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CHANGES IN PHOSPHORUS FRACTIONS ON AN ACIDIC SOIL INDUCED BY PHOSPHORUS FERTILIZER, ORGANIC MATTER AND LIME

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ABSTRACT

One month of incubation experiment was implemented to evaluate the changes of phosphorus fraction in inorganic P (Pi) and organic P (Po) induced by phosphorus fertilizer (KH_2PO_4), cow manure (manure) and $CaCO_3$ (lime). A 0.5 kg oven-dried weight of arable layers of Latosol from Darmaga, Bogor was used in this study. The rates of manure were 0, 12.5 and 25 t/ha, lime were 0, 1, 3 times the $CaCO_3$ equivalent required to neutralize exchangeable aluminum amounting to 0, 3.01, 9.03 t/ha respectively and the rates of phosphorus fertilizer in KH_2PO_4 were 0, 40 and 80 kg P/ha. All treatments increased resin-Pi (biologically available P). Application of phosphorus fertilizer also increased $NaHCO_3$-Pi which is also included as biologically available P, while manure and lime only tended to increase this fraction. Phosphorus fertilizer and manure application were able to enhance NaOH-Pi (moderately resistant P related to Al-P and Fe-P) but lime did not affect it. Phosphorus fertilizer, manure and lime increased HCl-Pi (moderately resistant P related to Ca-P). The changes of $NaHCO_3$-Pi to resin-Pi and P immobilization by microorganism, which was indicated by the increase of $NaHCO_3$-Po (readily mineralizable), can be attributed to the decrease of $NaHCO_3$-Pi. The increase of NaOH-Pi by phosphorus fertilizer and manure indicated that the complexation of P fixation sites by PO_4^- and organic acids likely had occurred.

Key words : Phosphorus fraction, phosphorus fertilizer, manure, lime, resin-Pi, $NaHCO_3$-Pi, $NaHCO_3$-Po, NaOH-Pi, HCl-Pi

INTRODUCTION

The decrease of P sorption of an acidic soil derived from Darmaga due to the application of phosphorus fertilizer, manure and lime was reported by Hartono (2000). One possible mechanism for this results, the PO_4^- released by phosphorus fertilizer and manure was sorbed by sites of P sorption (Reddy *et al.*, 1980; Iyamuremye *et al.*, 1996). While the declining of exchangeable Al was one of the reasons to explain the decrease of P sorption by lime (Frossard *et al.*, 1995).

Chemical fixation of P in soil is due to the ability of soils materials, such as allophanic, clay mineral, and Al or Fe oxides and hydrous oxides, to strongly sorb PO_4^- ion (Parfitt, 1978). Fixation sites in an acidic soil as occurred in the soil from Darmaga could be caused by Al or Fe oxides and hydrous oxides or soluble Al or Fe. The latter will react quickly with soluble P (Lee *et al.*, 1990).

As consequences, the decreased P sorption in acid soil from Darmaga due to complexation of fixation sites will change the distribution of P fractions. The objective of this study was to measure the changes of P fractions induced by phosphorus fertilizer, manure and lime application to an acidic soil from Darmaga Bogor.

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MATERIALS AND METHODS

An incubation experiment was conducted in the greenhouse of Department of Soil Sciences, Faculty of Agriculture, Bogor Agricultural University. Surface samples of arable layers of Latosol from Darmaga, Bogor was used in this study. The soil samples were collected from the practical field which has been applied phosphorus fertilization for thirteen years without organic matter and lime addition and the soil is always planted maize once in a year (Sutandi and Nugroho, 1998). The soil sample from the field were screened through 2 mm sieves and air-dried. Cow manure residue was obtained from the Animal Husbandry Faculty of Bogor Agricultural University. This manure residue was air-dried, ground and sieved using a 1 mm sieve. $CaCO_3$ was as liming material and KH_2PO_4 was used as phosphorus fertilizer.

Soil samples (0.5 kg oven-dried) were put into polybag pots and mixed with the combination of manure, $CaCO_3$ and P fertilizer. Manure was added at rates of 0 (control), 12.5 t/ha and 25 t/ha. $CaCO_3$ as lime source was added at the rates of 0, 1, and 3 times the $CaCO_3$ equivalent required to neutralize exchangeable aluminum amounting to 0, 3.01, 9.03 t/ha respectively and P fertilizer in KH_2PO_4 was added ranging from 0, 40 and 80 kg P/ha. Deionized water was added to the treated soil to bring the soil moisture to mount 66 % of water holding capacity.

All pots were incubated in the greenhouse for one month. The sampling was scheduled at the end of the incubation period. The water content of the pots were maintained every two days gravimetrically. After the period of incubation, the soil samples were air-dried before analyses. The experiment was completely randomized design and was analysed by standard ANOVA procedures with means separation by Tukey's procedures. Prior to the incubation experiment the initial chemical and physical properties of the soil, manure and lime were determined (Table 1).

Fractionation of P was performed in four sub-samples incubated soil by the method of Tiessen and Moir (1993), (Table 2).

The 0.5 g soil was weighted and put into 50-ml centrifuge tube, then 0.4 g resin (Dowex 1-X80-50 mesh) oversaturated with bicarbonate in nylon bags and 30 ml of deionized water were added and after that shaken overnight (16 h). The bag containing resin was removed and soil was washed off into the tube. Bag containing resin was placed in a clean 50-ml tube and added 20 ml 0.5 *M* HCl. It was set aside for 1 hour to allow gas out and then capped and shaken overnight (16 h). P inorganic (resin Pi) was determined.

The soil suspension was centrifuged at 10000 rpm for 5 minutes. Water was decanted through a millipore filter. Water was discarded and the soil was washed off filter back into the tube with a little 0.5 *M* $NaHCO_3$ (pH 8.5) and added more 0.5 *M* $NaHCO_3$ solution to bring solution volume to 30 ml and shaken suspension overnight (16 h). Soil suspension was centrifuged at 10000 rpm for 5 minutes. $NaHCO_3$ extract was decanted through a millipore filter into a clean vial. P inorganic ($NaHCO_3$-Pi) and total P on bicarbonate extract were determined. P organic ($NaHCO_3$-Po) was obtained by subtracting total P with $NaHCO_3$-Pi.

Any soil was washed back off filter into the tube using a little 0.1 *M* NaOH and added more 0.1 *M* NaOH solution to bring solution volume to 30 ml and shaken suspension overnight (16 h). Soil suspension was centrifuged at 10000 rpm for 5 minutes. NaOH extract was decanted through a millipore filter into a clean vial. P inorganic on NaOH extract (NaOH-Pi) was determined.

Any soil was washed back off filter into the tube using a little 1 *M* HCl and added more 1 *M* HCl solution to bring solution volume to 30 ml and shaken suspension overnight (16 h). Soil suspension was centrifuged at 10000 rpm for 5 minutes. HCl extract was decanted through a clean vial. P inorganic in HCl extract (HCl-Pi) was determined. P was measured by the method of Murphy-Riley (1962) using Hitachi UV 2000 Spectrophotometer with wave length 712 nm. All analyses were conducted in the Center for Soil and Agroclimate Research, Bogor.

RESULTS AND DISCUSSION

Biologically available P (Resin-Pi and $NaHCO_3$-Pi and P_o)

Resin Pi is readily available for plant uptake, and 0.5 *M* $NaHCO_3$-Pi is highly related to P uptake by plants (Schmidt *et al.*, 1996). The former represents soil solution P, soluble phosphate originating from calcium phosphates

Table 1. Initial soil, manure and lime analyses

Characteristics	Methods	Values
Soil		
pH	pH H_2O 1 : 2.5.	4.40
C-organic (%)	Walkley & Black	1.75
Total-N (%)	Kjeldahl	0.22
Available-P_2O_5 (mg kg^{-1})	Bray1	27.12
HCl-P_2O_5 (mg/100 g)	HCl 25 %	136.65
Cation Exchange Capacity (CEC) (cmol (+) Kg^{-1})	1 *N* NH_4OAc pH 7.0	12.64
Exchangeable Bases (cmol (+) Kg^{-1})		
Ca (cmol (+) kg^{-1})	1 *N* NH_4OAc pH 7.0	1.04
Mg (cmol (+) kg^{-1})	1 *N* NH_4OAc pH 7.0	0.40
K (cmol (+) kg^{-1})	1 *N* NH_4OAc pH 7.0	0.07
Na (cmol (+) kg^{-1})	1 *N* NH_4OAc pH 7.0	0.07
Exchangeable Al (cmol (+) kg^{-1})	1 *N* KCl	3.02
Available-Fe (mg kg^{-1})	DTPA	20.63
Available-Mn (mg kg^{-1})	DTPA	3.93
$Fe_{dithionite}$ (%)	Dithionite-citrate	5.48
$Fe_{oxalate}$ (%)	Oxalate	2.16
$Al_{dithionite}$ (%)	Dithionite-citrate	4.99
$Al_{oxalate}$ (%)	Oxalate	1.09
Texture	Pippete	
Sand (%)		4.50
Silt (%)		20.50
Clay (%)		75.00
Manure		
Total P (%)	Wet –Ashing (HNO_3+$HClO_4$)	0.30
Total C (%)	Walkley & Black	21.14
Total N (%)	Kjeldahl	1.18
C/P		70.74
C/N		18.00
Lime		
$CaCO_3$ (%)	0.25 *N* HCl	99.02

Table 2. Characterization of sequential soil-P extraction

P-extractant	P-extractant characteristic/interpretation
Biologically available P :	
Resin P inorganic (Pi) in 0.1 *M* HCl	Extract P inorganic that is readily available to plants
0.5 *M* $NaHCO_3$-Pinorganic (Pi) and P organic (Po)	Extract strongly related to P uptake by plants and microbial activity
Moderately resistant :	
0.1 *M* NaOH– Pinorganic (Pi)	More strongly held by chemisorption to Fe and Al components of soil surface
1 *M* HCl-Pinorganic (Pi)	Extract mainly Ca-P of low solubility

and loosely adsorbed P inorganic on ther surface of sesquioxides or carbonates (Tiessen and Moir, 1993).

Increasing rates of phosphorus fertilizer, manure and lime added to the soil increased the resin Pi significantly (Table 3). The increase was comparable although it was found little bit smaller on the application of lime.

Table 3. Effect of phosphorus fertilizer, manure and lime on the resin-Pi and $NaHCO_3$–Pi mean values after one month incubation

Treatment	Resin-Pi	$NaHCO_3$-Pi
	....................mg kg^{-1}....................	
Rate of P (kg/ha)		
0	3.20 c	28.67 b
40	6.06 b	30.38 ab
80	8.62 a	32.30 a
Rate of manure (t/ha)		
0	3.93 c	30.60 b
12.5	5.89 b	27.81 c
25	8.05 a	32.94 a
Rate of lime (t/ha)		
0	4.20 c	29.73 b
3.01	5.81 b	32.16 a
9.03	7.86 a	29.46 b

Mean values followed by the same letter within a column are not significantly different (Tukey's test, α = 0.05)

Schmidt *et al.* (1996) and Iyamuremye *et al.* (1996) found similar result with the application of phosphorus fertilizer and manure respectively and the former considered that resin-Pi as a sink to excess phosphorus.

The contrary result was mentioned by Iyamuremye *et al.* (1996) that lime did not affect resin Pi but it agrees with Taylor and Gurney (1965) that lime increased resin-Pi which can be attributed to the decrease of exchangeable Al precipitated by OH.

The increasing rates of phosphorus fertilizer increased $NaHCO_3$-Pi significantly. Manure with rate of 12.5 t/ha caused a significant decrease but on the contrary with the application of 25 t/ha. The decrease of $NaHCO_3$-Pi when treated by 12.5 t manure/ha may be because of the changes of $NaHCO_3$-Pi to resin Pi (Tiessen and Moir, 1993). A sink to excess phosphorus was explanation to the increase of resin-Pi and $NaHCO_3$-Pi because of the application of 25 t manure/ha.

Lime at the rate of 3.01 t/ha was able to increase $NaHCO_3$–Pi but at higher dosage did not show different effect. The changes of $NaHCO_3$-Pi to the resin Pi can be attributed to this phenomena. Beside that the immobilization of $NaHCO_3$-Pi by microorganism because of favorable changes of pH is also possible (Pavan and Carneiro, 1995). It is also confirmed by the result of $NaHCO_3$-P_o obtained by this research (Table 4) that pool of $NaHCO_3$-Po increased when $NaHCO_3$-Pi decreased.

It agrees with Iyamuremye *et al.* (1996) on the application of manure. The contrary result was found on the application of lime which resulted in little or no increase in the amount of $NaHCO_3$-Pi. In other investigation the application of phosphorus fertilizer and manure significantly increased $NaHCO_3$-Pi and Po (Reddy *et al.*, 1999).

Moderately resistant P (NaOH-Pi and HCl-Pi)

The NaOH extractant removes P which is less related to P plant uptake (Enwezor, 1977) and is associated with amorphous and crystalline Al and Fe phosphates. To that respect, NaOH-Pi is more strongly held by chemisorption to Fe and Al components of soil surface (Tiessen and Moir, 1993). It is shown that application of phosphorus fertilizer and manure was able to increase the NaOH-Pi significantly while lime did not have any effect on the NaOH-Pi (Table 5).

Pavan and Androcioli (1995) reported that application of compost and mulch was able to promote NaOH-Pi. While Schmidt et al. (1996) found that NaOH-Pi fraction also represents a sink for excess P fertilization and significantly increased across P treatments.

The increase of this fraction observed in this acidic soil amended by phosphorus fertilizer and manure was likely as a result of PO_4^- released from phosphorus fertilizer and manure. Unlike phosphorus fertilizer and manure, lime did not add any soluble inorganic

Table 4. Effect of phosphorus fertilizer, manure and lime on the $NaHCO_3$-Po mean values after one month incubation

Treatment	$NaHCO_3$-Po (mg kg^{-1})
Rate of P (kg/ha)	
0	28.22 b
40	30.81 a
80	29.75 ab
Rate of manure (t/ha)	
0	24.22 b
12.5	32.76 a
25	31.80 a
Rate of lime (t/ha)	
0	28.01 b
3.01	28.33 b
9.03	32.44 a

Mean values followed by the same letter within a column are not significantly different (Tukey's test, $\alpha = 0.05$)

Table 5. Effect of phosphorus fertilizer, manure and lime on the NaOH-Pi and HCl-Pi mean values after one month incubation

Treatment	NaOH-Pi	HCl-Pi
	....................mg kg^{-1}	....
Rate of P (kg/ha)		
0	445.80 c	15.70 b
40	477.73 b	15.80 b
80	514.80 a	21.71 a
Rate of manure (t/ha)		
0	460.99 c	15.17 c
12.5	481.45 b	18.44 b
25	495.89 a	19.60 a
Rate of lime (t/ha)		
0	478.95 a	16.87 b
3.01	480.39 a	17.48 b
9.03	478.95 a	18.87 a

Mean values followed by the same letter within a column are not significantly different (Tukey's test, $\alpha = 0.05$)

P or organic P so there is no phosphate precipitated by Fe and Al as shown by this experiment.

Furthermore, it is appeared that phosphorus fertilizer, manure and lime tended to enhance HCl-Pi (Table 4). Similar result was reported by Pavan and Androcioli (1995) in the application of compost and mulch. The absence of major changes in HCl-Pi is understandable because the soil is acid which would favor formation of Al and Fe P inorganic compounds over Ca products. The HCl-Pi fraction is associated mainly with insoluble Ca-P compounds such as hydroxyapatite (Tiessen and Moir, 1993).

CONCLUSIONS

Resin-Pi and HCl-Pi increased when treated with phosphorus fertilizer, manure and lime. The similar result was found for $NaHCO_3$-Pi, but only small increase recorded in lime and manure treatments.

The P immobilization by microorganism can be attributed to the decreased $NaHCO_3$-Pi which indicated by the increase of $NaHCO_3$-Po pool.

The decrease of $NaHCO_3$-Pi can also be attributed to the changes of this fraction to resin-Pi.

Phosphorus fertilizer and manure containing a lot of total P (0.3 %) also increased NaOH-Pi largely react with Al and Fe (chemisorbed P inorganic) but lime (inorganic amendment) did not affect this P fraction.

The increase of NaOH-Pi by phosphorus fertilizer and manure indicated that the complexation of surface sites of P sorption by PO_4^- and organic acids likely had occurred.

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