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Table of Contents: Volume 10 Number 6 June 2018

ARTICLES

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Journal of Agricultural Biotechnology and Sustainable Development

Full Length Research Paper

Growth and yield of common bean (*Phaseolus vulgaris* L.) cultivars as influenced by rates of phosphorus at Jimma, Southwest Ethiopia

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Common bean (*Phaseolus vulgaris* L.) is an important food and cash crop in southwest Ethiopia with multiple uses. Productivity of the crop is, however, low at national as well as regional levels, mainly due to low soil fertility. Phosphorus (P) deficiency is particularly important in acid soils of southwest Ethiopia affecting growth and yield of seed legumes in general and that of common beans in particular. Therefore, a field experiment was conducted to assess the response of common bean cultivars to P application on Nitisols of Jimma in 2016 main cropping season. The treatments consisted of three common bean cultivars (Ibbado, Tatu, and Remeda) and four P fertilizer rates (0, 23, 46, and 69 kg P_2O_5 ha^{-1}). The experiment was laid out in a Randomized Complete Block Design in a factorial arrangement replicated three times. Results indicated that interaction effects of cultivars and P rates significantly ($P < 0.01$) influenced phonological parameters, growth parameters, dry biomass yield and seed yield. The highest dry biomass yield (5874 kg ha^{-1}) and seed yield (2821 kg ha^{-1}) were obtained from the treatment combination of cultivar Tatu and 69 kg P_2O_5 ha^{-1}. The P use efficiency parameters (recovery efficiency, agronomic efficiency) were also significantly affected by the interaction effect of cultivar and P application rate. Cultivar Tatu was found to be more P efficient at P rate of 23 kg P_2O_5 ha^{-1}. In conclusion, the study pointed out that common bean cultivars responded differently to the various P application rates suggesting the possibility of exploiting cultivar differences to combat P deficiency under acidic conditions. Phosphorus at rate of 23 kg ha^{-1} will be recommendable for P-efficient cultivar based on phosphorus use efficiency parameters. Accordingly, farmer who has no capacity to buy fertilizer cultivar Tatu was recommended to specific soil of study area. However, since the data is only for one season and location repeating the experiment across location may be helpful to validate the results.

Key words: Common bean, phosphorus use efficiency, seed yield, and soil acidity.

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) belongs to the family Fabaceae and originated from Central and South America. It is now widely cultivated as a major food crop in many tropical and subtropical areas of America, Europe, Africa and Asia (Wortmann, 2006). It is highly polymorphic warm-season, herbaceous annual crop and which has two growth habit: erect herbaceous bushes (determinate), up to 20 to 60 cm high; and twining, climbing vines (indeterminate) up to 2 to 5 m long (Ecocrop, 2013).

Common bean is a major grain legume consumed worldwide for its edible seeds and pods. In Ethiopia, it is one of the most important cash crops and source of protein in many lowlands and mid land area areas. It is high in starch, dietary fiber and is an excellent source of potassium, selenium, molybdenum, thiamine, vitamin B6, and folic acid (Maiti and Singh, 2007). It is used as food in different form; the green unripe pods are cooked or conserved as vegetable and the ripe seeds cooked for "*nifro"* or boiled with mixed sorghum or maize and can be consumed as "*woti*" using powder form (MOARD, 2009). Common bean is highly preferred by Ethiopian farmers because of its fast maturing characteristics that enable households to get cash income required by purchasing food and other household needs when other crops have not yet matured (Legese et al., 2006). Its ability to fix nitrogen makes it important in cropping systems as it can enhance soil fertility. Common bean ranks third as an export commodity in Ethiopia, and contributing about 9.5% of total export value from agricultural income of the country (FAOSTAT, 2015). The amount of export per annum from common bean is about $70.187million (Boere et al., 2015).

In Ethiopia, it is widely grown as traditional pulse crop with area of about 0.37 million hectares and total annual production of 0.51 million MT at main season only (FAOSTAT, 2015). Among pulses it takes the largest share of in terms of area coverage, with an increasing trend for the last ten years (CSA, 2015). However, the national average yields (1.59t ha^{-1}) (CSA, 2015) is far lower than the average yield reported at research sites (2.5 to 3 t ha^{-1}) (Frehiwot, 2010). Production obtained from common bean at Jimma zone is about 4906.3 ha with the total production of 4,428.6 t and productivity of 0.9 t ha^{-1} (CSA, 2015).

Low yield of the crop in the country is attributed to declining soil fertility, drought and rainfall variability, pest attack, and poor agronomic practices (Katungi et al., 2010). Furthermore, poor availability of essential plant nutrients especially P is one of yield limiting factor in grain legumes (Kochian et al., 2004). Common bean has high nitrogen and P requirement for expressing its genetic potential. However, as bean has the ability to fix and use atmospheric nitrogen with regards to soil fertility and mineral nutrition requirement, P is considered as the first and nitrogen as the second limiting plant nutrient for bean yield in the tropical zone (Tesfaye et al., 2007). According to Amare (1987) cited in Gifole et al. (2011), the yield of common bean increases with P application and its nodulation and atmospheric nitrogen fixation can also be improved with P application. Legumes, including common bean, have high P requirement due to the production of protein containing compounds, in which P are important constituents. High seed production of legumes primarily depends on the amount of P absorbed (Khan et al., 2003).

It also plays a vital role in increasing plant tip and root growth, decreasing the time needed for developing nodules, increases the number and size of nodules and the amount of nitrogen assimilated per unit weight of nodules (Tsvetkova et al., 2003). Cultivars differ in their P nutrient uptake and utilization efficiency largely influenced by the environmental conditions. P-efficient common bean cultivars which increase below-ground biomass are able to acquire P in P-deficiency conditions (Namayanja, 2014). Blair et al. (2009) reported that greater production of adventitious roots in common beans helps in P acquisition by improving plant foraging in most P rich soil environment. Thus, the difference in root traits indicates the differences among common bean cultivars in P acquisition efficiency. 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, 2012).

Furthermore, various research findings indicated that bean respond differently to different rates of P at various locations. Gifole et al. (2011) reported that application of 23 kg P_2O_5 ha^{-1} significantly improved seed and biomass yield of common bean on Ultisols of Areka. Dereje et al. (2016) found that application of P at the rate of 69 kg P_2O_5 ha^{-1} at Areka and 23 kg P_2O_5 ha^{-1} at Kokate resulted in the highest seed yield of the crop on Haplic Alisol. Mesfin et al. (2014) showed the highest seed yield and yield components at 69 kg P_2O_5 ha^{-1} on Nitisols at Boloso Sore and Damot Woreda of Wolayita Zone. However, Amare et al. (2014) reported that application of 20 kg P_2O_5 ha^{-1} gave the maximum seed yield and related yield parameters of common bean at Arbaminch. Tesfaye et al. (2015) also pointed out that application of 2.7 t lime ha^{-1} and 30 kg P_2O_5 ha^{-1} had resulted in higher seed yield and economic return on acidic soil of Areka.
These studies have suggested that response of common bean to P application is site specific and agro-ecology dependent. This calls for further studies in southwest Ethiopia where information on the response of common bean cultivars to P fertilizer on Nitisols is scares. Therefore, this study was conducted with an overall objective of examining the influence of P rates on growth and yield of common bean cultivars at Jimma.

MATERIALS AND METHODS

Description of the study area

The experiment was conducted at Eladale Research Site of the

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Table 1. Monthly maximum and minimum temperature, monthly rainfall and relative humidity weather condition of experimental site at growing season of the crop.

Month	Weather elements			
	Average temperature (C)		Total rainfall (mm)	Average relative humidity (%)
	Max.	Min.		
June	26.42	13.8	149.9	64.96
July	24.99	14.61	185.7	72.29
August	25.74	14.06	334.2	67.548
September	26.37	13.98	153.1	65.1

Source: Weather Station and Jimma Meteorology Station (2016).

College of Agriculture and Veterinary Medicine, Jimma University, Ethiopia in 2016 main cropping season (June to September). The study area is located at 7° 42’ N latitude and 36° 48’ E longitudes at Oromiya Regional State, Jimma Zone, 356 km southwest of Addis Ababa, 7 km far from Jimma town. The altitude of the experimental site was 1710 m.a.s.l. Average temperature of growing season of the crop ranges from 14.11-25.88 ^{o}c (Table 1).

Experimental materials

The common bean cultivars Ibbado, Tatu and Remeda were used for the study. The cultivars were released by Hawassa Agricultural Research Centre in 2003, 2014 and 2014, respectively (MoA, 2014). Ibbado cultivar has large sized, round and mottled seed and white flower color with a maturity period of 90 to 120 days and yield on farmer field and research field was 2102 and 2400 kg ha^{-1}, respectively. Tatu cultivar has large sized, round and red mottled seed and white flower color with a maturity period of 85 to 90 days and yield on farmer field and research field was 2108 and 2400 kg ha^{-1}, respectively. Whereas, Remeda cultivar has large sized, kidney shape red seed and white flower color with a maturity period of 90 to 95 days and yield on farmer field and research field was 2012 and 2316 kg ha^{-1}, respectively. All the cultivars are bush type with determinate growth habit (MoA, 2014). The cultivars are adapted to an altitude range of 1400 to 1800 m above sea level with rainfall of more than 1200 to 1500 mm in growing season and high yield and resistance to disease; hence they are selected for the study.

Treatments and experimental design

The treatments consisted of three common bean cultivars (Ibbado, Tatu and Remeda) and four levels of phosphorus (0, 23, 46 and 69 kg P_2O_5 ha^{-1}). The source of P was Triple Superphosphate (TSP; 46% P_2O_5 P). Phosphorus rates were calculated on the basis of blanket recommendation of P for common beans on Nitisol which is 100 kg ha^{-1}. Treatments were arranged in a factorial combination using randomized complete block design (RCBD) with three replications. The gross plot size was 2 m × 2.4 m (4.8 m^2) and the plot had five rows and 23 seeds were sown per row. The common bean cultivars were sown in inter-row spacing of 40 and intra row spacing of 10 cm. The net plot size was 3 rows × 0.4 m × 2.2 m= 2.64 m^2. The spacing between blocks and plots was 1 and 0.5 m, respectively. The pre-sowing soil analysis showed that the experimental soil had a pH (H2O) of 5.43 (moderately acidic). FAO (2008) reported that the preferable pH ranges for most seed crops are in between 4 and 8. Thus, the pH of the experimental soil was within this range and suitable for common bean cultivation. Texture of the soil have compositions of 33% clay, 38% silt and 29% sand, which is in the textural class of clay loam in which it is also suitable for common bean as well as for other agricultural crops (Tekalign,1991). Total nitrogen and organic carbon content of the experimental site was 0.21% and 4.08%, respectively (Table 2). As the research site was previously covered by other cereal crops and continuously fertilized, the nitrogen and organic carbon contents of the soil was found to be in medium range Hazelton and Murphy (2007). Available P of the soils was 4.57 ppm (Table 2) and according to Hazelton and Murphy (2007), the experimental soil is found to be very low and deficient in P. As the area receives heavy rainfall, P is probably fixed by high concentrations of iron and aluminum because of leaching of the basic cations. In general, the experimental soil was found to be conducive for common beans cultivation with external P application.

Data collection

Average root length was measured from randomly selected five plants of each plot at pod setting time. Total number of nodules was determined by counting randomly taken five plants from boarder rows of each plot at pod setting time. Nodule dry weight was measured from five sample plants after oven dry at 70°C for 24 h. Days to 50% flowering was recorded as the number of days from sowing to 50% of the plants produced flowers. Days to 90% physiological maturity was recorded as the number of days from sowing to 90% of the pods become yellow. Number of pods per plant was determined as the total number of pods from randomly selected five plants of net plot area at physiological maturity. Number of seeds per pod was determined as the total number of seeds per pod from randomly selected five plants at maturity from net plot area. Dry biomass yield was determined by taking the total weight of the harvest including the seeds from each net plot area at physiological maturity after oven drying at 70°C for 48 h to a constant weight. Hundred seed weight was determined by taking 100 seeds from randomly taken plants that have been grown in the net plot area at 12% moisture content. Harvest index was expressed as the ratio of seed yield per total dry biomass of sampled plants multiplied by 100. Seed yield was taken from whole plants harvested from the net plot area, excluding plants grown in border rows at harvest and it was determined by weighing the beans using a sensitive balance and adjusted to 12% moisture level.

Based on the laboratory results of plant tissue analysis, recovery, utilization, agronomic and physiological efficiencies were computed according to the formulae described by Fageria and Barbosa Filho (2007).

Statistical data analysis

After the data were checked for normality, the data was subjected

Table 2. Initial physico-chemical properties of the soil.

Parameter	Value	Rating	Reference
Texture class	Clay loam	-	-
pH	5.43	Moderately acid	Landon (1991)
OC (%)	4.08	Medium	Hazelton and Murphy (2007)
TN (%)	0.21	Medium	Bruce and Rayment (1982)
Av. P (ppm)	4.57	Low	Hazelton and Murphy (2007)
CEC (Cmol)	16	Medium	Landon (1991)
Sand (%)	29	-	-
Clay (%)	33	-	-
Silt (%)	38	-	-

Cmol: Cent mole; pH=hydrogen power; %OC: percent of organic carbon; %TN: percent of Total nitrogen; Av. P.ppm: available P in parts per million; EC (ds m^{-1}): electrical conductivity in desisiemens; CEC: cation exchange capacity; %: percent; Txr class: texture class; Nd: not determined.

Table 3. Mean root length, and number of nodules per plant of common bean as influenced by interaction effect of P rate and cultivars at Jimma, 2016.

P rates P_2O_5 kg ha^{-1}	ARL (cm)			NNPP		
	Cultivars					
	Ibbado	Tatu	Remeda	Ibbado	Tatu	Remeda
0	15.07^{e}	15.47^{e}	13.33^{f}	30.07^{fg}	37.73^{ef}	21.80^{g}
23	17.20^{d}	17.80^{d}	17.07^{d}	41.93^{cde}	52.93^{c}	39.80^{def}
46	19.11^{c}	19.47^{c}	19.12^{c}	53.20^{c}	91.73^{b}	51.00^{cd}
69	20.93^{b}	23.57^{a}	21.23^{b}	47.00^{cde}	114.8^{a}	40.60^{def}
CV (%)	-	3.85	-	-	12.92	-
LSD $_{(0.05)}$	-	1.18	-	-	11.29	-

ARL: Average root length; NNPP: number of nodule per plants; CV: coefficient of variation; LSD: least significant difference. Means within the same factor and column followed by the same letter are not significantly different at 5% level of significance.

to Analysis of Variance using SAS software (SAS, 2009 version 9.2). When ANOVA showed significant difference, mean separations were carried out using LSD test at 5% probability level. Pearson's correlation analysis was done to observe the relationship between different parameters.

RESULTS AND DISCUSSION

Average root length

Average root length was significantly (P<0.01) influenced by the interaction effect of cultivars and P rate. The mean comparison showed that the highest average root length was recorded from Tatu cultivar at 69 kg P_2O_5 ha^{-1}, whereas the lowest value of average root length was observed in Remeda cultivar with no P application (0 kg P_2O_5 ha^{-1}) (Table 3). The increment in root length might be due to root morphological traits of common bean cultivars with increase in P levels. This result is inconformity with Dereje et al. (2016) who reported significant effect on root length of common bean cultivars at high level of phosphorus.

Nodule number per plant

Nodule number was significantly (P<0.01) influenced due to the main effects of common bean cultivars and P application. Common bean cultivars produced significantly different nodule number across the P levels. The maximum nodule number per plant was recorded from Tatu when grown on soil that received 69 kg P_2O_5 ha^{-1}, while the minimum nodule number per plant was recorded from Remeda at 0 kg P_2O_5 ha^{-1} (Table 3). The higher number of nodules at the highest rate of P indicated the influences of P in nodule development through its basic functions in plants as an energy source. P plays a vital function in increasing plant tip and root growth, decreasing the time needed for developing nodules to become active and of benefit to the host legume and P increases the number and size of nodules (Bashir et al., 2011). Different authors reported significant effects of P on common bean nodule number (Yoseph

Table 4. Mean days to 50% flowering and days to 90% physiological maturity of three common bean cultivars as influenced by interaction effect of Prate and cultivars at Jimma, 2016.

Cultivar	**DF**				**DPHM**			
	P rate (P_2O_5 kg ha^{-1})							
	0	**23**	**46**	**69**	**0**	**23**	**46**	**69**
Ibbado	48.33^{ab}	47.33^{bc}	47.33^{bc}	46.00^{de}	88.67^{b}	87.00^{c}	86.00^{c}	82.67^{e}
Tatu	45.67^{de}	45.00^{ef}	44.33^{f}	40.00^{g}	84.00^{d}	82.33^{e}	81.00^{f}	78.00^{g}
Remeda	49.00^{a}	48.33^{ab}	47.67^{bc}	46.67^{dc}	92.00^{a}	91.60^{a}	89.33^{b}	89.00^{b}
CV (%)		1.35				0.86		
LSD $_{(0.05)}$		1.05				1.25		

DF: Days to 50% flower; DPHM: days to 90% physiological maturity; CV: coefficient of variation; LSD: least significant difference. Means within the same factor and column followed by the same letter are not significantly different at 5% level of significance.

and Worku, 2014; Amare et al., 2014). The present result was also consistent with Tesfaye et al. (2015) on soybean that had showed nodule initiation increased as P nutrition increases. Moreover, the improvement in nodule number due to P fertilizer could be associated with its stimulating effect on growth as described by Tang et al. (2001). The variation in cultivars in nodule number under fertilizer treatment could be related to inherent symbiotic characteristics of common bean cultivars.

Days to 50% flowering

The interaction of cultivars and P rates had significant ($P < 0.01$) effect on days to 50% flowering. Cultivar Tatu was earlier to flower when 69 kg P_2O_5 ha^{-1} was applied. While cultivar Remeda took the longest days to flower at 0 kg P_2O_5 ha^{-1} (Table 4). Early flowering probably due to P increased cytokinins synthesis and enhanced photosynthates and flower formation in common bean (Tesfaye and Alemayehu, 2015). Moreover, significant variations among different levels of P application might be due to the fact that P fertilizer fastens flowering, photosynthesis and assimilate partitioning of crop from source to sink which is mainly determined by the ability of crop to utilize P (Iqbal et al., 2003). Adequate P enhances many aspects of plant physiology like fundamental process of photosynthesis, flowering, seed formation and maturation (Brady and Weil, 2002). On other hand, longest days to flower might be due to the fact that cultivars produce additional nodes after initial flowering and cultivars have different genetic characteristics. The present finding is in agreement with Beruktawit et al. (2012) who reported that significant differences were detected among cultivars of common bean on days to flowering.

Days to 90% physiological maturity

The interaction effect of cultivars and P rates had significant ($P < 0.01$) effect on days to 90% physiological maturity. Shorter number of days was recorded for cultivar Tatu when it was fertilized with a P rate of 69 kg P_2O_5 ha^{-1} while Remeda cultivar that received 0 kg P_2O_5 ha^{-1} took longer number of days to physiological maturity (Table 4). The days to maturity in the present study was within the range of 45 to 150 days as reported by Singh (1982) for common bean seed depending on the type of growth habit and location (Kelly et al., 1987). This could be due to the fact that P fertilizer enhanced the physiological maturity of plants and cultivars also exhibited different days to physiological maturity genetically. This result is in agreement with, Tesfaye et al. (2015) who reported that significant variations were found among the different levels of P application for physiological maturity period in common bean. Havlin et al. (1999) also indicated that ample P nutrition could reduce the time required for seed ripening. Likewise, Marshier (2002) also reported that P could reduce days to physiological maturity by controlling some key enzyme reactions that involve in hastening crop maturity.

Number of pods per plant

The productive potential of common bean is ultimately determined by number of pods per plant which is the main yield component. Number of pods per plant was significantly ($P<0.01$) influenced by the interaction effect of cultivar and P fertilizer rate. The results showed that Tatu cultivar produced the highest number of pods per plant when 69 kg P_2O_5 ha^{-1} was applied, whereas the lowest number of pods per plant was recorded from Ibbado cultivar that received 0 kg P_2O_5 ha^{-1} (Table 5). The variation on the number of pods per plant might be primarily related to the genotypic variation of the common bean cultivars. In general, the number of pods per plant significantly increased in response to increasing the rate of P up-to 69 kg P_2O_5 ha^{-1}. The increment in the number of pods per plant might be due the metabolic role that P plays in promoting the reproductive growth of the crop

Table 5. Mean number of pod per plant, pod length and number of seeds per pod on common bean cultivars as influenced by interaction effect of P rate and cultivars at Jimma, 2016.

P rates (P_2O_5 kg ha^{-1})	NPPP			PDL (cm)			NSPP		
	Cultivars								
	Ibbado	Tatu	Remeda	Ibbado	Tatu	Remeda	Ibbado	Tatu	Remeda
0	2.80^{h}	4.93^{fg}	4.57^{g}	9.46^{e}	9.75^{de}	9.83^{cde}	2.61^{f}	3.11^{cd}	2.65^{ef}
23	5.47^{fg}	6.53^{de}	5.83^{ef}	9.77^{cde}	10.10^{bcd}	10.01^{cde}	2.83^{def}	3.52^{bc}	2.77^{def}
46	7.07^{cd}	9.03^{b}	7.97^{c}	9.87^{cde}	10.33^{bc}	10.07^{bcd}	3.11^{cd}	3.83^{b}	3.36^{c}
69	9.17^{b}	11.83^{a}	9.50^{b}	10.14^{bcd}	11.44^{a}	10.59^{b}	3.51^{bc}	4.62^{a}	3.59^{bc}
CV (%)	-	7.91	-	-	3.6	-	-	7.7	-
LSD $_{(0.05)}$	-	0.94	-	-	0.57	-	-	0.43	-

NPPP: Number of pod per plant; PDL: pod length; NSPP: number of seeds per pod; CV: coefficient of variation; LSD: least significant difference. Means within the same factor and column followed by the same letter are not significantly different at 5% level of significance.

(Rafat and Sharifi, 2015). Besides, the improvement in the number of pods due to P could result from availability of plant nutrient which stimulated the plants to produce more pods per plant as compared to control treatment. Although P strongly encourages flowering and pod setting in common beans (Zafal et al., 2003). This result was in line with different authors, who reported that significant variations in the number of pods per plant on different crops including common bean due to P applications (Mesfin, 2014; Tesfaye et al., 2015; Dereje et al., 2016).

Pod length

Analysis of variance showed significant ($P<0.05$) variation in pod length due to the interaction effect of cultivar and P fertilizer rate. The results showed that Tatu cultivar produced the longest pod length at 69 kg P_2O_5 ha^{-1}. The smallest pod length was recorded from Ibbado cultivar with no P application (Table 5). Longer pod formation due to application of P might be attributed to improvement in growth attributes owing to improved availability of P that could play an important role in cell division (Zafar et al., 2013). There is better photo-assimilate translocation to other plant parts that would contribute to increase the yield attributing traits such as pod length. This result is inconformity with Dereje et al. (2016) who reported that significant effect of P application on pod length of common bean cultivars at Areka, south west Ethiopia.

Number of seeds per pod

Number of seeds per pod is perceived as a significant constituent that directly imparts in exploiting potential yield recovery in leguminous crops (Devi et al., 2012). Number of seeds per pod was significantly ($P<0.05$) influenced by the interaction of cultivars and P fertilizer rate. The results showed that Tatu produced the highest seeds per pod when 69 kg P_2O_5 ha^{-1} was applied. The lowest number of seeds per pod was recorded from Ibbado without P application (Table 5). The result may be attributed to the fact that applying P fertilizer increases crop growth and yield on soils which are naturally low in available P and in soils that have been sorbed (Mullins, 2001). This result agreed with Mesfin et al. (2014) who reported that number of seeds per pod was significantly affected by interaction effects of common bean cultivars and P on Nitisols at Boloso sore and Damot Woreda of Wolayita Zone.

Dry biomass yield

Interaction effect of cultivars and P rates had highly significantly effect ($P<0.01$) on dry biomass yield. Mean dry biomass yield of common bean cultivars varied across different rates of P. The maximum dry biomass yield was produced by Tatu from plots that received 69 kg P_2O_5 ha^{-1} while the minimum biomass was produced by Ibbado without P application. But the dry biomass produced by Ibbado and Remeda grown at both the highest and lowest P (control) was statistically similar (Table 6). The variation in dry biomass yield of the cultivars across P levels might be attributed to enhanced availability of P for root growth and number of nodules by which it increases nutrient absorption that contribute to full development of above ground parts of the plants and genotypic variations of the cultivars in leaf area index and number of branch, which may affect photosynthesis and photo-assimilate synthesis (Fujita et al., 1999). Furthermore, the significant increment in total dry mater might be ascribed to improvement in yield and yield components as demonstrated by Malik et al. (2006). Regarding cultivars, the response to applied P could be attributed to genotypic characteristics. Consistent with these results, Dereje et al. (2016) reported significant increases in biomass yield in response to P application. In a similar study, Mourice and Tryphone (2012) reported

Table 6. Mean dry biomass yield, hundred seed weight and seed yield on common bean cultivars as influenced by interaction effect of P rate and cultivars at Jimma, 2016.

P rates (P_2O_5 kg ha^{-1})	DBY (kg ha^{-1})			HSW (g)			SY (kg ha^{-1})		
	Cultivars								
	Ibbado	Tatu	Remeda	Ibbado	Tatu	Remeda	Ibbado	Tatu	Remeda
0	3080.3^{g}	3697.7^{ef}	3291.7^{fg}	25.43^{i}	28.37^{fgh}	27.63^{gh}	1402.3^{h}	1666.7^{fg}	1494.0^{gh}
23	3701.3^{ef}	4699.7^{bc}	3942.7^{de}	26.64^{hi}	31.91^{bcd}	29.82^{def}	1704.7^{fg}	2162.0^{c}	1835.7^{ef}
46	3944.7^{de}	5137.7^{b}	4374.0^{cd}	28.90^{efg}	33.24^{b}	30.97^{cde}	1896.3^{def}	2496.0^{b}	2093.3^{cde}
69	4426.0^{c}	5874.0^{a}	4815.7^{bc}	30.73^{de}	37.75^{a}	32.96^{bc}	2148.7^{cd}	2821.0^{a}	2349.7^{bc}
CV (%)	-	6.69	-	-	4.24	-	-	7.66	-
LSD$_{(0.05)}$	-	479.55	-	-	2.17	-	-	258.92	-

DBY: Dry biomass yield; HSW: hundred seed weight; SY: seed yield; CV: coefficient of variation; LSD: least significant difference. Means within the same factor and column followed by the same letter are not significantly different at 5% level of significance.

that common bean cultivars produced different dry matter at different P level. In other words, the cultivars have different fertilizer requirements. In contrast, Tesfaye et al. (2015) reported that application of P fertilizer on soybean did not significantly affect the above ground dry biomass yield.

Hundred seed weight

Hundred seed weight is also an important yield component which reflects the magnitude of seed development which ultimately reflects on the final yield of a crop. The results of analysis of variance showed that the interaction effect of P rates and cultivars significantly ($P<0.05$) influenced 100-seed weight. Hundred seed weight was the highest for Tatu cultivar at 69 kg P_2O_5 ha^{-1} whereas it was the lowest for Ibbado cultivar without P application (Table 6). The increase in hundred seed weight as a result of increased P application might be attributed to important roles that P played in regenerative growth of the crop (Zafar et al., 2013), leading to increased seed size which in turn may improve hundred seed weight. In a similar study, Amare et al. (2014) and Dereje et al. (2016) observed significant variations in hundred seed weights of common bean cultivars as a result of P application. Thus, application of P might improve the seed quality of beans.

Seed yield

Seed yield was significantly ($P<0.01$) affected by the interaction effect of cultivar and P rates. The results showed that Tatu cultivar produced the highest seed yield at 69 kg P_2O_5 ha^{-1}. The lowest seed yield was recorded from Ibbado cultivar without P application. But seed yield obtained from Ibbado and Remeda at control was statistically similar (Table 6). Moreover, application of P showed (69.25%) seed yield increment on Tatu cultivars treated with 69 kg P_2O_5 ha^{-1} as compared to control plot. Whereas, inter varietal variation showed (31.12 and 20.57%) seed yield increment by Tatu as compared to Ibbado and Remeda from the rate of 69 kg P_2O_5 ha^{-1}, respectively. Differences in seed yield among the common bean cultivars might be related to the genotypic variations for P use efficiency (Fageria et al., 2010; Dereje et al., 2016), which may arise from variation in P acquisition (Lynch, 1995) and translocation and use of absorbed P for seed formation (Shen et al., 2011). Hence, the cultivars which gave higher seed yield might have either better ability to absorb the applied P from the soil solution or translocation and use the absorbed P into plant biomass and seed yield, which is related to reduce P requirement in plant tissues than the low yielding cultivar (Blair et al., 2009). Similarly, increase in seed yield might be attributed to overall improvement in growth attributes such as number of primary branch and aboveground dry biomass yield, thereby increasing yield attributing traits such as number of pods per plant, number of seed per pod and hundred seed weight upon partitioning, which also showed an increasing trend as a result of P application.

Moreover, seed yield had significantly and positively correlated with number of pods per plant, number of seeds per pod and hundred seed weight (Table 10). Findings of this study is in agreement with other authors (Gobeze and Legese, 2015; Dereje et al., 2016) who observed significant variations in seed yield for different crops including common bean. Different authors also reported association of increase in these yield attributing traits with increase in seed yield (Sofi et al., 2011; Amare et al., 2014). This result is consistent with, Gifole et al. (2011) and Gobeze and Legese (2015) who reported significant increases in the seed yields of common bean in response to P application under field and greenhouse conditions. In contrast, Tolera et al. (2005) reported a non-significant effect of P application on seed yield of climbing bean intercropped with maize at Bako, Western Oromia region of Ethiopia on acid soil.

Table 7. Mean P uptake by seed, straw and total P uptake of common bean as influenced by interaction effect of cultivars and P rate at Jimma, 2016.

P rates (P_2O_5 kg ha^{-1})	PUS (kg ha^{-1})			PUSt (kg ha^{-1})			TPU (kg ha^{-1})		
	Cultivars								
	Ibbado	Tatu	Remeda	Ibbado	Tatu	Remeda	Ibbado	Tatu	Remeda
0	11.33^{g}	11.65^{f}	11.45^{fg}	5.91^{f}	6.43^{e}	6.20^{ef}	17.24^{j}	18.08^{i}	17.66^{ij}
23	12.36^{e}	12.61^{e}	12.46^{e}	6.50^{e}	7.47^{d}	6.47^{e}	18.86^{h}	20.08^{ef}	18.93^{gh}
46	12.97^{d}	13.51^{c}	13.15^{d}	6.61^{e}	8.06^{bc}	7.48^{d}	19.57^{fg}	21.57^{c}	20.63^{de}
69	13.24^{cd}	14.68^{a}	14.01^{b}	7.78^{cd}	8.66^{a}	8.01^{b}	21.02^{cd}	23.34^{a}	22.31^{b}
CV (%)	-	1.31	-	-	3.9	-	-	1.92	-
LSD $_{(0.05)}$	-	0.28	-	-	0.47	-	-	0.64	-

PUS: P uptake by seed; PUSt: P uptake by straw; TPU: total P uptake; CV: coefficient of variation; LSD: least significant difference. Means within the same factor and column followed by the same letter are not significantly different at 5% level of significance.

The lowest seed yield at the control plots could be explained by the fact that essential plant nutrients are deficient that can limit plant growth, flower number, pod setting and development. The present result is in line with Amare et al. (2014) who described that seed yield decreased without application of p fertilizer.

Seed, straw and total P uptake

Interaction effect of cultivars and P rates showed significant ($P<0.01$) variation on seed, straw and total P uptake. In general, the highest mean seed, straw and total P uptake was observed from Tatu when 69 kg P_2O_5 ha^{-1} was applied. However, the lowest of seed, straw and total P uptake was recorded from Ibbado at control (0 kg P_2O_5 ha^{-1}), respectively (Table 7). The seed P uptake accounted for 62.89% of the maximum total P uptake, whereas straw P accounted for 37.1%. Therefore, the variation in seed, straw and total P uptake might be due to plant root architecture regulates the capacity of soil explored by roots, thereby playing a central role in P acquisition. Since P content and availability are more in top than in subsoil, root architectural traits that allow the exploration and use of P from surface layers govern P acquisition (Beebe et al., 2010). Cichy et al. (2009) observed that the shallower the basal root angle the greater the total root length and root length of basal roots in the top 3 cm area, will help for greater P uptake. Thus, the difference in these root traits elucidates the differences among common bean genotypes in P acquisition efficiency. Furthermore, total P uptake had highly significantly and positively correlated average root length (Table 10). The results are in conformity with Gifole et al. (2011) who reported that application of P fertilizer highly significantly influenced the concentration of P in seed. Similarly, Dereje et al. (2016) observed that leaf P concentration varied by interaction effect of common bean cultivars and P. Tesfaye et al. (2015) reported that total P uptake by soybean was significantly affected by P application.

Phosphorus recovery (PR)

Analysis of variance showed that the interaction effect of cultivars and P rates significantly ($P<0.01$) influenced P recovery. The results showed that Tatu recorded the highest P recovery when 23 kg P_2O_5 ha^{-1} was applied. The lowest P recovery was recorded from Ibbado with 69 kg P_2O_5 ha^{-1}. However, the differences in P recovery between (46 kg P_2O_5 ha^{-1}) and (69 kg P_2O_5 ha^{-1}) were observed to be statistically similar (Table 8). The low recovery efficiency in the present study may be associated with high rate of P fixation in this soil due to the presence of Al and Fe compounds and clay minerals (Chaudhary et al., 2003). The differences in P recovery efficiency of common bean genotypes might be related to differences in their P uptake ability (Lynch, 1995). Similar result was also reported by Tesfaye et al. (2015) that the highest and lowest PR (12.52- 7.98%) was recorded with P rates ranging from 23 to 46 kg P_2O_5 ha^{-1} in soybean, respectively.

Agronomic efficiency

Agronomic efficiency (AE) was significantly ($P<0.01$) affected by the interaction effect of cultivars and P rates. The highest AE was obtained by Tatu when it was grown at application of 23 kg P_2O_5 ha^{-1}. The lowest agronomic efficiency was recorded from Ibbado at 46 kg P_2O_5 ha^{-1}. But the agronomic efficiency was recorded at 46 kg P_2O_5 ha^{-1} and 69 kg P_2O_5 ha^{-1} was not statistically different (Table 8). Agronomic efficiency showed that the increased grain yield for a unit of fertilizer P applied. As to the present experiment, the decrease in agronomic efficiency with the increase in P supply was reported for common bean (Girma et al., 2014) and soybean (Devi et al., 2012). This could be due to the limiting effect of other

Table 8. Mean Phosphorus recovery and P utilization efficiency of common bean as influenced by interaction effect of cultivars and P rate at Jimma, 2016.

P rates (P_2O_5 kg ha^{-1})	PR (%)			AE (kg kg^{-1})		
	Cultivars					
	Ibbado	Tatu	Remeda	Ibbado	Tatu	Remeda
0	-	-	-	-	-	-
23	7.0^{b}	8.7^{a}	7.0^{b}	15.9^{bc}	21.5^{a}	17.3^{b}
46	5.5^{cd}	7.2^{b}	6.5^{bc}	10.7^{d}	17.4^{b}	13.0^{cd}
69	5.1^{d}	7.3^{b}	6.7^{bc}	10.8^{d}	16.7^{b}	12.4^{cd}
CV (%)	-	15.4	-	-	19.3	-
LSD $_{(0.05)}$	-	1.3	-	-	3.9	-

PR: P recovery; AE: agronomic efficiency; CV: coefficient of variation LSD: least significant difference. Means within the same factor and column followed by the same letter are not significantly different at 5% level of significance.

Table 9. Mean of physiological efficiency and phosphorus utilization efficiency on common bean cultivars as influenced by interaction effect of cultivars and P rate at Jimma, 2016.

P rates (P_2O_5 kg ha^{-1})	PE (kg kg^{-1})			PUtE (kg kg^{-1})		
	Cultivars					
	Ibbado	Tatu	Remeda	Ibbado	Tatu	Remeda
0	-	-	-	-	-	-
23	149.7^{f}	211.7^{cde}	190.7^{de}	10.00^{d}	17.07^{ab}	12.28^{cd}
46	200.7^{cd}	281.3^{a}	225.3^{bcd}	11.01^{cd}	20.53^{a}	13.66^{bc}
69	190.7^{de}	244.7^{ab}	179.0^{ef}	11.53^{cd}	17.86^{ab}	14.03^{bc}
CV (%)	-	18.17	-	-	13.45	

PE: Physiological efficiency; PUtE: P utilization efficiency; CV: coefficient of variation; LSD: least significant difference. Means within the same factor and column followed by the same letter are not significantly different at 5% level of significance.

nutrients with increasing level of P (Mengel and Kirby, 2001), or because the rate of increase in seed yield was less than the rate of increase in P supply. Similarly, Dereje et al. (2016) reported higher AE by the interaction effect of P and common bean cultivars was recorded at low P rate. The decreasing trend in AE with increasing P rates was also reported by Gifole et al. (2011) who found a declining trend of agronomic efficiency (AE) from 69.8 to 9.3 kg kg^{-1} at the rates of P ranging from 23 to 137.4 kg P_2O_5 ha^{-1}.

Physiological efficiency (PE)

Interaction effect of cultivars and P rates showed significant ($P<0.01$) variation on physiological efficiency. The highest physiological efficiency (PE) was obtained by Tatu cultivars at 46 kg P_2O_5 ha^{-1} and the lowest value of physiological efficiency (PE) was recorded by Ibbado when 23 kg P_2O_5 ha^{-1} was applied. Furthermore, PE value recorded from application of 69 kg P_2O_5 ha^{-1} was not statistically different from that recorded from 46 kg P_2O_5 ha^{-1} (Table 9). The highest physiological efficiency of common bean cultivars might be the yield increases in relation to increase in crop uptake of the nutrient in the above ground part of the plants; relatively the highest portion was used in seed formation at the rate of 46 kg P_2O_5 ha^{-1}, whereas the lowest was used at 23 kg P_2O_5 ha^{-1}. The percent result is in agreement with Tesfaye et al. (2015) who reported that, application of 69 kg P_2O_5 ha^{-1} is optimum to obtain the highest physiological efficiencies on soybean.

Phosphorus utilization efficiency (PUtE)

Analysis of variance showed that the interaction effect of cultivars and P rates significantly ($P < 0.01$) influenced P utilization efficiency. The highest result of PUtE was obtained by Tatu when it has been grown on 46 kg P_2O_5 ha^{-1}. While the lowest PUtE was obtained by Ibbado that have been grown on 23 kg P_2O_5 ha^{-1}. But value obtained from P rate of 46 and 69 kg P_2O_5 ha^{-1} was statistically similar (Table 9). The highest P utilization efficiency of the efficient common bean cultivars might be linked to re-translocation of P from vegetative part and better

Table 10. Pearson correlation.

Correlation	ARL	NNPP	NDW	NPPP	NSPP	DBY	HSW	HI	SY	TPU	PRE	AE	PUtE
ARL	1	0.71**	0.76**	0.91**	0.73**	0.83**	0.76**	0.81**	0.86**	0.91**	0.67**	0.60**	0.76**
NNPP		1	0.88**	0.75**	0.83**	0.83**	0.77**	0.52**	0.82**	0.74**	0.54*	0.55*	0.66**
NDW			1	0.83**	0.85**	0.89**	0.83**	0.6**	0.88**	0.81**	0.62**	0.63**	0.86**
NPPP				1	0.81**	0.9**	0.89**	0.81**	0.93**	0.96**	0.63**	0.57*	0.84**
NSPPD					1	0.82**	0.83**	0.49**	0.8**	0.83**	0.57*	0.48*	0.72**
DBY						1	0.94**	-0.68**	0.99**	0.93**	0.66**	0.68**	0.97**
HSW							1	0.62**	0.93**	0.9**	0.59**	0.58**	0.89**
HI								1	0.75**	0.77**	0.50*	0.49*	0.7**
SY									1	0.94**	0.65**	0.69**	0.97**
TPU										1	0.70**	0.61**	0.84**
PRE											1	0.91**	0.90**
AE												1	0.93**
PUtE													1

ARL: Average root length; NNPP: number of nodule per plant; NDW: nodule dry weight; NPPP: number of pod per plants; NSPP: number of seed per pod; DBY: dry biomass yield; HSW: hundred seed weight; HI: harvest index; SY: seed yield; TPU: total P uptake; PRE: phosphorus recovery efficiency; AE: agronomic efficiency; PUtE: P utilization efficiency; NS: non-significant; * Correlation is significant at the 0.05 level. **Significant at the 0.01 level.

utilization of the trans-located P for seed formation (Shen et al., 2011). Differences in PUtE of common bean cultivars might be related to differences in their P uptake ability (Lynch, 1995), which is mainly dependent on root morphological characteristics (Ortiz-Monasterio et al., 2001). This implies that P efficient cultivars are more productive than P inefficient cultivars both under P deficient and P-sufficient conditions. Fageria et al. (2010) reported similar findings for efficient and inefficient common bean cultivars under P adequate and inadequate conditions. Greater P acquisition enables crops to accumulate more P in their tissue than inefficient crops when grown under P deficient soils (White et al., 2005). Higher P efficiency is associated with higher P uptake efficiency of plants (Nigussie et al., 2004). The present finding is in line with Dereje et al. (2016) who confirmed the varying response of PUtE of common bean cultivars at different rates of soil applied P.

Correlation analysis

Person's correlation analysis was done to show the association between yield and yield components as well as P uptake and use efficiency parameters (Table 10). A positive and highly significant correlation was obtained between root length and seed yield and root length was also highly significantly and positively correlated with number of nodules (r = 0.71^{**}), nodule dry weight (r = 0.76^{**}) and seed yield (r = 0.86^{**}). Number of pods per plant was highly and positively associated with seed yield (r= 0.93^{**}). Similarly, number of seeds per pod showed positive and highly significant correlation with seed yield (r = 0.8^{**}) and dry biomass yield (r = 0.82^{**}). This implies the higher number of pod per plants contributed to increased yield by increasing the number of seed. This result is in agreement with Beruktawit et al. (2012) who reported that seed yield was highly correlated with number of pods per plant, seeds per pod, dry biomass yield and hundred seed weight. Correlation analysis showed that number of nodules had significantly and positively correlated with seed yield (r = 0.82^{**}), total P uptake(r = 0.74^{**}) and P utilization efficiency (r = 0.66^{**}). Nodule number was significantly and positively associated phosphorus recovery (r = 0.54^{*}) and agronomic efficiency (r = 0.55^{*}). Likewise, 100-seed weight (r = 0.93^{**}), harvest index (r= 0.75^{**}), and seed yield were positively and highly significantly correlated total P uptake (r = 0.94^{**}). Moreover, recovery (r = 0.65^{**}), agronomic (r = 0.67^{**}) and utilization efficiency was positive and highly significantly correlated with seed yield (r = 0.97^{**}) and total P uptake (r = 0.84^{**}). Harvest index also showed a positive and highly significant correlation with number of pods per plant (r = 0.69**), 100-seed weight (r = 0.79**). But, the correlation between dry biomass yield and harvest index was highly significantly and negatively correlated (r =-0.68**), indicating that as the above ground dry biomass decreased, the harvest index increase due to more proportion of seed yield. This implies that applied phosphorus had more contribution to seed yield production. Interestingly, the increase in harvest index almost fully accounted for the progressive increase in the grain yield potential of common bean.

Conclusion

Field experiment was conducted on common bean cultivars against various rates of phosphorus at JUCAVM research site in 2016. The treatments were laid out using randomized complete block design. The results of this study showed that growth and yield parameters of common bean such as total root length, number of nodules per plant, nodule dry weight, days to 50% flowers, days to 90% maturity, number of pods per plant, seeds per pod, dry biomass yield and 100-seed weight of the crop increased as a result of interaction effect of cultivars and P rates. However, maximum seed yield was obtained from Tatu cultivar at 69 kg P_2O_5 ha^{-1}. Dry biomass yield (5874 kg ha^{-1}) and seed yield (2821 kg ha^{-1}) were obtained from the treatment combination of cultivar Tatu and 69 kg P_2O_5 ha^{-1}. Compared to Ibbado and Remeda, Tatu cultivar gave a yield advantage of 31.12 and 20.57% when grown at 69 kg P_2O_5 ha^{-1}.Likewise, interaction effect of cultivars and P significantly influenced P uptake in seed, straw, and total P. In general, the highest mean seed, straw and total P uptake was observed by Tatu (14.68, 8.66 and 23.34 kg ha^{-1}) when 69 kg P_2O_5 ha^{-1} was applied respectively. The P use efficiency parameters (recovery efficiency and agronomic efficiency) were significantly affected by the combined effect of cultivar and P application rate. Cultivar Tatu was found to be more P efficient at P rate of 23 kg P_2O_5 ha^{-1}. Whereas, P utilization efficiency and physiological efficiency increased when P rate increases; highest P utilization efficiency (20.53kg kg^{-1}) and physiological efficiency (281.3 kg kg^{-1}) were obtained by Tatu cultivars that received 46 kg P_2O_5 ha^{-1}, respectively. Correlation analysis indicates that number of nodules was significantly and positively correlated with seed yield, total P uptake and P utilization efficiency. More importantly, seed yield was significantly and positively correlated with total P uptake and P utilization efficiency.

The correlation between dry biomass yield and harvest index was significant but negative. This implies that applied phosphorus had more contribution to seed yield. In conclusion, the study pointed out that common bean cultivars responded differently to the various P application rates suggesting the possibility of exploiting cultivar differences to combat P deficiency under acidic soil. Phosphorus at the rate of 23 kg ha^{-1} will be recommendable for P-efficient cultivar based on phosphorus use efficiency parameters. Accordingly, farmer who has no capacity to buy fertilizer cultivar Tatu was recommended to specific soil of the study area. However, since the data is only for one season and location repeating the experiment across location may be helpful to validate the results.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Yield and agronomic performances of desi type chickpea genotypes against acidic soil of Western Ethiopia

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Currently, 40% of arable land in Ethiopia is affected by acidity and particularly the soil acidity problem that occurs in central and western zones of Oromia deserves immediate intervention for crop production. The objective of the present study was to examine responses of Desi type chickpea varieties against acidic soil of western Ethiopia. Pooled analysis of variance (ANOVA) indicated significant difference among genotypes indicating differential response of chickpea genotypes to acidic soil. The combined mean of genotypes indicates that Natoli and DZ-2012-CK-20113-2-0042 were top yielders. Differential response of chickpea genotypes indicates the possibilities of designing better chickpea breeding strategies that aim at screening large germplasms of chickpea genotypes for soil acidity tolerance and thereby developing a cultivar(s) with wider adaptations.

Key words: Chickpea (*Cicer arietinum* L.), yield, soil acidity, liming.

INTRODUCTION

Pulses play a significant role in sustaining food security, balancing ecosystem, and generating revenue in Ethiopia. Chickpea (*Cicer arietinum* L.) is the most important food legumes grown in Ethiopia. Although the ecological and economic contribution of chickpea is high, its productivity is by far below its potential because of the several biophysical and socioeconomic constraints in Ethiopia (Keneni et al., 2012).

Biotic and abiotic stresses cause significant economic losses to this crop (Datta et al., 2008). Among these factors, abiotic stresses due to soil acidity were one of the major factors that hamper chickpea productivity with worldwide distribution. Acidic soils limit crop production on 30-40% of the world's arable land and up to 70% of the world's potentially arable land. In Ethiopia 40% of arable land is currently affected by acidity and particularly the soil acidity problem that occurs in central and western zones of Oromia deserves immediate intervention and amelioration for crop production (Batjes, 1995; Abdenna et al., 2007; Abebe, 2007).

Soil pH is probably the most important principal chemical soil parameter and it mirrors the overall chemical status of the soil and influences a whole range of chemical and biological processes occurring in the soils. Most plants and soil organisms prefer pH range between 6.0 and 7.5 (Hazelton and Murphy, 2007; Hall,

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Table 1. Passport description of the test genotypes.

Genotype codes	Genotype names	Status	Year of release
G1	Akaki	Released	1995
G2	Dalota	Released	2013
G3	Dimtu	Released	2012
G4	Dubie	Released	1978
G5	Local	Local variety	-
G6	Mariye	Released	1985
G7	Minjar	Released	2010
G8	Natoli	Released	2007
G9	Teketay	Released	2013
G10	DZ-2012-CK-0032	Advanced line	-
G11	DZ-2012-CK-0034	Advanced line	-
G12	DZ-2012-CK-0233	Advanced line	-
G13	DZ-2012-CK-0237	Advanced line	-
G14	DZ-2012-CK-0312	Advanced line	-
G15	DZ-2012-CK-0313	Advanced line	-
G16	DZ-2012-CK-20113-2-0042	Advanced line	-

2008). Different scholars reported the pH of the soils in western Ethiopia is in acidic range and it needs immediate intervention and ameliorations for crop production (Chimdi et al., 2012; Deressa et al., 2013). Under such low pH, the availability of essential nutrients is critically affected. Moreover, the activities of microorganisms, which play pivotal roles in nutrient cycling in agro ecosystems, are affected (Addisu, 2007).

Several strategies have been pursued to manage acid soils including an application of lime (calcium carbonate) to raise soil pH to less toxic forms. Nevertheless, because of a topographic feature of the lands, affordability and logistics reasons, application of lime is not practicable for resource-poor farmers. Furthermore, soil pH below plow layer is raised very slowly by liming (Dall'Agnol et al., 1996).

Consequently, these reasons direct a need of developing cultivars that are adapted to acid soil complexes as a promising alternative for resource-poor farmers. Therefore, morphological characterization of plants that better tolerate acidity under the usual condition and give rise better yield and economic turn for poor farmers is a promising alternative to liming and related agronomic practices.

The present study was, therefore, conducted with the objective of examining the responses of Desi type chickpea genotypes against the acidic soils of western Ethiopia.

MATERIALS AND METHODS

Plant material and site description

Field experiment was conducted at five locations *viz.,* Shambu, Hawa Galan, Mata, Alaku Belle and Badesso, Western Ethiopia, during the 2016/2017 main cropping season. A total of 16 Desi type chickpea varieties *viz.,* 8 cultivars released over three decades, 1 local variety and 7 advanced lines introduced from Debre Zeit Agricultural Research Center (DZARC) were used (Table 1).

The experiment was laid out in a randomized complete block design (RCBD) with three replicates. The plot size was six rows of three-meter length (5.4 m^2). The central four rows were harvested to determine seed yield. Diammonium phosphate fertilizer (DAP) with a rate of 100 kg/ha was used and all other crop management and protection practices were applied uniformly as recommended.

Soil samples were collected and composited from each of the experimental sites at the depth of 0 to 20 cm using an auger to analyze the chemical properties of the soil. Description of the test locations for geographical position and the chemical properties of the soils in the study area are presented (Table 2).

Data collection and statistical analysis

Days to 50% flowering, days to 90% maturity, grain filling duration, number of pods per plant, number of seeds per pod, plant height, number of branches per plant, hundred seed weight, and grain yield data were collected based on chickpea (*Cicer arietinum* L.) descriptor (IBPGR, ICRISAT and ICARDA, 1993) and were subjected to analysis using statistical analysis software (SAS Inc., 2003).

RESULTS AND DISCUSSION

Analysis of variance

Pooled analysis of variance indicated highly significant differences for genotypes, environments and genotype × environment interaction (G×E). Variance component of sum squares were 55% for environments, 11% for genotypes and 12% for G×E. This indicated that

Table 2. Description of the test locations for geographical position and soil chemical properties.

Parameters	Sites				
	Shambu	**H. Galan**	**Mata**	**A. Belle**	**Badesso**
Latitude	09° 32'N	08° 38' N	08° 34' N	08° 37'N	08° 40' N
Longitude	037° 04'E	034° 50'E	034° 44'E	034° 42'E	034°47'E
Altitude (m.a.s.l.)	2776	1905	2016	2050	2054
Organic C (%)	4.01	3.27	3.64	3.95	3.61
TN (%)	0.40	0.22	0.33	0.33	0.37
pH (H_2O 1:2:5)	4.59	4.96	5.3	5.19	5.26
pH (KCl 1:2:5)	4.09	4.3	4.59	4.44	4.65
Exchangeable acidity	1.35	0.3	0.07	0.24	0.14
Exchangeable Al^{+3}	0.66	ND	ND	ND	ND
EC (S/m)	0.27	0.06	0.06	0.17	0.09
CEC	41.53	28.52	36.16	35.74	36.07
Na	0.16	0.1	0.13	0.24	0.09
K	0.34	0.81	0.06	1.13	1.26
Ca	8.1	11.55	16.69	19.11	11.77
Mg	4.6	3.85	7.7	5.46	9.42

Key: ND =Not detected.

Table 3. Combined analysis of variance of grain yield (t/ha) of chickpea genotypes tested across five environments.

Source of variation	DF	SS	MS
Environments (E)	4	79.62	19.9^{***}
Block (B)	10	10.62	1.06^{***}
Genotypes (G)	15	15.89	1.05^{***}
G×E	60	17.56	0.29^{***}
Error	150	19.76	0.13
Total	239	143.45	-
CV (%)	21.7	-	-
LSD	0.262	-	-
R^2	87%	-	-
Grand mean	1.67	-	-

environmental factors played a leading role for the variability observed among chickpea genotypes in western Ethiopia. In addition to the environmental factors, the contribution of G×E was also appreciable. The significant G×E suggests that grain yield of chickpea genotypes varied across environmental conditions (Table 3).

Yield performance

The mean grain yield of the sixteen genotypes tested at five environments of Western Ethiopia indicated statistically significant difference among genotypes. At Alaku Belle, genotype DZ-2012-CK-20113-2-0042 and Natoli were better performers while Dubie was the worst performer where the best performer genotypes exceeded it by more than two-fold.

At Badesso, genotype DZ-2012-CK-0237 performed better than any other genotype and Akaki was found to be the poorest of all at this location. At Hawa Galan and Shambu, genotype DZ-2012-CK-0032 out-performed the other genotypes while local variety was the poorest performer at both the locations. At Mata, genotype, DZ-2012-CK-20113-2-0042 was the best performer as in Alaku Belle and the performance of the local variety was the poorest in a similar fashion it displayed in Shambu and Hawa Galan (Table 4). This result is in agreement with the report of Getachew et al. (2015) who showed inconsistent performances of chickpea genotypes in central and eastern Ethiopia.

Tolessa (2015) conducted multi-locational studies of seventeen Faba bean varieties and reported that the varieties responded differentially in southeastern and central Oromia. Similar result was noted on sesame in northern Ethiopia (Tadesse and Abay, 2011). The combined mean of genotypes indicates that Natoli and DZ-2012-CK-20113-2-0042 were top yielders though they did not differ in a statistically significant manner from Minjar, Teketay, DZ-2012-CK-0032, and DZ-2012-CK-0237 (Table 4).

Agronomic performance

Differences among the genotypes were significant for a number of characters (Table 5). A local variety included in this investigation flower early (60) and relatively mature intermediary. This indicated that local landraces had a relatively longer grain filling period.

Table 4. Pooled mean grain yields (t/ha) of chickpea genotypes tested in five environments.

Genotypes Code	Environments					
	AB	BD	HG	MT	SH	Mean
G1	1.44	0.49	1.34	2.26	0.59	1.23^{e}
G2	1.76	1.31	1.48	2.51	0.73	1.56^{dc}
G3	1.94	1.88	1.49	2.62	0.75	1.74^{bc}
G4	1.22	1.24	1.46	2.25	0.68	1.37^{de}
G5	1.25	1.80	1.17	2.15	0.40	1.35^{de}
G6	1.55	2.13	1.25	2.33	0.49	1.55^{dc}
G7	2.06	2.11	1.60	2.75	0.86	1.88^{ab}
G8	2.46	2.20	1.65	2.95	0.94	2.04^{a}
G9	1.81	2.45	1.80	2.74	1.03	1.97^{ab}
G10	1.40	2.39	1.85	2.58	1.04	1.85^{ab}
G11	1.47	1.25	1.39	2.33	0.64	1.42^{de}
G12	1.66	2.43	1.42	2.48	0.66	1.73^{bc}
G13	1.87	3.07	1.38	2.59	0.63	1.91^{ab}
G14	1.28	1.53	1.30	2.21	0.53	1.37^{de}
G15	1.50	1.98	1.66	2.51	0.88	1.7^{1bc}
G16	2.48	1.97	1.71	2.98	0.99	2.02^{a}
Mean	1.69	1.89	1.49	2.52	0.74	1.67

N.B. Different letters within a column indicate significant differences among genotypes at (P>0.05) significance level.

Similarly, Summerfield and Roberts (1988) reported early flowering genotypes do not certainly mature early and some late flowering genotypes have a short reproductive period and mature concurrently with earlier flowering ones. Wakeyo (2012) also tested 155 chickpea germplasms including landraces, improved varieties and some introduced pipelines indicating that landraces had a relatively shorter period of vegetative growth and longer grain filling periods. Except DZ-2012-CK-0032 and DZ-2012-CK-0233, all other advanced lines and improved varieties included within this study showed delayed flowering. This might be due to higher asset they employ at vegetative growth.

In contrast to this, though Natoli was late to flower (71.60); it pays its late flower by filling the grain as short as possible (64.3). Mariye (72.33), Minjar (72.47), DZ-2012-CK-20113-2-0042 (73.80) and Teketay (74.07) were also acquired a short grain filling period, whereas DZ-2012-CK-0312 was the late maturing genotype with accompanied long grain filling period (78.27). Minjar, Mariye and local landrace developed relatively higher number pods than other genotypes. Even though improved genotypes display small difference among themselves for seeds per pod; the difference with landraces was very high.

On the other hand, in terms of plant height, Mariye, Akaki, Natoli and local landraces were the shortest, whereas DZ-2012-CK-0313, Teketay, DZ-2012-CK-0312, Dubie and Dimtu were comparatively taller genotypes. Nevertheless, the pod bearing character of the local landrace, Natoli, Mariye and Minjar may not emanate from their branches. The local landraces included in this study were by far inferior by their seed weight. Wakeyo (2012) also reported that the seed size of landraces was not comparable to improved genotypes and released varieties. However, among released and advanced genotypes there were differential seed weights. Some of the released varieties namely Akaki, Dubie and Minjar also possess small seed weights. In the contrary, DZ-2012-CK-0312 and Dimtu showed higher seed weight than all the tested materials.

Overall, Natoli, Minjar, Teketay, DZ-2012-CK-0032, DZ-2012-CK-0237 and DZ-2012-CK-20113-2-0042 were the best performing genotypes. Akaki, a variety released two decades ago, was the poorest performing variety across all test environments, followed by Dubie, Local variety, DZ-2012-CK-0034 and DZ-2012-CK-0312 (Table 5).

Conclusion

This study revealed that chickpea genotypes differ in tolerance to soil acidity. Although some genotypes exhibited an outstanding performance in terms of grain yield and yield related traits, soil fertility improvement through lime application would still be very important if economical chickpea production is to be practiced in places with strong acid soil as the one used in this study and other similar growing environments. Generally, differential response of chickpea genotypes indicates the

Table 5. Pooled mean of phenological traits, yield and yield components of chickpea genotypes grown across five locations in western Ethiopia.

Genotype	Traits							
	DF	DM	GFP	NPPP	SPP	PH	BRN	HSW
1	63.47^{bcd}	138.33^{abcde}	74.87^{cde}	29.67^{cd}	1.34^{ab}	46.41^{ef}	3.78^{c}	23.64^{g}
2	62.87^{cde}	139.13^{abc}	76.27^{abcd}	28.07^{cd}	1.24^{b}	53.39^{abc}	4.04^{bc}	33.64^{b}
3	60.73^{fg}	138.73^{abcd}	78.00^{ab}	26.59^{cd}	1.16^{b}	55.47^{ab}	4.16^{bc}	36.56^{a}
4	61.53^{efg}	138.93^{abcd}	77.40^{abc}	32.15^{bcd}	1.15^{b}	54.04^{abc}	4.19^{bc}	23.46^{g}
5	60.07^{g}	138.07^{abcde}	78.00^{ab}	41.74^{a}	1.47^{a}	46.81^{def}	4.25^{bc}	14.01^{h}
6	64.87^{b}	137.20^{cde}	72.33^{e}	39.17^{ab}	1.23^{b}	44.35^{f}	4.52^{ab}	26.20^{f}
7	64.20^{bc}	136.67^{de}	72.47^{e}	42.60^{a}	1.26^{b}	52.11^{abc}	4.95^{a}	23.10^{g}
8	71.60^{a}	135.93^{e}	64.33^{f}	33.41^{bc}	1.28^{ab}	46.68^{def}	3.89^{bc}	32.40^{bcd}
9	64.87^{b}	138.93^{abcd}	74.07^{de}	29.36^{cd}	1.20^{b}	56.14^{a}	4.09^{bc}	31.70^{cd}
10	60.67^{fg}	138.60^{abcd}	77.93^{abc}	31.97^{bcd}	1.18^{b}	52.80^{abc}	4.13^{bc}	29.05^{e}
11	61.73^{defg}	139.80^{ab}	78.07^{ab}	26.05^{cd}	1.22^{b}	50.17^{cde}	3.88^{bc}	33.77^{b}
12	60.93^{fg}	138.47^{abcd}	77.53^{abc}	29.09^{cd}	1.22^{b}	53.94^{abc}	4.07^{bc}	31.10^{d}
13	64.80^{b}	139.93^{ab}	75.13^{bcde}	30.08^{cd}	1.16^{b}	51.15^{bcd}	4.36^{abc}	33.21^{bc}
14	62.20^{def}	140.47^{a}	78.27^{a}	26.37^{cd}	1.18^{b}	56.08^{a}	4.29^{bc}	38.35^{a}
15	61.8^{defg}	139.07^{abcd}	77.27^{abc}	29.46^{cd}	1.24^{b}	56.51^{a}	4.39^{abc}	32.47^{bcd}
16	64.07^{bc}	137.87^{bcde}	73.80^{de}	25.12^{d}	1.18^{b}	53.02^{abc}	3.75^{c}	31.47^{cd}
CV	4.02	2.43	5.75	32.78	21.82	11.96	21.71	8.55
R	90%	74%	80%	53%	33%	83%	45%	92%
LSD	1.83	2.43	3.12	7.4	0.19	4.47	0.65	1.83

Key: -DF=Days to flower, DM = Days to mature, GFP=Grain filling period, NPPP=Number of pods per plant, SPP=Number of seeds per pod, PH =Plant Height (cm), BRN=Number of branches, HSW=Hundred seed weight (g), GYLD=Grain yield (t/ha).

possibilities of designing better chickpea breeding strategies that aim at screening large germplasm of chickpea for soil acidity tolerance and thereby developing a cultivar(s) with wider adaptations.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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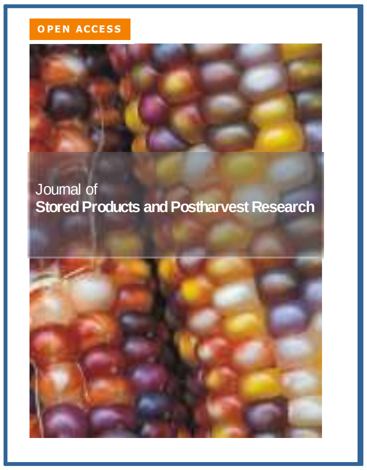

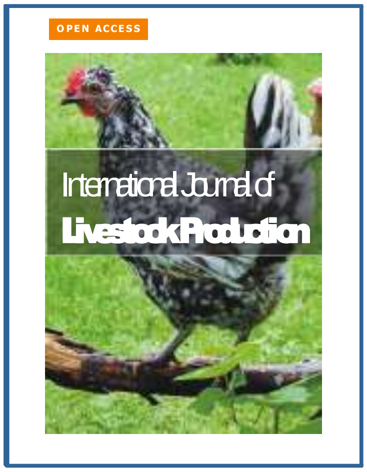

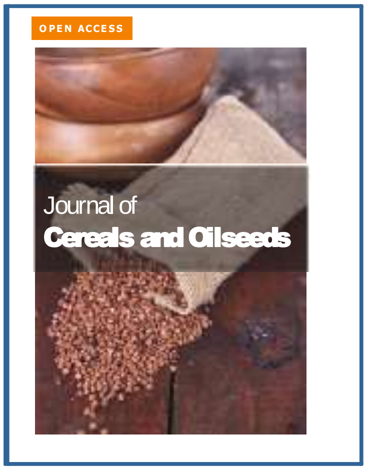

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