Response of Common Bean Cultivars to Phosphorus Application in Boloso Sore and Sodo Zuria Districts, Southern Ethiopia

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Abstract: Common bean (*Phaseolus vulgaris* L.) is an important food crop in Southern Ethiopia. However, the productivity of the crop is constrained by low soil fertility, particularly, phosphorus deficiency due to soil acidity. Therefore, field experiments were conducted to study the response of the crop to phosphorus application on Nitisols at Areka Agricultural Research Centre and Kokate research station in southern Ethiopia. The treatments consisted of three common bean cultivars (Hawassa-Dume, Nasir, and Red-Wolaita) and five phosphorus fertilizer rates (0, 23, 46, 69, and 92 kg P_2O_5 ha^{-1}). The experiments were laid out as a randomized complete block design in a factorial arrangement and replicated three times per treatment. Analysis of the data indicated that the main effects of cultivar and phosphorus significantly ($P < 0.05$) influenced grain yield, number of pods per plant, seed weight, leaf area index, and above-ground dry biomass yield. The interaction effects of cultivar and phosphorus rate also significantly ($P < 0.05$) influenced the number of pods produced per plant at one location (Areka). At Areka, Nasir produced a significantly higher grain yield (2504.8 kg ha^{-1}) than Hawassa-Dume (1951 kg ha^{-1}) and Red-Wolita (2198 kg ha^{-1}). However, at Kokate, the grain yields of the three common bean cultivars were in statistical parity. Application of 69 and 23 kg P_2O_5 ha^{-1} resulted in the optimum grain yields of the crop at Areka (2498 kg ha^{-1}) and Kokate (2219 kg ha^{-1}), respectively. The results of the economic analysis indicated that cultivar Nasir produced the highest net benefit (15903 Birr ha^{-1}). It could, thus, be concluded that cultivating Nasir at the rates of 69 P_2O_5 ha^{-1} at Areka and 23 kg P_2O_5 ha^{-1} at Kokate is most economical for smallholder farmers in the study area.

Keywords: Biomass yield; Economic analysis; Grain yield; *Phaseolus vulgaris* L.

1. Introduction

Common bean is one of the most important leguminous crops cultivated for direct human consumption (Broughton *et al.,* 2003). It is also among the most important legumes in Ethiopia with multiple uses. However, the national average yield of the crop at farmer field is about 1500 kg ha^{-1} (CSA, 2013), which is far lower than the average yield reported at research sites that which ranges from 2500 to 3000 kg ha^{-1} (Frehiwot, 2010).

The low yield of the crop in the country is attributed to declining soil fertility, rainfall variability, pest pressure, poor agronomic practices and poor accessibility to quality seed (Katungi *et al.,* 2010). Soil acidity is one of the problems constraining bean productivity in Ethiopia (Mesfin, 2007). Previous reports on physico-chemical properties of soils of the study areas indicated acidity of the soils (Abayneh *et al.,* 2003; Abay, 2011; Abay and Tesfaye, 2011). The major problems associated with soil acidity are toxicity of Aluminum (Al) and Magnisium (Mn) and poor availability of essential plant nutrients such as phosphorus (P), Calcium (Ca), Magnesium, Nitrogen (N), and Molybdenum(Mo) (Kochian *et al.,* 2004). Soil fertility problems related to soil acidity are common features of the study areas (Abayneh *et al.,* 2003; Abay, 2011). At low pH (<5.5), oxides and hydroxides of Iron (Fe) and Al react with phosphate, leading to strong adsorption and low availability of the nutrient (Fairhurst *et al.*, 1999). Hence, P is the major limiting nutrient in acid soils in the study areas (Abayneh *et al.,* 2003; Abay, 2011).Wortmann *et al.* (2004) also reported that P deficiency is a widespread problem in bean production areas of Eastern and Southern Africa.

Common bean production is often constrained by phosphorus deficiency in the soil since the nutrient plays pivotal roles in nodule initiation (Kouas *et al.,* 2005) and N_2 fixation (Kouas *et al.,* 2005; Tiessen, 2008; Fageria, 2009) and many other energy transfer processes in photosynthesis and other biochemical processes (Fageria, 2009). Furthermore, in Ethiopia, bean production is taking place on smallholder farms with little input (Ferris and Kaganzi, 2008). Under such production system, phosphorus becomes a serious yield-limiting factor (Lunze *et al.,* 2012).

Application of phosphate fertilizers has been suggested to enhance availability of soil P and crop yields (Vance *et al.,* 2003). One of the strategies to improve bean yield on P deficient soils is application of adequate levels of P (Fageria, 2002). Furthermore, various research findings revealed significant increments in the grain yields of legumes including beans in response to P fertilizer application (Birhanu,

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2006; Magani and Kuchinda, 2009). Previous research done on acid soils in Ethiopia revealed significant increases in yield of leagumes including common bean as a result of P fertilizer application (Getachew *et al.,* 2005; Gifole *et al.,* 2011). The grain yield of common bean was significantly influenced by the application of P fertilizer on acidic Nitisolsof Areka (Gifole *et al.,* 2011).

The grain yield of common bean obtained by smallholder farmers in Southern Ethiopia is low, which is about 1140 kg ha^{-1} (CSA, 2013). It is hypothesized that the low yield of the crop in the region is due to low availability of P in the soil and its consequent low uptake by crop plants. However, no research has been done in the study area to elucidate this problem. This research was, therefore, conducted to investigate the response of three common bean cultivars to phosphorus application.

2. Materials and Methods

2.1. General Description of the Study Areas

Field experiments were conducted in 2014 at Areka Agricultural Research Centre and Kokate Research Station, in Boloso Sore and Sodo Zuria districts, respectively, in Southern Ethiopia. Areka Agricultural Research Centre located between $7^0 3'25''$ N latitude and $37^0 40'52''$ E longitude. The altitude of Areka reaches up to 2230 meters above sea level (Abayneh *et al.,* 2003). The major soil type of the center is Haplic Alisol (FAO, 2006), which is very deep and clayey in texture (Abayneh *et al.,* 2003). On the other hand, the Kokate research center is situated in Wolaita zone, and is located at $6^0 52'42''$ N and $37^0 48' 25''$ E at an altitude of 2156 meters above sea level.

2.2. Soil Analysis

Samples were randomly collected using an auger to the soil depth of 30 cm in a zigzag pattern from the experimental field only at planting. Soil texture was determined by the Bouyoucas hydrometer method (Bouyoucos, 1951). Available P was determined by Bray I method using ammonium fluoride as an extractant and measuring the concentration of the nutrient at 880 nm (Bray and Kurtz, 1945). Soil organic carbon was determined by the wet digestion method (Walkley and Black, 1934). Total N was determined by the wet oxidation procedure of the Kjeldhal method (Bremner, 1995). Soil pH in water was determined potentometrically in a supernatant suspension of 1:2.5 soils: water ratio using a combined glass electrode pH meter (Chopra and Kanwar, 1976). Exchangeable potassium was estimated by the ammonium acetate (1M NH OAc at pH 7) extraction method as described by Rowell (1994).

2.3. Physico-chemical Properties of Soils of the Experimental Sites

The physico-chemical properties of the experimental soils determined before sowing of the common bean crop at the two locations are shown in Table 1.

Table 1. Physico-chemical properties of soils of the study area

Location	pH (1:25 Soil: H_20)	Total N (%)	OC (%)	Available P (mg kg^{-1})	Exchangeable K($cmol_{(+)}kg^{-1}$)	Soil Texture Sand (%)	Clay (%)	Silt (%)
Kokate	4.4	0.15	1.7	8.9	4.69	63	18	20
Areka	4.6	0.33	3.9	7.0	3.98	62	11	27

According to the rating of Landon (1991) and Hazelton and Murphy (2007), the pH of the soil is very strongly acidic at both locations. Similarly, according to the rating of Cottenie (1980), the available phosphorus content of the soil is low. The soils of both locations are sandy clay loam. This shows that the soil has limitation in terms of these two chemical properties for crop production. Therefore, managing soil pH and phosphorus availability is important for enhancing plant growth and production in the study area.

2.4. Meteorological Conditions of the Study Areas

In 2014, the rainfall was good in amount compared to the previous twelve years at both locations. The rainfall data showed the area received 1484 and 123.7 mm total annual and mean monthly rainfall, respectively in 2014 (Figure 1). Similarly, at Kokate, despite uneven distribution, the rainfall was higher in amount compared to the past twelve years. The total annual and mean monthly rainfall amounts received during 2014 were1552.1 and 158.6 mm, respectively (Figure 1).

Beans are well adapted to medium rainfall in tropical and temperate regions. Excessive rain causes flower drop (Fageria, 2011). A total rainfall of 350 to 500 mm during the growing season combined with low relative humidity is ideal for common bean growth (Salcedo, 2008). Hence, the rainfall received during the growing season at both locations was adequate for common bean growth.

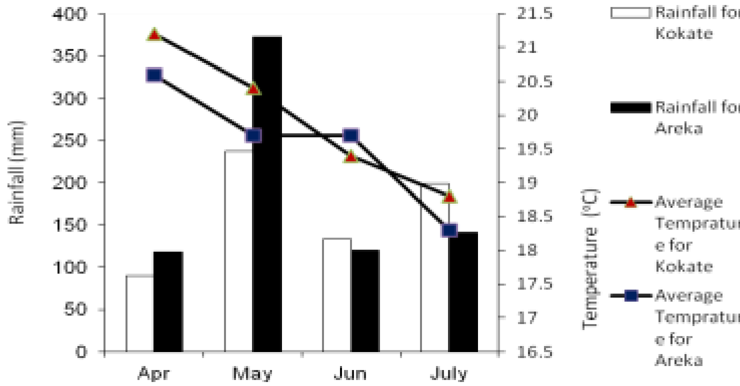

Figure 1. Monthly Rainfall and Monthly maximum and minimum temperatures for Areka and Kakate in 2014.
Source: Areka Research Center, Areka and National Meteorological Agency of Ethiopia Hawassa branch, Hawassa.

Temperature is another climatic variable that affects crop yield. In 2014, the average monthly temperature in the study area ranged from 18.8 to 21.9 ^{0} C at Kokate and 18.3 to 19.3 ^{0} C at Areka. Further, during the growing season, average monthly temperature varied from 18.8 to 21.6 ^{0} C at Kokate and 18.3^0 to 21.7 C at Areka (Figure 1). The crop grows well at temperatures ranging from 15 to 27°C and will withstand temperatures up to 29.5°C (Salcedo, 2008). The minimum and maximum tempratures atboth locations lies in the temprature range suitable for common bean growth (Figure 1).

2.5. Treatments and Experimental Design

The treatments consisted of three common bean cultivars (Hawassa-Dume, Nasir, and Red-Wolaita) and five phosphorus rates (0, 23, 46, 69 and 92 kg P_2O_5 ha^{-1}). The experiment was laid out as a Randomized Complete Block Design (RCBD) in a factorial arrangement and replicated three times per treatment. Each treatment was assigned to the plots randomly. The size of each experimental plot was 3.0 m x 2.8 m.

2.6. Experiment procedures

The experimental field was ploughed by a tractor three times prior to planting at both locations. The planting was done on 27 and 29 2014 at Areka and Kokate, respectively. The phosphorus fertilizer used was triple super phosphate [Ca $(H_2PO_4)_2$; 48.1% P_2O_5], which was applied in band at planting time based on the specific rates required. Nitrogen was applied at the rate of 18 kg N ha^{-1} in the form of urea [CO $(NH_2)_2$; 46% N], at the active stage of vegetative growth before flowering (MORAD, 2008). Weeding was done as required. Similarly, other crop management practices such as pest and disease control was done for all experimental plots. The outer most one row on each side of a plot was left as a boarder row. Two rows at one side and the other at the opposite side of the plots next to the boarder rows were used for destructive sampling. The remaining three rows were used for yield data measurement. The crop was harvested on 6 and 7 July 2014, respectively at Areka and Kokate.

2.7. Data Collection and Measurement

Leaf area was measured using a leaf area meter from five randomly selected plants from rows left for destructive sampling. Leaf area index (LAI) was calculated as the ratio of the total leaf area per plant to the area occupied by the plant. Days to flowering were recorded as the number of days from seedling emergence to the time when 50% of the plants in the net plot area had the first flower. Days to maturity were taken as the number of days from emergence to the days when 95% of the plants grown in the net plot area were ready for harvest. 100 seed weight was determined from 100 randomly taken seeds from plants grown in the net plot area. Number of pods per plant and number of seeds per pod were determined from 5 randomly selected plants in the net plot areas at harvest. Aboveground dry biomass yield was determined from the aboveground part of five randomly chosen plants that were cut at the ground level from the net plot area at maturity and by sun-drying the fresh aboveground biomass. Grain yield was taken from whole plants harvested from the net plot area, excluding plants grown in border rows at harvest. Grain yield was determined by weighing the beans using a sensitive balance and adjusted to 10 % moisture level.

2.8. Statistical Analysis

The data of the two locations were tested for homogeneity of variance using F-test (Gomez and Gomez, 1984). All data were subjected to analysis of variance using SAS version 8, Statistical software (SAS, 2004). Significant treatment mean differences were separated using the LSD test at 0.05 probability level.

2.9. Economic Analysis

Partial budget analysis to evaluate the economic viability of the technologies was performed following the procedures described by CIMMYT (1988).Only the costs that vary were considered for analysis. A treatment that is non-dominated and having a MRR of greater or equal to 100% and the highest net benefit is said to be economically profitable (CIMMYT, 1988).

3. Results and Discussion

3.1. Effect on Growth Parameters

Leaf area index

Leaf area index is an important trait, which contributes for increased crop production (Fujita *et al.,* 1999). Leaf area index responded to the main effects of phosphorus and cultivar at both locations (Table 2).

Table 2. Main effects of cultivar and phosphorus fertilizer rate on leaf area index at Areka and Kokate research centres in 2014 main growing season

Cultivar	Leaf area index		
	Areka	Kokate	Mean
Hawassa-Dume	2.9^{b}	3.2^{b}	3.027^{b}
Nasir	3.1^{b}	3.7^{a}	3.413^{a}
Red-Wolaita	3.6^{a}	3.1^{b}	3.287^{a}
F-value			
Cultivar	***	***	***
LSD	0.39	0.25	0.24
Phosphorus rate (P_2O_5 kg^{-1})			
0	2.5^{b}	2.9^{c}	2.73^{b}
23	2.6^{b}	3.1^{bc}	2.77^{b}
46	3.4^{a}	3.4^{ab}	3.39^{a}
69	3.8^{a}	3.5^{a}	3.63^{a}
92	3.8^{a}	3.6^{a}	3.68^{a}
F-value			
P	***	***	***
CV (%)	18.84	9.97	9.95
LSD (0.05%)=	0.58	0.32	0.31

Where, LSD = Least significant difference. Means followed by the same letter are not significantly different at 5% level of significance.

At Areka, significantly higher leaf area index was recorded for Red-Wolaita than the other cultivars. However, at Kokate, Nasir had significantly higher leaf area index than Red-Wolaita and Hawassa-Dume. On the other hand, Nasir and Hawassa-Dume at Areka and Red Wolaita and Hawassa-Dume at Kokate had leaf area indices that were in statistical parity (Table 2). Corroborating this result, Butraa, (2009) observed a highly significant effect (P = 0.001) of common bean genotype on leaf area index. Similarly, Fujita *et al.* (1999) reported significant variations in the leaf area index pigeon pea.

The optimum leaf area index at both locations was recorded when P was applied at the rate of 46 kg P_2O_5 ha^{-1}. As a result, compared to the control treatment, increasing the P rate up-to 46 kg P_2O_5 ha^{-1} resulted in 36 and 18% increases in leaf area index at Areka and Kokate, respectively (Table 2). Hence, the significant effect of P application on leaf area index might be due to unique bonding properties of P that make it critical in nucleotide-based metabolic processes and direct involvement of the nutrient in generation of high-energy compound such as ATP, which is essential for establishing enzymatic machinery for energy storage and transfer (Sinclai and Vadez, 1999), thereby playing a pivotal role in the synthesis of cellulose and hemicelluloses in leaves (Fujita *et al.,* 1999). In agreement with the findings of the present study, different workers also observed significant increases in leaf area index of different crops including common bean due to phosphorus application (Magani and Kuchinda, 2009; Olivera *et al.,* 2004; Meseret and Amin, 2014). For instance, Meseret and Amin, (2014) reported significant increases in common bean leaf area in response to P application at Arbaminch, Southern Ethiopia. However, the results of this study are in contrast to the findings of Sulieman and Hago (2009), who reported a non-significant effect of phosphorus application on leaf area index of common bean after 10 weeks, which was indicated to be due to heavy clay alkaline nature of the soil used for growing the crop.

Aboveground Dry Biomass

Three-factor interaction effect of location × cultivar × phosphorus was significant for aboveground dry biomass yield (Table 3). Means of aboveground dry biomass yield of the common bean cultivars varied across the locations when different rates of phosphorus were applied (Table 3). The maximum biomass was produced by Red-Wolaita from plots that received 92 kg P_2O_5 ha^{-1} at Kokate, which was in statistical parity with Nasir grown on plots that received 69 and 92 kg P_2O_5 ha^{-1} at the same location, whilst the minimum dry biomass was produced by Hawassa-Dume at Areka, when grown on plot receiving no phosphorus application.

The variation in aboveground dry biomass yield of the cultivars across P levels and location might be attributed to the genotypic variations of the cultivars in leaf area index, which may affect photosynthesis and photo-assimilate synthesis (Fujita *et al.,* 1999) and slight variations in inherent soil fertility status of the soils of the two locations. Consistent with these results, other researchers also reported significant increases in biomass yield in response to P application (Gifole *et al.,* 2011; Fageria *et al.,* 2010, 2012). In a similar study, Mourice and Tryphone, (2012) reported that common bean cultivars produced different dry matter at different phosphorus levels. In other words, the cultivars have different fertilizer and environmental requirements.

Table 3. Mean aboveground biomass yield as influenced by the interaction of phosphorus, location, and cultivar in 2014 main growing season.

Phosphorus ($kg\ P_2O_5\ ha^{-1}$)	Kokate			Areka		
	Aboveground dry biomass yield ($kg\ ha^{-1}$)					
	Hawassa-Dume	Nasir	Red-Wolaita	Hawassa-Dume	Nasir	Red-Wolaita
0	4854.2^{mno}	4817.2^{mnop}	4342.6^{nop}	3890.5^{p}	4460.6^{nop}	5291.3^{lmn}
23	7421.7^{def}	5656.6^{jklm}	5623.6^{kml}	4184.7^{op}	7049.8^{efgh}	6160.8^{hijkl}
46	5999.8^{ijkl}	6756.9^{fghi}	6403.4^{ghijk}	6721.5^{fghi}	8125.1^{cde}	6676.4^{fghi}
69	6784.9^{fghi}	8807.3^{ab}	7823.3^{cde}	7013.6^{efgh}	8162.5^{bcd}	6598.2^{fghij}
92	6932.9^{efghi}	8468.4^{abc}	9285.4^{a}	7830.1^{cde}	7360.1^{defg}	7536.7^{cdef}
LSD (0.05)=	962.59					

Where, LSD = Least significant difference. Means followed by the same letter are not significantly different at 5% level of significance.

However, application of P beyond 69 kg P_2O_5 ha^{-1} did not result in significant increases in aboveground dry biomass yield of Nasir. Similarly, at Areka, significant increase in aboveground dry biomass yield was not observed beyond 69 kg P_2O_5 ha^{-1} for this cultivar

3.2. Effect on Yield Components Number of Pods per Plant

Number of pods per plant was influenced significantly by the interaction of cultivar and phosphorus fertilizer rate only at Kokate (Table 4). The results showed that Red-Wolaita produced the highest number of pods per plant in response to the application of 92 kg P_2O_5 ha^{-1}, which was in statistical parity with the number of pods produced by Red Wolaita and Nasir at the rates of 69 kg P_2O_5 $ha^{-1}$and Hawassa-Dumeat at 69 and 92 kg P_2O_5 ha^{-1} at Kokate. Also at nil P rate, Red-Wolaita produced the highest number of pods per plant whilst Hawassa-Dume produced the lowest number of pods per plant, indicating this cultivar is more sensitive to P deficiency than the other cultivars. On the other hand, at 69 kg P_2O_5 ha^{-1}, all cultivars produced statistically equal numbers of pods per plant, suggesting that the three cultivars are responsive equally to high rates of P application. On the other hand, the lowest number of pods per plant was recorded for Hawassa-Dume. At Areka, cultivar Nasir produced a significantly higher number of pods per plant than Hawassa-Dume and Red Woliata (Table 7). The variation in the number of pods per plant might be related to the genotypic variation of the cultivars. In accord with the results of the present study, different authors reported significant variations in the number of pods per plant for common bean (Fageria *et al.,* 2010; Mourice and Tryphone, 2012) and soybean (Mahamood *et al.,* 2009) genotypes.

Table 4. Number of pods per plant as influenced by the interaction effect of cultivar and phosphorus at Kokate, Southern Ethiopia, in 2014 growing season

Phosphorus ($kg\ P_2O_5\ ha^{-1}$)	Cultivar		
	Hawassa-Dume	Nasir	Red-Wolaita
0	8.10^{h}	10.13^{egf}	12.90^{cd}
23	8.56^{hg}	11.03^{def}	12.66^{cd}
46	9.06^{hgf}	11.30^{de}	13.40^{bc}
69	14.60^{abc}	14.20^{abc}	15.33^{ab}
92	15.80^{a}	13.00^{cd}	16.1^{a}
F-value			
C×P	***		
CV (%)	9.94		
LSD (0.05) =	1.987		

Where, CV = Coefficient of variance; LSD = Least significant difference. Means followed by the same letter are not significantly different at 5% level of significance.

In general, the number of pods per plant significantly increased in response to increasing the rate of phosphorus up-to the highest rate (Tables 4 and 9). At Areka, application of 46 kg P_2O_5 ha^{-1} produced the optimum number of pods per plant (Table 9). In line with this result, different authors reported significant variations in the number of pods per plant for different crops including common bean due to P applications (Ali *et al.,* 2002; Meseret and Amin, 2014). In contrast, Malik *et al.* (2002) reported a non-significant increase in the number of pods produced per plant by rice bean.

Seeds per pod

Common bean cultivars produced significantly different numbers of seeds per pod when grown at different P rates; however in most cases, the cultivars produced statistically equal number of seeds per pod across the P rates (Table 5). This indicates that the trait is mainly controlled genetically rather than the variations in external environment. Hence, in agreement with this finding, Mesfin *et al.* (2014) reported significant common bean cultivars× phosphorus interaction effects on the number of seeds per pod in Dolla (Bolosso Sore district) and Gununo. However, the same authors reported significantly higher number of seeds per pod for some of the cultivars tested.

Table 5. Mean number of seeds per pod as influenced by interaction effect of cultivars and phosphorus in 2014, Southern Ethiopia.

Phosphorus ($kg\ P_2O_5\ ha^{-1}$)	Cultivars		
	Hawassa-dume	Nasir	Red-Wolaita
0	4.8^{bc}	4.5^{bcd}	5.7^{a}
23	4.7^{bcd}	4.8^{bcd}	4.7^{bcd}
46	4.4^{cd}	4.5^{bcd}	5.0^{bcd}
69	4.5^{bcd}	4.7^{bcd}	4.6^{bcd}
92	5.1^{ab}	4.2^{d}	4.8^{bcd}
Mean	4.7	4.54	4.96
LSD (0.05)=	0.64		

Where, LSD = Least significant difference. Means followed by the same letter are not significantly different at 5% level of significance.

Averaged across the P rates, Red-Wolaita produced the highest number of seeds per pod (Table 5). On the other hand, the minimum number of seeds per pod was produced by Nasir. Consistent with the results of this study, Mourice and Tryphonne (2012) also observed significant variations in number of seeds per pod among common bean genotypes. The variation in number of seeds per pod could be attributed to the variation in the size of seeds of the cultivars. In other words, a higher or relatively better number of seeds per pod at lower P level might be a compensation for small seed size at lower P levels. On the other hand, absence of significant variation among the cultivars across the P levels indicate that this trait is mainly controlled genetically rather than by application of phosphorus fertilizer as pointed out by other workers (Mourice and Tryphonne, 2012).

3.3 Effect on Plant Penology and Seed Weight

Days to maturity were significantly influenced by the main effects of location and phosphorus application. Increasing phosphorus rate hastened days to maturity (Table 6).

The early maturity of the crop due to P application might be related to the metabolic role phosphorus plays in hastening growth and physiological processes. Consistent with this result, Gefole *et al.* (2011) reported that phosphorus application significantly reduced days to maturity.

Table 6. Main effects of location, cultivar, and phosphorus fertilizer rate on mean seed weight and days to maturity of common bean at Areka and Kokate in 2014 growing season.

Location	Seed weight (g)	Days to maturity
Kokate	26.7[a]	90.8[a]
Areka	25.9[b]	89.3[b]
F-test		
Location	***	***
LSD(0.05)=	0.53	0.83
Cultivar		
Hawassa-Dume	26.3	90.7
Nasir	26.6	89.6
Red-Wolaita	26.0	89.8
F-test		
Cultivar	ns	ns
LSD (0.05) =	ns	ns
Phosphorus (kg P_2O_5 ha^{-1})		
0	25.1[c]	91.4[a]
23	25.2[c]	91.2[a]
46	26.6[b]	90.7[a]
69	27.2[ab]	88.6[b]
92	27.6[a]	88.2[b]
F-test		
Phosphorus	***	***
CV (%)	4.76	2.18
LSD (0.05)=	0.84	1.31

Where CV = Coefficient of variance; LSD = Least significant difference. Means followed by the same letter are not significantly different at 5% level of significance.

Hundred seed weight

Hundred-seed weight varied due to the main effects of location and phosphorus application (Table 6). The highest seed weight was recorded for Kokate whilst the lowest seed weight was recorded for Areka. The variation in hundred seed weight between the two locations might be attributed to the slight variation in inherent soil fertility status of the two locations (Table 1). Similarly, a significant increase in hundred seed weight compared to the control was observed only when the P rate was increased up to 46 kg P_2O_5 ha^{-1}. The increase in hundred seed weight as a result of increased P application may be attributed to important roles the nutrient play in regenerative growth of the crop (Zafar *et al.,* 2013), leading to increased seed size (Fageria *et al.,* 2009), which in turn may improve hundred seed weight. In a similar study, Amare *et al.* (2014) observed significant variations in thousand seed weights of common bean as a result of phosphorus application.

3.4. Effect on Grain Yield

Grain yield was significantly influenced by the main effect of cultivar only at Areka whilst phosphorus application had a significant effect at both locations on this parameter (Table 7).

At Areka, common bean cultivar, namely, Nasir produced a significantly higher grain yield than the other cultivars. The grain yield produced by Nasir exceeded that produced by Hawassa-Dume and Red-Woliata by nearly 28% and 14 %, respectively (Table 7). However, Hawassa-Dume and Red-Wolaita produced grain yields that were in statistical parity. Similarly, at Kokate, the highest and the lowest grain yields were produced by Red-Wolaita and Hawassa-Dume, respectively. Red-Wolaita produced 13% higher grain yields compared to Hawassa-Dume (Table 7).

Further, averaged across the two locations, no significant differences existed between the common bean cultivars, namely, Nasir and Red Wolaita. However, the grain yields of the aforementioned two common bean cultivars significantly exceeded that of Hawassa-Dume. Grain yield in common bean is related to yield attributing traits such as number of pods per plant and seed weight (Fageria *et al.,* 2009). Hence, the variation in grain yield among common bean cultivars might be related to the variations observed among the cultivars in the number of pods per plant and seed weight (Table 7). For instance, the high yielding cultivars Nasir and Red-Wolaita produced heavier seeds compared to the low yielding cultivar, Hawassa-Dume (Table 6).

Differences in grain yield among the common bean cultivars also might be related to the genotypic variations for P use efficiency (Fageria and Costa, 2000; Fageria *et al.,* 2010), which may arise from variation in P acquisition (Lynch, 1995) and translocation and use of absorbed P for grain formation (Horst *et al.,* 1993; Shen *et al.,* 2011) in common bean. Hence, the cultivars which produced higher grain yield might have either better ability to absorb the applied P from the soil solution or translocate and use it for grain formation than the low yielding cultivar. In agreement with the findings of this study, several researchers observed significant variations in grain yield for different crop genotypes, including common bean (Korkmaz, 2010; Fageria *et al.,* 2010, 2012; Mourice and Tryphone, 2012; Gobeze and Legese, 2015).

Table 7. Main effects of cultivar and phosphorus fertilizer rate on grain yield and number of pods per plant at Areka and Kokate in 2014 growing season

	Grain yield			Number of pods per plant		
Cultivar	Areka	Kokate	Mean	Areka	Kokate	Mean
Hawassa-Dume	1951.2^{b}	2178.3	2064.8^{b}	12.56^{b}	11.2^{b}	11.9^{b}
Nasir	2504.8^{a}	2352.8	2428.8^{a}	14.78^{a}	11.9^{b}	13.4^{a}
Red-Wolaita	2197.8^{b}	2467.1	2332.5^{a}	12.76^{b}	14.1^{a}	13.4^{a}
Mean	2217.9	2332.7				
F-test						
Cultivar	***	ns	***	*	***	***
LSD (0.05%)	257.8	ns	206.0	1.98	0.93	1.02
Phosphorus (kg P_2O_5 ha^{-1})						
0	1695.7^{d}	1889.3^{b}	1792.5^{d}	11.01^{b}	10.4^{b}	10.7^{c}
23	1994.1^{cd}	2218.9^{ab}	2106.5^{c}	11.51^{b}	10.8^{b}	11.2^{c}
46	2201.5^{bc}	2360.4^{a}	2280.9^{bc}	14.2^{a}	11.3^{b}	12.8^{b}
69	2498.3^{ab}	2546.2^{a}	2522.3^{ab}	15.0^{a}	14.7^{a}	14.9^{a}
92	2699.8^{a}	2648.8^{a}	2674.3^{a}	15.06^{a}	15.0^{a}	15.0^{a}
Mean	2217.9	2332.7				
Phosphorus	***	**	***	***	***	***
C*V	ns	ns	ns	ns	***	ns
CV	15.5	19.34	12.11	19.8	9.93	10.56
LSD (0.05%) =	332.8	435.8	266.0	2.6	1.2	1.3

Where, CV = Coefficient of variance; LSD = Least significant difference. Means followed by the same letter are not significantly different at 5% level of significance.

At Areka, increasing the rate of P from nil to 23 kg P_2O_5 ha^{-1} did not increase grain yield. Significant increase in grain yield of the crop was observed over the control treatment. However, at this location, the optimum grain yield was already obtained at 69 kg P_2O_5 ha^{-1}. This indicated that increasing the rate of phosphorus beyond 69 kg P_2O_5 ha^{-1} resulted in a non-significant yield increment (Table 7). Thus, increasing the rate of phosphorus from nil to 69 kg P_2O_5 ha^{-1} increased grain yield by nearly 47% compared to the control treatment. This result corroborates the finding of Gifole *et al.* (2011), who reported that increasing the rate of phosphorus application increased grain yield of common bean at Areka.

At Kokate, the pattern of response of the grain yield of common bean to the increasing rate of the P fertilizer was similar with that observed at Areka (Table 7). However, although the maximum grain yield was obtained at the highest rate of phosphorus (92 kg P_2O_5 ha^{-1}), the optimum grain yield was attained already at 23 kg P_2O_5 ha^{-1}, indicating that there was no need to increase the rate of the fertilizer beyond this rate at this location for enhancing the grain yield of the crop. Hence, increasing the rate of phosphorus application from nil to 23 kg P_2O_5 ha^{-1} resulted in about 25% increase in grain yield of the crop at this location (Table 7). The grain yield obtained at nil rate of phosphorus application at Kokate was higher than the one obtained at Areka at the same rate of the fertilizer by about 11%. This difference and the lack of response in grain yield to higher application rates of phosphorus than 23 kg P_2O_5 ha^{-1} at Kokate indicates that the soil of the latter is in a much better status in P content and availability for better growth and productivity of the crop than the soil of the former (Table 1).

The results of this study showed increased grain yields in response to the increasing the rate of P application. The increase in grain yield might be attributed to overall improvement in growth attributes such as leaf area index and aboveground dry biomass yield, thereby increasing yield attributing traits such as number of pods per plant, hundred seed weight upon partitioning, which also showed an increasing trend as a result of P application. Different workers also reported association of increase in these yield attributing traits with increase in grain yield (Ali *et al.,* 2002; Sofi *et al.,* 2011; Amare *et al.,* 2014).Consistent with the results of this study, other workers reported significant increases in the grain yields of common bean in response to phosphorus application under field and greenhouse conditions (Vesterager *et al.*, 2006; Gifole *et al.,* 2011; Gobeze and Legese, 2015;). In contrast, Tolera *et al.* (2005) reported a non-significant effect of P application on grain yield of climbing bean intercropped with maize at Bako, Western Oromia region of Ethiopia on an acid soil.

3.5. Economic Analysis

Grain yield was significantly influenced by the main effects of phosphorus fertilizer application at both locations (Tables 7). However, the effect of cultivar was significant only at Areka.

Table 8. Results of the economic analysis for common bean cultivars and P at Areka and Kokate in 2014 growing season.

Treatment	Study Area					
	Areka			Kokate		
	TCV (ETB ha^{-1})	NB (ETB ha^{-1})	MRR (%)	TCV (ETB ha^{-1})	NB (ETB ha^{-1})	MRR (%)
Cultivar						
Red-Wolaita	427.0	13957.4		-	-	-
Nasir	491.1	15903.1	3040	-	-	-
Phosphorus (kg P_2O_5 ha^{-1})						
0	-	-	-	0	11883.7	-
23	617	12434.5	-	617	13340.1	236
46	1234	13175.0	120	1234	13612.6	44
69	1851	14500.7	214	1851	14162.6	89
92	3132	14530.3	2.3	-	-	-

Where, ETB = Ethiopian Birr (currency); TCV = Total cost that vary; NB = Net benefit; MRR = Marginal rate of return; Price for phosphorus Fertilizer = 12.34 ETB kg^{-1}, Price for common bean cultivars Red-Wolaita = 7.0 ETB kg^{-1}, Nasir = 8.05 ETB kg^{-1}, Hawassa-Dume = 8.05 ETB kg^{-1}, average price for common bean = 7.7 ETB kg^{-1}.

The economic analysis for Areka indicated that planting of the cultivar Nasir produced the highest net benefit (15903.1 Birr ha^{-1}) with acceptable marginal rate of return compared to other cultivars (Tables 8). Further, compared to other phosphorus rates, the highest net benefit with acceptable marginal rate of return was obtained when phosphorus was applied at the rates of 69 and 23 kg P_2O_5 ha^{-1} at Areka and Kokate, respectively (Tables 7).

4. Conclusion

The results of this study have demonstrated that phosphorus application improved the performance of the common bean cultivars at both locations. However, the amounts of phosphorus fertilizer required for production of optimum grain yields of the crop at the two locations varied. Thus, application of phosphorus at the rates of 69 kg P_2O_5 ha^{-1} at Areka and 23 kg P_2O_5 ha^{-1} at Kokate resulted in optimum grain yields of the crop. Nasir was found to be the most productive cultivar for economical production in the study areas.

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