

The Role of Soil Amendment on Tropical Post Tin Mining Area in Bangka Island Indonesia for Dignified and Sustainable Environment and Life

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Abstract. Openly tropical tin mining in Bangka Island Indonesia expose heavy metal that had been buried became a part of our environment and life. This has become a major cause of land degradation and severe local-global environmental damages. This study aims to accelerate reconsolidation of degraded ecosystems on the former tin mine land, to increase land productivity and dignified environment through appropriate rehabilitation technology on marginal land that is inexpensive, environmentally friendly and sustainable. This study is a part of a roadmap research activities on the rehabilitation of degraded land in tropical ecosystem, that consist of (a) characterization of degraded tin mining lands through the determination of chemistry, physics, biology and mineral soil properties, (b) introducing multi-function pioneers plant for acceleration of peak pioneer plant in the reestablishment of degraded tin mining ecosystem (c) management of natural soil amendment (volcanic ash, organic waste materials and legume cover crop as a material for soil amelioration to increase land productivity, (d) role of biotechnology through the application of local bio-fertilizer (mycorrhizae, phosphate soluble bacteria, rhizobium). Soil from post tropical tin mining acid soil (pH 4.97) that dominated by sand particles (88%) with very low cation exchange capacity, very low nutrient contents (available and total-N, P, K, Ca, Mg) and high toxicity of Zn, Cu, B, Cd and Ti, but still have low toxicity of Al, Fe, Mn, Mo, Pb, As. Soil amendment of biogas and volcanic ash could improve soil quality by increasing of better pH, high available-P and cation exchange capacity and maintained their low toxicity. The growth (high, diameter, biomass, top-root ratio) of exotic pioneer plant of Kemiri sunan (*Reutealis trisperma*) increased in the better soil quality that caused by application of proper soil amendment. The grand concept and appropriate technology for rehabilitation of degraded tin-mining land ecosystems in tropical regions which are the lungs of the world have a high contribution for development of our dignified and sustainable environment and life.

1. Introduction

Over exploitation of tropical forest ecosystem is drastically leading to land degradation and damages [1]-[5]. Open mining become one of anthropogenic disturbance on tropical forest ecosystem drastically leading to land damage and degradation. Nevertheless, mining of natural resource is one of important industries because of its contribution to economic development in Indonesia. Approximately 30% of global tin production took place in two islands of Indonesia, which were Bangka and Belitung in which tin mining has been being operated since 1668 [6]. Indonesia was the second biggest mining



producer in 2013 (95,200 tons) and 2014 (84,000 tons) after China (110,000 tons in 2013 and 125,000 tons in 2014). Global tin reserve was predicted to be about 4.8 million tons and China ranked the highest (1.5 million tons) followed by Indonesia (800,000 tons) [7].

Tin mining process using simple purification process and sluice box was common method in Indonesia. The method was based on the difference in the weight of tin and quartz sands. Tin ore would be left in the sluice box, while the quartz sands would be carried by the water flow [8]. The tin mining process in huge tailing number resulted in very toxic metal concentration at low soil pH [9]. The removal of upper layer of ground in the mining process caused loss of important macro and micro nutrients useful for plants [10]. One of several soil health parameters was soil nutrient concentration and traditionally considered as important parameter in mining area.

The mining process by removing soil changes soil formation, texture and structure. The mining soil texture would be dominated by coarse quartz in ex-tin mining [10] that was prone to erosion [11]. The removal of vegetation and the lessening soil in steep slope resulted in the high risk of watershed degradation and sedimentation [10], [12]. Huge quantity of overburdened soil, dumping, reclamation of mining area and large scale cavity in the mining area and other phenomena of the impact of the mining has led to ecosystem destruction [12]-[19]. The condition caused unsporting environment for natural vegetation and other organisms to grow.

The high net primary production (NPP) of tropical forests are influenced more by nutrient cycling rate than by amounts of nutrient availability in soils [1]-[5]. The use of soil ameliorant is one of the alternatives in the rehabilitation of degraded land of post-mining area [15]. It was expected that organic and inorganic soil ameliorant materials would be able to improve physical, chemical, biological and mineral properties of the degraded soil [16], [17]. Initial step to improve the quality and the health of the ex-mining area was to increase the organic material content [18]. The organic materials were very useful in improving the physical and chemical properties of the soil that became the determinant factors of the fertility of the soil. The organic materials played an important role of soil conditioner. Soil organic material compounds increased main particles in chemical and physical aggregates that would in turn improve the aggregate stability and hamper the breaking of the aggregates. The organic materials also played an important role of providing nutrients, food and energy sources for soil microorganisms and also maintaining soil moisture [19].

Rehabilitation of extremely degraded areas through re-vegetation by fast growing species is expected to speedily recover their dynamic of organic-carbon stocks [5]. Kemiri sunan (*Reutealis trisperma*) was a pioneer plant able to grow in marginal land. It was a fast growing species and produced useful oil. Also, it was able to adapt to acid soil with low pH and to tolerate various types of soil, including saline, sandy, heavy clay soil, stony soil and inundated soil. It was expected that the introduction of soil ameliorating materials such as biogas waste, compost and volcanic dust in the ex-tin mining soil to boost the growth of the *R. trisperma* could give useful information to wisely rehabilitate the land in after the tin mining period has been over, especially in forestry areas [11].

2. Materials and method

The study used tailing soil obtained from the ex-tin mining area in Bangka Island in November 2016-March 2017. It was conducted in the Laboratory of Intensive Silviculture, Faculty of Forestry, Universitas Gadjah Mada (UGM), Yogyakarta. The test of the physical and chemical properties of the soil was carried out in the Soil Laboratory of the Faculty of Forestry UGM, the Laboratory of Soil-Faculty of Agriculture UGM and Integrated Laboratory of LPPT UGM.

It used completely randomized design with single factor, consist of 5 treatments of soil amendments, namely: Control (C), volcanic ash 5% (A5), volcanic ash 10% (A10), biogas waste 5% (B5) and biogas waste 10% (B10) with 6 replications and 1 tree-plot. The 5 months age of *Reutealis trisperma* seedlings were grown.

Data was analyzed using ANOVA complete randomized design to find out the impact of the treatments. Duncan's median value test was carried out to find out the best treatment at the confidence interval of 95% and 99% toward the median value that had significant impact. The *R. trisperma* was grown by introducing the ameliorant materials according to its respective treatment proportion in the

media of the ex-mining soil in polybags and then maintenance, pest and disease control, and regular watering were conducted once a day.

The chemical and physical tests of the soil were carried out before harvest after the introduction of the soil improving materials at the beginning of growing period. The height and the diameter of the plant were observed once in two weeks after the cultivation for 12 weeks. The physical properties of the soil observed/tested as parameters included soil texture by groping, pH H₂O, EC and EH were measured by electrometric methods, N was observed using Devarda's alloy method, P was observed using Bray II method, K was observed using ammonium acetate method, and Cation Exchange capacity (CEC) with the ammonium acetate method; the total macro nutrients of N, P, K and secondary elements and micro nutrients of Ca, Mg, S, B and metals and other elements were observed using SEM (Scanning Electron Microscopic) + EDX method. The harvest of the plant was conducted in the week 12, along with photographs and dry weight of biomass were analyzed using tissue analysis with SEM method. The data was analyzed using SPSS 16.

3. Results and discussion

Mining activity caused ex-tin mining tailing with bad physical and chemical properties (Table 1). The texture of the ex-tin mining tailing soil was classified into loamy sand dominated by 70-90% sand. The results of 50x and 1000x magnifications using SEM showed that the ex-tin mining tailing soil was dominated by big size single grain with big macro pore and many fissures. It resulted in very low capability of retaining water and nutrients that the water and the nutrients quickly released and were not retained for the growth of plants. The water loss per location and the nutrients dissolved in the water was excessive because of earth gravity, while the existing reserve of the water and the nutrients was very low. However, there was inundation in the land with low groundwater and it resulted in anaerobic condition and intensive soil reduction that had negative impact on land productivity and plant growth. The impacts of the tin mining on the soil physical properties were the loss of top soil and the change of soil structure [20]. The mean loss of the top soil was 27.6 cm and the texture of the soil became coarser, while the sand content increased from 70% to 90% in tin tailing soil.

The ex-tin mining soil was not productive soil because of its lack of macro elements necessary for the growth of plants. The pH of the soil was 5.34 (acid), electronic conductivity (EC) was 28.1 mS (very low), electronic hydrostatics was 147 mV (medium reduction), CEC was 3.61 me/100g (very low). C-total in ex tin mining was 18.65%, that categorized as very high, because of accumulation of CaCO₃. It had very small essential macro nutrients of N that was 23.18 ppm, P was 0.38 ppm and K was 0.07 me/100g (Table 1). The proportion of nitrite (NO₂) in extracted-N content of water logged soil was very high. Such condition resulted in very low productivity of the ex-mining land because it had very low capability to provide plants with necessary nutrients for growth.

The results of the test using Scanning Electron Microscopic (SEM) + EDX showed that the tailing soil of the ex-tin mining had very low total essential macro nutrients (Mg, P, Ca, and Mo). Some micro elements that played only minor role for plants to grow were available in excessive quantity or beyond normal condition, including B, Cu, Zn and Cd, so that they became toxic for the plants. Some micro elements were in fact in normal range (Al, S, K, Mn, and Fe) that they did not cause any significant disturbance for the plants to grow.

The use of soil amendment of volcanic dust to the tailing soil (control) changed into the same texture of the loamy sand because the quantity of the volcanic dust was not enough to give significant impact to the texture of the soil. Meanwhile, the most optimal treatment by introducing biogas waste was able to slightly reduce the sand content. The texture of the loamy sand of amended soil that had 50-70% sand, 15-20% clay and 10-40% loam, was quite ideal condition for some species of plants [21].

The treatment of biogas waste caused the increase in the pH from acid to neutral condition. However, the treatment of volcanic dust decreased the pH into more acid (4.9-5.1) compare to the control. It was consistent with the results of the study by [22], which was 4.7-5.6. It was because the main source of acidity was dominated by Al³⁺.

The micro element of Al³⁺ in acid soil was highly soluble in excessive quantity so that it became toxic for plants and even it fixed the element of P into Al-P and hence the P was not available for the plants. The treatment of the soil ameliorant of the volcanic dust caused the reaction of the soil that released

H⁺ ion and then it caused the increase in the soil acidity, while the treatment of the biogas waste increased the pH of the soil.

Table 1. Soil chemical properties of tailing ex-tin mining soil in Bangka Island and their treatment of soil ameliorant of volcanic ash and biogas waste at dosage of 5% and 10%.

Element	Control	Volcanic 5%	Volcanic 10%	Biogas 5%	Biogas 10%
pH (H ₂ O)	5.34	5.05	4.87	6.425	6.57
EC (μS)	28.1	125	154.5	413	614.5
EH	147	99.5	110	17.5	13.5
CEC (me/100g)	3.61	5.61	4.41	3.61	4.82
Macro nutrient					
C-total (%)	18.65	16.92	12.64	13.97	16.01
N-total(%)	6.28	7.06	5.2	5.73	5.62
N-extracted (ppm)	23.18	20.38	17.56	72.17	35.07
P total (%)	0	0	0.01	0	0.09
P-available (ppm)	0.38	0.22	1.78	6.8	19.61
K –total (%)	0.19	0.28	0.23	0.14	0.09
K-available (me/100g)	0.07	0.08	0.08	0.17	0.15
Secondary element					
Ca-total (%)	0	0.26	0.42	0.11	0.1
Mg-total (%)	0	0	0.2	0.01	0.01
Na-total (%)	0	0	0	0	0
S-total (%)	0.16	0.02	0.02	0	0
Micro element					
Fe-total (%)	0.67	0.67	1.01	0.57	0.42
Mn-total (%)	0.06	0.01	0	0	0
Zn-total (%)	0.39	0.14	0.02	0.15	0.21
B-total (%)	4.35	1.03	4.71	0	8.84
Cu-total (%)	0.35	0.24	0.07	0.54	0.4
Mo-total (%)	0	0	0	0.32	0
Cl-total (%)	0	0.07	0.03	0.04	0
Heavy metal					
Pb-total (%)	0	0.28	0	0.09	0.1
Cd-total (%)	0.02	0	0	0	0
Si-total (%)	20.54	23.39	21.92	27.41	17.2
As-total (%)	0	0	0	0.04	0.02
Ti-total (%)	0.39	0.27	0.67	0.15	0.16
Sn-total (%)	0	0.04	0.2	0	0
Pt-total (%)	2.73	3.13	1.96	3.7	1.36

At the neutral condition of pH the fertility status of the soil was good in which it was not deficient of the elements of N, P, and K. It was also the case of the micro nutrients such as Ca, Mg, S, Fe, Zn, Mn, Co, Bo, and Mo. At the condition of the pH value in the range of 6.0-7.5, all of the necessary elements were available for the majority of plants, except for the plants that grew in acid land [23].

The treatment of volcanic dust caused the increase in the electronic conductivity from 0.28 dS/m (very low) to 1.25-1.55 dS/m (low), whereas the treatment of biogas waste could increase 4.13-6.15 dS/m (very high) (Table 1). The condition of very low to low EC indicated that actually the salt content of the soil did not have any significant impact on the availability of the nutrients in the soil, but the high EC value would result in osmosis in which plants should use higher energy to absorb water from the soil and finally it hampered the growth of the plants and decreased their productivity [24]. The roots of the plants had semi-permeable membrane that faced difficulties in absorbing water and nutrients from the soil because of the presence of the dissolved salt. It was because the biogas waste had very high EC value as compared to the ameliorant of the volcanic dust. The range of the Eh value in all of treatment soil were almost the same as medium reduction, related to not so drainage land condition in which there was excessive water [24].

CEC the tin mining soil in were classified into very low, even after treatment by biogas dust, but treatment of 5% volcanic dust increased more significantly compare to the control, although still considered to be low. Soils with higher clay/colloid content or high organic content had higher CEC than those with low clay content (sandy soil) and low organic content [23].

The total-N of the ameliorated soil and control was considered to be very high. It was assumed that it was because nitrate (NH_4^+) evaporated. The N was changed into ammonium (NH_4^+) and then changed into nitrate and the nitrate evaporated because of the change by microorganisms into NH_3 (volatilization) and N_2O , NO , N_2 (denitrification) [23]. The treatment of biogas waste increased N-total significantly from 23.18 ppm to 35.07-72.17 ppm, while the treatment of volcanic dust decreased to be 17.56-20.38 ppm. It was assumed that the available inorganic N content in the form of NO_3^- and NH_4^+ plus the organic material of the biogas waste was bigger than the tailing soil without any addition of organic material (control). It was indicative of the presence of the mineralization process or the addition of inorganic N resulting from the weathering process of organic materials. The nitrogen value could be influenced by reorganizing the organic materials of the soil into N mineralization.

The available-P in the tailing soil was very low (0.38 ppm) with the total-P that was very low as well. The treatment of volcanic dust caused not any significant addition or remained in low category at 0.22-1.78 ppm. Meanwhile, the treatment of biogas waste was able to increase the available-P to 6.8-19.61 ppm and it was considered to be very high. The available-P in volcanic ash was smaller because the majority of the P was bound by the elements of Al, Fe and Mn that they could not easily be dissolved in soil [17].

The total-K in the tailing soil was 0.19%, it increased with the treatment of volcanic ash to 0.23-0.28%, while the treatment of biogas waste decreased to 0.09-0.14%. Available-K was 0.07 me/100g in the tailing soil, increased to be 0.15-0.17 me/100g, after treatment by biogas waste. Soil available-K was not constantly available, but it was changing slowly and hence it was difficult for plants to absorb it (i.e., slowly available). The sandy soil would be easily dried when the water came out, so that the availability of the K for the plants decreased [17]. The slow exchange of K because the CEC value of the tailing soil or the tailing soil after the treatment was still very low.

Total-Ca in the tin tailing soil was very small, but increased to 0.1-0.11% after the treatment of volcanic dust, and to 0.1%0.26-0.42% with the treatment of volcanic dust. The pH of the tailing soil was sufficiently acid and the Ca was very small that it could not increase its pH. Total Mg was very small, however, the treatment of volcanic dust was able to increase the total Mg that it reached 0.2% (normal range). The small total-Mg in the treatment of the biogas waste resulted from the total number of the Mg that was only 0.3%. The imbalance of the Ca and the Mg contained in the soil and the equally small number of the Mg contained in the CEC soil caused Mg deficiency [23].

There were 7 micro nutrients that played as important role as macro nutrients and secondary nutrients. However, the necessary micro nutrients are not as much as the macro nutrients and the secondary nutrients. The lack of the micro nutrients in the soil might also limit the growth of plants though other nutrients were sufficiently available. The soil acidity (pH) had significant impact on the availability of the micro nutrients, except Mo and Cl that would decrease if the pH increased. If the number of the Ca was bigger in the organic material of the biogas waste than that in the volcanic dust, the decrease in the acidity caused the decreased in the number of B contained in the soil. There were a lot of Boron (B) detected in the tailing soil and according to [25], it was beyond the standard limit of the number of the

B in the soil. After the treatment of the organic materials, the number of the B was still in the category of beyond the limit, except the treatment of 5% biogas waste.

The treatments of biogas waste decreased toxicity of some micro nutrients. Total-Mn, Zn, Fe, Al, Mo, and Cu had the same properties that their solubility would increase the acidity and toxicity. The abundantly available Fe in the tailing soil and the treatment of the volcanic dust and the treatment of the biogas waste related to the decrease in the availability of the P after the treatment. Other metals contained in the soil such as Fe, Mn, and Al influenced the availability of the Cu for the growth of plants. The excessive number of the Cu could suppress the activity of Fe and might cause the symptom of Fe deficiency [23].

Aluminum (Al) represented supporting nutrient that was not required by plants because the Al was toxic. It had the characteristics of providing and absorbing similar to the micro nutrients without any absorbing zone that in the excessive content it was toxic. Meanwhile, if the Al was not available sufficiently in the soil, the growth of the plants would be hampered and their flower and fruits would not be optimal. Total-Al in the tailing soil was 5.71% (in normal range) and the treatment of the ameliorant of the volcanic dust and the biogas waste caused the progressive increase in the number of the Al. Other micro nutrients that had metal properties and were detected in the tailing soil included Ti, Si, Cd and Pt.

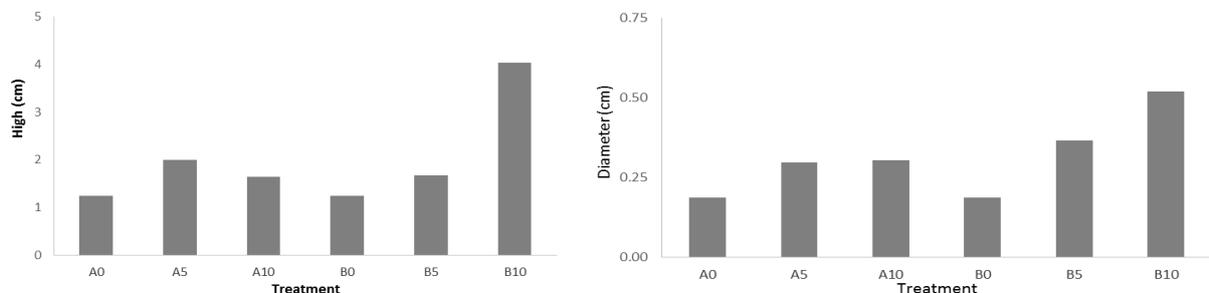


Figure 1. The growth of high and the diameter of *Kemiri sunan* on the ex-tin mining soil with the treatment of the soil ameliorants and the dosages till 12 weeks after cultivation.

The best treatment with high growth rate was the treatment of 10% biogas waste with the increased height of 4.03 cm for 12 weeks after cultivation, that mean 322% than their height on the tailing soil (only 1.25 cm). It also indicated that the increase in the height resulting from the treatment of 5% volcanic dust was 160%. The best treatment with the growth rate in the diameter was correlated to the height resulting from the treatment of the biogas waste at the dosage 10% with the increased diameter of 0.52 cm, that increasing of 274% compare to the tailing site that only 0.19 cm for 12 weeks. The treatment of the ameliorant materials at higher dosage did not cause the increase in the high and diameter (Figure 1).

During the growing period of the *Kemiri sunan* for 12 weeks after cultivation the leaves often fell down, except the plants on the tailing soil with the treatment of 10% biogas waste in which the color of the old leaves was yellow and they were rolled before they fell. The *Kemiri sunan* at all of the treatments tended to be susceptible to plant diseases such as insects and so on. It was clearly observed in the morphology of the leaves with holes as a result of the bite of the insects or the leaves full of with flour as a result of the plant animal disease of *embun jelaga*. The high value of the top-root ratio in the treatment of 10% biogas waste was the most optimal treatment in the growth of the *Kemiri sunan*, whereas the tailing soil gave the lowest top-root ratio value.

The treatment of the organic ameliorant that gave the highest N value was the treatment of ameliorants of both volcanic dust and biogas waste that the growth of the roots would be stimulated and the weight of the roots would increase. However, the high intake of the N resulted in soft leaves and caused the increase in the water content. The high N content would surely cause lower P content in the treatment of 5% organic materials than the treatment of 10% organic materials. The two organic materials at their respective dosages have proven to be able to increase the total dried weight and the top-root ratio value of the *Kemiri sunan* for 12 weeks. According to [21], non-fertile soil or low soil quality of tin

mining condition would cause low top-root ratio, while the application of organic fertilizer would be able to increase the top-root ratio value.

4. Conclusion

Soil from post tropical tin mining acid soil (pH 4.97) that dominated by sand particles (88%) with very low cation exchange capacity, very low nutrient contents (available and total-N, P, K, Ca, Mg) and high toxicity of Zn, Cu, B, Cd and Ti, but still have low toxicity of Al, Fe, Mn, Mo, Pb, As. Soil amendment of biogas and volcanic ash could improve soil quality by increasing of better pH, high available-P and cation exchange capacity and maintained their low toxicity. The growth (high, diameter, biomass, top-root ratio) of exotic pioneer plant of Kemiri sunan (*Reutealis trisperma*) increased in the better soil quality that caused by application of proper soil amendment. The grand concept and appropriate technology for rehabilitation of degraded tin-mining land ecosystems in tropical regions which are the lungs of the world have a high contribution for development of our dignified and sustainable environment and life.

5. Acknowledgment

The authors express their greatest gratitude toward Directorate of Research & Community Services Ministry of Research, Technologi & Higher Education RI and UGM Yogyakarta for their research funding, and local Government of Bangka and PT Tambang Timah for supporting of field research materials. This work is the revision and extension of the paper in 2017 8th International Conference on Environmental Engineering and Applications (ICEEA 2017). The opportunity is gratefully acknowledged.

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