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The Changes of P-fractions and Solubility of Phosphate Rock in Ultisol Treated by Organic Matter and Phosphate Rock

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ABSTRACT

Phosphorus (P) is one of the essential elements for plant, however, its availability is mostly very low in acid soils. It is well documented that application of phosphate rock and organic matter are able to change the level of availability of P-form in acid soils. The objective of the research were to evaluate the changes of P-fractions (resin-P, $NaHCO_3$-P_i, and $NaHCO_3$-P_o) and phosphate rock dissolution which were induced by application of organic matter (*Imperata cylindrica, Pueraria javanica*, dan *Colopogonium mucunoides*) and phosphate rock in Utisol Lampung. The experiment was designed in a completely randomized design with three factors and three replications. The first factor was the types of organic matter (*I. cylindrica, P. javanica*, and *C. mucunoides*), the second factor was the rate of organic matter (0, 2.5, and 5%), and the third factor was the rate of phosphate rock (0, 40, and 80 mg P kg^{-1}). The results showed that in the rate of 0 and 1% organic matter, the type of organic matter did not affect P-fraction of $NaHCO_3$-P_i, but in the rate of 2.5 and 5%, $NaHCO_3$-P_i due to application of *P. javanica*, and *C. mucunoides* higher than due to application of *I. cylindrica*. However, the increasing rate of organic matter increased $NaHCO_3$-P_i. Then, P-fraction of Resin-P_i was affected by the type of organic matter, the rate of organic matter, and the rate of phosphate rock, respectively. P-fraction of resin-P_i due to application of *P. javanica*, and *C. mucunoides* was higher than due to application of *I. cylindrica*, but the effect of *P. javanica*, and *C. mucunoides* was not different. Increasing the rate of organic matter and phosphate rock increased P-fraction of resin-P_i and $NaHCO_3$-P_i, but P-fraction of $NaHCO_3$-P_o was not affected by all treatments. Meanwhile, dissolution of phosphate rock was affected by the kind of organic matter and soil reaction. In the rate of 5% organic matter, dissolution of phosphate rock by application of *I. cylindrica* (70%) was higher than *P. javanica* (26.6%), and *C. mucunoides* (33.5%), but in the rate of 1%, the effect of *I. cylindrica , P. javanica*, and *C. mucunoides* were not different.

Keywords: *C. mucunoides, I. cylindrica, P. javanica*, phosphate rock, P-fractions

INTRODUCTION

Phosphorus (P) is one of the essential macro nutrients, however, its availability is very low especially in acid soils, weathered soils, and soil from volcanic material that contains amorphous clay mineral (Allophanes). This low availability is caused by P-fixation in the soils. Most of P added to the soil tends to be fixed even more than 90% so P availability status is very low, ranges between 10-20%. P-fixation is caused by the present of soluble Al and Fe ions, oxides/hydroxides of Al and Fe, and clay minerals in acid soils. In soils that highly weathered, it contains dominantly oxide minerals or kaolinite group and forms inorganic-P such as Fe-P and Al-P, while from allophane group forms Al-P. These kinds of P-inorganic forms are the P-forms that insoluble and unavailable.

Phophorus organic form is also the source of soil P which is fixed in the form of organic compound generally consists of three groups of P-organic compound *i.e.* phytin and its derivates, nucleic acid, and phospholipids. These forms are not available yet except phytin that can be absorbed by plant directly, although its absorption will be more effective when this compound is mineralized. Some methods for P fractionation have been developed for determination the forms of P in the soil such as by Hedley *et al*. (1982) and Tiessen and Moir (1993). Inorganic P that can be extracted by resin (resin-Pi) and $NaHCO_3$ ($NaHCO_3$-Pi) and organic P ($NaHCO_3$-Po) had been agreed by some researchers as P available form, and its concentration in the soil affected by weathering process and soil management (Guo *et al*. 2000). Inorganic P-resin (resin-Pi) and - $NaHCO_3$-Pi are a labile P form and this form is mostly available for plant, as well as organic-P ($NaHCO_3$-Po) as the source of P from the organic matter mineralization is a labile form, and those forms are in equilibrium with P- soil solution, which is immediately available for plants (De Brouwere *et al*. 2003; Beck and Sanchez, 1994; Bowman *et al*. 1978).

Mobility and availability of phosphorus (P) in the soil are affected by some factors such as pH (Sato and Comeford 2005), organic complexes of Fe and Al (Borggaard *et al*. 2005), organic anions (Afif *et al*. 1995), amount and type of clay minerals (Penn *et al*. 2005), extractable Fe and Al oxides, hydroxides, and oxyhydroxides (Wiriyakitnateekul *et al*. 2005; Li *et al*. 2007), content of Ca, Fe, and Al in the soil, and phosphorus content in the mineral material (Tisdale *et al*. 1985). Availability of P in the soil can be increased by P fertilization and lime, and some studies showed that application of organic matter increases availability of P by decreasing P fixation that is caused by organic acids produced during organic matter decomposition, and it is able to chelate Al/Fe so that P ion which is fixed at the Al/Fe compound can be released and available for plant (Iyamuremye *et al*. 1996: Hartono *et al*. 2000).

One of the soil organic matter resources is crop biomass, especially green plant fertilizer *i.e. Leguminoceae* family. This plant has many species and has been used generally as a cover crops. Advantages in using organic matter from leguminous plant are because this plant can grow in the marginal soils in relatively fast growing, low ratio-C/N, can be harvested periodically, and can be decomposed quickly if it is buried into the soil. Another organic matter resource that is also potential and a lot of it in the marginal soils is alang-alang (*Imperata cylindrica*). Alang-alang is a weed plant, fast growing plant, and able to grow in the poor soils, sandy soils, peat soils, and in the dry condition of soils (Aprisal 2000).

Meanwhile, a lot of phosphate rock (RP) is used as an alternative fertilizer of the conventional P such as TSP, SP-36/SP-18. However, low solubility of phosphate rock in the soil is a problem in developing it as a fertilizer P resource. In general, phosphate rock solubility increases by application of acid treatment, therefore by giving acid to the rock phosphate, solubility and availability of P will increase. Some researchers also showed that a combination of phosphate rock and organic matter was able to increase P availability of soil P (Ikerra *et al*. 1994; Purnomo *et al*. 1999; Djuniwati *et al*. 2007; 2008). It is because organic acids from organic matter decomposition will be able to increase rock phosphate solubility (Sagoe *et al*. 1997).

The main objective of this research was to study the effects of organic matters types (*Imperata cylindrical, Pueraria javanica*, dan *Colopogonium mucunoides*), the rates of organic matters, and rate of P (phosphate rock) on the availability of P fraction (Pi-resin, P-inorganic and organic $NaHCO_3$) and phosphate rock solubility in Ultisol Lampung.

MATERIALS AND METHODS

Soil and Organic Materials

The bulk soil used in this study was Ultisol that was collected from Terbanggi Besar, Middle Lampung District, for the surface 0-20 cm depth. This bulk soil samples was air dried, sieved with 2 mm size, and mixed evenly. Organic matters were sourced from biomass of alang-alang (*I. cylindrical* (Ic), leguminous plant *P. javanica* (Pj), and *C. mucunoides* (Cm), and phosphate rock (Rock-P) from Ciamis, West Java. This research was conducted at the soil chemical and fertility laboratory of the Department of Soil and Land Resources, Faculty of Agriculture, Bogor Agriculture University, Bogor.

Furthermore, organic matter from plant biomass *i.e.* Pj, Cm, and Ic (alang-alang) were cut to be smaller pieces, and then were decomposed. Soil sample, phosphate rock and organic matter characteristics before and after decomposed, and method of analysis are presented in Table 1 and 2.

Experimental Design and Treatments

This experiment was conducted in a completely randomized design with 3 factors and three replications. First factor was types of organic matter *i.e.* Pj, Cm, and Ic, second factor was organic matter rates *i.e.* 0, 1, 2.5, and 5%, and third factor was phosphate rock rates equivalent to 0, 40, and 80 mg P kg^{-1}. So there were 108 (3 × 4 × 3 × 3) experimental units.

Incubation and Maintained

Bulk soil sample was weighed equivalent to 200 g oven-dried-weight, then mixed with every kinds and rates of Pj, Cm, and Ic and phosphate rock corresponding to each treatment. The soil treated was put into the plastic bag, and then incubated for 4 weeks periods. During incubation period, soil moisture within each plastic bag was kept 70% of field capacity moisture by adding deionized water periodically. After the period of

Table 1. Characteristics of soil sample and phosphate rock used.

Characteristics	Methods	Value
pH H_2O (1 : 1)	pH meter	4.66
C-organic (%)	Walkley & Black	4.39
N-total (%)	Kjeldahl	0.19
Ratio C/N		23.10
P- available (mg kg^{-1})	Bray I	5.73
P- potential (mg kg^{-1})	HCl 25%	714.90
CEC (cmol kg^{-1})	NH_4OAc pH 7.0	14.45
Bases (cmol kg^{-1}):		
$Ca_{exchangeable}$	NH_4OAc pH 7.0	1.33
$Mg_{exchangeable}$	NH_4OAc pH 7.0	0.48
$K_{exchangeable}$	NH_4OAc pH 7.0	0.72
$Na_{exchangeable}$	NH_4OAc pH 7.0	0.61
$Al_{exchangable}$ (cmol kg^{-1})	1 *N* KCl	2.16
H_{dd} (cmol kg^{-1})	1 *N* KCl	0.31
Saturated Al (%)		35.57
Fe-available (mg kg^{-1})	0.05 *N* HCl	11.80
Mn-available (mg kg^{-1})	0.05 *N* HCl	12.48
Texture (%):	Pipet	
sand		59.14
silt		17.24
clay		23.62
Phosphate rock from Ciamis:		
P-total (%)	$HNO_3 + HClO_4$	9.90

Table 2. Chemical characteristics of organic matter Pj, Cm, and Ic before and after decomposed.

Analysis	Methods	Before			After		
		Pj	Cm	Ic	Pj	Cm	Ic
P-total (%)	Wet digestion ($HNO_3 + HClO_4$)	0.25	0.26	0.16	-	-	-
C-organic (%)	Mabeuse (dry	53.45	51.98	54.05	50.73	48.74	48.58
	oxidation)	2.83	2.89	0.79	4.25	4.28	2.59
N-total (%)	Kjeldahl	18.89	17.99	68.42	11.94	11.39	18.76
C/N	-	213.8	199.92	337.81	-	-	-
C/P	-	-	-	-	247.83	278.39	330.15

incubation, the soil samples were air dried before analysis.

Phosphate Analysis

Parameters were observed after incubation *i.e* soil pH, inorganic-P resin (resin-P_i) and inorganic-P $NaHCO_3$ ($NaHCO_3$-P_i) and organic-P $NaHCO_3$ ($NaHCO_3$-P_0) by using Tiessen and Moir Method (1993) and rock phosphate solubility by Solubility Method for Ca (Bolan and Hedley 1989). Phosphate rock solubility was measured by using indicator of the changes of calcium (Ca) solubility value (Bolan and Hedley 1989). Phosphate rock solubility persentages were calculated based on the different of Ca in the soil treated by phosphate rock and control (ΔCa) which was divided by Ca of phosphate rock × 100%.

Data Analysis

Analysis of variance (ANOVA) for the completely randomized design was done to determine main and interactive effects of treatment. Multiple comparisons for means separation was analyzed by Duncan's Multiple Range Test (DMRT) with a significance level of $P < 0.05$.

RESULTS AND DISCUSSION

Soil Characteristics

Soil characteristics analysis (Table 1) showed that Lampung Ultisol was an acid soil with high organic-C content and low total-N, while total-P was high, but available P was very low (PPT 1983). It showed that soil P is generally in the fixation and unavailable forms. Due to high acidity, saturated Al, and available Fe, it is possible for P fixation. The low of CEC value is related with low content of clay. Furthermore, content of bases Ca-$_{exch}$ and Mg-$_{exch}$ were low and very low, but K-$_{exch.}$ and Na -$_{exch.}$ were high and medium, respectively (PPT 1983). Because of these characteristics so this Ultisol was a soil with relatively low level of fertility.

Organic Matter

The organic matter analysis (Table 2) also showed that C-organic content in biomass of Pj, Cm, and Ic was relatively the same, however, N-content in biomass of Pj and Cm were higher than biomass of Ic, so C/N ratio of biomass alang-alang (Ic) which was much higher than Pj and Cm. It was due to Ic has higher lignin content than Pj and Cm, while Pj and Cm have high N-content. Because of high C/N-ratio of alang-alang (Ic) decomposition process was more difficult and took more longer time.

Interaction Effects of Types and Rates of Organic Matter and Phosphate Rock Application

Result of analysis of variance showed that combination of types of organic matter × rates of organic matter × phosphate rock only significantly affected soil pH, while combination of types of organic matter × rates of organic matter affected inorganic-P ($NaHCO_3$), phosphate rock solubility, and soil pH. Besides that, inorganic-P ($NaHCO_3$) ($NAHCO_3$-P_i) was significantly affected by combination of types of organic matter × rates of organic matter but also significantly affected by it single factor *i.e.* types of organic matter, rates of organic matter, and phosphate rock. However, inorganic-P resin (Resin-Pi) was only significantly affected by each single factor *i.e.* types of organic matter, rates of organic matter, and phosphate rock, except for P-organic ($NaHCO_3$) which were not affected by all treatments.

Soil Reaction (Soil-pH)

Result of Duncan Multiple Range Test about the effect of combination of types of organic matter × rates of organic matter × phosphate rock on soil pH (Table 3) showed that based on the combination of rates organic matter × phosphate rock, so at each rate of organic matter Ic (*I. cylindrica*), increasing rates of phosphate rock did not affect soil pH, and also at each rate of phosphate rock, increasing rates of organic matter Ic did not affect soil pH. Beside that, effect of type of organic matter *P. javanica* (Pj) showed that at rate 0.1 and 2.5% of Pj, increasing phosphate rock rates did not affect soil pH, but rate Pj 5% with 80 mg kg^{-1} P (phosphate rock), soil pH was higher than with 40 mg kg^{-1} P (phosphate rock).

At each rate of phosphate rock, application of Pj 5% showed the highest soil pH and at application of Pj 2.5% soil pH was higher than application Pj 0

Table 3. Effects of combination of types and rates of organic matter and phosphate rock on soil pH.

Types of organic matter	Rates of organic matter (%)	Rates of P (phosphate rock) (mg P kg^{-1}) 0	40	80
Ic	0	4.1 hi	4.2 hi	4.3 fghi
	1	4.1 hi	4.2 hi	4.3 fghi
	2.5	4.2 hi	4.2 hi	4.4 defgh
	5	4.3 fghi	4.3 fghi	4.4 defgh
Pj	0	4.1 hi	4.2 hi	4.3 fghi
	1	4.2 i	4.2 hi	4.3 fghi
	2.5	4.6 defg	4.6 defg	4.7 cd
	5	6.5 a	5.8 b	6.2 a
Cm	0	4.1 hi	4.3 fghi	4.3 fghi
	1	4.4 defgh	4.4 defgh	4.4 defgh
	2.5	4.9 c	4.7 cde	4.8 cde
	5	6.4 a	6.4 a	6.4 a

Note: Means followed by the same letters are not significantly different by DMRT at α 5% level different.

and 1%. Then, the effects of type of organic matter Cm had almost similar pattern with effect of Pj, that was at each rate of phosphate rock, application of Cm 5% showed the highest soil pH, and at addition of phosphate rock equivalent to 0, 40, and 80 mg P kg^{-1} were not different. Then, the effect of rate Cm 2.5% was higher than rate Cm 0 and 1%.

Among kind of organic matter it can be seen that at each rate of phosphate rock, effects of addition 0 and 1% of organic matter Ic, Pj, and Cm were not significantly different on soil pH, but effects of organic matter Pj and Cm at rates of 2.5 and 5% resulted the higher soil pH than addition of Ic at the same rates. Then, at rates of organic matter 2.5%, effects of organic matter Cm tended to be higher than effect Pj while at at rate of 5% effect Cm and Pj with application of rock phosphate equivalent to 0 and 80 mgP kg^{-1} were not significantly different and resulted the highest soil pH, while at rates rock phosphate equivalent to 40 mg kg^{-1} P, effct of Cm was higher than Pj on soil pH.

Based on the above results, it was shown that soil pH was determined by types and rates of organic matter that was added, and addition of phosphate rock did not affect without adding organic matter. It was assumed that due to the present of organic acids that was produced during organic matter decomposition process. Bolan *et al*. (1994) and van Hees *et al*. (2000) stated that organic acids, mainly when it had low molecular weight, was able to chelate or to complex Al and or Fe in solution so its activities decreased and resulting to increase pH. Djuniwati and Hartono (2002) also reported that addition of organic matter such as legume (*P. javanica* and *C. muconoides*) rates 2.5 and 5% decreased exchangeable-Al and Fe significantly, and increased soil pH of Ultisol Lampung.

The difference among kind of organic matter showed that effects of Cm on soil pH tended to be higher than Pj, and the effects of both was higher than Ic (alang-alang). It was assumed that it was related to higher C/N ratio of Ic (alang-alang) so that organic acids that was produced was more slower and more lower than result of organic matter Pj and Cm decomposition, so chelating resourced on the soil acidity becoming lower.

Phosphate Rock Solubility

Result of DMRT for the effects of combination of types and rates of organic matter on phosphate rock solubility (Table 4) showed that at type of organic matter Ic, increasing rates of Ic increased solubility of phosphate rock, but at type of organic matter Pj and Cm increasing rates of rock phosphate were occured at rates 1% while at rates of organic matter 2.5 and 5% rock phosphate solubility tended to decrease. It was assumed that it was related with soil pH (Table 3), *i.e.* effect of organic matter Pj and Cm at rate 2.5 and 5% was higher than effect of alang-alang (Ic). Effects of organic matter Ic resulted soil pH became very acid (< 4.5) while effects of organic matter Pj and Cm resulted soil pH became rather acid (5.8-6.5) (PPT 1983). The higher soil acidity, so effect of organic matter alang-alang (Ic) to increase phosphate rock solubility would be higher than effect of organic matter Pj and Cm.

Hammond *et al*. (1986) explained that phosphate rock solubility was determined by soil acidity, P adsoption capacity, Ca content in the soil, kinds of apatit mineral, particle size, and kind of it follower minerals, and Prasetyo cited by Purnomo (2002) proved that phosphate rock solubility was positively correlated with Al-exchange and H ion in the red soils in West Java. Furthermore, Khasawaneh and Doll (1978 cited by Hammond *et al*. 1986) explained that soil factor that influenced phosphate rock solubility was pH, Ca content, soil texture, and soil organic matter content. Phosphate rock solubility was higher at the soils with low pH (Chue *et al*. 1962). Increasing phosphate rock solubility on acid condition due to H ion in soil solution was able to release PO_4^{3-} anion and Ca^{2+} cation in the phosphate rock folowing this reaction (Bolan and Hedley 1989):

$$Ca_{10}(PO_4)_6F_2 + 12\,H^+ \rightleftharpoons 10\,Ca^{2+} + 6\,H_2PO_4^- + 2F^-$$

Table 4. Effects of kinds and rates of organic matter on phosphate rock solubility.

Types of Organic Matter	Rates of Organic Matter (%) 0	1	2.5	5
	.... (%)			
Ic	45.1 cdef	59.7 abc	56.7 abcd	70.0 a
Pj	52.1 cdef	68.4 ab	40.9 defg	26.6 g
Cm	45.7 cdef	60.7 abc	38.3 efg	33.5 fg

Note: Means followed by the same letters are not significantly different by DMRT at α 5% level different.

Table 5. Effects of combination of kinds and rates of organic matter on soil Inorganic-P $NaHCO_3$ ($NaHCO_3$-P_i).

Types of Organic Matter	Rates of Organic Matter (%)			
	0	1	2.5	5
	................................mg P kg^{-1}			
Ic	27.82 fg	30.63 ef	34.51 cd	36.14 bc
Pj	26.54 g	31.82 de	38.40 b	45.09 a
Cm	30.41 ef	31.89 de	39.52 b	44.10 a

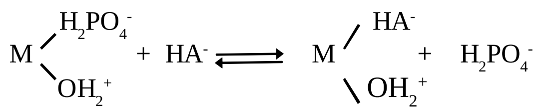
Note: Means followed by the same letters are not significantly different by DMRT at α 5% level different.

Soil P Fractions (Resin-P_i, Inorganic and Organic-P $NaHCO_3$)

Result of DMRT for the effect of combination of types and rates of organic matter on soil inorganic-P $NaHCO_3$ ($NaHCO_3$-P_i) is shown in Table 5. Table 5 showed that at each type of organic matter increasing rates of organic matter was able to increase soil $NaHCO_3$-P_i. At the rates of organic matter 0 and 1%, effect of organic matter Ic, Pj, and Cm the consentration of $NaHCO_3$-P_i did not significantly different, but at rates of organic matter 2.5 and 5% effect of type of organic matter Pj and Cm resulted $NaHCO_3$-P_i higher than effect of alang-alang (Ic).

Result of DMRT for single effects of types od organic matter, rates of organic matter, and rates of phosphate rock on the resin-P_i and inorganic and organic P-$NaHCO_3$, and P-organic (Table 6) showed that effect of organic matter Pj and Cm on resin-P_i was significantly higher than effect of Ic, and the same pattern occured on soil P-inorganic $NaHCO_3$ ($NaHCO_3$-P_i). The higher results of resin-$P_{i,}$ $NaHCO_3$-Pi, and average of $NaHCO_3$-Po were due to the effect of organic matter Pj and Cm than effect of organic matter Ic, because P content in organic matter Pj and Cm was higher than in Ic (Table 2). Besides that, it was assumed that it might also be related with the higher organic acids that produced by organic matter Pj and Cm. These organic acids were able to play role as organic ligans that able to chelate Al and or Fe, and to compete with adsorption site of P, so it was released into soil solution or in the labile form and became available for plant. The research of Djuniwati *et al.* (2007 and 2008) was also shown that application of cover crops organic matter (*C. pubescent* and *C. caeruleum*) was able to increase available-P, organic-P, and inorganic-P of Latosol Darmaga.

Effect of rates of organic matter showed that increasing rates of organic matter also increased either Resin-P_i or P-inorganic $NaHCO_3$ ($NaHCO_3$-P_i), because increasing rates would also increase P resource and organic acids produced. Thus, effect of rates of phosphate rock increased resin-P_i and $NaHCO_3$-P_i, it was clearly because phosphate rock was P fertilizer, so increasing P fertilizer would increase resin-P_i and $NaHCO_3$-$P_{i.}$ As long as organic ions from organic acids was able to compete with ortophosphate at adsorption site of P, it exsistence in the soil would increase availability of P in the soil solution (Appelt *et al.* 1975; Traina *et al.* 1986). These anions were capable to substitute site of phosphate linkage through ligan exchange reaction as illustrated below:



In which M is metal surface, OH_2 dan $H_2PO_4^-$ are inorganic ligans while HA^- is organic ligan.

CONCLUSIONS

Combination of types of organic matter x rates of organic matter significantly affected on inorganic-P, phosphate rock solubility, and soil pH, while resin-P_i was affected by its single factor *i.e.* types of organic matter, rates of organic matter, and rates of P (phosphate rock). Treatment of organic matter Pj and Cm on resin-P_i was higher than organic matter Ic treatment, but between Pj and Cm treatment were not different. Then, increasing rates of organic matter and rates of phosphate rock, respectively, increased resin-P_i and inorganic-P $NaHCO_3$ ($NaHCO_3$-P_i), while P-organic $NaHCO_3$ ($NaHCO_3$-P_o) was not affected by all treatments. Furthermore, at rates of organic matter 0 and 1%, types of organic matter did not affect inorganic-P $NaHCO_3$ ($NaHCO_3$-P_i) but at rates 2.5 and 5% effect of organic matter Pj and Cm resulted inorganic-P $NaHCO_3$ ($NaHCO_3$-P_i) was higher than effect of Ic. At each kind of organic matter, increasing rates of organic matter increased P-inorganic $NaHCO_3$($NaHCO_3$-P_i).

Solubility of phosphate rock tended to related with soil acidity. At the rate of organic matter 5%,

Table 6. Single Effect of Types and Rates of Organic Matter, and rate of P (phosphate rock) on the Resin-P_i and P-inorganic $NaHCO_3$ ($NaHCO_3$-Pi), and average of organic-P $NaHCO_3$($NaHCO_3$-Po).

Treatments	Resin-P_i	$NaHCO_3$	
		P-inorganic	P-organic
	.... mg P kg^{-1}		
Types of Organic Matter			
Ic	38.22 b	32.28 b	12.33
Pj	47.46 a	35.46 a	12.90
Cm	47.30 a	36.48 a	12.59
Rates of Organic Matter (%)			
0	37.36 d	28.26 d	10.65
1	40.43 c	31.45 c	12.03
2.5	46.26 b	37.48 b	12.56
5	53.26 a	41.78 a	15.19
Rates of P (Rock Phosphate) (mg P kg^{-1})			
0	34.05 c	31.20 c	10.90
40	43.69 b	34.67 b	12.85
80	55.24 a	38.35 a	14.08

Note: Means followed by the same letters are not significantly different by DMRT at α 5% level different.

solubility of phosphate rock in the soil that was applied organic matter treatment alang-alang (Ic) (70.0%) was higher than soil that was applied organic matter Pj (26.6%) and Cm (33.5%), but at rate 1%, solubility of phosphate rock with organic matter Ic, Pj, and Cm treatments were not significantly different.

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