Research article

Responses of Phosphorus Applications in Two Cultivars of Thailand's Dwarf Yard-Long Beans

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Abstract

Keywords

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dwarf yard-long beans

Phosphorus (P) fertilizer applications have been determined to greatly improve the growth and yield of dwarf yard-long beans. If the plants receive an insufficient amount of P, growth and yield may be reduced. We conducted a pot experiment to investigate the responses of two cultivars of dwarf yard-long beans (KKU25 and CLGC30), and the effects of the application of P fertilizer (0 and 150 kg/ha) on the growth, yield, nutrient values, P uptake and partitioning after harvesting in two soil series [Tha rua (Tr) and Ayutthaya (Ay) soil]. Our results demonstrated that the application of P fertilizer in soil with low available P (Tr soil) produced a significant difference in the yield and yield component of the plants. Pod tissue was an important source of P in the plants at maturity. The results also showed that over 40% of P was accumulated in the pod tissue. The CLGC30 variety showed higher total P uptake in plant tissue than that of the KKU25. It was also found that the application of P fertilizer gave a higher total P uptake than the control. Above-ground biomass (AB) and above-ground P content (APC) were significantly affected by cultivar with the application of P fertilizer. CLGC30 with applied P fertilizer produced higher AB and APC values than that of KKU25 without the application of P fertilizer. Consequently, the application of P fertilizer for dwarf yard-long bean production is recommended for the application of soil with low available P.

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1. Introduction

The yard-long bean is one of Thailand's most important horticultural vegetable crops as it is widely grown in all seasons and generates a high income for farmers. Improving new yard-long bean cultivars possessing higher yields is still an ultimate goal of breeders, which is also important and beneficial for farmers [1]. Dwarf yard-long beans are bred from a cross between the yard-long bean and cowpea, and they are currently gaining popularity due to several desirable traits, including disease resistance, drought tolerance, and long reproductive growth [2, 3]. Dwarf yard-long beans can be grown in different soil types and are tolerant to stressful environments. Fertilizer management remains one of the most important factors for dwarf yard-long bean production. The Department of Agricultural Extension in Thailand recommended that the formula rate of fertilizer for yard-long beans was 12-24-12 kg N-P_2O_5-K_2O at a rate of 312.5 kg/ha [4]. They further reported the necessity of phosphorus (P) in the production of dwarf yard-long beans as it generates higher growth than both nitrogen (N) and potassium (K) [4]. In legumes, such as dwarf yard-long beans, P plays an important role in nitrogen fixation. Nodule formation and nitrogen fixation activities in plants are dependent on the energy supplied by sugar. Consequently, P is essential for the formation of useful energy, which is essential for the formation and translocation of sugar in plants [5].

Dobermann and Fairhurst [6] confirmed that P represents a primary nutrient in plants involving constituents of nucleic acid, phospholipids, and adenosine triphosphate (ATP). Generally, P has many physiological roles in plants, including the promotion of tillering, root growth, photosynthesis, flowering, and seed development [7, 8]. In winter crops, P is a requisite for plant growth and cell division. When plant seedlings acquire P nutrition at an optimum rate, they grow vigorously, demonstrate better root development, and produce more grains per head, all of which result in higher grain yields [9]. In beans, P is the element used to determine critical yield, due to its involvement in growth stimulation, nodule formation, and its influence on the efficiency of the rhizobium-legume symbiosis. In addition, P is required in young cells, such as shoot and root tips, where metabolism is high and cell division is rapid [10]. Normally, plants absorb P in the form of orthophosphate ($H_2PO_4^-$ and HPO_4^{2-}), which is dependent on soil pH reaction, and orthophosphate can exist as either HPO_4^{2-} (pH >7.2) or $H_2PO_4^-$ (pH 4.0-7.2) within the normal pH range (4.0-9.0) of most soil [11]. The characteristics of the soil in each area influence the amount of available P. Acidic or calcareous soils are responsible for most of the causes of P deficiency. In tropical soil, which is acidic and contains a large amount of iron and aluminum, available P is readily precipitated as highly insoluble iron and aluminum phosphate, or adsorbed into the hydrous oxide of iron, aluminum, or manganese. When calcareous soil contains a large amount of calcium, most of the inorganic P is precipitated as calcium phosphate [12]. Consequently, the study of the responses of plants to P fertilizer when grown in various soil types was necessary, particularly in bean species with a high rate of P consumption. The objective of this study, therefore, was to investigate the effects of different cultivars and applications of P fertilizer on the growth, yield, nutritional values, P uptake, and partitioning in dwarf yard-long beans grown in two soil series in the Phra Nakhon Si Ayutthaya province of Thailand.

2. Materials and Methods

2.1 Soil samples and experiment setup

This study was conducted with two soil series with different P availabilities in Thailand's Phra Nakhon Si Ayutthaya province, from November 2020 to April 2021. The experimental soil consisted of soil with both low and high P levels; Tha Rua (Tr) soil, representing low available P

(4.58 mg/kg), and Ayutthaya (Ay) soil, characteristic of soil with high available P (26.1 mg/kg). The Tr and Ay soil types were collected from the Wang Dang sub-district, Tha Rue district (14°52' 90. 27" N, 100°67'28.60"E) and the Krachang sub-district, Bang Sai district (14°29'42.94"N, 100°49'94.25"E), respectively [13]. Surface horizon samples (0-30 cm) of both soil series were kept and analyzed for their properties, as shown in Table 1. A factorial randomized complete design (CRD) with two factors was employed. The first factor was the two cultivars of the dwarf yard-long bean: KKU25 (Department of Agronomy, Faculty of Agriculture, Khon Kaen University, Khon Kaen, Thailand); and CLGC30 (Central Laboratory and Greenhouse Complex, Faculty of Agriculture, Kamphaeng Saen, Kasetsart University, Nakhon Pathom, Thailand). The second factor was the P fertilizer application used: no P (-P) (control); and P fertilizer application (+P) at the recommended rate (150 kg P_2O_5/ha) [4]. Triple super phosphate fertilizer (0-46-0) was used as the source of P, in which the available P_2O_5 in the fertilizer was 46%. P fertilizer was applied at 100% at the basal stage. Nitrogen [N as urea (46-0-0)] and potassium [K as KCl (0-0-60)] were applied at the rate of 75-75 N-K_2O/ha. N fertilizer was administered in two split doses [50% at the seedling stage (21 days after sowing) and 50% at the flowering stage (38 days after sowing)]; whereas K was applied simultaneously with the P fertilizer. Three seeds of dwarf yard-long beans were planted in 8 kg of dry soil in plastic pots. After seven days of seed germination, excess plants were removed, resulting in a single seedling per pot. All pots were kept weed-free via the hand removal method.

2.2 Analysis of soil properties

Soil samples at the Apg horizon (0-30 cm depth) were collected and analyzed for their properties. In brief, the samples were homogenized, air-dried, ground, and passed through a 2 mm sieve size before analysis. Soil texture was analyzed via the pipette method [14]. Soil pH was determined using a portable pH meter at a 1:1 soil-to-distilled water ratio [15]. Soil electrical conductivity was determined by a conductivity meter [16]. Organic matter was measured by the Walkley and Black titration method [17]. Available P was extracted using the Bray II extractant [18] and determined through the colorimetric ascorbic acid method [19], which employed a spectrophotometer with a wavelength of 882 nm. The exchangeable potassium (K), calcium (Ca), and magnesium (Mg) were extracted with 1 M NH_4OAc at pH 7 [20]; and were detected by an atomic absorption spectrophotometer [21].

2.3 Growth and yield components

The parameters of plant growth, yield, and yield component were height, the weight of pod yield, number of pods, and the dry matter of the roots, stems, leaves, and pods. The contents of K, Fe, and Zn in the pod tissue were used as a representative of nutrient value. P concentration and P uptake in each plant part (root, stem, leaf, and pod) were also examined.

2.4 Plant analysis

The roots, stems, leaves, and pods were separately chopped and dried using a hot air oven at 70°C until constant weight was achieved. The dried samples were then digested using a mixture of nitric and perchloric acid at a ratio of 1:2 v/v [22]. The digested samples were filtered through Whatman® filter paper No. 5 and stored at 4°C in polyethylene bottles. Total P was determined by the vanado-molybdate yellow color method and measured by a spectrophotometer at a wavelength of 420 nm [23]. The P uptake of each part was calculated by multiplying dry matter and the concentration of P in the samples [24]. The amounts of K, Fe, and Zn were determined only in the pod tissue, and were measured by an atomic absorption spectrophotometer [21].

2.5 Statistical analysis

Data were determined using standard analysis of variance (ANOVA) by the SPSS software program (version 22). Differences between the means of each treatment were examined using Duncan's new multiple range test (DMRT) at a significance level of P<0.05 [25].

3. Results and Discussion

3.1 Soil characteristics

The initial properties of the two soil series used in this experiment are provided in Table 1. The Tr soil was classified as a very-fine, mixed, active, nonacid, isohyperthermic, Vertic (Aeric) Endoaquept [13]. The texture class was silty clay (152 g/kg sand, 439 g/kg silt, 409 g/kg clay), and the soil was of neutral pH (pH 6.57), non-saline (2.16 dS/m), and contained a medium of organic matter (13.6 g/kg). The available P and exchangeable K were low (4.58 and 57.2 mg/kg, respectively), while the exchangeable Ca and Mg (3,484 and 371 mg/kg, respectively) were high [26]. The Ay soil was classified as a very-fine, mixed, active, acid, isohyperthermic, Vertic Endoaquepts [13]. The texture class was clay (19 g/kg sand, 369 g/kg silt, 612 g/kg clay), and the soil was very strongly acidic (pH 4.87), contained no saline (1.99 dS/m), and had a very high level of organic matter (49.1 g/kg). In addition, the amounts of nutrients, such as available P, exchangeable K, Ca, and Mg (26.1, 120, 2,368, and 403 mg/kg, respectively), were high [26].

Table 1. Basic chemical properties of the topsoil (0-30 cm depth) at the start of the experiment

Soil property	Tha rua (Tr) soil series	Ayutthaya (Ay) soil series
Texture classes	Silty Clay	Clay
Sand (g/kg)	152	19
Silt (g/kg)	439	369
Clay (g/kg)	409	612
Soil pH reaction (1:1 H_2O)	6.57	4.87
Electrical conductivity, EC_e (dS/m)	2.16	1.99
Organic matter (g/kg)	13.6	49.1
Available phosphorus (mg/kg)	4.58	26.1
Exchangeable potassium (mg/kg)	57.2	120
Exchangeable calcium (mg/kg)	3,484	2,368
Exchangeable magnesium (mg/kg)	371	403

3.2 Growth and yields of the dwarf yard-long bean

As shown in Table 2, the application of the P fertilizer (+P) treatments produced significant differences (P<0.05) in the increases of yield and yield component, but only in the Tr soil. The number of pods and pod yield (26 pods/plant and 275 g/plant, respectively) of this treatment were higher than those of the plants grown without the benefit of P fertilizer (-P) (13 pods/plant and 131 g/plant, respectively). The cultivars of dwarf yard-long beans were shown to be significantly different (P<0.05). Within the Ay soil, KKU25 (84.5 cm) produced a higher plant height than that of CLGC30 (64.5 cm). In addition, the interaction between cultivars and P fertilizer applications was found to have a highly significant difference (P<0.01) in the number of pods and pod yield after planting in Tr soil. The A1B1 treatment showed the highest number of pods (27 pods/plant), whereas A2B1 gave the highest pod yield (282 g/plant). In the Ay soil, there was a highly significant difference (P<0.01) in plant height; however, the A1B1 and A1B2 treatments displayed similar values.

In our study, the soil with a low level of available P (Tr soil) produced greater pod numbers and pod fresh weight for dwarf yard-long beans than those in soil with a high available P level (Ay soil). This indicated that the plants responded to P fertilizer when growing in low-fertility soil. The data showed that plant growth greatly increased when phosphorus fertilizer was applied. However, there was no significant difference in yield and yield component between the cultivars of plants in both soil series (Table 2). Our findings were similar to Negasa *et al.* [27], who stated that the variety of faba bean showed no significant effect on grain yield, but the grain yield was significantly affected by different levels of P. This indicated that P plays an important role in the prescribed yields of beans. The response of P in plants is correlated with several factors. One of the most important factors is the initial level of available P in the soil. In soil with high available P (Ay soil), dwarf yard-long beans showed no response to P fertilizer. This indicates that the initial amount of available P in this soil was adequate for the growth of plants. Sukyankij *et al.* [28] assessed the efficacy of extractants for examining available P in soil and their responses in Pathum Thani 1 rice. They reported that rice plant grown in Ay soil showed no statistically different amounts of yield when receiving P fertilizer at different rates (0-62.5 kg P_2O_5/ha). In addition, Tesfaye and Balcha [29] studied the effects of P applications and varieties of common beans on grain yields and yield components. They revealed that the low yield of the common bean was partly attributed to the low phosphorus fertility of the soil.

Table 2. Responses of cultivars and application of P fertilizer to yield and yield component of dwarf yard-long bean in two soil series

Treatment	Tr soil series[1/]			Ay soil series[1/]		
	Plant high (cm)	Pod number (No./plant)	Pod fresh weight (g/plant)	Plant high (cm)	Pod number (No./plant)	Pod fresh weight (g/plant)
Cultivars of dwarf yard-long beans						
KKU25 (A1)	69.8	19	180	84.5 [a]	27	268
CLGC30 (A2)	67.0	20	227	64.5 [b]	23	254
F-test	ns	ns	ns	**	ns	ns
Phosphorus fertilizer						
+ P (B1)	68.7	26 [a]	275 [a]	75.0	27	288
- P (B2)	68.2	13 [b]	131 [b]	74.0	23	234
F-test	ns	**	**	ns	ns	ns
Interaction between cultivar and P fertilizer						
A1B1	70.0	27 [a]	268 [a]	84.3 [a]	28	304
A1B2	69.7	11 [b]	91 [c]	84.7 [a]	25	231
A2B1	67.3	25 [a]	282 [a]	65.7 [b]	26	272
A2B2	66.7	15 [b]	171 [b]	63.3 [b]	20	236
F-test	ns	**	**	**	ns	ns
CV (%)	4.2	30.6	22.2	4.9	24.0	23.5

[1/] Means within the same column followed by the same letters indicate no significant difference among treatments using DMRT.
** is a highly significant difference at 0.01 probability level and ns is no significant difference.

3.3 P partitioning and uptake in different plant parts

The partitioning of P in dwarf yard-long beans was considered in the P distribution within each tissue of the plant pod, leaf, stem, and root (Figure 1). The two cultivars of plants grown in two soil series produced similar patterns of P distribution. The greatest P distribution was observed in pod tissue, followed by the leaf, root, and stem, respectively. When comparing the plant cultivars of KKU25 and CLGC30, we found that KKU25 had greater P distribution in pod tissue than CLGC30 in both the Tr and Ay soil types. In Ay soil, the amount of P distribution in the root of CLGC30 was greater than that of KKU25 (Figure 1A). The application of P fertilizer produced P distribution patterns in each tissue that were similar in both cultivars (KKU25 and CLGC30). Over 40 % of the P distribution in the plant was displayed in the pod tissue.

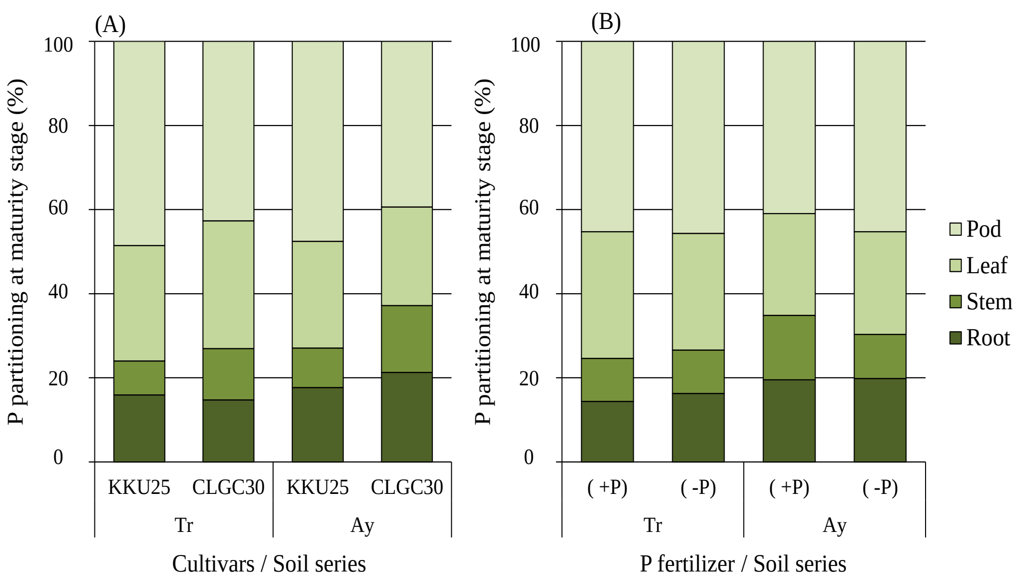

Figure 1. P partitioning of different parts of the dwarf yard-long bean grown in two soil series: A) cultivars of the dwarf yard-long bean; and B) P fertilizer application

The mean cumulative uptake of P in different plant parts was recorded at the maturity stage (Figure 2). CLGC30 grown in Ay soil generated a higher total P uptake (in the bean stem) than that of the KKU25 (Figure 2A). The application of P fertilizer produced a higher P uptake than in plants without P fertilizer application. While the greatest levels of P uptake were observed in pod tissue, the application of P fertilizer in the Ay soil series produced higher P uptake levels in pods and stems (Figure 2B). The lowest P uptake was found in the dwarf yard-long bean root tissue.

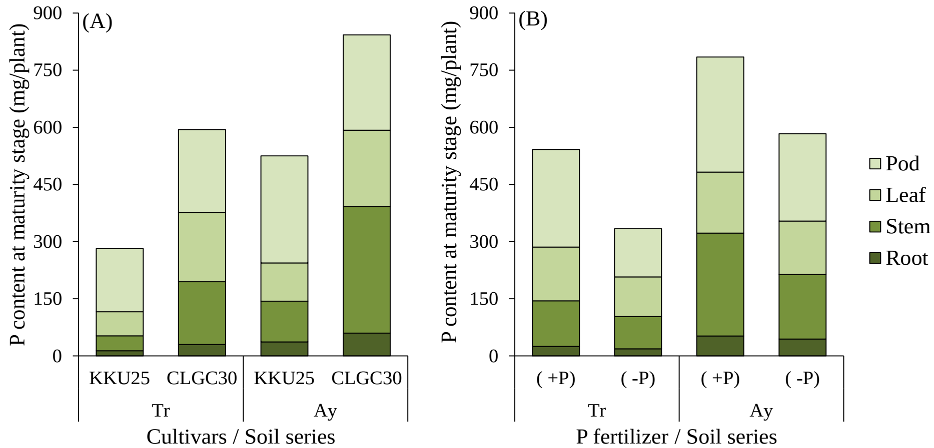

Figure 2. P content in different parts of dwarf yard-long beans grown in two soil series: A) cultivars of dwarf yard-long beans; and B) P fertilizer application

The partitioning and uptake of P were mostly observed in pod tissues (Figures 1 and 2). Mazlouzi *et al*. [30] investigated P uptake and partitioning in two durum wheat cultivars affected by varied P supplies during the grain-filling process. They established that both durum wheat cultivars had similar patterns of P distribution in each of their organs. Durum wheat lacking P nutrition was shown to have a higher P distribution than durum wheat receiving sufficient P; perhaps due to high P remobilization which is the major process for determining grain P concentration under P inadequacy [30]. Julia *et al*. [31] investigated P uptake, partitioning, and redistribution in rice during the grain-filling process in the Philippines. They reported that post-flowering, roughly 70 % of P accumulation was displayed in above-ground plants. The results indicated that the transfer of P to the grain might also follow a gradient orientated downward from the grain, meaning that an organ nearby the grain would likely receive insufficient P [31]. P is a dynamic element that can be transferred from both the phloem and xylem. Its transport within the plant organs depends on the developmental stage of plants and the amount of P in the soil. Particularly at the maturity stage, P is mainly allocated in grain [30, 32]. This indicates that at the maturity stage, all plant organs are a source of P capable of being transferred into the grain. In the study herein, over 40% of the P concentration was found in pod tissue (Figure 1). Similarly, Feng *et al*. [33] investigated P acquisition and allocation in soybean seed yields in China under P-limited conditions. They found that roughly 40 to 80% of P partitioning at the maturity stage was present in seeds and much less was present in the roots, stems, and leaves. However, the amount of P uptake was associated with the plant relative genotype [33].

3.4 Nutrient values in dwarf yard-long beans

Table 3 displays the amounts of K, Fe, and Zn in the plant samples. The nutrient values as affected by the growth factors, cultivar, and the application of P fertilizer, were not significantly different (P>0.05), except for total Fe and Zn in the treatment of P fertilizer in the Ay soil. The application of P fertilizer decreased the amount of Fe and Zn contents in the pod tissue with lower values (203 and 58.1 mg/kg of Fe and Zn, respectively) relative to treatments without P fertilizer (246 mg Fe/kg and 64.8 mg Zn/kg, respectively). The interaction between the two factors (cultivar and P fertilizer) was found to be not significantly different (P>0.05) in the contents of K, Fe, and Zn in pod tissue. The contents of K, Fe, and Zn were between 18.7-23.1 g K/kg, 188-258 mg Fe/kg, and 55.0-65.1 mg Zn/kg, respectively.

Table 3. Total K, Fe, and Zn in pod tissue of the dwarf yard-long bean grown in two soil series

Treatment	Tr soil series[1/]			Ay soil series[1/]		
	Total K (g/kg)	**Total Fe (mg/kg)**	**Total Zn (mg/kg)**	**Total K (g/kg)**	**Total Fe (mg/kg)**	**Total Zn (mg/kg)**
Cultivars of dwarf yard-long beans						
KKU25 (A1)	20.5	211	57.3	19.1	238	60.5
CLGC30 (A2)	21.1	211	58.9	21.7	211	62.4
F-test	ns	ns	ns	ns	ns	ns
Phosphorus fertilizer						
+ P (B1)	21.8	207	58.6	19.5	203 [b]	58.1 [b]
- P (B2)	19.8	215	57.6	21.3	246 [a]	64.8 [a]
F-test	ns	ns	ns	ns	*	*
Interaction between cultivar and P fertilizer						
A1B1	21.3	220	59.7	18.7	217	56.5
A1B2	19.7	202	55.0	19.5	258	64.5
A2B1	22.3	194	57.6	20.3	188	59.8
A2B2	19.9	228	60.2	23.1	234	65.1
F-test	ns	ns	ns	ns	ns	ns
CV (%)	12.3	17.6	6.8	10.8	11.6	5.5

[1/] Means within the same column followed by the same letters indicated no significant difference among treatments by using DMRT.
* is significant difference at 0.05 probability levels and ns is no significant difference.

The nutrients in dwarf yard-long beans were also shown to be not significantly different by cultivar, or by application of P fertilizer factors, particularly in the Tr soil. However, in the Ay soil, it was found that only total Fe and Zn in pods within the application of P fertilizer were significantly different (Table 3). The amounts of K, Fe, and Zn in the pods indicate the nutrient values of food plants. K is essential for the proper function of all cells, tissues, and organs in the human body. It is also crucial to heart function and plays a key role in skeletal and smooth muscle contraction, making it important for normal digestive and muscular functions [34]. Fe and Zn are constituents along with organic acids, amino acids, long-chain fatty acids, and beta-carotene in plant foods for human consumption [35]. In general, the amounts of K, Fe, and Zn in beans were recorded at 20 g/kg, 55, and 35 mg/kg, respectively [35, 36]. In the current study, the total K in dwarf yard-long bean pods fell in the range of 19.7-22.3 g K/kg, whereas total Fe and Zn were 194-228 mg Fe/kg and 55.0-60.2 mg Zn/kg, respectively; breaking the former records recorded by Welch and Graham [35]. We may conclude from these results that the dwarf yard-long bean was a plant species with more accumulative Fe and Zn in its pod than in other bean species.

3.5 Biomass, P content, and soil available P after plantation

The significant effects of cultivar and P fertilizer on above-ground biomass (AB) and above-ground P content (APC) are exhibited in Table 4. The AB and APC values of KKU25 and CLGC30 cultivars grown in the Tr and Ay soils were similar. The AB values of the CLGC30 cultivar grown in the Tr and Ay soils were 88.9 and 114.5 g/plant, respectively; whereas in the KKU25, the AB values were 42.5 and 85.6 g/plant, respectively. The APC value was similar to the AB in both soil types. The application of P fertilizer (+P) noticeably increased both AB and APC. This treatment produced higher AB and APC levels (77.9 and 105.2 g/plant and 517 and 723 mg/plant, respectively) than plants without the application of P fertilizer (-P) (53.4, 94.9 g/plant and 315, 539 mg/plant, respectively) in the Tr and Ay soils. The interaction between the cultivar and the application of P fertilizer was significantly different (P<0.05) in only the AB treatment, whereas the A2B1 treatment showed the highest values (93 and 122 g/plant in the Tr and Ay soils, respectively). Available P contents (SAP) in the soil after planting are presented in Table 4. Applying P fertilizer (+P) highlighted the differences in available P in the Tr and Ay soil types. The values of 54.1 and 43.3 mg P/kg were shown in the treatment of P fertilizer (+P) applications, while those with a lack of P fertilizer (-P) were 6.5 and 19.5 mg P/kg in the Tr and Ay soils, respectively. The interaction between cultivars and applied P fertilizer was found to be significantly different (P<0.01) in both Tr and Ay soil types. The highest value of available P was displayed in the treatment of A1B1, at 60.1 and 46.4 mg P/kg in the Tr and Ay soils, respectively.

Table 4. Accumulation in above-ground biomass (AB) and above-ground P content (APC) of dwarf yard-long beans, and soil available P (SAP) after planting in two soil series

Treatment	Tr soil series[1/]			Ay soil series[1/]		
	AB (g/plant)	APC (mg/plant)	SAP (mg/kg)	AB (g/plant)	APC (mg/plant)	SAP (mg/kg)
Cultivars of dwarf yard-long bean						
KKU25 (A1)	42.5 [b]	268 [b]	33.2	85.6 [b]	488 [b]	34.1
CLGC30 (A2)	88.9 [a]	564 [a]	27.4	114.5 [a]	783 [a]	28.7
F-test	**	**	ns	**	**	ns
Phosphorus fertilizer						
+ P (B1)	77.9 [a]	517 [a]	54.1 [a]	105.2	732 [a]	43.3 [a]
- P (B2)	53.4 [b]	315 [b]	6.5 [b]	94.9	539 [b]	19.5 [b]
F-test	*	**	**	ns	*	**
Interaction between cultivar and P fertilizer						
A1B1	62.9 [b]	405	60.1 [a]	88.4 [b]	549	46.4 [a]
A1B2	22.1 [c]	131	6.3 [b]	82.8 [b]	428	21.8 [b]
A2B1	93.0 [a]	630	48.1 [ab]	122.0 [a]	916	40.2 [a]
A2B2	84.8 [a]	499	6.7 [b]	107.1 [a]	650	17.2 [b]
F-test	*	ns	**	**	ns	**
CV (%)	19.3	22.8	7.7	12.9	20.2	19.1

[1/] Means within the same column followed by the same letters indicated no significant difference among treatments through DMRT.

**,* are significantly different at 0.01 and 0.05 probability levels, respectively, and ns is no significant difference.

AB and APC are important parameters as they indicate the loss of nutrition from the soil via crop removal; such as removal of seeds or plant biomass (stem and leaf) from the field. The plant stems and leaves of legumes are a source of nutrients and are, therefore, mostly used for animal feed [37], or are mixed with organic substances to produce organic fertilizer. Our results illustrated that AB and APC presented with significant differences among treatments. The cultivars of dwarf yard-long beans differed in AB and APC in the CLGC30 cultivar, producing higher values than those of the KKU25 (Table 4). Plant variety is an important parameter as it determines the growth and yield of the plant. Tesfaye and Balcha [29] stated that plants of different genotypes such as wheat, maize, and the common bean could be grown in P-limited soils, and yet each produced different yield. However, the differences in rhizosphere pH, organic compound release, root surface area, root production, and the secretion of phosphatase enzymes affected the amount of available P in soil, via the mineralization process, as well as the growth and yield production of plants. When considering the application of P fertilizer, our results exhibited greater values of both

AB and APC with the application of P fertilizer (+P) in contrast to the results seen for soil without the benefit of P fertilizer (-P) applications. Additionally, applying P fertilizer can increase the growth and yield of several crops; such as the common bean [5, 29, 38], faba bean [27], soybean [33], and cowpea [10], due to the P's involvement in promoting root development, early flowering, and the ripening of plants [6]. P is, therefore, considered to be an essential element for the general health and vigor of all plants, when applied at optimum rates.

Available P in soil (Tr and Ay) after planting and after the application of P fertilizer varied significantly. In the Tr soil, the application of P fertilizer created amounts of available P (8-fold) higher than those of the control treatment without P fertilizer, whereas the Ay soil showed lesser differences (Table 4). These observations may be the result of differences in soil texture and soil organic matter, as the Ay soil contained higher clay content and organic matter than the Tr soil. Both the clay and organic matter contents influenced soil chemical properties, particularly the amount of available P. Because P can be fixed more easily in soil of high clay contents, the soil had a higher specific surface area [39]. While organic matter can also absorb P in soil and act as a reserve source of P for the plants' future use. Yu *et al.* [40] studied the effects of organic matter applications on the P adsorption of three soil parent materials and found that the P adsorption capacities of soil are dependent on the type of organic substance and the amount of available P in the soil. However, the P adsorption efficiency and P buffering capacity of the soil decreased when the incubation period of the soil and organic substances increased [40, 41].

4. Conclusions

The differences in the cultivars of dwarf yard-long beans showed no noticeably different yield or yield components, whereas the application of P fertilizer produced significantly differences but only in the Tr soil. At the maturity stage, the pod tissues of the dwarf yard-long beans provided more P than other plant parts. The different cultivars and application of P fertilizer to the dwarf yard-long beans affected P content and partitioning in the plant tissues. Furthermore, there was no effect on the plant nutrients, except Fe and Zn contents for plants in Ay soil. Applying P fertilizer to the CLGC30 cultivar produced greater AB and APC than the KKU25 without the application of P fertilizer. The application of P fertilizer produced a heightened availability of P in the soil after planting in contrast to the soil (both Tr and Ay soil) without application of P fertilizer, which produced lower levels of available P. We may conclude that the application of P fertilizer was effective on the growth of dwarf yard-long beans, particularly when the beans were grown in soil with low available P, in which the dosage of fertilizer should be over 150 kg P_2O_5/ha.

5. Acknowledgements

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