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Effect of Fast Dissolved Phosphorus Fertilizer on the Growth, Seed Product, and Phosphorus Uptake Efficiency of Soybean (*Glycine max* L.)

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ABSTRACT

The appropriate method of P fertilizer application is very important for the efficiency of P uptake and yield improvement. This research aimed to assess the growth response, seed product, and P uptake efficiency of soybean to the application of fast dissolved phosphorus fertilizer. Two consecutive potted experiments under greenhouse condition were conducted using Alfisols from Jumantono Karanganyar as planting media. The soybeans were planted and treated with six doses of P fertilizer. The treatments were designed in a completely randomized experiment with 5 replications. In the first experiment, the plants were harvested at the maximum vegetative growth for measurement of plant growth components and P uptake. In the second experiment, the plants were harvested at optimum grain maturity for seed yield and P efficiency measurements. The results showed that the application of fast dissolved-P fertilizer improved plant growth, seed yield and P uptake efficiency. Fast dissolved-P fertilizer was optimum at a dose of 100 kg/ha which was applied in a split application method at 0, 15, and 30 days after planting. However further field research is necessary to confirm the results.

INTRODUCTION

Soybean in Indonesia is a strategic commodity in addition to rice and corn. The demand for national soybean continues to increase annually, due to the increasing human population. On the other hand, soybean production in Indonesia is still low, averaging only 1.33 t/ha, while the world productivity is as high as 2.42 t/ha (Nadapdap, 2017).

National soybean production in 2018 was 982,598 tons of dry beans, and the demand was 2.3 million tons. Therefore, domestic production was only able to cover 43% of national needs. Imports were pursued to fulfil the requirements of national demand. According to data from the Central Bureau of Statistics, Indonesia imported 2,585,809.1 tons of dry soybeans in 2018, most of which came from the United States with 2,520,253.2 tons of dry beans (Badan Pusat Statistik, 2020).

The increasing consumption of soybean requires efforts to increase production and expand the planting area, including the use of marginal, less productive land. Marginal lands with great potential in Indonesia are acid soils with high Fe and Al content (Triadiati et al., 2013) including Alfisols and Oxisols. However, marginal land use has many obstacles, and cultivation technology in Indonesia is dominated by application in productive land (Barus, 2013).

The use of synthetic fertilizers, including P fertilizer, in plant cultivation practices, cannot be avoided. It has been nearly impossible recently for farmers to grow crops without using synthetic fertilizers. Consequently, the consumption of mineral phosphorus fertilizers for cropland has tremendously increased globally. P fertilizer consumption which totaled 4.6 million tons in 1961, increased to as high as 21 million tons in 2015 and has taken part in the success of global food security. Moreover, the need for P fertilizer in the

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year 2050 is estimated as high as 26 – 39 million tons/year for cropland and grassland (Mogollón et al., 2018). This will also result in a corresponding increase in the demand for P fertilizers in Indonesia. The use of P fertilizers in 2014 was 798.816 tons/year, and increased until 819,195 tons/year in 2019 (Asosiasi Produsen Pupuk Indonesia, 2021). This increase was mostly due to an average increase in the dosage per area of cultivated land.

Unfortunately, phosphatic fertilizers have low uptake efficiency of about 10-30% (Veneklaas et al., 2012). This means that not all fertilizers applied to the soil are absorbed by plants, as much is bound by soil, forming a residual P pool, or lost through erosion and leaching to reach water bodies (Conijn et al., 2018). P leaching can be worsened by the depletion of soil humus due to P-induced changes in the microbial community that alter CO_2 cycle rate (Wakelin et al., 2017). P that is not absorbed by plants can also be fixed by FeOH, AlOH, $^{-}CO_3$, and phyllosilicate or fixed to organic compounds.

As the uptake efficiency of P fertilizer is low, its application in excessive doses should not be carried out. This practice is not only wasteful, but the remaining quantity not absorbed by plants also will pollute the soil ecosystem (Guo et al., 2019). The use of P fertilizer leaves a Cd residue in the soil which can be absorbed by plants. Cd which has high solubility and toxicity (Meng et al., 2019) is obtained from the phosphatic rock in the process of fertilizer manufacture.

The efficiency of P fertilization in various crops has been studied by several researchers. Volf & Rosolem (2021) studied the use of Triple Super Phosphate (TSP) and Super Phosphate (SP) coated with humic acid to control nutrient release and it was observed that there was no significant increase of P use efficiency on both P-fertilizers. Devi et al. (2012) observed the efficiency of P fertilization on soybean by applying different sources of P fertilizer. They discovered that the use of Single Super Phosphate (SSP) plus P solubilizing bacteria had a more pronounced effect compared to the other source of P, Di-ammonium phosphate (DAP), P-solubilizing bacteria (PSB) and DAP+PSB. Furthermore, Dalshad et al. (2013) studied the efficiency of P fertilization on three soybean cultivars.(Nebiyu et al., 2016) Nebiyu et al. (2016) observed the efficiency of P fertilization cultivars of faba bean under low input agro-ecosystem, while Daoui et al. (2012) studied faba bean under rainfed condition.

Efforts to increase the efficiency of P use have been developed through the slow-release P fertilizer approach. With this approach, it is expected that the physical relationship between P ions and soil reactive components will be limited. The longer the soil colloid reacts with P anion or forms a precipitated compound, the more stable the P-soil colloid bond (Barrow, 2015). Therefore, the use of slow-release P can minimize P bond by soil colloids and may better provide adequate P whenever plants require them.

Improving the efficiency of P fertilization can also be conducted by using foliar fertilizers (Ali et al., 2014; Rafiullah et al., 2020). Rafiullah et al. (2020) compared the foliar application and soil application methods. The soil application consisted of several doses that were applied by broadcasting and banding. It was observed that foliar application of P was able to improve P use efficiency and lowered the plant dependence on soil P. Furthermore, P use efficiency in maize and wheat decreased with increasing P content in the soil. This showed that plant response to foliar fertilizers was more significant under P deficiency. Similar results were discovered by Ali et al. (2014) which noted that the response of plants to the application of P foliar fertilizer will appear when the plant contained P as low as 0.3%.

The principle of P fertilization efficiency is signified by a synchronization between the plants need and the time of P supply. This condition can be obtained by the application of fast soluble P fertilizer according to the phase of plant growth. However, there are no research on the use of fast dissolved fertilizer on soybean. This research was carried out to assess the growth, seed yield and P uptake efficiency of soybean under the treatments of fast-dissolved-P (FDP) fertilizer.

MATERIALS AND METHODS

This research was conducted in a glasshouse of the Faculty of Agriculture, Universitas Sebelas Maret, Surakarta from March until September 2020, and consisted of two green-house experiments. The first experiment was conducted using a completely randomized design in five replications. A total of 30 potted Alfisols, 15 kg/pot, were prepared and administered with P fertilizations as follows: P_0 = 0 kg/ha Super Phosphate (SP); P_1 = 150 kg/ha SP administered on planting day as basalt fertilizer; P_2

= 150 kg/ha of Fast Dissolve Phosphorus (FDP) administered twice, each half dose given at planting day and 15 days after planting (DAP); P_3 = 100 kg/ha FDP administered twice, each half dose given at planting day and 15 DAP; P_4 = 75 kg/ha FDP administered twice, each half dose given at planting day and 15 DAP; P_5 = 50 kg/ha FDP administered twice, each half dose given at planting day and 15 DAP. The FDP fertilizer used in this research was SP36 fertilizer that its solubility was accelerated by reducing its grain size and pulverizing into powder.

Before soybean seeds, Grobogan variety, were sown in each pot, all soil in the pots were added with Nitrogen as urea and Potassium as KCl, at the rate of 175 and 200 kg/ha, respectively. The plants were harvested at the vegetative phase to measure plant height, shoot and root dry weight, and P uptake. Furthermore, soil analysis was performed to measure soil pH (H_2O, electrometric method) and available P (Bray II). Statistical analysis was conducted using ANOVA followed by mean comparison using Tukey test (5% HSD).

The second experiment was carried out in the same way as the first, except that the application of FDP at the treatments of P2, P3, P4 and P5 were performed in three split applications, each one-third dosage given at 0, 15 and 30 DAP. Soybean was harvested at the maturity phase for measurements of grain weight, the efficiency of P uptake, physiological and agronomic efficiency of P. Statistical analysis was conducted as described in the first experiment, and P efficiency was calculated using the following Mengel & Kirkby, (2001) formulas (1-3).

$$\text{P uptake efficiency} = \frac{(\text{P uptake } \textit{fertilized crops} - \text{P uptake } \textit{control treatment})}{\text{P applied}} x\ 100\% \quad \text{.....1}$$

$$\text{Physiological Efficiency of P} = \frac{(\text{Crop yield } \textit{fertilized crops} - \text{Crop yield } \textit{control treatment})}{(\text{P uptake } \textit{fertilized crops} - \text{P uptake } \textit{control treatment})} \text{ g/g} \quad \text{.....2}$$

$$\text{Agronomic Efficiency of P} = \frac{(\text{Crop yield } \textit{fertilized crops} - \text{Crop yield } \textit{control treatment})}{(\text{P applied})} \text{ g/g} \quad \text{.....3}$$

RESULTS AND DISCUSSION

Plant Growth on Application of FDP fertilizer

The data on the vegetative growth of soybean and P uptake are presented in Table 1. This research showed that the application of P fertilizers significantly influenced the shoot and root dry weigh and plant height. Furthermore, the plant height increased significantly with the application of P fertilizers, both super phosphate SP and FDP fertilizers. This research showed that the lower dose of FDP was able to produce a plant height equal to that of plants in the SP treatment. The plant height at a treatment of 75 kg/ha was not significantly different from that treated by 150 kg/ha SP with the values of 48.00 cm and 48.31 cm respectively.

Table 1. Plant growth and P uptake at the end of the vegetative phase

Treatments	Plant height (cm)	Shoot and root dry weight (g)	P uptake (mg/plant)	Soil Available-P (mg/kg)
P_0 = 0 kg/ha SP36	32.10a***	0.57a	1.65a	3.11a
P_1 = 150 kg/ha SP36*	48.31bc	1.12c	3.34c	7.02c
P_2 = 150 kg/ha FDP**	51.17c	1.23c	3.68c	9.27e
P_3 = 100 kg/ha FDP**	50.10c	1.17c	3.39c	8.19 de
P_4 = 75 kg/ha FDP**	48.00bc	0.93bc	2.42b	7.16 cd
P_5 = 50 kg/ha FDP**	42.11b	0.87ab	2.11ab	6.15 bc

Remarks: *) given at planting day; **) given twice at 0 and 15 DAP; ***) Mean values within the same column followed by the same letters are not significantly different at $p < 0.05$ according to HSD

A similar result was also observed in the shoot and root dry weight. The treatment of a lower dose of FDP was able to produce shoot and root which was equal to that of SP treatment. The use of 75 kg/ha FDP fertilizer successfully produced shoot and root dry weight of 0.93 g which was not significantly different from that of the SP treatment (1.12 g). These results showed that there was a positive response in the growth of soybean to the use of FDP fertilizer. Soybean plants at the use of 75 kg/ha FDP, half the dose of SP fertilizer, showed the same growth response when using SP fertilizer at a full dose, 150 kg/ha. This indicated that the use of FDP fertilizer produces an efficiency of P fertilizer by 50%. This agrees with Lamptey et al., (2014) who reported that P fertilizer sources and the application rates significantly influence the growth of soybean. Furthermore, this shows the significant role of soil soluble P in increasing plant growth. Plant growth is increased in the presence of the P nutrient because P is responsible for cell metabolic activity, photosynthetic processes and photosynthate assimilation. As a macro essential nutrient, P is needed by living cells for several processes of energy transformation and biochemical reactions (Devi et al., 2012). Additionally, Wahid et al. (2020)thus making it immobile in soil. Inoculation of arbuscular mycorrhizal fungi (AMF observed that increasing levels of soil P increased the plant height of corn.

Alfisols that were used in this research have low levels of available P, only 3.11 ppm. The application of Superphosphate fertilizers increased the available soil P. An application of 150 kg/ha SP36 increased available P to 7.02 ppm. An equivalent increase, 7.16 ppm was achieved by giving P fertilizer in form of FDP at only half the dosage, 75 kg/ha. The highest level of available soil P, 9.27 ppm, was obtained by the treatment of FDP fertilizer at a dose of 150 kg/ha.

The growth of soybean increased when FDP fertilizer was added in the split application method, as this fertilization method was able to supply P ion to the plant when the plant needs it. The data in Table 1 showed that the available P in the soil increased when P was applied as FDP fertilizer. The increase in available P will increase the uptake by plants. Meanwhile, Singh et al. (2018) observed that the biomass of soybean was produced maximally at a leaf P content of 0.2–0.3% by weight. The data in Table 1 shows that the P uptake by soybean plants increased from 1.65 to 3.34 mg/plant when the fertilizer was applied in form of SP36 fertilizer at a dose of 150 kg/ha. The equal P uptake was achieved by the treatment of 100 kg/ha FDP fertilizer. Therefore, the results of this research showed that the use of FDP was more efficient than the use of slow-release SP.

Seed Yield of Soybean on Application of FDP Fertilizer

Seed yield of soybean under the treatments of P fertilization is presented in Table 2. Soybean plants grown without the application of P fertilizer produced seeds as low as 11.54 g/plant only; and increased up to 29.3 g/plant when they were fertilized with 150 kg/ha SP. The use of FDP increased seed yield, and the data showed that the highest seed yield was 30.19 g/plant. This yield was achieved in the FDP fertilization treatment at a dose of 100 kg/ha. The results indicated that there was a positive response of soybean to the applied P fertilizers.

Table 2. Soybean seed yield and P uptake

Treatments	Seed yield per plant (g/plant)	P uptake (mg/plant)
P_0 = 0 kg/ha SP36	11.54a**	3.76a
P_1 = 150 kg/ha SP36 given at planting	29.23c	35.1d
P_2 = 150 kg/ha FDP fertilizer*	30.14c	39.2e
P_3 = 100 kg/ha FDP fertilizer*	30.19c	34.98d
P_4 = 75 kg/ha FDP fertilizer*	23.76b	29.45c
P_5 = 50 kg/ha FDP fertilizer*	20.37b	17.88b

Remarks: *) administered three times, at 0, 15, 30 DAP; **) Mean values within the same column followed by the same letters are not significantly different at $p < 0.05$ according to Honesty Significant Difference

The improvement of seed yield was observed on soybean plants tretaed by FSD fertilizers administered in a split application. The use of FSP at a dose of 100 kg/ha produced the same seed weight as the treatment of 150 kg/ha SP. Therefore, the efficiency of P fertilization was as high as 33.33%.

The increase in seed yield was relevant to the better growth of soybean plants and was due to the increase in P uptake by plants. The research showed that P uptake by soybean increased from 3.76 mg/plant to 35.1 mg/plant when the 150 kg/ha SP was applied. P uptake in this treatment was not significantly different from the results obtained by the FDP fertilizer treatment at a dose of 100 kg/ha, which was 34.98 mg/plant. The highest P uptake, 39.2 mg/plant, was achieved by the FDP fertilizer treatment at a dose of 150 kg/ha.

The quality and quantity of soybean seeds are influenced by the availability of P nutrients in the soil. The role of phosphate in plants is particularly important because phosphate is a building block of DNA. Subsequently, the element in the fertilizers is indispensable for plant growth, especially to synthesize adenosine triphosphate (ATP) compounds, an organic compound that plays an important role in various energetic reactions in metabolic processes (Marschner, 2012). Singh et al. (2018) stated that the seed yield of soybean was maximal when P concentration of the leaf reached 0.2–0.3% by weight.

Improvement of crop yield and yield components by application of P fertilizer has been recorded earlier. Amanullah and Khan A (2015) observed that phosphorus fertilization at doses of 75 and 100 kg/ha succeeded in increasing yield and yield components of maize. Lamptey et al.(2014) observed a significant increase in soybean seed yield by the application of P fertilizers. Additionally, Rafiullah et al. (2020) concluded that increasing yields of maize and wheat with increasing soil P content showed a response to P application in the treated area and plants.

This research showed that the use of FDP produced better growth and seed yield of soybean. This was presumably because the use of fast-dissolving P fertilizer which is given gradually allows for the synchronization of P release time and the duration of plant uptake as shown in Table 2.

P Uptake Efficiency on the Application of FDP Fertilizer

The efficiencies of P fertilization observed in this research included P uptake efficiency, physiological efficiency, and agronomic efficiency. This research showed that the method of P fertilizer application significantly influenced the P uptake efficiency. The data showed that the highest P uptake efficiency, 19.03%, was observed at the application FDP at a rate of 75 kg/ha, while the application of 150 kg/ha SP fertilizer only yielded a P uptake efficiency of 11.60% (Fig. 1). The results showed a tendency that the lower the dose of fertilizer was applied, the more efficient the P uptake was. Additionally, the data showed that the application of FDP at a dose of 75 kg/ha, at only half of the full dose of SP, will increase the P uptake efficiency by 64% compared to that of the SP fertilizer treatment.

The P uptake efficiency in this research was low compared to a previous research by Veneklaas, at al.(2012) who stated that P uptake efficiency was about 10 – 30%. This signifies that from the SP fertilizer that was applied, only 11.60% was utilized by the crops, while the other 88.40% remained in the soil to be fixed by soil colloid and to precipitate, leading to low P use efficiency. However, when P was applied in FDP fertilizer, a bigger P portion of the fertilizer was taken up by the plant.

The P uptake efficiency is an important index for determining the use of applied fertilizer. The P uptake efficiency is an increment of P uptake for every amount of P addition from fertilizer Mengel & Kirkby (2001). A high P uptake efficiency means that plants absorb more P from the added P fertilizer. Two factors that most determine the efficiency of P uptake are the number of P ions dissolved from the added fertilizers and the amount of P uptake by plants. Fageria et al. (2013) observed that the amount of P uptake efficiency in the shoot and seed yields of several seasonal plants followed a pattern, from high to low, corn > upland rice > soybean > dry bean.

Ions are dissolved in the soil solution and fixed by the soil over time after P fertilizer is added to the soil Miller et al. (2011) . The dissolved-P ions experience two fates, a small portion will either be absorbed by plants, or it will form insoluble bonds that are unavailable plant uptake (Shah et al., 2013; Shen et al., 2011). Jin et al. (2011) estimated that nutrient losses with conventional fertilizers were between 30-70%, depending on the application method and soil conditions.

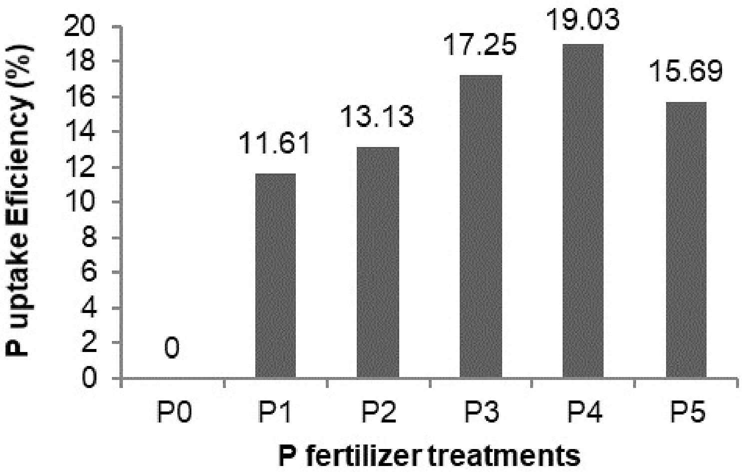

Fig. 1. P uptake efficiency of soybean on the application of FDP fertilizer

The large amount of P elements left in the soil because of not being absorbed by plants is not only wasteful but can also lead to serious environmental pollution (Azeem et al., 2014; Eghbali Babadi et al., 2015; Kuscu et al., 2014; Rashidzadeh & Olad, 2014; Zhang et al., 2011). (Meng et al., 2019) observed that the use of P fertilizer leaves a Cd residue in the soil which can be absorbed by plants. Cd originated from the phosphatic rock in the process of fertilizer manufacture also shows to have high solubility and toxicity.

The split application method of FPD fertilizer can avoid P fixation by P-binding elements, mostly Fe and Mn, and synchronize the time of P release and P absorption by plants. This method is also expected to limit the physical relationship between the P ions and soil reactive components, because the longer the anion is absorbed onto the colloidal surface or forms a compound that is precipitated, the more stable bond configuration tends to occur, and the more P will move from the surface to the uptake sites (Barrow, 2015). Therefore, the use of FDP applied several times along the growth phase was expected to minimize P fixation by soil colloids and may better provide P when the plants require them.

The availability of P at the early growth phase of the annual crop is crucial. Yan et al.(2016) observed the dynamics of P availability in soil solution during the growth phase of rice. It was observed that there was a gradual decrease in the concentration of available P as the plant grew. The concentration of soil P is still relatively high until the plants reaches 20 days old. Furthermore, a faster decrease happens at 30 days after planting.

The physiological efficiency of P is a ratio of the increase in seed weight due to P fertilization to the increase in P uptake due to P fertilization. A plant having high physiological efficiency signifies that the plant can use the uptake P to produce seeds of soybean. This research showed that the use of FDP fertilizers increased P physiological efficiency (Fig. 2). Subsequently, the application of 150 kg/ha SP36 fertilizer produced a physiological efficiency of 564.45 g of seeds per g P uptake, while the use of FDP fertilizers at the same dose produced an efficiency of 524.83 g of seeds per g of P uptake. Moreover, the lower the dose of FDP fertilizer, the higher the physiological efficiency. The results showed that the highest physiological efficiency was achieved in the FDP treatment at a dose of 50 kg/ha, which was as high as 625.35 g of seeds per g P uptake. These results showed that the increase in P uptake by soybeans was not followed by a proportional increase in grain yield.

The research showed that the agronomic efficiency was influenced by the use of FDP fertilizers (Fig. 3). The agronomic efficiency was a ratio of the increase in seeds to the weight of P added. Therefore, soybean having high agronomic efficiency signifies that the plant can produce seed maximally at every number of P added as fertilizer. The research showed that the lower doses of P applied produced a higher agronomic efficiency of P. Furthermore, the agronomic efficiency of the treatment of 50 kg/ha FDP produced as high as 98.11 g of soybean grains per g of P_2O_5 added. This is significantly higher than that of the treatment application of SP36 of 150 kg/ha, which was only 65.52 g of grains per g of P_2O_5 added. These results are in line with previous research. Cahyono & Hartati (2013) reported the effect of FDP fertilizer use on lowland rice plants. The application of 75 kg/ha FDP fertilizer (a half-recommended dose) produced rice grains as high as 7.360 kg/ha when applied in 3 times split application. This yield was slightly higher than the control treatment of 150 kg/ha of SP36 which yielded as high as 7.113 kg/ha.

Devi et al. (2012) observed that the use of P fertilizer at a dose of 60 kg/ha P_2O_5 produced a maximum agronomic efficiency of P, as indicated by the higher grain yield per unit of phosphorus applied. They also discovered that P fertilization at a dose of 40 kg/ha P_2O_5 produced the highest apparent phosphorus recovery. P fixation by the binding compound in the soil is believed to be the cause of the decrease in the agronomic and uptake efficiencies of P. Their research showed that P use efficiency increased until the use of 60 kg/ha P_2O_5 and decreased when the dose was raised.

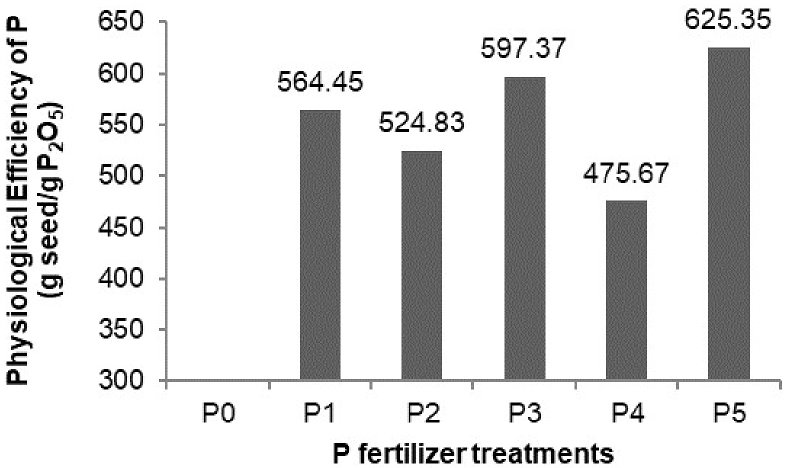

Fig. 2. Physiological efficiency of P at the treatments of P application

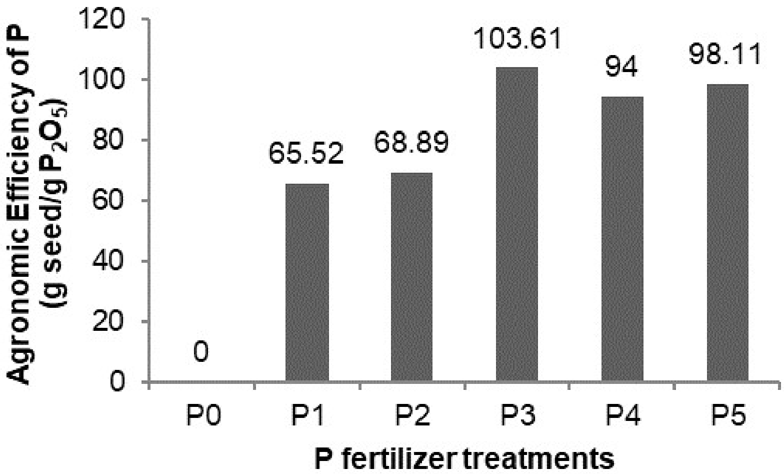

Fig. 3. Agronomic efficiency of P at the treatments of P application

To be more efficient, attention must be paid to the proper dosage, type, timing, and placement of fertilizers. More efficient fertilization can be more profitable from an economic, social, and environmental perspective (Johnston & Bruulsema, 2014). The common type of P fertilizer used by Indonesian farmers is the superphosphate fertilizer which is a slow-released P fertilizer. This type of fertilizer when applied to seasonal crops such as rice, corn, and soybeans, is not entirely taken up by the plant. Usually, the P from the fertilizers remains in the soil. Therefore, it is important to provide fast dissolved P fertilizer suitable for annual crops.

CONCLUSION

The use of FDP increased the growth, seed yield, and P efficiency of soybean in Alfisols. To produce the same soybean growth as that of the 150 kg/ha SP fertilizer treatment, the use of FDP only required half the dose, or a P use efficiency of 50%. To obtain seed yield equivalent to that of the SP treatment, the use of FDP only needed 100 kg/ha, producing efficiency of P fertilizer use of 33.33%. The P uptake efficiency in this research was low, while the use of 150 kg/ha SP only produced a P uptake efficiency of 11.60%. Furthermore, the use of FDP at a dose of 75 kg/ha produced a P uptake efficiency of 19.03 or an increase of 64% compared to the uptake efficiency of the SP fertilizer treatment. This research also showed that the lower the dose of P fertilizer, the higher the physiological and agronomic efficiency of P.

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