Available online at:
http://journal.unila.ac.id/index.php/tropicalsoil
DOI: 10.5400/jts.2012.18.1.

# Effectiveness of Direct Application of Phosphate Rock in Upland Acid Inceptisols Soils on Available-P and Maize Yield

Nurjaya[1] and Dedi Nursyamsi[2]

[1]*Indonesian Soil Research Institute, Jl. Tentara Pelajar No.12, Kampus Penelitian Pertanian Cimanggu, Bogor 16114, Indonesia, e-mail: nurjaya26@yahoo.com*
[2]*Indonesian Swampland Agricultural Researsch Institute, Jl. Kebun Karet, Lokatabat Utara, Kota Banjarbaru 70712, South Kalimantan, Indonesia, e-mail ddnursyamsi@yahoo.com*

Received 23 October 2012 / accepted 7 January 2013

## ABSTRACT

Source of P fertilizer which is used by farmers in upland acid soils area is generally acidulated phosphate rock (PR), such as tripel super phosphate (TSP), super phosphate 36% $P_2O_5$ (SP-36), as well as partial acidulated phosphate rock (PAPR) which contain 10-30% $P_2O_5$. Their effectiveness, however, varies and depends on the soil and plant types. Phosphate rock fertilizers have a high prospects for acid soils because its effectiveness equals to the SP-36, cheaper, slow release, and its application can also leave the residual P in the soil that available for plants for next few seasons. Field experiment aimed to study the effectiveness of direct application of PR at upland acid soils and its effect on soil available-P as well as maize (*Zea mays* L.) yield was conducted in Acid Inceptisols of Ciampea, Bogor in wet season years 2008/2009. The experiment was arranged by a Randomized Completely Block Design with 3 replications. Maize of P-12 variety was used as a plant indicator. The treatment consisted of 6 levels of phosphate rock: 0, 20, 30, 40, 50, and 60 kg P $ha^{-1}$, as well as one level of SP-36 40 kg P $ha^{-1}$ as standard fertilizer. In addition, urea of 300 kg $ha^{-1}$ and KCl of 100 kg $ha^{-1}$ were used as basal fertilization. The result showed that the application of PR in the amount ranging from 20 to 60 kg P $ha^{-1}$ increased total-P and available-P, and pH, decreased exchangeable Al in the soils as well as increased maize straw and grain. Phosphate rock application at 40 kg P $ha^{-1}$ level was equally effective as SP-36 in the tested soils. Critical level of soil P for maize grown in the soil was 675 and 5.00 mg $P_2O_5$ $kg^{-1}$ extracted with HCl 25% and Bray I, respectively. The requirement of P for maize grown in the soil to achieve maximum profit was 38 kg P $ha^{-1}$ and 17.5 kg P $ha^{-1}$ or equivalent to PR of 583 and 268 kg $ha^{-1}$ in low (soil P < critical level) and high (soil P > critical level) soil P status, respectively.

***Keywords***: Direct application, phosphate rock, soil available-P, upland acid soils.

## INTRODUCTION

Upland acid soils areas in Indonesia which have potential for food crop production are about102.8 million ha (Mulyani *et al.* 2004). One of the problems in cultivating the upland acid soils is costly for maintaining and increasing its productivity, because it is likely to decline after several-years of cultivation. The declining occurs faster if it is managed improperly such as poor erosion control and low fertilizer input. Among the major nutrients, phosphorous deficiency is the most constraint in the tropical acid soils (Zapata and Zaharah 2002). The efficiency of P fertilization in the soils is generally low due to high P-fixing capacity of the soil.

Phosphorous deficiency is often the limiting factor to plant growth in tropical acid soils (including Indonesia) because of strong P bound by Fe and Al at soil colloids. Due to this fact, phosphorous fertilizer is frequently needed for maintaining high yields and for their economical viability (Johnson and Loeppert 2006). Until this moment, sources of P fertilizer used by farmers in upland area are generally acidulated phosphate rock, such as tripel super phosphate (TSP), super phosphate 36% $P_2O_5$ (SP-36), and super phosphate 18% $P_2O_5$ (SP-18). Their effectiveness, however, varies and depends on soil and plant types used.

Many researches dealing with P management have been conducted to find out the optimum rate of P, P fertilizer application method, as well as improvement of P efficiency in upland food crops areas, through liming, organic matter application and the use of low water soluble P and slow release P fertilizer such as phosphate rock (PR) and partial acidulated phosphate rock (PAPR). Phosphate rock fertilizers have a high prospects of application in upland acid soils because of its equal effectiveness as SP-36, its price is cheaper, and it can release P into the soil solution slowly (slow release). The application of PR can also leave the residual P in the soil that can be absorbed by plants for the next few seasons. The agronomic effectiveness of PR depends on several factor including PR reactivity, soil properties, and crop species (Suzette *et al.* 2010). The results of long-term research, application of 1,000 kg $ha^{-1}$ phosphate rock on oxisols and ultisols increased maize yield for five seasons between 30-90% (Rochayati *et al.* 2009).

Experiments on the direct application of several sources of phosphate rock on food crops have been conducted since 1980's. The results indicated that the direct application of reactive PR at acid upland soils is more or equally effective compared to water soluble P (TSP or SP-36). Experiment was conducted on Ultisols in Sitiung, West Sumatra Province which was P deficient with pH 4.5 and Al saturation 78% during four seasons, indicated that with a total application of 160 kg P per ha from the four PR sources (North Carolina PR, Local PR, and Tunisia PR proved to be the best, surpassing the effectiveness of TSP (Adiningsih *et al.* 2001). Application of 40 kg P $ha^{-1}$ of Tunisia PR did not increase maize yield compared to application of SP-36 fertilizer at the same rate (Kasno 2009a). Phosphate fertilizer increased plant height, dry plant weight and grain yield. The effective dose of PR was 60 kg P $ha^{-1}$, obtaining the highest R/C ratio. (Kasno 2009b). Phosphate rock application with 30 kg P $ha^{-1}$ dosage increased soil available P 247% compared to without P. Phosphate-solubilizing bacteria and farm yard manure combination with PR 30 kg P $ha^{-1}$ dosage increased dry weight of soybean shoot 29% compared to control (Noor 2003)

Comparison of three types of Christmas Island PR with different sesquioxides content (Christmas A < Christmas B < Christmas C) and local PR from Gresik and Ciamis with TSP was conducted during four consecutive seasons at Ultisols in Terbanggi, Lampung Province which was P deficient, pH 5.3 and Al saturation < 1%. The rate of P was 80 kg $ha^{-1}$ and applied once in the first season and the crop rotation was upland rice – soybean.

Phosphate rock fertilizer quality is influenced by several factors, among others: mineralogical properties, solubility, grain size, free carbonate content, total $P_2O_5$ content and type of deposit. Its effectiveness is determined by the chemical reactivity, particle size, soil properties, time and method of application, dose of PR, plant species and planting pattern (Rajan *et al.* 1996). Phosphate rock fertilizing significantly increased soil P content, both P-reserved and P-available. The effectivity of PR on Typic Plintudults was less than that on Typic Kanhapludults (Kasno 2011).

Until this moment, research on the effectiveness of PR in acid soils have been carried out at weathered soils derived from sedimentary materials, such as Ultisols and Oxisols. Research at young soils derived from volcanic material such as Inceptisols is still limited, whereas Inceptisols cover area approximately 70.5 million ha or about 37% of agricultural land of Indonesia (Pusat Penelitian Tanah and Agroklimat 2000).

Based on the above mention, this research aimed to study the effectiveness of the direct application of PR and its effect on soil available-P as well as maize yield at upland acid Inceptisols derived from volcanic materials.

## MATERIALS AND METHODS

### Study Site

A field experiment was conducted at Dark Brown Latosol derived from parent material of intermediate volcanic tuff with physiographic volcanic (Lembaga Penelitian Tanah 1966) or equivalent with Inceptisols (Soil Survey Staff 2010), in Ciampea Subdistrict (about 350 m from sea level), Bogor District. The experiment was carried out on farmer land during the rainy season (RS) 2008/2009 and maize variety of P-12 was used as plant indicator. Initial analysis on PR fertilizer and soil samples taken after harvest were carried out at Research and Soil Test Laboratory of Indonesian Soil Research Institute Bogor, Indonesia.

### Experimental Set Up

A field experiment was arranged by a Completely Randomize Block Design with 3 replications. The treatments consisted of six levels of P, *i.e.*: 0, 20, 30, 40, 50, and 60 kg P $ha^{-1}$, equivalent to 0, 307, 460, 614, 767, and 920 kg PR $ha^{-1}$ plus one treatment of 40 kg P $ha^{-1}$ from SP-36 or equivalent to 250 kg SP-36 $ha^{-1}$ as a standard. Furthermore, 135 kg N $ha^{-1}$ and 60 kg K $ha^{-1}$ were also used as basal fertilizer.

Phosphate rock, KCl, and urea fertilizers were incorporated into the soil about a 3-5 cm depth and a 5 cm distance from plant rows. Urea fertilizer was given twice, *i.e.* at planting and one month after planting, each at half dose, while the other fertilizers were given entirely at planting time. Seeds of maize (P-12 variety) were planted with spacing of 75 cm × 20 cm, each with two plants $hill^{-1}$ in 6 m × 5 m experimental plots. On 7 day after planting, some plants were removed out to become one plant $hill^{-1}$.

**Soil and Plant Analysis**

Initial analysis of topsoil samples (0-20 cm) are presented in Table 1. Analysis was also carried out on composite topsoil samples taken from each experiment plot after harvesting to determine soil potential P content (HCl 25%), available-P content (Bray I), pH (water) and exchangeable Al (KCl 1 *N*). Plants were harvested at physiological maturity phase, at about 95 days after planting. Maize straw and grain yield were weighed immediately, then after drying the yields were also weighed.

The effectiveness of tested PR fertilizer is calculated using the variable of Relative Agronomic Effectiveness (RAE), which is a ratio between the yield increase by the application of PR and yield increase by the use of a standard fertilizer (SP-36) multiplied by 100 (Machay *et al.* 1984). The formula is as follows:

$$\text{RAE} = \frac{\text{Yield of PR treatment} - \text{Control}}{\text{Yield of standard treatment} - \text{Control}} \times 100\%$$

Critical level of soil P for maize grown in acid Inceptisols was determined by Cate and Nelson method (1971), by plotting soil P concentration as X axis and percentage of maize yield as the ordinate (Y axis). Percentage of maize yield is defined as $(P_0/P_X) \times 100\%$, where $P_0$ is the yield without P treatment and $P_X$ was the yield with P treatment. Furthermore, the cross-shear axis is shifted at 85% of percentage of yield so that the number of points in quadrants I and III are the maximum, while the numbers in quadrants II and IV are minimum.

**Data Analysis**

Data of production costs and selling price of the crops were collected by way of direct interviews with 20 maize farmers who lived around the location of the experiment. Production cost (input) included expense for: labor, urea, KCl, phosphate rock, as well as pesticides, while the output (revenue) was maize yield multiplied by the farm price of dry grain maize yield. Analysis of the farming was done by calculating profits, *i.e.* output minus the cost of inputs.

Maximum and optimum dose of fertilizers recommendation were calculated with using Heady *et al.* (1955) procedures. The maximum dose of

Table 1. Soil properties from initial anlyses of topsoil samples (0-20 cm) taken from field experiment site.

| Soil properties | Unit | Method/extraction | Values* |
|---|---|---|---|
| Texture | | Pipet | |
| Sand | % | | 10.67 |
| Silt | % | | 26.00 |
| Clay | % | | 63.33 |
| pH | | pH meter | |
| $H_2O$ (1:5) | | | 5.23 |
| KCl (1:5) | | | 4.40 |
| Organic matter | | | |
| Total-C | % | | 1.15 |
| Total-N | % | | 0.15 |
| C/N ratio | | | 7.60 |
| Potential-P | mg $P_2O_5$ kg$^{-1}$ | HCl 25% | 718.66 |
| Potential-K | mg $K_2O$ kg$^{-1}$ | HCl 25% | 57.00 |
| Available P | mg $P_2O_5$ kg$^{-1}$ | Bray I | 4.85 |
| Cation exchange | | $NH_4OAc$ 1 *N* pH 7.0 | |
| Ca | cmol(+) kg$^{-1}$ | | 6.05 |
| Mg | cmol(+) kg$^{-1}$ | | 2.35 |
| K | cmol(+) kg$^{-1}$ | | 0.096 |
| Na | cmol(+) kg$^{-1}$ | | 0.23 |
| CEC | cmol(+) kg$^{-1}$ | $NH_4OAc$ 1 *N* pH 7.0 | 19.25 |
| Base saturated | % | | 45.00 |
| Acidity | | KCl 1 *N* | |
| Exch. Al | cmol(+) kg$^{-1}$ | | 0.10 |
| Exch. H | cmol(+) kg$^{-1}$ | | 0.15 |

*n = 3

PRF is the level that can produce the highest dry grain maize yield. This is achieved if the first derivative from the equation of the yield curve is equale to zero ($\delta y/\delta x = 0$). The optimum dose is the level that can provide the highest profits which is occurred when the yield curve touches the PR cost. Dry maize grain yield curve due to the addition of PR is expressed by the equation: $Y = aX^2 + bX + c$, where Y = dry maize grain yield (Mg ha$^{-1}$), X = dose of PR (kg P ha$^{-1}$), while a, b, and c are constants. Phosphate rock cost curve is expressed by the equation: L = mx, where L = cost of buying PR (Rp ha$^{-1}$), X = dose of PR (kg P ha$^{-1}$) and m = PR price (Rp 1800 kg$^{-1}$). Based on the above explanation, the maximum dose of PR fertilizer = -b/2a, while the optimum dose of the fertilizer = (mb)/2a.

## RESULTS AND DISCUSSION

### Soil Phosphorus and Acidity

Soil samples taken from Ciampea Sub-district, Bogor District had sandy clay texture, soil reaction was acid, organic C and N contents were very low, exchangeable Al and H as well as base saturation were also low. Exchangeable cations (Ca, Mg, and K), cation exchange capacities (CEC), and base saturation (BS) were low (Table 1). The variables were closely related to the rate of leaching and soil parent materials. Leaching soil nutrient (especially cations $NH_4^+$, $K^+$, $Ca^{2+}$, and $Mg^{2+}$) in Bogor was very high because of the high amount of rainfall.

Content of soil potential P (HCl 25%) was higher but soil available P (Bray I) was very low, *i.e.* each 278-36 and 1.56-2.63 mg P kg$^{-1}$, respectively. This phenomenon was closely related to soil parent material, namely the soil derived from intermediate volcanic tuff material (Lembaga Penelitian Tanah 1966). Based on these data, it was likely that P nutrient could become a limiting factor for plant growth in the tested soils. Thus, P fertilization is an important management in increasing agricultural production in the soils.

Results of analysis on PRF which was used in this experiment indicated that available and total P were 6.74% and 7.36% of P respectively, while its water content was 7.86%. Total Pb, Cd, As, and Hg were < 1.00, 10.69, 4.20, and < 0.01 mg kg$^{-1}$, respectively. Based on these variables, it met requirements to Indonesian National Standard (SNI-02-3776-2005) as a phosphate rock fertilizer, C quality (Table 2).

Application of PRF significantly increased content of soil potential P (HCl 25%) and available P (Bray I) in the tested soil (Figure 1). Soil P content gave an increase trend due to the application of PR until 40 kg P ha$^{-1}$ and it decreased when the application dose exceed this levels. These phenomena indicated that most of the added P could be adsorbed by the soil colloid because the soil had a high P adsorption. The maximum adsorptions of P at volcanic soils could achieve 5,000 mg kg$^{-1}$, much higher than at Ultisols (kaolinite soils) which was only 1,429 mg kg$^{-1}$ (Nursyamsi *et al.* 2003). Applied P fertilizer to the soil entered into the equilibrium of soluble and adsorbed P, so that the levels of both P forms increased.

Application of PRF significantly increased soil pH and reduced exchangeable Al in the tested soils. Its application until 60 kg P ha$^{-1}$ increased soil pH from 4.87 to 5.40 and reduced exchangeable Al from 0.37 to 0 cmol(+) kg$^{-1}$ (Figure 2). Phosphate rock contains a lot of apatite mineral which has a general formula $Ca_{10}(PO_4)_6(X)_2$, where X is $F^-$, $OH^-$, or $Cl^-$. Generally, mined PR is floroapatite ($F^-$ form of PR) containing 10-40% $P_2O_5$ (total-P) extracted with HCl 25% and about 35% Ca (Havlin *et al.*1999). Buried PR into acid soils will react through dissolution process to produce ions of $Ca^{2+}$, $PO_4^{2-}$, $F^-$, and $OH^-$ (He *et al*. 2005). Release of $OH^-$ into the soil solution causes the soil pH increases. Furthermore, $Ca^{2+}$ will replace Al in the adsorption complex into the soil solution and form $Al^{3+}$. Cation $Al^{3+}$ reacts with $OH^-$ to form $Al(OH)_3$ (precipitated) immediately so that soil exchangeable Al decreased (Fageria 2009).

Table 2. Properties of PR used in the field experiment.

| Properties | Unit | Extraction method | Measurement method | Value |
|---|---|---|---|---|
| Available P | % | Citric acid 2% | Spectrofotometry | 6.74 |
| Total P | % | HCl 25% | Spectrofotometry | 7.36 |
| Water content | % | - | Gravimetry | 7.86 |
| Pb | mg kg$^{-1}$ | HCl 25% | AAS | < 1.00 |
| Cd | mg kg$^{-1}$ | HCl 25% | AAS | 10.69 |
| As | mg kg$^{-1}$ | HCl 25% | AAS | 4.20 |
| Hg | mg kg$^{-1}$ | HCl 25% | AAS | < 0.01 |

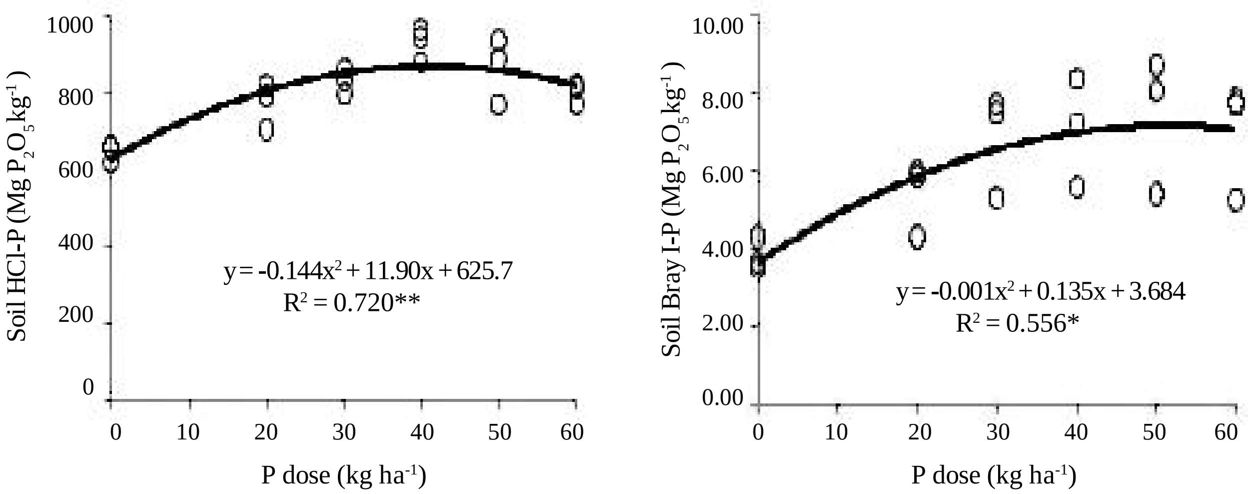



Figure 1. Effect of application of phosphate rock on soil HCl and Bray I-P after harvest at Acid Inceptisols of Ciampea, Bogor.

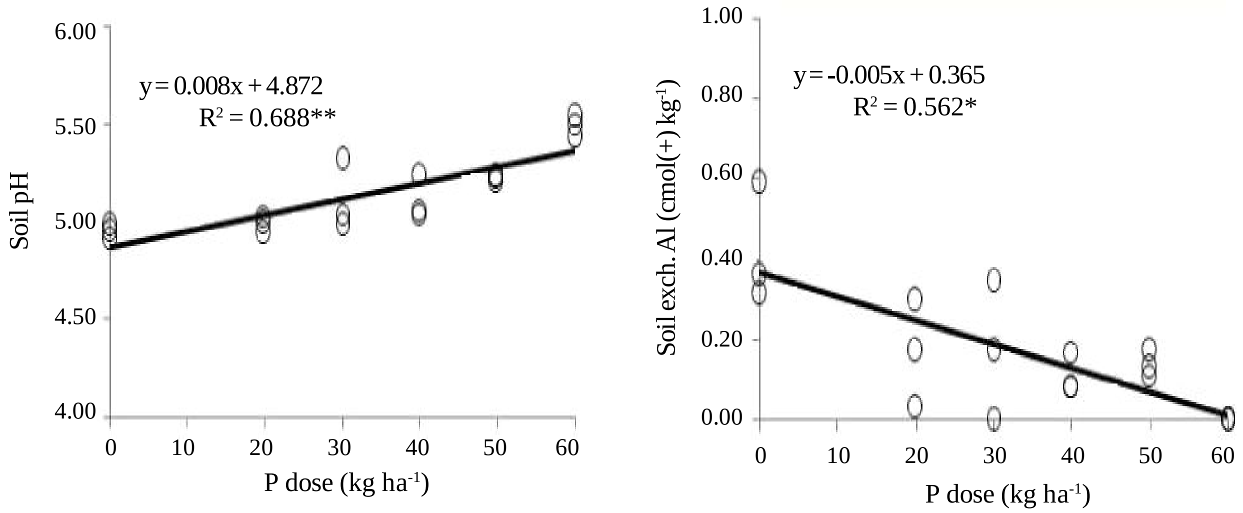



Figure 2. Effect of application of phosphate rock on soil pH and exchangeable Al after harvest at Acid Inceptisols of Ciampea, Bogor.

## Effect of Phosphate Rock on Maize Yield

Effect of application of PR on straw and grain yield is shown in Figure 3. The application of PR significantly increased dry weight of maize straw and grain (standardized weight or weight at 12 % water content). The highest dry weights of maize straw and grain were obtained at the level of PR of 40 kg P $ha^{-1}$, *i.e.*: 7.04 and 6.01 Mg $ha^{-1}$, respectively.

The tested soil contained very low available P (Bray I-P), *i.e.* only 1.56-2.63 mg P $kg^{-1}$, despite the potential P (HCl 25%-P) was quite high which was 278-336 mg P $kg^{-1}$ (Table 1). The use of P fertilizer which significantly increased crop yields indicates that the soil requires P to support optimum plant growth. Soil P was observed mostly in the form not available to the plants growth so that it still needs the addition of P to increase its availability. The

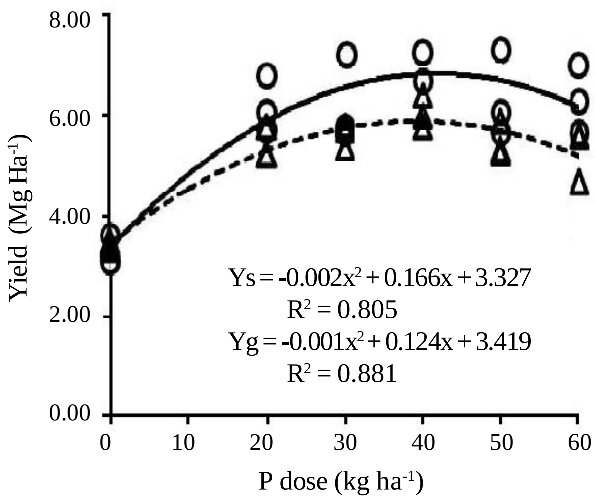



Figure 3. Effect of application of phosphate rock on straw and grain yield in Acid Inceptisols of Ciampea, Bogor. ○ = Straw and △= Grain.

results of this study was in line with Nursyamsi and Setyorini (2009) which reported that approximately 70% of soil P form in neutral and alkaline soils was in the unavailable form. Similarly, research results conducted in volcanic acid soils (Inceptisol) in Cibatok, Bogor indicated that the form of available P (Fe-P, Al-P, and Ca-P) was approximately 26%, while the remaining form approximately 74% was not available form (Nursyamsi *et al.* 2011). Applied P into the soils entered the equilibrium system of soluble P and adsorbed P forms so that both forms in the soil increased. Soluble P was absorbed by plants for its growth so that the concentration of P in solution decreased. Thus, the adsorbed P form is very important in maintaining soil P availability to plants.

Relative agronomic effectiveness (RAE) of the application of PR for maize growth in the Acid

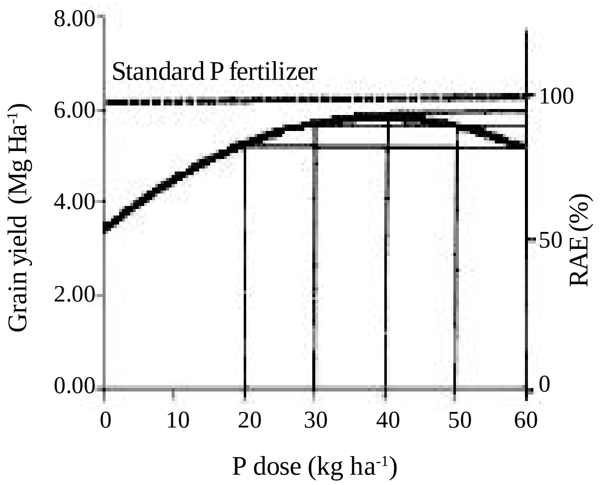
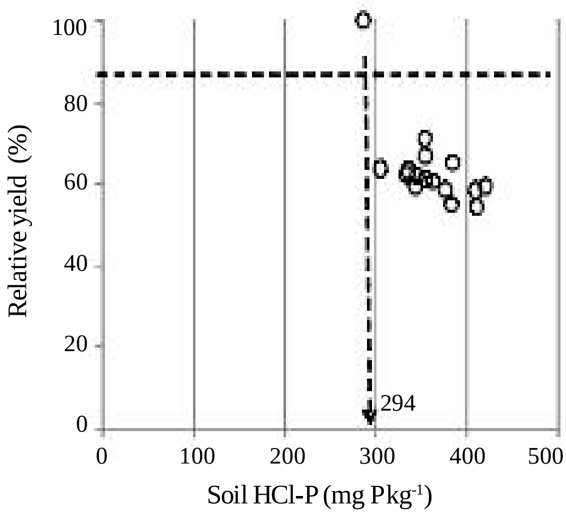



Figure 4. Relative agronomic effectiveness (RAE) on application of phosphate rock at Acid Inceptisols of Ciampea, Bogor.

Inceptisols is shown in Figure 4. It shows that the application 40 kg P $ha^{-1}$ of PR gave 95% of RAE. This means that the application of PR in the tested soil equalized to the effectiveness of the standard fertilizer (SP-36). Results of research conducted in the Acid Volcanic Soil (Inceptisol) of Cibatok, Bogor for maize also showed that the use of PR had the same effectiveness with the SP-36 (Nursyamsi 2010). Application of PR in acid soil was more effective when it was combined with arbuscular mycorrhizal fungi (AMF) (Alloush and Clark 2001) and biofertilizer such as *Acidithiobacillus* (Stamford *et al.* 2007).

## Critical Level of Soil P

Critical level of soil P was determined using the extraction methods that had a significant correlation with the plant response, *i.e.* Bray I (Nursyamsi *et al.* 2004) and HCl 25% (Nuryamsi and Fajri 2004). Using the Cate and Nelson (1971) method, the critical level of soil for maize grown in the tested soil were 294 and 2.18 mg P $kg^{-1}$ extracted with HCl 25% and Bray I, respectively (Figure 5). This means that Acid Inceptisols containing P lower than the critical level should be added P fertilizer to get the optimum maize production. Meanwhile, if soil P is higher than the critical level, then the soil should be cultivated with a maintenance dose, *i.e.* the amount dose that equivalent to P remove through harvest. The critical level of soil P depends on the extraction method. The more powerful the extractant of soil P, the higher the value of critical level. Extraction of HCl 25% was more powerful in extracting soil P than the Bray I solution (Sulaeman et al.2005). Besides that, soil-plant systems also affected the value of the critical level. The critical



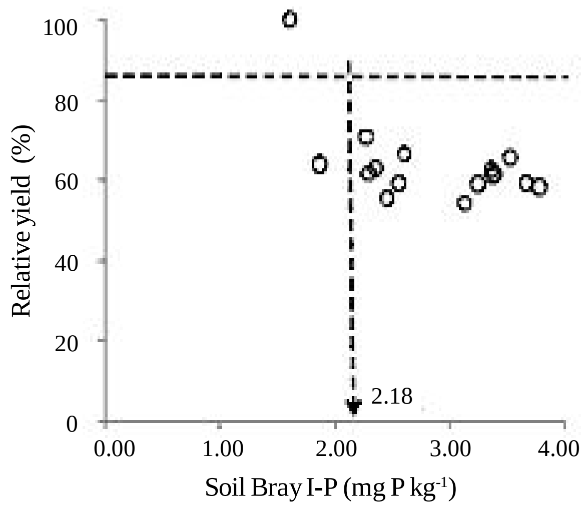




Figure 5. Critical level of soil P extracted with HCl 25% and Bray I for maize at Acid Inceptisols of Ciampea, Bogor.

levels of soil P for soybeans grown in Typic Kandiudoxs were < 3, 3-9, and > 9 mg $kg^{-1}$ P (Bray I), and < 5, 5-16, and > 16 mg $kg^{-1}$ P (Bray II) in low, medium, and high class of soil P status, respectively (Nursyamsi *et al.* 2004). In Vertisols, the critical level sfor soybeans were 196, 39, 26, and 17 mg $kg^{-1}$ P for the extraction method of HCl 25%, Colwell, Truogh, and Olsen, respectively (Nursyamsi and Fajri 2004).

**P Fertilizer Recommendations**

Financial analysis on direct application of PR in Acid Inceptisols of Ciampea, Bogor for maize is presented in Table 3. The table shows that planting maize in tested soil using PR fertilizer directly as a P nutrient source was profitable enough. The profit from maize farming for every one hectare of land in one growing season ranged between Rp505,000.00 to Rp5,997,300.00. The highest profit of Rp5,997,300.00 was achieved at the dose of PR 40 kg P $ha^{-1}$ or equivalent to 614 kg PR $ha^{-1}$.

The effect of PR on the dry grain yield of maize (left) and farmer's income (right) in Acid Inceptisols of Ciampea is presented in Figure 6. Based on these curves, several variables that must be considered in formulating fertilizer recommendations were computed and the results are presented in Table 4. The maximum dose of PRF for maize grown in the soils was 40 kg P $ha^{-1}$, while the optimum one was 38 kg P $ha^{-1}$ or equivalent to 614 and 583 kg PR $ha^{-1}$, respectively. The net gain using the optimum dose was higher than maximum dose, although the maize yield at optimum dose was lower than at maximum dose. The net gain by using the maximum and optimum doses were Rp5,573,300.0 and Rp5,625,550.0, respectively. Based on economic considerations or efficiency of production cost, PRF recommendations for maize grown in the soil was 38 kg P $ha^{-1}$ or equivalent to 583 kg PR $ha^{-1}$.

The Acid Inceptisols of Ciampea contained P nutrients 1.56 – 2.63 and 278-336 mg P $kg^{-1}$ extracted with Bray I and HCl 25%, respectively (Table 1). This soil P content was around the critical

Table 3. Analysis of farmer income on the application of phosphate rock in Acid Inceptisols of Ciampea, Bogor for maize during one season for 1 ha area.

| Phosphate rock (kg P $ha^{-1}$) | Cost (× 1,000 Rp $ha^{-1}$) Urea | KCl | Phosphate rock | Seed | Salary | Pesticide | Input | Yield (Mg $ha^{-1}$) | Output (× 1,000 Rp $ha^{-1}$) | Profit (× 1,000 Rp $ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 600 | 600 | 0 | 875 | 5100 | 800 | 7,975.0 | 3.39 | 8,480.0 | 505.0 |
| 20 | 600 | 600 | 552.6 | 875 | 5100 | 800 | 8,527.6 | 5.38 | 13.445.0 | 4,917.4 |
| 30 | 600 | 600 | 828.0 | 875 | 5100 | 800 | 8,803.0 | 5.61 | 14,020.0 | 5,217.0 |
| 40 | 600 | 600 | 1,105.2 | 875 | 5100 | 800 | 9,080.2 | 6.03 | 15,077.5 | 5,997.3 |
| 50 | 600 | 600 | 1,380.6 | 875 | 5100 | 800 | 9,355.6 | 5.46 | 13,645.0 | 4,289.4 |
| 60 | 600 | 600 | 1,656.0 | 875 | 5100 | 800 | 9,631.0 | 5.27 | 13,165.0 | 3,534.0 |

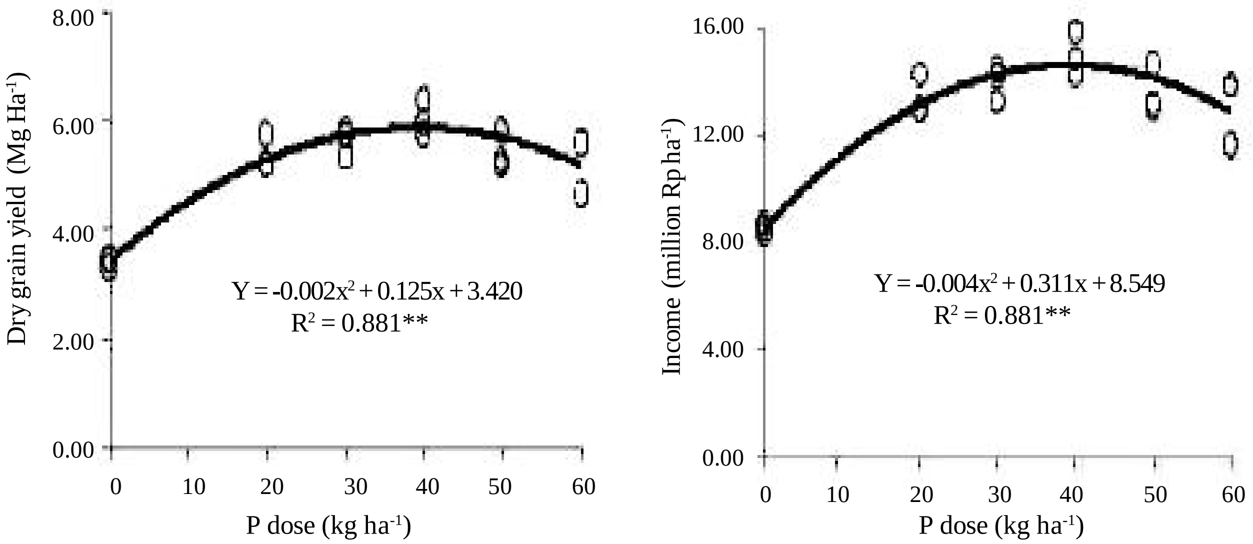



Figure 6. Relationship between the rate of phosphate rock and maize grain yield and farmer income at Acid Inceptisols of Ciampea, Bogor.

Table 4. Farmer incomes from maize grown in Acid Inceptisols of Ciampea, Bogor.

| Variable | Maximum dose | Optimum dose |
|---|---|---|
| Phosphate rock (kg P $ha^{-1}$) | 40.0 | 38.0 |
| Maize yield (kg $ha^{-1}$) | 5,861.0 | 5,860.0 |
| Gross farmer income (Rp $ha^{-1}$) | 14,653,500.0 | 14,650,490.0 |
| Cost of phosphate rock (Rp $ha^{-1}$) | 1,105,200.0 | 1,049,940.0 |
| Other cost (Rp $ha^{-1}$) | 7,975,000.0 | 7,975,000.0 |
| Net farmer income (Rp $ha^{-1}$) | 5,573,300.0 | 5,625,550.0 |

level of soil P, namely 2.18 and 294 mg P $kg^{-1}$ extracted with Bray I and HCl 25%, respectively (Figure 5). For the Acid Inceptisols which contain P higher than the critical level, the maintenance dose is recommended. Assuming the soil P nutrient that is transported by harvest equals to 2.9 kg P $ha^{-1}$ (Dierolf *et al.* 2001) and the optimum dry maize grain yield in the tested soil is 6.03 Mg $ha^{-1}$ (Figure 3), then the dose of P for maize growth maintenance is 17.5 kg P $ha^{-1}$, or equivalent to 268 kg PR $ha^{-1}$.

Plant P requirement depends on the soil P status and its behavior in the soil which is closely related to the inherent properties of the soils, such as amount and type of clay mineral and other nutrient balances of the soils. Research conducted in volcanic acid soils (Inceptisols) in Cibatok, Bogor required 68 kg P $ha^{-1}$ or equivalent to 1043 PR $ha^{-1}$ (Nursyamsi 2010). Required P fertilizer for maize grown in Ultisols of Sitiung (kaolinitic soils) ranged from 8-45 kg P $ha^{-1}$ or equivalent to 50-300 kg TSP $ha^{-1}$ (Nursyamsi *et al.* 1996).

Plant P requirement also depends on the plant species, where P-tolerant crops require P in small amounts, whereas P deficiency sensitive crops require it in a large amounts. Soybean grown in Oxisols of Lampung required about 15-60 kg P $ha^{-1}$ or equivalent to 100-400 kg SP-36 $ha^{-1}$ (Nursyamsi *et al.* 2004).

## CONCLUSIONS

Application of phosphate rock in the amount ranging from 20 to 60 kg P $ha^{-1}$ significantly increased soil HCl-P, Bray I-P, and pH, decreased soil exchangeable Al as well as increased maize straw and grain in Acid Inceptisols of Ciampea, Bogor; and application at 40 kg P $ha^{-1}$ level was equally effective as SP-36 in the tested soils. Critical level of soil P for maize grown in the soil was 294 and 2.180 mg P $kg^{-1}$ extracted with HCl 25% and Bray I, respectively. The requirement of P for maize grown in the soil to achieve maximum profit was 38 kg P $ha^{-1}$ and 17.5 kg P $ha^{-1}$ or equivalent to PR of 583 and 268 kg $ha^{-1}$ in low (soil P < critical level) and high (soil P > critical level) soil P status, respectively.

## REFFERENCES

Adiningsih JS, D Nursyamsi and S Partohardjono. 2001. Direct application of phosphate rock: Indonesia's experience and constraints of adoption at farmer level. Paper presented at the International Meeting on the Use of Phosphate Rock for Direct Application and Related Technology, Kuala Lumpur, Malaysia, July 16-20, 2001.

Alloush GA and RB Clark. 2001. Maize response to phosphate rock and arbuscular mycorryzal fungi in acidic soil. *Com Soil Sci Plant Anal* 32: 231-254.

Cate RB Jr and LA Nelson. 1971. A simple statistical procedure for partioning soil-list correlation into two classes. *Soil Sci Soc Am Proc* 35: 858-860.

Dierolf T, T Fairhurst and E Mutert. 2001. Soil Fertility Kit: A toolkit for acid, upland soil fertility management in Southeast Asia. Potash and Phosphate Institute of Canada (PPIC), Canada.

Fageria NK. 2009. The Use of Nutrients in Crop Plants. CRC Press, Taylor & Francis Group, Boca Raton, p 430.

Havlin JL, JD Beaton, SL Tisdale and WL Nelson. 1999. Soil Fertility and Fertilizers. An Introduction to Nutrient Management. Sixth Edition. Prentice Hall. Upper Saddle River, New Jersey 07458.

He ZL, H Yao, DV Calvert, PJ Stoffela, XE Yang, G Chen and GM Lloyd. 2005. Dissolution characteristics of central Florida phosphate rock in an acidic sandy soil. *Plant Soil* 273: 157-166.

Heady EO, JT Pesek and WG Brown. 1955. Crop response surfaces and economic optima in fertilizer use. *Res Buletin* 424: 293-332.

Johnson SE dan RH Loeppert. 2006. Role of organic acids in phosphate mobilization from iron oxide. *Soil Sci Soc Am J* 70: 222-234.

Kasno A. 2009a. Respon tanamam jagung terhadap fosfat pada Typic Dystrudepts. *J Trop Soils* 14: 111-118 (in Indonesian).

Kasno A. 2009b. Respon tanamam jagung hibrida terhadap fosfat alam pada tanah Inceptisol. *J Pen Pert Tan Pangan* 28: 89-94 (in Indonesian).

Kasno A and MT Sutriadi. 2011. Indonesian rock-phosphat effectivity for maize crop on Ultiosol soils. *Agrivita* 34:14-21.

Lembaga Penelitian Tanah. 1966. Peta Tanah Tinjau Propinsi Jawa Barat, Jawa Tengah, dan Jawa Timur, Skala 1:250.000. Lembaga Penelitian Tanah, Bogor (in Indonesian).

Machay AD, JK Syers and PEH Gregg. 1984. Ability of chemical extraction procedures to assess the agronomic effectiveness of phosphate rock material. *NZJ Agric Res* 27: 219-230.

Mulyani A, Hikmatullah dan H Subagyo. 2004. Karakteristik dan potensi lahan masam lahan kering di Indonesia. Buku 1: 1-32 dalam Prosiding Simposium Nasional Pendayagunaan Tanah Masam. Bandar Lampung, 29-30 September 2003. Puslittanak, Bogor (in Indonesian).

Noor A. 2003. Pengaruh Fosfat Alam dan Kombinasi Bakteri Pelarut Fosfat dengan Pupuk Kandang terhadap P Tersedia dan Pertumbuhan Kedelai pada Ultisol. *J Agron Indon* 31: 100-106 (in Indonesian).

Nursyamsi D, SM Nanan, Sutisni, dan IPG Widjaja-Adhi. 1996. Erapan P dan kebutuhan pupuk P untuk tanaman pangan pada tanah-tanah masam. *J Trop Soils* II: 55-61 (in Indonesian).).

Nursyamsi D, Gusmaini dan A Wijaya. 2003. Erapan P tanah Inceptisol, Ultisol, Oxisol, dan Andisol serta kebutuhan pupuk P untuk beberapa tanaman pangan. *Agric J I Pert* 16 (2): 103-114.

Nursyamsi D, MT Sutriadi dan U Kurnia. 2004. Metode ekstraksi dan kebutuhan pupuk P tanaman kedelai (*Glycine max* L.) pada tanah masam Typic Kandiudox di Papanrejo, Lampung. *J Tanah Iklim* 22: 15-25 (in Indonesian).

Nursyamsi D dan Nurul Fajri. 2004. Metode ekstraksi dan batas kritis hara fosfor tanah Vertisol untuk kedelai (G*lycine max*, L.). *Agric J I Pert* 17: 98-110 (in Indonesian).

Nursyamsi D dan RD Widayati. 2005. Batas kritis hara fosfor dalam tanah Inceptisol dan Ultisol untuk kedelai (*Glycine max* L.). *J Tanah Air* 6: 26-41 (in Indonesian)..

Nursyamsi D dan D Setyorini. 2009. Ketersediaan P tanah-tanah netral dan alkalin. *J Tanah Iklim* 30: 25-36 (in Indonesian).

Nursyamsi D, L Anggria and Nurjaya. 2011. Pengaruh pemberian P-alam terhadap jerapan dan bentuk-bentuk P tanah pada Inceptisol Cibatok, Bogor. *J Tanah Iklim* 34: 1-12.

Nursyamsi D. 2010. Pengaruh pemberian batuan fosfat terhadap ketersediaan P tanah dan hasil jagung pada tanah Inceptisol Cibatok, Bogor. *Agrivita* 31: 103-112 (in Indonesian).

Pusat Penelitian Tanah and Agroklimat. 2000. Atlas Sumberdaya Tanah Eksplorasi Indonesia, Skala 1 : 1.000.000. Pusat Penelitian Tanah dan Agroklimat, Badan Penelitian dan Pengembangan Pertanian, Bogor (in Indonesian).

Rajan SSS, JH Watkinson and AG Sinclair. 1996. Phosphate rocks for direct application to soils. *Adv Agron* 57: 77-159.

Rochayati S, MT Sutriadi dan A Kasno. 2009. Pemanfaatan Fosfat Alam untuk Lahan Kering Masam. *Dalam* Buku Fosfat Alam, Pemanfaatan Pupuk Fosfat Alam sebagai Sumber Pupuk P. Balai Penelitian Tanah, Balai Besar Litbang Sumberdaya Lahan Pertanian (in Indonesian).

Soil Survey Staff. 2010. Keyss to Soil Taxonomy. Eleventh Edition. 2010. United States Departemen of Agriculture, pp. 161-195..

Stamford NP, PR Santos, CES Santos, ADS Freitas, SHL Dias and MA Lira Jr. 2007. Agronomic effectiveness of biofertilizers with phosphate rock, sulphur, and *Acidithiobacillus* for yam bean grown on a Brazillian tableland acidic soil. *Biores Technol* 98: 1311-1318.

Sulaeman, Suparto, and Eviati. 2005. Petunjuk Teknis Analisis Kimia Tanah, Tanaman, Air, dan Pupuk. Balai Penelitian Tanah, Badan Penelitian dan Pengembangan Pertanian, Departemen Pertanian. Bogor (in Indonesian).

Suzette AS, Chien, HH Singh and U Hena J. 2010. Relative agonomic effectiveness of phosphate rock comapared with triple superphosphate for initial Canola, Wheat, or Ryegrass, and residual Wheat in two Acid Soils. *Soil Sci* 175: 36-43.

Zapata F and AR Zaharah. 2002. Phosphorous availability from phosphate rock and sewage sludge as influence by the addition of water soluble phosphate fertilizer. *Nutr Cycl Agroecosys* 63: 43-48.