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Jurnal: ***JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT***

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Penulis: **Edy Jamal Tuheteru, Faisal Danu Tuheteru, Pantjanita Novi Hartami, Muhammad Burhannudinnur, Suryo Prakoso, Husna, Albasri, Dian Asraria**

No	Uraian	Tanggal
1.	Bukti registrasi sebagai penulis	8 Februari 2023
2.	Bukti konfirmasi submit artikel dan artikel yang disubmit	10 Februari 2023
3.	Cek Similarity	12 Februari 2023
4.	Konfrimasi perbaikan paper	14 Februari 2023
5.	Bukti konfirmasi review	17 Maret 2023
6.	Bukti respon kepada reviewer	22 Maret 2023
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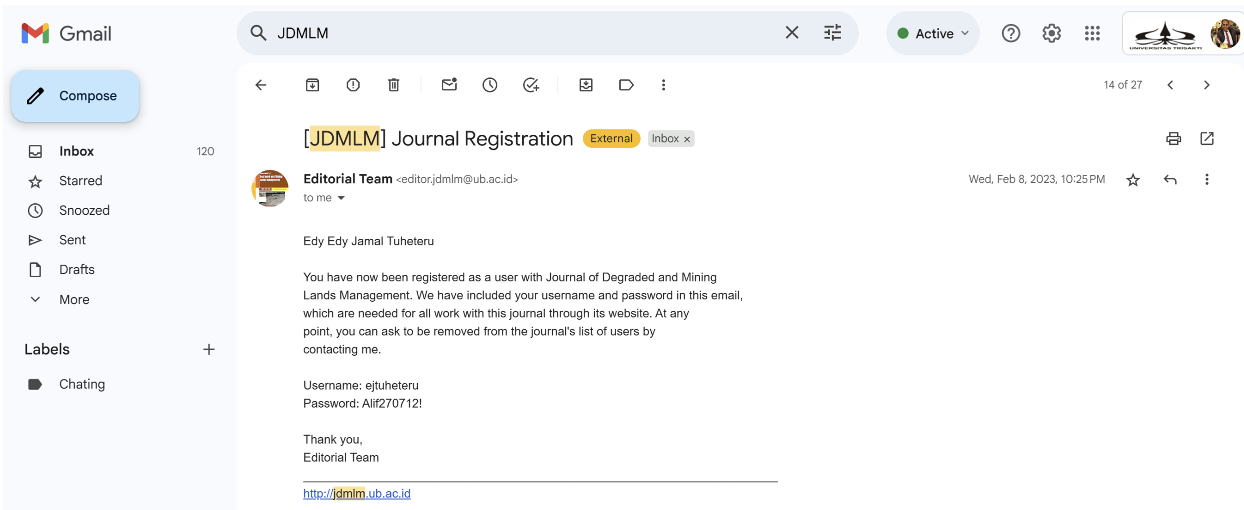

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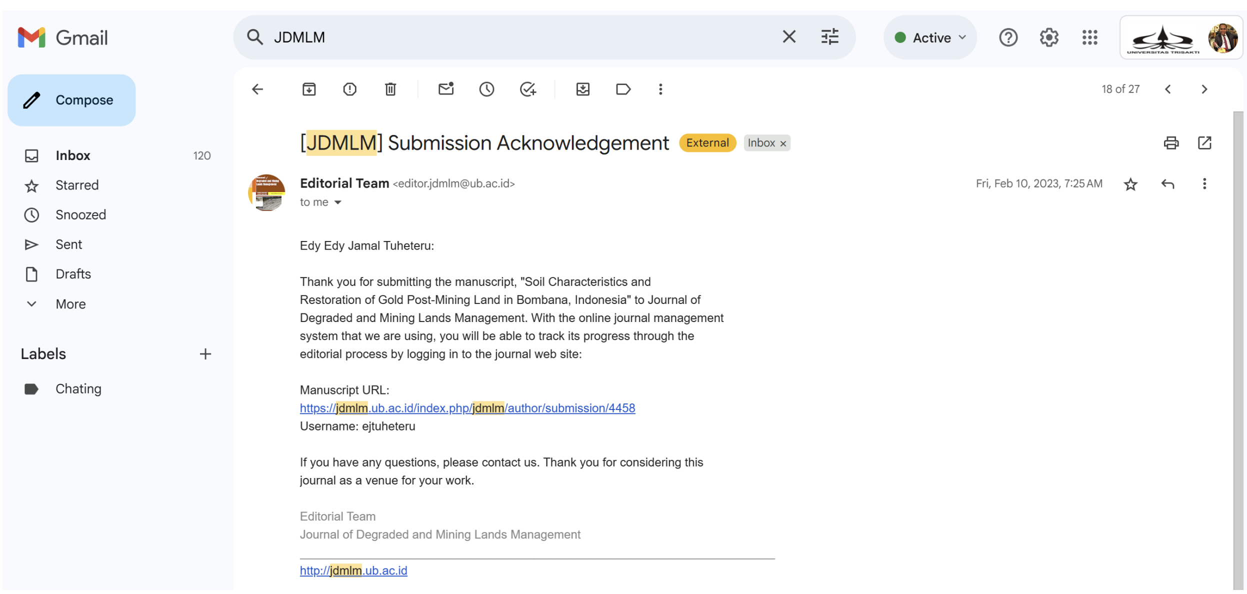

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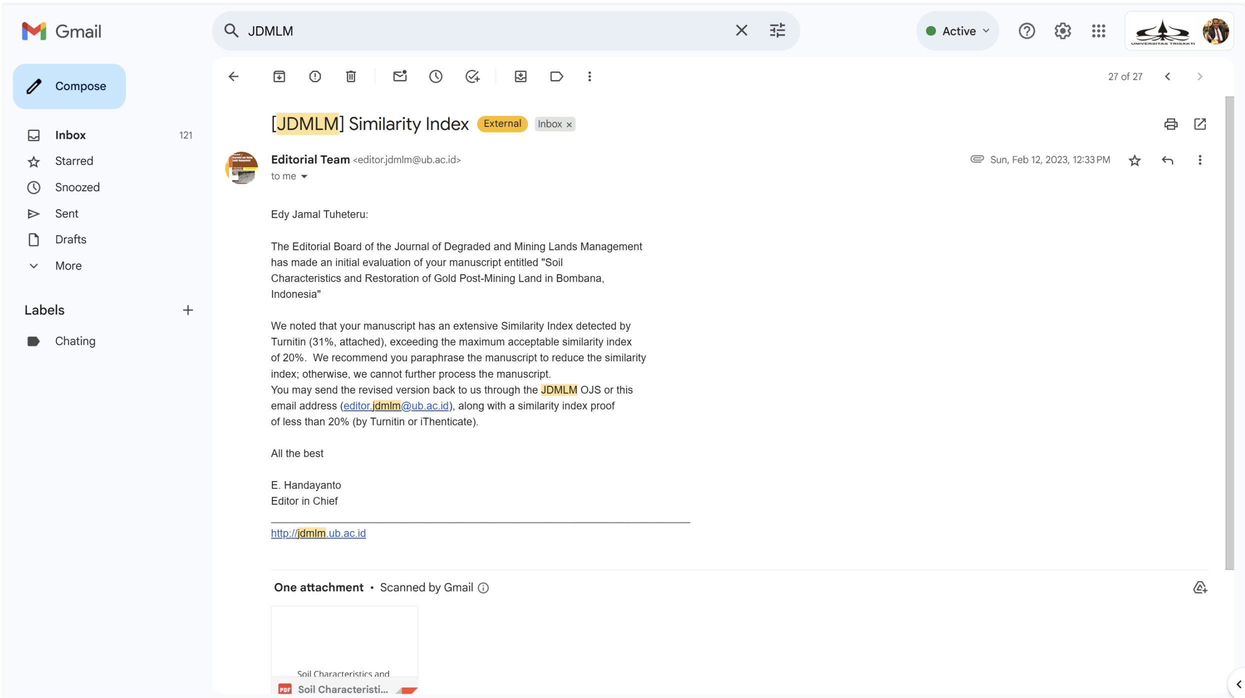

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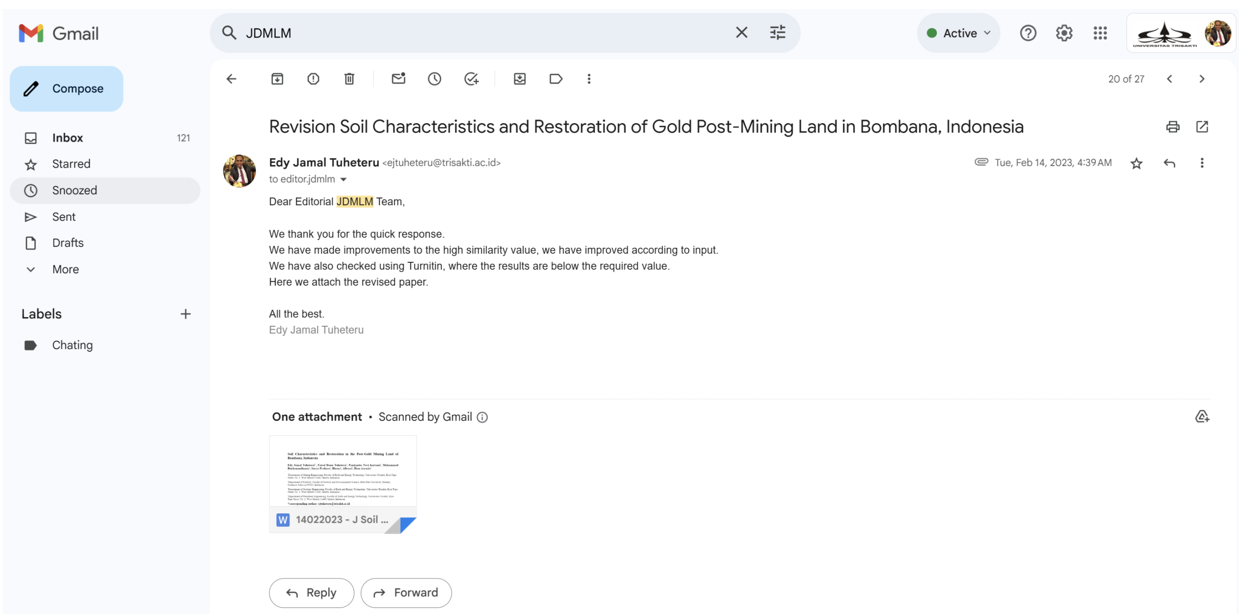

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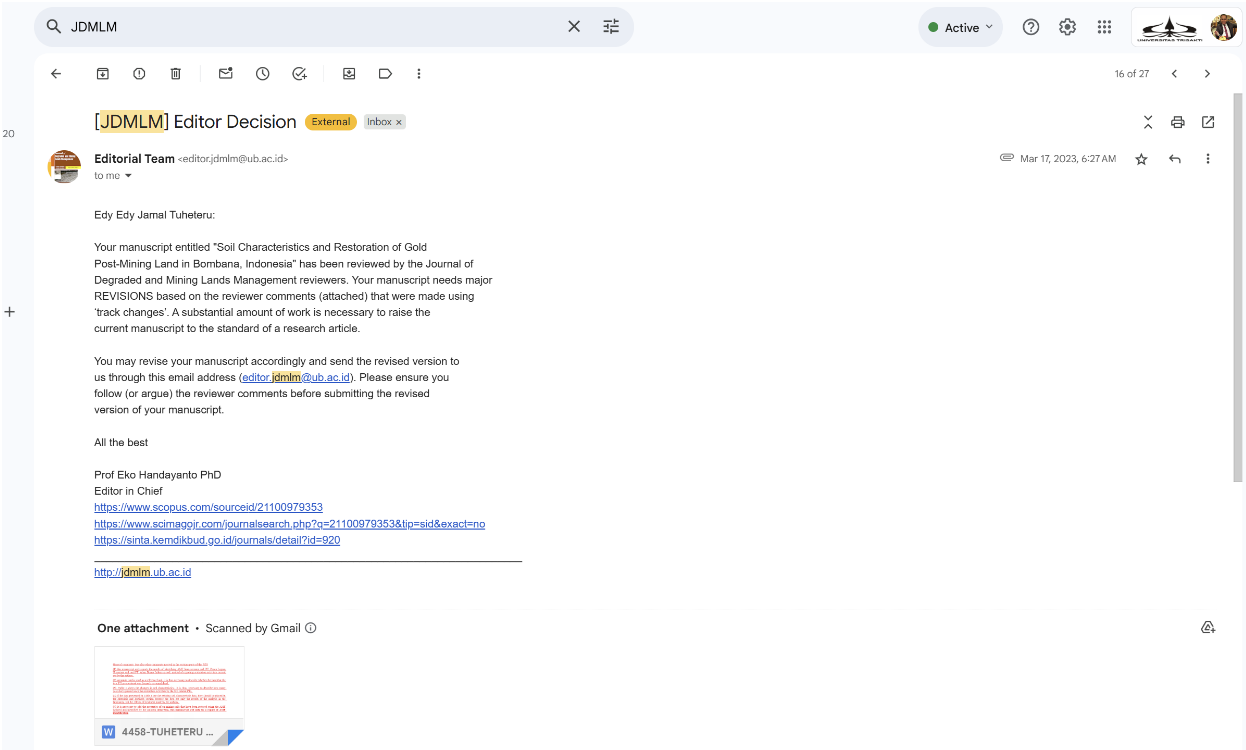

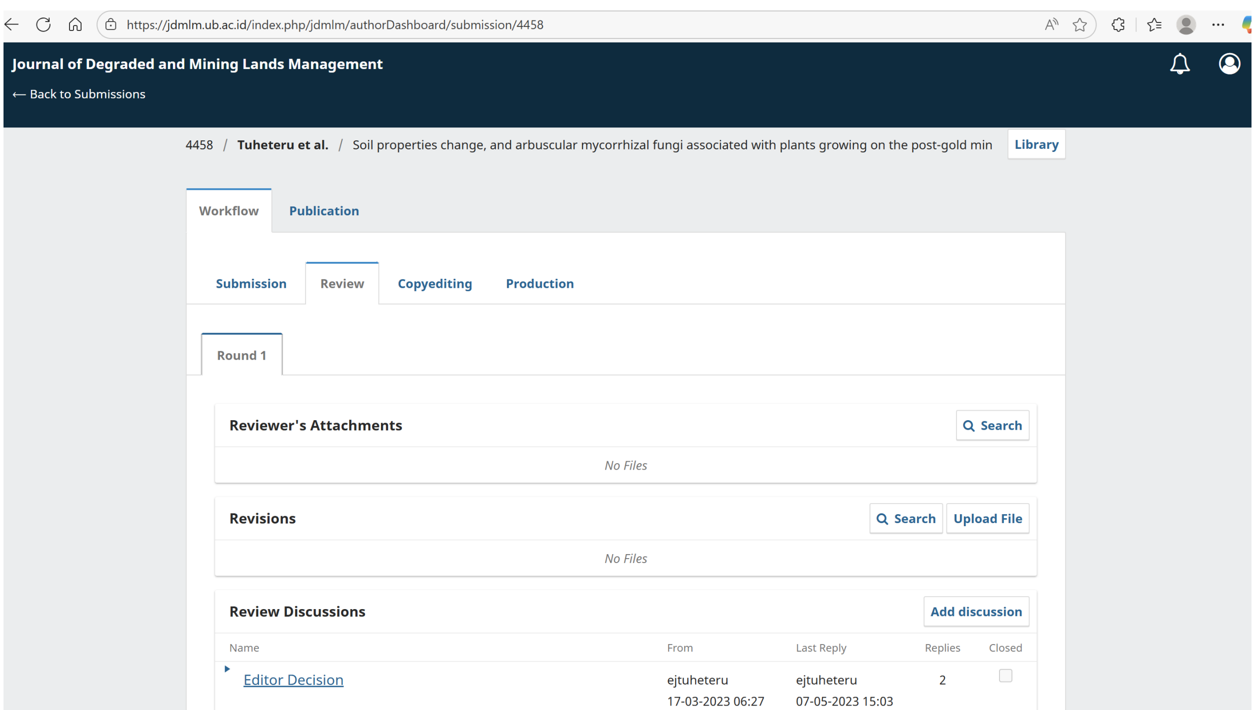

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Edy Jamal Tuheteru <ejtuheteru@trisakti.ac.id>
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Mar 22, 2023, 6:17 PM

Dear Prof. Eko Handayanto, Ph.D
(Editor in Chief).

Thank you for the correction delivered.

In the following, we submit the paper that we have revised according to the input or correction.

All the best.

Edy Jamal Tuheteru

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7. Bukti Copyediting, layout dan Proofreading serta pembayaran

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JDMLM Editorial Office <editor.jdmlm@ub.ac.id>
to me

Tue, May 9, 2023, 1:25 PM

Dear Authors,

We are sending herewith the Galley Proof of your ready-to-publish article **"Soil properties change, and arbuscular mycorrhizal fungi associated with plants growing on the post-gold mining land of Bombana, Indonesia"** for proofreading.

You can make corrections by marking yellow on the attached file, not on another new one, and kindly send the corrections back to us through this email address at the earliest opportunity. Your article will likely come in Vol. 11, No. 1 (1 October 2023). However, the article pages have not been set up yet; waiting for your confirmation.

We would like to inform you that starting from 1 July 2022, Journal of Degraded and Mining Lands Management applies APC (article processing charge) of US$ 100 for an article of no more than 12 pages (10-point font, including figures, tables, and references). Regarding this, you are kindly requested to deposit **US$ 100 (IDR 1,480,000)** to the following Bank Account at the earliest opportunity.

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Dr Reni Ustiatik
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Edy Jamal Tuheteru <ejtuheteru@trisakti.ac.id>
to JDMLM

May 9, 2023, 6:52 PM

Dear Dr. Reni Ustiatik (Associate Editor in Chief JDMLM)

Thank you for the opportunity given to publish our paper with the title **"Soil properties change, and arbuscular mycorrhizal fungi associated with plants growing on the post-gold mining land of Bombana, Indonesia"** in Vol. 11, No. 1 (1 October 2023).

For your information, we have made the payment as attached.

Best Regards.
Edy Jamal Tuheteru.

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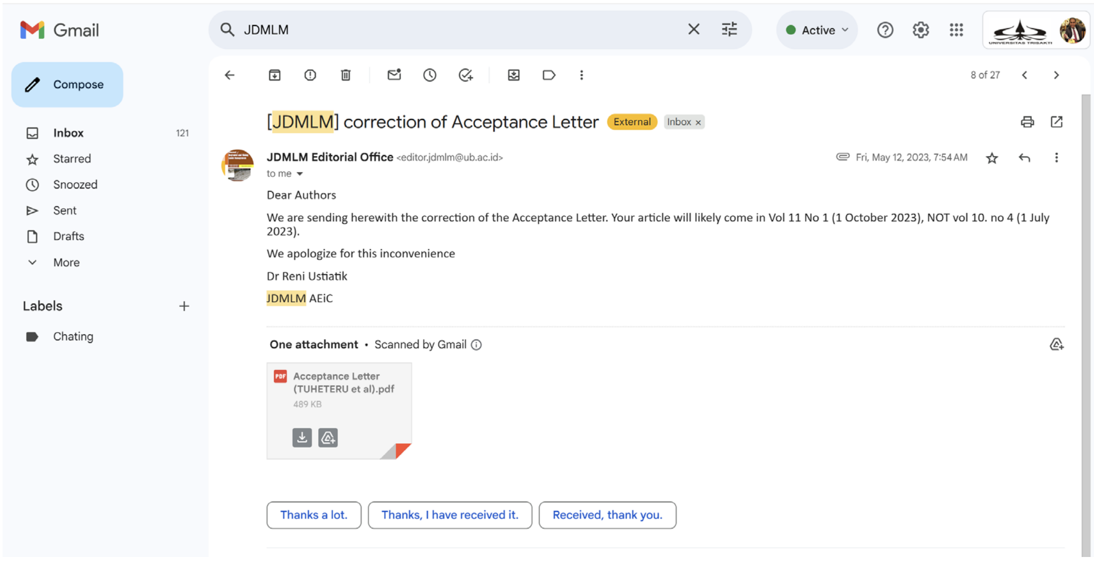
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JDMLM Editorial Office <editor.jdmlm@ub.ac.id>
to me

Fri, May 12, 2023, 7:54 AM

Dear Authors

We are sending herewith the correction of the Acceptance Letter. Your article will likely come in Vol 11 No 1 (1 October 2023), NOT vol 10. no 4 (1 July 2023).

We apologize for this inconvenience

Dr Reni Ustiatik

JDMLM AEiC

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Acceptance Letter (TUHETERU et al).pdf

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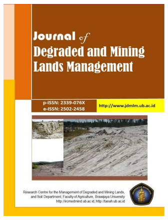

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Research Centre for the Management of Degraded and Mining Lands
and Soil Department, Faculty of Agriculture, Brawijaya University

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Date: 9 May 2023

LETTER OF ACCEPTANCE

Paper No: 4458-32716-1-SM

To,

Edy Jamal Tuheteru[1], Faisal Danu Tuheteru[2], Pantjanita Novi Hartami[1], Muhammad Burhannudinnur[3], Suryo Prakoso[4], Husna[2], Albasri[2], Dian Asraria[2]

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Dear Authors,

We are pleased to inform you that your article entitled **"Soil properties change, and arbuscular mycorrhizal fungi associated with plants growing on the post-gold mining land of Bombana, Indonesia"** has been **accepted** for publication in the Journal of Degraded and Mining Lands Management (p-ISSN: 2339-076X, e-ISSN: 2502-2458). The article will likely come in Vol. 11. No. 1 (1 October 2023).

Sincerely yours

Prof Eko Handayanto MSc PhD
Editor in Chief

General comments: (see also other comments inserted in the sections parts of this MS)

(1) this manuscript only reports the results of identifying AMF from savanna soil, PT. Panca Logam Nusantara soil, and PT. Alam Buana Indonesia soil, instead of reporting restoration activities carried out by the authors,

(2) savannah land is used as a reference land; it is thus necessary to describe whether the land that the two PT have restored was formerly savannah land,

(3) Table 1 shows the changes in soil characteristics; it is thus necessary to describe how many years have passed since the restoration activities by the two related PTs,

(4) if the data presented in Table 1 are the existing soil characteristic data, they should be placed in the Materials and Methods section because the data are only the results of the analysis in the laboratory, not the effects of treatment made by the authors,

(4) it is necessary to add the properties of ex-mining soils that have been restored using the AMF isolated and identified by the authors**; otherwise, this manuscript will only be a report of AMF identification**

Recommendation: this manuscript requires **major revisions** as in this present form, this manuscript cannot be considered as a research article by this journal. A substantial amount of work is necessary to raise the current manuscript to the standard of a research article

Soil Characteristics and Restoration in the Post-Gold Mining Land of Bombana, Indonesia → This title is not related to the contents of this MS, as this MS only reports AMF from different soils of different land uses, which, of course, undoubtedly have different AMF population

Edy Jamal Tuheteru[1*], Faisal Danu Tuheteru[2], Pantjanita Novi hartami[1], Muhammad Burhannudinnur[3], Suryo Prakoso[4], Husna[2], Albasri[2], Dian Asraria[2]

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***corresponding author: ejtuheteru@trisakti.ac.id**

Abstract
This study aims to investigate the effect of gold mining towards soil properties. Soil samples were taken from the post-gold mining land, the property of PT Panca Logam Nusantara and PT Alam Buana Indonesia, and a nearby natural forest in Bombana, Southeast Sulawesi Province. The next step focused on specifying soil pH, total nitrogen (TN) and carbon (TC) concentration, C/N ratio, available phosphorus (P) concentration, cation exchange capacity (CEC), and exchangeable K, Na, Mg, Ca, Fe, Mn, Cd and Pb concentration, texture and spore amount, AMF resource and AMF colonization. The result shows that the pH in post-gold mining soil was higher than that in natural forest soil. Meanwhile,

TN, TC, available P, and CEC of post-gold mining soil got lower compared with these of natural forest soil. The texture in the post-mining soil was clay loam, while that in natural forest soil was clay. Total of 10 AMF species belonging to five genera and three families were found in a post-gold mining area. Soil pH, CEC, soil texture, Mn, and total Fe had a negative relation with AMF colonization and spore count, while organic C, total N, C/N ratio, P_2O_5 and silt had a positive relation. Sand was proven to have a strong and positive correlation with the amount of AMF species. Adding organic matter and fertilization as well as applying mycorrhizal biofertilizers were urgently required to support the effort in restoring post-gold mining soil.

Keywords: gold mining, Glomeraceae, soil restoration

Introduction

Gold mining is a sector that has been cultivated for a long time in Indonesia. Furthermore, Indonesia is known as the sixth largest gold producer worldwide, with total production reaching 190 ton in 2018 (Retinitiv, 2019). Large enterprises as well as other small-scale groups have participated in gold mining management in Indonesia (Artisanal and small-scale gold mining, ASGM). Over two thousand gold mining locations can be found throughout Indonesia. Bombana, in Southeast Sulawesi Province, has the potential gold resource, while this area has been managed since mid-2008. This gold mining industry has made a considerable contribution to the country in social and economic terms (Martins et al., 2020). However, mining activities can negatively affect the environment, as proven by the landscape change, particularly damage and loss of natural vegetation (Tepanosyan et al., 2018), land degradation (Ahyani, 2011; Wawo et al., 2015; Buchori, 2019) and soil and water contamination (Basri et al., 2017; 2020; Sakakibara et al., 2017; Hidratmo et al., 2019; Meutia et al., 2022), human health (Arifin et al., 2015) and other social aspects (Upe et al., 2019). Besides, mining activities generally result in low fertility and degradation in post-mining land (Ma et al., 2019). It was reported that soul degradation occurred in almost all activities for mining nickel (Prematuri et al., 2020a), coal (Pandey et al., 2014, Ma et al., 2019), and bauxite (Prematuri et al., 2020b).

Reclamation to the post-gold mining land is significantly urgent, and it has been implemented for a long time in Indonesia. Some enterprises, namely PT ANTAM Tbk Pongkor, Bogor (Siregar et al., 2013) and PT Newmont Minahasa Raya, North Sulawesi (Pollo et al., 2012), have successfully carried out reclamation to the post-gold mining land. The success of a reclamation effort is determined by the commitment of a company to having the permit and knowledge of its technical aspects. Thalib et al. (2020) reported that almost all companies in the gold mining sector of Bombana did not yet perform reclamation for the post-mining land. On a small scale for research, a reclamation effort has been made by designing a conservation plot towards the endangered legume species in accordance with mycorrhizal biofertilizers at PT Panca Logam Makmur (Husna et al., 2021; Arif et al., 2021). Thus, the first step was the evaluation of soil properties and vegetation succession levels. Tree growth and quality of the post-mining land should be considered in the evaluation process (Maiti, 2013).

The soil itself can be a limiting factor in the post-mining area and determine the success of revegetation in reclamation (Matichenkov and Bocharnikova, 2021; Prescot et al., 2021). Soil is believed to be a fundamental aspect in a restoration effort towards a landscape of degraded land, including post-mining land (Stanturf et al., 2021). Physical, chemical and biological traits in post-mining land do not allow the plant to grow well in any restoration activity (Sheoran et al., 2010). In the long run, soil quality improvement in the post-mining area mainly aims to build a sustainable forest ecosystem through the improvement of soil nutrients and plant growth (Pietrzykowski et al., 2013). Therefore, soil properties on the gold post-mining land need to be identified for selecting an appropriate restoration method to apply. Restoration of the post-mining land can be passively performed through natural regeneration and actively through human intervention. The active restoration was performed by planting the tree. Thus, the data on soil properties can be made into the database for choosing tree species and appropriate soil manipulation methods. Beneficial soil microbes, arbuscular mycorrhizal fungi (Husna et al., 2021a), for example, were applied as a method for soil manipulation.--> **insert here the objective(s) of this study**

Material and Method

Sampling and preparation of soil material

Soil samples were collected around the root of an adaptive plant in a post-gold mining area owned by PT Panca Logam Nusantara (PLN) and PT Alam Buana Indonesia (ABI), Bombana Regency, Southeast Sulawesi Province (Figure 1). The sample was taken from the rhizosphere in every living plant at a weight of approximately 1 kg and a depth of 0-20 cm. The next step was to put a soil sample in a respective plastic bag and to write the location code and the name of plant for every sampling point or plot. The whole soil samples were air-dried inside the laboratory, in which this stage was intended for the isolation and identification of AMF spores. Composite soil (± 1 kg) in every location was shipped to SEAMEO BIOTROP Soil and Plant Laboratory in Bogor City.

Laboratory analysis of soil

In SEAMEO BIOTROP's Soil and Plant Laboratory of Bogor, Indonesia, an analysis was conducted on physical and chemical properties in soil. Soil pH used the method as described in SNI 03-6787-2002 for the measurement process. Soil organic C was analysed using a method of SNI 13-4720-1998 (Walkey-Black). Total N was measured using micro-Kjeldahl (SNI 13-4721-1998), while available phosphorus in the form of P_2O_5 was measured using Bray method I/II (SL-MU-TT-05). Furthermore, Ca, Mg, Na, K and CEC were measured by SL-MU-TT-07c (buffer extract NH_4OAc 1.0 N pH 7.0). Texture analysis of three fractions of sand, silt, and clay was conducted using SL-MU-TT-10 (Hydrometer) method. Total metal (Mn, Fe_2O_3, Cd and Pb) was measured by HNO_3-$HClO_4$-ASS.

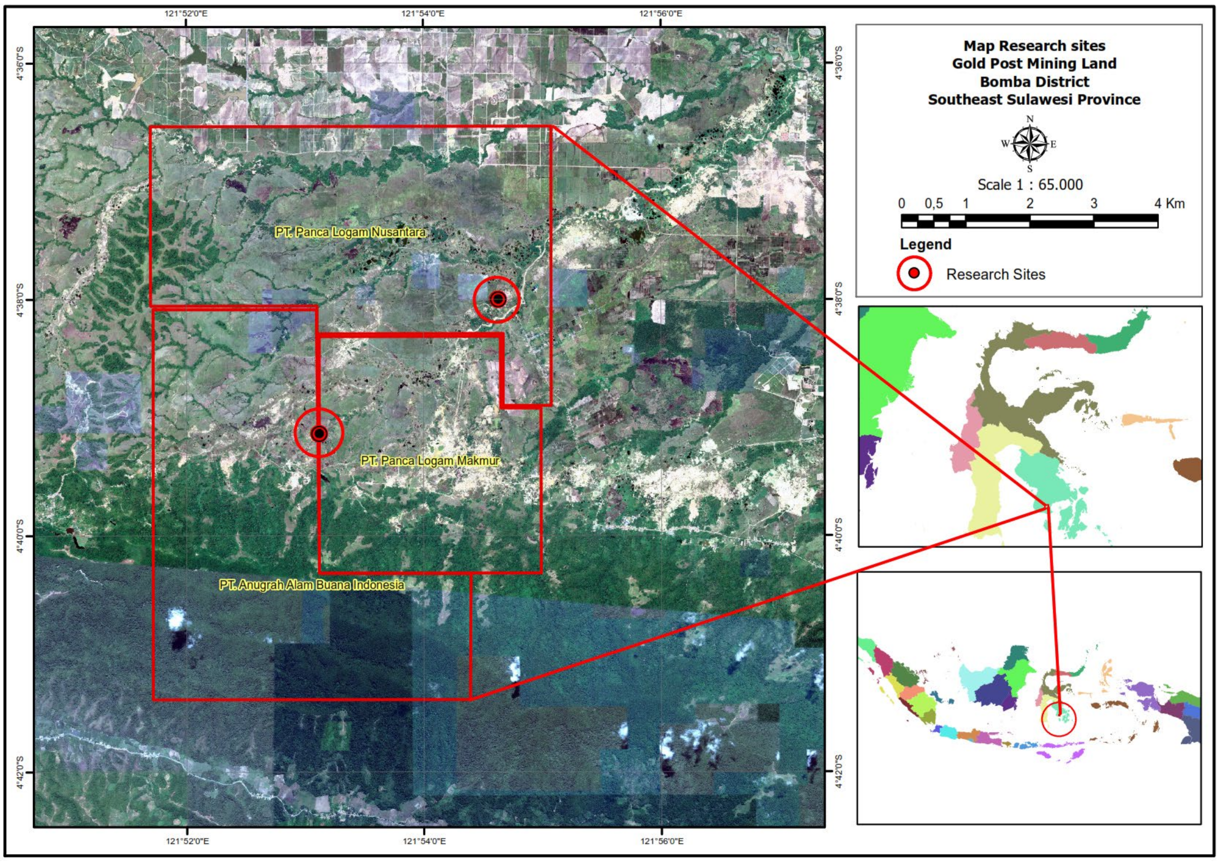


Figure 1. Location of the area studied → the legends are too small and blurry; please improve them

Soil trap culture

The trapping technique was implemented with a method as stated by Brundrett et al. (1996) using open culture pots. The medium used for planting was a mixture of 50 g of soil sample and 150 g of zeolite rock. Weaning Sorghum bicolour sprouts were planted in the pot. Watering, nutrient administration, and manual pest control were carried out as a maintenance effort.

AMF colonization

A root sample was cleaned and put in an alcohol solution at 70%. Meanwhile, AMF colonies were observed with the trypan blue stain (Phillips and Hayman, 1970). Mycorrhizal roots were analysed to determine AMF percentage, using the formula as follows: [Σ mycorrhizal roots / Σ total observed field of view] x 100%

AMF isolation and identification

AMF spores were isolated with a wet pour-strain technique, as stated by Pacioni (1992), followed by centrifugation with a technique from Brundrett et al. (1996). Meanwhile, healthy spores were selected and stored in a glass treated with PVLG and Melzer solution and covered. AMF spores were identified by observing their morphology in terms of shape, size, colour, carrier hyphae, spore ornaments, spore mother cells, as well as bulbous suspensors. The nomenclature of AMF spores was conducted by following the guidelines by Schüßler and Walker (2010) and Redecker (2013). AMF spores were identified under a Nikon Eclipse 80i Microscope at the Cryptogam Laboratory, Centre for Biology Research, LIPI, Bogor City.

Parameters

This study observed physical and chemical properties in the soil, spore density, species resource (Husna et al., 2015), and AMF colonization (Brundrett et al. 1996). Soil was restored by following guidelines by Stanturf et al. (2021) and Young et al. (2022).

Data Analysis

The whole data were analysed through Microsoft Excel. Relation among soil properties, the amount of vegetation with AMF spore density, species resource, and root colonization was analysed using Pearson's correlation.

Result and Discussion

Soil properties

Soil Chemical Properties

The result of the analysis of physical and chemical properties in the soil is shown in Table 1. In soil analysis, the result shows soil pH that was slightly alkaline in both post-gold mining locations. Total N content, C/N ratio, and P_2O_5 belonged to a low category. Meanwhile, soil organic C, Mn, and Fe belonged to a very low category. Soil K and Mg levels were in a very high category. Soil pH, organic C, total N, C/N ratio, and P_2O_5 in post-mining soil were lower than those in savannah soil. Fe in the post-mining soil was higher than that of savannah soil. CEC in PT PLN soil was lower than CEC in savannah soil, while the total Mn of the post-mining soil was higher than that of savannah soil.

Mining activities can lead to the damage of land. Soil pH, organic C, total N, P_2O_5 of the post-mining land were lower than those of savannah soil, as shown in Table 1. Besides the level change, organic C of the post-mining land belonged to a very low category, while total N, C/N, P_2O_5 and Ca belonged to a low category. The damage to land and soil as a consequence of the mining activities has been shown, including nickel (Prematuri et al., 2020a), coal (Pandey et al., 2014, Ma et al., 2019), and bauxite (Prematuri et al., 2020b) mining. Soil and overburden of artisanal gold mining in Sekotong provided plant nutrients at a very low level (Siswanto et al., 2012). It is also proven that Ca<Mg level, base saturation > 20%, and CEC > 16 cmol/kg. Ca<Mg level was a cause of the stagnation in growth during reclamation activities.

Soil Physical Properties

Physical properties in soil analyzed in this research were soil texture. Soil texture in the savannah and both post-gold mining locations was clay loam. Clay loam soil can be applicable for most the tree species for having the capability to support water flow and nutrients for these trees (Osman, 2013). Clay loam soil was discovered in artisanal gold mining land in West Lombok, Indonesia (Siswanto et al., 2012). The proportion of the sand in both post-mining locations was higher than that in savannah soil, while silt and clay were lower, as shown in Table 1.

Table 1. Chemical and physical properties in soil

No.	Parameter	Unit	Soil				
			Savannah (reference)*	PT. Panca Logam Nusantara		PT. Alam Buana Indonesia	
				Value	Change (%)	Value	Change (%)
1	pH H_2O		8.07±0.15	7.8±0.39	- 0.96 (4)	7.7±0.12	-0.95 (5)
2	Organic C	%	0.76±0.16	0.6±0.11	- 0.79 (21)	0.5±0.11	- 0.66 (34)
3	Total N	%	0.11±0.0	0.1±0.00	- 0.91 (9)	0.1±0.01	- 0.91 (9)
4	C/N ratio		7±1.73	6.6±1.19	- 0.94 (6)	7.2±0.97	+1.03 (3)

5	P_2O_5	ppm	18.70±1.06	7.1±3.48	- 0.38 (62)	6.6±1.20	- 0.35 (65)
6	Ca	cmol/kg	nd	6.9±0.94	nd	3.6±0.20	nd
7	Mg	cmol/kg	nd	4.5±0.21	nd	4.7±0.17	nd
8	Na	cmol/kg	nd	0.4±0.13	nd	0.3±0.05	nd
9	K	cmol/kg	nd	0.2±0.00	nd	8.9±0.13	nd
10	CEC	cmol/kg	23.77±2.04	20.8±3.33	- 0.87 (13)	25.4±0.52	+1.07 (7)
11	Texture						
	Sand	%	35.07±3.50	44.6±4.61	+ 1.27 (27)	40.3±4.92	+1.15 (15)
	Silt	%	30.13±0.23	24.9±5.42	- 0.83 (17)	25.8±2.93	- 0.86 (14)
	Clay	%	34.80±3.41	30.5±1.91	- 0.87 (12)	33.9±2.04	- 0.97 (3)
12	Mn	ppm	853.0±89.11	1000±0.02	+ 1.17 (17)	1000±0.02	- 1.17 (17)
13	Fe	%	1.30±0.09	2.8±0.65	+ 2.15 (115)	3.3±0.11	+ 2.54 (154)
14	Cd	ppm	nd	1.2±0.10	nd	1.2±0.03	nd
15	Pb	ppm	nd	18.6±3.93	nd	24.8±0.57	nd

Nd=not data

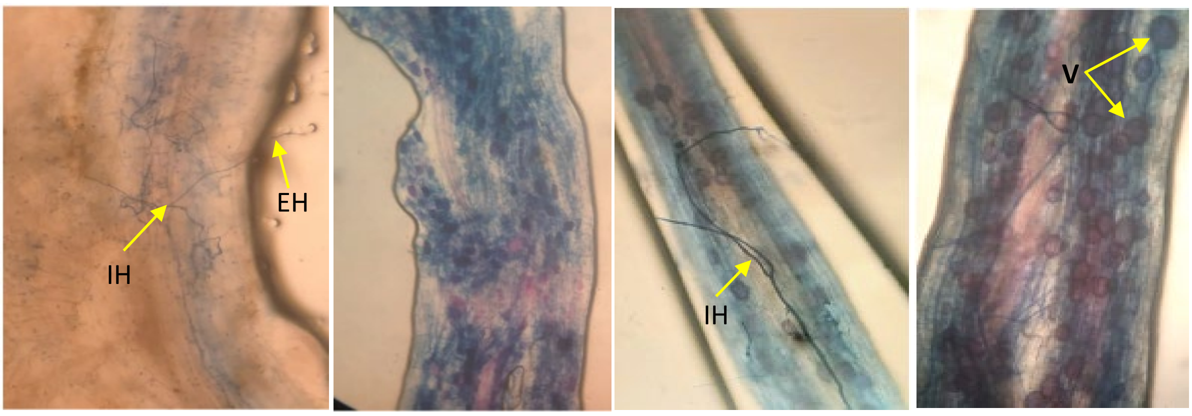
Soil Biological Properties

AMF Colonization and Spore Density in the Arbuscular Mycorrhizal Fungi

Based on the result of microscopic observation of plant roots, AMF structures were discovered, including internal hyphae, vesicles, external hyphae and coil hyphae (Figure 2). The average value of AMF colonization on plant roots was from 57% to 61%, as shown in Table 2. Table 3 shows the AMF colonization on plant roots. There were three AMF spores per 100 g of soil, from the field. The highest amount of spores from the field was discovered in the savannah, in which it got lower after being cultured in the trapping culture media (Table 2). Johnson et al. (2013) and Wang (2017) reported that soil damage as a consequence of mining activities might lead to a reduction or loss in AMF propagule and infectivity. Several plant species, namely *C. odorata, C. mucunoides, Oldenlandia diffusa*, and *I. cylindrica*, were reported to be colonized by AMF in PT Panca Logam Makmur in Bombana (Tuheteru et al., 2019).

Table 2. AMF Colonization and Spore Density

Site	Plant richness	AMF Colonization (%)	Spore density	
			Field (100 g soil)	Trap culture (50 g media)
Savannah*	14	72	12	17
PT. Panca Logam Nusantara	24	57	3	541
PT. Alam Buana Indonesia	36	61	3	320
Means		59		



AMF colonization in adaptive plant roots *Codariocalyx* sp. *Acacia mangium*, *Calopogonium mucunoides* and *Imperata cylindrica* (IH Internal hyphae, EH external hyphae, V Vesicle)

Table 3. Percentage of AMF colonization on plant roots at PT PLN and PT ABI

No	Species	Family	AMF colonization (%)	
			PT. Panca Logam Nusantara	PT. Alam Buana Nusantara
1	*Chromolaena odorata*	Asteraceae	-	53
2	*Fimbristylis dichotoma*	Cyperaceae	53	-
3	*Rhynchospora* sp.		93	-
4	Cyperaceae (sp. 1)		-	88
5	*Merremia hederacea*	Convolvulaceae	93	-
6	*Euphorbia* sp.	Euphorbiaceae	50	53
7	*Euphorbia hyssopifolia*		73	-
8	Euphorbia heterophylla		-	98
9	*Acacia mangium*	Fabaceae	68	-
10	*Aeschynomene americana*		-	43
11	*Alysicarpus vaginalis*		100	17
12	*Crotalaria* sp.		5	43
13	*Codariocalyx* sp.		63	-
14	*Indigofera* sp.		-	93
15	*Mimosa pudica*		95	30
16	*Uraria* sp.		30	68
17	*Melochia odorata*	Malvaceae	68	-
18	*Phyllanthus* sp.	Phyllanthaceae	100	68
19	*Calopogonium mucunoides*	Poaceae	30	73
20	*Chrysopogon* sp.		53	-
21	*Digitaria* sp.		-	100
22	*Imperata cylindrica*		50	93
23	*Saccharum* sp.		-	63
24	*Sorghum* sp.		-	50
25	Poaceae (sp. 1)		-	95
26	Poaceae (sp. 2)		-	100
27	*Oldenlandia diffusa*	Rubiaceae	43	-

Total AMF types in field and trap culture

Total of ten AMF species, including five genera viz, were identified at two sites. *Acaulospora, Glomus, Sclerocystis, Gigaspora*, and *Scutellospora* (Table 4 and Figure 3). The fact shows that 70% of total 10 AMFs belonged to Glomeraceae, followed by Gigasporaceae and Acaulosporaceae. The amount of AMF species in the savannah soil was lower than that in gold post-mining soil. This research shows that a dominant AMF family was Glomeraceae at a percentage of 70%. Meanwhile, several studies have shown the same result, in which Glomeraceae was dominant in the post-mining area for its nickel (Prayudyaningsih et al., 2019), coal (Ezeokoli et al., 2020), asphalt (Tuheteru et al., 2022), gold (Tuheteru et al., 2019, 2020), and limestone (Suting and Devi, 2021). Glomeracecae was reported to be dominant in the rhizosphere of several tropical tree species (Husna et al., 2015; Husna et al. 2022a). In Indonesia as a tropical country, Glomeraceae was reported to be dominant, having 36 species or 53% of 72 AMF species (Husna et al., 2021b). Glomeracecae was dominant for having AMF species that were tolerant and adaptive to the diverse condition of soil and environment, as well as the capability to survive in acid and alkaline soil to produce small spores in a shorter time, compared with *Gigaspora* and *Scutellospora. Glomus* had the most species in the phylum Glomeromycota (Schüßler and Walker, 2010). Glomeraceae family was widely distributed and discovered in four climatic zones, seven continents, seventeen biomes, and many countries (Strumer et al., 2018).

This study shows that the amount of AMF species in post-mining soil was higher compared with savanna soil. *G. coronatum, Glomus sp. 1* and *S. sinousa* were discovered in savannah and post-mining soil. *A. scrobiculata* was discovered in post-gold mining owned by PT Panca Logam Makmur and a mining community in Bombana (Tuheteru et al., 2019; 2020). AMF discovered in three locations was *Glomus* sp. 1. Wide distribution of *Glomus* sp. 1 was attributed to a small size relatable to a high sporulation capacity, adaptability to the soil, climate and diverse plant (Morales et al., 2019).

Table 4. Glomeromycota species recovered from field soil and trap culture

Family	**AMF species**	Savannah*	ABI	PLN

		Fs	Tc	Fs	Tc	Fs	Tc
Acauloporaceae	*Acaulospora scrobiculata*			√	√		
Glomeraceae	*Glomus coronatum*	√		√	√	√	√
	Glomus agrregatum			√	√		
	Glomus sp.1	√		√	√	√	√
	Glomus sp.2			√		√	
	Sclerocystis rubiformis			√			
	Sclerocystis sinousa	√		√		√	
	Sclerocytis clavispora			√			
Gigasporaceae	*Gigaspora* sp.			√		√	
	Scutellospora sp.					√	
	Total	**3**		**9**		**6**	
				10			

*Tuheteru et al. (2020), Fs (Field soils), Tc (Trap cultures)

Relation between soil properties and Arbuscular Mycorhizal Fungi parameters.

The whole soil properties were negatively related to an amount of AMF species, excluding its total Mn, total Fe and amount of plants. Soil pH, organic C, total N, P_2O_5, silt, and clay positively related with AMF colonization and spore count (Table 5), while total Mn and Fe, sand, and vegetation were negatively related. The difference in the AMF types from every location was arguably caused by diverse ecological preferences in every AMF type. One of the factors affecting AMF abundance and diversity was soil property. This study shows that soil pH, CEC, soil texture, total Mn and Fe, as well as vegetation had a negative relation with AMF colonization and spore count. Meanwhile, organic C, total N, C/N ratio, P_2O_5 and silt had positive and strong correlation. Sand had a strong and positive correlation with the amount of AMF species. Soil pH determines spore density and AMF distribution (Bainard et al., 2015). High pH in soil is capable of reducing the abundance of AMF species (Bainard et al., 2015). This research is in line with another research by Wei et al. (2014) and Xu et al. (2017), which showed that soil Mn concentration is negatively related with AMF diversity. This research shows that P is positively related to spore amount and AMF colonization. The result of this research is in line with that of research by Husna et al. (2022) and in contrast to previous research, which showed that low P was capable of improving AMF diversity (Soka and Ritchie, 2018; Chiomento et al., 2019; Wei et al., 2014). Johnson et al. (2013) reported that intense use of land was capable of changing soil properties and resulted in a decrease of species and AMF diversity.

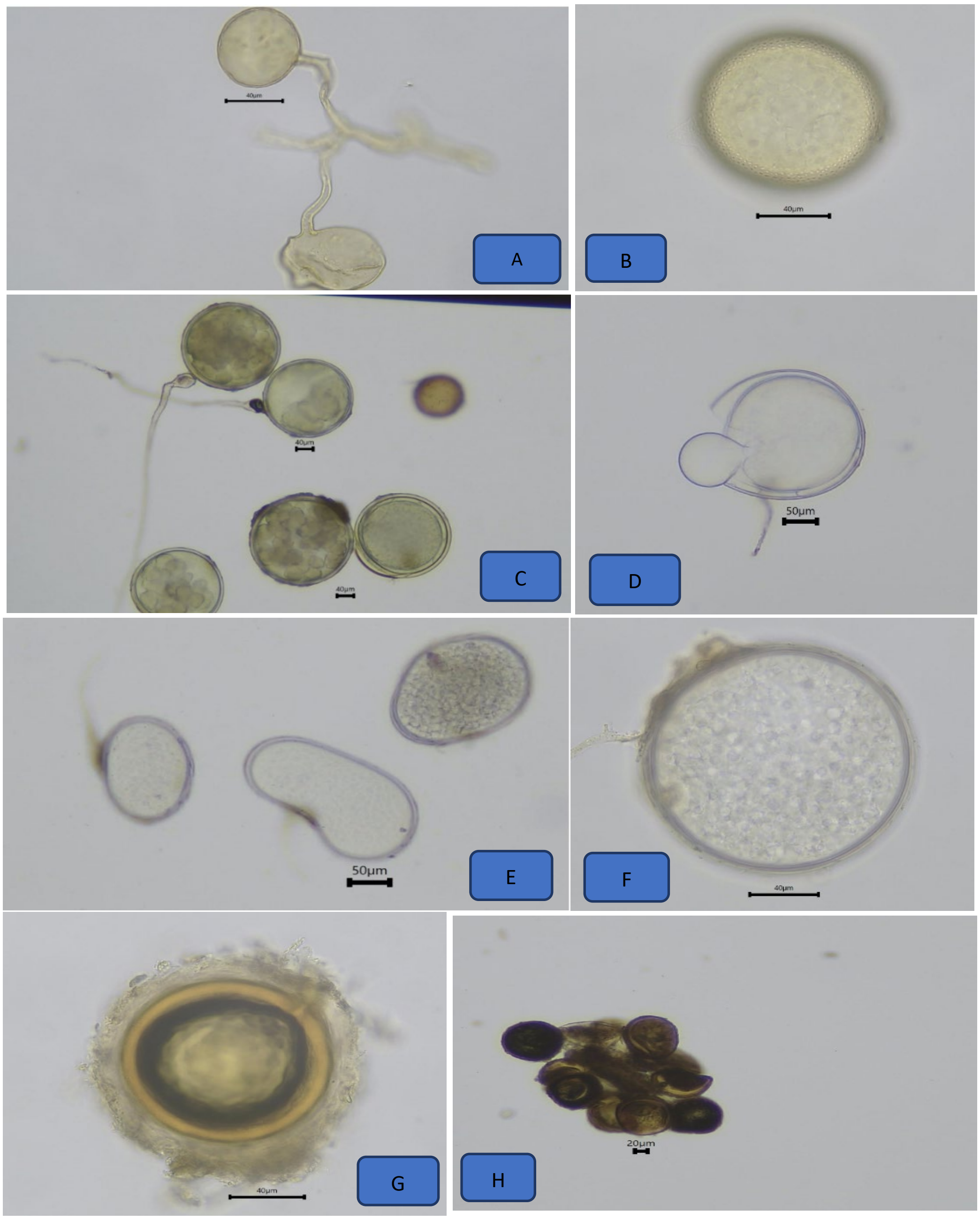


Figure 3. Types of AMF found. (A = *Glomus aggregatum*, ABI., *A. scrobiculata*, ABI., C. *Gigaspora* sp. ABI, D. *Gigaspora* sp., ABI, E. *Gigaspora* sp, PLN, F. *Gigaspora* sp. ABI, G. *Glomus coronatum*, H. *Glomus rubiforme*)

Table 5. Relation among soil properties, colonization, amount of species, and amount of AMF spores

	*pH	*C Org	*N Total	C/N	*P2O5	CEC	Texture			Mn Total	Fe Total	plant
							sand	silt	clay			
	H2O	%	%		ppm	cmol/kg	%	%	%	ppm	%	
AMF colonization	0,864	0,794	0,707	0,437	0,956	0,416	-0,979	0,995	0,839	-0,966	-0,875	-0,669
Species richness	-0,705	-0,610	-0,866	-0,655	-0,847	-0,637	0,998	-0,935	-0,951	0,866	0,721	0,454
Spore number	0,965	0,924	0,500	0,189	0,999	0,166	-0,893	0,987	0,669	-1,000	-0,971	-0,839

Restoration of soil/land → this is just the theories and works from others, this does not seem tol be your research works

The restoration is required to improve soil conditions in post-gold mining land and Bombana. Restoration can be carried out on the damaged and degraded land in a passive way through natural regeneration or in an active one by involving human intervention (Bandyopadhyay and Maiti, 2019). Martins et al. (2020) stated six ways to recover degraded land as a result of mining activities, in which two of these choices are seedling planting and natural regeneration. Restoration methods can be selected by determining ecosystem resilience, restoration purpose, landscape context, and expenditure for the restoration project (Festin et al., 2019). After any choice is made and the land can be restored like before, savannah, for example, it is possible to depend on passive restoration. Referring to this option, most of the corporates having a gold-mining permit are not willing to carry out the mine reclamation (Thalib et al., 2020). Natural regeneration in the post-gold mining field in Bombana has been reported (Tuheteru et al., 2021; Albasri et al., 2021a, b). Post-gold mining area was dominated by grass and covered with various trees, including *Acacia mangium, Alstonia scolaris, Neolamarckia cadamba, N. macrophyllus*, as well as *Nauclea orientalis*. However, all corporates were asked to reclaim the post-mining land by implementing an active restoration effort as stipulated in Law No. 3 of 2020 concerning Mineral and Coal Mining.

A form of reclamation in post-mining land is revegetation. Revegetation is an activity for planting forest plant species on degraded land. Revegetation is mostly determined by the option of tree species and the condition of the mining soil (Ahirwal and Maiti, 2021). The right choice of tree species was capable of improving the success rate of reclamation activities on post-nickel mining land. Reclamation for the post-mining land required 1) the use of locally adaptive species, 2) the use of relatively fast-growing tree species, 3) sufficient light and low nutrients provided, 4) the use of tree species having a lot of decomposable litter, 5) the use of tree species in catalytic type, 6) the use of tree species easy to propagate, 7) the use of tree species having a low cost for planting and maintenance, and 8) the use of tree species easy to manage (Maiti, 2013; Pancel, 2015). Common tree species to choose includes Fabaceae (Legume) family (Maiti, 2013). Legume species capable of growing well on post-gold mining land in Bombana were *Pterocarpus indicus, Pericopsis mooniana, Dalbergia latofolia*, and *Kalappia celebica* (Husna et al., 2021, 2022; Arif et al., 2021). As described above, local tree species had the potency to grow on post-gold mining land.

To ensure the success of revegetation in the post-mining land, soil manipulation was required. This kind of manipulation can be performed by adding soil amendment in the form of organic matter input, mulch, fertilization, and mycorrhizal inoculum (Stanturf et al., 2021). Soil amendment, namely biochar and compost can improve soil condition in plant growth (Ghosh and Maiti, 2021; Worlanyo and Jiangfeng, 2021). Arbuscular mycorrhizal fungi included beneficial soil microbes belonging to an Endomicorhiza group. Based on a report, AMF served as a tool for restoring the degraded land and the disturbed ecosystem (Asmelash et al., 2016), for the post-mining land (de Moura et al., 2022) in particular. Several studies stated that AMF was capable of accelerating the succession of natural vegetation in several post-mining land conditions worldwide, including nickel (Husna et al. 2017), coal (Husin et al. 2017), gold (Tuheteru et al., 2019; 2020), and asphalt (Tuheteru et al., 2022). According to a report, AMF was capable of improving the growth of tropical tree species in soil media from a post-gold mining land at a nursery (Husna et al., 2019, 2021) and field scale in Bombana (Husna et al., 2021, 2022; Arif et al., 2021). The literature review shows that restoration of a post-gold mining in Bombana can be performed. On a small scale, the reclamation of a post-gold mining land owned by PT Panca Logam Makmur in Bombana has made use of mycorrhizal biofertilizers on four species from local and endangered legumes, while the result was proven to be excellent (Husna et al., 2021, 2022b, Arif et al., 2021). Implementation of the reclamation effort can be replicated in another area of Bombana, Southeast Sulawesi.

Conclusion

Soil fertility of the opencast gold mining land was lower than that in the savannah of Bombana. Level of pH in a post-mining soil was lower than that of savannah soil. Total N, total Carbon, available P, and CEC in post-gold mining soil were lower than those of savannah soil. Texture of post-mining soil and savannah was clay loam. Total ten AMF species, from five genera and three families, were discovered from the post-gold mining area. Soil pH, CEC, soil texture, total Mn and Fe had a negative relation with AMF colonization and spore count. Soil restoration can be performed as an approach by applying soil conditioner (organic matter), mycorrhizal biofertilizers, and appropriate tree species selection.

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