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Influence of SP-36 and Phosphate Rock on Changes in Soil Available P, Leaf P Content, and Growth of Physic Nut (*Jatropha curcas* L.) in an Ultisol

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ABSTRACT

A study was carried out to determine the effects of rates and types of P fertilizer (SP-36 and Phosphate Rock) on the growth of physic nut (*Jatropha curcas* L.), leaf P content, and soil available P in an Ultisol in a glasshouse. The treatments consisted of four rates of P (0, 50, 100 and 150 mg P_2O_5 kg^{-1} soil) given in two different types of P fertilizer, namely SP-36 (total P_2O_5 = 36%) and Phosphate Rock (total P_2O_5 = 28%, particle size distribution = 75%<0.25 mm, 85%<0.50 mm, 90%<1.00 mm). Treatments were arranged in a Completely Randomized Design with three replications. The results showed that at the rates of 50 and 100 kg P_2O_5 ha^{-1}, there was no difference in soil available P due to the application of SP-36 and Phosphate Rock, indicating that both types of P fertilizer had the same dissolution values after 8 months of P fertilizer application. At the rate of 50 kg P_2O_5 ha^{-1}, the application of SP-36 and Phosphate Rock gave the same leaf P content. This could indicate that up to the first 8 months, the addition of the cheaper Phosphate Rock and the SP-36 to the soil had similar effectiveness. The response of tree biomass to P fertilization followed a quadratic pattern, in which for the application of Phosphate Rock, the P optimum rate was achieved at the rate which was lower than that for the application of SP-36. This suggests that the application of Phosphate Rock to physic nut trees was more efficient and effective compared to the application of SP-36.

Keywords: Leaf P, phosphate Rock, physic nut (*Jatropha curcas* L.), soil available P,

INTRODUCTION

The raw material of biodiesel from physic nut (*Jatropha curcas* L.) lately is getting a lot of attention by many countries, such as African countries, India and Brazil (Colín and Jiménez, 2009; Behera *et al*. 2010; Biswas *et al*. 2010; Balota *et al*. 2011; do Amaral *et al*. 2012). Today, in many regions of Indonesia physic nut trees have not been widely cultivated, only grown as fences of agricultural land or along the side of the road (Puslitbangbun 2006).

As one of the most important elements supporting life on earth, together with N and K, the P element (phosphate) is a vital nutrient in world agricultural production and food security systems (Vance *et al*. 2003; Radersma and Grierson 2004; Ulrich *et al*. 2009), where its function can not be replaced by another element in physiological and biochemical processes (Syers *et al*. 2008). All plants need sufficient amount of P since the beginning of growth until the age of production (Grant *et al*. 2001). Especially for grain crops, such as physic nut, P plays very important role in determining the level of crop production (Norrish and Rosser 1983; Mosali *et al*. 2006; Owolade *et al*. 2006; Zeidan 2007), so that P fertilization is a key component in maximizing physic nut beans.

Ultisol is a heavily weathered and acidic soil distributed widely in Indonesia, primarily in Sumatra, Kalimantan, Sulawesi and Irian Jaya. This soil type occupies a total area of 42.3 million ha or 22% of the entire land of Indonesia (Rochayati *et al*. 1997). Under such soil conditions, the soil available P that may be absorbed by the plant directly ($H_2PO_4^-$ or HPO_4^-) becomes to be low because the P compounds form insoluble complexes with Fe and Al elements (Anderson 1980; Crews *et al*. 1995; Wang *et al*. 2000; Prasetyo and Suriadikarta 2006; Condron and Newman 2011; Wright *et al*. 2011; Oladiran *et al*. 2012).

The increase of fuel prices forced the government to stop Triple Superphophate (TSP) production, since it required a very large subsidy. While the SP-36 as artificial fertilizer is also subsidized and the price is also quite high. Direct application of Phosphate Rock (PR) to physic nut plantations could be a more effective and efficient alternative than the use of SP-36. The use of PR to the plantations is not only expected to be cost-effective, but also environmentally friendly as it is slow released (McDowell *et al*. 2003). However, the information on direct application of PR as P fertilizer to physic nut plantations is still very limited, although the price is much cheaper than the artificial P fertilizers (TSP, DSP and SP-36). To support the development of sustainable physic nut production, it is required to find out information on technology innovation of the effectiveness and efficientcy P of fertilization. Therefore, the objectives of the present study were to determine the effect of different rates and types of P fertilizer (SP-36 and PR) on the growth of physic nut, leaf P concentration, and available P in an Ultisol soil.

MATERIALS AND METHODS

The trial was installed in a glasshouse of the Research Institute for Spice and Industrial Crops, Sukabumi, West Java. The physic nut seeds used were IP-1 P (Improved Population-1, Pakuwon) obtained from the physic nut parental seed garden in Pakuwon, Sukabumi. All seedlings used were a two-week old after germinated in the nursery, then transplanted into plastic pots (one seedling per pot) containing 10 kg of soil. The bulk sample of soil collected from Citayam Village, Bogor, taken from an area of 3 x 3 m^2 with a depth of 10 cm under bushes vegetation and cleared of branches and roots. The soil was classified as Ultisol (PPT 1983) having chemical and physical properties that can be seen in Table 1. Before it put into the pots, the soil was air-dried and passed through a 5 mm sieve. Three days before planting, all pot soils were given basal fertilizers, namely 100 kg urea ha^{-1} and 75 kg KCl ha^{-1} (Prawitasari, 2005). As the treatment, P fertilizer (0, 50, 100 and 150 mg P_2O_5 kg^{-1} soil or P_2O_5 ha^{-1}, BD = 1 t m^{-3}) was given in two different types, namely SP-36 (total P_2O_5 = 36%) and PR (total P_2O_5 = 28 %, particle size distribution = 75% <0.25 mm, 85% < 0.50 mm, 90% < 1.00 mm), which were applied into pots after finely ground, and then evenly mixed with the soil. Treatments were arranged in a CRD with 3 (three) replications. Each experimental unit consisted of 10 seedlings. Observations were made on soil available P (Bray-1 P), leaf P content, and growth of physic nut (tree height, stem diameter, leaf number, and dry matter yield).

Plant Sampling

Leaf samples were taken from the 2nd leaf from the plant shoots (Rivaie et al. 2007) in August 2007, when nearly most of plant population had begun to start flowering. The leaf samples were taken from 10 sub-samples of leaves that were put together in the same paper bag. Then, samples were dried in an oven at 70°C for 3 (three) days before being sent to the Soil and Plant Testing Laboratory of the Indonesian Centre for Agricultural Land Resources Research and Development, Bogor, for the measurement of leaf P concentrations.

Soil Sampling

Soil sampling was conducted in the same time with plant sampling (8 months after planting, August 2007). Samples were taken from the same experiment unit of plant sampling. All soil samples were air-dried and passed through a 5 mm sieve to remove debris before being sent to the Soil and Plant Testing Laboratory of the Indonesian Centre for Agricultural Land Resources Research and Development, Bogor, for the measurement of soil available P (Bray-1 P). Measurement of plant dry matter yield (biomass) was carried out after the plant and soil sampling were done by cutting the shoots approximately 1 cm above the soil surface. After the roots of all plants were washed for free of soil, and then all plant parts were dried in an oven at 70°C for 48 hours and weighed.

An analysis of variance (ANOVA) for a completely randomized design was performed. The least significant difference test at $P < 0.05$, unless otherwise stated, was used to separate the means when the ANOVA results indicated that there were significant treatment effects (Steel and Torrie 1997).

RESULTS AND DISCUSSION

Soil Plant-available P

The application of P fertilizer significantly ($p<0.0001$) increased available P concentrations

Table 1. Selected chemical and physical properties of Ultisol Jasinga Bogor (0-10cm).

Parameter	Value
pH H_2O (1 : 5)	5.1, A
pH KCl (1 : 5)	4.5
C-organic (%)	2.3, M
N-total (%)	0.32, M
P-available (mg P_2O_5 kg^{-1})	5.2, VL
K-exchangable (cmol(+) kg^{-1})	0.09, SR
Ca- exchangable (cmol(+) kg^{-1})	3.96, L
Mg- exchangable (cmol(+) kg^{-1})	1.83, M
CEC (cmol(+) kg^{-1})	14.54
Bases Saturation (%)	38
Texture – sand (%)	10.63
– silt (%)	43.77
– clay (%)	45.60

Note: A = acid, L = low, VL = very low, M = moderate (assessment based on criteria of PPT 1983).

(Bray-1 P) in an Ultisol under physic nut seedlings (Table 2). Increased rates of both forms of P fertilizer (SP-36 and PR) increased Bray-1 P concentrations in the soil (tended to be linear). This is probably due to the soil used in the study was very P deficient (Table 1) and had the pH value (5.1) lower than the upper limit of 6.0 for PR dissolution (Mackay *et al*. 1986; Bolan and Hedley 1989; White *et al*. 1989; Nying and Robinson 2006). The Bray-1 P results in the present study were in line with the findings of Lima *et al.* (2011) and Do Amaral *et al*. (2012) who tested the response of physic nut genotypes to the application of P fertilizer rates. They reported that soil available P under the plant genotypes increased with the increased of applied P fertilizer rates.

At rates of 50 and 100 kg P_2O_5 ha^{-1} there was no difference in soil available P concentration due to the application of different types of P fertilizer (SP-36 vs. PR). These results indicated that at both P rates, 8 months after the application, PR had the same P solubility with SP-36. The reason for the increased in soil available P concentration even when the relatively insoluble PR was applied at both P rates was that the soil had pH lower than the upper limit for PR dissolution as explained above. According to Khasawneh and Doll (1978), the supply of H^+ is a driving force for the dissolution of PR, along with the removal of the dissolution reaction products Ca^{2+}, $H_2PO_4^-$ and F^- from the site of dissolution. Studies had reported the increases in PR dissolution soils, from 12.5% to 60.3%, 29.3% to 83.5%, 18.2% to 78.9% for Nauru PR, North Carolina PR, and Jordan PR, respectively, when the soil pH decreased from 6.5 to 3.9 (Bolan *et al.* 1990). Whereas, the magnitude of increase in soil available P concentrations at the rate of 150 kg P_2O_5 ha^{-1} due to the application of SP-36 was higher than that of PR (Table 2). This was because of SP-36 has a higher solubility than PR (water and citric acid solubility).

Many studies reported that direct application of PR to grassland and other perennial crops that did not require a high P within a short term showed that PR had the same effectiveness with single superphosphate (SSP) or triple superphosphate (TSP) (Harrison and Hedley 1987; Bolan *et al*. 1990; Smith *et al*. 1990; Rajan *et al*. 1994; Smalberger *et al*. 2010; Nurjaya and Nursyamsi 2013). Furthermore, Kasno *et al*. (1999) who tested the effectiveness of PR on maize reported that in the first growing season, the PR had a lower effectiveness compared to SP-36. While in the second growing season, the PR had a higher effectiveness than the SP-36.

P Concentration in Leaf

Analysis of variance showed that the effect of P fertilizer was significant on leaf P concentration of physic nut (p<0.0041) (Table 2). At the rate of 50 kg P_2O_5 ha^{-1}, there was no difference in leaf P concentration with the application of different types of P fertilizer (SP-36 vs. PR). The application of PR beyond 50 kg P ha^{-1} (100 and 150 kg P_2O_5 ha^{-1}) had no significant effect on leaf P concentration. The addition of SP-36 at the rate of 150 kg P_2O_5 ha^{-1} significantly had higher leaf P concentration than that at of 50 kg P_2O_5 ha^{-1}. These results also indicate that up to the first 8 months for the low rate, the direct application of the cheaper PR fertiliser gave the same effectiveness with the application of SP-36. A study conducted by Balota *et al*. (2011), Lima *et al.* (2011), and Do Amaral *et al*. (2012) also reported there was an increase of leaf P concentrations with the increasing of P fertilizer rates.

Table 2. Effects of SP-36 and Phosphate Rock on soil available P (Bray-1 P) and leaf P concentrations of physic nut seedlings after 8 months of the P fertilizer application in an Ultisol Soil.

P Fertilizer Rate (mg P_2O_5 kg^{-1})	Soil Available P (µg P_2O_5 g^{-1})	Leaf P Concentration (%)
0	5.9 e	0.139 d
50 SP-36	11.2 d	0.165 c
100 SP-36	20.8 c	0.181 ab
150 SP-36	32.9 a	0.193 a
50 Phosphate Rock	11.7 d	0.166 c
100 Phosphate Rock	17.8 bc	0.171 bc
150 Phosphate Rock	25.5 b	0.169 bc

Note: Numbers followed by the same letters in same column are not significantly different at $p < 0.05$ by Least Significant Different's (LSD) Test.

Unlike the soil available P concentrations, the leaf P concentrations were regressed against P fertilizer rates, the regression analysis showed that the data fit best to quadratic equations (Figure 1). For the application of SP-36, it is showed that the optimum rate was achieved at the rate of 300 kg P_2O_5 ha^{-1} (R^2 = 0.93). While for the application of PR, it is showed that the optimum rate was achieved at the rate of 100 kg P_2O_5 ha^{-1} (R^2 = 0.90). The reason for the higher optimum rate of the application of SP-36 compared to the application of PR was most likely related to the solubility of SP-36 which was higher than that of PR, hence, most of the soil available P derived from SP-36 formed complex compounds with elemental Fe and Al in this P-deficient acidic Ultisol soil (Crews *et al*. 1995; Wang *et al*. 2000; Prasetyo and Suriadikarta 2006; Smalberger *et al*. 2010; Wright *et al*. 2011; Oladiran *et al*. 2012).

Many other studies have also found that the direct application of PR in Ultisol showed an equal effectiveness even more effective than the application of TSP along with a slow release of phosphate and a long residual effect (Adiningsih 1987; Kasno *et al*. 1999; Hartatik *et al*. 2004; Smalberger *et al*. 2010).

Plant Growth

Analysis of variance showed that 8 months after the application, P fertilizer significantly increased plant height and dry matter yield or biomass of physic nut on an Ultisol (p<0.0428 and p<0.0006, respectively). These results were consistent with the increase of leaf P concentration with the increase of P rates.

The results in Table 3 show that at the rate of 150 kg P_2O_5 ha^{-1}, direct application of PR had significantly higher plant dry matter yield (biomass) than that of the application of SP-36. Furthermore, at the lower P rates (50 and 100 kg P_2O_5 ha^{-1}) the application of PR tended to have greater plant height and biomass than that of SP-36. This was most likely due to the improvement of soil pH and the availability of nutrients, especially Ca originated from the dissolution of PR (Bolan and Hedley 1989; Rajan *et al*. 1996). These results are consistent with the findings of several other studies which reported that there were positive responses of physic nut biomass to the application of P fertilizer on acidic soils in the tropics (Maharani 2006; Balota *et al*. 2011; Lima *et al*. 2011; do Amaral *et al*. 2012).

As with the response of leaf P concentrations to the application of P fertilizer, in Figure 2 it can be seen that for the regression analysis of the response of plant biomass to P fertilizer addition, the data fit best also to quadratic equations. It is showed that for the application of SP-36, the optimum P rate (236 kg P_2O_5 ha^{-1}, R^2 = 0.91) was higher than that for the application of PR (164 kg P_2O_5 ha^{-1}, R^2 = 0.95). These results suggest that after 8 months direct application of PR has more effective results than the application of SP-36. This is an advantage of the direct application of PR in acid soils as

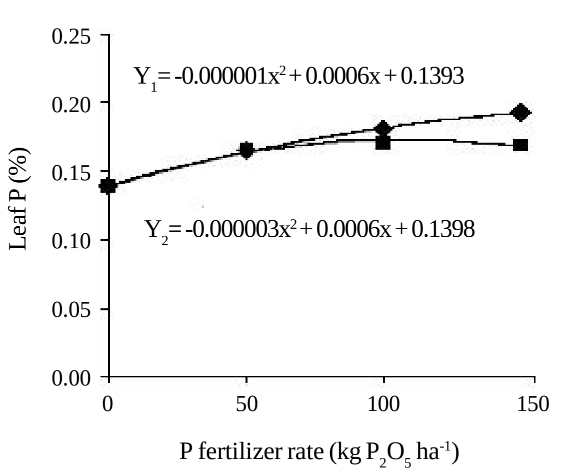

Figure 1. Relationship between P fertilizer rates and leaf P concentrations of physic nut after 8 months of the fertilizer application in an Ultisol Soil, ◆ = SP-36; ■ = PR.

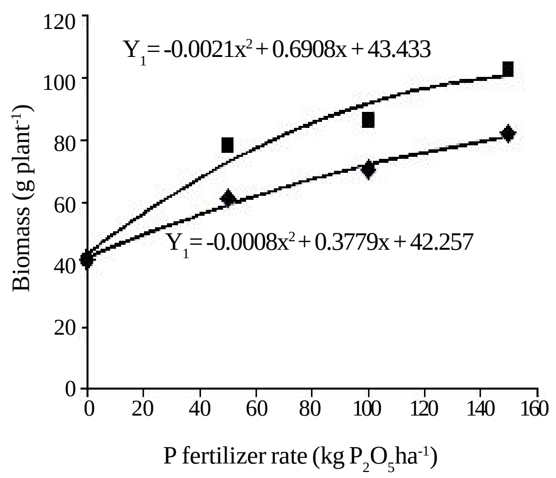

Figure 2. Relationship between P fertilizer rates and biomass of physic nut after 8 months of the P fertilizer application in an Ultisol Soil, ◆ = SP-36; ■ = PR.

Table 3. Effects of SP-36 and Phosphate Rock on growth parameters of physic nut seedlings after 8 months of the P fertilizer application in an Ultisol Soil.

P Fertilizer Rate (mg P_2O_5 kg^{-1})	Plant Height (cm)	Leaf Number	Stem Diameter (cm)	Biomass (g tan^{-1})
0	62.27 c	30.08 a	3.42 a	41.60 d
50 SP-36	69.43 bc	33.62 a	3.43 a	61.14 dc
100 SP-36	70.33 bc	28.99 a	3.47 a	62.72 c
150 SP-36	74.83 ab	36.45 a	3.39 a	81.75 abc
50 Phosphate Rock	74.00 ab	32.89 a	3.34 a	78.31 bc
100 Phosphate Rock	69.54 bc	29.87 a	3.38 a	86.38 ab
150 Phosphate Rock	81.42 a	29.54 a	3.57 a	102.43 a

Note: Numbers followed by the same letters in same column are not significantly different at $p < 0.05$ by Least Significant Different's (LSD) Test.

explained earlier (Adiningsih 1987; Bolan and Hedley 1989; Rajan *et al*. 1996; Kasno *et al*. 1999; Hartatik *et al*. 2004; Smalberger *et al*. 2010).

The role of the P element in the processes of physiology and biochemistry is a vital where its function could not replace by other elements (Ulrich *et al*. 2009; Syers *et al*. 2008), hence, especially for grain crops including physic nut, P fertilization is a key component in maximizing seeds production (Owolade *et al*. 2006; Peltonen-Sainio *et al*. 2006; Zeidan, 2007). In Indonesia, actually estate or plantation sector has been quite a long using PR as P fertilizer, among others in the plantations of oil palm, rubber and cocoa, which showed equivalent or more effective results than the use of TSP (Suwandi dan Lubis, 1990).

Therefore, like other plantation trees, the reasons that direct application of PR in physic nut plantations might be expected not only to be more efficient, but also to be more effective than the use of SP-36 is because the physic nut is a perennial plant, which generally does not require a high P nutrient in a short time (Mackay *et al*. 1980; Harrison and Hedley, 1987; Bolan *et al*. 1990; Smith *et al*. 1990; Rajan *et al.* 1994) and has intensive roots, that can help to dissolve the PR using several weak acids or organic compounds as the root exudates.

CONCLUSIONS

The application of P fertilizers had significant effects on soil plant-available P (measured by Bray-1 P), leaf P concentration, plant height and dry matter yield (biomass) of physic nut. The increase of soil available P tended to be linear with the increasing of P fertilizer rates.

At the rate of 50 kg P_2O_5 ha^{-1}, there was no difference in leaf P concentration between the direct application of PR and the application of SP-36. Whereas, at the rate of 150 kg P_2O_5 ha^{-1}, the dry matter yield for the direct application of PR was significantly higher than that for the application of SP-36. Furthermore, like the response of leaf P concentrations to the addition of P fertilizers, the response of the dry matter yield to P fertilization followed a quadratic pattern, where the optimum P rate for the application of SP-36 was also higher than that for the direct application of PR.

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