

Research Article

Post Bauxite Mining Land Soil Characteristics and Its Effects on the Growth of *Falcataria moluccana* (Miq.) Barneby & J. W. Grimes and *Albizia saman* (Jacq.) Merr.

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The remediation of opencast bauxite mines in the natural forests of Indonesia is difficult. We have investigated and contrasted the chemical characteristics of soils from natural forests and mining sites and their effects on plant growth. The 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 determined. *Falcataria moluccana* and *Albizia saman* were then grown in these soils for 15 weeks, and their shoot heights, shoot dry weights, and root dry weights determined. The post bauxite mining soils' N, C, and available P concentrations and exchangeable Ca, Mg, and Na concentrations decreased by 75, 75.7, 15.7, 92, 100, and 52%, respectively, in comparison with the natural forest soils. The shoot and root dry weights of *F. moluccana* when grown in the post bauxite mining soils were also lower than those from the natural forest soils. However, there was no difference in the shoot and root dry weights of *A. saman* when grown in the two soil types. The results suggest that opencast mining decreases the soil fertility, which in turn inhibits the initial growth of tree seedlings, and reduces the carbon stock in the land.

1. Introduction

The tropical rainforests on the Indonesian islands of the Riau Archipelago (Sumatera) vary greatly in their biodiversity but have soils that are generally poor in nutrients. In tropical rainforests, however, the biomass is the major pool for nutrients and not the forest soil content, as is found in temperate forests. While the material organic content of tropical soils is low overall, the decomposition processes on the forest floor and nutrient uptake are fast [1]. The organic carbon in tropical forests declined with depth, in the topsoil layer of East Kalimantan, Indonesia [2]. Information on soil characteristics in tropical rain forests, especially in Indonesia, is still very limited. Knowing the characteristics of the

soil in tropical rainforests is important to take a strategic step in the process of rehabilitation of degraded land.

Forest land cover has been decreasing due to forest conversion into cropland, oil palm, rubber plantations, and opencast mining, in Indonesia [3]. Bauxite is important for aluminium production, and one of its main producers globally, via opencast mines, is Indonesia. The process of opencast mining consists of clearing vegetation, topsoil stripping, and mining for the minerals [4]. This process affects the landscape of the local environment and its social well-being, as it causes tremendous physical, chemical, and biological damage to forests, impacting on their vegetation and animal biodiversity [5]. Further, the removal of the top layer of soil causes loss of structure and functionality and a

subsequent reduction in its biodiversity, resulting in socioeconomic impacts [6, 7]. A study provides a selection of 20 forest plant native species for increasing biodiversity and restoration of area disturbed by petroleum extraction activities in the Ecuadorian Amazon [8].

The rehabilitation of postmining land is required to repair damage to local environments. Various methods are employed to achieve this, such as landscape reclamation, planting ground cover crops, utilization of fast-growing plants, and remediation of water and soil contaminants. As soil pH declines, the supply of most plant nutrients decreases, while aluminium and a few micronutrients become more soluble and toxic to plants. The problems are particularly acute in humid tropical forests that have been highly weathered. The soil pH beneath dipterocarp forests and plantations in East Kalimantan, Indonesia, were on average below 4 [9]. According to Sanchez and Logan [10], for example, one-third of the tropical forests, or 1.7 billion hectares, is acidic enough for soluble aluminium to be considered toxic for most crop plants. In tropical forests, deep tropical weathering and decomposition of rocks have caused excessive solution and leaching of bases, leaving insoluble Fe and Al sesquioxides.

The rehabilitation of tropical forest ecosystems disturbed by bauxite mining is the aim of an increasing number of programs in many parts of the world, including Indonesia. However, bauxite mining is an impermanent activity that has long-term negative effects on tropical forests [6]. During the process of opencast mining, all vegetation and topsoils are removed, the soil fertility in each horizon is shuffled, and chemical, physical, and biological conditions rapidly deteriorate. The removal of vegetation and the disturbance of the soil profile reduce the nutrient pools available for seedling trees during mine site rehabilitation [7]. Forest soil compaction and erosion increase surface flow, flooding, and droughts in natural dipterocarp forests and the forest plantation industry in East Kalimantan, Indonesia [9]. The number of plant species and the amount of cover vegetation are thus found to be lower in post bauxite mining land than in those of natural forests.

Typically, bauxite is covered by a thick lateritic zone. This lateritic zone is completely removed to access the bauxite ore. Bauxite mining processes consist of blasting, removal of ore, and the movement of heavy vehicles that alter the soils physical and chemical properties [6]. The chemical properties of post bauxite mining soils can be strongly influenced by the presence of vegetation and tree species. It is necessary to know the chemical characteristics of the soil in post opencast mining land before implementing rehabilitation programs.

Selecting fast-growing tropical trees is important to increase the success rate of rehabilitation in degraded mining lands. *Falcataria moluccana* (Miq.) Barneby & J. W. Grimes and *Albizia saman* (Jacq.) Merr. are two tropical fast-growing species that are intensively grown to support rehabilitation programs of industrial forest plantations in Southeast Asia. *F. moluccana* is native to Molluca, New Guinea, the Bismark Archipelago, and the Solomon Islands and has been recognized as a multipurpose species as it can

be used for pulp and paper, fuel wood, and ornamental plantings, as a shade tree, and as a nitrogen supplier to soils [11]. *A. saman* is an important species used in the furniture and craftwork industries and has moderate wood density, attractive wood color, excellent workability properties, and natural durability, is considered a shade tree, and is also useful for animal feed [12]. It is necessary to select plant species that adapt to degraded post-opencast mining lands. The rehabilitation of postmining lands starts with rebuilding the soils biological capacity, mineral nutrient cycling, and establishment of plant communities [13]. Dissemination of successful rehabilitation activities on postmining land requires new collaborative science and technology-driven innovations [14].

The purpose of this study was to clarify the effects of opencast bauxite mining on the chemical characteristics of soil and its effect on the plant growth of *F. moluccana* and *A. saman* under greenhouse conditions.

2. Materials and Methods

2.1. Study Site and Soil Sampling. Soil was collected from both a natural Adinandra belukar forest, a secondary succession after cleared land exploitation of the primary lowland rain forest [9], and a post bauxite mining site, on Bintan Island, Sumatera, on 10 May 2011 (Figure 1). The samples were collected from 3 samplings points at the natural forest site of Adinandra belukar (0°52'21"N, 104°39'02"E) and 3 samplings point at the postmining site (0°49'22"N, 104°39'61"E) (Figure 2). Surface litter, fine roots, and stones were scraped away before taking the soil samples, and soils were collected from each sector at a depth of 0–25 cm. Fifteen soil samples from 3 randomized sampling points of the natural forest and 15 soil samples from 3 randomized sampling points of the postmining land were collected with a hand scoop, mixed, and placed in a clean plastic bag. A smaller portion of these homogenized samples (approximately 1000 kg) was diced and ground before laboratory analysis.

2.2. Soil Chemical Analysis. The soil samples were air-dried, passed through a <2 mm sieve, and used for the analysis of pH (H₂O) and pH (KCl). The use of the two methodologies for the measurement of pH was to indicate the presence of exchangeable protons or ions in the soil. The pH (H₂O) shows the actual pH of the solution in the soil while pH (KCl) is a potential pH of soil indicating pH in the soil solution and soil bonding complex. In pH potential, H⁺ ions are measured more than the actual pH. Furthermore, pH (KCl) was compared with pH (H₂O). Available phosphate (P) [15] was extracted with a 0.001 M sulfuric acid solution and analyzed using the ammonium molybdate method. Total carbon (TC) and total nitrogen (TN) were determined by a C:N analyzer (Sumigraph NC-220F, Tokyo). Exchangeable potassium, sodium, magnesium, and calcium 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

West Java (6°36''S, 106°45''E). The temperature varied between 26 to 35°C, relative humidity was 80 to 90%, and the photoperiod was about 12 h. The plants were grown for 15 weeks. Deionized water was added as required to maintain the moisture content to field capacity, by slowly pouring water over the pot that contains the plant, until the water excesses come out from the bottom of the pot.

2.4. Harvest and Analysis of Plants. Shoot height, from one cm above the soil surface, was measured every 2 weeks, until 15 weeks after transplanting when plants were harvested and the shoots and roots were separated. The shoots were oven-dried at 70°C for 72 h, and the shoot dry weight was measured.

2.5. Statistical Analysis. All experiments were laid out in a random block design with fifteen replicates. All the data were analyzed with Student's *t*-test, using the Minitab package (Minitab, U.S.A.). When *F* values were significant, the least significant difference test (LSD) was used to compare the significant differences between treatment means.

3. Results

3.1. Soil Chemical Characteristics of the Natural Forest and Post Bauxite Mining Land. The soil pH (KCl) of the post-mining land was higher than that of the natural forests (Table 1), but there was no difference between the soils for pH (H₂O). Total nitrogen, carbon, and available P concentrations in the soils of the postmining lands were lower than those in the natural forests, and the C/N ratio was higher. The CEC was not different between the postmining land and the natural forest. The exchangeable Ca, Mg, and Na concentrations of the postmining land were lower than those of the natural forest, and there was no difference in the exchangeable K, Fe, and Ni concentrations.

3.2. Growth of *Falcataria moluccana* and *Albizia saman* in Natural Forests and Postmining Land. Shoot height of the *F. moluccana* grown in both the natural forest and postmining soils increased from 2 to 15 weeks after planting (Figure 3(a)); however, 2, 4, 13, and 15 weeks after planting, those on the postmining soil were shorter compared with those in the natural forest soils. Shoot height of the *A. saman* seedlings in both the natural forest and postmining soils also increased from 2 to 15 weeks after planting (Figure 3(b)); however, 8, 10, 13, and 15 weeks after planting, those on the postmining soil were shorter compared with those in the natural forest soils.

The shoot and root dry weights, 15 weeks after transplanting, for the *F. moluccana* grown in the postmining soils, were lower than those in the natural forest (Figure 3). There was no difference in the shoot and root dry weights for *A. saman* for the different soil treatments (Figure 4).

4. Discussion

4.1. Effect of Opencast Bauxite Mining on Soil Chemical Characteristics. Opencast bauxite mining decreased the soil

fertility overall and the TN concentrations by 75% (Table 1). The reduction was due to the removal of tree cover, litter, and topsoil by the processes used to create the opencast mines. The reduction was higher than the 53% reduction reported for soil from an opencast coal mining site in India [16] and the 53–80% reduction in soil from an opencast coal mining site in the U.S.A. [17]. The effect of opencast mining on soil fertility in tropical areas is higher than that in nontropical areas. The reduction in TN was also higher than the 45% reduction in farmland compared with forests [18] and the 36% reduction after forest fires [19]. Deforestation by opencast mining overall affected soil fertility more severely than the other causes of deforestation.

The soil fertility of the postmining soils in Bintan Island was very poor in comparison to the natural soil. The soil pH is an important factor to support the growth of plants [20]. The pH of the postmining soils of the Bintan Island soils varied from 4.96 ± 0.05 for pH (H₂O) and 4.52 ± 0.09 for pH (KCl). The pH of KCl was lower than the pH of H₂O. These results could indicate the presence of exchangeable protons or ions in the soil. The soil can hold the cation exchanged in the plants. The pH of H₂O and pH of KCl of the postmining soils of the Bintan Island, however, were higher compared to the average soil pH of 3.6 from the Adinandra belukar in Singapore [9] and the Acrisols beneath the dipterocarp forest and plantation in East Kalimantan, that had pH values from 3.70 to 3.75 [2]. Because the soil pH of postmining land of Bintan Island were higher compared with the Adinandra belukar in Singapore, and the location of Bintan Island is geography adjacent to Singapore, thus reforestation of post bauxite mining land of Bintan Island may approachable by using a type of plant that grows in the Adinandra belukar in Singapore, such as *Adinandra Dumosa*, *Dillenia Suffruticosa*, and *Fragraea fragrans* [9]. Reforestation may also be approachable by the species plant from the dipterocarp forest. The total N of the postmining of Bintan Island was 0.4 ± 0.2 (g/kg). It was lower than the total N of 0.08 (%) of Adinandra belukar in Singapore [9] and 1.5 ± 0.6 (mg/g) of N at heat forest on Gunung Keriong, Pahang, Malaysia [21]. The species of nitrogen-fixing from leguminous trees could be used for reforestation of post bauxite mining land in Bintan Island with low of TN concentrations. The introduction of leguminous trees are able to form symbioses with nodulating N₂-fixing bacteria. The successful results using of nitrogen-fixing legume trees for the reclamation of areas degraded by mining activities in Brazil have been reported [22]. Soil physical characteristics can be different between natural soil and postmining soil and can affect the growth of plants.

4.2. Reduction in Carbon Stock by Bauxite Mining. Total C concentrations of the post bauxite mining soils were lower than those of the natural forest soils. The removal of the topsoil from a post bauxite mining site and mixing it with the underlying soil considerably reduced the relative proportion of organic carbon. The C concentration in the post bauxite mining soils was $0.7 \pm 0.2\%$; this range included in the level of organic carbon in overburden was found to be 0.35% to 0.85% [23]. C is an important parameter for any

TABLE 1: Chemical characteristics of the soils from the natural forests and post bauxite mining land.

Location	pH (H ₂ O)	PH (KCl)	Total carbon (g/kg)	Total nitrogen (g/kg)	C/N ratio	Available P (mgP ₂ O ₅ /kg)	CEC (cmol/kg)	Ca (mg/kg)	Mg (mg/kg)	K (mg/kg)	Na (mg/kg)	Fe (mg/kg)	Ni (mg/kg)
Natural forest	5.06	3.99	2.88	1.6	19.0	13.4	12.75	11.24	1.82	38.04	1.35	4.49	7.82
SE	0.07	0.04	4.1	0.3	0.9	0.2	1.71	0.29	0.74	19.39	0.52	0.52	1.02
Postmining	4.96	4.52	7.0	0.4	39.4	11.3	8.90	0.92	bdl*	81.54	0.65	3.72	5.72
SE	0.05	0.09	2.5	0.2	8.8	0.1	2.44	0.22		45.05	0.08	0.18	1.52

Different letters within column indicate a significant differences ($P < 0.05$) by the t test. Mean \pm standard error (SE) is shown ($n = 15$). *bdl: below the detection limit.

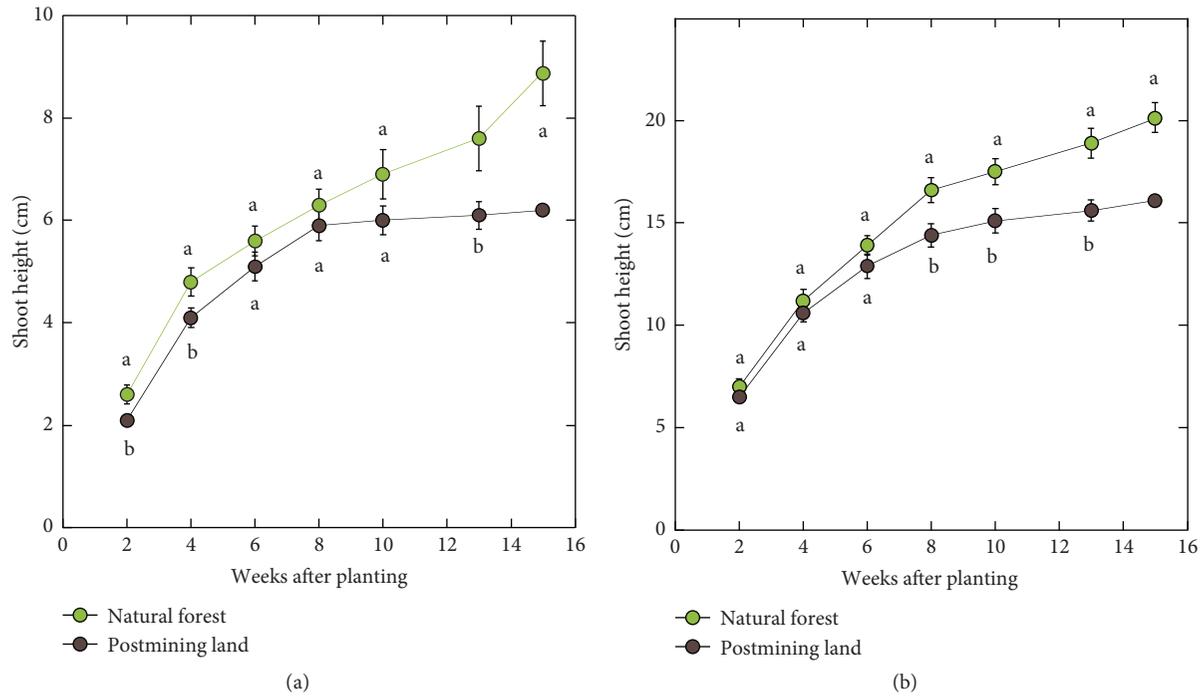


FIGURE 3: Shoot height of *Falcataria moluccana* (a) and *Albizia saman* (b) grown on natural forest soils and post bauxite mining soils for 15 weeks under greenhouse conditions. Different letters of each week indicate a significant difference ($P < 0.05$) by the t test. Mean \pm standard error is shown ($n = 15$).

soil, as it improves both the physical and chemical properties of the soil and has several favorable effects on soil quality. The advantages and functions of natural forest ecosystems are, for example, wildlife habitats, erosion, and flood defenses, water regulator, carbon sequestration, protecting shallow water ecosystems such as coral reefs and seagrass beds, and so forth [24]. Therefore, the forest type significantly affects the soil physicochemical property of the soil's microbial biomass carbon, nitrogen, and phosphorous [25]. It could be applied to the organic compost to increase C concentration in post bauxite mining for the rehabilitation activities. The use of organic fertilizers of chicken manure increases the organic C in the soil. It is better than that of cow manure and organic litter compost on *Samanea saman* tree on postmining land [26].

4.3. Growth of Plant in Post-Opencast Mining Land. Shoot dry weight of both *F. moluccana* and *A. saman* decreased in

the postmining soils, but the degree of the decrease was different between the two species (Figures 4 and 5). *A. saman* seedlings were more tolerant than the *P. moluccana* in the postmining soils after 15 weeks of growth under greenhouse conditions. The soil chemical characteristics, such as pH, are important factors to determine the growth of plants in soil postmining [20]. *A. saman* adapts to a wide range of soil types and pH levels, has a massive root system that expands both horizontally and vertically [27], can grow in soils that are free draining or those that have impeded drainage, can sometimes tolerate growth under waterlogged conditions, and finally, can grow in slightly acidic to neutral pH (6.0–7.4) soils while tolerating pH values as high as 8.5 and as low as 4.7. These characteristics of *A. saman* indicate that it would be ideal to use for the reforestation of post bauxite mining land. Many studies of postmining land in Africa have proven that pioneer leguminous trees show good adaptations and higher survival rates [28]. After *F. moluccana* and *A. saman* are established and grow well in post bauxite

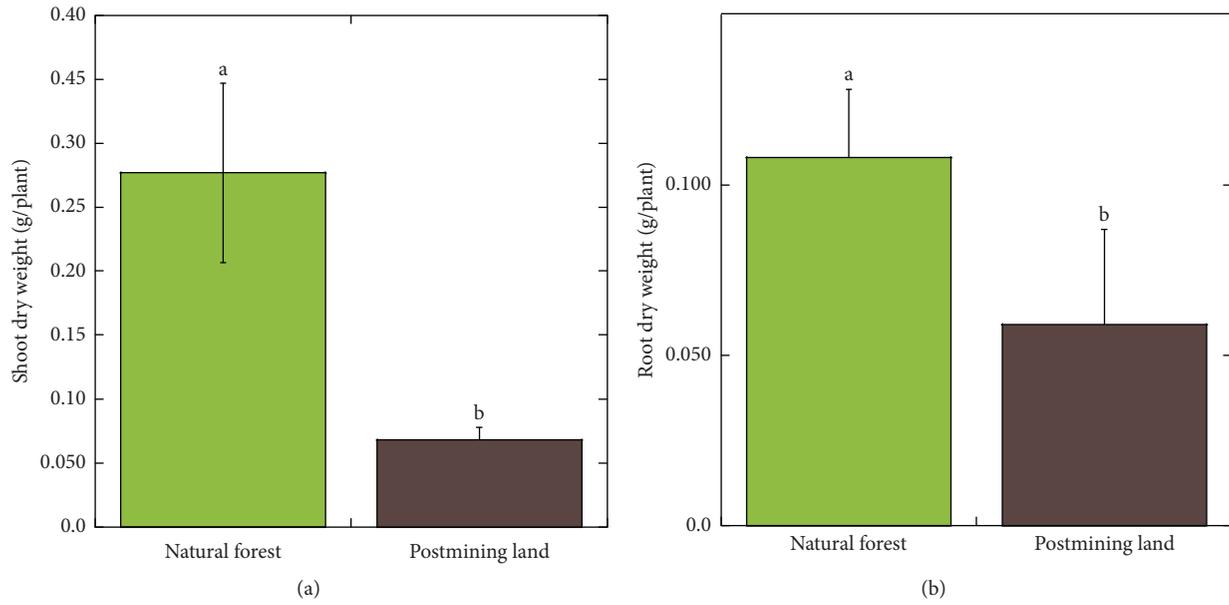


FIGURE 4: Shoot dry weight (a) and root dry weight (b) of *Falcataria moluccana* grown on natural forest soils and post bauxite mining soils for 15 weeks under greenhouse conditions. Different letters of each column chart indicate a significant difference ($P < 0.05$) by the t test. Mean \pm standard error is shown ($n = 15$).

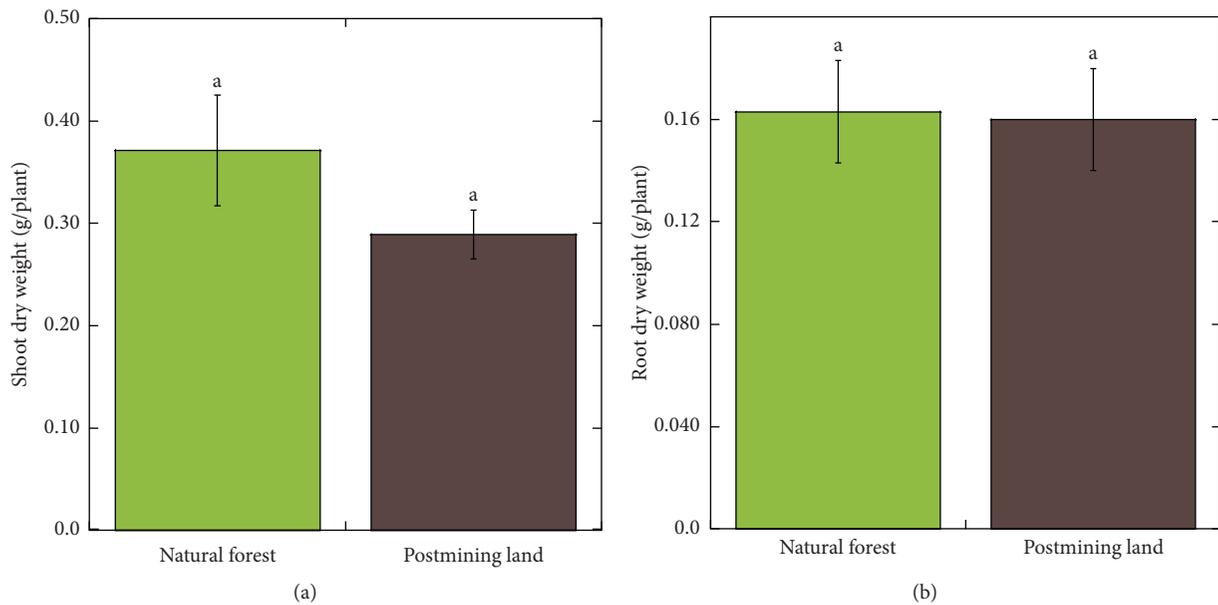


FIGURE 5: Shoot dry weight (a) and root dry weight (b) of *Albizia saman* grown on natural forest soils or post bauxite mining soils for 15 weeks under greenhouse conditions. Different letters of each column chart indicate a significant difference ($P < 0.05$) by the t test. Mean \pm standard error is shown ($n = 15$).

mining lands, there will be enrichment plantation using local species, including lots of local fast-growing trees species such as *Jacaranda obtusifolia*, *Macaranga bancana*, *Macaranga conifera*, and *Macaranga gigantea*. These species were identified as suitable in previous research if good quality and quantities of seeds can be sourced [29]. The bauxite mining activities decreased the fertility of natural forest soil. The application of fertilizer to improve soil fertility of post-

opencast mining land and the inoculation of effective microorganisms to increase the initial growth of tree species are necessary for the rehabilitation of post bauxite mining land. This strategy of rehabilitation activity is to develop bio-indicators of hydro-geochemical and reconstruct root zones, which can enhance the recovery of the microorganism communities and ecological networks with rehabilitated plant communities in post bauxite mining land [13]. *F.*

moluccana and *A. saman* are widely used rehabilitation of disturbed land in Indonesia. The present result shows that *A. saman* is more suitable for the rehabilitation of post bauxite mining land. Growth response of plants in post opencast mining land should also be investigated under field conditions.

5. Conclusions

Soil fertility of opencast bauxite mining land was lower than that in the natural forests in Indonesia. Organic carbon concentrations were also lower in the opencast bauxite mining land than in the natural forest, suggesting a reduction in carbon stock by opencast mining. The soil fertility of post bauxite mining soils for total N, C, available P concentrations, exchangeable Ca, Mg, and Na concentrations decreased by 75, 75.7, 15.7, 92, 100, and 52%, respectively. Reduced soil fertility in post bauxite mining land decreased the growth of tree species. However, *A. saman* seemed to be the more tolerant tree species for rehabilitation on post bauxite mining land.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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