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Application of Biocom-Phosphate Solubilizing Fungi and Coal Fly-Ash to Increase P-Availability of Peat Soil in Kalimantan

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ABSTRACT

The peatlands have the potential to support food security efforts. However, there is have constraints on soil fertility, especially the P nutrients availability. The biotechnology approach, the application of ameliorant (biochar-compost carrier medium (biocom)) enriched with phosphate solubilizing fungi (PSF) and coal fly ash (CFA), was expected to increase the P-availability in peat soils. The research aimed to study the application of biocom enriched with PSF and CFA to increase soil P-availability and plant P-uptake. The study was conducted using peat soil media with the formulation of CFA and biocom enriched with PSF and CFA as treatments. The treatment effect was observed through soil P available and plant P uptake of maize. The results showed PSF application was inconsistent in improving P available in peat soils in Kalimantan. In Central Kalimantan, Biocom + PSF was able to increase P available in peat soils by up to 406.18% (*A. oryzae*-Tb7) and 353.44% (*N. fischeri*-Tm8). However, in South Kalimantan P available in peat soil was only 8.04% (*A. oryzae*-Tb7) and 12.86% (*N. fischeri*-Tm8). The CFA+ (biocom+PSF) formulation increased P available in Central Kalimantan peat soils, but it was different from South Kalimantan peat soils. The application of biocom+PSF and CFA has not been able to increase the P uptake of maize plant in peatlands of South Kalimantan.

Keywords: Biochar, coal fly-ash, peat soil, phosphate solubilizing fungi

INTRODUCTION

Peatlands are an alternative for expanding agricultural land. Indonesia's peatland area is around 14.9 million ha (7.8% of the total area of Indonesia), and 30% has the potential for agriculture. The Peatland area of South Kalimantan is 107,344 ha (BBSDLP, 2015; Sudrajat and Subekti 2019). However, nutrient availability is a limiting factor for peat soils. The low phosphate (P) availability is a significant nutrient problem for peat soil (Noor *et al.* 2016). The low nutrient availability in peat soils is an obstacle that causes a lack of nutrients for plants. The element phosphorus (P) in peat soil is mainly found in the form of organic P. P-organic compounds will undergo a process of mineralization into P-inorganic by microorganisms, so it takes time for the mineralization process until soil P available can be used by plants.

The biotechnological approach in the form of ameliorant enriched with beneficial microbes is an alternative to overcome the low availability of phosphate. Amelioration can reduce the risk of degradation in peat soil (Maftu'ah and Indrayati 2013), thereby improving the quality of peat soils to support agriculture. Ameliorant potential from local natural resources can be obtained from oil palm plantations and steam power plants.

In 2018, the oil palm plantation area of South Kalimantan was around 542,420 ha, the total production of crude palm oil (CPO) was 1.46 million tons, and the potential for oil palm empty fruit bunches (OPEFB) was 0.33 million tons (Central Bureau of Statistics 2019). Handling OPEFB biomass in oil plam plantations is minimal, and there is a risk of increasing greenhouse gas emissions through biomass decomposition. OPEFB biomass is a source of phosphate solubilizing fungi (PSF) which helps increase soil P availability and can be modified into biochar (Ichriani *et al.* 2018). Applying biochar plus compost improved the properties of acidic soil in upland (Nurida and Jubaedah 2019). PSF are microbes that release phosphorus bound by soil components to be available for plants. PSF isolated from peat soil samples were tested for their ability to dissolve phosphate (Istina *et al.* 2019). The study to obtain phosphate solubilizing microorganisms that can increase the availability of dissolved phosphate in the soil is very necessary, considering that these microbes can be an alternative to support the use of productive land for agriculture.

Local ameliorant such as coal fly ash (CFA) has the potential to improve peat soil fertility. Burning coal in power plants produces 5% of ash pollutants. The resulting ash consists of 80-90% CFA. Indonesia's CFA potential reached 6.65 million tons in 2019. CFA contains Ferrum (Fe), calcium (Ca), aluminum (Al), silica (Si), potassium (K), and magnesium (Mg) in a high percentage; zinc (Zn), boron (B), manganese (Mn), and cuprum (Cu) in moderate amounts; while carbon (C) and nitrogen (N) in small amounts (Murugan and Vijayarangam 2013). The content of heavy metals is less than specified, is almost non-toxic, and is relatively harmless (Dzantor *et al.* 2015; Damayanti 2018). It also contains phosphorus (P), bases, and microelements that are important for plants (Sheoran *et al.* 2014). Using CFA as an ameliorant can increase rice (Prasetyo *et al.* 2010) and maize yields (Kaur and Goyal 2015; Fahrunsyah *et al.* 2018). CFA is used to increase soil fertility, and it mainly increases the availability of micro-nutrients such as copper (Cu), zinc (Zn), and manganese (Mn) to promote plant growth.

This research aimed to study the effect of the biocom application enriched with PSF and CFA to increase phosphate availability and P uptake of maize plant in peat soils.

MATERIAL AND METHODS

The OPEFB material was air-dried for one week and cut into 5-10 cm pieces. The production of OPEFB biochar is carried out at the Bioenergy Laboratory, Tribuwanatunggadewi University, Malang. The production of OPEFB biochar used a slow pyrolysis system with a heating temperature of 400 ^{o}C and a heating time of 6 hours. The chilled OPEFB biochar was filtered through a 10-mesh diameter sieve (<2mm). The OPEFB compost was obtained from the Compost Division of PT. Surya Inti Sawit Kahuripan oil palm plantation, Subdistrict of Parenggean, East Kotawaringin Regency, Central Kalimantan. The OPEFB is crushed and mixed with oil palm liquid waste at the field of the Compost Division for six weeks (mature compost). The OPEFB compost was air-dried for one week and sifted with a sieve with a diameter of <0.5 mm through holes. The CFA material is taken from the Pulang Pisau PLTU, Central Kalimantan. For this study (Research 1), peat soil were taken from Kalampangan, Sebangau, Central Kalimantan (2^{o}16'57.9"S and 114^{o}01'27.0"E). Previous research (Research 2), peat soil were taken from Sukamaju, Landasan Ulin, Banjarbaru, and South Kalimantan (3^{o}24'87"S and 114^{o}43'50"E).

The preliminary results of peat chemical properties from peat soil of Kalampangan (Central Kalimantan) were pH H_2O (1:5) 3.63, total-P 0.10%, available-P (Bray I) 43.37 ppm, K-exch 0.61 cmol kg^{-1}, Mg-exch 1.32 cmol kg^{-1}, and Ca-exch 4.34 cmol kg^{-1}. The chemical properties of peat soil from Sukamaju (South Kalimantan) were pH H_2O (1:5) 5.60, total-P 0.32%, available-P (Bray I) 81.21 ppm, K-exch 0.11 cmol kg^{-1}, Mg-exch 0.25 cmol kg^{-1}, and Ca-exch 14.99 cmol kg^{-1}.

Previous research has obtained two isolates of PSF, namely *Aspergillus oryzae*-Tb7 (*A. oryzae*-Tb7) and *Neosartorya fischeri*-Tm8 (*N. fischeri*-Tm8), which were able to dissolve the highest phosphate in *Pikovskaya* media (Ichriani *et al.* 2017). PSF (*A.oryzae*-Tb7 and *N.fischeri*-Tm8) were cultured on PDA agar media according to required treatments. PSF were inoculated on a biochar-compost carrier medium (biocom). Biochar OPEFB and compost OPEFB mixed at the best ratio based on the early study. The best biocom as a carrier medium for each PSF were isolated by *A.oryzae*-Tb7 at ratio biochar OPEFB 60%:compost OPEFB 40% (biocom 60:40+PSF *A.oryzae*-Tb7) and *N.fischeri*-Tm8 at ratio biochar OPEFB 70%:compost OPEFB 30% (biocom 70:30+PSF *N. fischeri*-Tm8) (Ichriani *et al.* 2018). Biocom that has been mixed with PSF was incubated for one week. Biochar and biocom- PSF uses the equivalent of 15 Mg ha^{-1}. The density of PSF in each carrier medium was 10^8 conidia^{-1} ml^{-1} 10 g biocom. The dose for CFA given was equivalent to 5 Mg ha^{-1}. The chemical properties of CFA were pH H_2O 13.04, P- total 0.60%, N-total 0.16%, and K-total 0.27%, Ca-total 9.30%, and Mg-total 0.389%. The carrier media inoculated with PSF was placed in a closed container and a clean room. The chemical properties of the compost OPFEB were pH H_2O (1:5) 4.47, total-P 0.93%, N-total 2.21%, K_2O 0.67%, and C/N ratio 14.66, respectively. The

OPFEB biochar had pH H_2O (1:5) 9.90, total-N 0.95%, total-P 0.22%, and total-K 1.10 ppm (Ichriani *et al.* 2018).

Application of Indigenous PSF and CFA to Increase the Availability of P in Peat Soils

This research was to study the ability of the indigenous PSF biotechnology approach with CFA to increase the availability of P in peat soils. Research 1 was arranged using a single factor Completely Randomized Design (CRD). The soil ameliorant material (biocom and CFA) consisted of 6 treatment levels, namely: (1) P0 = without ameliorant; (2) P1 = CFA; (3) P2 = CFA+ PSF *A.oryzae*-Tb7; (4) P3 = CFA+ PSF *N. fischeri*-Tm8; (5) P4 = CFA + (biocom 60:40+PSF *A.oryzae*-Tb7); (6) P5 = CFA+ (biocom 70:30+PSF *N. fischeri*-Tm8). Each treatment was repeated three times. Observations were made three times and were carried out destructively.

Peat soil for each Kalampangan and Sukamara was weighed 400 g, applied, and incubated for four weeks. The soil conditions were kept moist (in 80% field water capacity). P available (ppm P_2O_5) was analyzed by Bray I-method, pH soil (pH-H_2O 1:5) by Electrode glass method, and the total population of PSF (CFU g^{-1} soil) by pour method with PDA media.

Data from available P and soil pH observations were processed and analyzed using the F-test variance analysis and DMRT-test (á 5%). The total population of PSF was only observed in the treatment that was applied to PSF (P2, P3, P4, and P5). The total PSF population (CFU g^{-1}) was calculated using a colony counter based on the Total Plate Count (TFC) calculation method (Husen *et al.* 2007).

The total population:

$$\text{CFU/g of soil} = \frac{\text{(number of colonies)} \times \text{(fp)}}{\text{dw}}$$

Remarks:

fp = dilution factor in Petri dishes whose colonies are counted

dw = dry weight of soil (g) = wet weight of soil x (1 – the soil water content)

Effects of Indigenous PSF and CFA on Plant Nutrient Uptake in Peat Soil

The research amied to determine the effect of the given treatment on the level of plant P uptake and levels of metal compounds in plant tissues. Research 2 was an experiment in a greenhouse using maize plant as an indicator plant. The study was arranged based on a single factor completely randomized design (CRD) The teratments were peat soil ameliorant formulation in the form of P-fertilizer, biochar, biocom-PSF, and CFA. There were eight treatments and three replications, so 24 experimental units were obtained. The treatments were: (1) A0 = without ameliorant; (2) A1 = P-fertilizer; (3) A2 = P-fertilizer + biochar; (4) A3 = P-fertilizer + CFA; (5) A4 = P-fertilizer + (biocom 60:40+*A.oryzae*-Tb7+); (6) A5 = P-fertilizer + (biocom 70:30+*N.fischeri*-Tm8); (7) A6 = P-fertilizer + CFA + (biocom 60:40+*A.oryzae*-Tb7); and (8) A7= P-fertilizer + CFA + (biocom 70:30+*N.fischeri*-Tm8).

Research 2 only used peat soil of Sukamara (Landasan Ulin, Banjarbaru, South Kalimantan). The treatment was applied to the peat soil of Sukamara, and maize was planted. The soil media used was 10 kg pot^{-1}. All treatments were applied by 150 kg P_2O_5 ha^{-1} as P-fertilizer except A0 treatment. N-fertilizer and K-fertilizer were given as essential fertilizers with doses of 200 kg N ha^{-1} and 150 kg K_2O ha^{-1}, respectively. Eight weeks after planting (wap), the upper crown of maize was harvested for P-tissue analysis (plant P uptake).

RESULTS AND DISCUSSION

Application of Indigenous PSF and CFA to Increase the Availability of P in Peat Soil

Phosphate Solubilizing Fungi (PSF) Population

The total PSF population in the P2-P5 treatment increased and decreased according to the incubation period and can be seen in the total dynamics image of the PSF population presented in Figure 1. In the first week, the highest total PSF population was in the CFA+ (Biocom 70:30+PSF *N.fischeri*-Tm8) (P5) treatment with a total of 29.2×10^5 CFU g $soil^{-1}$, and the lowest total population of PSF was in the treatment of CFA + PSF *N.fischeri*-Tm8 (P3), which was 1.7×10^4 CFU g $soil^{-1}$. At three weeks, the trend of increasing the total PSF population was shown by the CFA+PSF *N.fischeri*-Tm8 (P3) treatment and the CFA+ (Biocom 60:40+PSF *A.oryzae*-Tb7) (P4) treatment. The highest total PSF population reached 36.9×10^5 CFU g $soil^{-1}$ in the P4 treatment.

The trend of increasing the total PSF population of *N. fischeri*-Tm8 in the P3 treatment indicated that *N. fischeri*-Tm8 was more adaptable in the peat soil environment even without the biocom carrier medium. On the other hand, *A. oryzae*-Tb7 can adapt to the peat soil environment in synergy with biocom carrier media. The total population of *A. oryzae*-Tb7 in the *A. oryzae*-Tb7 treatment

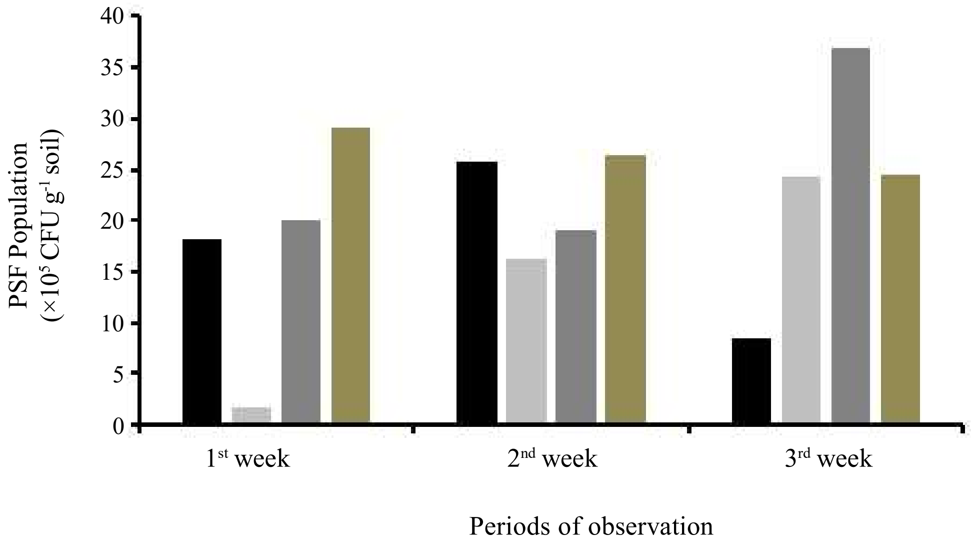

Figure 1. The dynamics of total PSF population on peat soil in 1-3 weeks after incubation. ■ : P2 = CFA+ PSF A.oryzae-Tb7; ■: P3 = CFA+ PSF N. fischeri-Tm8; ■: P4 = CFA + (Biocom 60:40+PSF A.oryzae-Tb7); ■: P5 = CFA+ (Biocom 70:30+PSF N. fischeri-Tm8).

decreased without biocom (P2= CFA+ PSF *A. oryzae*-Tb7), while the total population of *A. oryzae*-Tb7 increased in the *A. oryzae*-Tb7 treatment using a biocom (P4= CFA+ PSF *A. oryzae*-Tb7). The application of biochar and Mycorrhizal arbuscular can significantly increase the population of this fungus compared to without biochar (Bibiana *et al.* 2021).

Microorganism activity is influenced by environmental factors such as humidity, temperature, media pH value, redox potential, oxygen content, and osmotic concentration. Microorganisms such as bacteria perefer slightly alkaline environmental conditions with an optimum pH value of 7-7.5, while fungi prefer an acidic environment in the optimum pH range of 5.2-5.6 (Stanaszek-Tomal 2020). The presence of *Aspergillus sp.* in the soil is strongly influenced by soil pH. Fungi can grow optimally in acidic soil pH conditions (Sagala *et al.* 2015; Mawarni *et al.* 2021). This fungus can still live well up to a thickness of >8 cm due to soil pH conditions that support its growth. In addition, *Aspergillus sp.* is cosmopolitan. Its conidia are very light and with a reasonably small size, very easily carried by the wind (Tyasningsih 2010), and in relevant environmental factors, it becomes easier to grow.

In the P2 treatment (CFA+ PSF *A.oryzae*-Tb7), PSF that did not use biocom continued to experience a drastic decrease in the third week, even though it increased in the second week. The ability of *A.oryzae*-Tb7 increased due to the presence of biocom as a carrier and nutrient storage for PSF (Ichriani *et al.* 2017). Using husk charcoal biochar as a carrier also increases soil microbial activity (Liu *et al.* 2017). The P2 (CFA+ PSF *A.oryzae*-Tb7) treatment (without biocom) experienced a decrease in the third week. The microorganisms activity in the soils are influenced by pH, humidity, temperature, soil structure, and others, so it requires high adaptation for the isolate when applied to different media from the origin of the isolate (Stanaszek-Tomal 2020).

Soil pH

The CFA and PSF treatment with and without biocom on peat soil was able to have a significant effect on increasing soil pH. Adding CFA to peat soils gave an increase pH in average of 0.4 points. The addition of CFA plus the addition of PSF caused the increasing pH of the peat soil by 0.7 (1st week), 0.8 (2nd weeks), and 0.5 (3rd weeks). However, over time, the pH of peat soil at two weeks tends to decrease up to three weeks (Table 1).

The application of CFA can increase the pH of mineral soils (Shaheen and Tsadilas 2013; Skousen *et al.* 2013; Cieæko *et al.* 2015). Applying CFA to peat soils can increase the pH value of the soil, the available P content, and the base cations availability (Oklima 2014; Ichriani *et al.* 2021). The addition of CFA increases the soil's negative charge by deprotonating H^+ ions in clay minerals. An increase in soil pH indicates the occurrence of deprotonation of H+ ions. Observations on soil chemical properties showed that the application of CFA only significantly affected soil pH and CEC on dry land and paddy fields. Adding 25 – 75 Mg ha^{-1} of coal ash to the soil

Table 1. The changes of pH (H_2O) in peat soils during 3 weeks.

Treatments	Soil pH (pH-H_2O)		
	1st week	2nd weeks	3rd weeks
P0	4.00[a]	3.90[a]	3.80[a]
P1	4.38[b]	4.45[b]	4.22[b]
P2	4.70[c]	4.72[b]	4.39[b]
P3	4.69[c]	4.69[b]	4.56[c]
P4	4.73[c]	4.76[b]	4.58[c]
P5	4.93[d]	4.77[b]	4.99[d]

The mean value followed by the same letter in the same column shows no significant difference in the 5% DMRT test. P0 = Without ameliorant; P1 = CFA; P2 = CFA+ PSF A.oryzae-Tb7; (4) P3 = CFA+ PSF N. fischeri-Tm8; (5) P4 = CFA + (Biocom 60:40+PSF A.oryzae-Tb7); (6) P5 = CFA+ (Biocom 70:30+PSF N. fischeri-Tm8)

increase soil pH and CEC (Priatmadi *et al.* 2014). CFA containing elements of CaO and MgO will be able to increase the soil pH (Haryanti 2014). CaO and MgO in the soil will experience lime and produce Ca^{2+} and Mg^{2+} and OH^- ions in the soil solution. At the same time, H^+ ions are neutralized by OH ions, and Ca and Mg combine with HCO_3^- to form $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$. This mechanism causes the pH of acidic soil to increase (Paradelo *et al.* 2015).

In the third week, all treatments decreased soil pH significantly (Table 1). The decrease in soil pH was likely to be caused by the applied PSF. A decrease in soil pH can indicate the release of organic acids by phosphate solubilizing microbes (Sharma *et al.* 2013; Osorio *et al.* 2015). These organic acids result from microbial metabolism, generally from oxidative respiration or the fermentation of organic carbon such as glucose (Sharma *et al.* 2013). The decrease in pH caused by the secretion of organic acids is one of the main mechanisms of P solubilization by phosphate solubilizing microbes (Osorio *et al.* 2015).

Peat soil has organic compounds from the imperfect decomposition of organic matter. In addition, peat soil organic matter has a high lignin content. Under anaerobic conditions, decomposed lignin compounds will produce humic compounds and phenolic acids. One of the factors that contribute to the acidity of peat soil is phenolic acid compounds. These compounds have functional groups from, among others, a carboxyl or hydroxyl group. Humic acid extract from Muara Kuang peat soil, Ogan Ilir, is dominated by a carboxyl group (–COOH) of 560 mmol kg^{-1} and a hydroxyl group of 125 mmol kg^{-1} (Lesbani and Badaruddin 2012). The organic acid activity of phenolic acid derivatives in peat soils can be reduced by applying ameliorant materials with a high pH and functional groups, such as CFA, boiler ash, or biochar. OPEFB boiler ash application can reduce the concentration of phenolic acid derivative compounds such as ferulic, syringic, and p-cumarate (Haryoko 2012). The application of 15 Mg biochar ha^{-1} (Ichriani *et al.* 2021) and 15 Mg CFA ha^{-1} (Syafitri *et al.* 2012) can increase the pH of peat soil.

In this study, the increase in soil pH was still not maximal due to the addition of coal fly ash as a neutralizer of H^+ in peat soil, so the pH of peat soil increased at one week but decreased at three weeks presumably due to the high CEC of the soil. A high CEC value in peatlands does not indicate that the content of basic cations is relatively high. The colloid adsorption complex of peat soil is dominated by hydrogen ions (H^+). To increase the pH of peat soil, a higher dose of CFA is needed, and for a longer time.

Additional treatments on peatlands, such as applying fertilizers and ameliorants, will affect the pH of the peat soil, which is formed from carboxyl and hydroxyl groups (Yondra and Wawan 2017). Organic acids in peat soil can be neutralized with fly ash containing Ca and Mg. The neutralization reaction of organic acid compounds with compounds contained in fly ash can be explained as follows:

$$2CH_3COOH + CaO \longleftrightarrow (CH_3OO)_2\ CA + H_2O$$

Soil Available P

In the first week, the highest available P value was found in the CFA + (Biocom 60:40+PSF *A. oryzae*-Tb7) (P4) treatment, with an increase of 92% compared to P0. However, the available P-value in P1, P2, and P3 treatments was 55-60% lower than P0. In the third week, soil available P increased significantly in all treatments. However, soil available P in the P1, P2, and P3 treatments

Table 2. Mean of P-available (ppm) Bray-I peat soils at the first and third week.

Treatments	P-available (P-Bray I) (ppm)	
	1st week	3rd week
P0	82.65b	99.96b
P1	32.47a	55.34a
P2	31.84a	39.51a
P3	35.01a	42.32a
P4	161.17c	146.84c
P5	158.75c	179.59c

The mean value followed by the same letter in the same column shows no significant difference in the 5% DMRT test. P0 = Without ameliorant; P1 = CFA; P2 = CFA+ PSF A.oryzae-Tb7; (4) P3 = CFA+ PSF N. fischeri-Tm8; (5) P4 = CFA + (Biocom 60:40+PSF A.oryzae-Tb7); (6) P5 = CFA+ (Biocom 70:30+PSF N. fischeri-Tm8).

were still lower than P0. The highest value in the third week was found in P5 (CFA+ (Biocom 70:30+PSF *N. fischeri*-Tm8), with an increase of 79.66 % compared to P0.

The soil available P in the P0 treatment was higher than in the P1, P2, and P3 treatments in the first and third weeks (Table 2) due to the presence of CFA having an immobilizing effect on the soil available P. The results showed that CFA from PLTU Asam-Asam, South Kalimantan contained 2.40% CaO; 2.03% MgO; 0.06% NaO; 5.70% Al_2O_3; 14.40% Fe_2O_3 and SiO_2 (Haryanti 2017). The presence of elements in CFA, such as Ca, Mg, Al, and Fe, which are high, has the potential to bind P nutrients that are already available in peat soils, causing a decrease in P in P1, P2, and P3 treatments. The orthophosphate ions in peat soil are more bound to the Ca organo-cation complex because the orthophosphate ion content (H_2PO_4) reacted with Ca^{2+} cations to produce $Ca(H_2PO_4)_2$. $Ca(H_2PO_4)_2$ compounds are very soluble in water. If the Ca ion content in the soil is still high, then there is a tendency to react with Ca compounds. This reaction will produce $Ca_3(PO_4)_2$ compound, which is difficult to dissolve, so compound P becomes fixed.

In addition, the proportion of CFA–fungi is affected due to the high pH of CFA so that the PSF reform process in increasing available P in the soil is hampered. The study's results on the application of CFA and organic matter of chicken manure showed a decrease in soil available P at the composition of 75% and 100% CFA, namely 44.40 ppm P_2O_5 and 6.00 ppm P_2O_5, respectively. At the composition of the mixture of 75% CFA, the lower available P content was thought to be due to the insufficient added organic C content for microbes to dissolve P from CFA, and the P contribution from chicken manure was relatively less (Hermawan *et al.* 2013). The decreasing occurred because the Ca, Mg, Al, and Fe content in CFA had an immobilizing effect on soil available P.

However, this immobilization can be overcome by giving biocom + PSF. It was shown that soil available P in P4 and P5 treatments were higher than soil available P in P2 and P3 (PSF without biocom). In the first week, the soil available P in P4 reached 406.18% compared to P2; while, it increased at P5 by 353.44% compared to P3. These results indicate that the P availability in peat can be improved by giving CFA + (biocom+PSF), which is found in P4 and P5 treatments. Biocom is a mixture of biochar and organic compost, the carrier medium for PSF. In addition to the carrier media, biocom can be a source of food or nutrition, which the PSF uses as a carbon source. The presence of biocom carrier media supports the ability of isolates to function as PSF, which was shown by the total microbial population of PSF in the P3 and P5 treatments, but the dissolution of P (soil available P) in P5 with biocom was higher than in P3 (without biocom).

PSF assists to dissolve immobilized soil P. Dissolution of P by *Aspergillus spp*. by decreasing the pH of the solution medium, causing an increase in P dissolution (Acevedo *et al.* 2014). The organic acid compounds play an essential role in the P dissolution process. These compounds help to release P by providing protons and anion complexes or through ligand exchange reactions or metal ion complexes (Scervino *et al.* 2010). Availability of organic matter for microbial respiration and chemical requirements of inorganic oxides, such as Fe^{3+}, Mn^{4+}, NO^{3-}, SO_4^{2}, CO_2, and H^+ are used by anaerobic microorganisms.

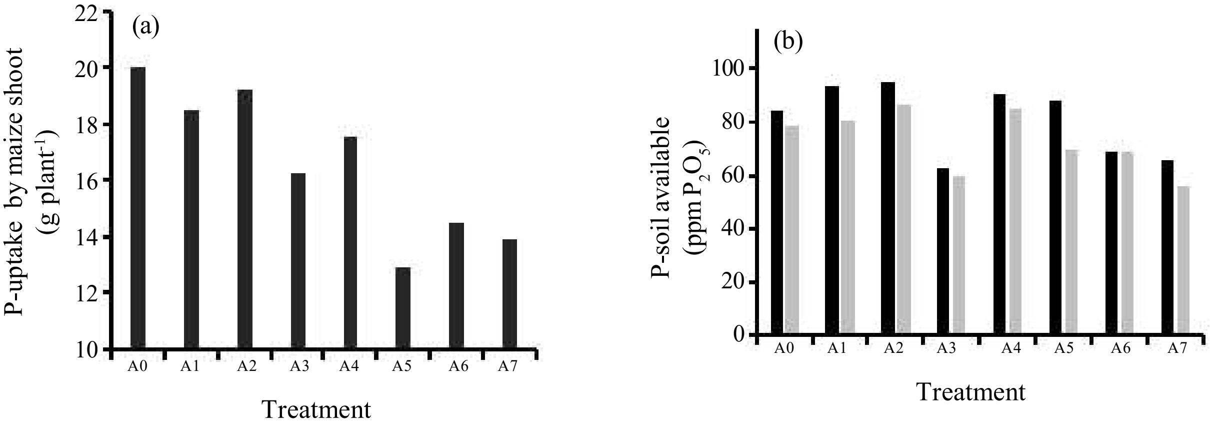

Figure 2. P-uptake by maize shoot (g plant^{-1}) (a); and soil P-available (ppm P_2O_5) in peat soil. A0 = Without ameliorant; A1= P fertilzer; A2= P fertilzer+Biochar; A3= P fertilzerCFA; A4= P fertilzer+(biocom 60:40+PSF A.oryzae-Tb7); A5= P fertilzer+(biocom 70:30+PSF N.fischeri-Tm8); A6= P fertilzer+CFA+ (biocom 60:40+PSF A.oryzae-Tb7); A7= P fertilzer + CFA+ (biocom 70:30+ PSF N.fischeri-Tm8).

Effects of Indigenous PSF and CFA on Plant Nutrient Uptake in Peat oil

P Uptake of Maize Plant

Research 2 was conducted to determine the uptake of P nutrients from maize plants treated with the CFA+biocom-PSF formulation. The treatment application did not show a significant effect on the P uptake of maize plants. Although the treatment given was able to show a significant pattern of influence on the soil Pavailability, the plant P uptake showed a pattern of soil available P (Figure 2)

In general, the plant P uptake in the treatment without ameliorant, with the addition of P-fertilizer and P-fertilizer+biochar, were high. The application of PSF isolates to treatments of A4 (P-fertilizer + (biocom 60:40+*A.oryzae*-Tb7)) and A5 (P-fertilizer + (biocom 70:30+*N.fischeri*-Tm8)) on peat soil also did not increase P-absorption in plants, although the availability of P-soil has increased.

All treatments using CFA (A3, A6, and A7) in Research (2), as in Research (1), also showed low soil available P values. Applying biochar with or without PSF on peat soil in Research 2 can only increase the soil available P (Figure 2b) compared to other treatments. However, the causes of the low P uptake of maize in Research 2 are unknown.

The results of this study differed from the results of applying the CFA+ (biocom-PSF) formulation in Ultisol soil. Application of this formulation increased P availability in Ultisols through an increase in initial soil P (because soil pH increased), P contribution from CFA (Fahrunsyah *et al.* 2018), and compost of OPEFB (Ichriani *et al.* 2018). The ability of CFA+ (biocom-PSF) to increase P-available in Ultisols increased P uptake in plants (Ichriani *et al.* 2018; Fahrunsyah *et al.* 2019; Wilujeng *et al.* 2020).

CONCLUSIONS

The effect of applying phosphate solubilizing fungi to improve available P in peat soil was inconsistent. The presence of PSF + carrier media (biocom) can increase the P-available value in peat soils of Central Kalimantan by reaching 406.18% (*A. oryzae*-Tb7) and 353.44% (*N. fischeri*-Tm8), only 8.04% (*A. oryzae*-Tb7) and decreased by 12.86% on peat soils of South Kalimantan.

Then, coal fly ash can increase available P with additions such as PSF + biocom on peat soils of Central Kalimantan, with an increase in P-available value at P4 (CFA + PSF *A. oryzae*-Tb7 + biocom) 396.36% and P5 (CFA+ PSF *N. fischeri*-Tm8 + biocom) 388.91%. On the other hand, in South Kalimantan peat soil, this formulation reduced 14.29-40.90% soil available P.

Moreover, the application of biocom-PSF and CFA has not increased the P uptake of maize plant in the peat soil of South Kalimantan.

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