Available online at:
http://journal.unila.ac.id/index.php/tropicalsoil
DOI: 10.5400/jts.2021.v26i1.19

# Revegetation of Critical Land with Gaharu (*Aquilaria malaccensis*) under Various Ameliorants Application

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Received August 27, 2020; Revised October 19, 2020; Accepted 31 December 2020

## ABSTRACT

Rehabilitation of post-mining limestone soils is often a challenge due to a lack of nutrients and poor soil humus. The research aims to study the effect of various ameliorants on soil chemical properties, growth, and P uptake of *gaharu* plant (*Aquilaria malaccensis*) in post-mining limestone soil for revegetation of critical land. The research was conducted in a Completely Randomized Design with three replications. The treatments were P0 (Control, without ameliorant); P1 (Humic Acid, HA, 4 kg ha$^{-1}$); P2 (Phosphate Rocks, PR, 350 kg ha$^{-1}$); P3 (Vesicular Arbuscular Mycorrhizal Fungi, AMF, 500 spores plant$^{-1}$); P4 (HA+AMF); P5 (PR+AMF); and P6 (HA+PR+AMF). Data were analyzed using ANOVA at 95% confidence level and continued with the LSD test. The use of various types of ameliorants (HA, RP, and AMF) significantly increased root length, root volume, wet and dry weight of roots, shoot wet and dry weight, and P uptake of *gaharu* tree. The best ameliorant in increasing *gaharu* tree growth was AMF (P3) treatment, and AMF combined with HA (P4) treatment. Thus, for revegetation of critical land, especially post-mining limestone land, using *gaharu* tree requires HA and AMF inoculation.

***Keywords***: Critical land, gaharu plant, land rehabilitation, post-mining limestone soil

## INTRODUCTION

*Gaharu* is a local plant and many distributed in Lampung, Sumatra. According to the IUCN Red List (2020), *gaharu* is one of the rare types of plants with CR (*Critically Endangered)* status. *Gaharu* is categorized as a critical plant due to overexploitation and conversion of its natural habitat. Therefore, *gaharu* cultivation and reintroduction are crucial to do immediately so that this species does not become extinct.

Currently, there are about 27 species of *gaharu* scattered in Indonesia, but the ones that grow and develop in Sumatra are *Aquilaria malaccensis, Aquilaria microcarpa,* and *Grynops sp.* This research uses *Aquilaria malaccensis,* which is widespread in Sumatra, assuming that this species is still in the same ecoregion as the research location so that genetically and environmentally, these species will be easier to develop in the research location. Based on Law Number 32 of 2009 concerning the protection and management of the environment, an ecoregion is a geographical area that has the same characteristics of climate, land, water, native flora and fauna, as well as patterns of human-nature interaction that illustrate the integrity of the natural system and the environment.

*Gaharu* tree is usually used in post-mining land reclamation because it grows fast, does not require a lot of nutrients and light, is easy to grow, low costs in planting and maintenance, and is easy to manage (Lawing 2018 ). In this study, *gaharu* seedlings were used as an effort of revegetation on post-mining limestone soils in Camang Hill, Bandar Lampung. The post-mining limestone soil is an unfertile soil with low organic matter and nutrient content and low soil microorganisms activity, and it is categorized as a critical land. The use of ameliorants can be suggested to improve the soil fertility of critical land. There is a different role between fertilizers and soil amendments/ameliorants. Fertilizers impact plant growth directly, while soil ameliorants affect growth indirectly and sometimes deliver nutrients as a side effect. Soil ameliorants are not fertilizer substitutes. Soil ameliorants also change the soil in ways that affect the availability of plant nutrients that occur naturally or added by fertilizers.

Many studies show that apply ameliorants can improve soil fertility and increase crop yields

(Baloyi *et al.* 2014; Ghorbani *et al.* 2010; Sindhu *et al.* 2016; Smith and Read 2010 ). Baloyi *et al.* ( 2014) also state that the different ameliorants (IMBA types) significantly increased organic C contents, available N, and P in light-textured soils. Moreover, the different IMBAs promoted higher microbial biomass-C immobilization at 4-weeks after planting, while biomass-C mineralization was predominant at flowering and crop harvest regardless of soil type. Rusli *et al.* (2016) found that optimizing the rubber growth at post-mining tin land needs soil ameliorants application such as clay and compost.

This study used arbuscular mycorrhizal fungi (AMF), humic acid (HA), and rock phosphates (RP) as ameliorants. AMF fungi infect plant roots of most species under various soil conditions (Smith and Read 2010) and provide plant nutrients, especially phosphorus, from the soil solution solution (Mosse 1973).

Hajoeningtijas (2009) stated that mycorrhizae play a role in improving plant nutrition and increasing plant growth and as a biological protector that can increase plant resistance to soil-borne pathogens. Thus, AMF can be used as an alternative technology to help growth, increase productivity, and improve plants, especially those planted on marginal, less fertile soils. While, uric acid increases plant growth, production, and quality improvement of agricultural yields (Abdel-Mawgoud *et al.*2007) and also increases absorption of nitrogen, potassium, calcium, magnesium, and phosphorus by the plant (Haghighi *et al.*2011). Also, rock phosphate fertilization increased the dry matter yield of wheat plants Omar (1997). Moreover, the application of phosphate rock and AMF as ameliorants gave the highest percentage of root infection by mycorrhizae at 4-month-old *gaharu* (*Aquilaria malaccensis*) seedlings (Alawiyah 2020).

The research aims to study the effect of various types of ameliorants, namely AMF, HA, and RP, on the chemical properties of soil, growth, and P uptake of *gaharu* (*Aquilaria malaccensis*) in post-mining limestone soils for revegetation of critical land.

## MATERIALS AND METHODS

### Study Site

Research was done in the Greenhouse of Botanical Institute of Technology Sumatra (ITERA) and soil analysis in the Soil Science Laboratory, University of Lampung.

### Experimental Set-Up

This study was designed in a completely randomized design with seven treatments and three replications. The treatments were a combination of ameliorants, namely P0 (without ameliorant, Control); P1 (Humic Acid, HA); P2 (Rock Phosphate, RP); P3 (Vesicular Arbuscular Mycorrhizal Fungi, AMF); P4 (a combination of HA and AMF); P5 (a combination of RP and AMF); and P6 (a combination of HA, RP, and AMF). Each treatment used six plants for each replication so that there were 126 experimental units.

### Preparation of Plant Seedlings, Planting Media, and Maintenance of Plant Growth

*Gaharu* tree seedlings at 4-months of age from Persemaian Permanen Balai Pengelolaan Daerah Aliran Sungai dan Hutan Lindung (BPDASHL) Way Seputih-Way Sekampung, Kalianda, South Lampung. The planting media use a mixture of post-mining limestone soil from Camang Hill in Bandar Lampung, rice husks, cow manure, and topsoil from the Botanical Gardens of the Sumatra Institute of Technology with a ratio of 2: 2: 2: 1. The post-mining limestone soils come from limestone rock debris that descends into the transportation route area at the foot of Camang Hill. The properties of the limestone soil of Camang Hill is presented in Table 1. It can be seen that the limestone soil of Camang Hill has low soil fertility with a sandy texture. However, it has a slight acidity-neutral pH with high available-P. Phosphorus (P) is readily available in the pH range 5.5 to 7.0, at pH below 5.5 P will be bound by Al and Fe to become Al-P and Fe-P while at pH above 7.0 P will be bound by Ca become Ca-P (Weil and Brady 2017).

Preparation of planting medium is done by filtering ground post-mining limestone and topsoil using a sieve size of 1 cm × 1 cm. Each limestone soil and topsoil was weighed individually as much as 0.5 kg. After that, the materials were mixed with cow manure as much as 0.5 kg and rice husk 0.25 kg until blended. The mixture was then put into the

Table 1. The limestone soil properties of Camang Hill Bandar Lampung.

| Properties | Value |
|---|---|
| pH | 5.59 |
| Total N (%) | 0.01 |
| Available-P (mg kg $^{-1}$) | 15.17 |
| Organic-C (%) | 0.07 |
| Exec-Al (me 100g $^{-1}$) | 0.09 |
| Water Content (%) | 0.22 |
| Texture | Sandy |
| Sand | 83.68 |
| Silt | 8.00 |
| Clay | 8.32 |

Figure 1. The appearance of gaharu roots under various ameliorants application.

polybags until the media's weight for each treatment was 1.75 kg polybag$^{-1}$. RP (350 kg ha$^{-1}$) was given to the media by mixing and stirring until blended. Simultaneously, HA (4 kg ha$^{-1}$) was dissolved with water according to the dosage and sprinkled on the planting medium. HA and RP applications were carried out one week before planting. AMF (500 spores plant$^{-1}$) was applied when planting the plant seedlings by spreading mycorrhizal spores around the roots. The AMF used are mixtures of a genus of glomus, gigaspora, acaulospores, and entropospores.

*Gaharu* trees were grown up to 12 weeks. The trees were maintained by watering everyday. The growth variables were plant height, stemdiameter, number of leaves, root length, root volume, root wet weight, shoot wet weight, root dry weight, shoot dry weight, and plant P uptake. All variables were observed until 12 weeks after planting (WAP).

**Soil Medium Analysis**

Analysis of soil medium (pH, total-N, organic-C, availableP and Exch-K) performed twice which was at initially before applying ameliorant, and at the 12 WAP. Meanwhile, the plant P-uptake was analyzed at 12 WAP. Soil pH measurements used the Electrometric method (1:2.5), total-N using the Kjeldahl method, available-P using the Olsen method, Exch-K using the $NH_4OAc$ pH 7.0 method, and organic-C using the Walkley and Black method, and Plant P-uptake using the $HNO_3 + HClO_4$ method.

**Data Analysis**

Data were analyzed using analysis of variance (ANOVA) with SAS software. Before ANOVA, data were checked its homogenity and additivity. If the ANOVA treatments had a significant difference, then the analysis was continued with the Least Significant Difference (LSD) with a significant level of 5%. The correlation between the soil variables and the growth variables was also carried out.

## RESULTS AND DISCUSSION

Results the analysis of variance showed that the use of ameliorant had a significant effect on the growth of *gaharu* tree which were root length, root volume, root wet and dry weight, shoot wet and dry weight, and plant P-uptake (Data not shown).

Table 2. Effect of ameliorant on root lengths and root volumes of gaharu tree seedlings at 12 WAP.

| Treatment | Root length (cm) * | Root volume (ml) * |
|---|---|---|
| P0 (without ameliorant, Control) | 14.0 ± 1.15 d | 2.0 ± 0.00 d |
| P1 (HA) | 20.0 ± 0.58 b | 4.5 ± 0.87 cd |
| P2 (PR) | 22.5 ± 0.87 ab | 4.5 ± 0.29 cd |
| P3 (VAM) | 17.0 ± 0.58 c | 17.5 ± 1.44 a |
| P4 (HA + VAM) | 24.5 ± 0.29 a | 11.5 ± 2.02 b |
| P5 (PR + VAM) | 17.0 ± 1.15 c | 2.0 ± 0.00 d |
| P6 (HA + PR + VAM) | 21.5 ± 1.44 b | 7.5 ± 0.29 c |
| LSD (0.05) | 2.9 | 3.1 |

* Mean ± SE (Standard Error). The numbers followed by the same letter were not significantly different based on the LSD test (á 0.05).

Table 3. Effect of various types of ameliorant on wet weight and dry weight of gaharu roots at 12 WAP.

| Treatment | Root wet weight (g)* | Root dry weight (g)* |
|---|---|---|
| P0 (without ameliorant, Control) | 1.60 ± 0.13 d | 0.27 ± 0.01 d |
| P1 (HA) | 2.12 ± 0.50 d | 0.43 ± 0.05 cd |
| P2 (PR) | 4.54 ± 0.02 cd | 0.74 ± 0.01 bcd |
| P3 (VAM) | 15.4 ± 2.55 a | 1.01 ± 0.44 bc |
| P4 (HA + VAM) | 11.1 ± 1.79 b | 1.69 ± 0.26 a |
| P5 (PR + VAM) | 1.69 ± 0.12 d | 0.37 ± 0.01 d |
| P6 (HA + PR + VAM) | 6.67 ± 0.35 c | 1.11 ± 0.00 ab |
| LSD (0.05) | 3.65 | 0.60 |

* Mean ± SE (Standard Error).
The numbers followed by the same letter were not significantly different based on the LSD test á 0.05.

**Root Length and Root Volume**

The appearance of *gaharu* roots under various ameliorants application can be seen in Figure 1. The use of ameliorants significantly increased root length of *gaharu* plant on 12 WAP (Table 2). The longest *gaharu* roots were in treatment P4 (HA+AMF) and did not differ from P2 (RP) but significantly longer than other treatments. The shortest roots were found in the treatment without ameliorant (Control). Humic Acid and AMF play a role in increasing the availability of soil nutrients. Humic Acid used in this study contained of 85.32% humic acid, exch-K of 20.47%, pH of 9.3, the water content of 8.47%, and the solubility level is very high, namely 94.08% (source: Surmikas PT Mulia Bintang Utama).

The increase in plants nutrient content will affect the physiological processes of plants that play a role in plant growth and development. One indication of a good plant growth form is the increasing length and number of roots, both primary and secondary. Root growth is also closely related to the soil structure of the media used for growth. In addition to Camang Hill limestone soil, the planting medium for this study also used organic matter as cow manure. Hayati *et al.* (2012) stated that to improve soil structure, one thing that can be done is to add organic matter to the planting medium.

Furthermore, based on the data on the average volume of *gaharu* roots on post-mining limestone soil, it can be seen that the best root volume is in P3 (AMF) treatment and the lowest is in P0 (without ameliorant, Control) treatment and at P5 (RP +AMF) treatment (Table 3). AM fungi can solubilize P that is not available to become available to plants by releasing phosphatase enzymes and organic acids, especially oxalates, which can release phosphate, where phosphate is needed in nucleotides and plays a role in energy metabolism (Weil and Brady 2017). However, AMF that was given RP decreased the root volume due to P availability from RP, thus reducing the function and activity of AMF. A similar condition with available N, Streeter (1988) stated in the presence of high concentrations of combined nitrogen (i.e., nitrate, ammonium), plants do not need $N_2$-fixation and nodule formation is suppressed.

The differences between ameliorant treatments on root length and root volume at different observation times (4, 8, and 12 WAP) are presented in Figure 2. It can be seen that at the beginning of growth, the length and volume of the roots at without ameliorant (control) and at HA and RP have better long root and root volume than AMF and other combined ameliorants application. However, as time passes, the opposite occurs, application of AMF and its other combination has a better root length and root volume. The functions of AMF, HA, and RP play a role in dissolving and providing P nutrients, affecting root growth.

**Roots Wet and Dry Weight**

The most significant wet weight of *gaharu* roots at 12 WAP treated with various ameliorant treatments was P3 (AMF) (Table 3). The AM fungi helps provide P to plants. Phosphorus plays a vital role in the growth of plant roots. According to Weil and Brady (2017), P is needed in vast amounts for cell division and growth in meristematic tissues. Root growth, particularly the development of lateral roots and fibrous rootlets, is encouraged by phosphorus.

The roots wet weight are closely related to the moisture content in the roots. Plant roots will absorb water well when the media used can store water properly. So that when plants need water, the roots can easily absorb it. The planting medium used is a mixture of sandy limestone soil, rice husks, cow manure, and topsoil, creating suitable physical, chemical, and biological conditions for plant growth. When the soils physical, biological, and chemical

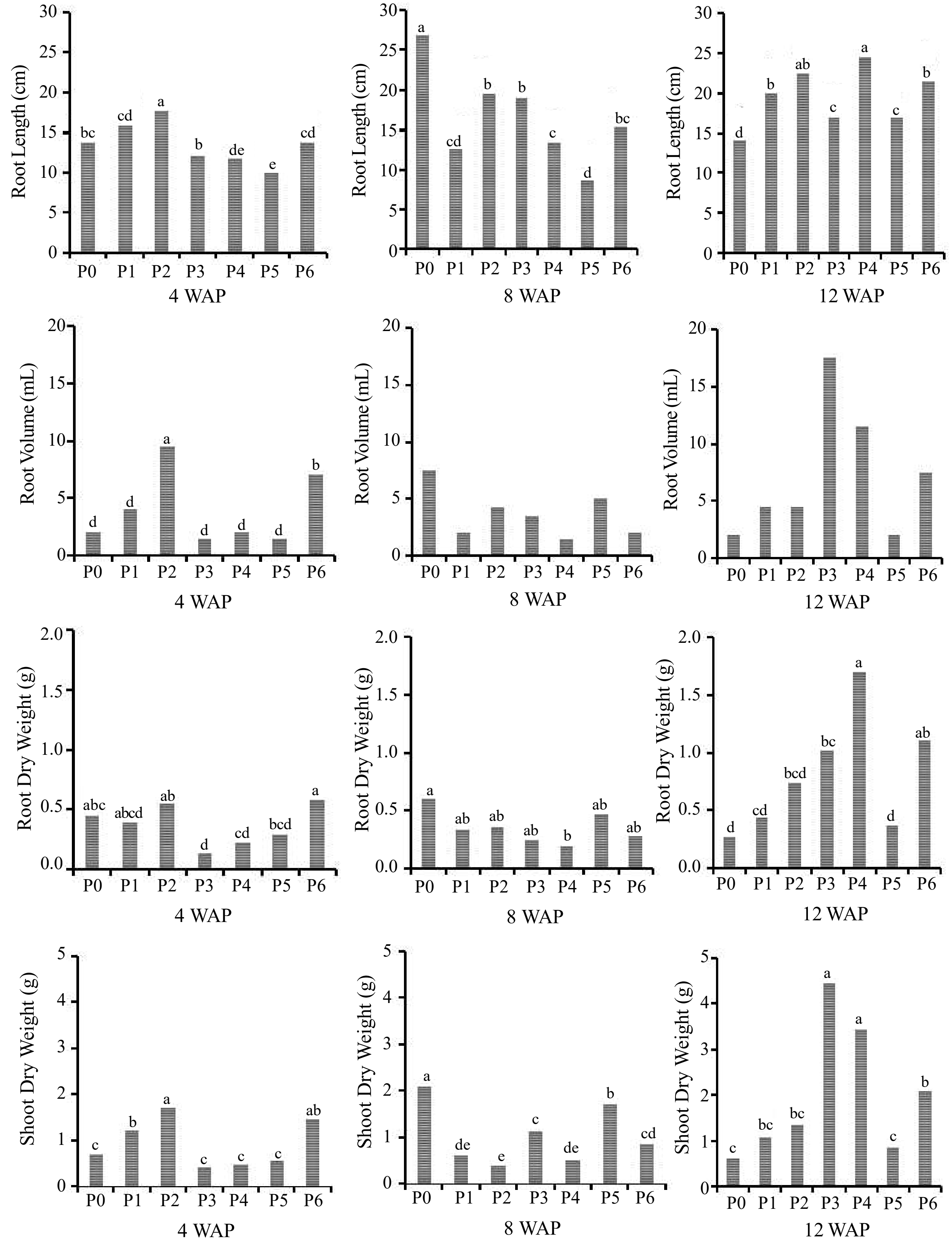


Figure 2. Differences in gaharu plant growth (root length, root volume, root dry weight, and shoot dry weight) at 4 WAP, 8 WAP, and 12 WAP under various types of ameliorant. (P0 = without ameliorantt, control ; P1 = HA ; P2 = RP ; P3 = AMF ; P4 = H A+AMF ; P5 = RP+AMF ; and P6 = H A+RP+AMF ).

conditions are reasonable, good availability of water stored in the planting medium will be followed by good availability of water and will increase the wet weight of the roots.

Table 4. Effect of various ameliorant types on shoots wet and dry weights of gaharu at 12 WAP.

| Treatment | Shoots wet weight (g)* | Shoots dry weight (g)* |
|---|---|---|
| P0 (without ameliorant, Control) | 2.16 ± 0.21 c | 0.62 ± 0.02 c |
| P1 (HA) | 3.51 ± 0.54 c | 1.07 ± 0.08 bc |
| P2 (PR) | 4.78 ± 0.27 bc | 1.34 ± 0.12 bc |
| P3 (VAM) | 15.7 ± 2.49 a | 4.45 ± 0.72 a |
| P4 ( HA + VAM) | 4.48 ± 1.74 bc | 3.43 ± 0.72 a |
| P5 ( PR + VAM) | 2.94 ± 0.24 c | 0.85 ± 0.04 c |
| P6 (HA + PR + VAM) | 7.38 ± 0.13 b | 2.08 ± 0.09 b |
| LSD (0.05) | 3.57 | 1.19 |

* Mean ± SE (Standard Error)
The numbers followed by the same letter were not significantly different based on the LSD test (á 0.05).

Furthermore, the dry weight of *gaharu* roots given various ameliorant types on post-mining limestone soil can be seen in Table 4. It can be seen that the most enormous root dry weight was in the P4 (HA+AMF) treatment and was not significantly different from the P6 (HA+RP+AMF) at 12 WAP. The lowest root dry weight was in P0 (without ameliorant, Control) and in P5 (PR + AMF) treatments. There was no difference between the P0 and P5 treatments due to sufficient P available from the PR treatment (Table 5) so that AMF did not function appropriately in dissolving the nutrient P.

The differences between ameliorant treatments for root wet and dry weight at different observation times (4, 8, and 12 WAP) can be seen in Figure 2. The wet weight of the roots will be followed or directly proportional to the results of the roots dry weight. Water in plant tissue will evaporate when dried and play a role in producing plant weight (Kuswandi and Sugiyarto 2015). Apart from water, the provision of ameliorants also plays a role in providing nutrients needed by plants to increase plant dry weight (Septiyana *et al.* 2017). Giving each application HA and PR did not significantly contributing to the water growing media, so there is no difference between the the roots wet and dry weights. However, giving AMF together with HA ameliorants can contribute water, so there is a difference between wet weight and dry weight of *gaharu* plant roots. AMF can expand the root surface, while HA can improve soil fertility.

**Shoots Wet and Dry Weight**

Different types of ameliorants gave different effects on the shoots wet and dry weight of *gaharu* tree at 12 WAP (Table 4). The application of various ameliorants to *gaharu* seedlings showed that an enormous shoot wet weight was in the P3 (AMF) treatment. AMF plays a role in increasing P-uptake in plants. Phosphorus needed in plants is one of the factors that affect the wet weight of the shoots. The P element helps in protein formation, stimulates root growth and development, and circulates energy to all parts of the plant (Kurniaty *et al.* 2013). Likewise, in his research, Same (2011) found that giving 10 g of mycorrhizae per plant was able to increase the wet weight of the oil palm seedlings.

The differences between ameliorant treatments on shoot wet and dry weight at different observation times (4, 8, and 12 WAP) are presented in Figure 2. The increase in shoot wet weight from month to month in each plant type is a normal metabolic process under enough water condition. Water is essential for various cell metabolism processes and photosynthesis, which are necessary for plant growth and development (Kuswandi and Sugiyarto 2015).

Based on data on the average shoot dry weight of *gaharu* tested on post-mining limestone soil, it can be seen that the most extensive shoot dry weight was in the P3 (AMF) and P4 (HA+AMF) treatments. AMF can increase P-uptake in plants, so that, the availability of P elements can increase plant growth. The synergy relationship between HA and AMF affects the shoot growth of *gaharu* tree seedlings. HA improves the soils chemical and biological fertility, and AMF fungi help dissolve P nutrients so that sufficient nutrient availability will increase shoot growth. Shoot dry weight is an indicator of plant growth and development because dry weight is an accumulation of organic compounds successfully synthesized by plants and is closely related to nutrient availability and reflects these plants nutritional status (Sitompul *et al.* 2014).

**Plant P-Uptake**

DDifferent types of ameliorants had different effects on the P-uptake of *gaharu* tree seedlings at 12 WAP (Table 5). The application of P2 (RP)

Table 5. Effect of various types of ameliorants on the plant P-uptake of gaharu at 12 WAP.

| Treatment | P-uptake (%) * |
|---|---|
| P0 (without ameliorant, Control) | 0.200 ± 0.032 bc |
| P1 (HA) | 0.137 ± 0.013 bc |
| P2 (PR) | 0.333 ± 0.077 a |
| P3 (VAM) | 0.247 ± 0.049 abc |
| P4 (HA + VAM) | 0.300 ± 0.023 ab |
| P5 (PR + VAM) | 0.187 ± 0.007 bc |
| P6 (HA + PR + VAM) | 0.227 ± 0.028 abc |
| LSD (0.05) | 0.119 |

* Mean ± SE (Standard Error)
The numbers followed by the same letter are not significantly different based on the LSD test.

ameliorant in the mixtured post-mining limestone medium resulted in the highest plant P-uptake, but it was not different from P3 (AMF), P4 (HA+AMF), and P6 (HA+PR +AMF). Except for P2 treatment, the plant P-uptake of *gaharu* did not differ between other treatments. The high P content in the growing medium (Table 6) did not affect the plant P-uptake of *gaharu* in general.

The RP application can increase the availability of P in the growing medium. The results of initial soil analysis showed that available-P content is very low on the post-mining limestone soil (Table 1), application RP through slow release can increase the availability of P element needed by plants in the growth phase. The application of AMF also dramatically supports plants ability to absorb P (Budi and Christina 2013). Several studies have shown that the application of AMF to plants can increase the P- uptake. Nurmasyitah and Khairuna (2017) research showed the higher the AMF dose given, the higher the P-uptake in Acehnese local pepper seeds. The results also supported by the research of Nurrobifahmi (2017) who states that a combination of mycorrhizae (AMF) and natural Morocco phosphate (RP) by the percentage degree of root colonization is 20.00 ± 11.26 %, the highest yield grain weight of 22.53 g per plant in sorghum plant.

Ameliorant HA plays a role in improving the physical, chemical, and biological properties of soil and can accelerate energy metabolism in cells. Humic acid as a soil ameliorant can enrich 5-9% of the soil C content (Suwahyono 2011). Mycorrhizae can increase P uptake, while humic acid can increase other macros and micronutrients (Mosse 1973).

Chen and Aviad (1990) stated that humic acid applied to plants could increase plant height, roots wet and dry weight, number of lateral roots, shoot growth, and nutrient uptake. Humic acid plays a role in plant physiology, improves soil structure and soil chemical fertility, affecting nutrient uptake and plant growth (Ikbal et al. 2016), and plays a role in binding Al and Fe so P become available for plants (Wijayanto and Azis 2013).

**Soil Chemical Properties**

The available-P is high in *gaharu* plant growing media at initial before ameliorant application (Table 6) and at 12 WAP (Table 7).

Based on Table 5, it can be seen that the P2 (RP) treatment has a higher available-P value than other treatments. Nevertheless, statistically, it has the same value as treatment P4 (HA+AMF), P3 (AMF), P1 (HA),and P6 (HA+RP+AMF). One of the factors that influence plant P-uptake is the water

Table 6. Soil chemical properties in the initial planting medium (before ameliorant application).

| Soil Properties | Measurement value | Category * |
|---|---|---|
| pH | 6.7 | Neutral |
| Total-N (%) | 0.29 | Moderate |
| Available-P (mg kg $^{-1}$ ) | 369.29 | Very high |
| Exc-K (%) | 0 56 6 | Moderate |
| Organic-C (%) | 4.66 | Very low |

* Categories based on Soil Research Institute (2009)

Table 7. Soil chemical properties of gaharu plant growing media at 12 WAP.

| Treatment | pH | Total-N (%) | Available-P* (mg $kg^{-1}$) | Exch-K (% ) | Organic-C (%) |
|---|---|---|---|---|---|
| P0 (without ameliorant, Control) | 6.55 | 0.07 | 70.23 c | 1.22 | 4.37 |
| P1 (HA) | 6.44 | 0.12 | 141.96 abc | 0.85 | 4.63 |
| P2 (PR) | 6.17 | 0.25 | 178.18 a | 1.12 | 3.71 |
| P3 (AMF) | 6.78 | 0.26 | 156.29 ab | 1.36 | 4.64 |
| P4 (HA + AMF) | 6.23 | 0.22 | 163.40 a | 1.34 | 4.09 |
| P5 (PR + AMF) | 6.77 | 0.20 | 80.85 bc | 1.05 | 3.66 |
| P6 (HA + PR + AMF) | 6.77 | 0.37 | 135.30 abc | 1.15 | 3.75 |
| LSD (0.05) | | | 78.48 | | |

*The numbers followed by the same letter's is not significantly different based on LSD test.

factor which functions to dissolve nutrients and minerals so that absorption is related to the P concentration in the soil solution, which is influenced by soil pH (Rosi *et al.* 2016). Related to initial soil pH of the planting medium (Table 7) and soil pH at plant harvest 12 WAP (Table 5) they have a pH ranging between 6.17 and 6.77, which is slightly acidic to neutral so that the P element becomes available for plants.

Soil chemical properties results at the initial media and the final growth *gaharu* plants experienced significant changes, especially in the available-P and exch-K parameters. There was a decrease in P in all ameliorants treatments. The available P in the initial media was 369.29 mg $kg^{-1}$, but after 12 weeks, the available-P content in plants decreased significantly, ranging from 70.23 to178.18 mg $kg^{-1}$, although still in the high range. The P

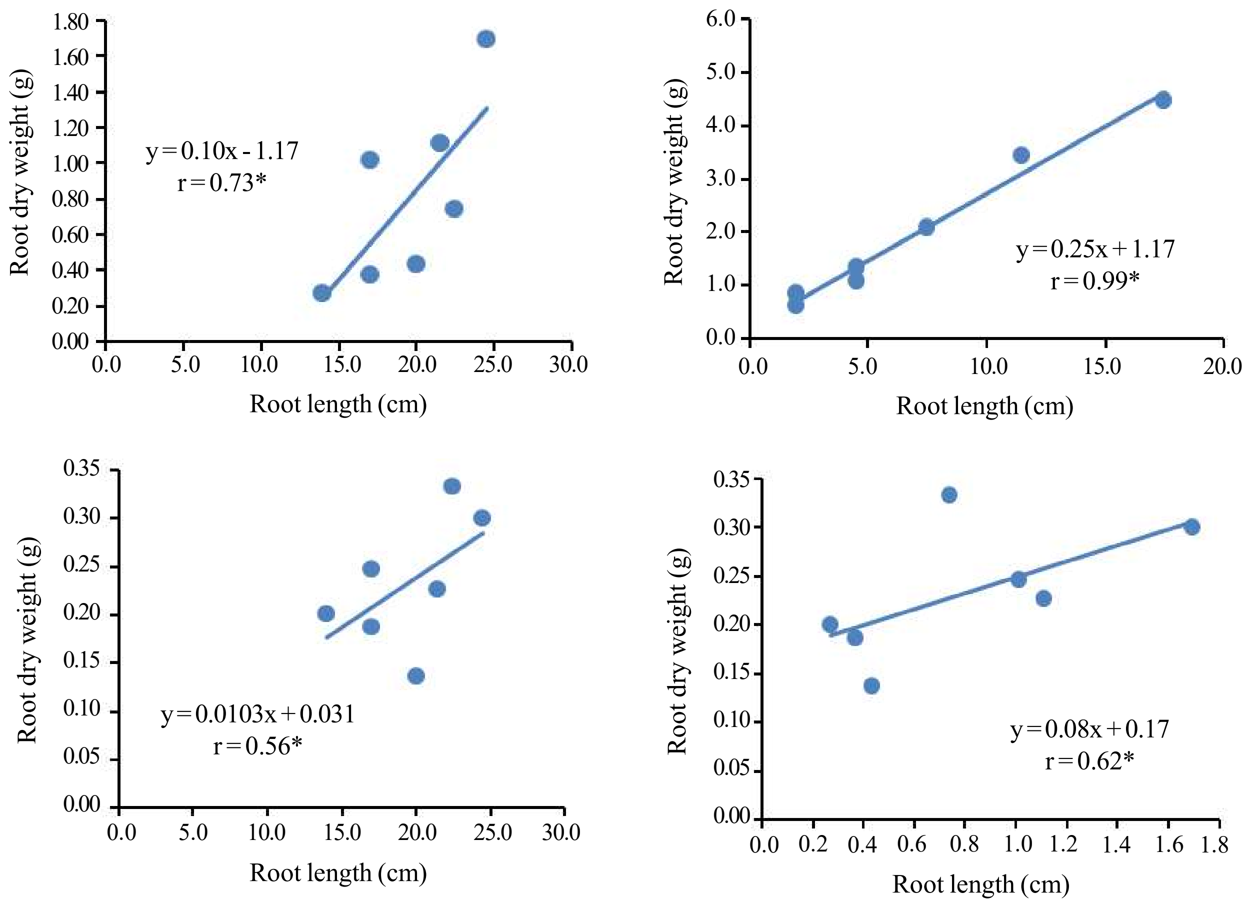


Figure 3. A correlation between root length and root dry weight (upper left), root volume and shoot dry weight (upper right), root length and plant P-uptake (bottom left), and between root dry weight and plant P-uptake (bottom right).

contained in the initial media is partially absorbed by plants and is mainly eroded (Faizin *et al.* 2015) or washed into deeper soil layers (Purwantono *et al.* 2011). Moreover, the post-mining limestone soil has sandy texture that is easily eroded. On the other hand, in the medium for *gaharu* 12 WAP, there was an increase in exch-K content. In the initial medium, the interchangeable K is 0.566 % while at the end of the planting medium, 12 WAP, ranged from 0.85 to 1.36%. The increase in K content can be exchanged in the planting medium, presumably because in addition to post-mining limestone soil, the planting medium also consists of topsoil, rice husks, and cow manure. Also, the application of organic matter in the form of humic acid or microorganisms in AMF is thought to act as a catalyst that can increase soil exch-K. The application of organic materials can stimulate the growth of microorganisms and bacteria that affect K content in the soil. Hidayati *et al.* (2011) suggested that potassium can be bound and stored in cells by bacteria and fungi.

### Correlation Test

There is a positive and significant correlation between root length and root dry weight, root volume and shoot dry weight, root length and plant P-uptake, and between root dry weight and plant P-uptake (Figure 3 ). The increase in root length will increase in dry root weight and P-uptake of *gaharu*. Furthermore, increasing root volume will increase plant shoot dry weight, and increasing root dry weight will increase the P-uptake of *gaharu*. The treatment of various types of ameliorants affect the development of plant roots. A good root development will increase the roots' ability to absorb water and nutrients so that plant growth will be better and P uptake will also be higher.

## CONCLUSIONS

The use various types of ameliorants (HA, RP, and AMF) significantly increased root length, root volume, roots wet and dry weight, shoot wet and dry weight, and P-uptake of *gaharu* tree seedlings. Treatment P3 (AMF) significantly increased root volume, shoot dry weight, and plant P-uptake, while P4 treatment (HA+AMF) significantly increased root length, root dry weight, shoot dry weight, and plant P-uptake of *gaharu* at 12 WAP. Thus, the best ameliorant in enhancing the *gaharu* plant growth is AMF (P3) and a combination of HA and AMF (P4) treatments. Thus, for revegetation of critical land, mainly post-mining limestone land, using *gaharu* tree seedlings requires HA and AMF inoculation.

## ACKNOWLEDGMENTS

We thank the University of Lampung (Unila), the Faculty of Agriculture Unila, and the Sumatra Institute of Technology, Bandar Lampung, Indonesia to facilitate this research. DIPA BLU Unila funded the research through the 2019 Unila Postgraduate Grant program. Thank also to Dr. Christine Wulandari and Dr. Asmarhansah, who has provided many suggestion during writing this paper.

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