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P USE EFFICIENCY BY CORN (*Zea mays* L.) ON ULTISOL DUE TO APPLICATION OF COAL FLY ASH-CHICKEN MANURE MIXTURE

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ABSTRACT

Low P availability is the main constraint for crops on acidic soil such as Ultisols due to high soil P sorption. The objective of current research was to determine the effect of coal fly ash-chicken manure mixture application on P use efficiency by corn (*Zea mays* L.) on Ultisols. The research was arranged according to Factorial Completely Randomized Design with three replicates. The treatments tested were the rates of FA-CM mixture (w/w of 1:1) which consisted of 0, 15, 30, 45 and 60 tons ha^{-1}, and P fertilizer rates that consisted of 0, 0.5, 1.0, 1.5 and 2.0 times of P requirement to achieve 0.2 µg P mL^{-1} in soil solution (equivalent to 0, 87, 174, 261 and 348 kg P_2O_5 ha^{-1}). Results of current research showed that P use efficiency by corn on Ultisols had been increased through the addition of FA-CM in combination with P fertilization at the rate of 87 kg P_2O_5 ha^{-1}. The optimum rate of FA-CM in combination with P fertilizer at the rate of 87 kg P_2O_5 ha^{-1} was 28.60 tons ha^{-1}, with P uptake efficiency of 42.41 % and agronomic P efficiency of 82.53 mg shoot dry weight/mg P from fertilizer.

Keywords: chicken manure, coal fly ash, Corn, P efficiency, ultisol

INTRODUCTION

Low P availability and high P sorption are the main constraint for crop production on acid mineral soil such as Ultisols (Prasetyo and Suriadikarta, 2006). The high P sorption results in high requirement of P fertilizer in order to provide the availability of P for crop which in turn produces inefficient fertilization and high operational cost for its application. One alternative that can be applied to increase P fertilization efficiency in Ultisols is addition of substances capable of decreasing soil P sorption.

Coal fly ash is complex material produced from coal burning at high temperature. This material is dominated by minerals of Ca and Mg silicates as well as aluminosilicates (such as mullite and silimanite) and oxides such as silica (SiO_2), alumina (Al_2O_3), iron (Fe_2O_3), calcium (CaO) and magnesium (MgO) (Brouwers and Van Eijk, 2003) so that it can neutralize soil acidity. Mineralogical characteristics of coal fly ash is more complex than lime material so that its neutralization reaction is also involved other minerals such as Ca silicate, Mg silicate and aluminosilicate as well as oxides of Ca and Mg (Brouwers and Van Eijk, 2003; Pandey and Singh, 2010). Hydrolysis reaction of oxides compound and aluminosilicates on coal fly ash will produce negative charge (Brouwers and Van Eijk, 2003) and is capable of decreasing soil acidity (Stevens and Dunn, 2004; Tarkalson *et al*., 2010), which will affect the decrease in soil P sorption.

Several study results revealed that the utilization of coal fly ash for agricultural effort was more effective if combined with organic matter (Aggarwal *et al*., 2009; Kishor *et al*., 2010). Organic acids from organic matter decomposition such as humate and fulvate have very reactive functional groups such as –COOH, –OH (phenolic, alcoholic) which have an important role in increasing P availability in soil (Haynes and Mokolobate, 2001; Yang *et al*., 2013). The addition of organic matter can increase P availability through the formation of organo metal complexes between organic acid and metal ions such as Al, Fe and Mn that absorp P through anion exchange process or as a result of competition between organic acid and P in competing exchange sites (Tan, 2003; Yang *et al*., 2013).

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The results of previous study showed that coal fly ash-chicken manures mixture (w/w of 1:1) as an ameliorant decreased P sorption but it increased available P in Ultisols by increasing both soil pH and negative charges (Hermawan *et al*., 2014). The decrease of P sorption and increase in P availability were also capable of increasing P use efficiency by crop. The objective of current research was to determine the effect of coal fly ash-chicken manure mixture application on P use efficiency by corn (*Zea mays* L.) on Ultisols.

MATERIALS AND METHODS

Soil and Mixture of Coal Fly Ash-Chicken Manure

The bulk soil used in this study was collected from Arboretum Land, Soil Science Department, Sriwijaya Univesity, Inderalaya, South Sumatra, for the surface 0-20 cm depth. Soil sample was air dried, sieved with 2 mm size sieve, and mixed evenly. The soil used for the experiment was 10 kg pot^{-1}. The soil used in this research had P availability content rated as low (6.60 mg kg^{-1}) with P sorption capacity of 846.94 mg kg^{-1}. Soil pH was acid (pH H_2O = 4.54) with C-organic (1.70 g kg^{-1}) and N-total (0.20 g kg^{-1}) contents were rated as very low. Exchangeable Aluminum (Al-exch.) was 1.88 cmol$_{(+)}$ kg^{-1}. Cation Exchange Capacity (CEC) was rated as medium (17.40 cmol $_{(+)}$ kg^{-1}) and base saturation was rated as very low (86.2 g kg^{-1}). Soil texture was classified as clay with clay content of 512.9 g kg^{-1} (Hermawan *et al*., 2014).

Coal fly ash obtained from a coal-fired thermal power station in Muara Enim District, South Sumatra. Chicken manure was taken from the chicken farm in Inderalaya, Ogan Ilir District, South Sumatra. Coal fly ash and chicken manure sample were air dried and sieved in 0.05 mm and 2.0 mm size sieve, respectively. The fly ash and chicken manure (w/w of 1:1) were mixed thoroughly and incubated for 45 days. During the incubation period, the water content of the mixture was maintained at field capacity by adding deionized water based on water losses. The mixture of coal fly ash-chicken manure (w/w of 1:1) with 45 days incubation times was alkali (pH = 7.77), available P and P sorption capacity of 94.80 mg kg^{-1} and 570.55 mg kg^{-1}, respectively. C-organic content and cation exchange capacity (CEC) were 48.20 g kg^{-1} and 26.10 cmol$_{(+)}$ kg^{-1}, respectively (Hermawan *et al*., 2013).

Experimental Design

The treatments tested were the FA-CM mixture (w/w of 1:1; 45 days incubation) at the rates of 0, 15, 30, 45, dan 60 ton ha^{-1}, and P fertilizer rates including: 0, 87, 174, 261, and 348 kg P_2O_5 ha^{-1}. The experiments were arranged according to Factorial Completely Randomized Design with 3 replicates. P fertilizer at the rate of 174 kg P_2O_5 ha^{-1} as a standard P fertilizer requirement for plant was determined according to the required P quantity to achieve concentration of 0.2 µg P mL^{-1} in equilibrium solution (Fox and Kamprath, 1970; Sanchez and Uehara, 1980). After the treatments were set up, hybrid corn planting was done in each experimental pot. Plant keeping was conducted by daily watering, weeding as well as pest and disease control by using pesticides if necessary. Urea and KCl fertilization were given at the rate of 300 and 150 kg ha^{-1}, respectively.

Data Analysis

Efficiency of P nutrient utilization by corn due to the addition of coal fly ash-chicken manure mixture was evaluated according to P uptake efficiency and P use efficiency or agronomical efficiency. P uptake efficiency indicates P nutrient quantity absorbed by plant. The P use efficiency or agronomic P efficiency indicates nutrient quantity estimation from fertilizer that is converted into plant biomass. P uptake efficiency and agronomic P efficiency were calculated using the formula (Syers *et al*., 2008; Johnston dan Syers, 2009; Norton, 2013):

1. Pue (%) = ((Sx – So) / the rate of P) x 100%
2. APep = (Bx –Bo) / the rate of P

where:

So	=	P uptake in the treatment without P fertilizer
Sx	=	P uptake in the treatment with P fertilizer
Bo	=	Shoot dry weight or plant production in the treatment without P fertilizer
Pue	=	P uptake efficiency
APeP	=	Agronomic P efficiency P

Table 1. The application effect of coal fly ash-chicken manure mixture and P fertilizer on P uptake by corn (mg plant^{-1}) at anthesis phase

Doses of ATB-KA (A)	P Fertilizer Doses (x P requirement for plan)					Effect of ATB-KA (A)
	P0 (0)	P1 (0.5)	P2 (1.0)	P3 (1.5)	P4 (2.0)	
A0 (0 ton ha^{-1})	28.49 a	116.34 ab	207.45 abc	324.75 b-e	469.81 e-i	229.37 a
A1 (15 ton ha^{-1})	203.52 abc	300.94 b-e	438.05 d-i	346.13 c-f	602.22 hik	378.17 b
A2 (30 ton ha^{-1})	188.42 abc	393.76 c-h	481.20 e-i	591.34 g-k	389.88 c-g	408.92 b
A3 (45 ton ha^{-1})	226.11 abc	459.11 d-i	562.90 g-k	546.60 f-k	694.72 k	497.89 c
A4 (60 ton ha^{-1})	250.49 bcd	460.19 e-i	574.59 g-k	623.65 ik	605.13 ik	502.81 c
P Effect	179.41 a	346.07 b	452.84 c	486.49 cd	552.35 d	
$HSD_{(0,05)}$	A = 68.74	P = 68.74	AxP =209.68			

Remarks: numbers followed by the same letters are not significantly different (P<0.05)

The obtained data was subsequently analyzed by using Analysis of Variance (ANOVA) followed by Honestly Significance Different (HSD) test at level of $P<0.05$. Regression and correlation tests were also conducted in order to determine the nature of relationship between treatments and the observed parameters.

RESULTS AND DISCUSSION

P Uptake by Plant

Analysis of variance showed that the rate of FA-CM and P fertilizer, and their interaction had highly significant effect on P uptake by corn ($P<0.01$). Results of HSD test showed that P uptake by plant on FA-CM treatment was significantly higher than the treatment without FA-CM addition (control). P uptake by plant on FA-CM treatment with the rate of 60 ton ha^{-1} was not significantly different from that of 45 ton ha^{-1} dose, but it was significantly higher than that of lower rates. For P fertilizer treatment, P uptake by plant showed significant increase along with the increase in P fertilizer dose, except for treatment doses of 1 and 2 times P required for plant (Table 1).

Table 1 also showed that P uptake for treatment combination of FA-CM with the dose of 45 ton ha^{-1} and P fertilizer with the dose of 2 times P requirement for plant (348 kg P_2O_5 ha^{-1}) were not significantly different from that of FA-CM with the dose 45 ton ha^{-1} and P fertilizer with the dose of 1 and 1.5 times P requirement for plant as well as FA-CM with the dose of 60 ton ha^{-1} and P fertilizer with the dose of 1 and 1.5 times P requirement for plant (174 and 261 kg P_2O_5 ha^{-1}), but it had significantly higher P uptake than the combination of other treatments. This condition is estimated to be related to the decrease of P sorption and the increase in soil P availability due to addition of coal fly ash-chicken manure mixture (Hermawan *et al*., 2014), resulting in the increase in P uptake by plant (Table 1). Decomposition results from chicken manure and coal fly ash rich in alkali are estimated to have a role in affecting P uptake by plant and can increase shoot dry weight. Macro nutrient content such as P, Ca, Mg, K and S as well as micro nutrient such as Fe, Mn, Zn, Cu, Co, B and Mo found in coal fly ash and chicken manure were relatively high and became the nutrient source for plant through decom-position and mineralization process (Hartatik and Widowati, 2006; Pandey and Singh, 2010, Kishor *et al*., 2010). Increase in P uptake by plant will increase plant biomass formation which is characterized by the increase in plant growth and shoot dry weight (Syers *et al*., 2011; Norton, 2013).

P Fertilization Efficiency

The treatments of FA-CM, P fertilizer and their interaction had significantly influenced P uptake efficiency and P agronomical efficiency by corn at anthesis phase ($P<0.01$). Results of HSD test on P uptake efficiency showed that FA-CM treatment with the dose of 30 tons ha^{-1} was not significantly different from that of FA-CM treatment with higher doses, but it was significantly higher than that of FA-CM treatment with lower doses. P uptake efficiency for corn treated with P fertilizer dose of 0.5 time P requirement for crop (87 kg P_2O_5 ha^{-1}) was not significantly different from that of 1.0 time (174 kg P_2O_5 ha^{-1}), but it was significantly higher than treatment having higher dose of P fertilizer. This showed that an increase in FA-CM dose or P fertilizer dose was not always followed by the increase in P uptake efficiency by plant. Increase in P uptake in this case was not proportional with the addition of P fertilizer. This condition showed that P uptake by plant tended to be more efficient on FA-CM and P fertilizer treatments with lower doses. This is in line with the study result by Purnomo *et al*. (2001) showing that an increase in natural phosphate doses and P fertilizer had decreased the utilization efficiency of these fertilizers for corn planted on Oxisol. Efficiency of P by plant is affected by P concentration in soil, root contact with P nutrient and plant ability to absorb P nutrient in soil (Marschner, 1990; Shen *et al*., 2013). Results of several studies showed that P uptake by plant tended to increase along with the increase in P availability in soil due to the addition of organic fertilizer and P fertilizer (Mahbub, 2004; Darman, 2008; Syers *et al*, 2008).

The combination of FA-CM at the rate of 45 tons ha^{-1} and P fertilizer at the rate of 87 kg P_2O_5 ha^{-1} gave P uptake efficiency which was not significantly different from that of P uptake efficiency at the treatment of FA-CM at the rate of 30 tons ha^{-1} in combination with P fertilizer at the rates of 87, 174, dan 261 kg P_2O_5 ha^{-1}, not significantly different compared to P uptake efficiency in the combination of FA-CM at the rate of 45 tons ha^{-1} and P fertilizer at the rate of 87 and 348 kg P_2O_5 ha^{-1}, not significantly different when compared to P uptake efficiency in the treatment of FA-CM at the rate of 60 tons ha^{-1} combined with P fertilizer at the rate of 87, 174 and 261 kg P_2O_5 ha^{-1}, but it gave significantly higher uptake efficiency than that of other combinations (Table 2). Agronomic P efficiency for the combination of FA-CM at the rate of 30 ton ha^{-1} and P fertilizer at the rate of 87 kg P_2O_5 ha^{-1} was not significantly different from agronomic P efficiency in the combination of FA-CM at the rate of 30 tons ha^{-1} in the combination with P fertilizer at the rate of 87 and 174 kg P_2O_5 ha^{-1}, not significantly different from agronomic P efficiency in FA-CM treatment at the rate of 45 and 60 tons ha^{-1} in combination with P fertilizer at the rate of 87 kg P_2O_5 ha^{-1}, but it gave significantly higher agronomic P efficiency than that of other combinations (Table 2). The results indicated that the increase in P uptake by plant due to the treatment application did not always produce the increase in P uptake efficiency and agronomic P efficiency. P uptake of plants possessed no closely positive correlation with P uptake efficiency ($r = 0.26^{tn}$, $P > 0.05$) and agronomic P efficiency ($r = 0.11^{tn}$, $P > 0.05$). Increase in P uptake in this case was not proportional with the addition of P fertilizer. This, among others, can be caused by root contact with P nutrient and plant ability to take P nutrient in soil (Marschner, 1990; Shen *et al*., 2013), thus increasing the availability of P no longer resulted in an increase in P uptake by plants.

Table 2. The influence of coal fly ash-chicken manure mixture and P fertilizer addition on P efficiency by corn

Dose of ATB-KA (A)	**P Fertilizer Dose (P) (x P requirement for plant)**					**Effect of ATB-KA (A)**
	P0 (0)	**P1 (0.5)**	**P2 (1.0)**	**P3 (1.5)**	**P4 (2.0)**	
			P Uptake Efficiency (%)			
A0 (0 ton ha^{-1})	-	20.20 ab	20.57 ab	22.70 ab	25.36 a-d	22.21 a
A1 (15 ton ha^{-1})	-	22.40 ab	26.96 a-e	10.93 a	22.91 ab	20.80 a
A2 (30 ton ha^{-1})	-	47.20 cde	33.65 a-e	30.88 a-e	11.58 a	30.83 b
A3 (45 ton ha^{-1})	-	53.56 e	38.71 b-e	24.56 abc	26.93 a-e	35.94 b
A4 (60 ton ha^{-1})	-	48.21 de	37.25 b-e	28.59 a-e	20.38 ab	33.61 b
P Effect	-	38.31 b	31.43 b	23.53 a	21.43 a	
$HSD_{(0,05)}$	A = 7.90	P = 8.29	AxP =23.44			
			Agronomic P Efficiency (mg plant dry weight/ mg P fertilizer)			
A0 (0 ton ha^{-1})	-	17.31 ab	27.69 abc	39.26 a-d	36.76 a-d	30.26 a
A1 (15 ton ha^{-1})	-	39.04 a-d	56.01 b-e	24.13 abc	28.65 abc	36.96 a
A2 (30 ton ha^{-1})	-	99.39 e	50.61 a-e	29.06 abc	5.53 a	46.15 a
A3 (45 ton ha^{-1})	-	86.58 de	39.92 a-d	23.13 abc	15.01 ab	41.16 a
A4 (60 ton ha^{-1})	-	70.43 cde	32.07 abc	19.68 ab	12.90 ab	33.77 a
P Effect	-	62.55 c	41.26 abc	27.05 ab	19.77 a	
$HSD_{(0,05)}$	16.96	P = 17.79	AxP =50.31			

Remarks: numbers followed by the same letter are not significantly different ($P < 0.05$)

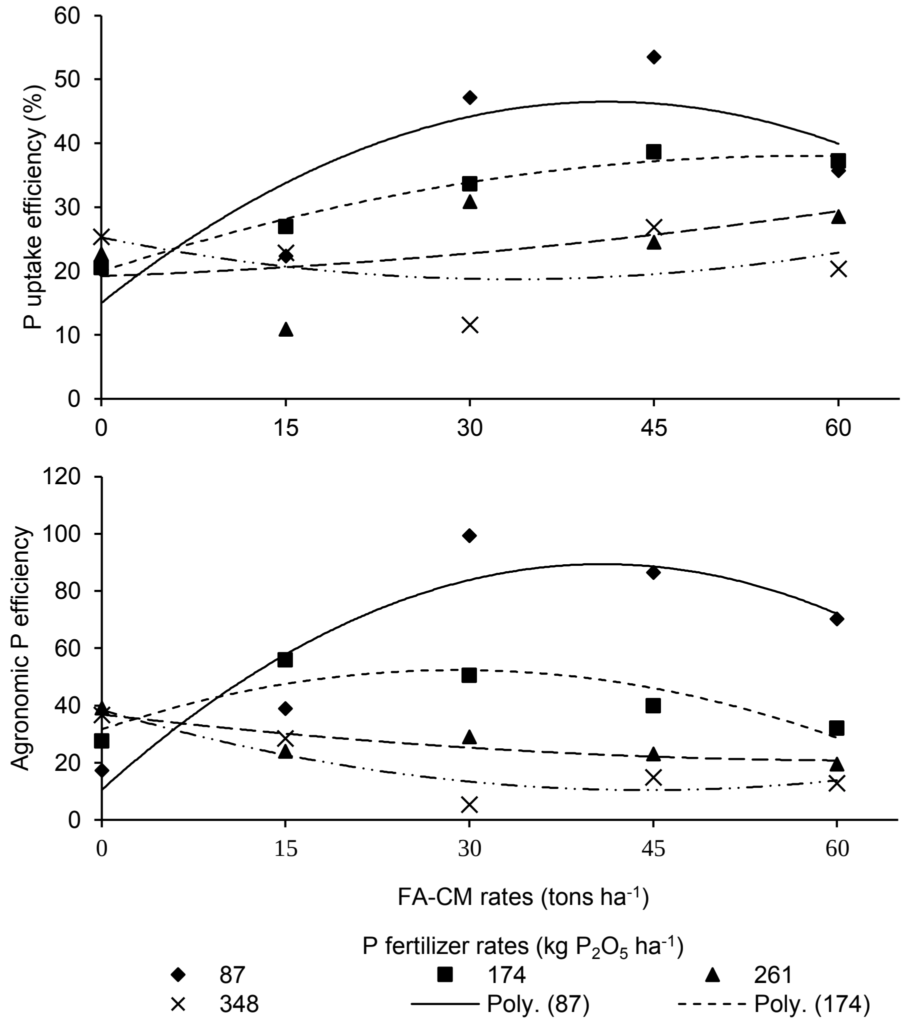

Figure 1. Relationship between FA-CM rates and P efficiency for each rate of P fertilizer.

Results of HSD test above (Table 2) showed that P efficiency of crop could be increased by adding FA-CM with the dose of 30 ton ha^{-1} combined with P fertilizer with the dose of 0.5 time of P requirement (87 kg P_2O_5 ha^{-1}) and higher doses of P fertilizer were not capable of increasing P efficiency of crop. Table 2 also showed that P efficiency tended to increase along with the increase in P fertilizer dose in the treatment without FA-CM. The treatment of FA-CM showed that increase in P fertilizer dose tended to reduce P efficiency. This showed the effect of coal fly ash-chicken manure mixture on the increase in P use efficiency by plant.

Figure 1 showed that P uptake efficiency and agronomic P efficiency on the FA-CM in combination with low rate of P fertilizer (87 kg P_2O_5 ha^{-1}) tended to be higher than the P uptake efficiency and agronomic P efficiency on the FA-CM in combination with higher rate of P fertilizer. These results indicate that the application of FA-CM could reduce the rate of P fertilizer to 87 kg P_2O_5 ha_{-1} or to 0.5 times from the standard P requirement for plant to achieve the concentration of 0.2 µg P mL^{-1} in soil. P uptake efficiency and agronomic P efficiency had a quadratic relationship with the rate of FA-CM in combination with fertilizer P at the rate of 87 kg P_2O_5 ha^{-1}, each row with the equation: y = 15.01

+ 1,528x – 0.018x^2, R^2 = 0,73 and y = 10,52 + 3.86x – 0,05x^2, R^2 = 0,86 (Figure 1). Based on these equations obtained the optimum rate of FA-CM to achieve 90 % (Syers *et al*., 2008) of maximum P use efficiency, equal to 28.60 tons ha^{-1}, with P uptake efficiency of 42.41 % and agronomic P efficiency of 82,53 mg shoot dry weight/mg P from fertilizer.

The research results also showed that the increase in P availability in soil (Hermawan *et al*., 2014), increase in P uptake by plant (Table 1) due to treatments did not always trigger the increase in P use efficiency by plant. The difference in P use efficiency was assumed to be related with nutrient balance in soil. Some experts stated that one factor which made lower efficiency of P nutrient utilization from fertilizer was plant growth constraints such as water shortage or other nutrient deficiency, so that the nutrients can't be used to increase plant tissue and seeds development although nutrients from fertilizer were absorbed by plants (Rendig and Taylor, 1989; Marschner, 1990; Syers *et al*., 2008).

CONCLUSION AND SUGGESTIONS

Treatment combination of FA-CM with the dose of 45 ton ha^{-1} and P fertilizer with the dose of 1.0 times of P requirement (174 kg P_2O_5 ha^{-1}) produced higher P uptake by corn than that of other treatment combinations. P use efficiency by corn on Ultisols had been increased through the addition of FA-CM in combination with P fertilization at the rate of 0.5 times of P requirement (87 kg P_2O_5 ha^{-1}). The optimum rate of FA-CM in combination with P fertilizer at the rate of 87 kg P_2O_5 ha^{-1} is 28.60 tons ha^{-1}, with P uptake efficiency of 42.41 % and agronomic P efficiency of 82.53 mg shoot dry weight/mg P from fertilizer.

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