Improvement of phosphatic fertilization method in soybeans 
(*Glycine max* L.) cultivation

O Cahyono\(^{1,2}\) and S Minardi\(^1\)

\(^1\)Department of Soil Science, Sebelas Maret University  
Jl. Ir. Sutami 36 A, Keningan, Surakarta, 57126, Indonesia  
\(^2\)Corresponding author: ongko_c@yahoo.com

**Abstract.** The efficiency of phosphatic (P) fertilization in seasonal crops is commonly low, and most of the residual fertilizer remains in the soil. Increasing the efficiency of phosphate fertilizer is urgent to reduce its contribution to the warming climate, hence promoting climate change. Increasing the efficiency may be done by applying fast soluble phosphate (FSP) fertilizer which is applied in split application method. The research aimed to assess the growth response of soybean to the application of fast soluble P fertilizer and obtain a more efficient P fertilization method for soybean in potentially P-binding soils, Alfisol. This research was conducted using potted Alfisols of Jumapolo Karanganyar treated with several doses of slow and fast soluble P fertilizers which were arranged in a factorial design. This research concluded that FSP fertilizer in Alfisol has increased growth and P uptake of soybean. The treatment of FSP fertilizer at the dose of 100 kg ha\(^{-1}\) produced soybean biomass significantly higher than the application of slow-released Superphosphate (SP36) fertilizer at 150 kg ha\(^{-1}\). The application of FSP also increased the uptake efficiency of P fertilizer and agronomic efficiency compared to the use of SP36 fertilizer.

1. Introduction

Phosphorus (P) has numerous roles in growth and development of plants [1]; because it is an essential nutrient for plants growth which is responsible for energy transformations and biochemical reactions [2][3]. Phosphorus increases pods and improves root development of legumes [4]. The use of synthetically phosphatic fertilizers for plant cultivation has increased tremendously globally. In Indonesia, Superphosphate fertilizers' consumption was only 58,000 tons per year in 1973 but then increased to 861,614 tons per year in 2018 [5]. A significant increase in the consumption of human-made fertilizers requires increased fertilizer manufacturing plants. As a result of the increasing number of fertilizer factories, it will increase the volume of factory exhaust emissions, which in turn will cause climate change.

Despite the high level of applied doses, phosphatic fertilizers have low use efficiency because of chemical bindings in soil [6] and low availability of indigenous soil phosphorus. Sometimes there is an accumulation of insoluble phosphorus caused by the application of synthetic phosphorus fertilizers [7]. Most of the soluble part of phosphatic fertilizer that is added to the soil will go into the immobile pools via chemical bond with some cations which are dominant in the soil solution, such as aluminum (Al) and ferrum (Fe) in the low pH soils and calcium in calcareous or normal soils [8]. Due to the low efficiency of P fertilizer, which is only around 10-25 % [9] or less than 20 % [10], it is not recommended to use phosphatic fertilizers in excessive dosage. Because it would not only be wasteful, but it will also
pollute the soil environment. Moreover, in the soils which are rich in iron and manganese, the remaining P fertilizer will be fixed to form a stable occluded-P [11][12].

Concerns about unbalanced use of fertilizers leading to environmental pollution have been globally expressed. Therefore, studies on how to use efficient methods to reduce nutrient applications while increasing or maintaining crop yield, reducing nutrient losses and improving nutrient use efficiency are imperative [13]. For instance, agronomic practices could attain sustainable nutrient use efficiency, which considers the timely synchronization of nutrient application with plant roots development, slow-release fertilizers and foliar feeding [13][14]. Efficiency of fertilization depends on fertilizer characters and soil conditions such as size and type of granules, soil moisture, granular distribution, amount of fertilizer applied and phosphatic residues in the soil. The efficiency of the crops in accumulating more nutrients depends on the fertilizer forms applied. Mustafa et al [15] stated that Superphosphate is the superior source compared to the other P fertilizers in soybean. The crops are more suitable to phosphorus fertilizers that in the form of water-soluble than in other forms.

The granular size of phosphatic fertilizer determines solubility of the fertilizers. Generally, the smaller size will dissolve more quickly than the bigger ones. Previous study showed that powdered-size Superphosphate’s application increased the available soil P significantly in Entisol within a week after application compared to granular-size Superphosphate [12]. This research's objectives were to study the response of soybean to the use of FSP fertilizer and obtain more efficient P fertilization method in an Alfisol.

2. Material and methods
This study was carried out in the greenhouse of the Faculty of Agriculture, Sebelas Maret University, Surakarta, with a completely randomized design. The soil used in this research is Alfisol. Air-dried soil was sieved and put into a plastic pot as much as 15 kg per pot, and then treated with the following phosphate fertilization: 0 kg ha\(^{-1}\) Super Phosphate (SP36); 150 kg ha\(^{-1}\) Super Phosphate (SP36) given once on planting day; 150 kg ha\(^{-1}\) of powdered SP36 (FSP) given 2 times, half the dose on the day of planting (0 days after planting) and the other half dose 15 days after planting (dap); 100 kg ha\(^{-1}\) FSP given 2 times (0 and 15 days); 75 kg ha\(^{-1}\) FSP given 2 times (0 and 15 days); 50 kg ha\(^{-1}\) FSP given 2 times (0 and 15 days). All the soils in the pots were added with the same dosage of nitrogen and potassium fertilizers, 175 kg urea per hectare and 200 kg KCl per hectare [16]. One soybean seed was sown in each pot and grown until the vegetative phase.

The plants were harvested at the vegetative phase for P uptake measurements, dry shoot+root weight, while the soil was analyzed for soil pH H\(_2\)O (electrometric method) and available P (Bray II). The data were then analyzed statistically using Variance Analysis and 5% Honesty Significant Difference test (HSD). The effects of the different phosphorus efficiency treatments were calculated using the formulas as done by Mengel and Kirkby [17].

\[
\text{Apparent P Recovery (APR)} = \frac{(P_{\text{uptake}} \text{ fertilized crops} - P_{\text{uptake}} \text{ control treatment})}{P_{\text{applied}}} \times 100\% \quad (1)
\]

\[
\text{Physiological Efficiency of P (PEP)} = \frac{(\text{Crop yield fertilized crops} - \text{Crop yield control treatment}) \text{ g g}^{-1}}{(P_{\text{uptake}} \text{ fertilized crops} - P_{\text{uptake}} \text{ control treatment})} \quad (2)
\]

\[
\text{Agronomic Efficiency of P (AEP)} = \frac{\text{Crop yield fertilized crops} - \text{Crop yield control treatment}}{P_{\text{applied}}} \text{ g g}^{-1} \quad (3)
\]

3. Results and discussions
The fast soluble P (FSP) fertilizer application can accelerate the supply of available P to the plants. Our preliminary study showed that the application of 150 kg ha\(^{-1}\) FSP significantly increased the available phosphorous (P) in Entisol, but it did not increase in Alfisol and Oxisol. P element of the fertilizer applied to the Alfisol and Oxisol will be primarily fixed to form Fe-P bonds soon after application. The
study also showed that the fast soluble P fertilization in Fe rich soils (Alfisol and Oxisol) is more effective given in split application, by 2 or 3 times the application [12]. The recent study examined the soybean growth and P efficiency as the response to FSP fertilizer application. The effect of the treatments on the soil chemical properties and plant growth at the end of vegetative phase are presented in Table 1. The data in Table 1 revealed that the application of Superphosphate fertilizers, either slow or fast soluble fertilizers, had no significant effect on soil pH. This is because Superphosphate has neutral reaction in the soil [18]. P fertilizers can increase the solubility of aluminum. However, the soluble OH⁻ in the soils will react with Al⁺ to form insoluble Al(OH)₃ [19].

Table 1. Chemical properties of the soil and plant growth at the end of vegetative phase

| Treatments  | Soil after treatment | Plant at vegetative phase |
|-------------|----------------------|---------------------------|
|             | Soil pH              | Available-P (mg kg⁻¹)     | Height of plant (cm) | Dry weight of root & shoot (g) | P uptake (mg/plant) |
| P₀ = 0 kg ha⁻¹ SP36 | 5.51 a | 3.11a | 32.10 | 0.57 | 1.65 |
| P₁ = 150 kg ha⁻¹ SP36 | 5.59 a | 7.02c | 48.31 | 1.12 | 3.34 |
| P₂ = 150 kg ha⁻¹ FSP | 5.76 a | 9.27e | 51.17 | 1.23 | 3.68 |
| P₃ = 100 kg ha⁻¹ FSP | 5.68 a | 8.19 de | 50.10 | 1.17 | 3.39 |
| P₄ = 75 kg ha⁻¹ FSP | 5.58 a | 7.16 ed | 48.00 | 0.93 | 2.42 |
| P₅ = 50 kg ha⁻¹ FSP | 5.53 a | 6.15 bc | 42.11 | 0.87 | 2.11 |

This study showed that the use of FSP fertilizer increases the availability of soil P. SP36 fertilizer application at 150 kg ha⁻¹ on planting, resulting in available P levels as much as 7.02 mg kg⁻¹. P in the soil's availability will increase if the same amount of P fertilizer was given in FSP form, and even with a lower dose of 75 kg ha⁻¹ (Tabel 1). The results of this study are in accordance with the results of previous studies [12]. However, if the FSP fertilizer is applied to high P-fixing soil (Alfisol) with a full dose as basic fertilizer (given on the day of planting), it cannot increase the available soil P content. This is because Fe and Al will bind P in fertilizers. Therefore, giving FSP fertilizer should be done gradually using a split application. The greater the amount of P fertilizer added, the greater the retention. This is in accordance with the theory that the soluble P fertilizer in the soil will soon enter the immobile pool to form an insoluble compound with binding ions P [8]. In Alfisol, the binding ions are Fe and Al. The solubility of those ions has relation with soil pH. The lower the soil pH the higher P binding capacity.

The study showed that FSP fertilizers' application significantly affected the growth of soybean (plant height and dry weight of shoot and root). The height of the soybean plant at the end of the vegetative phase increases significantly with FSP fertilizer application. The use of FSP fertilizer at a dose of 100 kg ha⁻¹ increased the height of soybean plants significantly compared with Superphosphate fertilizer (SP36) at a dose of 150 kg ha⁻¹, namely from 48.31 cm to 50.10 cm. The same result was also shown at the dry weight of shoot and root. The use of FSP at a dose of 100 kg ha⁻¹ in Alfisol resulted in the weight of shoot and root of as high as 1.17 g or an increase of 50 mg compared to Superphosphate fertilizer doses of 150 kg ha⁻¹. This result is in agreement with Lamptey et al [20], who reported that fresh and dry shoot weight of soybean were affected by P fertilizer sources and the application rates. Dugje et al [21] stated that phosphorus is often the most deficient nutrients, and when an optimum level is applied, it improves the weight of shoot and grain yield. This is because the application of phosphorus influences noduleation and nitrogen fixation in beans [22].

The data in Table 1 also shows that the higher P fertilizer dose added, the higher the growth of soybean. This study proved that the increase of plant growth is influenced by the amount of soluble P in the soil because P is an essential nutrient in producing plant biomass. The soil P levels of Alfisol used in the study is very low, 3.11 mg kg⁻¹. Therefore it is unable to meet the needs of soybean. Plant growth is affected by phosphorus's solubility in the soil, because phosphorus is an essential nutrient having an
important role in several energy transformation processes and biochemical reactions [3]. Phosphorus has a significant role in plant assimilation, nitrogen binding, root development, flowering, seed formation, fruiting and crop quality [23].

The plants added with the FSP fertilizer will get more phosphorous supply, resulting in increased growth and crop yields. The results of this study proved this phenomenon. Use of FSP fertilizer increased available P (Table 1), followed by an increase in P uptake by plants. At the same dose (150 kg ha\(^{-1}\)) the uptake of P by soybean increased from 1.65 mg plant\(^{-1}\) to 3.34 mg plant\(^{-1}\). P uptake by soybean on the treatment of Superphosphate fertilizer at the dose of 150 kg per ha was equivalent to FSP fertilizer treatment at the dose of 100 kg per ha; this finding confirmed that application of FSP fertilizer is more efficient than application of slow-released Superphosphate fertilizer.

FSP treatment's effect improves P uptake efficiency, physiological efficiency of P and agronomic efficiency of P. The study showed that P uptake efficiency increased with the lower P fertilizer dose. The highest P uptake efficiency in Alfsisol was achieved by the FSP fertilizer treatment of 100 kg ha\(^{-1}\), which was as high as 22.48\%, while P uptake efficiency at the treatment of the 150 kg SP36 per hectare only as low as 17.48\%. The trend of the effects of FSP treatments on P uptake efficiency is illustrated in Figure 1.

![Figure 1. Effect of the use of FSP fertilizer on P uptake efficiency](image)

P uptake efficiency shows an increase of P absorbed by the plant for every P added as fertilizer. The higher P uptake efficiency means more P from the added fertilizer that can be absorbed by the plant. The most affecting factor to P uptake efficiency is the amount of nutrients released from the fertilizer. The more nutrients released, the higher the fertilizer efficiency. This is explained by Dobermann [24]. P uptake's efficiency is affected by the balance between the plant's needs and the amount of nutrients released from the fertilizer. P uptake efficiency is an important index in determining the use of applied fertilizer by a crop species. P uptake efficiency in literature is defined in several waysDry matter yield divided by nutrient accumulation is one way to express nutrient use efficiency in crop plants. Phosphorus use efficiency in shoot, as well as grain of several seasonal crop, followed the pattern of corn > upland rice > soybean > dry bean [25].

FSP fertilizer application was also able to improve the physiological efficiency of P. Figure 2 shows that physiological efficiency in Alfsisol increases with increasing dose of P. The highest efficiency was found in the FSP fertilizer treatment of dose of 50 kg ha\(^{-1}\) resulting in a physiological efficiency of 0.65 g of dry shoot and root per g of P\(_2\)O\(_5\). This result was higher than the physiological efficiency in Superphosphate fertilizer at doses of 150 kg ha\(^{-1}\), 0.32 g dry seed per g of P\(_2\)O\(_5\).
This study revealed that the method of P application on soybean has more significant role than the dose. P fertilizer given in the form of fast soluble fertilizers that was applied in split application method can increase the physiological efficiency of P. High physiological efficiency also indicates that the plant can convert optimally the nutrients absorbed from the fertilizer into the biomass of the plant. The study showed that the use of FSP fertilizers could also increase agronomic efficiency (Figure 3). The agronomic efficiency shows the number of plant biomass produced from every gram of P added as fertilizer. High agronomic efficiency also indicates that the plant can produce biomass efficiently from every gram of P added as fertilizer.

There was an agronomic efficiency of 3.33 g of dry shoot and root per g of P₂O₅ added and it was higher than that of the treatment of Superphosphate fertilizer at the dose of 150 kg ha⁻¹ which was only as low as 2.04 g of shoot and root per g of P₂O₅ added. This study’s results are in accordance with the results of previous research that the use of FSP fertilizer in rice can save fertilizer up to half of the recommended dose [16].

4. Conclusion
The application of fast soluble phosphatic (FSP) fertilizer in Alfisol increases growth, P uptake efficiency, physiological efficiency and agronomic efficiency of soybean. Therefore, in the future, P fertilizer, especially for seasonal crops, needs to be provided with P fertilizers that faster solubility than SP36.
References

[1] Fageria N K 2009 The Use of Nutrients in Crop Plants (Boca Raton, FL: CRC Press).
[2] Fageria N K, Baligar V C and Jones C A 1997 Growth and Mineral Nutrition of Field Crops (New York: Marcel Dekker).
[3] Devi K N, Singh L N K, Devi T N, Devi H S, Singh T B, Singh K K and Singh W M 2012 Response of Soybean [Glycine max (L.) Merrill] to Sources and Levels of Phosphorus Journal of Agricultural Science 4.
[4] Fageria N K, Baligar V C and R B Clark 2006 Physiology of Crop Production (New York: The Haworth Press).
[5] Santos O D 1996 Development of phosphorus fertilizer use on acid soils in Indoensia In: Nutrient Management for Sustainable Food Production in Asia Impnos-AARD/CSAR International Conference in Asia Bali Indonesia pp 1-12.
[6] Gaur A C 1983 A Manual of rural composting Project Field Document No. 15 (Rome: FAO).
[7] Dubey S K 1997 Co-inoculation of phosphorus bacteria with Bradyrhizobium japonicum to increase phosphate availability to rainfall soybean in Vertisol J. Indian Soc. Soil Sci. 45 506-09.
[8] Gyaneshwar P, Kumar G N, Parekh L J and Poole P S 2002 Role of soil microorganisms in improving P nutrition of plants Plant Soil 245 83-93. DOI 10.1023/A:1020663916259
[9] Hao X, Cho C M, Racz G J and Chang C 2002 Chemical retardation of phosphate diffusion in an acid soil as affected by liming Nutr. Cycl. Agroecosystems 64 213-24. DOI 10.1023/A:1021470824083
[10] Ball-Coelho B, Salcedo I H, Tiessen H and Stewart J B W 1993 Short and long-term phosphorus dynamic in a fertilized ultisol under sugarcane S.S. Am.J. 57 1027-34.
[11] De datta S K, Biswas T K and Charoenchamracheep 1990 Phosphorus requirement and management for lowland rice. In: Nutrient requirement for sustainable agriculture in Asia Oceanica. Proceedings of a Symposium IRRI, Philippine.
[12] Cahyono O 2009 Pembentukan Senyawa Occluded-P dari Sisa Pupuk Fosfat Tidak Terserap dalam Tanah Sawah Agrivita Jurnal Ilmu Pertanian 31 243-48.
[13] Oosterhuis D M and Howard D D 2008 Evaluation of slow-release nitrogen and potassium fertilizers for cotton production Afr. J. Agric. Res. 3 68-73.
[14] Matson P A, Parton W J, Power A G and Swift M J 1997 Agricultural intensification and ecosystem properties Science 277 504509.
[15] Mustafa K K, Darwesh D A and A A Luay 2004 Effect of mycorrhiza, phosphorus and urea on ammonia volatilization and soybean growth Journal Dohuk University 7 101-05.
[16] Karsidi P nd Y Haryati 2015 Pemberian Pupuk N, P dan K Berdasarkan Pengelolaan Hara Spesifik Lokasi untuk Meningkatkan Produktivitas Kedelai AGROTROP 5 1-8.
[17] Mengel K and Kirkby E A 2001 Principles of Plant Nutrition. 5th Ed. (London: Kluwer Academic Publishers).
[18] Damanik M M B, Hasibuan B E, Fauzi, Sarifuddin and Hanum H 2010 *Kesuburan Tanah dan Pemupukan* (Medan: USU-Press).

[19] Tisdale S L, Nelson W L and Beaton J D 1985 *Soil fertility and fertilizers* (New York: Macmillan Publ. Co.) p 754.

[20] Lamptey S, Ahiabor B D K, Yeboah S and Asamoah C 2014 Response of Soybean (*Glycine max*) to Rhizobial Inoculation and Phosphorus Application *Journal of Experimental Biology and Agricultural Sciences* 2 72 – 7.

[21] Dugje I Y, Omoigui L O, Ekeleme F, Kamara A Y and Ajeigbe H 2009 *Farmers’ Guide to Cowpea Production in West Africa* (Ibadan, Nigeria: a IITA) p 20.

[22] Solaiman A R M and Habibullah A K M 1990 Response of groundnut to Rhizobium rhizobium inoculation *Bangladesh Journal Soil Science* 21 42-6.

Hoque M M and Haq M F 1994 Rhizobial inoculation and fertilization of lentil in Bangladesh *Lens Newsletter* 21 29–30.

[23] Brady N C 2002 Phosphorus and potassium In: *The nature and properties of soils.* (pp. 352). Prentice – Hall of India, Delhi.

Havlin J L, Beaton J D, Tisdale S L and Nelson W L 1999 *Soil Fertility and Fertilizers An Introduction to Nutrient Management, Sixth Edition* (Upper Saddle River, New Jersey: Prentice Hall) 07458.

[24] Dobermann A 2007 *Nutrient Use efficiency – Measurement and Management* (Lincoln, USA: University of Nebraska).

[25] Fageria N K, Moreira A and dos Santos A B 2013 Phosphorus Uptake and Use Efficiency in Field Crops *Journal of Plant Nutrition* 36 2013–22.

[26] Cahyono O and Hartati S 2013 Improvement of phosphate fertilization method in wetland rice *Agrivita – Journal of Agricultural Science* 35 81-7.