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Chemical Characteristic of Forest Soil and Gold Mine Tailings and Their Effect to the Plant Growth of Two Leguminous Trees

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Authors' contributions

This work was carried out in collaboration among all authors. Authors RP, MT, TS and KT designed the study, performed the experiment and wrote the protocol. Authors RP and KT drafted the manuscript and edited the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To clarify chemical characteristic of gold mine tailings and its effect to the growth of two leguminous trees of *Falcataria molucana* and *Albizia saman* under greenhouse conditions.
Study Design: Field samples collection, analyze their samples of forest soil and tailings from gold mining area and determined the effect to the plant growth of two leguminous trees.
Place and Duration of Study: Laboratory of Plant Nutrition and Soil Science, Faculty of Agriculture, Yamagata University, and The Forest Research and Development Centre, Bogor, West Java, Indonesia between 2012 to 2013.
Methodology: Soil pH, total carbon (C), nitrogen (N), and available phosphorus (P) concentrations, cation exchange capacity, C/N ratio and exchangeable K, Na, Mg, Ca, Fe and Ni concentrations were analyzed. *F. moluccana* and *A. saman* were grown for 15 weeks and their shoot heights, shoot and root dry weights were calculated.

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Results: Total N, carbon and available P of gold mine tailings were lower than that of forest soil. CEC, Mg, K and Fe of gold mine tailings were lower than that of forest soil. C/N ratio of gold mine tailings werehigher than that of forest soil. Soil chemical characteristics of pH (KCL), pH (H_2O), Ca and Na of gold-mine tailings were higher than that of forest soil. There was no difference in Ni between forest soil and gold mine tailings. Shoot dry weight and root dry weight of *F. molucana* on gold mine tailings were lower than that of forest soil. Root dry weight of *A. saman* grown on gold mine tailings were higher than that of forest soil. Shoot dry weight of *A. saman* grown on gold mine tailings were tended to have higher than that on forest soil.

Conclusion: Gold mine tailings resulted from gold processing decrease chemical characteristic compare to the forest soil and its inhibit to the growth of two leguminous tree, *F. molucana* and *A. Saman.*

Keywords: Gold mine tailings; forest soil; chemical characteristic; leguminous trees.

1. INTRODUCTION

Indonesia is one of the gold producing countries that belongs to the top 10 gold producing countries in the world. Production in the archipelago nation, with the number seven on the list of top global producers. In 2018, Indonesia gold mine production was reported 190 tons [1].

One technique used in gold mining is underground mine which is referred as the processes and techniques to extract gold from the ground besides being recovered as a by-product of refining the ores of other metals [2]. Mining activities of gold however, produce large quantities of waste materials such as gold mine tailings. These are the materials left over after the process of separating the valuable fraction from the uneconomic fraction of mining ore. Tailings are the components of the primary mineral-bearing rock left after the extraction of minerals like gold, copper, and silver [3]. Mining processed residues such as gold mine tailings, may dump on forest land and occupy a large land area. The impacts that might occur as a result of poor processing of tailings is a disruption of natural ecosystem as indicated by a decline in quality and productivity of the environment due to changes in soil morphological, physical, chemical, and biological properties. The current global gold rush, driven by increasing consumption in developing countries and uncertainly in financial markets is an increasing threat for tropical forests [4].

On gold-mine tailings, certain extreme soil conditions may occur that prevent tree growth, referring particularly to physical, chemical properties, and extreme lack of certain nutrients for tree growth. The understanding of soil degradation and the tolerance of native tree species against the extreme conditions of mined area is still incomplete [5]. It is still unclear how the relative importance of soil conditions influences species growth under varying degraded gold mine tailings. Soil is a vital natural resource, constituing a critical controlling component during the early stage of tropical forest ecosystem development [6]. Gold mining activities are invariably associated with the removal of fertile soil organic layer enriched with vegetation cover and hence has environmental consequences. Important step of the activities for reclamation in post gold mining is revegetation, however revegetation is not easy. Since gold mine tailings area of post gold mine has limitation as medium for planting a successful revegetation would be quite challenging [7]. These factors slow down or prevent the revegetation process and consequent stabilization of mine tailings [2].

In order to increase the success of the re-vegetation of gold mine tailings, in addition to knowing the consideration of soil characteristics, the selection of types of tolerant trees species is indispensable. *Falcataria molucana* is one of the most important pioneer multipurpose tropical tree species in Indonesia [8]. *F. molucana* is native to Indonesia, Papua New Guinea, Solomon Islands and Australia [9]. It is one of the tree species preferred for industrial forest plantations in Indonesia because of its very fast growth, its ability to grow on a variety soils. Its does not require fertile soil; it can grow well on dry soils, damp soils and even on salty to acid soils as long as drainage is sufficient. *Albizia. saman* is a large leguminous tree found in the tropical forests and which is well known as a source of a wide range of useful products [10]. The ripe pods can be used as an edible pulp, or they can be dried and ground into a meal for animal feed, and the timber is used in furniture manufacture. *A. saman* is also valuable as a shade tree in pastures, where it stimulates the growth of grass. *A. saman* was the only tropical tree species in the study to perform close to plantation standards [11].

The purpose of this research was to clarify chemical characteristics of gold mine tailings and its effect to the growth of *F. molucana* and *A. saman* under greenhouse conditions.

2. MATERIALS AND METHODS

2.1 Forest Soil and Gold Mine Tailings Samples Collection

Forest soil and gold mine tailings samples were collected from the rhizosphere of natural forest and gold mine tailings dumps in a gold mining at Pongkor, Bogor, West Java, Indonesia. The samples were collected in three sites of natural forest (6°39'06"S, 106°21'31"E; 6°39'25"S, 106°22'01"E ; 6°38'69"S, 106°23'21"E) and three sites of gold mine tailings dumps (6°39'56"S, 106°33'31"E; 6°38'40"S, 106°34'15"E; 6°38'40"S, 106°21'31"E) to characterize the chemical properties. Before taking the forest soil and gold mine tailings samples, surface litter, fine roots and stones were scraped away and samples were collected from each of this sectors at a depth of 0 – 25 cm. The samples were collected by hand scope and intimately mixed and placed in a clean and seal plastic bag. Five soil samples were collected from each site. A smaller portion of theses homogenized samples (approximately 1000 kg) were drawn and ground, before laboratory analyzed.

2.2 Forest Soil and Gold Mine Tailings Chemical Analysis

Tailing samples from gold mine tailings dumps and forest soil from natural forest were air-dried and passed through a < 2 mm sieve. The passed dried forest soil and gold mine tailings was used for analysis of pH (H_2O) and pH (KCl). Available phosphate (P) [12] was extracted with 0.001 M sulfuric acid solutions and analyzed by the ammonium molybdate method [13]. Total carbon (TC) and total nitrogen (TN) were determined by a C:N analyzer (Sumigraph NC-220F, Tokyo). Exchangeable potassium (K), sodium (Na), magnesium (Mg), and calcium (Ca) were extracted with 1 M (pH 7) ammonium acetate solution and their concentrations were determined using an atomic absorption spectrophotometer (Hitachi model Z-5000 series Polarized Zeeman, Tokyo). After removing excess NH_4^+, the sample was extracted with 100 g L^{-1} KCl solution and the supernatant was used to determine cation exchange capacity (CEC) using the semi-micro Schöllenberger method. Base saturation (BS) was calculated by dividing the sum of exchangeable cations (K, Na, Mg, Ca) by CEC and multiplying the result by 100%.

2.3 Tree Growth

Two tropical leguminous tree seedling used were *Falcataria molucana* (Miq.) Barneby & J.W. Grimes and *Albizia saman* (Jacq.) Merr. Seed of both species were purchased from a local seed company, Solo, Central Java, Indonesia. The seeds soaked in water at 80°C for two minutes. Seeds of these two trees species were pregerminated on plastic bag container using zeolite as growth medium. After the radicles appeared, they were selected for uniformity before sowing. Two hundreds gram of each soil sample was placed into polyethylene pot (7,5 cm height x 5 cm diameter).

30 pots from 6 treatments (3 forest soils and 3 gold mine tailings) with 5 replications were placed in the randomized block design. Two different trees were transplanted for each treatment and replicate to get a total of 60 pots. The experiment was conducted in the greenhouse at the Forest Research and Development Centre, Bogor, West Java (6°36” S, 106°45” E). Temperature varied between 26 to 35°C, relative humidity was 80 to 90% and the photoperiod was about 12 h. The seedlings were grown for 15 weeks. De-ionized water was added as required to maintain moisture content to the field capacity.

2.4 Harvest and Tree Analysis

The tree seedlings were harvested 15 weeks after transplanting. Some growth parameters were measured. Shoot height at one cm from the soil surface were measured every two weeks until 15 weeks after transplanting. After 15 weeks, shoot and root dry weight were harvested and recorded. Shoots and roots were then separated. Shoots were oven-dried at 70°C for 72 h before dry weighing.

2.5 Statistical Analysis

All experiments were laid out in a Completely Randomized Design with 15 replicates. All the data were analysis by using t-student analysis, using the package of minitab (Minitab, U.S.A). When F value were significant, the least significant different (LSD) was calculated to compare significant differences between treatment means.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Soil chemical characteristics of forest soil and gold mine tailings

Total N, carbon and available P of gold mine tailings were lower than that of forest soil. CEC, Mg, K and Fe of gold mine tailings were lower than that of forest soil. C/N ratio of gold mine tailings were higher than that of forest soil. Soil chemical characteristics of pH (KCL), pH (H_2O), Ca and Na of gold mine tailings were higher than that of forest soil. There was no difference in Ni between forest soil and tailings on gold mining (Table 1.)

3.1.2 Tree growth

Shoot height rate of *F. molucana* seedling on 8, 10, 13 and 15 weeks after planting was lower on gold mine tailing than that of forest soil (Fig. 1). There was no difference in shoot height between *F. molucana* seedling grown on forest soil and gold mine tailings on 2, 4 and 6 weeks after planting. Shoot height rate of *A. saman* grown on gold mine tailings was higher 6, 8, and 10 weeks after planting than that of forest soil. There was no difference in shoot height between *A. saman* seedling grown on forest soil and gold mine tailings on 2, 4, 13 and 15 weeks after planting.

Root dry weight of *A. saman* grown on gold mine tailings were higher than that of forest soil (Fig. 2) while shoot dry weight of *A. saman* grown on gold mine tailings were tended to have higher than that on forest soil. Shoot and root dry weight of *F. molucana* on gold mine tailings were lower than that of forest soil on gold mining (Fig. 3).

3.2 Discussion

3.2.1 Forest soil and gold mine tailings chemical characteristics

The process of gold production in gold mining, produces many tailings that have lower fertility than that in forest soil. Total N (TN), and available P concentration in gold mine tailings were lower than that in original forest soil before mining. It was decreased by 91.3%, and 35.8% respectively. The reduction of soil fertility was due to the removal of soil, plant material, and litter that was resulted from the processes of gold production. Total N and available P concentration of gold mine tailing were lower than that total N (0.429 g Kg^{-1}) and P (552 mg Kg^{-1}) of lead/zinc mine tailings in southern China [14], while total N of gold mine tailings similar to total N (0.36 g Kg^{-1}) of gold mine tailings in Malaysia. Available P, however lower than that P (0.76 g Kg^{-1}) of gold mine tailings in Malaysia [15]. On tailing, N is a major limiting nutrient and regular addition of fertilizer. N may be required to maintain healthy growth and persistance of tree seedlings [16]. An alternative approach might be to introduce legumes and other nitrogen-fixing species. Nitrogen fixing species have a dramatic effect on soil fertility through production of readly decomposable nutrient rich litter and turnover of fine roots and nodules. Also, native legume trees are more efficient in bringing out differences in soil properties than exotice legumes in the short term. Available P in gold mine tailings was decreased. After gold mining, the soil loses structure and fertility through the increased proportion of sand (lacking silt and clay particles) and deficiency in the organic matter content and cation exchange capacity [17]. This causes low water and nutrient holding capacity, thereby decreasing soil fertility to levels insufficient to support normal tree growth. The loss and deficiency of soil phosphorus (P) and bases generally constrain biomass production; however, high productivity on nutrient-deficient soils of tropical forests is to be maintained by plant and microbes adaptation to an acidic soil environment [18].

Total C concentration in forest soil was higher almost three times. Total C in gold mine tailings decreased by 75% compared to forest soil. The gold production process that produces gold mine tailings, affects the loss of soil organic matter (SOM), including organic carbon. This problem has serious implications because of the role of SOM in fertility, water holding capacity and overall quality of soil used for site reclamation. Soils from natural ecosystem may have high carbon stock [19]. The high value of C concentration in forest soil is supplied by the amount of vegetation and fauna in the forest [20]. It has been suggested that the soil C stock may comprise as much as 50% of the terrestrial C stock in the tropical rainforest [21]. While carbon storage in above ground biomass of tropical forests is commonly measured [22], this is not the case for other components, such as roots, understory vegetation, coarse woody debris, fine litter and soil. All these components can play an

Table 1. Soil chemical chracteristic between forest soil and tailing of gold mining

Location	Total nitrogen (%)	Total carbon (%)	C/N ratio	pH(H_2O)	pH(KCl)	Available P (mg P2O5/100 g)	CEC (cmol/kg)	Ca (mg/kg)	Mg (mg/kg)	K (mg/kg)	Na (mg/kg)	Fe (mg/kg)	Ni (mg/kg)
Forest soil	a	5.53 a	24.46 a	4.28 a	3.77 a	2.15 a	30.96 a	57.09 a	10.30 a	89.65 a	2.07 a	3.21 a	4.86 a
SE	0.04	0.53	7.71	0.11	0.08	0.19	2.91	10.98	1.49	25.64	0.25	0.05	1.00
Tailing	0.04 b	1.26 b	38.77 b	6.48 b	6.74 b	1.31 b	7.58 b	347.29 b	5.41 b	28.21 b	12.28 b	0.89 b	1.60 a
SE	0.00	0.16	5.91	0.04	0.06	0.07	0.80	5.61	5.41	5.34	2.12	0.38	0.80

Different letters within collum indicate significant difference ($p<0.05$) by t-test. Mean +/- standard error are shown (n=15) important role in the carbon storage and cylcling in tropical forest ecosystems.

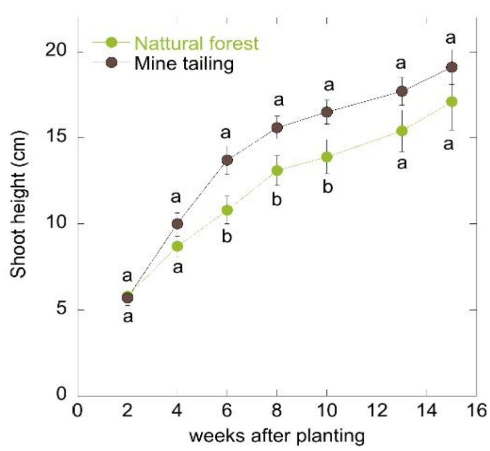
Soil pH in forest soil was very low compared with soil pH in gold mine tailings of gold mining. A very drastic change in pH is influenced by the soil factor and the living components, such as fungi, which has symbiotic relationships with plant roots helping in nutrient absorption from the soil. In tropical forest ecosystems, a paradoxical relationship is commonly observed between massive biomass production and low pH [18]. Soil acidification driven by plants and microbes does not simply mean "soil degradation" in tropical forests. Rather, this process reflects mineral weathering induced by plants and microbes and their acquisition of soil nutrients. The high biomass production by tropical trees is supported by the adaptions of plants and microbes to an acidic soil environment.

3.2.2 Growth of tree on gold mine tailings

Tree growth of *F. molucana* seedlings was extremely lower in gold mine tailings than that in forest soil (Fig. 1 and Fig. 3). Tree growth rate of *A. saman* grown on gold mine tailing, however was tend to have higher than that of forest soil even thought there is no significant difference (Fig. 1 and Fig. 2). *A. saman* seedlings were more tolerant than *F. molucana* in the gold mine tailings after 15 weeks of growth in the green house. *A. saman* has an indication to be ideal plant for being used on reclamation of gold mine tailings. The soil from gold mine tailings was characterized as having low levels of fertility sufficient to negatively affect tree growth. Young et al. [23], reported that low levels of organic amendments improved soil fertility and plant cover on old mine tailings. This means that organic matters provide a source of soil biota including bacteria, fungi as well as invertebrates capable of mineralizing the organic matter into plant available nutrients. Furthermore, other studies have reported that addition of compost and microbes not only increased soil fertility and plant biomass, but also reduced the concentration of trace elements in plant species growing on metal-contamined mine soils [24].

The soil chemical characteristic such as total N (TN), carbon and available P are very low on gold mine tailings .These are the factors that interfere with restrict to the growth of reclamation plants in the area of gold mine tailings. The use of organic fertilizer such as chicken manure, cow manure or litter compost may increase the success of plant growth for land reclamation of gold mine tailings. Chicken manure is the best organics fertilizer to increase the growth of *A. Saman* on post coal mining land in Indonesia that has very low of total of N, C and available P in the soil [25].

Management of soils and lands subjected to human perturbation is crucial to post gold mining rehabilitation of the impacted area [26]. Because soils are a fundamental component of tropical forest ecosystems from which most organism obtain essential materials such as nutrients and energy, as well as habitat, successful restoration of a disturbed area is highly dependent on maintenance of soil quality. Therefore, management practices that minimize detrimental impacts of human activities to the soil resource can prevent further site degradation and facilitate site rehabilitation. Alternatively, it is advisable to use a clay cover as barrier of air and water infiltrations. Undisturbed top soil is recommended to be used for clay cover, and this also serves as a fertilizer source for revegetation [27].



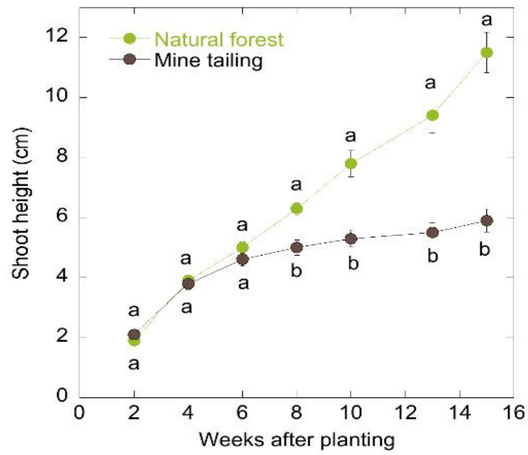


Fig. 1. Shoot height of *Albizia saman* (A) and *Falcataria molucana* (B) grown on forest soil and gold mine tailings for 15 weeks under greenhouse conditions

Different letters of each week indicate significant difference (P =.05) by t-test. Data are shown as mean +/- standard error (n=15)

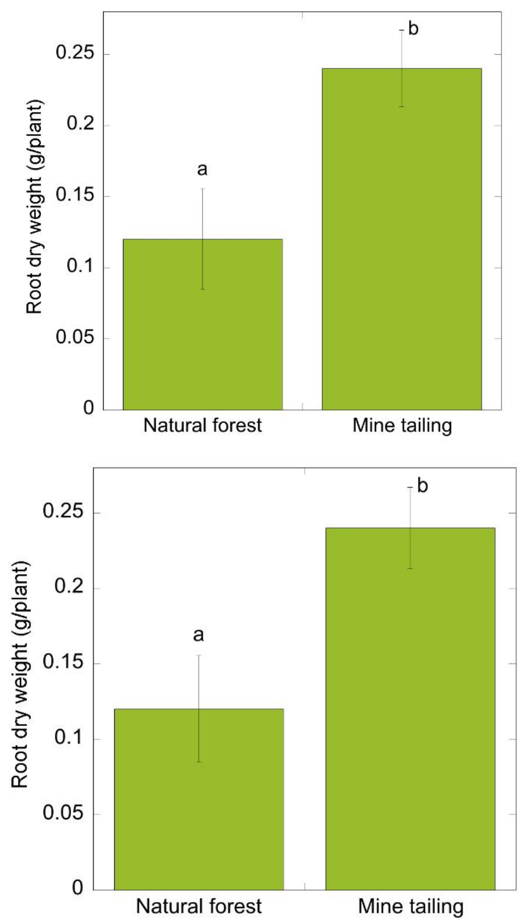


Fig. 2. Shoot and root height of *Albizia saman* grown on natural forest soil and gold mine tailing for 15 weeks

Different letters of each column chart indicate significant difference (P =.05) by t-test. Data are shown as mean +/- standard error (n=15)

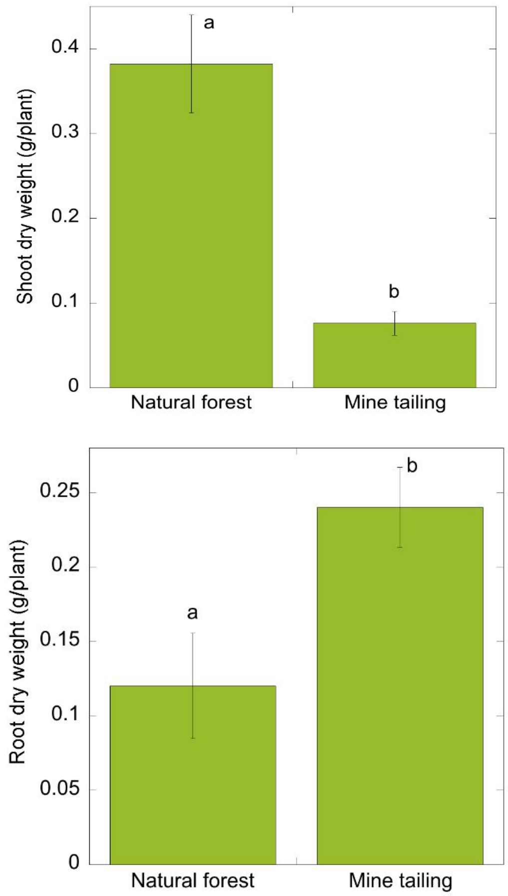


Fig. 3. Shoot and root height of *Falcataria molucana* grown on natural forest soil and gold mine tailing for 15 weeks

Different letters of each column chart indicate significant difference (P =.05) by t-test. Data are shown as mean +/- standard error (n=15)

Native grass species should be sown early to stabilize the top soil surface and to protech soil erosion. In addition, recommended practices/ managements for the company include the following: (i) Monitoring program of surface, deep well and shallow well waters should be performed every 6 months; (ii) pH plays a very important role for leaching of metals. Thus, it is strongly recommended to measure pH in all monitoring programs. Low soil fertility, species slow growth rates, and traces of heavy metal in plant tissues indicate that remediation and rehabilitation in areas degraded by gold mining can be very challenging.

4. CONCLUSION

Fertility of gold mine tailings as a result of the gold production process is lower compared to the forest soil in Indonesia. Total Carbon was also lower on gold mine tailings compared to forest soil. The declining in gold mine tailings fertility affects the success of the reclamation plant growth on post gold mining.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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