified 41 families, 108 species and 2,820 individuals of woody plants as well as 52 families, 102 species and 28,224 individuals of cover crop, lianas, herbs and epiphytes. Some of them are included in the IUCN Red List Vulnerable category, such as: *Dalbergia latifolia, Khaya anhtotecha, Swietenia macrophilla.* In the revegetation area aged 1-3 years, the plants that reached the sapling level were found, while the level trees were only found in revegetation above 10 years. *Elaeocarpus angustifolius* and *Acacia auriculiformis* have been found as the most important species in trees and pole level with IVI 300 (Table 3). The vegetation canopy stratification is dominated by stratum C (12-20m) and D (1-4m), with canopy density reaching 77.06%. The horizontal and vertical canopy stratification performance is shown in Figure 1.

To understand the possibility of plant role to stabilize the heavy metal of tailing, several woody plant were observed the Pb content in plant tissue. Pb content in plant roots (0.5-4.3 mg/kg)>leaves (0.1-0.7 mg/kg)>stems (0.03-0.1 mg/kg). The highest Pb content was found in grass (4.317 mg/kg) and trembesi (2.452 mg/kg), with transport factor (TF) < 1.

Table 3. Important Value Index of stage growth of woody plant on reclamation area of PT ANTAM Tbk. Pongkor Gold-mining Unit Business, West Java, Indonesia

Revegetation age (year)	Trees*		Pole		Sapling		Seedling	
	Species	IVI (%)	Species	IVI (%)	Species	IVI (%)	Species	IVI (%)
10 up	Afrika**	95,24	Afrika	106,34	Afrika	44,05	Afrika	40,00
	Ganitri	300,00	Jati Putih	116,22	Ganitri	64,39	Matoa	100,00
	Waru Lot	76,41	Kaliandra	174,40	Kaliandra	103,73	Beunying	80,00
	Jati Putih	112,53	Kaliandra	91,24	Kaliandra	155,06	Kaliandra	134,71
	Rasamala	35,84	Rasamala	68,35	Kaliandra	42,32	Afrika	71,94
	Sonobrit	176,19	Sonobrit	300,00	Ganitri	138,10	Ganitri	100,00
	Pinus	68,80	Akasia	91,73	Puspa	36,67	Ki Harendong	66,67
	Akasia	300,00	Jati Putih	124,36	Rasamala	58,46	Ganitri	80,00
	Akasia	151,24	Puspa	122,29	Calik Angin	200,00	Ki Pare	200,00
5-7	none	0	Afrika	134,19	Afrika	53,33	Puspa	84,44
	none	0	Sengon	119,39	Ganitri	121,05	Durian	66,67
	none	0	Manglid	59,51	Nangka	53,57	Leungsir	88,89
	none	0	none	0	Rasamala	171,00	Ki Harendong	83,33
1-3	none	0	none	0	Parempeng	52,27	Ganitri	76,19
	none	0	none	0	Puspa	52,09	Trembesi	61,80
	none	0	none	0	Ki Damar	95,00	Ganitri	66,67
	none	0	none	0	Trembesi	96,67	Ganitri	61,80
	none	0	none	0	Mara	67,61	Ganitri	75,00

Note:
*Seedlings: woody plant with high/ tall < 150 cm; Saplings: woody plant with high > 150 cm, trunk diameter < 10 cm; Poles: woody plant with diameter 10 cm - 20 cm; Trees: woody plant with diameter > 20 cm.
**Afrika (*Maesopsis eminii*), Ganitri (*Elaeocarpus angustifolius*), Waru Lot (*Hisbiscus decasperum*), Jati Putih (*Gmelina arborea*), Rasamala (*Altingia excelsa*), Sonobrit (*Dalbergia latifolia*), Pinus (*Pinus merkusii*), Akasia (*Acacia auriculiformis*), Puspa (*Scima walicii*), Matoa (*Pometia pinnata*), Beuying (*Ficus hispida*), Kaliandra (*Caliandra calothersus*), Ki Damar (*Agathis damara*), Ki Harendong (*Melastoma malabathricum*), Calik Angin (*Malotus paniculatus*), Nangka (*Arthocarpus heterphyllus*), Mara (*Macaranga tanarius*), Manglid (*Manglietia glauca*), Mahoni (*Swietenia machrophylla*), Parempeng (*Croton argyratus*)

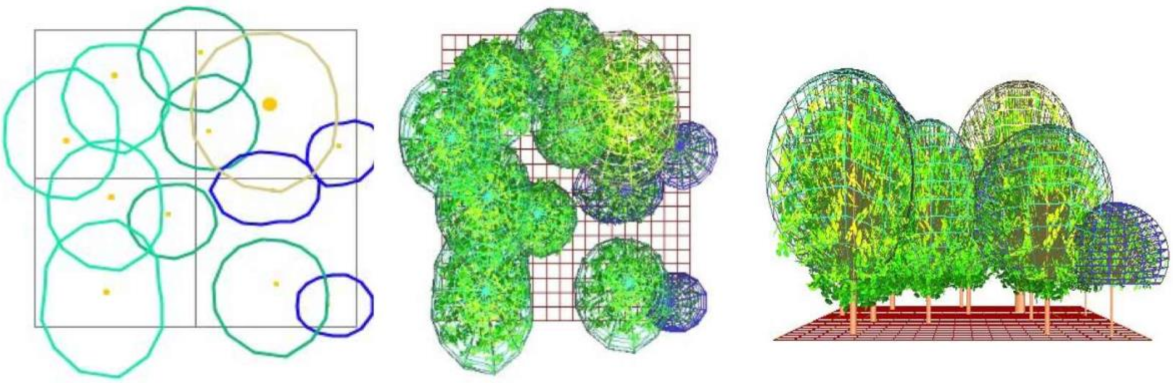

Fig. 1: Horizontal canopy structure (left and middle) and vertical canopy structure (right) of Trees stand age 7 years revegetation in area of ex gold mining area

source

Discussion

Improvement of land properties and plant growth

The results showed that the application of compost had improved the physical and chemical properties of the reclamation land, such as an increase in the balance of organic C content, an increase in the solubility of macronutrients (P, N), and a decrease in the solubility of Pb in the growing media. Improvement of the physical and chemical properties of the soil/tailings also encourages the improvement of plant growth. The same condition was also reported by Juniarto et al (2018) that compost from oil palm bunches applied to the former coal mine area of PT Bukit Asam (PT BA) in Tanjung Enim, South Sumatra, Indonesia, increased survival and growth of samama (*Neolamarckia macrophylla* Roxb.).

Since the tailings land is dominated by sand and dust, it is necessary to consider the use of compost block model in the hope that it will help to prevent leaching to the sand during heavy rains, considering that Bogor rainfall reaches 300 – 550 mm in wet months, with 17 rainy days a month (Indonesian Statistics Center Agency, 2021).

Local plant species including *Rasamala*, *trembesi*, *ganitri*, *gmelina*, the majority were able to live on tailings land and mineral soil. This shows that local plants had a high adaptability to the surrounding degraded land and this is in line with the finding of Komara et al (2018), who found 18 woody species, including *Cassia siamea* and *Ficus uncinata* and non-woody species. This results also support the hope that reforestation activities in ex-mining reclamation areas can maintain the biodiversity of local tree species.

The occurrence of waterlog on tailings land has reduced the success of the *trembesi* plant. Waterlog is a common phenomenon on land with sludge tailings texture composition which is dominated by sand and dust. Therefore, it is important to arrange good drainage on the reclaimed tailings land.

The application of AMF and Rhizobium have improved the growth performance of forest plant seedlings. The positive role of these microbes has also been reported in several applications in ex nickel mining areas and associated with *Canavalia ensiformis* (Akib et al. 2019) and in ex coal mining areas with *Pometia pinata* plants (Agus et al. 2018). AMF and Rhi helped the increase of plant growth either directly, by increasing the availability of macro nutrients, increasing the ability of plants to absorb macro elements, P, N, K, or through indirect mechanisms such as bio-control, or increasing water uptake etc. (Chen et al 2018). The benefits of microbial mutualism symbiosis can also be more sustainable, as long as there is colonization between these microbes and plant roots. Therefore, one application of this microbe is sufficient, especially at the seedling level, and of course this will be efficient in nutrient input.

Land cover improvement, remediation and biodiversity

Revegetation of ex-mining reclamation land, not only increased land surface cover with tree crowns and understory plants, but also increased flora and fauna biodiversity. The emergence of understory plants with a variety of flowers encouraged the emergence of insects and birds, which acted as seed distributors and assisted crossbreeding in reproduction. The increasingly closed land surface increased humidity and reduced soil temperature, which resulted in the increase of soil organism's activity (Komara et al. 2018, Salim et al. 2020). Another important role of soil organisms is decomposer which can increase the decomposition process of organic biomass or litter from revegetation plants. Complete decomposition will encourage improvements in the physical and chemical properties of the soil to support plant growth.

The ability of revegetation trees and other undergrowth to absorb heavy metal Pb on tailed land and store it mostly in the roots, shows that revegetation plants can remediate by stabilizing heavy metals or known as rhizostabilizers (Setyaningsih, 2018, Akib 2019). The potential of revegetation plants in carrying out phytoremediation gives great hope that cleaning contamination can be done cheaply, safely and sustainably.

Thus, revegetation activities have caused changes slowly, or succession is running with certainty, indicated by improvement in land quality, which changes from vacant land to well-covered land. If the succession goes well, energy cycles and food cycles occur again, then in a certain time there will be ecosystem stability towards the reconstruction of new forest again. Vertical strata formed with high biodiversity, indicated that reforestation in mining areas was successfully carried out which led to the return of tropical rain forest ecosystems. This triparty revegetation approach has been applied to several post mining areas such as to Coal mining in Kalimantan, nickel mining in Soroako Sulawesi, Indonesia.

Reforestation on ex-mining land is very much in line with the SDGs. Selection of plant species for reforestation based on local plants, restoration of biodiversity in reclamation areas from non-planted areas to areas of moderate diversity, establishment of conservation groups, will be in line with SDG 15- Protect, Restore and Promote Sustainable Use of Land Ecosystems, Manage Forests Sustainably, Ending Desertification, Restoring Land Degradation, and Stopping Biodiversity Loss, particularly at 15.1, 15.3, 15.4, 15.5, 15.9, 15.a.1.

While the following efforts: remediation or cleaning of heavy metal Pb on a regular and sustainable basis by using plants as remediators, utilization of landscape reclamation areas to produce environmental services and nature tourism, forest plants in reclamation areas aged 1-12 have certainly contributed to emission absorption, community participation in both reforestation and utilization of non-timber forest products, in line with SDGs 13- Take rapid action to address climate change and its impacts, especially in (13.2, 13.3, 13.3).

Conclusions/ wider implications of findings

Reforestation in ex-mining reclamation areas needs to pay attention to 3 main approaches, namely the selection of plant species, the addition of compost and the application of symbiotic mutualism microbes. Reforestation techniques are very likely to be replicated in other areas, especially ex-mining areas. Reforestation in ex-mining reclamation areas, in addition to increasing the area's biodiversity, can also play an important role in increasing remediation of heavy metal contamination. Reforestation is very much in line with efforts to fulfill/achieve SDGs, especially indicators in No. 13 and 15.

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