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Changes in Soil Available Phosphorus, Leaf Phosphorus Content and Yield of Sword Bean (*Canavalia ensiformis* (L.) DC.) by Application of SP-36 and Phosphate Rock on Acid Upland Soil of East Lampung

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ABSTRACT

A glasshouse trial was performed to determine changes in phosphorus (P) nutrition and the yield of sword bean (*Canavalia ensiformis* (L.) DC.) following the application of different rates and types of P fertilizer in an acid upland soil of East Lampung. Two different types of P fertilizer, namely SP-36 (total P = 36%) and Phosphate Rock (PR) (total P = 24.3%, particle size distribution = 75% <0.25 mm, 85% < 0.50 mm, 90% < 1.00 mm) were used in the trial. For the treatment, each P fertilizer type consisted of four rates (0, 50, 100 and 150 mg P_2O_5 kg^{-1} soil) that were arranged in a Completely Randomized Design with four replications. The results showed that the application of P fertilizers had significant effects on soil pH, soil plant-available P, the potential-P (HCl 25%), leaf N and P concentrations, the yield of sword bean. Increased rates of both forms of P fertilizer increased the soil pH values. As the soil used had low pH and very high exchangeable Al, hence, this result is most probably related to the addition of Ca^{2+} to the soil solution that resulted from the P fertiliser applied (liming effect), either from SP-36 (monocalcium phosphate) or PR (flour apatite). There was no difference in soil available P concentration due to the different in P fertilizer types, indicating that 4 months after the fertilizer application, the relatively insoluble Phosphate Rock had the same P solubility with SP-36. Increased rates of both forms of P fertilizer increased the sword bean yield. For the application of 0 kg P_2O_5 ha^{-1}, although sword bean crops had pods, but, they did not give any seed. Whereas, at the addition of P fertilizer at the rate of 50, 100, and 150 kg P_2O_5 ha^{-1} for both P fertilizer types, the crops were able to give the seeds in the pods.

***Keywords*:** Bean yields, phosphorus concentrations, P fertilizer

INTRODUCTION

In many developing countries, protein rich foods, such as meat, milk, fish are still quite expensive, hence, many people still suffer from malnutrition. For this reason, most of food scientists are doing an effort that focusing on legumes to be developed as source of non-conventional protein (Adebowale *et al*. 2005; Adeniyi and Ehiemere 2003). Sword bean (*Canavalia ensiformis* (L.) DC.) is a family of Leguminosae commonly grown as a green manure and cover crops in soil erosion control program (Kay 1979; Smartt 1990), because it can be grown on marginal lands of arid to semi-arid climate areas that are not suitable for other legumes, such as beans and red beans (Akpapunam and Sefa-Dedeh 1997). The bean contains 23% - 34% of protein, which is equivalent to soybeans and also a source of Ca, Zn, P, Mg, Cu and Ni (Ekanayake *et al*. 2004). In addition, it can also be used as a mixture of animal feed (chicken, goats, and sheep and fish) (Dixon *et al*. 1983). To date in many regions of Indonesia only few farmers know how to cultivate this crop on acid upland soils. Moreover, information on the cultivation technology is still very limited. Therefore, through application of proper cultivation technology innovations, the productivity still has a big chance to be increased.

In general for all crops, phosphorus (P) is the second most vital plant nutrient that has important effects on photosynthesis, root development, fruiting and improvement of crop quality (Sara *et al*. 2013), especially for legumes, it plays important role in root proliferation, thus atmospheric nitrogen fixation. Singh *et al*. (2008) found that legume yield along with the nutritional quality is greatly affected by the application of P. Haru and Ethiopia (2012) suggested that in tropical soils, P deficiency is one of the most important fertility problems. However, the role of P is very important in biological nitrogen fixation as it is an energy driven process (Haru and Ethiopia 2012). Meanwhile, Bashir *et al*. (2011) stated that P plays a vital function in nodule development and growth of plant tip and root. Therefore, it is not surprising if P deficiency in legumes will not only result in poor nodulation, but also it will result in poor growth and yield (Kamara *et al*. 2010; Bekere *et al*. 2012).

Studies have shown that the effectiveness of direct application of phosphate rock (PR) in acid upland soils is similar to that of SP-36. In addition, compared to SP-36, PR is cheaper, release slower and it has the residual effect for the next few seasons (Smallberger *et al*. 2010). The quality of PR fertilizer is determined by several factors, including mineralogical properties, solubility, grain size, free carbonate content, total P_2O_5 content and type of deposit. Meanwhile, according to Rajan *et al*. (1996), the effectiveness of PR fertilizer is influenced by the chemical reactivity, particle size, soil properties, time and method of application, dose of PR, plant species and planting pattern. Actually, in Indonesia food crops on acid upland soils, a series of experiments on the direct application of PR has been conducted since 1980's. The results of the experiments suggested that the effectiveness of direct application of PR was similar or better than that of the water soluble P (TSP or SP-36) (Adiningsih *et al*. 2001; Indiati *et al*. 2002; Szilas *et al*. 200). For instance, the results of long-term research on the application of 1,000 kg ha^{-1} PR on Oxisols and Ultisols increased maize yield for five seasons between 30- 90% (Rochayati *et al*. 2009).

In Indonesia, Ultisol occupies a total area of 42.3 million ha or 22% of the entire land of the country. This type of soil is a heavily weathered and acidic soil distributed widely in Indonesia, primarily in Sumatra, Kalimantan, Sulawesi and Irian Jaya (Rochayati *et al*. 1997). In the soil, available P is low because the P compounds form insoluble complexes with Fe and Al elements (Crews *et al*. 1995; Wang *et al*. 2000; Prasetyo and Suriadikarta 2006; Wright *et al.* 2011; Oladiran *et al*. 2012). However, until now only a few studies have been conducted on the direct application of PR to sword bean on acid upland soils (Ultisol) of East Lampung. To support the development of sustainable sword bean production in the region, it is required to find out information on technology innovation of P 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 and P nutrition of sword bean on an acid upland soil of East Lampung.

MATERIALS AND METHODS

The glasshouse trial was installed at the Research Station of Assessment Institute for Agricultural Technology, Natar, South Lampung, from February up to May 2014. The sword bean seeds used were obtained from Indonesian Legumes and Tuber Crops Research Institute, East Java. Seeds were directly planted into plastic pots (three seeds per pot) containing 5 kg of soil. Two seedlings were maintained in each pot and watered regularly to maintain soil moisture at ûeld capacity. The bulk sample of soil collected from Research Station of Indonesian Soil Research Institute, Taman Bogo, East Lampung, 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 is 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 25 kg urea ha^{-1} and 75 kg KCl ha^{-1}. 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 g cm^{-3}) was given in two different types, namely SP-36 (total P = 36%) and PR (total P = 24.3%, 2% citric acid = 33.9%, 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.

Table 1. Selected chemical and physical properties of an Ultisol of Taman Bogo, East Lampung, prior to the trial (0-10 cm depth).

Parameter	Value
pH H_2O (1 : 5)	4.2, A
pH KCl (1 : 5)	3.8
C-organic (%)	13.30, VL
N-total (%)	0.80, VL
P-available (mg P_2O_5 kg^{-1})	26.2, H
K-exchangable ($cmol_{(+)}$ kg^{-1})	0.78, L
Ca-exchangable ($cmol_{(+)}$ kg^{-1})	3.04, L
Mg-exchangable ($cmol_{(+)}$ kg^{-1})	0.55, VL
CEC ($cmol_{(+)}$ kg^{-1})	7.63 L
Bases Saturation (%)	25 L
Al-exchangable ($cmol_{(+)}$ kg^{-1})	1.22 H
Texture – sand (%)	54
– silt (%)	22
– clay (%)	24
	(sandy clay loam)

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

Treatments were arranged in a Completely Randomized Design (CRD) with 4 (four) replications. Each experimental unit consisted of 8 pots. Observations were made on soil pH (H_2O 1:5), available P (Bray-1 P), potential-P (HCl 25%), leaf N and P contents (Kjeldahl), growth and yield of sword beans.

Plant sampling

Leaf samples were taken from the 2nd and 3rd leaves from the plant shoots in April 2014, when nearly most of plant population had begun to start flowering. The leaf samples were taken from 8 sub-samples of plants 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 Assessment Institute for Agricultural Technology of Lampung, Natar, Lampung Selatan for the measurement of leaf N and P concentrations.

Measurement of plant dry matter (biomass) was carried out after harvesting (May 2014) by cutting the shoots approximately 1 cm above the soil surface. After the roots of all plants were washed free of soil, and then all plant parts were dried in an oven at 70°C for 48 hours and weighed.

Soil sampling

Soil sampling was in the same time with plant sampling (3 months after planting, April 2014). Samples of the soil 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 Assessment Institute for Agricultural Technology of Lampung, Natar, South Lampung to determine soil pH, available P (Bray-1 P), potential-P (HCl 25%).

An analysis of variance (ANOVA) for a completely randomized design was performed. The Least Significant Different's (LSD) 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 *et al*. 1997).

RESULTS AND DISCUSSION

Soil pH and Available Phosphorus

The application of P fertiliser significantly ($p < 0.05$) increased soil pH. In general, increased rates of both forms of P fertilizer (SP-36 and PR) increased the soil pH values (Table 2). The soil used in the present study had low pH and very high exchangeable Al (Table 1). Therefore, it is probably related to the addition of Ca^{2+} to the soil solution that resulted from the fertiliser applied (liming effects), either SP-36 (monocalcium phosphate, $Ca(H_2PO_4)$ or PR (flour apatite, $Ca_{10}(PO_4)_6(X)_2$), except for the addition at the rate of 50 kg P_2O_5 ha^{-1}. According to Fageria (2009), in the soil Ca^{2+} will replace Al in the adsorption complex into the soil solution, and form Al^{3+}. Afterward, cation Al^{3+} will react with OH^- to form $Al(OH)_3$ that will precipitate immediately, hence, soil exchangeable Al will decrease.

A study reported that the application of PRs with low free-carbonate contents on acid soils (pH value < 5.5) had significant liming effects with significant decrease in exchangeable Al although the increase in pH is only less than 0.5 units (Chien and Friesen 2000). Another study on an Ultisol with low exchangeable Ca to assess the potential Ca value

Table 2. Effects of SP-36 and Phosphate Rock on soil pH, available P and Potential-P after 3 months of the P fertiliser application in an Ultisol of East Lampung.

P Fertiliser Rate (mg P_2O_5 kg^{-1})	Soil pH	Plant Available P (µg P_2O_5 g^{-1})	Potential-P (µg P_2O_5 g^{-1})
0	4.01 b	31.97 d	34.20 d
50 SP-36	4.30 ab	79.30 c	40.39 c
100 SP-36	4.48 a	99.93 b	44.90 b
150 SP-36	4.55 a	139.33 a	49.96 a
50 Phosphate Rock	4.64 a	78.04 c	38.28 c
100 Phosphate Rock	4.61 a	110.97 b	46.73 b
150 Phosphate Rock	4.68 a	131.02 a	52.35 a

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

of some PRs showed that medium and high reactivity PRs might be able to supply Ca for plant nutrition (Hellums *et al*. 1989).

Soil pH plays a critical role in plant growth. The effect of pH especially on plant performance and persistence (Edmeades and Ridley 2003). The availability of many essential nutrients in the soil solution is determined by the pH value. Under low pH values or acidic conditions, Mo and P are the main limiting nutrients, meanwhile, Al is the most likely nutrient to become toxic. Incorporation of lime in soils may increase pH values, thus, followed by an increase in the soil plant available P a decrease in the toxicity from Al and Mn (Wheeler and O'Connor 1998). When Al in the soil solution becomes toxic, some plant characteristics can be seen, such as overall stunting of plants, dark green leaves, and purpling of stems. Furthermore, Al toxicity will decrease water and nutrient uptake because it causes the death of leaf tips and damages to the root systems of plants by inhibiting the root cell elongation and division (Kabata-Pendias 2001; Langer *et al*. 2009).

The addition of P fertiliser significantly ($p < 0.05$) increased soil available P (Bray-1 method). Increasing rate of P fertilizer (SP-36 and PR) increased the soil available P concentrations, although the plant available P in the soil of the present study was high. For the application of both fertiliser types, at rates of 50, 100, and 150 kg P_2O_5 ha^{-1}, there was no difference in soil available P concentration (SP-36 vs. PR), indicating that 4 months after the fertiliser application, the relatively insoluble PR had the same P solubility with SP-36. This result is most likely due to the soil used in the study had the pH value (4.2) lower than the upper limit of 6.0 for PR dissolution (Bolan and Hedley 1989; White *et al*. 1989; Nying and Robinson 2006). Under such conditions, therefore, the supply of H^+ is a driving force for the PR dissolution. Other reason for this result is that the removal of the dissolution reaction products Ca^{2+}, $H_2PO_4^-$ and F^- from the site of PR dissolution is also a driving force for the PR dissolution (Khasawneh and Doll 1978).

In accordance with the results in the present study, Bolan *et al*. (1989; 1990) reported that there were increasing in PR dissolution in soils in New Zealand, from 12.5% to 60.3%, 29.3% to 83.5%, 18.2% to 78.9% for Nauru phosphate rock, North Carolina phosphate rock, and Jordan phosphate rock, respectively, when the soil pH decreased from 6.5 to 3.9. Furthermore, Nurjaya and Nursyamsi (2013) suggested that direct application of PR to perennial crops showed that PR had the same effectiveness with single superphosphate (SSP) or triple superphosphate (TSP). Whereas, Kasno *et al*. (1999), who studied the effectiveness of PR on maize, found that for the first growing season, the PR had a lower effectiveness compared to SP- 6. However, for the second growing season, PR had a higher effectiveness than SP-36.

As with the soil available P concentrations, the potential-P (HCl 25%) concentrations in the soils were influenced by the application of P fertiliser. Increasing rate of P fertilizer (SP-36 and PR) increased the soil potential P concentrations. The magnitude of increase in the potential P concentrations due to the addition of P fertiliser rates was lower than that in the plant available P concentrations for the rates of 50, 100, and 150 kg P_2O_5 ha^{-1}. However, the magnitude of increase in the potential P concentrations due to the addition of SP-36 was relatively similar to that of due to the addition of PR. This could be because of the soil used in the study had the pH value (4.2) lower than the upper limit of 6.0 for PR dissolution as explained earlier and due to the PR had high reactivity (2% citric acid soluble P was 33.9% total P), therefore, 4 months after the fertiliser application, the degree of P dissolution of the two P fertiliser types for the rates of 50, 100, and 150 kg P_2O_5 ha^{-1} was relatively similar.

Nitrogen and Phosphorus Concentrations in Leaf

The effect of P fertilizer was significant ($p < 0.05$) on leaf N concentration of sword bean. The application of SP-36 at all the rates (50, 100, 150 kg P_2O_5 ha^{-1}) had no effect on leaf N concentration. However, the addition of PR at the rate of 50, 100, 150 kg P_2O_5 ha^{-1} significantly gave higher leaf N concentration than that at the rate of 0 kg P_2O_5 ha^{-1} (Table 3). These increases in leaf N concentrations could be related to the addition of Ca^{2+} to the soil solution through the application of PR (flour apatite, $Ca_{10}(PO_4)_6(X)_2$) to the soil under sword bean crops (liming effects). The flour-apatite (PR) has 27 - 36% P_2O_5 and 40% CaO (Truong *et al*. 1978). Following the incorporation of the PR into acid soils, the dissolution of the flour apatite will result in ions of Ca^{2+}, PO_4^{2-}, F^-, and OH^- (He *et al*. 2005), followed by the increases of soil pH and the decreases of soil exchangeable Al (Fageria 2009). Legumes are particularly sensitive to low pH. In legume farm, liming by using PR is one way to increase soil pH to improve the availability of macro and micro elements required for growth of legumes and N fixation (Jordan 2011).

The application of P fertiliser had significant ($p < 0.05$) effect on leaf P concentration of sword

Table 3. Effects of SP-36 and Phosphate Rock on N and P concentrations in leaf after 3 months of the P fertiliser application in an Ultisol of East Lampung.

P Fertiliser Rate (kg P_2O_5 kg^{-1})	N Concentration (%)	P Concentration (%)
0	2.60 d	0.17 b
50 SP-36	2.63 dc	0.19 ab
100 SP-36	2.61 d	0.18 ab
150 SP-36	2.71 bcd	0.20 ab
50 Phosphate Rock	2.78 bc	0.18 ab
100 Phosphate Rock	2.84 b	0.19 ab
150 Phosphate Rock	3.05 a	0.22 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

bean. Only at the addition of PR at the rate of 150 kg P_2O_5 ha^{-1} that significantly increased leaf P concentration. This result is most likely due to the soil used in the present study had a high plant available P; therefore, there was no response in leaf P because of the addition of P fertiliser. In general, increased rates of both forms of P fertilizer (SP-36 and PR) increased the leaf P concentrations. However, there was no difference in leaf P concentration due to the application of different types of P fertilizer (SP-36 vs. PR), indicating that up to the first 3 months, direct application of PR fertiliser to the soil under sword bean had the same effectiveness with the application of SP-36. In line with this result, a study conducted by Smallberger *et al*. (2010) showed that the direct application of PR in Ultisol had an equal effectiveness even more effective than the application of TSP.

Plant Yield

As observed for the N and P concentrations in leaf, the growth and yield of sword bean were significantly ($p < 0.05$) influenced by the application of P fertiliser.

It can be seen in Table 4 that in general, at the rate beyond 50 kg P_2O_5 ha^{-1} there was no increase in plant biomass and pod weight due to the increase of P rates applied (SP-36 and PR). There was also no different in plant biomass and pod weight due to the different in P fertiliser types added (Figure 1a), indicating that the application of the PR had the same effectiveness with the application of SP-36 in acid upland soil under sword bean.

Increased rates of both forms of P fertilizer (SP-36 and PR) increased the sword bean yield. At the application of 0 kg P_2O_5 ha^{-1} (control treatment), although sword bean crops gave pods, they did not give any seed at all. Whereas, at the addition of P fertiliser at the rate of 50, 100, and 150 kg P_2O_5 ha^{-1} for both P fertiliser types, the crops were able to give the seeds in the pods. The reasons for the crops were able to produce seeds in this acid soil at the addition of P fertiliser (50, 100 and 150 kg P_2O_5 ha^{-1}) could be related to the improvement soil conditions

Table 4. Effects of SP-36 and Phosphate Rock on plant biomass, pod and seed weight after 4 months of the P fertiliser application in an Ultisol of East Lampung.

P Fertiliser Rate (kg P_2O_5 kg^{-1})	Biomass	Pod Weight	Seed Weight
		----------(g pot^{-1})--------	
0	51.34 c	11.66 b	0.00 c
50 SP-36	69.34 ab	32.00 a	6.80 bc
100 SP-36	72.00 ab	32.34 a	8.92 abc
150 SP-36	74.34 a	35.00 a	16.72 a
50 Phosphate Rock	61.66 b	31.66 a	6.20 bc
100 Phosphate Rock	71.34 ab	30.66 a	11.16 ab
150 Phosphate Rock	78.34 a	38.66 a	17.62 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

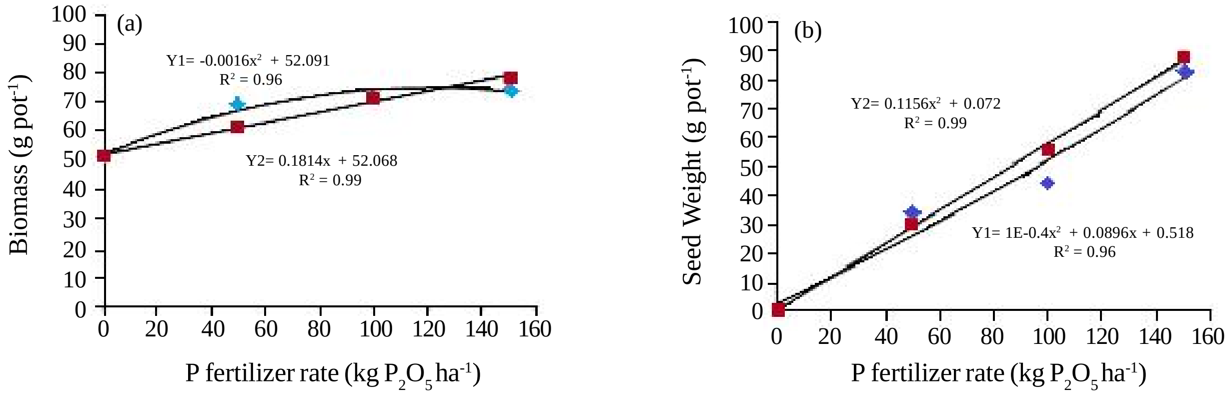

Figure 1. Relationship between P fertiliser rates and plant biomass (a) and seed weight of sword beans b) after 4 months of the fertiliser application in acid upland soil of East Lampung, ◆ : SP-36; ■: PR.

and the availability of nutrients required as explained earlier (Wheeler and O'Connor 1998; Edmeades and Ridley 2003; Jordan 2011).

The application of 150 kg P_2O_5 ha^{-1} had the highest seed weight. However, there was no different in seed weight due to the different in P fertiliser types added for the corresponding rate (Figure 1b). In accordance with the trend in plant biomass, the trend in the seed weight yield also indicated that both P fertiliser types had the same effectiveness in this acid soil under sword bean 4 months after the P fertiliser application. The results in the present study are in line with other studies suggested that the direct application of PR had the same effectiveness with SSP or TSP (Smalberger *et al.* 2010; Nurjaya and Nursyamsi 2013). A possible reason for the high dissolution of the relatively insoluble PR in the soil of the present study is that the pH value (4.2) in the soil of the present study was lower than the upper pH limit of 6.0 for PR dissolution as explained in the preceding paragraph (Hammond *et al.* 1986; Mackay *et al.* 1986; Bolan and Hedley 1989; McClellan and Kauwenbergh 1990; Chien and Menon 1995; Nying and Robinson 2006).

CONCLUSIONS

The application of P fertilisers had significant effects on soil pH, soil plant-available P, the potential-P (HCl 25%), leaf N and P concentrations, plant growth and yield of sword bean on the acid upland soil. Increased rates of both forms of P fertilizer (SP-36 and PR) increased the soil pH values. As the soil used in the present study had low pH and very high exchangeable Al, hence, it is most probably related to the addition of Ca^{2+} to the soil solution that resulted from the fertiliser applied (liming effects), either SP-36 (monocalcium phosphate) or PR (flour apatite).

Increased rates of both forms of P fertilizer (SP-36 and PR) increased the soil available P concentrations, although the plant available P in the soil of the present study was high. For the application of both fertiliser types, at rates of 50, 100, and 150 kg P_2O_5 ha^{-1}, there was no difference in soil available P concentration (SP-36 vs. PR), indicating that 4 months after the fertiliser application, the relatively insoluble PR had the same P solubility with SP-36. This result is most likely due to the soil used in the study had the pH value (4.2) lower than the upper limit of 6.0 for PR dissolution, in which H^+ is a driving force for the PR dissolution.

There was no difference in leaf P concentration due to the application of different types of P fertilizer (SP-36 vs. PR), indicating that up to the first 3 months, direct application of PR fertiliser to the soil under sword bean had the same effectiveness with the application of SP-36.

As observed in the soil available P concentrations, increased rates of both forms of P fertilizer (SP-36 and PR) increased the sword bean yield. For the application of 0 kg P_2O_5 ha^{-1} (control treatment), although sword bean crops had pods, but, they did not give any seed. Whereas, at the addition of P fertiliser at the rate of 50, 100, and 150 kg P_2O_5 ha^{-1} for both P fertiliser types, the crops were able to give the seeds in the pods. The reasons for the crops were able to produce seeds in this acid soil at the addition of P fertiliser (50, 100 and 150 kg P_2O_5 ha^{-1}) could be related to the improvement soil conditions and the availability of nutrients required.

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