

Research Article

The use of ash and biochar derived oil palm bunch and coal fly ash for improvement of nutrient availability in peat soil of Central Kalimantan

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Abstract

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The increment of peat soil productivity meets through ameliorant addition. Ameliorant sources can be obtained from oil palm plantation and electric steam power station waste. The study aimed at investigating the ability of the oil palm fruit empty bunch (OPFEB) biochar, oil palm boiler ash (POBA) and coal fly ash (CFA) as alternative ameliorants besides compost to improve nutrient availability in peat soil of Central Kalimantan. Treatments tested were OPFEB biochar, POBA, CFA, compost, OPFEB biochar+compost, POBA+compost, and CFA+compost. The seven treatments were arranged in a completely randomized design of single factor with four replications. The results revealed that the ameliorants increased peat soil pH at a rate of 0.7 compared to those in initial soil used and available P of 135.7% even though there was no significant increment of exchangeable cations of K, Ca and Mg. Mixing of biochar, POBA or CFA with compost improved nutrients availability in peat soil.

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Introduction

Peat soils have low fertility due to their high acidity, with pH value at a rate of 3-4. In Central Kalimantan, the pH value on uncultivated soil is about 3.9-4.3 while cultivated soil is 2.11-4.38 (Ichriani and Pituaty, 2012). The low content of P and other nutrients, as well as the high content of organic acid compounds, limit this soil to be used as agricultural land. The uncultivated peat soil has 10.7-22.72 ppm P (Ichriani and Pituaty, 2012). The availability of macronutrients is low in the form of organic compounds. Most micronutrients are chelated by organic compounds.

Efforts to overcome the low fertility of peat soil can be performed by ameliorant application while reducing the degradation of the soil can be maintained (Maftu'ah and Indrayati, 2013). The application of ameliorant reduces peat degradation through improved soil stabilization mechanisms, strengthens cation and

anion bonds to store nutrients longer, and reduces levels of phenolic acid compounds (Hartatik et al., 2003). Generally, biomass such as compost and manure are applied as ameliorants in peat soil (Widyati et al., 2010; Maftu'ah and Indrayati, 2013; Damanik and Anwar, 2016). However, this practice could increase the amounts of carbon emissions into the atmosphere due to the decomposition of organic matter (Widowati et al., 2011). Therefore, wise efforts to reduce the increasing carbon emissions due to organic matter decomposition and the maintaining of soil fertility are greatly needed.

The potential ameliorant which can improve peat soil fertility can be obtained from oil palm plantation and electric steam power station (PLTU). Productive waste from the manufacture of crude palm oil (CPO) can be used in the form of oil palm empty bunches biochar (OPFEB) and oil palm boiler ash (POBA). One of the productive wastes in the PLTU is coal fly

ash (CFA). Indonesia has 14.3 million hectares of oil palm plantation areas with CPO production at a rate of 29.3 million tons in 2018. In the same year, Central Kalimantan has 1.51 million ha with a total CPO production of 6.04 million tons (Central Bureau of Statistics, 2019). OPFEB contribute 23% of biomass from CPO production (Indriyati, 2008). Therefore, the potential biomass obtained reached 1.39 million tons from 6.04 million tons of CPO processed. Management of OPFEB is still limited. Generally, some of them are just stacked around the road, and others are composted. OPFEB biomass modified into biochar has been investigated by Ichriani et al. (2018). In addition, the oil palm boiler ash (POBA) derived from the shell, and palm fibre combustion at 800-900°C is generated by CPO production. The POBA has alkaline pH and contains 30-40% K₂O, 7% P₂O₅, 9% CaO and 3% MgO (Ricki et al., 2014).

The coal combustion process in power plants station produces 5% solid pollutants in the form of ash. The resulting ash consists of 80-90% CFA, and the rest is coal bottom-ash. The estimated coal demand for domestic power plant station fuel needs by 2027 reaches 162 million tons (PT. PLN, 2018). Coal fly ash contains a high amount of Fe, Ca, Al, Si, K and Mg, a moderate amount of Zn, B, Mn and Cu, and a small amount of C and N percentage. The chemical and biological toxicity analysis showed that CFA contains less leached heavy metal, it is almost non-toxic, and it is relatively harmless (Dzantor et al., 2015; Damayanti, 2018). Therefore, CFA can be utilized for improving rice productivity (Prasetyo et al., 2010) and maize productivity (Kaur and Goyal, 2015; Fahrumsyah et al., 2018).

The objective of this research was to study the ability of OPFEB biochar, POBA, and CFA in enhancing the nutrient availability in peat soil of Central Kalimantan.

Materials and Methods

Peat soil used was collected from Kalampangan, Sebangau, Central Kalimantan (2°16'57.9" S and 114°01'27.0" E). Oil palm fruit empty bunch (OPFEB) was kindly donated by PT Surya Inti Sawit Kahuripan, Parenggean, Kotawaringin Timur, Central Kalimantan. The production of biochar from OPFEB was conducted in the Laboratory of Bioenergi, Universitas Tribuwana Tunggaladewi, Malang. The biochar construction was done as a slow pyrolysis at 400°C heating for 6 hours in the minimal oxygen content (Ichriani et al., 2018). The OPFEB biochar has pH H₂O (1:5) = 9.90, total N = 0.95%, total P = 0.22% and total K = 1.10 ppm. Oil palm boiler ash (POBA) was obtained from PT. Archipelago Timur Abadi, Gunung Mas, Central Kalimantan. The POBA has pH H₂O (1:5) = 9.93 and contains 67% total P. Coal fly ash (CFA) was taken from PLTU PT. Cahaya Fajar Kaltim located in Embalut village, Tenggarong Seberang sub-district, Kutai Kartanegara district, East

Kalimantan. The chemical properties of CFA were the pH H₂O = 9.8, total P = 1378.56 ppm, total N = 0.05%, and total K = 719.35 ppm (Fahrumsyah et al., 2018). The giant *Salvinia* aquatic plant (*Salvinia molesta*) was used as compost raw materials. The production of *S. molesta* compost was carried out in the greenhouse of the Department of Agronomy, Faculty of Agriculture, Palangka Raya University. The chemical properties of the compost were pH H₂O (1:5) = 4.87, total P = 0.1%, total N = 0.6%, MgO = 0.19%, CaO = 0.77%, and K₂O = 0.31%. The peat soil was air-dried for 7 days and sieved using a 2 mm mesh sieve, and weighed by 500 g/polybag. The preliminary results of chemical properties of peat were pH H₂O (1:5) = 3.06, available P (Bray I) = 82.11 ppm, exchangeable K = 0.61 cmol/kg, exchangeable Mg = 1.32 cmol/kg, and exchangeable Ca = 4.34 cmol/kg. Each ameliorant material was applied on peat at a rate of 15 t/ha (biochar, POBA, and CFA) and 20 t compost/ha. Seven treatments, namely OPFEB biochar, oil palm boiler ash (POBA), coal fly ash (CFA), compost, OPFEB biochar + compost, POBA + compost, and CFA + compost, were arranged in a completely randomized design of single factor with four replications. The ameliorant sources were applied on peat soil and incubated for four weeks. The humidity was maintained at field capacity. At the end of incubation, soil samples were taken for laboratory analysis of pH H₂O 1:5 (electrode glass), exchangeable K, Ca, and Mg (atomic absorption spectroscopy), and available P (Bray I) (Soil Research Institute, 2005). Statistical analysis of observed data was done using Analysis of variance with F-test at 5% level of significance followed by Duncan's Multiple Range Test (DMRT) at $p = 0.05$.

Results and Discussion

Soil pH

Biochar, POBA, CFA and compost gave significant enhancement of peat soil pH compared to its initial pH (Figure 1). The low increment at a rate of 0.1 point occurred on CFA treatment which was higher than POBA, CFA and compost application. The result is in line with Maftu'ah and Indrayati (2013) investigation on coconut shell biochar in peat soil. Application of biochar + compost that increased the pH by 0.72 points showed that the combination of compost with inorganic ameliorant (biochar and CFA) increased soil pH. The effective improvement of pH that was resulted from the soil buffering reaction was caused by the combination of organic and inorganic ameliorant, particularly biochar. The decomposition and mineralization of compost produce CO₂ functioning as a buffer compound to increase soil pH (Bohn et al., 1985; Stevenson, 1994). In addition, the compost and biochar contain the negatively functional groups (Ichriani et al., 2018) that are beneficial to bind soil H⁺ (Bohn et al., 1985). Peat soil has organic compounds that come from the result of decomposition of organic

matter and high in lignin content. Lignin which undergoes a degradation process under anaerobic condition, will break down into humic compounds and phenolic acids. Phenolic acid is one of the contributors to acidity in peat soils due to the functional groups (i.e. carboxyl groups, hydroxyl groups). Lesbani and Badaruddin (2012) reported that humic acid extracted from Muara Kuang Ogan Ilir peat soil was dominated by carboxyl groups (-COOH) of 560 mmol/kg and hydroxyl groups (-OH) of 125 mmol/kg.

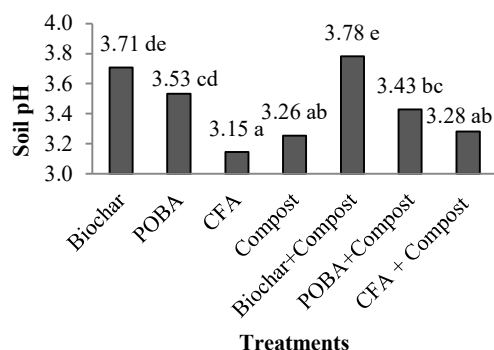


Figure 1. The differences in peat soil pH due to ameliorant application.

Remarks: Similar letters above columns indicate no statistical difference between the treatments based on the DMRT test at $P < 0.05$.

The activity of organic acids (especially phenolic acid derivatives) can be reduced through the provision of biochar, POBA, and CFA. Increasing the resistance of rice against organic acid poisoning resulted from the application of EPOEB ash was able to reduce the concentration of phenolic acid derivatives, i.e. ferulic, syringic, and p-cumarate (Haryoko, 2012). The decreasing of hydroxybenzoic acid and p-coumaric from 53.45 ppm and 26.18 ppm to 0.24 ppm and 0.13 ppm were demonstrated by ameliorating peat soil using fly-ash from pulp boiler waste (Rini et al., 2007). The addition CFA of 5% by (Sunardi et al., 2009) and 15 t/ha by (Syafitri et al., 2012) increased soil pH on peat soil. In our study, the increase in soil pH was low, indicating the organic acid activity decrease was not maximal.

The availability of K, Ca, and Mg

The peat soil nutrient status underwent changes with the application of biochar, POBA, CFA and compost (Figure 2). A significant increment occurred on exchangeable K and exchangeable Ca except for exchangeable Mg. However, these ameliorants showed inconsistent positive effects in the availability of peat soil nutrients such as compost, which impacted the increase of availability of K, Ca, and Mg. The application of CFA on peat soil has not been able to increase exchangeable Mg and exchangeable K, except for exchangeable Ca. The exchangeable Ca has increased by 28.57% compared to the exchangeable Ca of the initial soil. In addition, the availability of soil

nutrients impacted by POBA that was higher than CFA treatment has not been able to improve the soil nutrients in the short term (Utami, 2018). This phenomenon was due to the impact of CFA and POBA as slow-release ameliorant resulting in a long time to dissolve and increase the nutrient content in the soil. The CFA and POBA ameliorant sources contain high macro and micronutrients (Sulistiyo et al., 2015; Fahrussyah et al., 2019).

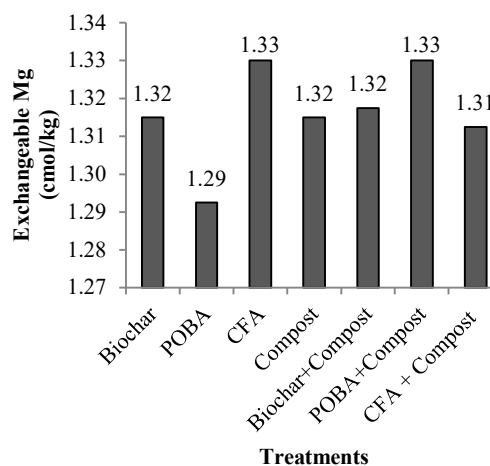
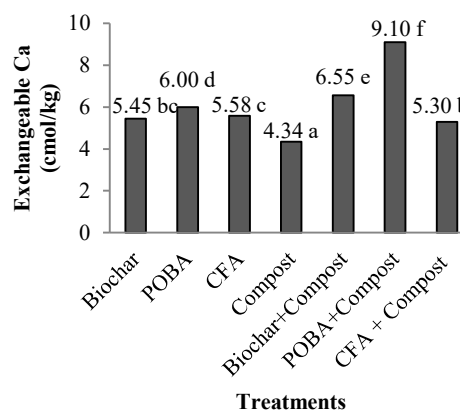
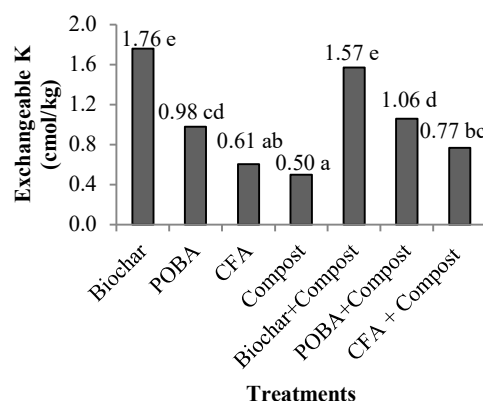


Figure 2. The availability of exchangeable K, Ca, and Mg on peat soil due to ameliorant application.

Remarks: Similar letters above columns indicate no statistical difference between the treatments based on the DMRT at $p = 0.05$.

However, the compounds contained in CFA and POBA were crystalline silicate compounds that were formed due to heating to high temperatures. The crystalline silicate compounds resulted in macro and micronutrients difficult to dissolve (Mulyani et al., 2016). Likewise, OPEFB biochar has a structure of aromatic ring compounds ($C = C$) and crystalline which is formed from cellulose and lignin compounds. These structures are formed due to the high heating of cellulose and lignin compounds in the slow pyrolysis process (Joseph et al., 2010; Shaaban et al., 2014).

The GCMS analysis of OPEFB biochar indicated that the dominant organic compounds were presumably in the form of cyclopropane compounds (15.51%) and cycloheptatriene compounds (12.04%) (Ichriani et al., 2018). The application of biochar or biochar+compost could escalate the availability of K nutrient, among others. In the short term, biochar was able to increase the availability of K, and in the long term, it had the effect of preserving nutrients (Biederman and Harpole, 2013). Biochar application has increased 69-89% availability of soil K (Widowati et al., 2014) and the residual biochar still has a positive effect on the availability on the soil K in the next growing season (Widowati et al., 2017). Synergism between the mixing of inorganic ameliorants (biochar, POBA, and CFA) and organic ameliorants (compost) triggered an increase in exchangeable K and exchangeable Ca because of its capability to provide higher K and Ca availability compared to the unmixed treatments.

The increase in soil nutrients availability was thought to be due to the presence of organic acid compounds such as humic acid compounds from compost (Mulyani et al., 2016). Besides, the process of decomposition and minerals release through compost mineralization results in increased nutrient availability.

Availability of P

The application of biochar, POBA, and CFA provided a significant increase in the peat soil P availability (Figure 3). The biochar + compost amendment produced the lowest P compared to other treatments, even though there was an increase of 135.7% available P compared to the initial P of the soil. Application of coconut shell biochar mixed with chicken manure was able to increase the available P of peat soil from 31.63 ppm P_2O_5 to 232.03 ppm P_2O_5 (Maftu'ah and Indrayati, 2013). Other studies have shown similar results that the CFA application can increase the availability of nutrients in the soil, including the P nutrient (Rani and Kalpana, 2010; Fahrumsyah et al., 2018). The significant enhancement in P availability was not optimal when compared with the total P content in the ameliorant source because all P compounds were not changed completely into available form. The total P content at POBA was 6,492.44 ppm P_2O_5 (Sulistiyo et al., 2015) and 1,378 ppm P_2O_5 at CFA (Fahrumsyah et al., 2019). In peat soil, the availability of inorganic P is low (Aryanti

et al., 2016). This is because soil P is dominated by organic P (Ilham et al., 2019). Soil P is also bound by organic acid compounds (Istina et al., 2019). The total organic P of peat soils from Air Sugihan Kiri, South Sumatra, ranged from 77-90% and P-inorganic 10-23% (Hartatik et al., 2003).

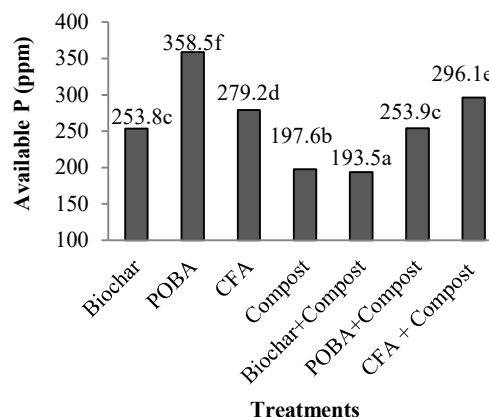


Figure 3. The P availability of peat soil due to ameliorants.

Remarks: Similar letters above columns indicate no statistical difference between the treatments based on the DMRT at $p = 0.05$.

The not optimal availability of P is thought to be due to not all P compounds contained in the ameliorant material have changed into available forms. Another thing is thought to be due to the low activity of soil microbes that help dissolve phosphate, especially phosphate solubilizing microbes. Soil microbes helped dissolve phosphate, especially phosphate solubilizing microbes, through their organic acid secretion (Cunningham and Kuiack, 1992). The soil pH of peat soil was low (Figure 1), indicating a high level of acidity. Soil acidity conditions do not support the presence of microbes, so that the activity of the phosphate solubilizing microbial is still low. Phosphate solubilizing microbes are able to secrete the enzyme phosphatase and low molecular weight organic acids, namely oxalate, malic, succinic, and fumarate (Ingle and Padole, 2017). The existence of the enzyme helped the hydrolysis of P soil which were still bound to form soluble P or available P (Lal, 2002). Soil cations (Al^{3+} , Fe^{3+} , and Ca^{2+}) which fixation of P can also be chelated by organic acids derived from phosphate solubilizing microbes (Ingle and Padole, 2017; Istina et al., 2019). This mechanism has the effect of increasing soil P availability and efficiency of P fertilization (Istina et al., 2019). The production of phytohormones, vitamins, or amino acids resulted from the activity of soil microorganisms may also affect soil P release (Chakkaravarthy et al., 2010). Therefore, further research on the application of the indigenous phosphate solubilizing microbes and specific locations needs to be studied to maximize the availability of P in agriculture on peat soils.

Conclusion

Application of biochar, POBA, CFA, compos, and the mix with compost were able to reduce acidity and increase available P in peat soil. The increment of pH was approximately 0.1- 0.7 above the initial soil pH. Compared to the initial available P there was an increase P of more than 135.7%. The amelioration supplied K and Ca nutrients but not with Mg. The results confirmed that the mixing of biochar, POBA, or CFA with compost increased peat soil nutrients availability.

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