Original Research Article||

Phosphorus uptake and use efficiency of fenugreek (*Trigonella foenum-graecum* L.) genotypes in response to phosphorus availability, central highland, Ethiopia

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Abstract

A field experiment was conducted at Debre Zeit Agricultural Research Center in 2018 to evaluate the response of fenugreek genotypes to phosphorus availability in terms of phosphorus uptake and use efficiency. The experiment consisted of six genotypes (Bishoftu, Chala, Ebbisa, Hunda, 28605 and 28606) and four P levels (0, 9, 17 and 26 kg P ha^{-1}). The experiment was set up in completely randomized block design with factorial arrangement in three replications. The results showed that P uptake efficiency was significantly differed among the genotypes. Chala variety had better total P uptake and P uptake efficiency among the tested genotypes. Phosphorus application significantly influenced haulm P concentration, haulm P uptake, total uptake, P uptake efficiency and P utilization efficiency. Total P uptake was enhanced to the varied magnitude up to 17 kg P ha^{-1}. As P supply increased P uptake efficiency and utilization efficiency were decreased. Seed yield, seed P concentration, seed P uptake and P use efficiency were influenced by interaction effect of genotype and P supply. Based on P use efficiency expressed in seed yield; three genotypes (Bishoftu, Chala and 28606) were grouped as efficient responders. The other genotypes (Ebbisa, Hunda and, 28605) were grouped into inefficient non-responders. Therefore, the efficient responder varieties; Bishoftu and Chala can be recommended for farmers in the study area and areas of similar agro-ecology. Furthermore, 28606 accession as efficient and responder genotype for P availability can also be recommend for future improvement in fenugreek breeding programs.

Key words: Concentration**,** Efficiency, P supply, Responsive, Yield

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INTRODUCTION

Fenugreek (*Trigonella foenum-graecum* L.) is the annual herbaceous legume crop that is deliberated as one of the oldest multipurpose medicinal herbs (Paul and Pal, 2014). Due to its high protein content (32-36%) most of the time fenugreek is used to supplement low protein food crops such as rice, wheat, sorghum and tef (Uhl, 2000). It's widely cultivated in Mediterranean region that extends from west to the south (Rathore 2001). Its productivity in Ethiopia during 2017/2018 cropping season was 1.33 ton ha-1 (CSA, 2018), which is low as compared to its potential yield of 1.8 ton ha-1 (MoA, 2014). One of the primary production constraints is poor soil fertility especially P deficiency and also fenugreek crop is reported to be sensitive to P-deficient soils (Ruchita, 2008). Similar trends are expected in the study area.

Phosphorous deficiency problems can be overcome through development and use of integrated plant nutrition systems that includes the use of nutrient efficient and responder genotypes (Ahmad et al., 2001). Genotypes that are efficient in a soil with P deficiency and respond well to available P are the most desirable from a practical point of view. In acquiring of this, previous study by Wissuwa et al (2009) showed that under high input conditions modern varieties were selected, which may not have the capability of high nutrient use efficiency. Other study revealed that higher P use efficiency found with unimproved genotypes as compared with modern varieties when grown in deficient soil (Wissuwa and Ae, 2001). So far in Ethiopia, fenugreek varieties released by national research centers had showed different characteristics in growth performance and yield in response to P application (Personal communication). There is little information on the P uptake and use efficiency of fenugreek accession in Ethiopia.

Genotypic variation in P uptake and use efficiency under P availability has been reported in several legume crops such as chickpea (Keneni et al., 2015) and mung bean (Muhammad et al., 2017). However, most fenugreek breeding programs and variety evaluation trials based mainly on productivity traits, with minimum attention to resource utilization including P use efficiency and responsiveness. The information in fenugreek genotypic variation for P uptake and use efficiency under different P availability is scanty. Furthermore, the study of fenugreek genotypes yield sensitivity to P deficiency and responsiveness to available P has been limited. Therefore, improving fenugreek productivity through increasing P availability and selection of genotypes with high P use efficiency is important. Thus, the aim of this study was to evaluate fenugreek genotypes to P availability in terms of P responsiveness, uptake and use efficiencies.

MATERIALS AND METHODS

Description of the study area

A field experiment was conducted during 2018 cropping season at Debre Zeit Agricultural Research Centre (DZARC) which is located at 8° 44′ N latitude, 38° 58′ E longitudes and 1900 m. a. s. l. in Oromia Regional State, Ethiopia. The area received an annual rainfall of 690 mm during the cropping season which was higher than the mean annual rainfall (558.18 mm) of the ten last years. Mean maximum (26.84°C) and minimum (11.01°C) temperatures were recorded at the station during cropping season. The average temperature and rainfall of the cropping season were in line with prier 10 years average and suitable for fenugreek production.

Experimental materials, treatments and design

Seeds of four improved fenugreek varieties namely Bishoftu, Chala, Ebbisa and Hunda were acquired from Debre Zeit Agricultural Research Centre while seeds of two accessions named as 28605 and 28606 were obtained from Ethiopia Biodiversity Institute. The experiment consisted of 24 treatment combinations comprising of six fenugreek genotypes and four levels of P supply (0, 9, 17 and 26 kg P ha^{-1}) arranged in a factorial combination. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications.

Experimental procedure and crop management

The experimental plot was cleared and ploughed three times before it was divided into three blocks each containing 24 plots for each treatment. The experiment was set on 2 m x 1.5 m (3 m^2) plot size. The seeds were planted at 30 cm spacing between rows and 10 cm spacing between plants. The spacing between plots and block were 0.5 m and 1m, respectively. Seeds were sown in 5 rows uniformly at each plot in August 2018. Thinning was done manually after germination by maintaining healthy and vigorous seedlings, with each plot holding 100 plants. The P fertilizer was applied as triple superphosphate (TSP) (0-46-0). Treatments were randomly assigned to the experimental plots of each replication. At sowing P fertilizer was banded into the soil along rows depending on the treatment and covered with soil. A recommended dose of nitrogen (20 kg N ha^{-1}) in the form of urea was uniformly applied to all the plots.

Soil analysis

Initial soil samples from depth of 0-20 cm were collected randomly in zig-zag pattern from the entire experimental site and composited for determination of selected physicochemical properties before planting. The collected samples were allowed to air dry at room temperature and ground to pass through a 2 mm sieve. Available soil N was estimated by Kjeldahl method (Jackson, 1958), available P was determined by Olsen's method (Olsen et al., 1954), then readings were performed using spectrophotometer (at 882 nm). Available K was estimated by Flame photometer. Organic carbon was estimated by Walkley and Black method (Walkley and Black, 1934), soil pH was estimated in 1:2.5 soil-water ratio using an electrode pH meter, particle size distribution by hydrometer method (Day, 1965) and bulk density was determined by using core-sampling method.

Phosphorus concentration, uptake and efficiency

The middle three rows of each plot and six representative plants from the rows were selected for sampling. The seed as well as haulm samples were collected from sample plants and separately oven dried at 65°C to a constant weight. Then the samples were ground to pass through a 1 mm sieve and saved for plant tissue analysis of seed and haulm. Phosphorus concentration was determined using spectrophotometric vanadium phosphomolybdate method by tri-acid mixture (HNO_3, H_2SO_4 and $HClO_4$) in the ratio of 9:4:1 for sample digestion (FAO, 2008). The P in the solution was determined calorimetrically using ammonium meta vanadate and ammonium molybdate for color development. The reading of P was made at 660 nm using spectrophotometer and calculated using the following equations (1 – 6; Moll et al., 1982):

$$\text{Seed P uptake (kg ha}^{-1}) = \text{Seed P concentration (\%) x Seed yield (kg ha}^{-1}) \qquad - \text{Eq. (1)}$$

$$\text{Haulm P uptake (kg ha}^{-1}) = \text{Haulm P concentration (\%) x Seed yield (kg ha}^{-1}) \qquad - \text{Eq. (2)}$$

$$\text{Total P uptake (kg ha}^{-1}) = \text{Seed P uptake (kg ha}^{-1}) + \text{ Haulm P uptak (kg ha}^{-1}) \qquad - \text{Eq. (3)}$$

$$\text{P Uptake Efficiency} = \frac{\text{Total P uptake (kg)}}{\text{P supply (kg)}} \qquad - \text{Eq. (4)}$$

$$\text{P Utilization Efficiency} = \frac{\text{Seed Yield (kg)}}{\text{Total P uptake (kg)}} \qquad - \text{Eq. (5)}$$

$$\text{P Use Efficiency (Seed yield per P supply)} = \text{P uptake efficiency x P utilization} \qquad - \text{Eq. (6)}$$

Where, P supply = available soil P at planting plus P fertilization in each level added;

According to Valle et al. (2011) P supply was estimated as the sum of potentially available soil P at planting and P applied. The potential of soil to supply P at planting was estimated using the initial soil Olsen P content (mg kg^{-1}) in the top 20 cm of composited soil.

P sol: represents available P from the soil itself estimated as indicated d*S*Z*P(sol), where, d: dry bulk density (1.07 g/cm3), S: total area (1 ha), Z: estimated rooting zone for mineral nutrition (20 cm) and P(sol) represents P content as indicated by Olsen method (9.04 mg kg^{-1}); We estimated initial available soil P as 19.34 kg P ha^{-1}.

Data analysis

The data collected were subjected to analysis of variance (ANOVA) using GLM procedure in SAS version 9.0 for windows. Mean separation was done using Duncan's Multiple Range Test (DMRT) at 5% probability level.

RESULTS AND DISCUSSION

Soil physical and chemical properties

The soil analysis result indicated that the experimental soil particles distribution constitutes of 56% clay, 26% silt and 16% sand. The soil pH was 7.32 with (pH H_2O), organic carbon (1.41%), total N (0.09%), available P (9.04 ppm) and K (1.01 meq/100 g soil). The analysis of the collected samples indicated that the soil is clay in texture, neutral in reaction, low in organic carbon, low in total N and high in K content (Tadese, 1991). The soil test showed (Marx 1996) that it is categorized with low available P (<10 ppm) and hence the present experimental site had low available P (9.04 ppm).

Seed phosphorus (P) concentration and uptake

Seed P concentration and P uptake were significantly ($p<0.001$) varied in response to genotype, P supply and the interaction effect of the two factors. The increase in P supply resulted in relatively increased P concentration and P uptake across all varieties and accessions, though genetic differences were evident. Almost all genotyped (varieties and accessions), exhibited higher seed P concentration when 17 kg P ha^{-1} was applied and then declined. However, accession 28606 at control treatment resulted in lower seed P concentration. Similarly, the highest seed P uptake was obtained when 17 kg P ha^{-1} was applied to Chala variety (Table 1).

Seed P concentration differences were principally related to P availability in the soil and to the high capacity of genotype to acquire it. Baligar and Fageria (1997) indicated that the nutritional differences among genotypes might be due to genetic control of inorganic plant nutrition. The increase in P concentration with increasing available P was expected due to increase in P availability to plant roots (Fageria et al., 2011). In agreement to this result, Abbasi et al. (2010) observed P content in grain being significantly influenced by genotype × P level interactions. The seed P uptake of Chala at intermediate P application (17 kg P ha^{-1}) was outstanding as compared to other combinations. This indicates that both the genotype of the variety and P availability affect seed P uptake (Mourice and Tryphone, 2012) and Chala variety can be the best choice under intermediate P availability.

Table 1. Interaction effect of genotype (G) and phosphorus (P) levels on seed P concentration and uptake

Genotype	Seed P Concentration (%) P (kg ha^{-1})				Seed P uptake (kg ha^{-1}) P (kg ha^{-1})			
	0	9	17	26	0	9	17	26
Bishoftu	0.31^{c-e}	0.31^{c-e}	0.37^{a-c}	0.33^{bc}	3.66^{f-j}	3.7^{fi}	5.00^{bc}	4.05^{d-g}
Chala	0.34^{a-c}	0.35^{a-c}	0.41^{a}	0.35^{a-c}	4.46^{c-f}	5.21^{bc}	6.63^{a}	5.42^{b}
Ebbisa	0.27^{e}	0.35^{a-c}	0.37^{a-c}	0.41^{a}	2.40^{k}	3.58^{g-j}	3.82^{e-h}	4.19^{d-g}
Hunda	0.28^{de}	0.35^{a-c}	0.36^{a-c}	0.39^{ab}	2.95^{i-k}	4.01^{d-g}	4.19^{d-g}	4.60^{c-e}
28605	0.33^{bc}	0.35^{a-c}	0.36^{a-c}	0.39^{ab}	2.75^{k}	3.16^{h-k}	3.86^{d-h}	4.17^{d-g}
28606	0.25^{e}	0.26^{e}	0.34^{a-c}	0.33^{bc}	2.88^{jk}	2.99^{i-k}	4.65^{b-d}	3.80^{e-h}
CV (%)		7.13				9.38		

Means followed by different letter (s) in the same parameter are significantly different

Haulm P concentration, uptake and total P uptake

Haulm P concentration and haulm P uptake were significantly affected due to genotype ($p<0.05$) and P supply ($p<0.001$) but not by the interaction of the two factors. Bishoftu and Chala varieties showed better performance over accession 28605 and Ebbisa variety in P concentration and uptake. With regard to P supply, both 17 kg P ha^{-1} and 26 kg P ha^{-1} were observed in similar and better haulm P concentrations than control and 9 kg P ha^{-1} plots (Figure 1). Chala variety showed higher haulm P uptake as compared to the other three genotypes (Ebbisa, Hunda and accession 28605). Accession 28606 showed higher accumulation of P in haulm and lower accumulation of P in seed. The supply of 17 kg P ha^{-1} and 26 kg P ha^{-1} similarly brought significantly higher haulm P uptake as compared to control and 9 kg P ha^{-1}plots.

In terms of haulm P concentration, the variation existed among genotypes express ability of genotypes to absorb available soil P as well as contain P within their straw and the final allocation of P within plant tissue. In line with this, previous study reported variation in straw P concentration among pigeon pea genotypes (Clemens et al., 2016). In regard to P supply the variation in haulm P concentration may be an established fact that P promotes root proliferation and growth, which in turn enhanced the absorption of P and finally resulting in increased haulm P concentrations (Purbey and Sen, 2005). The observation is in line with Godara (2015) as that P concentration in haulm got enhanced significantly with increased fertility levels.

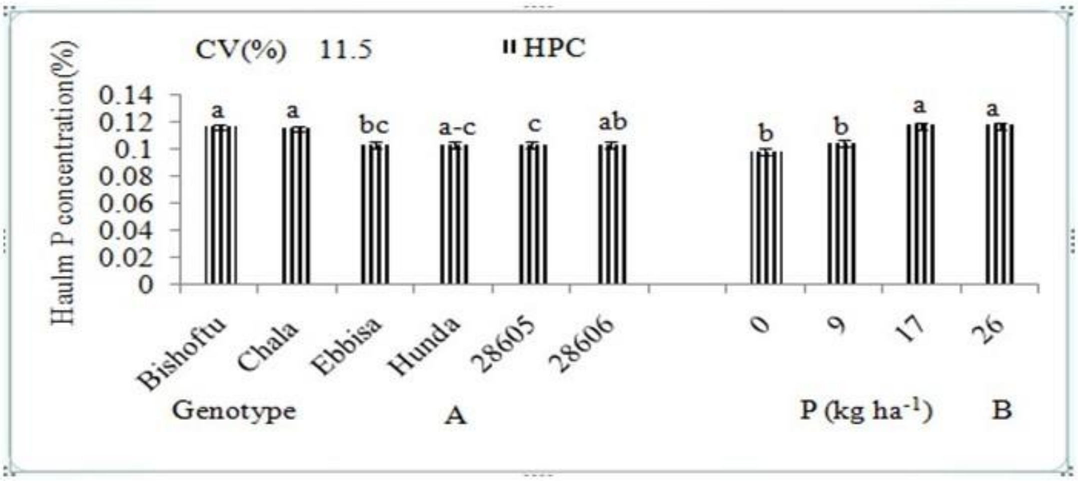

Figure 1. Haulm P concentration (HPC) as influenced by genotype (A) and P supply (B). Means with different letter on the figure are statistically different.

In the current study, total P uptake got enhanced to the varied magnitude up to 17 kg P ha^{-1}. The increased total dry matter production and nutrient concentration seems to be the major causes of the higher P uptake under the influence of P, since P uptake depends mainly on the dry matter accumulation followed by the nutrient content at cellular level. This is in line with the report of Khiriya et al. (2003) who indicated nutrient management influencing crop uptake.

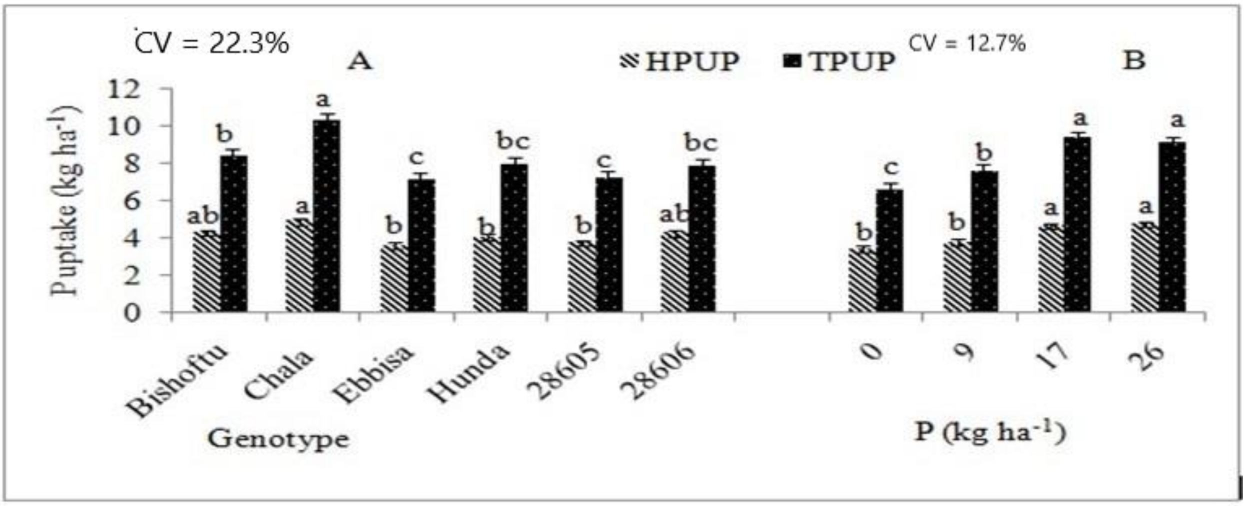

Figure 2. Haulm P uptake (HPUP) and total P uptake (TPUP) as influenced by genotype (A) and P supply (B). Means with different letter on the bars are statistically different.

Phosphorus uptake efficiency (PUPE) and utilization efficiency (PUTE)

The results of the present study demonstrated that Chala variety had the highest PUPE over all the tested genotypes. Ebbisa variety was observed with lower P uptake efficiency but statistically at par with accession 28605. P uptake efficiency ranged from the lowest value of 0.20 to the highest value of 0.34 for 26 kg P ha^{-1} and control plots, respectively (Table 2). Phosphorus utilization efficiency was significantly (p<0.001) influenced by P supply. PUTE varied (134.26 – 162.06 kg seed yield per kg total P uptake) in response to P supply. The highest PUTE was resulted at control plot overall of P supply (Table 2).

The sensitivity of P uptake efficiency (PUPE) between genotypes those recorded higher and lower was 45.4% to Chala vs Ebbisa and 39.1% to Chala vs 28605 in reduction. Accession 28606 was efficient in seed yield but lower at P uptake efficiency as compared to Chala variety. Thus, further improvement is possible with genotype which has higher P uptake quality in root traits. By comparing various parameters of the genotypes group (improved varieties and accessions), improved variety (Chala) showed better performance in relation to total P uptake and P uptake efficiency than accessions. The variation might be due to acquisition of P from the soil depending on root architecture which is highly flexible trait and varying among genotypes. In agreement to this results, significant difference among mung bean genotypes for P uptake efficiency was reported by Muhammad et al. (2017). In case of P availabilities each level of P increment to 9 kg P ha^{-1}, 17 kg P ha^{-1} and 26 kg P ha^{-1} underwent reduction of P uptake efficiency by 20%, 30% and 70% as compared to control plot. The high P supply had been showed reduction of the P uptake efficiency. The improved P uptake efficiency under control over P applied might be due to fenugreek roots having the ability to trap higher levels of P and use it for growth and development of the plant (Randhawa et al.,1996).

Table 2. Phosphorus(P) uptake efficiency and utilization efficiency of fenugreek as influenced by main factors effect of genotype and P supply

Genotype(G)	P uptake efficiency (kg total P uptake kg^{-1} P supply)	P utilization efficiency (kg seed yield/kg P uptake)
Bishoftu	0.27^{b}	147.34
Chala	0.32^{a}	149.59
Ebbisa	0.22^{d}	143.05
Hunda	0.25^{bc}	145.47
28605	0.23^{cd}	133.96
28606	0.27^{bc}	154.74
P supply xz x(kg ha^{-1})		
0	0.34^{a}	162.06^{a}
9	0.26^{b}	151.03^{b}
17	0.24^{b}	135.43^{c}
26	0.20^{c}	134.26^{c}
CV (%)	12.52	11.55
G*P	Ns	Ns

Means followed by different letter(s) in each column of each factor are significantly different

Phosphorus use efficiency (PUE)

The analysis of variance revealed that phosphorus use efficiency (PUE) was influenced significantly (p<0.001) by genotype, P supply and the interaction of the two. Chala variety produced the maximum PUE under control as compared to all other combinations. Hunda and Ebbisa varieties as well as accessions 28605 and 28606 combined with 26 kg P ha^{-1} recorded statistically similar and lower PUE values (Figure 3).

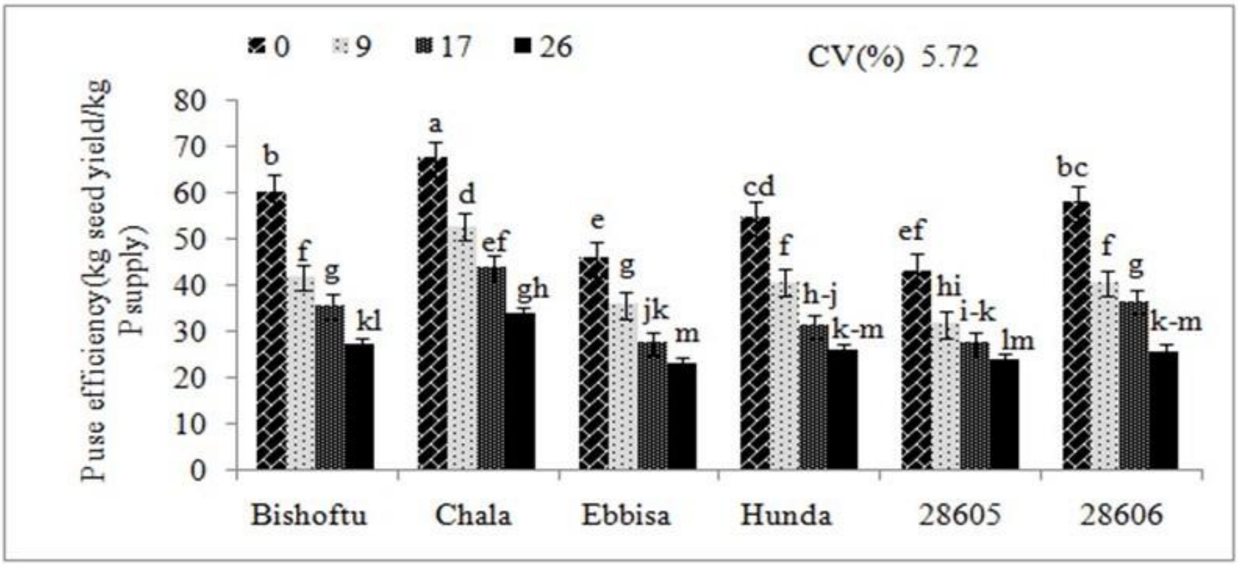

Figure 3. **P use efficiency of fenugreek as influenced by interaction of genotype with P. P supply = available soil P at planting at control plot plus P fertilization in each level added.**

Based on P use efficiency, the seed yield obtained from each treatment combinations were used for categorization of genotypes into efficiency and responsiveness class using the method initially suggested by Gerloff (1977), which later was used by many authors (Gunes et al., 2006). Keneni et al. (2015) in their characterization of Ethiopia chickpea scattered the genotypes in to efficiency and responsiveness class using seed yield performances in the absence and presence of P fertilizer. Thus, using absence and presence of P fertilizer as the cutting points, an efficient genotype has higher seed yield than average performance of genotypes under absence of P fertilizer and inefficient genotypes were reverse of this. A responder genotype has higher seed yield than average performance under P fertilizer and non-responder genotype has lower seed yield than average performance of genotypes (Gerloff, 1977; Gunes et al., 2006). Having the above delineation two varieties (Chala and Bishoftu) and accession 28606 were grouped as efficient responder genotypes. The other genotypes were grouped into inefficient non-responder genotypes (Figure 4). Being efficient of the genotypes may be due to roots have the ability to trap P from the soil and high P use efficiency of the genotypes (Randhawa et al., 1996).

The current result is supported by similar reports of Korkmaz et al. (2009), where significant differences for uptake efficiency were observed when genotypes were grown at different P levels. The supply of 9 kg P ha^{-1}, 17 kg P ha^{-1} and 26 kg P ha^{-1} decreased P utilization efficiencies (PUTE) by 7.3%, 19.6% and 20.7% respectively, compared to the controls. This might be due to low P concentration observed at control plot, since low P concentration could enhance P utilization efficiency. According to Batten (1992) low P concentration in grain may improve P utilization efficiency. The improved P utilization efficiency under control in this experiment may be contribute to reduction in the environmental problems that is caused by the application of excessive P fertilizer. The result is in line with the reports of Sandana (2016) where P application decreased PUTE compared to P deficient soils. The maximum P use efficiency (PUE) observed could be due to high P acquisition and utilization efficiency recorded at control plot combined with the high potential of each genotype to acquire and utilize P. Most of the genotypes recorded low PUE when 17 and 26 kg P ha^{-1} (P supply) was applied. This might be due to genes controlling traits of benefit under lower soil fertility were lost as they conveyed no advantage under very high soil fertility (Wissuwa et al., 2009). Moreover, decreased PUTE and PUPE results in declining of PUE directly. The result of this research was in agreement with the report of Ruchita (2008) where the highest PUE was recorded at 9 kg P ha^{-1} and further increase corresponded to decreased the PUE.

In the current experiment, accession 28606 was found to be more efficient and responsive over improved varieties of Ebbisa and Hunda. Being efficient of the genotypes may be due to roots having the ability to trap P from the soil and high P use efficiency of the genotypes for growth and development (Randhawa et al., 1996). Chala variety categorized as efficient in seed P uptake (total P uptake kg^{-1} P supply) was also higher in terms of P uptake, use, and utilization efficiency. Thus, efficient and responder genotypes considered as desirable and can help for plant breeders in further developments. Those seed P efficient (high uptake efficiency) as well as responder genotypes are important for further improvement and to gain reasonable yields with minimal level of P. Since efficient and responder genotypes are more preferable than high yielding but inefficient and non-responsive varieties based on high investments for fertilizer inputs for the majority of resource limited farmers dwelling under marginal situations. The classification was similar with previous grouping style reported earlier. Silva et al. (2016) showed that seven common bean genotypes were classified as efficient and responsive, those performances were above the average at both levels, while the others eight genotype classified as inefficient non-responder, whose performances were below the average at both levels. Gemechu et al. (2015) also worked on similar classification in chickpea genotypes under P levels.

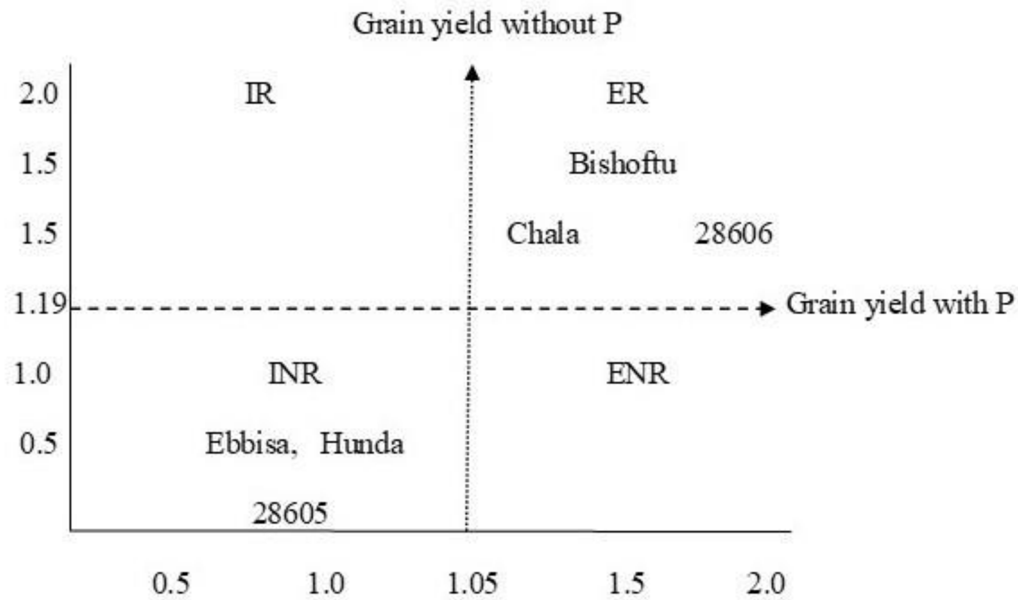

Figure 4. Efficiency and responsiveness classification of fenugreek genotypes
Where, grain yield; ton ha^{-1}, ER; efficient responder, ENR; Efficient non-responder, IR; In-efficient responder, INR; In-efficient non-responder.
Note: Grain yield is used as mean value of all seed yield with P fertilizer supply (with P) and control plot (without P).

CONCLUSION AND RECOMMENDATIONS

The present investigation indicated a considerable fenugreek genotypic variation in terms of P uptake and use efficiency in response to P availability. Chala variety showed a higher total P uptake (haulm + seed) and P uptake efficiency among the tested genotypes. Total P uptake got enhanced to the varied magnitude up to 17 kg P ha^{-1} supply. The combination of genotypes with increased P availability showed declining of P use efficiency mainly due to genes controlling traits of benefit under lower soil fertility were lost as they conveyed no advantage under very high soil fertility. Based on P use efficiency expressed in seed yield capacity three genotypes (Chala, Bishoftu and 28606) were grouped as efficient responder genotypes. These genotypes are desirable both at low and high input systems. The other genotypes were grouped into inefficient non responder genotypes. Therefore, the efficient responder varieties: Bishoftu and Chala can be recommended for production by farmers in the study area and areas of similar agro-ecology. Furthermore, since it is efficient and responder, 28606 accession can be recommended for further breeding uses for future improvement in fenugreek breeding programs in Ethiopia.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest with the publication of this article.

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