Improvement of post-nickel mining soil fertility with biochar and calcite

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Improvement of post-nickel mining soil fertility with biochar and calcite

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Abstract

Reclamation of post-nickel mining soil requires a long process and renewable innovations to improve soil properties. One of the alternative technologies for post-mining soil reclamation is utilizing oil palm empty fruit bunches (OEFB) as biochar and applying calcite ($CaCO_3$). The objective of this research was to determine the effect of OEFB and the application of $CaCO_3$ on the properties of post- nickel mining soil and the growth of *Mucuna sp*. This research was pot experiment using 2-factor randomized block design method. The biochar (B) consisting of 3 levels, namely B1 = 2.5%, B2 = 5%, and B3 = 7.5% of soil weight, and calcite (K) consisting of 3 levels, namely K1 = 1.5, K2 = 3, K3 = 4.5 t ha^{-1}. The soil parameters measured included soil pH (H_2O and KCl), available P, organic C, cation exchange capacity, exchangeable aluminum, exchangeable based cations (Ca, Mg, K, Na), and ratio of Ca and Mg. The parameters of Mucuna include plant height and plant dry weight. The results showed that the application of biochar and calcite significantly increased soil pH, available P, organic C, cation exchange capacity, growth of Mucuna and decreased exchangeable Al content. Treatment of biochar 7.5% by weight of soil and calcite 4.5 t ha^{-1} were the best effect on improving soil fertility and growth of Mucuna compared to other treatments.

Keywords: post-mining soil, soil amendments, land reclamation, cover crops, calcite

1. Introduction

The open pit mining can cause damage to the ecology (Thomas, Sexstone, and Skousen 2015) mainly to soil physical damage and chemical soil fertility due to loss of top soil along with the organic matter, compaction and the unavailability of nutrients that are needed by plants, soil organic matter content is very low, soil pH varies and there may be symptoms of toxicity of certain elements (Bato, 2016). Mining activities can increase the soil acidity which directly affects the availability of macronutrients P and K needed by plants as well as high Fe and Al content, so that they can be toxic to plants (Allo, 2016).

Management of post-mining soil requires serious attention and goes through a long process in rehabilitating it so that environmentally friendly innovations are needed. One of them is by utilizing OEFB to overcome the problem of post-mining soil. The reason for using OEFB as the source of biochar, in addition to the nutrient content possessed by OEFB, the source of this material is abundantly available around the nickel mining area in Sorowako, Indonesia, namely oil palm plantations scattered in several districts adjacent to the mining area. According to Erwinsyah (2007) and Hidayah (2019), OEFB is the largest solid waste generated from the processing of the palm oil industry. OEFB contains chemical constituents of fat, cellulose, lignin and hemicellulose. In the process of producing crude palm oil in palm oil mills, the amount of OEFB produced reaches 21-23% of the total weight of fresh fruit bunches (Kresnawaty, 2017).

Biochar is a porous substance of wood charcoal which provide a good environment for microbes and keep the carbon-nitrogen balance, it is even able to hold and provide water and nutrients for plants (Sihotang, 2018). OEFB biochar produced by the pyrolysis process is proven to be effective in increasing soil fertility because biochar is able to hold water, maintain the availability of nutrients that are important for plants by reducing soil acidity (Kresnawaty, 2017). To increase the effectiveness of the use of biochar in post-mining soil, it is necessary to add other substances, especially according to Allo (2016), the soil in Sorowako is included in the Oxisols soil type, which is soil that has advanced development formed from ultrabasic rock. These rocks are characterized by low silica content (<45%), dominated by dark ferromagnesia crystallized minerals, such as olivine, pyroxene, amphibole, which are generally dark gray to black or greenish in color (Fox and Tan 1971). These rocks are rapidly weathered (Lee et al. 2004), releasing very high amounts of Mg due to the dominance of ferromagnesia as a rock constituent. This conditions lead to an imbalance of cations in the soil, consequent Mg toxicity and other cation deficiencies (Anda, 2012) to solve the problem by means of calcium carbonate ($CaCO_3$), which aims to reduce the imbalance cations and increase the soil pH to keep the availability of nutrients in the soil the main elements of P and Mo, reduce toxicity Fe, Mn and Al (Irwan, 2018). The objective of this research was to analyze the effect of OEFB biochar and calcium carbonate ($CaCO_3$) on the soil fertility and the growth of *Mucuna sp* in post-mining land reclamation areas.

2. Methods

This study used the pot experiment method with a factorial randomized block design. The biochar (B) factor consists of 3 level (% of the weight of the soil) were B1 (2.5), B2 (5.0), and B3 (7.5). The calcite (K) factor consists of 3 dosage were K1 (1.5 t ha $^{-1}$), K2 (3 t ha $^{-1}$), K3 (4.5 t ha $^{-1}$). Treatments combination were obtained as shown in Table 1 and replicated 3 times. In each unit or experimental pot, 5 kg of post-nickel soil was used. The results of the observations were analyzed by means of variance and continued with the Tukeys's test at the 95% confidence level. Soil samples were obtained from the post-nickel mine reclamation site in East Luwu Regency, Indonesia as shown in Figure 1. Soil sample analysis was carried out at the Department of Soil Science Laboratory, Hasanuddin University, Indonesia. The tools used in this research are a set of assembled biochar making tools to burn OECB by pyrolysis method, planting pots, a set of soil sampling equipment. The materials used included samples of soil, biochar of OECB, and *Mucuna sp* seeds.

Table 1. Combination treatment of biochar (B) and $CaCO_3$ (K)

Treatment combination	Description
B1KI	Biochar 2.5% soil weight + calcium carbonate 1.5 t ha $^{-1}$
B1K2	Biochar 2.5% soil weight + calcium carbonate 3 t ha $^{-1}$
B1K3	Biochar 2.5% soil weight + calcium carbonate 4.5 t ha $^{-1}$
B2K1	Biochar 5.0% soil weight + calcium carbonate 1.5 t ha $^{-1}$
B2K2	Biochar 5.0% soil weight + calcium carbonate 3 t ha $^{-1}$
B2K3	Biochar 5.0% soil weight) + calcium carbonate 4.5 t ha $^{-1}$
B3K1	Biochar 7.5% soil weight + calcium carbonate 1.5 t ha $^{-1}$
B3K2	Biochar 7.5% soil weight + calcium carbonate 3 t ha $^{-1}$
B3K3	Biochar 7.5% soil weight + calcium carbonate 4.5 t ha $^{-1}$

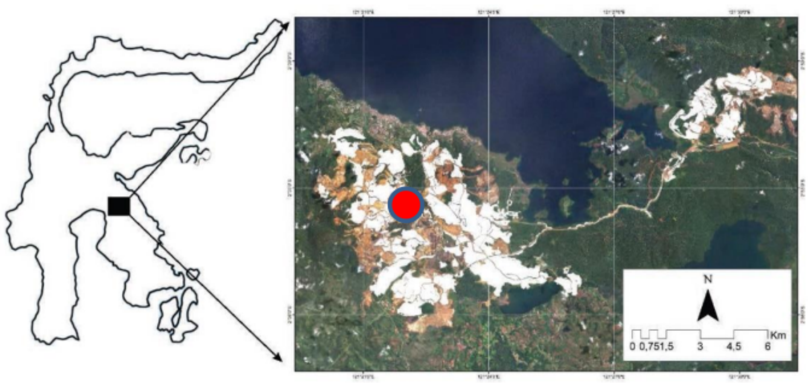

Figure 1. Location of soil sampling (red dot)

The parameters of the soil chemical properties measured in this study were soil pH, organic C, cation exchange capacity (CEC), exchangeable bases (Ca, Mg, K, Na), available P, exchangeable Al and ratio Ca/Mg. The growth parameters of *Mucuna sp* cover crops measured were plant height, number of leaves, and plant dry weight. Measurement of soil parameter values using the analytical method as shown in Table 2.

Table 2. Soil analysis methods in the laboratory

Parameter	**Method**
Soil pH (H_2O and KCl)	pH meter
C-organic	Walkey & Black (1947)
Cation Exchange Capacity (CEC)	Ammonium-saturation method (Chapman, 1965)
Excheageable basic cations (Ca, Mg, K, Na)	Ammonium-saturation method (Chapman, 1965)
P-available	Olsen (1954)
Al-dd	KCl 1 N

3. Results and Discussion

3.1. Effect treatments to soil properties

The results showed that the effect of biochar and calcite treatment on chemical properties and soil fertility and plant growth of *Mucuna sp* was statistically significant at the 95% confidence level as shown in Table 3.

The results of soil chemical analysis showed improvement in soil fertility after biochar and calcite combinations treatments which was indicated by an increase in soil pH, C-organic, CEC, base saturation, available P, and Ca/Mg ratio and a decrease in Al-dd. Soil reaction (pH), organic-C and CEC with B3K3 treatment have higher value and significantly different from other treatments. The similar result was also found in the available-P parameter, which the highest was found in the B3K3 treatment (14.80 ppm) and was significantly different from other treatments. The lowest Al-dd value was found in the B3K3 treatment (0.88 $cmolkg^{-1}$) and significantly different from other treatments with Al-dd values > 1 $cmolkg^{-1}$ and some even reached a value of 3.76 $cmolkg^{-1}$.

The value of exchangeable bases which include Ca, Mg, K and Na cations is significantly affected by the increase due to the treatment being tested. The highest values of Ca, Mg and Na were found in the B3K3 treatment, namely 4.16, 5.32 and 0.42 $cmolkg^{-1}$ respectively and significantly different from other treatments. As for the K parameter, the highest value was found in the treatment that gave the best effect, indicated by the B3K2 treatment, which was 0.51 $cmolkg^{-1}$ and significantly different from the B3K1, B1K1, and B1K2 treatments. The highest Ca and Mg ratio values were found in the B3K3 treatment, which was 0.78 and significantly different from the B3K1 and B1K1 treatments.

Table 3. Results of soil analysis after treatment

Treatments	pH		C- org	CEC	Avail. P	Al-dd*	Ca	Mg	K	Na	Ca/Mg
	H_2O	KCl	(%)	($cmolkg^{-1}$)	(ppm)			($cmolkg^{-1}$)			
B1K1	5.71^{ab} ++	5.89^{a} ++	1.47^{g} **	15.50^{e} **	7.99^{h} **	3.76^{f} *****	1.41^{g} *	1.91^{e} ***	0.28^{cd} **	0.20^{e} **	0.46^{c}
B1K2	5.66^{bc} ++	5.92^{a} ++	1.56^{f} **	15.97^{e} **	9.29^{fgh} **	3.28^{ef} *****	1.84^{f} *	2.83^{d} ****	0.27^{d} **	0.30^{cd} **	0.66^{ab}
B1K3	5.70^{ab} ++	5.95^{a} ++	2.21^{de} ***	16.41^{de} **	8.51^{gh} **	2.96^{de} *****	2.30^{e} **	3.53^{c} ****	0.42^{ab} ***	0.31^{cd} **	0.66^{ab}
B2K1	5.75^{a} ++	5.89^{a} ++	2.21^{e} ***	15.87^{e} **	9.79^{ef} **	2.24^{cd} ****	2.70^{d} **	3.67^{c} ****	0.40^{ab} ***	0.33^{c} **	0.73^{a}
B2K2	5.71^{ab} ++	5.93^{a} ++	2.44^{c} ***	19.40^{bc} ***	10.54^{de} **	2.16^{bcd} ****	2.85^{d} **	3.64^{c} ****	0.47^{ab} ***	0.31^{cd} **	0.74^{a}
B2K3	5.73^{a} ++	5.94^{a} ++	2.49^{bc} ***	20.28^{ab} ***	13.08^{c} ***	2.08^{bc} ****	2.92^{cd} **	3.90^{bc} ****	0.45^{ab} ***	0.34^{bc} **	0.74^{a}
B3K1	5.62^{c} ++	5.85^{a} ++	2.21^{e} ***	18.42^{c} ***	8.99^{fgh} **	1.68^{ab} ****	2.96^{c} **	5.06^{a} ****	0.39^{b} **	0.25^{de} **	0.59^{b}
B3K2	5.70^{ab} ++	5.88^{a} ++	2.53^{ab} ***	19.31^{bc} ***	13.31^{bc} ***	1.04^{a} ***	3.65^{b} **	4.90^{a} ****	0.51^{a} ***	0.34^{c} **	0.74^{a}
B3K3	5.76^{ab} ++	5.95^{a} ++	2.60^{a} ***	21.28^{a} ***	14.80^{a} ***	0.88^{a} ***	4.16^{a} **	5.32^{a} ****	0.43^{ab} ***	0.42^{a} ***	0.78^{a}

Notes: Numbers followed by the same letter (a, b, c, d) means that there is no significant difference in the treatment of biochar and $CaCO_3$ in the BNJ test of $_{0.05}$
++ Slightly acid * Very Low *** Medium ****High ** Low ***** Very High

The results of soil analysis after treatment showed an increase in the pH value along with an increase in the dose of biochar and calcite treatment. This indicates that the provision of biochar and $CaCO_3$ can an enhance soil pH. This is in similar with the opinion of Setiawan et al. (2018) that an increase in pH due to the addition of organic material in this case is biochar occurs because the process of mineralization of organic anions into CO_2 and H_2O. According to Steiner (2007), an increase in pH associated with the addition of biochar to acid soils caused by an increase in the concentration of basic cations (Ca^{2+}, Mg^{2+} and K^{+}) and a decrease in the concentration of soluble Al^{3+} in the soil. The pH value of KCl on all treatments was higher than the pH of $H_2 0$, which indicates that soil is advanced developed that has been is associated with intensive leaching and strong oxidizing conditions, decaying further so dominated by the Fe and Al oxides so that the concentration of H^+ increases resulting in a pH of H_2O is lower. In addition to soil pH, C-organic and CEC parameters also experienced a significant increase. The increase in C-Organic and CEC was influenced by the addition of biochar and $CaCO_3$. This is in similar with the opinion of Cheng (2006) that the increase in soil CEC after biochar application was caused by the formation of carboxylate groups resulting from abiotic oxidation that occurred on the outer surface of the biochar particles. In addition, according to Lehman (2009), biochar in the soil is in the form of particles which can cause stable organic C-form mineralization and create a negatively charged particle surface which makes CEC larger and nutrient retention increases. Furthermore, Lehmanm (2009) states that biochar contains high C atoms which form aromatic compounds linked by six C atoms together without Oxygen or Hydrogen (Lehmanm, 2009). In addition, the increase in CEC and C-Organic is influenced by the function of $CaCO_3$. This is in accordance with Rowley (2019) who stated that calcium carbonate is a contributor to the important C fraction in the soil that links the long-term geological C cycle with the long-term biogeochemical cycle of soil organic carbon. This underlies the increase in CEC and C-organic values after the application of biochar and $CaCO_3$.

The results of the available P analysis showed that the B3K3 treatment gave the highest effect compared to other treatments, which was indicated by an increase in available P from 6.60 ppm to 14.80 ppm. This increase in available P was influenced by the P nutrient content in biochar and an increase in pH by $CaCO_3$. This is in line with Muhammad's research (2019) which used biochar and manure on Ultisols which showed that the combination of biochar and manure treatment could improve soil properties, in particular an increase in the available P. Deluca (2009) states that the biochar is a direct source of grams of dissolved P and P which can be exchanged for biochar is a complexing metal ameliator P (Al^{3+}, Fe^{3+}, Ca^{2+}), modifiers soil pH and biochar as a promoter of microbial activity and P mineralization. In addition, the increase in P availability was influenced by an increase in soil pH. This is correlated with the increase in soil pH value with increasing doses of biochar and calcite. Munawar (2011) stated that P was most widely available in the pH range between 5.5 and 6.5.

Based on the results of the Al-dd analysis, it was found that the B3K3 treatment gave the best effect compared to other treatments as indicated by the decrease in Al-dd from 3.80 $cmolkg^{-1}$ to 0.88 $cmolkg^{-1}$. This indicates that biochar and $CaCO_3$ can reduce the content of Al in the soil. It is appropriate Ratmini opinion (2018) that the provision of biochar can improve soil pH, lowering the concentration of aluminum can exchange and reduce the ability of iron and aluminum oxide in a bind P. In addition, the provision of $CaCO_3$ in addition to raising the pH of the soil as well as to liberate the N and P from Al and Fe bonds. Rais (2017) stated that the administration of $CaCO_3$, where calcium replaces hydrogen and aluminum ions in the adsorption complex. The resulting hydrogen ions react with carbonates to form carbonic acid (H_2CO_3). The carbonic acid produced will dissociate to form CO_2 and H_2O. The carbon dioxide (CO_2) produced will be released into the atmosphere, so that the final result of this lime reaction is H^+ ions whose activity is decreasing and the more OH- dissolved in the soil which can increase soil pH. This is supported by research by Angelita et al. (2019), regarding the improvement of post-nickel soil quality with the use of mycorrhiza and OEFB biochar, it was found that the use of mycorrhizae and biochar could improve the chemical properties of post-nickel soil by increasing soil pH and decreasing Al-dd from 2.61 $cmolkg^{-1}$ to 1.58 $cmolkg^{-1}$.

The results of the analysis of exchangeable bases showed that B3K3 gave the highest effect compared to other treatments, which was indicated by an increase in Ca, K, and Na as well as a decrease in Mg. Based on the analysis of the ratio of Ca/Mg in the soil obtained a ratio of <1 which means the number of cations Mg>Ca. This will cause a nutrient imbalance (Anda, 2012). This imbalance is influenced by several factors such as parent material, soil pH and the ratio with other cations in the soil. According to Hutabarat (2015) ultramafic rocks are characterized by high content of magnesian olivine (Mg_2SiO_4) and low SiO_2 (less than 45%). In addition, it is also influenced by soil pH where these exchangeable bases will be optimally available at pH 6.5-7.5. This right is in accordance with the opinion of Munawar (2018) that the elements Ca, Mg and K are mostly available in soils with a pH greater than 6. Hanafiah (2014) stated that the availability of elements is also influenced by the ratio between cations, Ca is influenced by high Al and H activity, Mg is influenced by high K and Al content, K is influenced by Ca and Mg. The improvement of the chemical properties of soil fertility given biochar is supported by the quality of the biochar. The results of the analysis of the biochar used showed that the levels of C-organic, total N and C/N ratio of biochar were: 18.26%, 0.86% and 21.2%, respectively. This value means that quality of OEFB biochar is quite good and fit to the standard requirements for soil amendment. According to the Decree of the Minister of Agriculture of Indonesia no: 28/Permentan/SR.130/B/2009 concerning the minimum technical requirements for organic and soil amendment, for C-organic are: >7%, total N is <6% , and the C/N ratio is 8-15% (Soil Research Center, 2009).

3.2. Effect treatments to crop properties

The Mucuna parameters measured in this study were: plant height, number of leaves and plant dry weight. The measurement results are shown in Table 4 below.

Table 4. Observations of *Mucuna sp* at 48 DAP (days after planting)

Treatment	Plant Height (cm)	Number of Leaves (Strand)	Dry Weight (g)
BIKI	0.00 [b]	0.00 [b]	0.00 [b]
BIK2	4.33 [b]	1.00 [b]	0.16 [b]
BIK3	4.67 [b]	1.67 [ab]	0.19 [b]
B2K1	1.17 [b]	0.67 [b]	0.06 [b]
B2K2	4.00 [b]	1.67 [ab]	0.39 [b]
B2K3	3.67 [b]	1.00 [b]	0.43 [b]
B3K1	3.33 [b]	1.00 [b]	0.14 [b]
B3K2	6.67 [b]	3.33 [a]	0.34 [b]
B3K3	15.83 [a]	3.67 [a]	1.15 [a]

The treatment that gave the highest effect on plant height, number of leaves and dry weight was found in the B3K3 treatment and was statistically significantly different from the other treatments. The increasing dose of biochar and calcite was accompanied by an increase in the value of the measured parameters. It is influenced by the addition of biochar and $CaCO_3$ which significantly affect the chemical properties of soil fertility improvement. Biochar contains essential nutrients, able to increase soil pH, availability of P and reduce Fe, Mn and Al. This is in accordance with the opinion of Gani (2010), besides containing macro and micro nutrients, biochar is also able to improve soil physical, chemical and biological properties, biochar is able to increase pH, organic C, available P, total N and soil CEC. According to Tambunan (2014), most of the cations Ca^{2+}, Mg^{2+} and K^{+} in the soil which biochar was added were not bound by electrostatic forces, but as dissolved salts and were therefore easily available and absorbed by plants. This is also supported by Tarigan's research (2020), that the application of OEFB biochar and mycorrhizae had a significant effect on the growth of the sweet corn. Another study conducted by Muhammad (2019) found that the addition of biochar and manure had a very good effect on plant height, plant fresh weight and plant dry weight. Biochar is safe to use in the long term (Gani, 2019). Biochar keeps the balance of carbon-nitrogen, retain water and nutrients availability to plants.

Conclusion

The use of a combination of biochar 7.5% by weight of soil and $CaCO_3$ 4.5 t ha^{-1} (B3K3) significantly improve the chemical properties of post-nickel mining soil (enhance of soil pH, C-organic, available P, cation exchange capacity, basic cations and reduce exchangeabled-Al). The B3K3 treatment had a significant effect on the growth of *Mucuna sp* as indicated by the highest plant height, number of leaves and plant dry weight compared to other treatments.

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