Heavy metal absorption of four fast growing tree species on media containing tailing from Pongkor gold mining in Indonesia

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Abstract. Gold mining often left tailing that contains heavy metals which is hazardous to the environment. Phytoremediation is one of cheap strategies which usually utilized to manage the heavy metal pollution. This study aimed at investigating the potential ability of four fast growing tree species, i.e. Mahogany (Swietenia macrophylla King.), Red Jabon (Anthocephalus macrophyllus (Roxb.) Havil.), Kayu Afrika (Maesopsis eminii Engl.), and Suren (Toona sureni (Blume) Merr.) to absorb heavy metal on media which contain tailing from Pongkor gold mining, Indonesia. Seedlings of those species were planted on two kinds of growing media, i.e. tailings and mixture of tailings + compost with 3:1 ratio, in a Completely Randomized Factorial Design. Soil analysis on growth media were done at the beginning and the end of experiment after four months, as well as the plants. Observation was made on concentration of 6 heavy metals, i.e. Cu, Fe, Hg, Mn, Pb and Zn. Results showed that all four tree species used were able to absorb those heavy metal from the media with different concentrations, however none of them could be categorized as hyperaccumulator. The highest total absorption was observed on media containing 1200g tailing by S. macrophylla King at amount of 1862.78 ppm.

1. Introduction
Indonesia ranks 10th in the top 10 gold producers in the world and at present produces around 4% of global gold production. Gold mining however, often left tailings that contains heavy metals which is hazardous to the environment. Tailings is a mixture of solid wastes of fine particles, size 0,001−0,6 mm, in the form of mud, which is often deposited in a pond. Without proper treatment tailings poses threats to the environment since the volume is usually very large and the heavy metals contained in the tailings could leak anytime to the surrounding ecosystem. Remediation of tailings and contaminated soil with heavy metal is very important aspect of ex-mining activities in order to restore the mining area back to normal.

Most of mining activities in Indonesia usually take place in a forested area. One example is gold mining and processing by PT Antam at UBPE Pongkor, Bogor, Indonesia which takes place at Halimun-Salak National Park. The mining company has made great effort to keep the ecosystem intact by closed, cut and fill-mining, however many local miners conduct traditional mining without thinking of its environmental impacts, similar to other mining locations in Indonesia [1, 2, 3]. Ex-gold mining area and tailings were reported containing heavy metal such as Cu and Pb [4] Mn and Zn [5]
Hg, Cd [6]. To sum up the problems of ex-mining reclamation, phytoremediation is inevitable to maintain the national park ecosystem [7].

In Indonesia phytoremediation has been popular recently because usual reclamation techniques are expensive. Phytoremediation is a green technology that uses plants to rehabilitate ex-mining and contaminated land [8, 9]. The mechanisms to remediate contaminated land and clean the heavy metal pollution is by phytoextraction, phytostabilization, phytovolatilization, and rhizofiltration [8, 10]. In almost all phytoremediation activities utilization of a hyperaccumulator plant species is necessary to accumulate the heavy metal or other contaminants. Hyperaccumulator is a plant species that could potentially absorb heavy metals higher than normal plants, often up to at least 0.1% of its dry biomass [11].

This study aimed to investigate ability of seedlings of four tropical tree species, i.e. Mahogany (Swietenia macrophylla), Red Jabon (Antocephalus macrophyllus), Kayu Afrika (Meisopsis eminii), and Suren (Toona sureni) to absorb heavy metal contaminants from media containing tailings from gold ex-mining in Pongkor, Bogor, Indonesia.

2. Method

2.1. Materials
There were two types of media used in this experiment, i.e. pure tailings and a mixture of tailings and compost with a ratio of 3:1, of which consisted of 900g tailings mixed with 300g compost. Tailings was taken from PT Antam UBPE Pongkor, Bogor and sent to a greenhouse at Department of Silviculture, Faculty of Forestry, IPB University, as well as compost obtained from a Permanent Nursery at Darmaga, Bogor. The weight of media put in a polybag was 1200g each. Seedlings of four tropical tree species, i.e. Mahogany (S. macrophylla), Red Jabon (A. macrophyllus), African wood (M. eminii), and Suren (T. sureni) of age 3 months old and at similar height and diameter were recruited from Permanent Nursery, Darmaga, Bogor.

2.2. Procedure
Seedlings were transplanted carefully to polybags and whole experimental units were placed inside the greenhouse. Seedlings were watered every day and media were maintained at optimum field capacity. Maintenance such as weeding was done to take out the undesirable plants. Experimental units were kept for 4 months. In the beginning all media components, i.e. tailing, soil and compost were analyzed, later at the end of experiment, all growth media were also analyzed in SEAMEO BIOTROP. Plants analysis were also conducted only at the final period.

2.3. Factorial design & data analysis
The experiment used Completely Randomized Factorial Design with two factors, of which growth media and tree species were served as treatments, with 3 replications. Possible combinations out of the treatments, i.e. 2 types of growth media (A) and 4 kinds of tropical tree species (T), replicated 3 times is presented in Table 1. Each experimental unit consisted of 10 individuals, which made 240 polybags in total.

Furthermore, data was analyzed by using linear model to calculate a response variable (Y) on each experimental unit using the equation of Wilkinson and Rogers [20]:

\[ Y_{ijk} = \mu + a_i + b_j + (a\beta)_{ij} + \varepsilon_{ijk} \]

Where :
- \( Y_{ijk} \) = The observation of the response variable on the \( k^{th} \) replication of the \( i^{th} \) level of A (media type) and the \( j^{th} \) level of B (tree species)
- \( \mu \) = The mean value
- \( a_i \) = The effect of the \( i^{th} \) level of A
- \( b_j \) = The effect of the \( j^{th} \) level of B
$$\alpha \beta \gamma ij = \text{The interaction between the i}^{\text{th}} \text{ level of A and the j}^{\text{th}} \text{ level of B}$$

$$\epsilon ijk = \text{The residual effect}$$

i = Media type (pure tailings, mixed tailings+compost)

j = Tree species (mahogany, red jabon, African wood, suren)

k = replication of 1, 2, and 3

In this study, F-test was employed to test the effect of treatments. Data were computed on SAS 9.1.3 software with following hypothesis:

a. P-value > $\alpha$ (0.05) indicated the treatments did not have a significant effect on the parameters tested.

b. P-value < $\alpha$ (0.05) indicated the treatments have a significant effect on the parameters tested. In this study, these treatments would be tested by Duncan’s test, a post-test to measure specific treatment.

**Table 1. Layout of experimental design**

| Growth media | Replication | Tropical tree species |
|--------------|-------------|-----------------------|
|              |             | T1                    | T2 | T3 | T4 |
| A1           | 1           | A1T11                 | A1T21 | A1T31 | A1T41 |
|              | 2           | A1T12                 | A1T22 | A1T32 | A1T42 |
|              | 3           | A1T13                 | A1T23 | A1T33 | A1T43 |
| A2           | 1           | A2T11                 | A2T21 | A2T31 | A2T41 |
|              | 2           | A2T12                 | A2T22 | A2T32 | A2T42 |
|              | 3           | A2T13                 | A2T23 | A2T33 | A2T43 |

Note: A1 = Tailings (1200g); A2 = Tailings (900g) + compost (300g); T1 = Mahogany (*Swietenia macrophylla*); T2 = Red Jabon (*Antocephalus macrophyllus*); T3 = Kayu Afrika (*Meisopsis eminii*); T4 = Suren (*Toona sureni*)

3. Result and discussion

Tailing often contains hazardous substances. Soil analysis (Table 2) showed that tailing sample contained heavy metals, including Cu, Zn, Mn, Fe, Pb, and Hg. Heavy metallic element such as Pb is commonly found to be associated with Zn-Cu in the ore body. High accumulation of Pb leads to environmental damage and its massive dispersion should be controlled, as well as Hg [12]. Table 2 also showed that original soil from PT Antam UPBE Pongkor area, where mining is not taking place have relatively low concentration of heavy metal. The hazardous elements contained in the control show innumerable value or negligible (ne), indicating the soil is not composed of heavy metals. For instance, concentration of each Cu and Mn in the control is only 0.00119% and 0.00175% of the tailings. Therefore, heavy metal content in the tailings is much at higher level that could drive stress on any plant.

**Table 2. Heavy metal content on tailings, original soil, and compost used in this study**

| Media        | Cu (ppm) | Fe2O3 (%) | Hg (ppm) | Mn (ppm) | Pb (ppm) | Zn (ppm) |
|--------------|----------|-----------|----------|----------|----------|----------|
| Tailing      | 58.5     | 3.62      | 0.11     | 2288     | 75.1     | 49.1     |
| Soil         | 0.07     | ne        | ne       | 4.02     | ne       | ne       |
| Compost      | ne       | 1.68      | ne       | ne       | ne       | 583.5    |

The analysis of variance shows that all treatments, media types and tree species, equally affected heavy metal contents in the media at the end of experiment. Duncan’s test ranges are depicted in Table 3. Treatment T2A1 (1200g of tailings media planted with *A. macrophyllus*) has the highest Cu content at amount of 49.4 ppm, while Mn and Hg contents were at 120.6 ppm and 0.04 ppm respectively. Heavy metal contents of Cu and Pb in A2 media (900g tailings + 300g compost) were lower than A1 media (1200g tailings). Other elements, Fe and Hg contents found in A2 media (900g tailings + 300g compost) planted with T1 (*S. macrophylla*), T2 (*A. macrophyllus*) also had lower metal content.
compared to A1 media (1200g tailings). Generally, mixed media planted with any type of plants had smaller heavy metal content than pure tailings.

### Table 3. Summary of Duncan’s test on heavy metal contents of media with respective plant types in this study

| Treatment | Cu     | Fe   | Hg     | Mn     | Pb    | Zn     |
|-----------|--------|------|--------|--------|-------|--------|
| T1A1      | 49.0 b | 40000 a | 0.03 b | 101.9 g | 83.9a | 222.7 b |
| T1A2      | 40.7 g | 27700 h | 0.02 c | 104.1 f | 75.5e | 219.4 e |
| T2A1      | 49.4 a | 36300 d | 0.04 a | 120.6 a | 78.9d | 218.9 f |
| T2A2      | 41.8 f | 34000 e | 0.03 b | 111.5 c | 74.5g | 222.3 c |
| T3A1      | 46.8 d | 38900 b | 0.01 d | 114.2 b | 80.7b | 221.5 d |
| T3A2      | 44.2 e | 32300 f | 0.01 d | 97.60 h | 74.7f | 226.0 a |
| T4A1      | 48.9 c | 29000 g | 0.02 c | 109.7 d | 80.6d | 217.4 h |
| T4A2      | 36.7 h | 38400 c | 0.02 c | 109.4 e | 66.5h | 218.3 g |

Note: The same letter in a column shows no significant effect at 95% confidence level.

The addition of compost in growth media as ameliorant could increase soil fertility by improving its physical and chemical properties. Good ameliorant criteria are having high base saturation, being able to increase the pH level, improve soil structure, and remove dangerous compounds, particularly organic acid, as well as having complete nutrient content. Ameliorant can be either organic or inorganic. Provision of ameliorant, such as organic fertilizer, mineral soil, zeolite, dolomite, natural phosphate, manure, plant lime, ash husk, and Chinese water chestnut (Eleocharis dulcis) can increase soil bases and pH. As an ameliorant substance, polyvalent cations can also reduce the impact of toxic organic acids [13].

The percentage of differences in heavy metal content of all media (Table 4) was calculated from collected data in the beginning and at the end of experiment. The result shows that all treatments of tree species and growth media combinations responded well to the reduction of Cu, Mn, and Hg marked by (-) symbol. The decreasing of Mn is the highest, reaching more than 90%. Thus indicate all types of tree species (S. macrophylla, A. macrophyllus, M. eminii, and T. sureni) can be considered as phytoremedians in absorbing Cu, Mn, and Hg contained in the tailings. Symbol of (+) indicates increasing metal contents, particularly Zn element on all treatments, which were enhanced more than 300%. This particular results might be due to unusually high content of Zn in the compost (Table 2), although it didn’t explain the case of pure tailings media.

### Table 4. Summary of percentage of differences of heavy metal content in the media compared to original tailings

| Treatment | Cu   | Fe   | Hg   | Mn   | Pb   | Zn   |
|-----------|------|------|------|------|------|------|
| T1A1      | -16.24 | +10.50 | -72.73 | -95.55 | +11.72 | +353.56 |
| T1A2      | -30.43 | -23.48 | -81.82 | -95.44 | +0.53 | +346.84 |
| T2A1      | -15.56 | +0.28 | -63.64 | -94.73 | +5.06 | +345.82 |
| T2A2      | -28.55 | -6.08 | -72.73 | -95.13 | -0.80 | +352.75 |
| T3A1      | -20.00 | +7.46 | -90.91 | -95.01 | +7.46 | +351.12 |
| T3A2      | -24.44 | -10.77 | -90.91 | -95.73 | -0.53 | +360.29 |
| T4A1      | -16.41 | -19.89 | -81.82 | -95.21 | +7.32 | +342.77 |
| T4A2      | -37.26 | +6.08 | -81.82 | -95.22 | -11.45 | +344.60 |

Note: (-) = decreasing heavy metal content in respective media after 4 months

(+ ) = increasing heavy metal content in respective media after 4 months
Mixed growth media could reduce the heavy metal content of Cu and Pb greater than pure tailings media. In addition, all tree species types planted on mixed media can also reduce the heavy metal content of Fe and Hg greater than planted on pure tailings media. This is caused by the organic material contained in compost improve the physical and chemical properties of tailings. According to Jhonson et al. [2002] in Inonu et al. [14], organic matter plays important role in improving soil aggregate stability, increasing water holding capacity, soil cation exchange capacity, providing carbon for soil microorganisms and as a source of nutrients.

In general, plants can absorb heavy metals without damaging their growths, and some of them can avoid the presence of heavy metals at high concentrations. Plants that have the ability to absorb and concentrate heavy metals in their biomass at high levels without endangering plant life are defined as hyperaccumulators [15]. Research on hyperaccumulator plant species is essential to determine the potential rate of heavy metals absorption, without reducing its resistance aspect due to heavy metal poisoning. Study of the absorption ability (Table 5) is estimated from metal elements content contained in plant tissue by comparing the experimental data with previous research held by [16, 17, and Alloway 1995 in Santoso et al. [18].

Table 5 shows all treatments can absorb metals with different concentrations. T1A1 treatment (S. macrophylla on tailings media) has the highest ability with the total absorption reached 1862.78 ppm, while T4A1 treatment (T. sureni on tailings media) absorbs the least heavy metal with a total absorption of 837.6 ppm. T1 or S. macrophylla absorbs Fe content at 1523.2 ppm which is the highest concentration compared to other elements. However, some of S. macrophylla species died in this experiment, which might be caused by exceeding Fe concentration in the tissue more than the capacity of the species tolerance to the toxic substance. The symptom was withering of the lower leaves, followed by the upper leaves in the second month. The death of S. macrophylla's seedlings was found in the fourth month. T2A1 treatment (A. macrophyllus on tailings media) accumulates the second-highest heavy metal content with a total of 1826.67 ppm and accumulates Fe at 1474.3 ppm. However, all A. macrophyllus seedlings of this treatment did not die during observation [7]. In addition, there are some recommended pioneer that suitable to be used as phytoremediation, i.e. red jabon (Anthecephalus macrophyllus) [19], Gmelina (Gmelina arborea) [20], as well as rosewood (Dalbergia latifolia) and pine (Pinus merkusii) [10].

4. Conclusion
All treatments, i.e. media types and tree species, equally affect heavy metals content in the experimental units, of which Anthecephalus macrophyllus performed well in tailings media. Mahagony (Swietenia macrophylla King.), Red Jabon Merah (Anthecephalus macrophyllus (Roxb.)

Table 5. Heavy metal contents in plant tissues of tree species types grown on respective media

| Treatment | Heavy metal content (ppm) |
|-----------|---------------------------|
|           | Cu (5-20) | Fe (10-1000) | Hg (0.01-0.3) | Mn (20-500) | Pb (0.1-10) | Zn (25-150) | Total      |
| T1A1      | 33.9      | 1523.2     | 0.18        | 223.7       | 8          | 0.18        | 1862.78    |
| T1A2      | 123.6     | 526.5      | 0.18        | 183         | 10.4       | 0.18        | 901.48     |
| T2A1      | 15.6      | 1474.3     | 0.07        | 183.7       | 14.7       | 0.07        | 1826.67    |
| T2A2      | 22.7      | 1282       | 0.05        | 192.6       | 5.5        | 0.05        | 1640.15    |
| T3A1      | 19.8      | 1224.6     | 0.19        | 279.6       | 11.3       | 0.19        | 1512.89    |
| T3A2      | 15.7      | 979.5      | 0.09        | 162.6       | 7          | 0.09        | 1265.89    |
| T4A1      | 12.9      | 643.2      | 0.10        | 91.7        | 8          | 0.10        | 837.6      |
| T4A2      | 30.9      | 816.5      | 0.12        | 79.1        | 10.3       | 0.12        | 1012.52    |

Note: a Estimated metal content in plant tissue by Munawar [16]  
      b Estimated metal content in plant tissue by Barchia [17]  
      c Estimated metal content in plant tissue by Alloway 1995 in Santoso et al. [18]

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Havil.), Kayu Afrika (Maesopsis eminii Engl.), and Suren (Toona sureni (Blume) Merr.) were able to absorb heavy metals, i.e. Cu, Fe, Hg, Mn, Pb and Zn from the media with different concentrations, however none of them could be categorized as hyperaccumulator. The highest total absorption was observed on media containing 1200g tailing by S. macrophylla at amount of 1862.78 ppm.

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