JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
ISSN: 2339-076X (p); 2502-2458 (e), Volume 8, Number 1 (October 2020): 2471-2480
DOI:10.15243/jdmlm.2020.081.2471

Research Article

The possible use of coal fly ash and phosphate-solubilizing fungi for improving the availability of P and plant growth in acid soil

Retno Wilujeng[1], Gusti Irya Ichriani[2], Fahrunsyah[3], Yulia Nuraini[4], Eko Handayanto[4*]

[1] Postgraduate Programme, Faculty of Agriculture, Brawijaya University, Jl. Veteran, Malang 65145, Indonesia
[2] Faculty of Agriculture, Palangka Raya University, Jl.Yos Sudarso, Palangka Raya 74874, Central Kalimantan, Indonesia
[3] Faculty of Agriculture, Mulawarman University, Jl. Paser Belengkong, Samarinda, East Kalimantan, Indonesia,
[4] Research Centre for the Management of Degraded and Mining Lands, Brawijaya University, Jl. Veteran, Malang, 65145, Indonesia

[*]corresponding author: handayanto@ub.ac.id

Received 10 July 2020, Accepted 20 September 2020

Abstract: The availability of P in acid soils may be raised through the application of phosphate-solubilizing fungi (PSF). Coal fly ash (CFA) that has a high pH and contains a relatively high P may also be used to raise the availability of P in acid sois. The purpose of this study was to explore the possible use of CFA and PSF in a biochar-compost carrier to improve the availability of P and plant growth in acid soil. Combined applications of two PSF isolates (*Aspergillus oryzae* = F1, and *Neosartorya fischeri* = F2) carried in three levels of biochar-compost (80% biochar + 20% compost = B1, 70% biochar + 30% compost = B2, and 60% biochar + 40% compost =B3), and two doses of CFA (60 t/ha = C1, and 80 t/ha = C2) were tested in this study through two experiments. The results of experiment 1 (laboratory experiment) showed that the application of *N. fischeri* carried in 70% biochar + 30% compost combined with 80 t CFA/ha (F2B2C2 treatment) significantly increased the available P more than other treatments. In comparison with control, the increase of soil available P content ranged from 13% in the F1B1C1 treatment (*A. oryzae* in 80% biochar + 20% compost combined with 60 t CFA/ha) to 101% in the F2B2C2 treatment (*N.fischeri* in 70% biochar + 30% compost combined with 80 t CFA/ha). The results of experiment 2 (glasshouse experiment) showed that the highest dry weight of maize shoot was obtained by the F2B2C2 treatment that increased 123% compared to control. The highest P uptake by maize was obtained by the F2B2C2 treatment (*N. fischeri* in 70% biochar + 30% compost combined with 80 t CFA/ha).

Keywords: *biochar, coal fly ash, phosphate-solubilizing fungi, acid soil*

To cite this article: Wilujeng, R., Ichriani, G.I., Fahrunsyah, Nuraini, Y. and Handayanto, E. 2020. Combined application of coal fly ash and phosphate-solubilizing fungi improve P availability and plant growth in acid soil. J. Degrade. Min. Land Manage. 8(1): 2471-2480, DOI: 10.15243/jdmlm. 2020.081.2471.

Introduction

Ultisols that are considered as acid soils have fertility problems for food crop production due to the low available P content in the soil. In Indonesia, Ultisols that are mostly found in Kalimantan, Sumatra, Java, Sulawesi and Papua, cover almost 46 million hectares (Subagyo et al., 2000). Various attempts have been made to increase the availability of P in Ultisols by the addition of inorganic fertilizers, as well as organic matters into the soil. The results of previous studies showed that the application coal fly ash (CFA), which was combined with phosphate-solubilizing fungi (PSF), and compost from oil palm empty fruit bunches (OPEFB) could increase the availability of P in an Ultisol of Kalimantan (Ichriani et al., 2017; Ichriani et al., 2018; Fahrunsyah et al., 2018; Wilujeng and Handayanto, 2019). However, the increase was not yet optimal. This is thought to be related to the suboptimal role of PSF isolated from the OPEFB. The non-optimal role of PSF was suspected to be related to the lack of adaptation of PSF in the carrier media used. Ichriani et al. (2017) succeeded in getting four PSF isolates from OPEFB, namely *Acremonium ciliens*, *Aspergillus oryzae*, *Hymenella Fr.,* and *Neosartorya fischeri*. Each of the four PSF isolates could increase available P by 451%, 400%, 216% and 114%, respectively on the 5th day in liquid Pikovskaya media containing tricalcium phosphate (Ichriani et al., 2017). However, only *A.oryzae* and *N.fischeri* that were able to increase the availability of P in an Ultisol even though the increase in available P was less than 10%. Fahrunsyah et al. (2018) reported that application of 80t CFA/ha and 40 t OPEFB / ha increased the available P on an Ultisol of East Kalimantan by 54%. However, very high doses of CFA can cause pollution of the natural environment by heavy metals such as Cu, Ni, Cr, Zn, Cd, Mo, Se, Pb, As, Hg, and B contained in CFA (Lee at al., 2006; Sharma and Karla, 2006; Mahale et al., 2012). Efforts are still needed to enhance the role of PSF in increasing the availability of P in Ultisols to improve growth and yield of maize plant, as well as to reduce the supply of CFA into the soil which is suspected of causing soil pollution by heavy metals contained in the CFA. The purpose of this study was to study the effect of the application of a combination of phosphate-solubilizing fungi (PSF) with "biocom" (biochar-compost), and coal fly ash (CFA), to improve growth and yield of maize plant, and P uptake by maize plant grown on an Ultisol.

Materials and Methods

Experiment 1: The effect of the application of PSF and CFA on soil chemical properties

The experiment was conducted in the Soil Biology Laboratory, Faculty of Agriculture, Brawijaya University in May-August 2019. The materials used were biochar generated from oil palm empty fruit bunches (OPEFB), OPEFB compost, phosphate-solubilizing fungi (PSF) isolates, and coal fly ash. The OPEFB was obtained from PT. Dharma Satya Nusantara, tbk in Muara Wahau District, East Kutai Regency, East Kalimantan. The OPEFB biochar was made using a pyrolysis system with a temperature of 400^oC for 2 hours. The PSF isolates used were those from the study of Ichriani et al. (2017), namely *Aspergillus oryzae* and *Neosartorya fischeri*. The CFA was obtained from the PT. Cahaya Fajar Kaltim, Tenggarong Seberang District, Kutai Kartanegara Regency. The soil (an Ultisol) used for this study was obtained from Tenggarong District, Kutai Kartanegara Regency. The characteristics of soil, coal fly ash, biochar, and oil palm empty fruit bunch compost used for this study are presented in Table 1.

Table 1. Characteristics of coal fly ash, and oil palm empty fruit bunches used for the study.

Characteristics	Soil *)	Coal Fly Ash*)	Oil Palm Empty Fruit Bunch **)	Biochar **)
pH	4.10	9.80	6.70	9.90
Organic-C (%)	1.23	0.82	17.30	0.89
Total-N (%)	0.14	0.05	1.56	1.01
Total-P (ppm)	37.22	1,378.56	3,700	2,200
Total-K (ppm)	232.87	719.35	1,100	6,700
Available P (ppm)	3.76	5.73		
Exchangeable cations:				
Ca^{2+} (me/100 g of soil)	3.17			
Mg^{2+} (me/100 g of soil)	1.08			
K^+ (me/100 g soil)	0.12			
Na^+ (me/100 g soil)	0.13			
Cation Exchange Capacity (me/100 g soil)	21.18			

*) Fahrunsyah et al. (2018), **) Ichriani et al. (2018).

The treatments tested consisted of combinations of two PSF isolates (F1 = *A. oryzae*, and F2 = *N.fischeri*) (Ichriani et al., 2017), three "biocom" levels (biochar-compost combination as PSF carrier media, B1 = 80% biochar + 20% compost), B2 = 70% biochar + 30% compost, and B3 = 60% biochar + 40% compost) (Ichriani et al., 2018), two doses of CFA (C1 = 60 and C2 = 80 t/ha) (Fahrunsyah et al , 2018), and one control treatment (without PSF and carrier media, without CFA). The thirteen treatments were arranged in a completely randomized design with three replications. Two isolates of PSF (*A. oryzae* and *N. fischeri*) were inoculated in the mixtures of biochar and compost with the proportion: 80% biochar + 20% compost (B1); 70% biochar + 30% compost (B2), and 60% biochar + 40% compost (B3). The biochar-compost mixture as a carrier is called 'biocom' (B). The weight for each carrier medium was 10 g. The density of each PSF inoculated was 10^8 conidia/mL/10 g of biocom. Each treatment combination was mixed with 100 g of soil, placed in a 200 g plastic bottle, and water was added to 80% of field capacity. The soil mixtures were then incubated for 10 weeks in a control room with a temperature of 25ºC. After 10 weeks, soil samples were collected from all bottles for analysis of pH, total-P, available-P, organic-C, exchangeable Al, and exchangeable H. Soil pH was determined using a pH meter, soil total-P content was determined using the method of Olsen and Sommers (1982), soil available-P was determined using the method of Bray and Kurtz (1945), soil organic-C content was determined using the method of Walkley and Black (1934), and exchangeables Al and H were determined using the method of Rayment and Higginson (1992). The PSF population that survived in the carrier media (biocom) were observed on a Potato Dextrose agar at 2, 4, 8, 12 and 16 weeks. The effects of the application of PSF in various biochar-compost mixture media combined with CFA on pH, total P, available P, exchangeable Al, and exchangeable H of the soil were statistically tested by one-way ANOVA, followed by the Least Significant Difference test at p = 0.05.

Experiment 2. The effect of the application of PSF and CFA on maize plant growth

The study was conducted in a glasshouse of the Faculty of Agriculture, Brawijaya University from April to September 2019. The materials used for this study were similar to those used in experiment 1, i,e. CFA, biochar from oil palm empty fruit bunches (OPEFB), OPEFB compost, PSF isolates, and an Ultisol. Thirteen treatments combinations similar to those of experiment 1 were arranged in a completely randomized block design with three replications. The density of each PSF inoculated was 10^8 conidia/mL/10 g biocom. A maize seed of the NK33 variety was planted in each pot containing 10 kg of soil (top layer 0-15 cm, air-dried, passing through a 2 mm sieve) according to treatments. Each pot was supplied with 100 kg N/ha and 50 kg K_2O/ha as basic fertilizers. The biocom containing PSF was applied at a dose of 15 t biocom/ha (Ichriani et al., 2018). The pot was periodically watered with distilled water to maintain soil moisture so as not to inhibit the growth of maize for 10 weeks. At harvest (10 weeks after planting), the shoots and roots of the plants were separated, and then dried for 48 hours at 60ºC. The total P-content in the maize shoot and root was measured by the Olsen and Sommers method (1982). P uptake by maize plant = shoot or root dry weight (g) x P concentration in maize shoot or root (%). The effect of the application of PSF in various biochar-compost mixture media combined with CFA on growth and biomass yield of maize, and P uptake by maize were statistically tested by one-way ANOVA, followed by the Least Significant Difference test at p = 0.05.

Results and Discussion

Experiment 1

Soil pH, exchangeable Al and H

The application of PSF-biocom and CFA increased soil pH compared to initial soil pH of 4.10. The highest pH change (5.36) was found in the F2B2C2 treatment (*N. fischeri*, biocom 70-30, 80 CFA/ha), followed by the F1B2C2 treatment (*A. oryzae*, biocom 70-30, 80 CFA/ha). In general, the application of PSF-biocom 70-30 was better compared to PSF-biocom 80-20 and biocom 60-40. Judging from the CFA application, the application of 80 t CFA/ha was better for increasing soil pH compared to the application of 60 t CFA/ha. These results are consistent with the results of a study reported by Fahrunsyah et al. (2018) where the application of 80 t CFA/ha combined with oil palm empty fruit bunch compost gave the greatest pH improvement. The amount of exchangeable Al and exchangeable H decreased with increasing CFA dose. The addition of PSF-biocom to the mixture of CFA and soil further increased soil pH and decreased the amount of exchangeable Al and exchangeable H, which coincided with the application of PSF-biocom 70-30. The highest increase in pH occurred in the F2B2C2 treatment, that increased from 4.10 to 5.25 (Table 2). Ciećko et al. (2015) reported that the use of CFA as soil ameliorant with doses between 200 and 800 t/ha increased soil pH and soil P availability. According to Ram et al. (1995), CFA contains a high amount of silicate minerals that can bind H^+ that causes neutralization through the formation of silicic acid. Thus, dissolving silicate minerals can lead to an increase in soil pH. Priatmadi et al. (2014) revealed that the application of CFA to acid soils could increase the soil negative charge due to the deprotonation of H^+ ions in soil clay minerals. In this study, the deprotonation of H^+ caused a decrease in the amount of exchangeable H^+ (Table 2). Compared with the initial exchangeable Al content, the application of a combination of CFA and PSF-biocom 60-40 reduced the exchangeable Al content from 2% (F2B1C1 treatment) to 90% (F2B2C2 treatment) (Table 2). Increased soil pH as a result of the addition of CFA as a soil amendment is thought to occur due to the release of Ca, Na, Al and OH from the CFA (Wong and Wong, 1986). Because CFA contains hydroxide and carbonate salts, CFA has the ability to neutralize soil acidity (Pathan et al., 2003). The change in pH of the mixture of soil and CFA is thought to be related to the process of decomposition of organic matter in the mixture. Increased decomposition of organic matter can cause a decrease in pH, among others, by the release of CO_2 from the respiration process of microorganisms that can react with H^+ ion to form weak acids (H_2CO_3) and also through the nitrification process that produces H^+ ion (Tan, 2003). According to Farrell et al. (2010), the application of compost increases the Ca^{2+} content in soil solutions. An increase in Ca^{2+} ion in aqueous solution can replace Al^{3+} and H^+ and bind Al^{3+} to an insoluble Al^{3+} complex, so the pH of the soil increases, which in turn increases the availability of P in the soil.

Table 2. Effects of PSF-biocom and CFA application on pH, exchangeable Al and H of an Ultisol from East Kalimantan.

Treatment	pH	Exch. Al (me/100 g)	Exch. H (me/100 g)
F1B1C1	4.41 ef	4.25 c	2.04 a
F1B1C2	4.31 g	4.87 a	2.19 a
F1B2C1	4.69 bc	2.12 f	1.21 cde
F1B2C2	5.25 a	0.48 h	0.63 f
F1B3C1	4.52 de	3.01 e	1.44 bc
F1B3C2	4.80 bc	1.79 g	1.03 e
F2B1C1	4.34 f	4.56 b	2.26 a
F2B1C2	4.44 ef	3.57 d	1.59 b
F2B2C1	4.62 cd	2.94 e	1.34 bcd
F2B2C2	5.36 a	0.46 h	0.54 f
F2B3C1	4.73 bc	1.97 fg	1.12 de
F2B3C2	5.25 bc	0.50 h	0.66 f
Control	4.31 g	4.83 a	2.13 a

Remarks: F1 = *A. oryzae*, F2 = *N. fischeri*, carrier of 80% biochar + 20% compost, 60 CFA / ha, B1 = carrier of 80% biochar + 20% compost, B2 = carrier of 70% biochar + 30% compost, B3 = carrier of 60% biochar + 40% compost, 60 CFA/ha, C1 = 60 CFA/ha, C2 = 80 CFA/ha, control = without PSF and carrier media, without CFA. Numbers followed by the same letters in the same column show no significant difference according to the Least Significant Different test at at p = 0.05.

Soil total P and available P

Application of CFA with high pH and PSF-biocom in an Ultisol having a low pH of 4.1 caused the pH of the mixture of soil-CFA-PSF-biocom to be more optimal for the total P solubilization process in CFA, soils and compost by PSF to become available P (Jala and Goyal, 2006; Ichriani et al., 2018). Application of CFA and PSF-biocom increased the amount of available P (4-24%) and total P (13-101%) in the soil compared with the initial soil available P content of 3.76 ppm (Figure 1). The amount of total P in the F1B1C2, F2B1C2, and F2B1C1 treatments decreased by 1-3%. The decrease, however, was not significant. Except the F1B1C2 treatment, all treatments had significantly different effects with control. In the treatment of CFA combined with PSF-biocom, the amount of soil available P increased with the higher dose of CFA given (Figure 1). In the F2B1C1 treatment, the amount of soil available P was higher than that in control but lower than that in the F2B1C2 treatment. This shows an important role of CFA in increasing the availability of P in the soil. However, in other treatments, the addition of PSF in biocom 70-30 combined with 60 and 80 t CFA / ha further increased the amount of soil available P compared to the addition of PSF in biocom 80-20, and PSF in biocom 60-40, both for *A.oryzae* and *N.fischeri*. The highest increase in available P (542%) was found in the F2B2C2 treatment (*N. fischeri* in biocom 70-30, 80 kg CFA/ha), while the lowest available P increase (6%) was in the F1B1C2 treatment (*A. oryzae* in biocom 80-20, 80 kg CFA/ha) (Figure 1). This increase is in line with the results of the study of Pathan et al. (2003) that there is a minimum of 2.5 to 4.5 times the increase in extracted P content due to the addition of CFA. In general, data presented in Figure 1 show that *N.fischeri* in 70% biochar + 30% compost carrier media combined with 80 t CFA/ha caused a more significant increase in the soil available P compared to other treatments. In addition to increasing soil available P content, the application of CFA and PSF-biocom also increased soil total P content after 10 weeks. Compared with the initial soil total P content of 37.22 ppm, except for F1B1C2, F2B1C2 and F2B1C1 treatments, all treatments experienced an increase in soil total P content ranging from 13% in the F1B1C1 treatment to 101% in the F2B2C2 treatment (Figure 1).

The increase in the amount of soil available P might not be due to the supply of available P from CFA and PSF activities in solubilizing P in compost or CFA. The increased of available P in the soil was thought to be due to the high total P content in CFA (1,379 ppm) and OPEFB (3,700 ppm) which were used as PSF carrier. Hermawan et al. (2014) reported that a mixture of CFA and chicken manure could be used as a soil ameliorant to reduce P sorption and to increase P availability in Ultisols by increasing soil pH and negative charge. CFA can improve acid soils and degraded soils for the following reasons: CFA increases the surface area available of elemental sorption, improves soil physical properties (Gorman et al., 2000), neutralizes the pH of acid soils, and produces metal cations to be less mobile (Ciccu et al., 2003). In addition, CFA contains K and base elements (Ca, Mg) which are essential nutrients for plants. Mixing CFA with organic material in acid soils is expected to enhance biological activity in the soil (Jala and Goyal, 2006), reduce nutrient leaching (Sajwan et al., 2003) and benefit plants (Rautaray et al., 2003; Tripathi et al., 2009). Rani and Kalpana (2010) also reported that the application of CFA to the soil increased the availability of nutrients such as nitrogen, phosphorus, and other micronutrients. Das et al. (2013) reported that the application of CFA at rates of 5 t/ha, 10 t/ha and 15 t/ha increased the P content available in the soil. The increase of P_2O_5 content due to CFA application was also reported by Lee et al. (2006). The beneficial effect of CFA on the availability of soil P is expressed as its effect on biotic activities and release of P through biotic activities. The Si element in CFA also plays an important role in the release of P to be available from insoluble sources in CFA and soil (Lee et al., 2006). Im-Erb et al. (2004) who conducted a study on the effect of CFA on soil chemical properties also stated that the application of CFA increased soil pH compared to control. According to Khan and Khan (1996), the increase of the CFA concentration in normal soils from 0, 10, 20 to 100% volume increased the pH, which in turn raised the availability of sulfate, carbonate, bicarbonate, chloride, P, K, Ca, Mg, Mn, Cu, Zn and B.

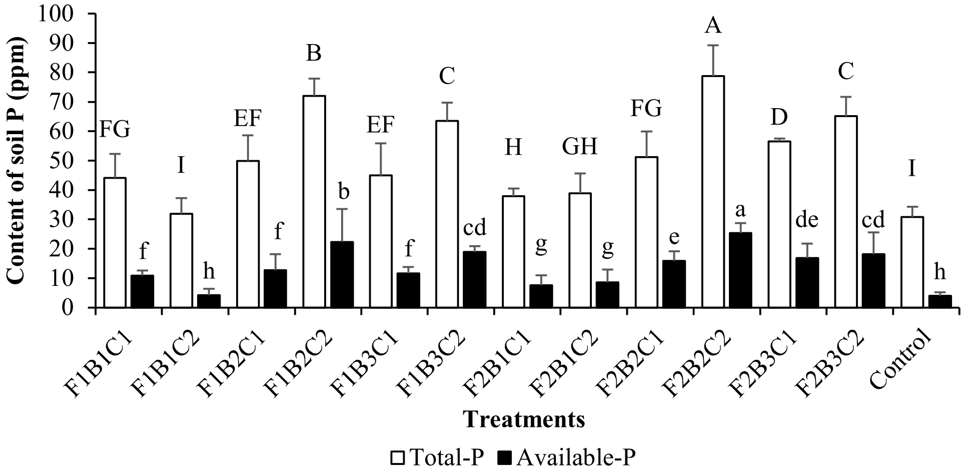

Figure 1. Effect of the application of PSF-biocom and CFA on total P and available P in an Ultisol from East Kalimantan. F1 = *A. oryzae*; F2 = *N. fischeri*; B1 = 80% biochar + 20% compost; B2 = 70% biochar + 30% compost; B3 = 60% biochar + 40% compost; C1 = 60 t CFA/ha; C2 = 80 t CFA/ha; control = without PSF and carrier, without CFA. Bars followed by the same lowercase letters or the same uppercase letters show no significant difference according to the Least Significant Different test at at p = 0.05.

Experiment 2

Growth of maize

The application of CFA with PSF-biocom had no significant effect on plant height and number of leaves at 2 weeks after planting (Figures 2 and 3). However, at the age of 4 and 6 weeks after planting, the application of CFA with PSF-biocom significantly affected plant height and number of leaves. The control treatment (without CFA, without PSF-biocom) produced the lowest growth which was significantly different from the CFA treatment with PSF-biocom. The F2B2C2 treatment (*N. fischeri*, biocom 70-30, 80 t CFA/ha) produced the best plant growth. This is thought to be related to the increase in P availability in the soil due to application of CFA (Fahrunsyah et al., 2018) and PSF-biocom (Ichriani et al., 2018), which in turn increased P uptake by maize. Some researchers have reported that the application of CFA could increase plant growth and yield due to improved soil aeration and nutrient supply (Bharti et al., 2000; Reddy et al., 2010; Muduli et al., 2014; Panda et al., 2015). However, the effect of CFA concentrations on plant growth varied from plant to plant (Pathan et al., 2003).

The yield of maize plant biomass

The application of CFA with PSF-biocom had a significant effect on the dry weight of maize shoot and root biomass (Figure 4). was obtained in the F2B2C2 treatment that increased 123% compared to the control. Application of materials produced from oil palm empty fruit bunches (biochar, compost, and phosphate-solubilizing fungi) to an Ultisol from East Kalimantan increased growth and yield of maize, as well as P uptake by the plant (Ichriani et al., 2018). In general, the application of 80 t CFA/ha yielded higher biomass of maize plant than that due to the application of 60 t CFA/ha. The application of PSF2 (*N.fischeri*) in 70% biochar + 30% compost carrier resulted in higher shoot biomass compared to the application of PSF2 (*N.fischeri*) in 60% biochar + 40% compost carrier, PSF1 (*A. oryzae*) in 70% biochar carrier + 30% compost, and 60% biochar + 40% compost.

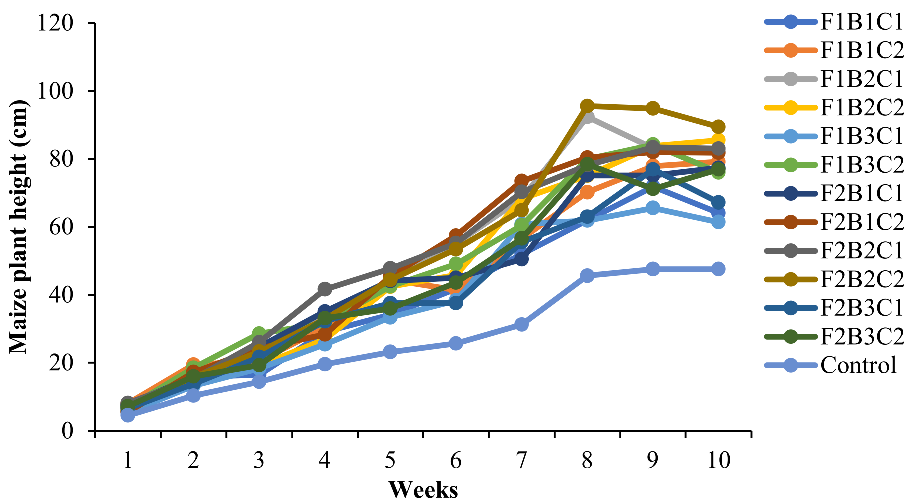

Figure 2. Effect of application of PSF-biocom and CFA on height of maize plant grown for 10 weeks on an Ultisol from East Kalimantan. F1 = *A.oryzae*; F2 = *N.fischeri*; B1 = 80% biochar + 20% compost; B2 = 70% biochar + 30% compost; B3 = 60% biochar + 40% compost; C1 = 60 t CFA/ha; C2 = 80 t CFA/ha; control = without PSF and carrier, without CFA.

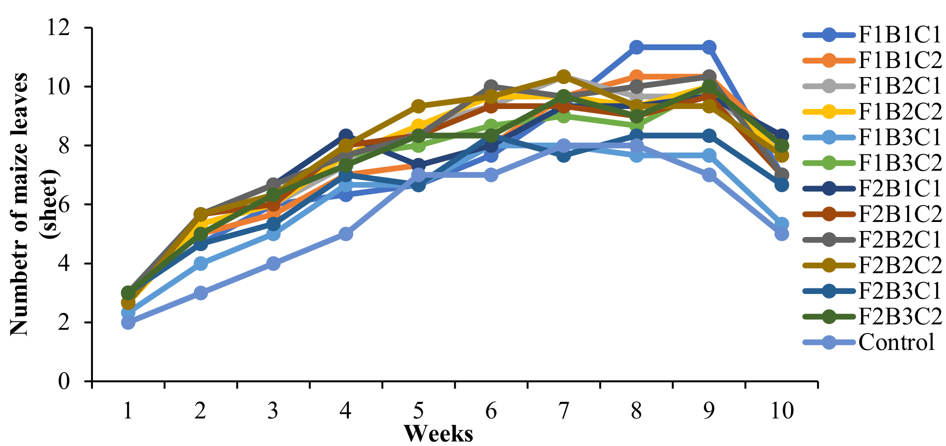

Figure 3. Effect of application of PSF-biocom and CFA on number of leaves of maize plant grown for 10 weeks on an Ultisol from East Kalimantan. F1 = *A. oryzae*; F2 = *N.fischeri*; B1 = 80% biochar + 20% compost; B2 = 70% biochar + 30% compost; B3 = 60% biochar + 40% compost; C1 = 60 t CFA/ha; C2 = 80 t CFA/ha; control = without PSF and carrier, without CFA.

Generally, biological fertilizer in carrier media promotes plant growth more effectively than free cell biological fertilizer; this is because the carrier material protects functional microbes from soil pressure or climate (Jain et al., 2010). Mechanisms such as the production of phytohormones, vitamins or amino acids can be involved in the influence of microorganisms on phosphate solubilization (Chakkaravarthy et al., 2010). Other mechanisms of solubilization of phosphate minerals by microorganisms are the production of inorganic acids (such as sulphuric acid, nitrates and carbonates) and the production of chelating agents (Alori et al., 2017).

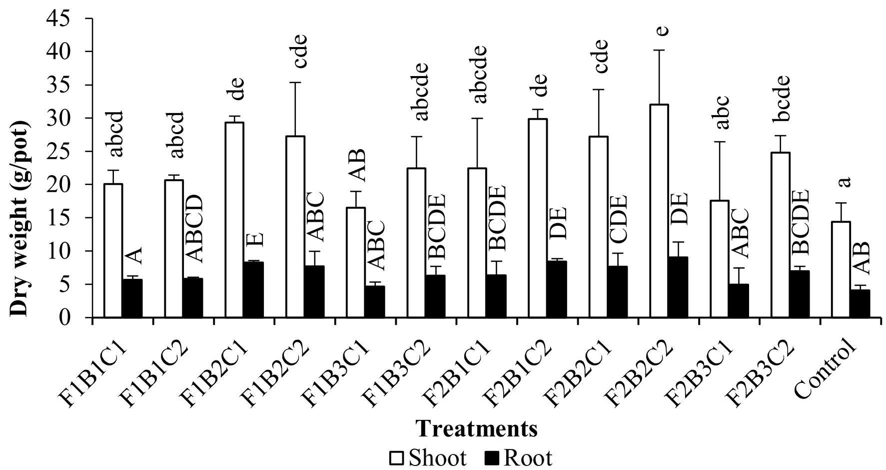

Figure 4. Effect of application of PSF-biocom and CFA on shoot and root biomass of maize plant grown for 10 weeks on an Ultisol from East Kalimantan. F1 = *A.oryzae*; F2 = *N. fischeri*; B1 = 80% biochar + 20% compost; B2 = 70% biochar + 30% compost; B3 = 60% biochar + 40% compost; C1 = 60 t CFA/ha; C2 = 80 t CFA/ha; control = without PSF and carrier, without CFA. Bars followed by the same lowercase letters or the same uppercase letters show no significant difference according to the Least Significant Different test at at p = 0.05.

The ability of PSF to solubilize P depends on the chemical nature of the P source (Scervinod et al., 2013). Previous studies revealed that the solubilization of P by *Aspergillus spp.* generally decreases the pH of the liquid medium, which in turn causes P solubilization (Acevedo et al., 2014). Thus, the type of P source and the secretion of organic acids by PSF can collectively contribute to the solubilization of P. Organic acids play an important role in the process of phosphate solubilization, which can help the release of P by providing protons and complex anions, or ligand exchange reactions or metal ion complex which is released into solution (Zhang et al., 2018). Organic acid production depends on the interaction of P sources and fungi (Scervinod et al., 2013). Solubilization of P of different sources depends largely on the amount of acid production (Cunningham and Kuiack, 1992).

P uptake by maize

The application of CFA combined with PSF-biocom had a significant effect on P uptake by maize (Figure 5). P uptake by maize increased with increasing dose of CFA applied. The lowest P uptake of 5.6 mg/plant was found in control. The low P uptake in control is thought to be due to the low available P content of 3.76 ppm in the soil used in this study because P uptake by plants is largely determined by P concentration in the soil and the ability of plants to absorb soil P (Minardi et al., 2017). The highest P uptake by maize of 21.6 mg/plant was obtained in the F2B2C2 treatment (*N. fischeri*, biocom 70-30, 80 t CFA/ha) which was not significantly different from the F1B2C2 treatment (*A. oryzae*, biocom 70-30, 80 t CFA/ha), but it was significantly different from other treatments. The F2B2C2 treatment (*N. fischeri*, biocom 70-30, 80 t CFA/ha) produced the best plant growth. This is thought to be related to an increase in P availability in the soil due to CFA (Fahrunsyah et al., 2018) and PSF-biocom (Ichriani et al., 2018), which in turn increased P uptake by maize. When compared with P uptake by maize in the control treatment, the F2B2C2 treatment increased P uptake by 289%. Data presented in Figure 4 show that the application of CFA with PSF-biocom resulted in an increase in P uptake in the following order F1B3C1 = 6%, F1B1C1 = 19% F1B1C2 = 38%, F2B1C1 = 67%, F2B3C1 = 82%, F1B2C1 = 6%, F1B1C1 = 19% F1B1C2 = 38%, F2B1C1 = 67%, F2B3C1 = 82%,

F1B2C1 = 121%, F2B1C2 = 129%, F1B3C2 = 136% F2B2C1 = 141%, F2B3C2 = 147%, F1B2C2 = 233%, and F2B2C2 = 289%, compared to control.

The ability of CFA with PSF-biocom in increasing P uptake by maize is thought to be caused by an increase in the availability of P in the soil, both from the initial soil P (through pH increase) and P from CFA (Fahrunsyah et al., 2018), and P from compost OPEFB (Ichriani et al., 2018). The ability of PSF-biocom in increasing P uptake by maize seemed to be related to the decomposition process of OPEFB compost and solubilization of soil P by PSF activity (Ichriani et al., 2018). Decomposition of OPEFB compost used as a carrier medium for PSF can produce organic acids that can bind metals such as Al, Fe and Mn, thereby reducing the activity of metals in absorbing P and increasing the availability of soil P (Haynes and Mokolobate, 2001; Ifansyah, 2013). Another mechanism for increasing the availability of soil P is that the OPEFB compost used as a PSF carrier media had a high total P content of 3,700 ppm. Fahrunsyah et al. (2018) reported that the application of OPEFB compost at a dose of 20 t/ha could increase the availability of soil P by 158.79%. The application of OPEFB compost at a dose of 21 t/ha increased soil P availability by 73.8% and increased 198% of P uptake by soybean compared to control (Budianta et al., 2010). The ability of plants to take up P is determined by the availability of P in the soil; soils that have high P availability have the potential to produce greater P uptake (Balemi and Negisho, 2012).

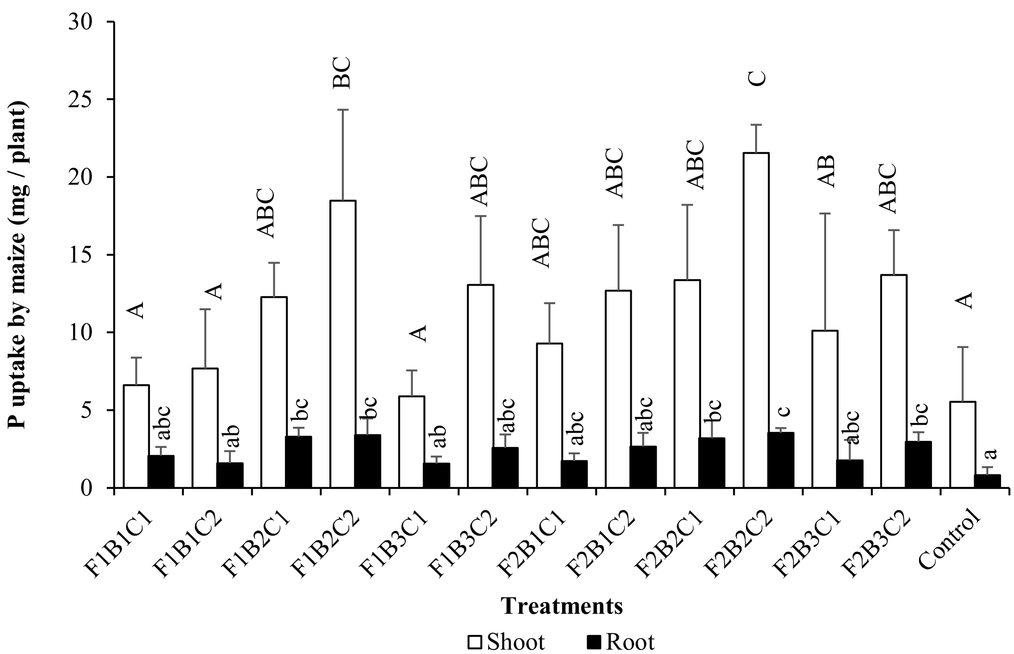

Figure 5. Effect of application of PSF-biocom and CFA on P uptake by shoot and root of maize plant grown for 10 weeks on an Ultisol from East Kalimantan. F1 = *A.oryzae*; F2 = *N. fischeri*; B1 = 80% biochar + 20% compost; B2 = 70% biochar + 30% compost; B3 = 60% biochar + 40% compost; C1 = 60 t CFA/ha; C2 = 80 t CFA/ha; control = without PSF and carrier, without CFA. Bars followed by the same lowercase letters or the same uppercase letters show no significant difference according to the Least Significant Different test at at p = 0.05.

Conclusion

The application of PSF-biocom and CFA decreased the amount of exchangeable Al and exchangeable H, and increased soil pH, the amount of soil available P of 4-24%, and the total soil P of 13-101%. The application of *N. fischeri* in 70% biochar + 30% compost (biocom 70-30) carrier media with 80 t CFA/ha caused a higher increase in available P compared to other treatments. The application of *N. fischeri* in biocom 70-30 with 80 t CFA/ha yielded the best maize growth and biomass, as well as the best P uptake by maize compared to other treatments. The combined application of *N.fischeri*, biocom 70-30, 80 t CFA/ha (F2B2C2 treatment) increased the weight of plant biomass by 123%, and P uptake by 289% compared to control.

Acknowledgements

The authors thank the Ministry of Research and Technology / National Agency for Research and Innovation for funding this study through PTUPT 2019-2020 scheme. Special thanks are forwarded to PT. Dharma Satria Nusantara, tbk, for providing oil palm empty fruit bunches, and PT. Cahaya Fajar Kaltim for providing coal fly ash.

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