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Impact of phosphate solubilizer fertilizer on phosphorus availability and potato yield in Andisols of Indonesia

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Abstract

Andisols are soil types formed in volcanic ash characterised by high adsorbed phosphate unavailable to plants. Farmers use manures to increase the availability of phosphorus in Andisols although this seems less than effective. The purpose of the research was to formulate a phosphate solubilizer fertilizer (PSF) to increase P solubility and enhance Andisols potato yields. PSF was made from chicken manure enriched with phosphate bacteria, Humic-fulvic (HF) acids and N-Acyl Homoserine Lactone. PSF effectiveness was tested in Pikovskaya and in Andisols to increase P solubility and enhance potato yield. The best of PSF formula based on P solubility was for chicken manure enriched with 4% HF acids and at 2% dose. The PSF P solubility efficiency in Pikovskaya was 51% and 80% in Andisols. Andisols potato yield at the same dose of PSF 20 Mg·ha^{-1} compared to chicken manure enhanced with the some dose by up to 2 Mg·ha^{-1}.

1. Introduction

Andisols in Indonesia are quite extensive at around 5 million hectares (Fiantis et al., 2005). In addition to vegetable plants, suitable annual plants grown in Andisols include tea, coffee, quinine, apples, oranges and cinnamon and forestry plants such as Eucalyptus and Casuarina. Andisols have characteristics in high adsorbed phosphate because of aluminol group (Al-OH and Al-OH_2^+), ferrihydrite and Al-humus complex making the phosphate unavailable to plants (Fiantis et al., 2005; Pizarra et al., 2008). Estimated maximum P sorption in Andisols Indonesia is 300–2500 mg P kg^{-1} soil (Fiantis et al., 2005; Pizzara et al., 2008). P sorption in soils is increases with increasing the content of iron and aluminium ion (Szafranek, 1998; Pizzara et al., 2008). Farmers usually use manures to increase soil fertility. The manures are however less effective in increasing Andisols P availability.

One obstacle to Andisols fertility is low P availability. The availability of P in Andisols can be enhanced by the application of organic and P-biological fertilizers. Humic-fulvic (HF) acids as soil ameliorants and organic fertilizers can interact with metal ions forming relatively stable complexes (Łabaz, 2007; Klučáková and Pavlíková, 2017). Humic-fulvic (HF) acids containing carboxyl and hydroxyl groups may cover the P adsorption site in soil that significantly decrease (Łabaz, 2007; Wibowo et al., 2017).

Phosphate bacteria (PB) as P-biological fertilizers may increase P availability through: 1) acidification (citric, malic, oxalic, gluconic and acetic), 2) chelating by acid anion group-containing organic hydroxyl and carboxyl against cations Al, Fe and Ca, 3) exchange ligand by organic anions to phosphate Al, Fe and Ca so that the phosphate becomes available, and 4) charging site colloids by organic acids sorption (Arcand and Schneider, 2006; Achal et al., 2007; Bashir et al., 2017). PB like *Pseudomonas trivialis, P. putida* and *P. fluorescens* on Pikovskaya are capable of dissolving the P-inorganic and mineralizing P-organic so that they can be used as inoculants. The PB inoculants dissolve P effectively. They increase 535–575% inorganic-P and mineralization organic-P of 336–387% and decrease P adsorbed 15–30% in Andisols (Tamad, 2012).

Biochemical that regulating microbial behavior is known as signal *quorum sensing* (QS). Teplitski et al. (2011) and Ma et al. (2016) stated that bacterial QS is an autoinducer. Generally, gram negative bacteria produce a signal QS in the form of N-Acyl Homoserine Lactone (N-AHL). The N-AHL derivative are N-butanoyl (C4), N-hexanoyl (C6), N-octanoyl (C8), N-decanoyl (C10) and N-dodecanoyl (C12) homoserine lactones (Tinh et al., 2007; Rani et al., 2011; Mahmoudi, 2015). Extract of rice, corn, bamboo, banana and peanut roots can be used as sources of N-AHL (Tamad et al., 2013).

The potential of Andisols for agricultural centres especially horticulture, is correlated but is constrained by low P availability. The purpose of this research was to formulate PSF to Andisols. The best PSF formula was used to increase P availability and enhance the potato yield in Andisols. PSF is expected to be a solution to increase Andisols productivity. The research hypothesis is using PSF to enhance P availability and potato yield in Indonesian Andisols.

2. Materials and methods

2.1 HF acids extraction

Some organic matters can be used as Humic-fulvic (HF) acids sources. Source of HF acids include straw compost, mushroom media waste and organic market waste. HF acids were extracted with the Stevenson (1994) method with 0.5 N NaOH through intermittent agitation over 24 hours. HF acids were precipitated by the addition of 6 N HCl to pH 2 and washing in purified five times. HF acids were determined by Forier Transfer Infra Red (FTIR). HF acids extract is used to enrich chicken manure into PSF.

2.2 PB culture

Phosphate bacteria (PB) can increase the solubility of some P compounds. A consortium PB of *Pseudomonas trivialis, P. putida* and *P. fluorescens* were grown in Pikovskaya for five days (stationary phase) (Tamad, 2012). Population PB is determined using Standard Plate Count with a population of at least 10^7 cfu·cm^{-3}. PB culture is used to enrich chicken manure into PSF.

2.3 N-AHL extraction

Plant root exudates contain QS signal compounds for microbes. The roots of rice, corn, bamboo, banana and peanut was extracted by acetonitrile as a source of N-AHL as QS signal of phosphate bacteria. N-AHL was determined by High Performance Liquid Chromatography (HPLC) (Rani et al., 2011). The selected plant root extract was used as a QS signal source for PB to enrich chicken manure into PSF.

2.4 PSF formulation

The PSF formula consists of chicken manure enriched with PB, HF acids, and signal QS. HF acids, PB (10^{10} cfu·g^{-1}) and N-AHL as much as 5% were added to chicken manure. PSF formula consisted of P1–5 (2, 4, 6, 8 and 10% HF acids). PSF is used to increase the availability of phosphorus for plants in Andisols.

2.5 PSF test effectivity in Pikovskaya and in Andisols

PSF is formulated to increase the solubility of P from Andisols. PSF effectiveness was tested in 100 cm^{-3} Pikovskaya and 200 g sterile Andisols. The experiment was arranged in a completely randomized design with factors of: 1) PSF formula (P1–5), 2) PSF dose 1–3% (D1–3), 3) time of PSF application (together with P fertilizer application (T1) and PSF given two weeks prior to P fertilizer application (T2). Source of P fertilizer was Super Phosphate 36% P_2O_5 (SP 36) at a dose 200 kg P2O5·ha^{-1}. Observed variables in Pikovskaya were pH, population PB and P-dissolved, while in Andisols was pH and P dissolved.

2.6 PSF test effectivity at potato crops

PSF is expected to increase P solubility and increase potato yield in Andisols. PSF effectivity was carried out on potato crops at Andisols Kaligua, Brebes, Central of Java, Indonesia. The treatments used were P1 (20 Mg of chicken manure·ha^{-1}), P2–6 (20, 15, 10, 5 and 2.5 Mg of PSF·ha^{-1}) on balanced inorganic fertilization so Urea 300 kg, SP-36 500 kg and KCl 200 kg·ha^{-1}. The cultivated potato variety was Granola. Observed variables were P sorption and potato tuber yield.

2.7 Statistical analysis

The data of Pikovskaya pH, PB population on Pikovskaya, soluble P and P solubility efficiency on Pikovskaya, Andisols pH, Andisols P soluble and P solubility efficiency, HF acids, P sorption of potato and potato tuber yield were analyzed of varian using F-test with α 5%. Significantly different data were analyzed of mean using Duncant Multiple Range Test (CoStat-Statistics Software).

3. Results

3.1 PSF formula

PB can increase the solubility of insoluble P compounds. PB collection of Soil/Land Resources Laboratory Agriculture Faculty Jenderal Soedirman University are suitable for culture. The clear zone around PB colonies in Pikovskaya on four P source types indicated that PB was effective in dissolving P (Fig. 1). P was dissolved by PB into an available P form.

Organic matter is one source of HF acids. Rice straw compost, mushroom media waste and market organic waste can be used as a source of HF acids. The results showed that the market organic waste containing HF acids total gave the highest number (Fig. 2). Market organic waste can be used as a source of HF acids.

Plant root exudates contain signal compounds for microbes. Rice, corn, bamboo, banana and peanut roots extract can be used as a source of N-AHL as QS of PB. Based on seven of N-AHL types, corn root extract contained the most N-AHL (Table 1). Corn root extract is a potential source of QS signals for PB.

Farmers usually use chicken manure itself to increase Andisols fertility. The best PSF formula, based on P solubility, was chicken manure enriched with 4% HF and at 2% dose. The PSF had P solubility efficiency in Pikovskaya about 51% (Table 4) and about 80% in Andisols (Table 6). Chicken manure formulation into PSF effectively increases the solubility of P in Andisols.

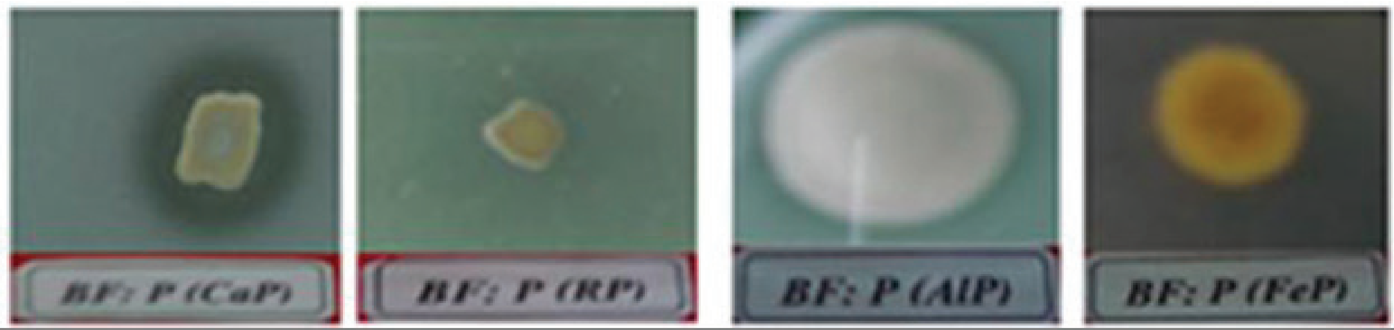

Fig. 1. PB colonies and P dissolution clear zone on Pikovskaya with four P source types, five days incubation at room temperature.

3.2 PSF test in Pikovskaya and Andisols

The solubility of P compounds increases by acidification among others things. Application of different PSF types, PSF dose and PSF longer incubation time caused pH in Pikovskaya decreased (Table 2), contrary to BF population (Table 3). Increased HF acids in PSF could improve P dissolving ability. So differences in application of PSF dose affect soluble P. The length of time incubation increased P due to the P accumulation result (Tables 3 and 4). Deprotonation of HF acids functional group will increase the amount of charge, thereby increase the P solubility. The formula PSF showed the highest P solubility and highest P solubility efficiency in Pikovskaya (Table 4). PSF through acidification effectively increases the solubility of P compounds.

The PSF inoculation secrete organic acids thereby reducing pH. PSF inoculation decreases the pH of Andisols (Table 5).

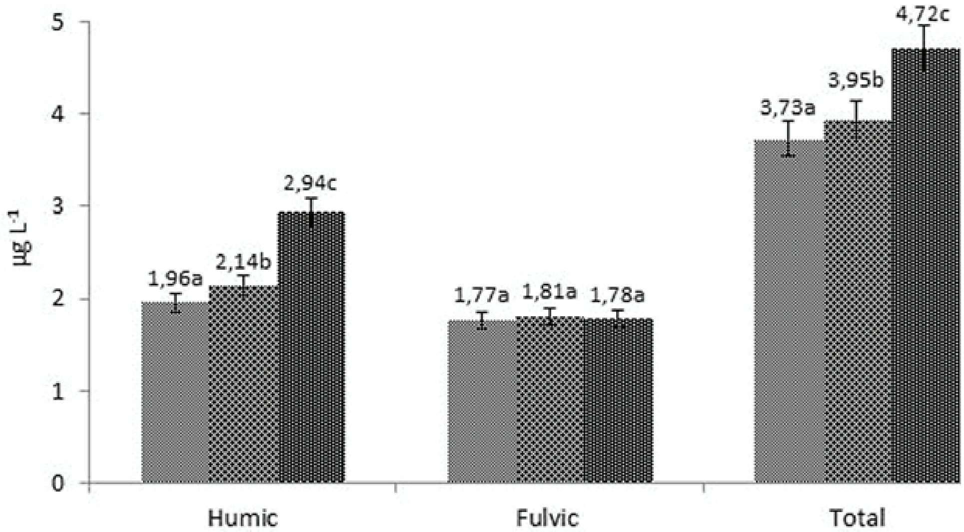

Fig. 2. Humic-fulvic acids content of three organic matter types (extracted according Stevenson (1994) method)

Table 1.
N-Acyl Homoserine Lactone content of five plant root types extract (extracted according Rani et al. (2011) method)

No	N-AHL Type	N-AHL content of five root types extract [µg·cm^{-3}]				
		Rice	Corn	Peanut	Banana	Bamboo
1	C4 (N-butanoyl) HL	1.16	1.16	1.16	2.32	9.28
2	C6 (N-hexanoyl) HL	nd	6.04	6.04	2.00	52.24
3	C7 (N-pentanoyl) HL	nd	2.84	7.52	0.96	6.60
4	C8 (N-octanoyl) HL	nd	6.20	1.76	0.44	nd
5	C10 (N-decanoyl) HL	nd	37.24	30.12	6.32	21.40
6	C12 (N-dodecanoyl) HL	nd	5.00	1.44	nd	1.44
7	C14 (N-dobutanoyl) HL	0.32	99.44	0.64	nd	nd
	Total (µg·mL^{-1})	1.48	157.92	48.68	12.04	90.96

Abbreviation: nd = not detection

Table 2.
Pikovskaya pH influence of PSF on one and two week incubation

	PSF dosages (One week incubation)			PSF dosages (Two week incubation)		
Types	1% (D1)	2% (D2)	3% (D3)	1% (D1)	2% (D2)	3% (D3)
2% HF (P1)	3.12dD	3.08cD	3.12dB	5.77aA	4.13bB	3.88bC
4% HF (P2)	3.73bC	2.73eE	3.23bD	4.74cA	3.69dC	4.20aB
6% HF (P3)	3.05eE	3.34aD	3.31aD	4.06eB	4.39aA	3.66dC
8% HF (P4)	3.99aB	3.15bD	3.15cD	4.46dA	3.93cB	3.79cC
10% HF (P5)	3.54cC	2.98dD	3.07eD	5.67bA	3.71dB	3.77cB

Note:
pH (one and two week incubation) of Pikovskaya (Pvk) = 3.29; 4.38 and pH of Pvk + carrier = 3.66; 4.21. The number in a column followed by the same lowercase and in line followed by the same capital letters are not significantly different at DMRT α 5%.

Table 3.
Phosphate bacteria population on Pikovskaya influence of PSF types and PSF dosages, one and two week incubation

	PSF dosages (One week incubation) [log cfu·cm^{-3}]				PSF dosages (Two week incubation) [log cfu·cm^{-3}]			
Types	1% (D1)	2% (D2)	3% (D3)	Mean	1% (D1)	2% (D2)	3% (D3)	Mean
2% HF (P1)	8.159	8.159	8.160	8.160a	9.130	9.130	9.129	9.130a
4% HF (P2)	8.159	8.159	8.159	8.159a	9.128	9.128	9.128	9.128a
6% HF (P3)	8.159	8.159	8.159	8.159a	9.129	9.142	9.128	9.129a
8% HF (P4)	8.159	8.159	9.159	8.159a	9.129	9.129	9.129	9.129a
10% HF (P5)	8.159	8.159	8.159	8.159a	9.128	9.129	9.128	9.128a
Mean	8.159A	8.159A	8.160A		9.128A	9.129A	9.128A	

Note:
The number in the column followed by the same lowercase and in line followed the same capital letters are not significantly different at DMRT α 5%.

Table 4.
Soluble P and P solubility efficiency on Pikovskaya (Pvk) influence of PSF types and PSF dosages, one and two week incubation

	PSF dosages (One week incubation)			PSF dosages (Two week incubation)		
Type	1% (D1)	2% (D2)	3% (D3)	1% (D1)	2% (D2)	3% (D3)
	g P·dm^{-3}			g P·dm^{-3}		
2% HF (P1)	2.32bA	1.76cB	1.67dC	2.55bA	2.54bA	1.94dB
4% HF (P2)	2.55aA	2.55aA	2.17cC	2.44cB	2.59aA	2.61bA
6% HF (P3)	1.84cC	2.14bB	2.23bB	1.87eC	2.57bA	2.60bA
8% HF (P4)	2.64aA	2.56aB	1.25cE	2.37dC	2.62aA	2.05cD
10% HF (P5)	2.64aA	2.01bC	2.64aA	2.69aA	2.41cB	2.68aA
	%			%		
2% HF (P1)	46.48bB	35.28dD	33.33dE	51.02bA	50.74aA	38.89dC
4% HF (P2)	50.93aA	50.95aA	43.33cB	48.80cA	51.80aA	52.22bA
6% HF (P3)	36.85cC	42.87cB	44.63bB	37.31eC	51.39aA	52.04bA
8% HF (P4)	52.78aA	45.18bB	24.91eD	47.41dB	52.41aA	40.93cC
10% HF (P5)	52.87aA	40.09cC	52.78aA	53.89aA	48.24bB	53.61aA

Note:
P (g·dm^{-3}) (one and two week incubation) on Pikovskaya = 0.60; 0.90 and on Pvk + carrier = 0.31; 0.42; soluble P efficiency (%) (P Pvk 500 ppm): 13.28; 13.80. The number in a column followed by the same lowercase and in line followed same capital letters are not significantly different at DMRT α 5%.

Increasing the PSF dose could increase the amount of HF acid contained. PSF types 2 (4% HF acids) and application at dose of 2% to Andisols improved the highest P solubility in Andisols (Tables 6) parallel with the decreasing pH (Table 5). PSF inoculation decreases Andisols pH, thus increasing the solubility of Andisols P compounds.

3.3 PSF application in potato

Andisol is reactive to P so the availability of P in the soil is low. PSF can increase the availability of P for plants in andisol. PSF application 20 Mg·ha^{-1} in Andisols showed the highest P potato sorption was greater than the others and twice as much as chicken manure (Fig. 3). Application of PSF could increase tuber yield (Fig. 4). PSF application at 20 Mg·ha^{-1} increased potato yield up to 2 Mg·ha^{-1} compared to the chicken manure. Application of PSF at 2.5, 5, 10 and 15 Mg·ha^{-1} increased tuber up to 0.5 Mg·ha^{-1}, compared to application of chicken manure as 20 Mg·ha^{-1}. PSF is effective in increasing the availability of P in Andisols and increasing the tuber yield of potatoes in Andisols.

4. Discussion

The solubility of P is influenced by a decrease in pH, in line with the increase in the population of PB. There is a linear relationship between increasing PB population increase and decreasing pH and increasing P-soluble in Pikovskaya and Andisols. PB are capable of dissolving P because PB produces some organic acid. PB may dissolve P on RP (rock phosphate), CaP, AlP and FeP through: 1) acidification (citric, malic, oxalic and acetic), 2) chelating cations of Al, Fe and Ca by anions of organic acids and 3) exchange of ligands against phosphate on Al, Fe and Ca by organic acids anion (Arcand and Schneider, 2006; Achal et al., 2007; Bashir et al., 2017). PB can also mineralize organic P from para-Nitro Phenyl Phosphate (pNPP) and Na-phytate as PB secrete the phosphatase and phytase (Zeng et al., 2017; Delfim et al., 2018). PB was attractive to colloidal (Allophane) because it has a surface charge and biological affinity (Motamedi et al., 2016; Rathi and Gaur, 2016) so that the solubility of P in Andisols increased. PSF containing PB through the above mechanism effectively increases the solubility of P in Andisols.

The microbial populations in the rhizosphere are relatively numerous because plant roots secrete numerous compounds as a food source and as a signal QS to microbes. Generally plant roots were associated with producing N-AHL as microbes signal QS (DeAngelis, 2006; Tinh et al., 2007). QS signal molecules were classified on N-AHL, ɣ-butyrolactones, 2-alkyl-4-quinolones, furanones, fatty acid derivatives and peptides (Mahmoudi, 2015; Ma et al., 2016). Many bacteria strains were confirmed to produce N-Butanoyl Homoserine Lactone (C4-HSL) (Tinh et al., 2007; Teplitski et al., 2011; Tan et al., 2014). The quorum microbial population effectively expresses the ability of these microbes.

The expression of microbial ability is in line with the microbial quorum population. Increasing doses of PSF applied consisted of Humic-fulvic (HF) acids component, thereby potentially lowering to decrease pH of media (Achal et al., 2007; Abbasi et al., 2015; Bashir et al., 2017), so composition of HF acids correlated with soil properties (Łabaz, 2007; Wibowo et al., 2017). The long incubation of up to two weeks slightly increase the PB population because in five days the PB isolates had entered the stationary phase (Tamad, 2012; Pande et al., 2017). In the population of PB quorum it effectively increases P solubility.

The P solubility in Andisols increases with a decrease in pH. Andisols could decrease in pH caused by HF acids and PB organic acid secretion in PSF. The organic acid was capable of releasing Si and Al into solution from Allophane as adsorp P (Johnson and Loeppert, 2006; Zeng et al., 2017). The organic acid was capable of forming Allophane-humus complex (Stella and Halimi, 2015; Pande et al., 2017) so that the soluble P increased. PB was attractive to colloidal (Allophane) because it has a surface charge and biological affinity (Johnson and Loeppert, 2006; Zeng et al., 2017) so that P solubility in Andisols increased.

Table 5.
Andisols pH influence of PSF and P application on two week incubation

Type	Dosages	P application time: Coincide P and PSF (T1)	P application time: Two week after PSF (T2)	Mean
2% HF (P1)	1% (D1)	6.50	6.59	6.55±0.05A
	2% (D2)	6.30	6.37	6.31±0.06B
	3% (D3)	6.20	6.49	6.36±0.16B
	Mean P1	6.30	6.48	6.41±0.09A
4% HF (P2)	1% (D1)	6.30	6.50	6.40±0.10A
	2% (D2)	6.30	6.39	6.35±0.05A
	3% (D3)	6.20	6.25	6.22±0.03B
	Mean P2	6.30	6.38	6.32±0.06A
6% HF (P3)	1% (D1)	6.30	6.43	6.35±0.06A
	2% (D2)	6.20	6.50	6.37±0.15A
	3% (D3)	6.10	6.22	6.16±0.06B
	Mean P3	6.20	6.38	6.29±0.09A
8% HF (P4)	1% (D1)	6.30	6.45	6.40±0.08A
	2% (D2)	6.30	6.46	6.37±0.06A
	3% (D3)	6.30	6.52	6.42±0.11A
	Mean P4	6.30	6.48	6.40±0.09A
10% HF (P5)	1% (D1)	6.40	6.57	6.48±0.09A
	2% (D2)	6.40	6.62	6.51±0.10A
	3% (D3)	6.10	6.45	6.29±0.16B
	Mean P5	6.30	6.55	6.42±0.09A
	Mean	6.30±0.20b	6.45±0.21a	

Note: pH of Andisols (A) = 6.46; pH of A + PSF1 = 6.25; pH of A + PSF2 = 6.25; pH of A + PSF3 = 6.17; pH of A + PSF4 = 6.30; pH of A + PSF5 = 6.41; pH of A + SP36 = 6.45; pH of A + Carrier = 6.53. The number in line followed by the same lowercase and in column followed same capital letters are not significantly different at DMRT α 5%.

Phosphorus is an essential nutrient for plants. An acid and alkaline soils have low availability of this nutrient (Lošák et al., 2016; Mühlbachová et al., 2018), which constrains crop production (Ziadi et al., 2013; Sandana et al., 2018). A strategy to increase P availability is to a use phosphate solubilizing microorganism. Evaluating the phosphate solubilizing efficiency for P in Pikovskaya showed the following solubilization sequence: Ca-P> Al-P> Fe-P (Abbasi et al., 2015; Cisneros et al., 2017). PSF containing PB can increase the P dissolved ability, because PB produce organic acids including citrate, malate, and acetate (Fiantis et al., 2005; Bashir et al., 2017; Delfim et al., 2018). The P solubility compounds in Andisols increases with PSF inoculation.

PSF containing PB is able to increase the solubility of P. PB inoculation increased soluble-P from 30 to between 150 and 195 mg·kg^{-1} P, increased mineralize-P from 23.7 to between 63.6 and

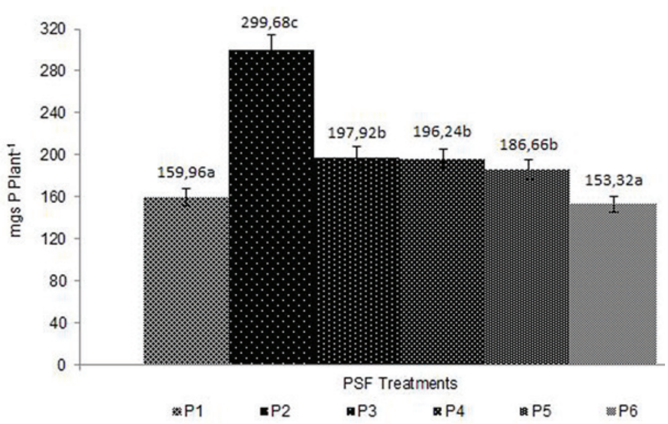

Fig. 3. P sorption of potato plant tissue at the application of six doses of organic matter (P1 = 20 Mg chicken manure·ha⁻¹, P2 – 6 = 20, 15, 10, 5 and 2.5 Mg PSF·ha⁻¹) at Kaligua, Brebes, Central of Java, Indonesia

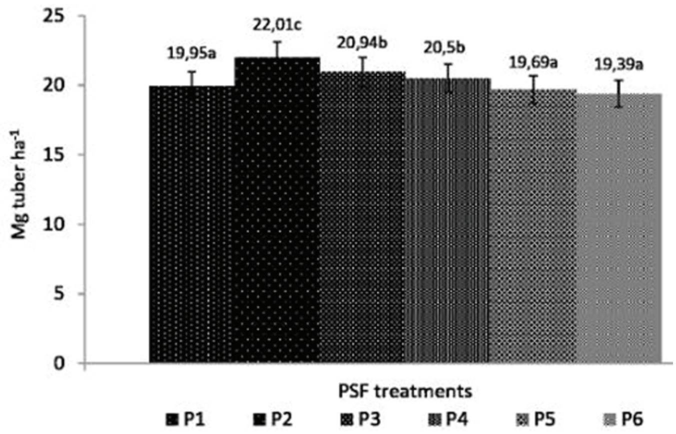

Fig. 4. Potato tuber yield in application of six doses of organic matter (P1 = 20 Mg chicken manure·ha⁻¹, P2–6 = 20, 15, 10, 5 and 2,5 Mg PSF·ha⁻¹) at Kaligua, Brebes, Central of Java, Indonesia

Table 6.
Andisols P soluble and P solubility efficiency influence of PSF and P application on two week incubation

		P application time					
		Coincide P and PSF (T1)		Two weeks after PSF (T2)		Mean	
Type	Dosages	mg·kg⁻¹	%	mg·kg⁻¹	%	mg·kg⁻¹	%
2% HF (P1)	1% (D1)	51.0	71.09	40.0	55.42	45.4±4.5B	63.26±7.84A
	2% (D2)	47.0	65.26	43.9	61.17	45.4±1.5B	63.21±2.05A
	3% (D3)	47.0	65.61	50.9	70.88	49.0±2.0A	68.24±2.64A
	Mean P1	48.0	67.32	44.9	62.49	46.6±1.5C	64.90±2.42C
4% HF (P2)	1% (D1)	60.0	84.23	45.3	63.08	52.9±7.5B	73.65±10.58B
	2% (D2)	67.0	94.01	47.1	65.63	57.3±10.0A	79.82±14.19A
	3% (D3)	76.0	105.42	39.1	54.49	57.4±18.5A	79.96±25.46A
	Mean P2	68.0	94.56	43.8	61.07	55.9±12.0A	77.81±16.75A
6% HF (P3)	1% (D1)	58.0	81.22	36.5	50.76	47.4±11.3B	65.99±15.23B
	2% (D2)	65.0	91.15	34.8	48.43	50.1±15.0A	69.79±21.36A
	3% (D3)	71.0	99.02	35.8	49.86	53.5±12.5A	74.44±24.58A
	Mean P3	65.0	90.46	35.7	49.68	50.3±11.6B	70.07±20.39B
8% HF (P4)	1% (D1)	51.0	70.99	22.3	31.07	36.6±14.4C	51.03±19.96B
	2% (D2)	58.0	80.97	26.4	36.80	42.3±18.6B	58.89±22.09A
	3% (D3)	61.0	85.63	31.8	44.30	46.6±15.0A	64.96±20.66A
	Mean P4	57.0	79.19	26.9	37.39	41.9±15.0D	58.29±20.90D
10% HF (P5)	1% (D1)	51.0	70.97	21.4	29.83	36.2±15.0B	50.40±20,57B
	2% (D2)	54.0	74.92	27.8	38.76	40.8±13.6AB	56.84±18.08AB
	3% (D3)	58.0	80.57	28.9	40.19	43.4±15.0A	60.38±20.19A
	Mean P5	54.0	75.49	26.0	36.26	40.1±14.0D	55.88±19.62E
	Mean	58.0± 12.0a	81.40± 16.88a	35.5± 15.0b	49.38± 19.91b		

Note:
P (mg·kg⁻¹ P) of Andisols (A) = 2.52; A + PSF4 = 3.81; A + PSF1 = 3.11; A + PSF5 = 3.33; A + PSF220 = 3.52; A + SP36 = 3.96; A + PSF3 = 3.52; A + Carrier = 2.78; soluble P efficiency (%) (P Andisols 71.80 mg·kg⁻¹) = 14.7. The number in line the same variable followed by the same lowercase and in column the same variable followed same capital letters are not significantly different at DMRT α 5%.

91.7 mg·kg^{-1} P and decreased P-adsorption from 95 to between 36 and 13% (Tamad, 2012) thus increasing acid phosphatase activity in Andisols (Fitriatin et al., 2014; Ichriani et al., 2017; Delfim et al., 2018). PSF containing PB effectively increases the solubility of P in Andisols. Any soils have phosphatase activities to mineralized soil organic P (Lemanowicz and Koper, 2010; Rathi and Gaur, 2016; Zeng et al., 2017).

PSF inoculation containing PB effectively increases the availability of P for plants in Andisols. PSF application in an Andisols increase P sorption in potato tissue up to 300 mg P plant^{-1}. Therefore, we suggest the critical P value of 33 mg P·kg^{-1} for potato growers (Ziadi et al., 2013; Sandana et al., 2018). Normal healty P concentration basis plant dry weight is 0.05–1.0%. so, increase of P sorption by potato in an Andisols increases potato tuber yields (Frydenvang et al., 2015; Mohidin et al., 2015; Stammer and Mallarino, 2018). PSF inoculation in Andisols is one solution to increase crop production.

5. Conclusions

The phosphate solubilizer fertilizer with chicken manure formula enriched with phosphate bacteria, Humic-fulvic acids and N-Acyl Homoserine Lactone effectively increased the solubility of P and increased potato tuber yields in Andisols. The best of PSF formula, based on P solubility in Pikovskaya and Andisols was chicken manure enriched with PB (10^{10} cfu·g^{-1}) and N-AHL as much as 5% and 4% HF acids at 2% dose. The PSF formula had P solubility efficiency of ca 51% in Pikovskaya and ca 80% in Andisols. Potato yields in the same dose PSF formula 20 Mg·ha^{-1} compared to only chicken manure enhanced tuber yields by up to 2 Mg·ha^{-1}.

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